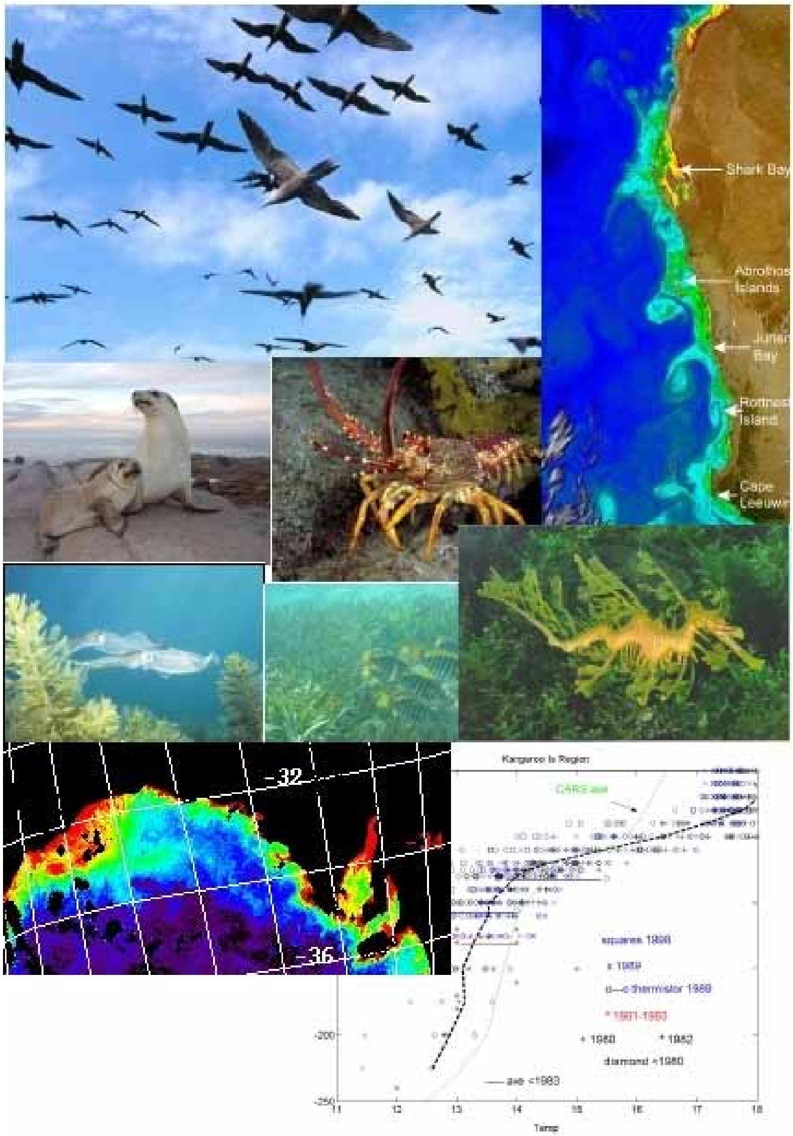
The South-west Marine Region:
Ecosystems and Key Species Groups

Department of the Environment and Water Resources



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1 Executive summary

1.1 Purpose, focus, and structure of the report

The purpose of this report was to undertake a comprehensive review of the current knowledge of the key ecological characteristics of the South-west Marine Region (the Region). This region covers Australian waters from the eastern-most tip of Kangaroo Island (South Australia) to the outer coast of Shark Bay (Western Australia) (Figure 1.1.1). The focus of this report is waters beyond three nautical miles from the coastal baseline; information on inshore waters is included only where there are important processes that influence processes on the shelf and slope. The objective is to produce an integrated report on the ecosystem of the Region, which is aimed at scientists who are not necessarily specialists in the area. The information embodied in the report will provide background to inform policy decisions where there is a need for scientific information about the region; information that was previously widely scattered and less accessible.

The Department of the Environment and Water Resources defined a list of functional groups of organisms that have either commercial (target and significant by-catch species), recreational, conservation, or cultural importance. The list includes introduced species. These functional groups are:

- Flora including Seagrasses, Mangroves, kelp, etc.
- Corals
- Seabirds
- Echinoderms
- Sharks and rays
- Squids and cuttlefish
- Crabs and lobsters
- Prawns
- Molluscs of commercial, recreational, cultural or ecological significance
- Cetaceans
- Seals and sea lions (or Pinnipeds)
- Seahorses, sea-dragons and pipefish
- Mackerels and tunas
- Small pelagic fish
- Inshore demersal (those species predominantly caught in waters less than 50 metres in depth)
- Deepwater fish (those species predominantly caught in waters greater than 50 metres in depth) (treating slope and shelf communities separately)
- Introduced marine species.

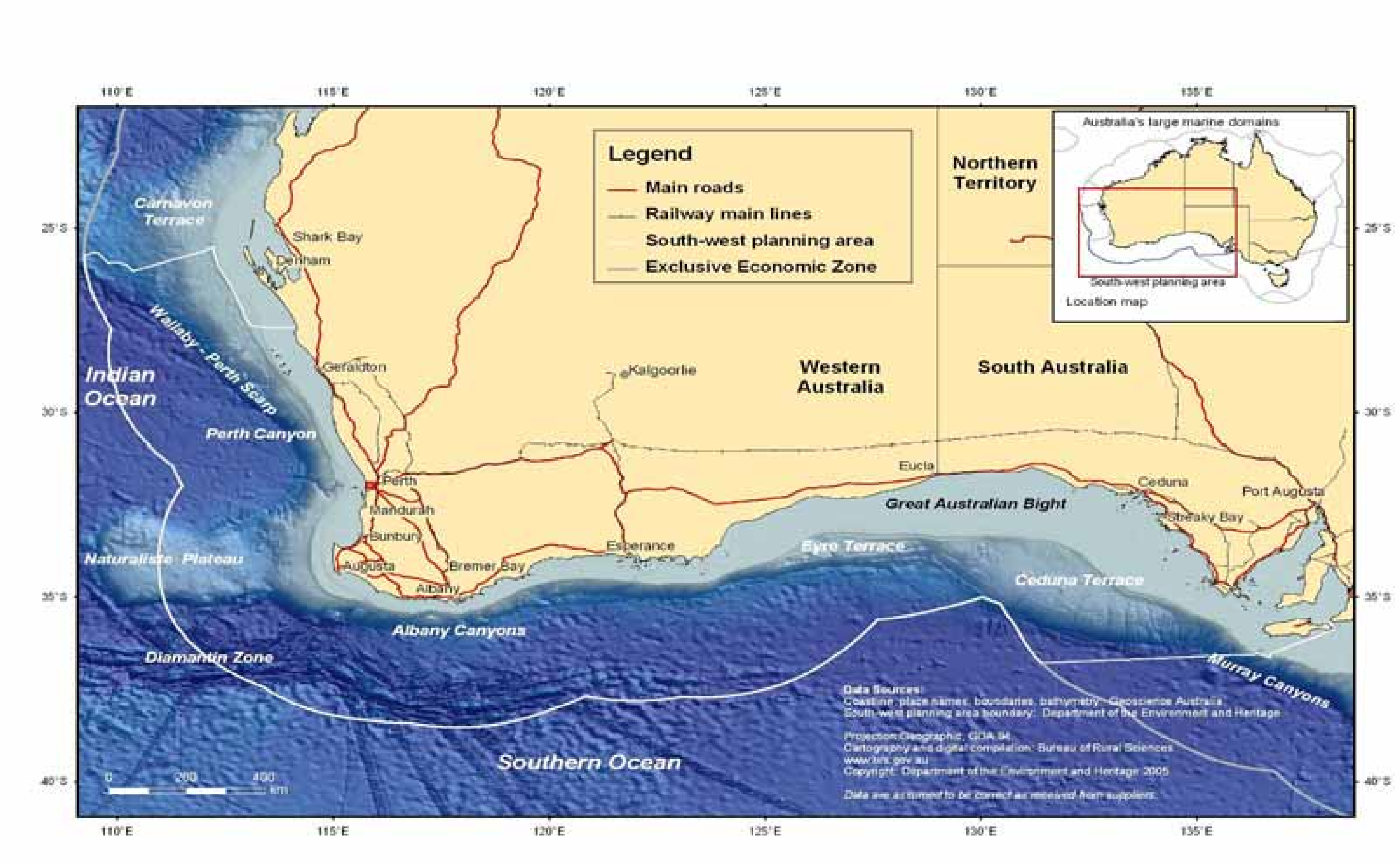

Figure 1.1.1 Boundaries of the South-west Marine Region. The focus of this report is on the shelf and slope, including the inshore only where there are important processes that influence processes on the shelf and slope**.**

The Department of the Environment and Water Resources also provided a list of species that were considered to be of significance to commercial, recreational fisheries, of conservational value, or to have cultural importance in the Region. Knowledge of each of these species is addressed within the descriptions of the respective functional groups. Although the focus of this report is on the shelf and slope, there is a certain inconsistency between the shelf/slope focus and some of the species that are predominantly inshore (such as seagrasses, mangroves, kelp, and inshore fishes).

Sections 2 and 3 (Part 1) of this report provide an overview of the physical and ecological characteristics of the Region. Readers should note that the Region's physical environment is better understood than that of the Region's ecology. As result, it is considered that while this report provides an appropriate overview of the Region's physical environment, coverage of the regions ecology remains partially incomplete — reflecting the current state of knowledge. A separate reference list is provided for the ecological and physical overviews of the region (sections 2 and 3).

Section 4 (see Part 2 of the report) comprises the bulk of the report. The species included in this section are made up of functional groups that have either commercial (target and significant by-catch species), recreational, conservation, or cultural importance – including introduced species. Each of the chapters in Section 4 describes the functional species groups, and was written as a stand-alone contribution that is intended to be a reference point. As such, each chapter has a reference list that is specific to the functional species group. These reference lists are intended to provide a means for interested readers to access more specialised studies and to a large extent do not overlap with each other or with the reference list for sections 2 and 3.

1.2 Overview

The Region encompasses a range of biogeographical provinces (defined by the Integrated Marine and Coastal Regionalisation for Australia version 4.0 (IMCRA v4.0) and the National Marine Bioregionalisation). Major oceanographic current systems within the region include the Leeuwin Current and Flinders Current as well as the seasonal current systems such as the Capes Current (along the south-west coast), and those within the Great Australian Bight. The region also consists of different local scale marine "systems" where the geomorphology and physical processes exercise a certain amount of control on the ecological processes. These processes include the seasonal upwelling systems (off the West Australian and South Australian) coasts, submarine canyon systems, island and headland wake regions, and offshore eddy systems.

The physical environment has a great effect on the functioning and structure of the Region. Effects range from the near isolation of commercially important species within the South Australian gulfs, to the enrichments driven by seasonal upwelling, transport of whole communities by eddies, and the role of sedimentary facies in structuring benthic communities on large scales. Interannual changes in the physical regime, such as El Niño also impact the biological communities by intensifying currents and altering the upwelling regime. However, it is important to bear in mind that we still do not fully understand the drivers of ecosystem structure in the Region.

Executive summary

Ecosystems can be structured by bottom-up forces, top-down forces, or may operate as wasp-waist systems. Bottom-up structure implies the importance of physics, through nutrients to primary production; top-down systems are structured by the pressures imposed by higher predators on the food web; and in wasp-waist systems, the influence of physics is mediated by the role of intermediate trophic levels, and the non-linear dynamics that relate them to both higher and lower trophic levels in the system. Until we understand which paradigm best fits the Region, we cannot say that we understand how the system works, and what the drivers of change are.

One of the most important drivers of ecosystem change is climatic influences. Climate variability operates on a range of time-scales, and can be conceived as the noise that occurs around a trend. Trends in climate operate on much longer time-scales and are referred to as climate change. Climate variability includes the effects of El Niño or La Niña cycles. Little is known about the effects of climate variability in the Region, and much of what is known was studied in the context of fisheries recruitment and the effects of environmental variability on recruitment. Recent modelling studies, summarised in Section 2 of this report, indicate that intensification of current systems during El Niño, and subsequent relaxation in the summer after an El Niño event, can increase the intensity of upwelling along the South Australian coast. This may lead to enhanced productivity, a result contrary to what is observed with El Niño in the northern hemisphere. However, the time-series are short and so these effects are difficult to verify statistically.

There is almost no work addressing how pelagic communities, benthic communities or fisheries would respond to interannual climate variability and long-term climate change. We are only beginning to understand how large-scale ocean-atmosphere interactions such as El Niño affect the physical oceanography of the region. There is also limited information on the effects of environmental variability on fisheries recruitment of species like rock lobster, King George whiting, garfish, Australian salmon, herring, pilchard, or prawns. Most of the studies cited in this report are relate to the western part of the Region. There is a need for integrated studies of the effects of environmental variability of productivity as well as recruitment of commercially important species in the South Australian region. There is reason to believe that there will be significant relationships between recruitment and environmental variables for scale fish, rock lobster and prawns.

Seasonal coverage is limited for virtually all of the studies and all of the taxa of the Region. The exception is the seasonal information derived from satellite remote sensing of phytoplankton. The seasonal cycle of phytoplankton pigments at large scale, low-resolution (5 km, monthly composites) is provided by satellite imagery from the MODIS-Aqua sensor. While this information is extremely valuable, it misses some important features. These data are limited to the upper layer (~ upper 10 m), and so miss the deep chlorophyll maxima known to occur over the shelf in the eastern Great Australian Bight. They also suffer from uncertainties in calibration, particularly in near-shore Case 2 waters (i.e. waters where the backscattered irradiance is derived from other substances in addition to phytoplankton).

The widely accepted concept that the southern Australian coast supports a uniquely rich regional biodiversity still needs further quantitative study. Non-quantitative evidence suggests higher regional biodiversity in some well-known groups (e.g.

benthic algae), as well as a high degree of endemism, but the area is under-explored for many groups (e.g. sponges). The spatial coverage of sampling in the region is patchy, and large areas have not received much attention. The current state of knowledge of ecological structure and function of the Region is quite unbalanced in the sense that some taxa, such as fish, sponges or benthic macroalgae, are much better catalogued than others.

The largest part of this report (Part 2) deals with the species group descriptions. These descriptions are necessarily uneven because there is far more information about some groups than others. Each chapter is designed to provide a stand-alone review and reference point on the current state of knowledge and literature for the respective groups. The functional groups described are (in alphabetical arrangement for easy reference) Ascidians, Bryozoans, Cetaceans, Corals, Demersal fish (inshore, shelf and slope), Elasmobranchs, Infauna, Mackerels, Tunas and billfishes, Macroalgae, Mangroves, Marine pests, Molluscs, Phytoplankton, Pinnipeds (seals and sea lions), Prawns, Rock lobster, Seabirds, Seagrasses, Sponges, Small pelagic fish, Syngnathids and Zooplankton.

Part 1 - Ecosystems

2 Physical oceanography

Principal contributors

Chari Pattiaratchi
John Middleton

2.1 Shark Bay to Esperance

Introduction

During the past two decades the physical oceanographic processes off Western Australia have been the subject of many studies. One motivating factor for these studies was the observation that, as a rule, eastern ocean basins are highly productive ecosystems supporting high primary productivity and large pelagic finfish stocks. However, the exception to this rule is the Western Australian coast where although the wind regime is similar to other eastern ocean margins, the waters are oligotrophic. Thus, the initial studies were concentrated on addressing why the circulation off Western Australia was different to other eastern margins. This led to the discovery of the Leeuwin Current and the subsequent determination of its dynamics. Indeed, it has been shown that the Leeuwin Current system is made up of three currents: the Leeuwin Current, the Leeuwin Undercurrent and shelf current systems consisting of the Ningaloo, Capes and Cresswell currents (Woo et al. 2005).

The main contribution to the understanding of the physical oceanography of this region has come from Andrews (1976, 1977, 1983); Cresswell and Golding (1980); Hamilton (1986); Smith et al. (1991); Pearce and Walker (1991); Cresswell and Peterson (1993); Gersbach et al. (1999); Pearce and Pattiaratchi (1999); Feng et al. (2003); Morrow et al. (2003); Ridgway and Condie (2005); Woo et al. (2005); and Rennie et al. (2005).

The main oceanographic features of the region between Shark Bay and Esperance are comprised primarily of the following surface and subsurface current systems (figures 2.1.1 and 2.1.2):

- The West Australian Current
- The Leeuwin Current
- The Leeuwin Undercurrent
- The Flinders Current
- Continental shelf current systems: the Ningaloo, Capes and Cresswell currents

Physical oceanography: Shark Bay to Esperance

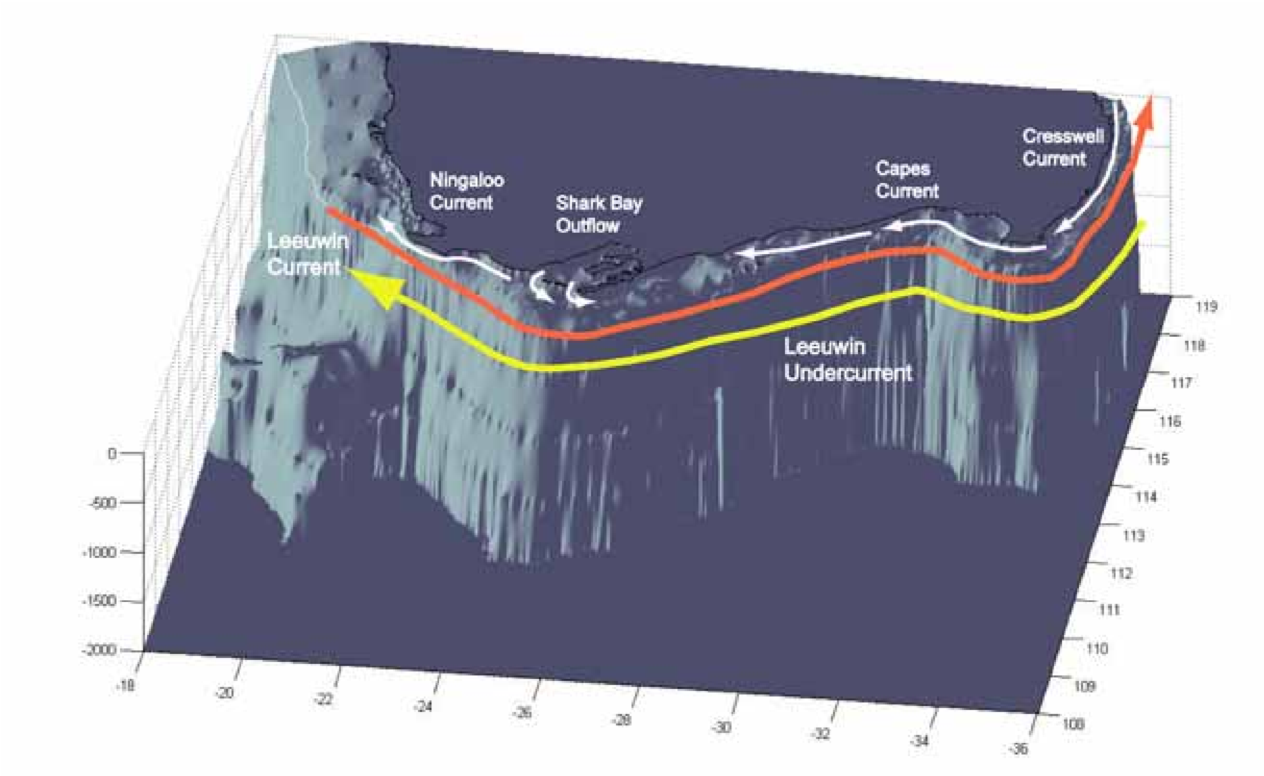

Figure 2.1.1 Schematic of surface and subsurface currents along the Western Australian coastline

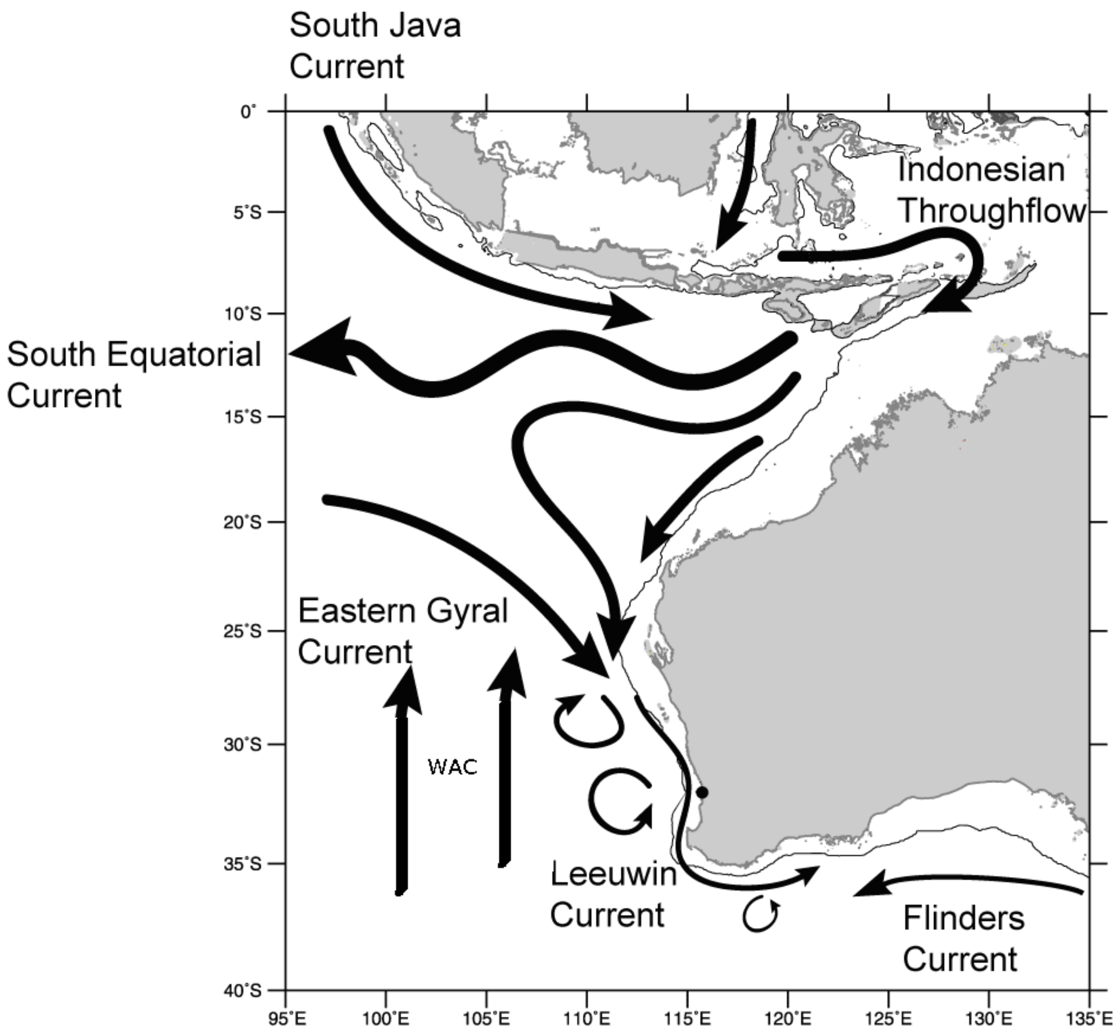

Figure 2.1.2 Schematic of surface currents along the Western Australian coastline (WAC = Western Australian Current).

The West Australian Current

Eastern boundary currents occur along most eastern ocean boundaries as slow and broad equatorward currents (in contrast to the intensified poleward western boundary currents) and make up one part of the anticyclonic subtropical gyre in each hemisphere's oceans. These gyres result from the Sverdrup balance: a balance between wind stress, pressure gradients and coriolis acceleration. The eastern boundary current regions are characterised by cooler (through upwelling) water and high primary productivity thus supporting major pelagic finfish industries. Western Australia does not have the level of biological productivity induced by the Humboldt Current (South America) or the Benguela Current (Africa) because the Leeuwin Current opposes the equatorward West Australian Current and suppresses the upwelling of cooler nutrient-rich water along the continental shelf (see below). The continuity of mass required for maintaining the anticyclonic subtropical gyre in the southern Indian Ocean is achieved through the West Australian Current, which is necessarily located further offshore. Schott and McCreary (2001) postulated that the northward current extends westward from Western Australia up to latitude of 60° E (Figure 2.1.3).

Earlier, Andrews (1977, 1983) described the West Australian Current as a much narrower 100–200 km-wide cyclonic stream identified during the summer months as a trough, shown by mixed layer depths, surface isotherms and dynamic height anomaly. The current here was identified to be centred over the Naturaliste Plateau (Figure 2.1.2) and extends 800 km north-east to the coast where it turns south along the south-west coast of Western Australia. The transport of this current is 10 Sverdrups (10^7 m^3 s^{-1}) towards the north-east and is confined near the surface. The discrepancy of size and location of the West Australian Current, with that later suggested by Schott and McCreary (2001) is likely due to the effects of mesoscale eddies and also the general lack of data for the region.

Recent work by Cresswell and Peterson (1993) focused on the source of the Leeuwin Current in the summer months, which they linked to the West Australian Current. This study was motivated by the observation that the Leeuwin Current flowing eastward along the south coast of Western Australia during the summer months had a higher salinity signature in summer than in winter, implying that its source was more of subtropical origin. It is unclear whether the inflow of subtropical water is due to geostrophic inflow or the inflow of the West Australian Current, though the work of Andrews (1977, 1983) appeared to be consistent with the investigations of Wyrtki (1962), Hamon (1972) and, to a limited extent, Cresswell and Peterson (1993). Observations of the West Australian Current have not been repeated during the winter months and therefore the contribution of the West Australian Current during this period is unclear.

Andrews (1983) emphasised this problem by stating that the eastward inflow had rarely been studied in winter and the Leeuwin Current had not generally been investigated in summer, implying that the Leeuwin Current and the West Australian Current might be seasonally mutually exclusive or might coexist. It is therefore often implied or stated (Cresswell & Peterson 1993, for example) that the West Australian Current supplements the Leeuwin Current in the summer months.

While the details of the current system are not well understood, the results of Andrews (1983) do show that the West Australian Current does have some features in common with other eastern boundary current systems. It is relatively shallow, with 66% of the total transport above the depth of 1300 m contained in the region above 400 m depths. Similarly, Andrews (1983) surmised that the West Australian Current transports marginally less volume than a typical eastern boundary current system, with a representative flow of 10 Sv (1 Sv = 10^6 m^3 s^{-1}) that may be compared to values of 18 Sv and 15 Sv for the other southern ocean eastern boundary currents: Humboldt (Peru) and Benguela (Africa) currents respectively.

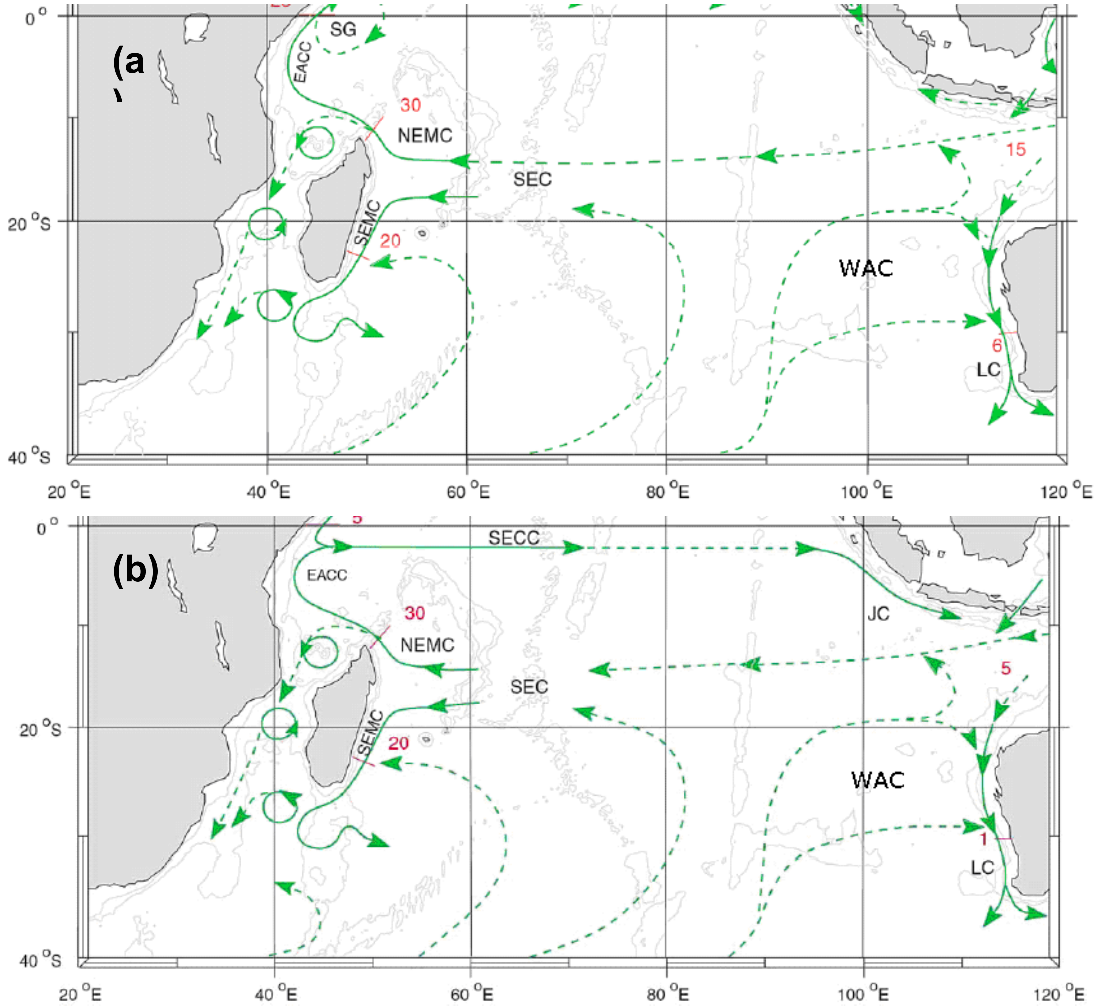

Figure 2.1.3 A schematic representation of the surface circulation in the southern Indian Ocean Monsoon, including the volume transport (1 Sv = 10^6 m^3s^{-1}). Currents indicated are the (possible location) of the West Australian Current (WAC), the South Equatorial Current (SEC), the South Equatorial Countercurrent (SECC), the Northeast and Southeast Madagascar currents (NEMC and SEMC), the East African Coast Current (EACC), the South Java Current (JC) and the Leeuwin Current (LC)
(a) South-west monsoon – austral winter; and, (b) north-east monsoon – austral summer (from Schott & McCready 2001)

The Leeuwin Current

It has been known for several decades that the circulation off the Western Australian coast is different from any other western continental margin (Schott 1935; Smith et al. 1991; Pearce 1991). In each of the main ocean basins, the surface circulation forms a gyre with poleward flow along the westward boundary of the basin and equatorward flow along the eastern margin. In addition, the eastern margins (off South America and South Africa, for example) are areas of high productivity due to upwelling. The exception to this rule is off the Western Australian coast, where the Leeuwin Current transports water poleward (Figures 2.1.1 and 2.1.2).

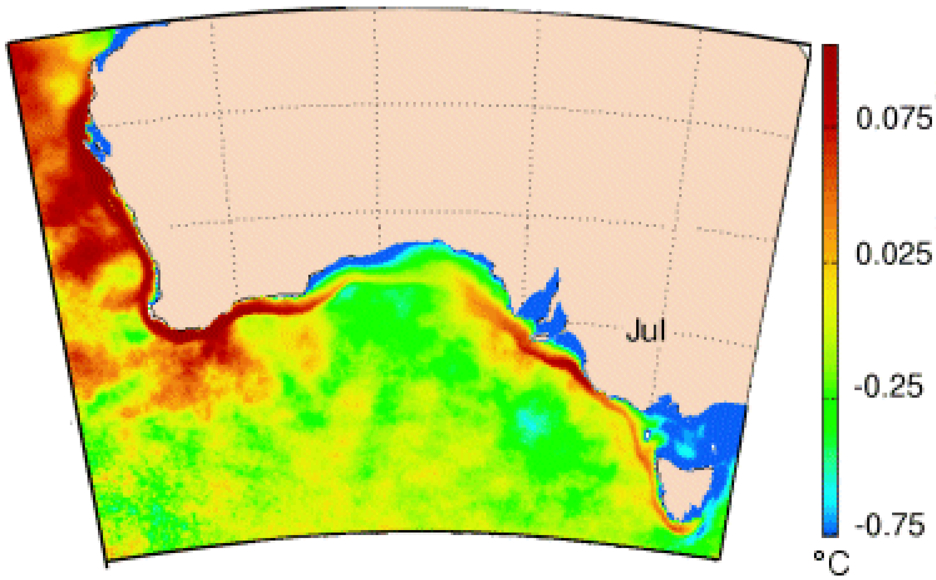

Figure 2.1.4 A composite satellite image of sea surface temperature anomalies in July. The Leeuwin Current can be identified as a narrow band of warmer water adjacent to the coast (from Ridgway & Condie 2004) extending from Western Australia to the mid-Bight and Eyre Peninsula region.

The Leeuwin Current is a shallow (<300 m), narrow band (<100 km wide) of warm, lower salinity, nutrient depleted water of tropical origin that flows poleward from Exmouth to Cape Leeuwin and into the Great Australian Bight (Church et al. 1989; Smith et al. 1991; Ridgway & Condie 2004). Together with the South Australian Current and eastward shelf currents off South Australia and Tasmania, the Leeuwin Current forms the longest boundary current in the World (Ridgway & Condie 2004; Cirano & Middleton 2004). Here, we follow the same definition as Cresswell and Petersen (1993) to define the Leeuwin Current as "a warm water current of tropical origin that, during the summer months, is augmented by the addition of (salty) water from the West Australian Current" (see Section 3.2).

Warmer, lower salinity water flows through the Indonesian archipelago from the Pacific to the Indian Ocean and results in lower density water being present between Australia and Indonesia compared to the cooler and more saline ocean waters off south-western Australia. This density difference results in a change in sea level of about 0.5 m along the Western Australian coast and is the driving force of the Leeuwin Current. Due to the effect of the earth's rotation, water is entrained from the Indian Ocean into the Leeuwin Current as it flows southward; thus, the Leeuwin Current becomes stronger as it flows southward.

Studies undertaken over the past decade have shown that, along the west coast, the Leeuwin Current is driven by an alongshore pressure gradient which overwhelms the opposing equatorward wind stress (Thompson 1984; 1987; Godfrey & Ridgway 1985; Weaver & Middleton 1989; Batteen & Rutherford 1990; Godfrey & Weaver 1991; Pattiaratchi & Buchan 1991). These investigators have demonstrated that the pressure gradient (in the upper 250–300 m of the ocean) overcomes the upwelling favourable winds inducing an onshore surface flow resulting in downwelling at the coast. Onshore geostrophic flow from the central Indian Ocean occurs towards Western Australia between the latitudes of approximately 15° S and 35° S. Geostrophic inflow in the north (15–28° S, augmented by tropical water from the North-west Shelf, forms the warm, low salinity core of the Leeuwin Current (Smith et al. 1991; Woo et al. 2005).

It has been postulated that south of about 30° S the Leeuwin Current intensifies (increase in the transport and the velocity) due to the geostrophic inflow of subtropical water from the south-west, especially during the summer months (Hamilton 1986; Cresswell & Peterson 1993). The current continues beyond Cape Leeuwin eastward into the Great Australian Bight (Ridgway & Condie 2004). Here, the dynamics are thought to be similar to that along the west coast in that the current is still driven by the alongshore pressure gradient, the magnitude of which is slightly lower than that along the west coast (Godfrey & Vaudrey 1985). However, the results of Ridgway and Condie (2004) and Cirano and Middleton (2004) indicate that alongshore winds play a more dominant role – compared to the alongshore pressure gradient – in driving eastward currents along the south coast during winter.

Leeuwin Current eddies

The Leeuwin Current is generally associated with mesoscale eddies and meanders (Pearce & Griffiths 1991; Fang & Morrow 2003; Morrow et al. 2003; Feng et al. 2005; Fieux et al. 2005). Eddies form at the shelfbreak and eventually separate from the current and drift westward. These eddies are apparent in sea surface temperature satellite imagery (Griffin et al. 2001) and in altimeter data (Fang & Morrow 2003). Interaction of the Leeuwin Current with changes in the bathymetry and offshore water of different densities results in the generation and subsequent offshore transport of eddies – in particular, off Shark Bay, the Abrolhos Islands, Jurien Bay, Rottnest Island and Cape Leeuwin (Figure 2.1.5).

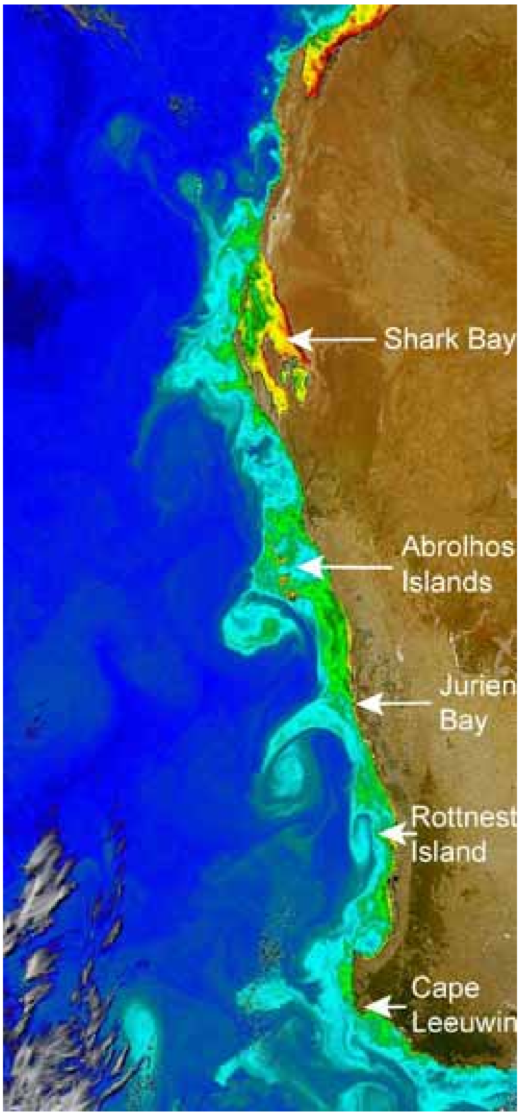

Figure 2.1.5 Ocean colour image showing the eddy structure of the Leeuwin Current. Water with higher chlorophyll levels is located on the shelf and is entrained into the Leeuwin Current.

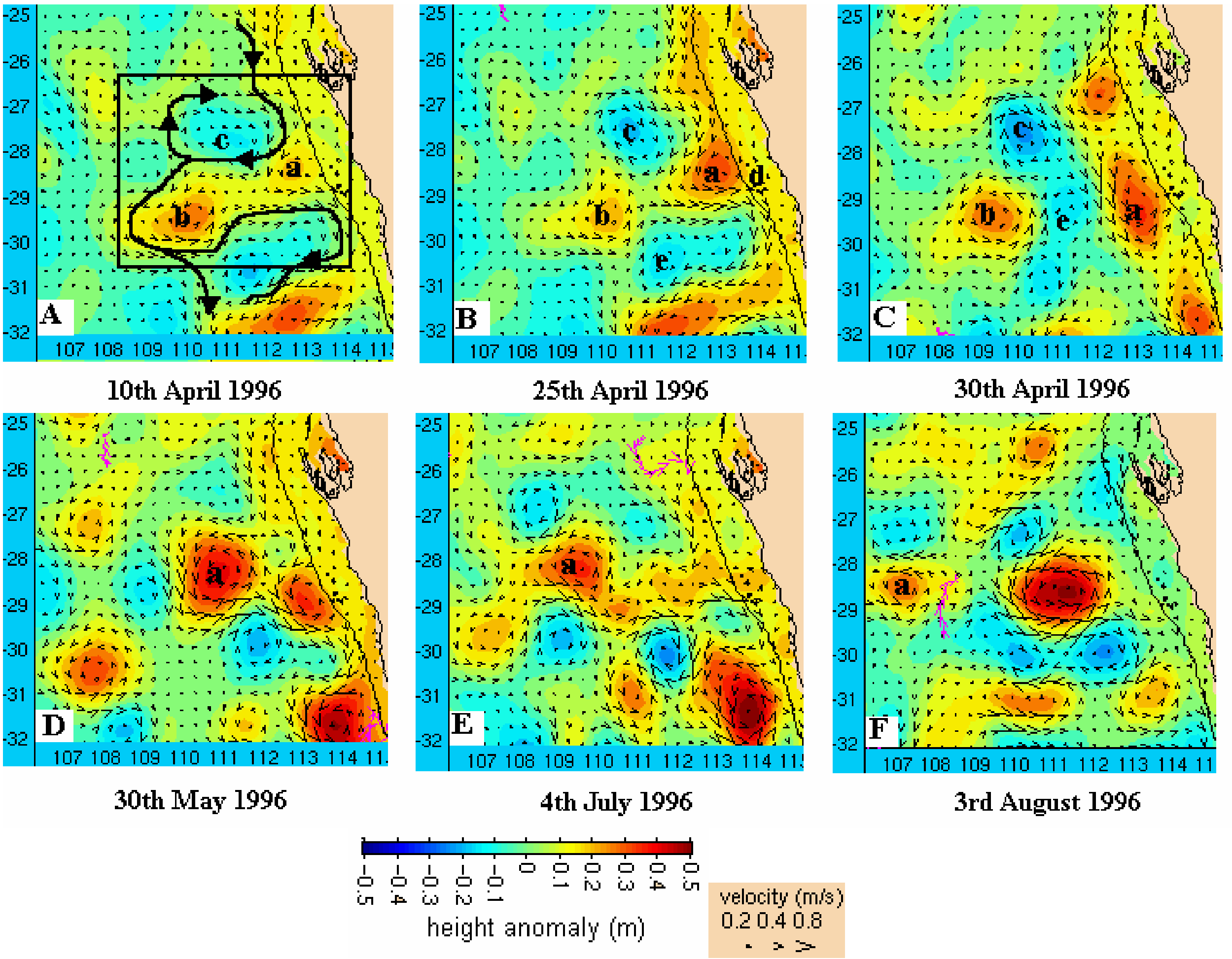

Figure 2.1.6 Time series of satellite altimeter imagery of the surface height anomaly revealing the dynamic nature of the Leeuwin Current off the Abrolhos Islands (from Meuleners et al. 2005)

Pearce and Griffiths (1991), Fang and Morrow (2003) and Morrow et al. (2003) have shown the complex nature of the Leeuwin Current system. A sequence of TOPEX/POSEIDON satellite images of the surface height anomaly (Figure 2.1.6) highlights a number of key mean flow and eddying features of the Leeuwin Current. Figure 2.1.6A shows the meandering nature of the mean current (Pearce & Griffiths 1991) and demonstrates that the path of the mean current is closely linked with the generation of anticyclonic eddies near the shelfbreak. More specifically, the time sequence shows the entrainment of the warm water offshore by a cyclonic eddy "c" forming a dipole eddy pair with anticyclonic eddy "b" (Figure 2.1.6A). The importance of the cyclonic eddy "e" in a detachment process of the anticyclonic eddy "b" is shown on figures 2.1.6B and 6C. As eddy "b" migrates westwards, it remains attached to the shelfbreak until eddy "e", located initially to the south (Figure 2.1.6B), migrates northward between it and the generation site (Figure 2.1.6C) entraining the offshore flow and isolating the eddy. The detachment time scale is of the order of 30 inertial periods (at this latitude the inertial period = 24.7 hours). Observations and modelling studies (Meuleners et al. 2005) have indicated that anticyclonic eddies are initiated and developed in close proximity to the shelfbreak and often in association with a cyclonic eddy before either dissipating or detaching and moving offshore.

The flow that initiates these eddy features can persist for considerable time. The sequence of images show the formation of the anticyclonic eddy “a” which subsequently detaches and migrates within the boxed area (Figure 2.1.6A) for approximately 115 inertial periods (~118 days) before moving beyond the image boundary. The mean speed of migration over this time is of the order of 8 km/day. Similarly, the cyclonic eddy annotated ”c” develops and remains almost stationary during its development stage but as it begins to dissipate, it moves within the eddy field at speeds comparable with its anticyclonic eddy neighbours and has a life cycle of the order of 90 inertial periods (~93 days). Fang and Morrow (2003) and Morrow et al. (2003) give a similar description of the eddying dynamics and the associated temporal and migrational scales.

Fang and Morrow (2003) identified a number of locations along the west coast of Australia for preferential eddy shedding: each was associated with some topographic features including headlands and changes in shelf width. Results from other studies in the south-west and southern coasts of Western Australia also reveal the role of topography in eddy generation (Cresswell & Petersen 1983; Rennie et al. 2005). The main regions of eddy generation may be summarised as follows:

1. West of Rankin Bank (20–21.5° S, 114.5–115.5° E). Here, the slope of the continental slope changes abruptly due to the presence of the Ranking Bank. One third of all long-lived, warm-core eddies were shed from this region (Fang & Morrow 2003).
2. South-west of Shark Bay (26–27° S, 113–114° E) over one third from 28–31° S. At Shark Bay (~25° S, Figure 2.1.5) the coastal topography undergoes a 90-degree change in orientation: to the north, flow along isobaths is directed to the south-west; to the south, the flow turns abruptly to the south-east (Fang & Morrow 2003; Woo et al. 2005). Field data indicate that in this region the strength of the Leeuwin Current changes. In the wider shelf off Shark Bay the current speed is weaker as it is distributed along the wider shelf. To the south, the current accelerates as the continental shelf narrows and continental slope becomes steeper (Woo et al. 2005).
3. Western edge of the Abrolhos Island chain (28–29° S, 113–114° E). The instabilities generated in the Leeuwin Current as it flows past Shark Bay and accelerates (see (2) above), together with interaction with the Leeuwin Undercurrent results in the generation of eddies in this region (Meuleners et al. 2005).
4. South-west of Jurien Bay (29–30° S, 114–115° E). The eddies generated offshore of the Abrolhos Islands have a length scale of approximately 200 km (Figure 2.1.5) and the interaction between the eddies generated to the north and the coastline at Jurien Bay results in the offshore movement of water resulting in the generation of eddies (Figure 2.1.5).
5. Perth Canyon (32° S, 115° E). The Perth canyon is the major topographic feature along the continental slope and has the effect of trapping eddies within the canyon. The influence of the Leeuwin Undercurrent in the formation of eddies has been documented by Rennie et al. (2005).
6. South-west of Cape Naturaliste and Cape Leeuwin. At Cape Leeuwin (34–35° S, Figure 2.1.5), the coastal topography undergoes a 90-degree change in orientation: to the north, flow along isobaths is directed to the south whilst to the south, the flow turns abruptly to the east.

7 South of Albany. Here, the coastal topography also undergoes a change in orientation: to the west, flow along isobaths is directed to the south-east whilst to the east, the flow is directed to the east-north-east.
8 South of Esperance. Similar to Albany, the changes in bathymetry, location of the numerous islands (Recherche Archipelago) result in the generation eddies.

Numerical Modelling studies of the Leeuwin Current system

Numerical modelling studies of the Leeuwin Current system have been predominantly large-scale investigations of the general ocean dynamics. Thompson (1987) investigated why the flow was poleward and why no upwelling was observed given the favourable alongshore wind stress. Weaver and Middleton (1989) using the Bryan-Cox Ocean General Circulation Model investigated the mechanisms for the generation of the Leeuwin Current. Batteen and Rutherford (1990, 1992) investigated the generation and stability of the Leeuwin Current using wind and thermal forcing respectively; they found mixed barotropic/baroclinic instability was the primary driving mechanism. Batteen and Butler (1998) also examined eddy development using thermal forcing and confirmed the earlier findings of Batteen and Rutherford (1990, 1992). Batteen and Huang (1998) investigated the effect of salinity on the density driven flow and found that both the temperature and salinity are required to accurately characterise the large-scale circulation of the Leeuwin Current system.

More recently, Griffin et al. (2001) simulated the ocean dynamics of the Leeuwin Current using the Regional Ocean Model System together with an idealised bathymetry to ensure computational stability, and a data-assimilation technique to force the model. The results simulated the observed features of the circulation, although there were discrepancies with the in situ observations of the surface current. However, Griffin et al. (2001) indicated that the model's poorest estimates of the surface velocity occurred where the model's topography differed most from the reality. All of the previous studies, including the current study, used a multi layered primitive equation model resolving the eddy field, explicitly. However, in the study of Griffin et al. (2001), a finer resolution model, incorporating detailed bathymetry and coastline features, is used to examine oceanic processes in a specific region.

Seasonal changes

Many investigators (see for example, Sturges 1974; Reed & Schumacher 1981; Pearce & Phillips 1988) have shown that changes in mean sea level monitored at tide gauges may be used to derive oceanographic information such as variations in flow and/or changes in thermohaline properties.

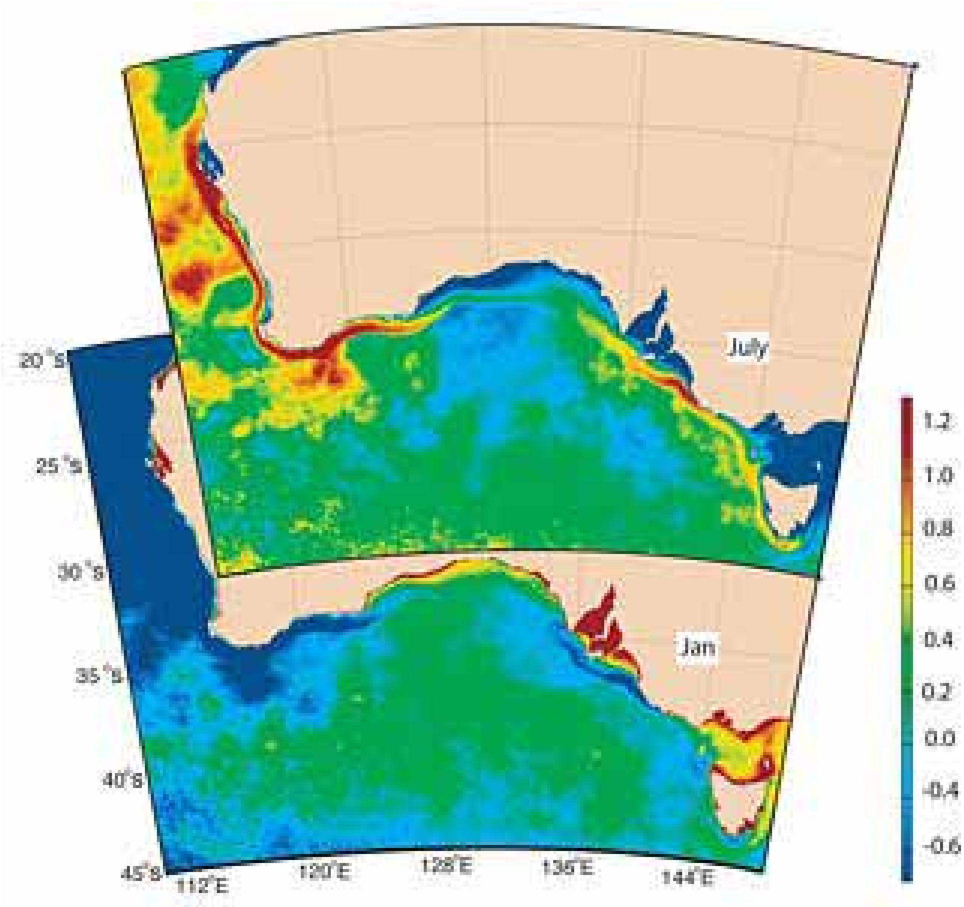

Figure 2.1.7 Composite satellite images of sea surface temperature anomalies in July and January showing the seasonal variability of the Leeuwin Current for the Western Australian region (Ridgway & Condie 2004). The anomalies represent departures from the annual mean.

For the Leeuwin Current, Pearce and Phillips (1988) have assumed that changes in the strength of the current are reflected in mean sea level changes that have annual mean amplitude of 20 cm (Pattiaratchi & Buchan 1991). Feng et al. (2003) demonstrated that the changes in Fremantle sea level anomalies (departures from the annual mean) result from changes in the strength of the Leeuwin Current. The sea level is higher between April and August than it is between October and January. During October to March the Leeuwin Current flows against the maximum southerly winds, whereas between April and August, the southerly winds are weaker (Godfrey & Ridgway 1985). Thus the Leeuwin Current is stronger during winter and weaker during the summer months due mainly to changes in the wind stress which is reflected in remotely sensed data (Figure 2.1.7).

Geographical distribution of the seasonal variations in mean sea level along the west coast of Australia indicates a progressive feature (Pariwono et al. 1986). On the North-west Shelf, the maximum occurs during March whilst in the south-west corner, the maximum occurs in May or June; this seasonal movement of the sea level maximum reflects the southward passage of the Leeuwin Current pulse (Church et al. 1989).

In summary, although the Leeuwin Current flows all year round, it exhibits a strong seasonality with the stronger flows occurring during the winter months (May–July) which is reflected in the coastal mean sea level. Godfrey and Ridgway (1985) have also shown that there is a very good correlation between the coastal mean sea level at Geraldton and the steric sea level. Hence, the mean sea level at Fremantle (or at any other south-west coast station) may be used as an indicator of the strength of the current.

Inter-annual variability

El Niño – Southern Oscillation events are the result of complex interactions between the ocean and the atmosphere in the tropical Pacific Ocean and have been associated with climatic and environmental anomalies around the world (Philander 1990). During El Niño – Southern Oscillation events, warm equatorial water from the western Pacific Ocean is transported eastward and flows southwards along the Peruvian coast to replace the cold, nutrient-enriched waters.

Pearce and Phillips (1988) have demonstrated a strong correlation between the Southern Oscillation Index (the normalised difference in surface atmospheric pressure between Darwin and Tahiti; a measure of the potential of El Niño – Southern Oscillation events), west coast sea levels (a measure of the strength of the Leeuwin Current; see above) and the Puerulus Settlement Index (a measure of recruitment to the rock lobster fishery). During normal years, the coastal annual mean sea levels are relatively high indicating that the Leeuwin Current is strong and the settlement of pueruli in coastal reefs is relatively high. During El Niño – Southern Oscillation years, coastal sea levels fall and the inferred transport in the Leeuwin Current is weaker (Feng et al. 2003).

As the Leeuwin Current is driven by the alongshore geopotential gradient, any changes to this gradient will result in changes to the strength of the current. Although the alongshore geopotential gradient is almost constant throughout the year, it varies during El Niño – Southern Oscillation events (Feng et al. 2003).

A weaker Leeuwin Current during an El Niño – Southern Oscillation event may be explained as follows: in a “normal” situation, the south-east trade winds in the Pacific Ocean set up high steric heights at the northern end of the Australasian continent; the gradient between these high steric heights and the thermally set low steric height off south-western Australia drives the Leeuwin Current. During El Niño – Southern Oscillation years, the trade winds relax and the steric height at the northern end of the Australasian continent is lower. This results in a decreased alongshore pressure gradient along the West Australian coastline resulting in a weaker Leeuwin Current.

The Leeuwin Undercurrent

The Leeuwin Undercurrent has received the least attention in the literature. Studies by Thompson (1984, 1987) indicated that there was an equatorward undercurrent flowing beneath the Leeuwin Current. Current meter data from the LUCIE experiment (Smith et al. 1991) confirmed the observations of Thompson (1987) and indicated that the equatorward undercurrent was narrow and situated between 250 m and 450 m in depth over the continental slope. The undercurrent transports 5 Svedrups of higher salinity (> 35.8 ppt) oxygen-rich nutrient-depleted water northward at a rate of 0.32–0.40 m s-1 (Thompson 1984). Measurements indicate that the current is stronger during November–January (Thompson 1984; Smith et al. 1991; Woo 2005).

The Leeuwin Undercurrent is driven by an equatorward geopotential gradient located at the depth of the undercurrent (Thompson 1984). This geopotential gradient or force arises from the equatorward slope of sea level (higher sea level to the north) and density (lighter, warmer water to the north). The sea level and density slopes oppose each other, but at depths of 250–450 m, the slope and resultant pressure force is to the north and drives the Leeuwin Undercurrent. Evidence of this pressure force, and by implication the Leeuwin Undercurrent, is apparent in the geopotential anomaly data at depths of 500 db/3000 db (Wyrtki 1971) and 450 db/1300 db (Godfrey & Ridgway 1985). Sub-surface slopes of 0.4×10^{-7} and 0.2×10^{-7} were reported by Thompson (1984) and Smith et al. (1991), respectively; Woo et al. (2005) estimated a slope to be much larger at 1×10^{-7}. These variations in slope are indicative of variations in the strength of the Leeuwin Undercurrent.

The Leeuwin Undercurrent is closely associated with the Subantarctic Mode Water (see Section 3.5). A feature of this water mass, resulting from convection to the region south of Australia, is high dissolved oxygen concentration and thus a cross-section of the Leeuwin Undercurrent core can be identified from the dissolved oxygen distribution; the core of the current consists of dissolved oxygen maximum (252 μM/L) centred at a depth of approximately 400 m (Figure 2.1.8).

The Leeuwin Undercurrent may be considered as an extension of the Flinders Current northwards along the west coast. The Flinders Current has a subsurface maximum located at 400 m depth adjacent to the continental slope similar to that of the Leeuwin Undercurrent. Along the south coast, the Flinders Current interacts with the Leeuwin Current at the shelfbreak, where the Flinders Current flows beneath the eastward-flowing Leeuwin Current similar to the Leeuwin Undercurrent observed on the west coast. This behaviour together with numerical model results (Figure 2.1.9) and temperature or salinity characteristics indicate that the Flinders Current is one source of the Leeuwin Undercurrent (Church et al. 1989; Woo et al. 2005).

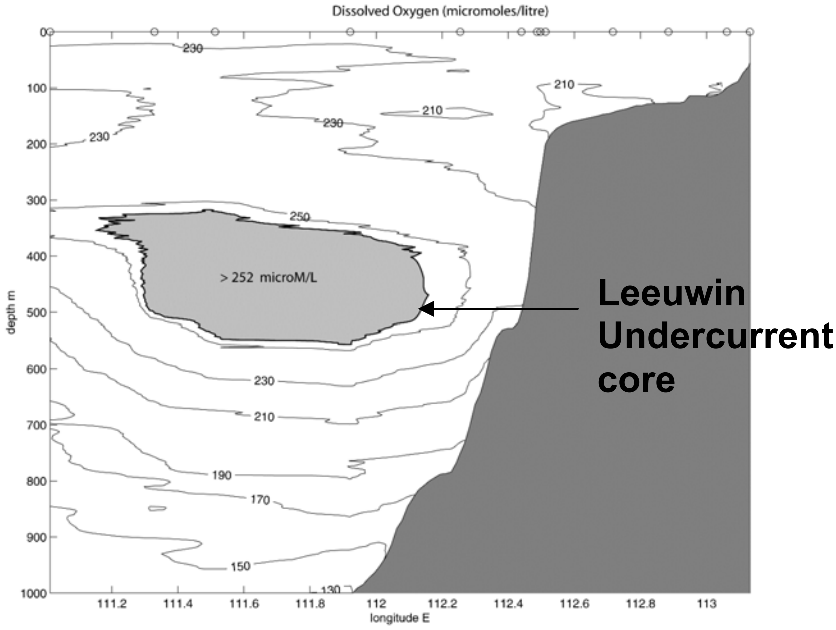

Figure 2.1.8 Cross-section of dissolved oxygen concentration along 29° S shows the presence of a >252 microM/L core at 400 m depth – which is interpreted as the core of the Leeuwin Undercurrent

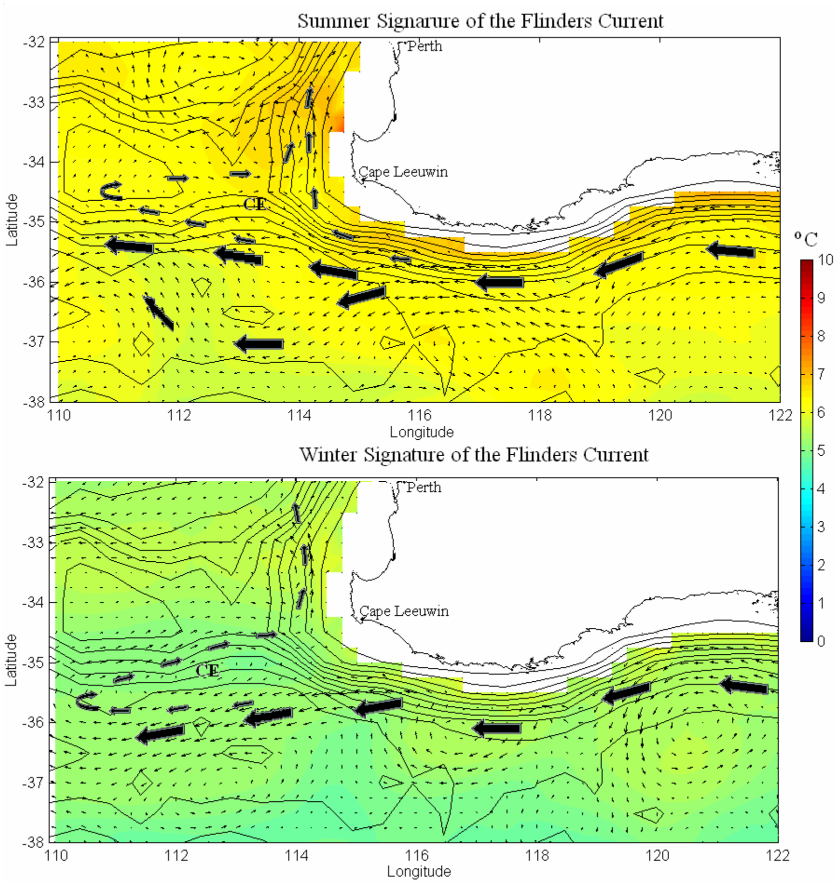

Figure 2.1.9 Velocity and potential temperature at 400 m depth during summer and winter obtained from the OCCAM global model showing the path of the Flinders Current along the south coast flowing from east to west. The continuation of the current northward along the west coast is the Leeuwin Undercurrent.

Coastal currents off Western Australia

The structure of the continental shelf circulation during the summer months along the west coast of Australia has been addressed in several recent studies using field data and satellite imagery (Cresswell et al. 1989; Cresswell & Peterson 1993; Pearce & Pattiaratchi 1997; Pearce & Pattiaratchi 1999; Gersbach et al. 1999; Woo et al. 2004). These studies have shown the existence of a cooler northward current on the continental shelf (the Capes and Ningaloo currents) with the southward-flowing Leeuwin Current, in general, located further offshore.

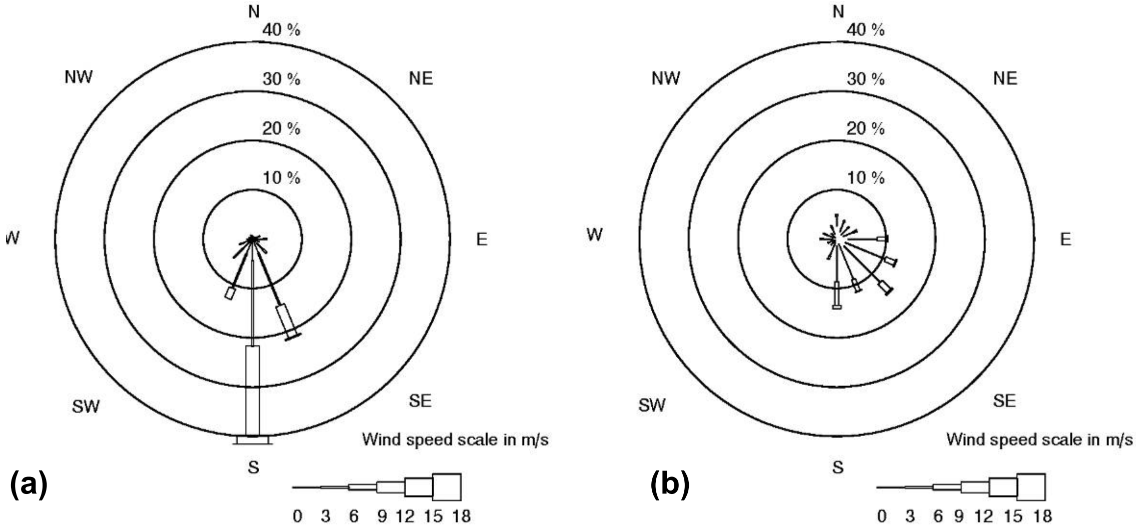

Figure 2.1.10 Seasonal wind roses from Rottnest Island showing the predominantly southerly winds during the summer (a) and variable wind directions during winter (b).

The Capes Current

Pearce and Pattiaratchi (1999) defined the Capes Current as a cool inner shelf current, originating from the region between capes Leeuwin (34° S) and Naturaliste, which moves equatorward along the south-western Australian coast in summer (figures 2.1.11 and 2.1.12). It has been postulated the Capes Current may extend as far north as the Abrolhos Islands (32° S); this has been confirmed through field data by Woo et al. (2005). The current is more saline (35.37–35.53 ppt) and cooler (21.0–21.4 °C) than the Leeuwin Current.

The Capes Current appears to be well established around November when winds in the region become predominantly southerly (Figure 2.1.10) due to the strong sea breezes (Pattiaratchi et al. 1997) and continues until about March when the sea breezes weaken. Gersbach (1999) has shown that the source water of the Capes Current arises from upwelling between capes Leeuwin and Naturaliste and is augmented by water from the south, to the east of Cape Leeuwin.

The dynamics of the Capes Current, off Cape Mentelle, has been described by Gersbach et al. (1999). Here, the southerly wind stress overcomes the alongshore pressure gradient. This results in the surface layers moving offshore, colder water upwelling onto the continental shelf, and the Leeuwin Current migrating offshore (Figure 2.1.13). Numerical model results have shown that a wind speed of 8 ms^{-1} is sufficient to overcome the alongshore pressure gradient on the inner continental shelf (Gersbach 1999).

The Capes Current is sourced from shallow upwelling of water from the bottom of the Leeuwin Current (~100 m) (Gersbach et al. 1999; Pearce & Pattiaratchi 1999; Hanson et al. 2005). This water mostly comes from the region between capes Naturaliste and Leeuwin.

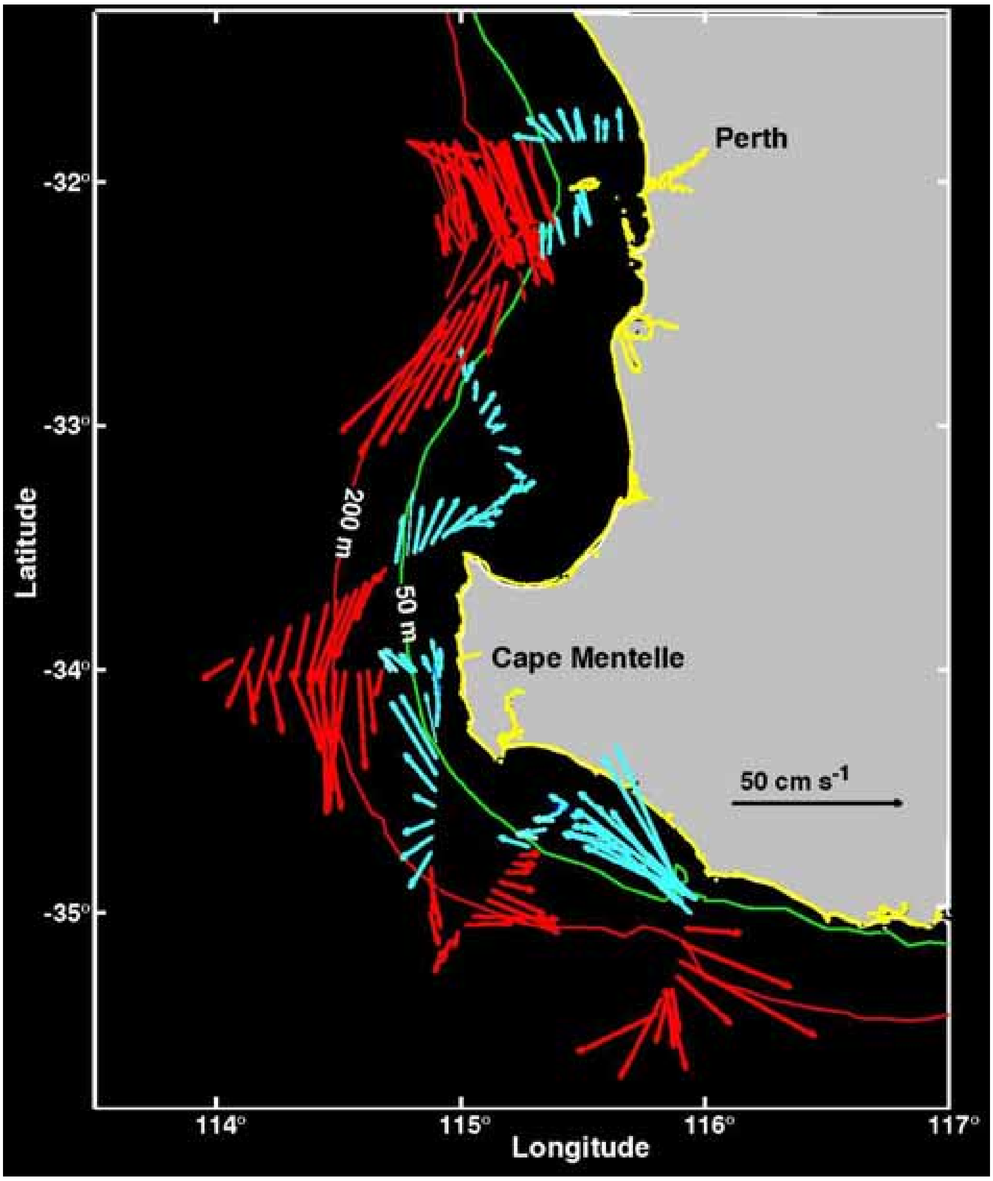

Figure 2.1.11 Depth averaged current vectors from 15–18 December 1994 showing the northward flowing Capes Current inshore of the 50 m depth contour (green) and the southward flowing Leeuwin Current (from Gersbach et al. 1999).

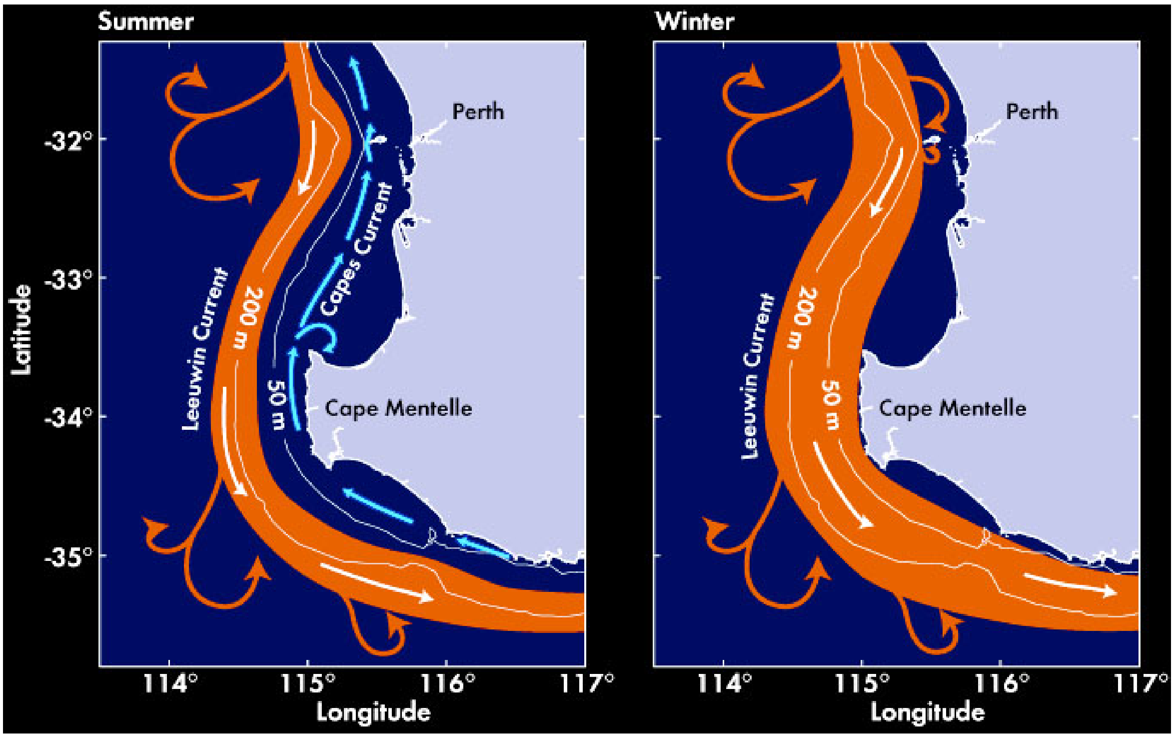

Figure 2.1.12 Schematic of the surface summer and winter current regime off south-western Australia (from Hanson et al. 2005)

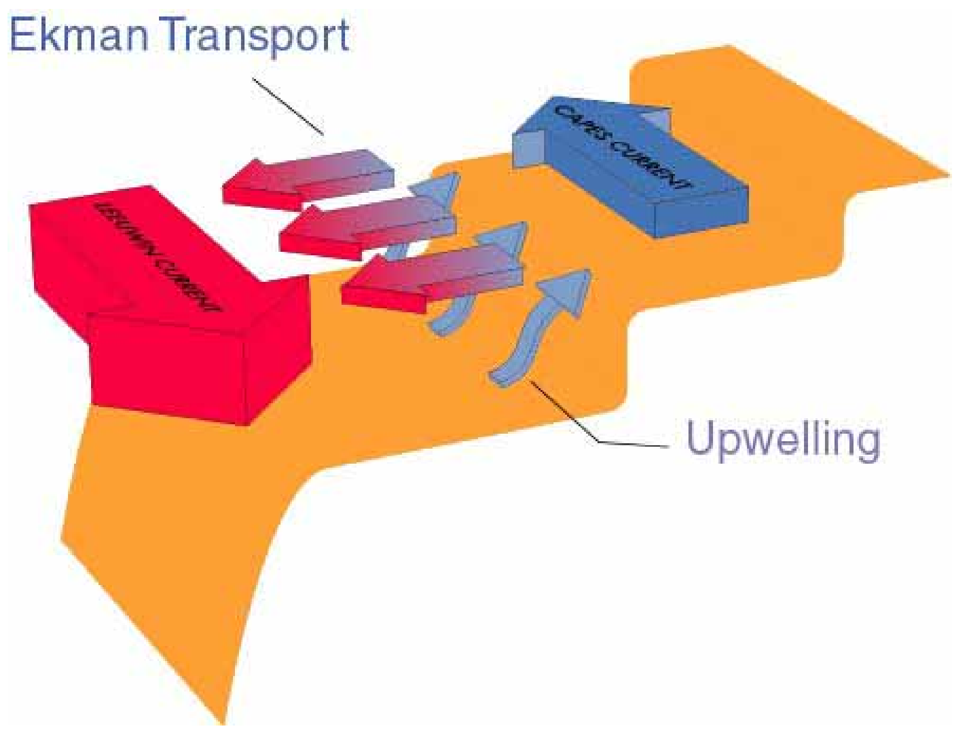

Figure 2.1.13 Cross-sectional schematic of the steady-state summer current regime off south-western Australia (from Gersbach et al. 1999)

Ningaloo Current

The Ningaloo Current, which is defined as a coastal current, is identical to the Capes Current and flows counter to the Leeuwin Current. It was observed in the north-west region of Western Australia between 21° S and 24.5° S. CTD and ADCP data indicated the coastal flow consisted of colder (<23 °C) saline (34.92 ppt) water when compared with offshore waters (Woo et al. 2005). Woo et al.'s (2005) field measurement data also showed the surface water mass, with a depth of 50 m, moved northward with the prevailing wind.

Cresswell Current

The dynamics of coastal circulation in the southern region are largely unknown. Upwelling of cold deep water in this region was observed in recent studies from the Recherche Archipelago and adjacent waters (van Hazel, 2001) and is illustrated by the schematic (Figure 2.1.14). It has been postulated that the wind-driven coastal current (the Cresswell Current) which moves westward with the south-easterly wind south of Western Australia in summertime, is similar to the Capes Current and the Ningaloo Current and causes this upwelling.

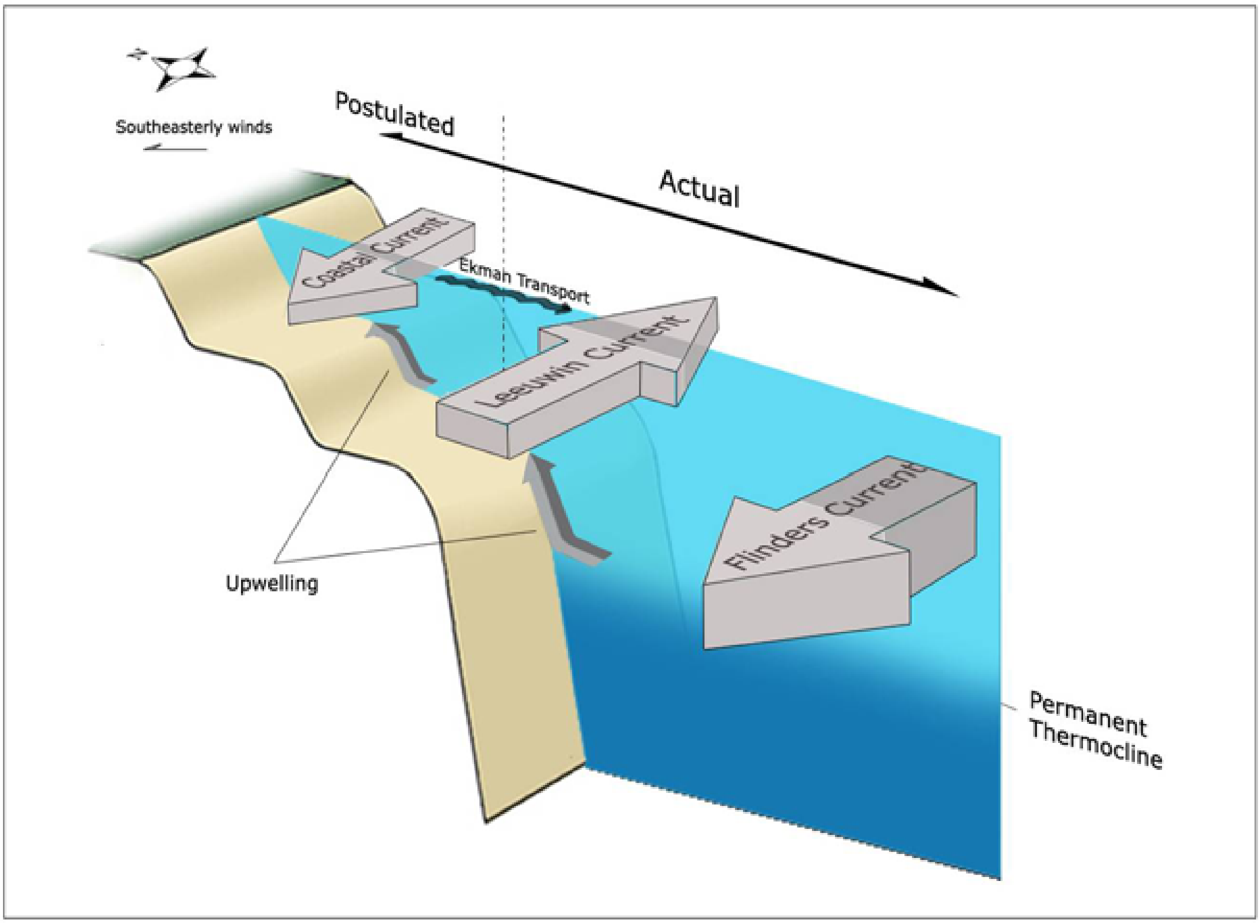

Figure 2.1.14 Cross-sectional schematic of summer current regime south of Western Australia, showing the Cresswell (or Coastal), Leeuwin, and Flinders currents

Water mass characteristics

Analysis of temperature data from bathythermographs and CTDs, reveals the general structure of the water column. Usually a well mixed layer exists at the surface and is produced by turbulent mixing; for example, by surface wind stress, and also by the presence of the Leeuwin Current. The well mixed layer is deeper within the Leeuwin Current than onshore or offshore. The variation in the well mixed layer can be greater than 100 m. The mixed-layer depth varies with season and with El Niño – Southern Oscillation events (Feng et al. 2003). Below the well mixed layer, the thermocline usually descends to around 400 m, although sub-layers may exist in this depth range. The seasonal changes include a cooler sea surface temperature corresponding to the austral winter, and a warmer sea surface temperature in the austral summer, with the deepest mixed-layer depths occurring during winter (Hamilton 1986; Feng et al. 2003).

Woo et al. (2005) identified five different water mass types in the upper Indian Ocean along the Western Australian coast (see Table 1) and they correspond with accepted classical water masses of the Indian Ocean (Wyrtki 1971; Warren 1981). These were observed in the vertical distribution of salinity and dissolved oxygen as interleaving layers of salinity and dissolved oxygen. In terms of increasing depth, these water masses were:

(i) lower salinity tropical surface water
(ii) higher salinity South Indian Central Water
(iii) higher oxygen Subantarctic Mode Water
(iv) lower salinity Antarctic Intermediate Water
(v) lower oxygen North West Indian Intermediate water

The location of each of the above five water masses and their position relative to each other can be identified for the whole length of the coastline from North West Cape (21° S) to Cape Leeuwin (35° S) using both salinity and oxygen (Figure 2.1.15). In the following sections, the characteristics of each of the water masses are discussed in detail.

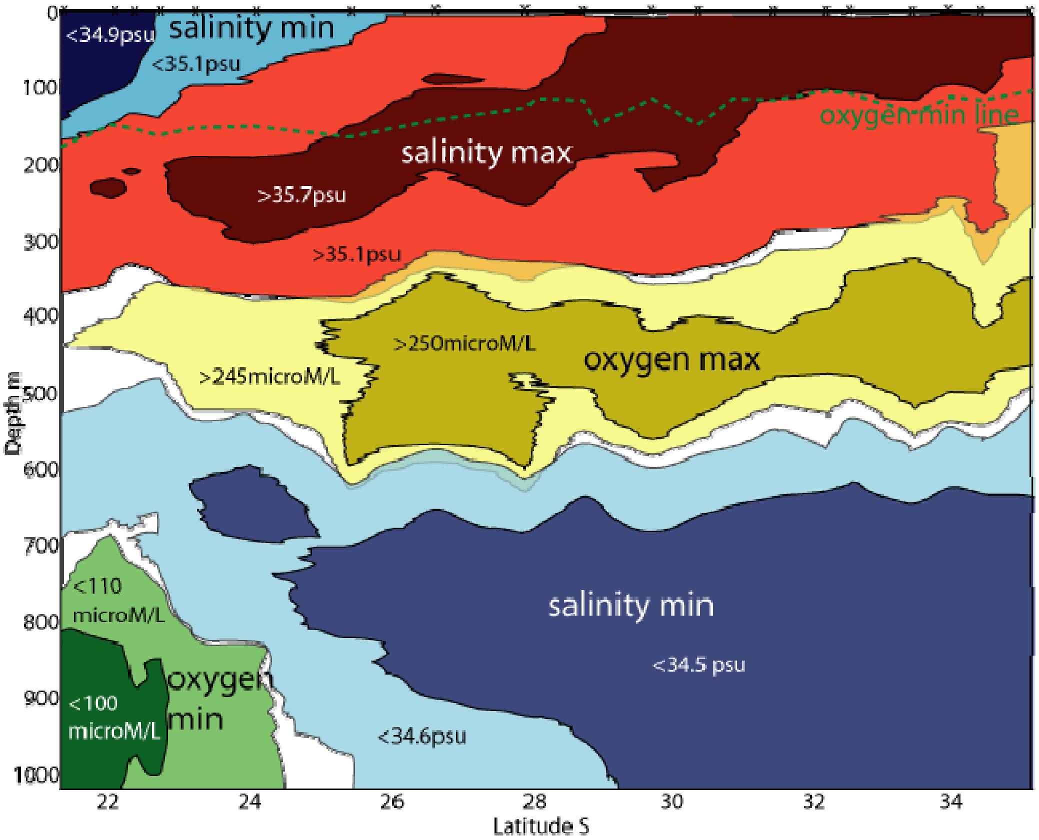

Figure 2.1.15 Major water masses observed at the 1000 m isobath along the Western Australian shelf. Asterisks on the surface indicate CTD station positions.

Table 2.1.1 Characteristics of the water masses found in the upper 1000 m of the water column along the Western Australian coastline

Water mass	Temperature range (°C)	Salinity range (ppt)	Dissolved oxygen range (µM/L)
Tropical surface water	**22–24.5**	**34.7–35.1**	**200–220**
South Indian Central Water	**12–22**	**35.1–35.9**	**220–245**
Subantarctic Mode Water	**8.5–12**	**34.6–35.1**	**245–255**
Antarctic Intermediate Water	**4.5–8.5**	**34.4–34.6**	**115–245**
North West Indian Intermediate water	**5.5–6.5**	**~ 34.6**	**100–110**

Tropical surface water – salinity minimum

In the top 300 m, a layer of lower salinity (<35.1 ppt) warmer (>22 °C) tropical water was found in the surface water in the northern region and corresponded with the temperature or salinity characteristics of the Leeuwin Current water. This water mass is derived from the Australasian Mediterranean Water (AAMW), a tropical water mass with origins in the Pacific Ocean Central Water and formed during transit through the Indonesian archipelago (Tomczak & Godfrey 1994). Tomczak and Godfrey's (1994) field data revealed that this surface water mass was associated with lower nutrient (near zero) and higher dissolved oxygen concentrations.

At the North West Cape (21° S), the northern extent of the study region, this water mass extends to 180 m (Figure 2.1.15) with the surface salinity less than 34.9 ppt. The depth of the water mass decreases southwards with the passage of the Leeuwin Current and at approximately 26° S its salinity signature (<35.1 ppt) disappears. This is due to the dynamics of the Leeuwin Current. The Leeuwin Current is driven by an alongshore geopotential gradient; entrainment of cooler more saline South Indian Central Water (see below) from offshore due to geostrophic inflow is a feature of the Leeuwin Current (Woo et al. 2005a).

South Indian Central Water – salinity maximum

South Indian Central Water is identified here as a salinity maximum layer (35.1–35.9 ppt). Along the 1000 m bathymetric contour, ADCP data revealed the core of the South Indian Central Water to be moving northward along the 26.8 (σT) density surface, with a maximum speed of 0.3 m s^{-1}. However, near the shelfbreak this same water mass is part of the Leeuwin Current flowing southwards (Woo et al. 2005a). Here, ADCP data indicated that the Leeuwin Current extends up to 300 m water depth which is the total depth of this water mass (Figure 2.1.15). South Indian Central Water had a temperature range of 12 °C to 22 °C and was associated with weak minima of dissolved nitrate, silica, and phosphate. It was found at the surface south of 29.0° S and the depth of the salinity maximum increased northward: from the surface at 29.0° S to 245 m at 21.5° S.

In the northern latitudes of the study region, the water mass subducted underneath the tropical surface water derived from Australasian Mediterranean Water. The observation of surface salinity maximum is in agreement with Wyrtki (1971) who found higher salinity water across the breath of the Indian Ocean surface at latitude range 25–35° S. At these latitudes, an excess of evaporation over precipitation forms the higher salinity water at the sea surface (Baumgartner & Reichel 1975). This water is then subducted below the surface water (Karstensen & Tomczak 1997), extending northward until 12–16° S (Church et al., 1989) where it meets the lower salinity Australasian Mediterranean Water flowing westward from the Indonesian archipelago in the South Equatorial Current (Sharma 1972; Tomczak & Godfrey 1994).

In addition to being termed 'South Indian Central Water' (Webster et al. 1979; Rochford 1969a) and 'Indian Central Water' (Karstensen & Tomczak 1997), this high salinity band has also been referred to as 'southern subtropical surface water'

(Muromtsev 1959), 'tropical surface waters' (Ivanenkov & Gubin 1960) and 'subtropical surface water' (Wyrtki 1973).

Subantarctic Mode Water – oxygen maximum

Beneath the South Indian Central Water, a water mass with high dissolved oxygen concentrations of 245–255 μM/L can be identified as Subantarctic Mode Water, the core of which occurred at 400–510 m. The data revealed that Subantarctic Mode Water consisted of water with a temperature range of 8.5–12 °C and salinity range of 34.6–35.1 ppt. Its density ranged between 28.9 ppt and 29.5 ppt.

Subantarctic Mode Water is formed by deep winter convection at 40–50° S in the zone between the Subtropical Convergence and the Subantarctic Front to the south of Australia (Wyrtki 1973; Colborn 1975; McCartney 1977; Toole & Warren 1993; Karstensen & Tomczak 1997). It is postulated that the Subantarctic Mode Water formed to the south of Australia is transported westward by the Flinders Current (Middleton & Cirano 2002) and is the source water for the Leeuwin Undercurrent, transporting water northward along the Western Australian coast (see below).

As Subantarctic Mode Water is formed by deep convection rather than subduction, newly formed Subantarctic Mode Water penetrates to a greater depth than the newly subducted South Indian Central Water (thus, it is comparatively better ventilated) and then moves northward from its formation region. Due to its high oxygen content, the Subantarctic Mode Water plays an important role in ventilating the lower thermocline of the southern hemisphere subtropical gyres (McCartney 1982).

Subantarctic Mode Water also corresponds to the Indian Ocean Central Water defined by Sverdrup et al. (1942). Subantarctic Mode Water and Indian Ocean Central Water often have similar temperatures and salinities; consequently Subantarctic Mode Water has been thought to contribute to the depth range of Indian Ocean Central Water (Karstensen & Tomczak 1997). According to Karstensen and Tomczak (1997), the source characteristics of Subantarctic Mode Water differ from region to region depending on prevailing atmospheric conditions during its formation.

Antarctic Intermediate Water – salinity minimum

Below the Subantarctic Mode Water,a salinity minimum (34.4–34.6 ppt) was observed, indicating the presence of Antarctic Intermediate Water along the coast. The water was cold (4.5–8 °C) and the position of its core became shallower northward (core depth of 875 m at 27.5° S and 520 m at 21.5° S). Its σT values spanned 30.3–31.0. It has been reported that the Antarctic Intermediate Water extends northward from the Antarctic Polar Front to latitudes 10–15° S, and is thought to flow more slowly than the oxygen maximum layer above it (Warren 1981).

Northwest Indian Intermediate water – oxygen minimum

An oxygen minimum signature of less than 110 μM/L in the northern region (21.3–24.5° S) indicated the presence of Northwest Indian Intermediate water immediately beneath the Antarctic Intermediate Water. Occupying depths of 800–1175 m, with density values of 31.8–32.4, its orientation implied southward deepening. As such, it is possible that North West Indian Intermediate water extends further south into the deeper ocean. The temperature of the North West Indian Intermediate water was recorded at less than 5 °C and its salinity ranged 34.55–34.6 ppt. North West Indian Intermediate water was associated with maxima of dissolved nitrate, silica and phosphate.

A similar water mass of Red Sea origin (Rochford 1964) was observed by Rochford (1961), Newell (1974), Webster et al. (1979), Warren (1981), and Toole and Warren (1993) in other regions of the Indian Ocean. The low oxygen values are the result of in-situ consumption of dissolved oxygen in water that has not been in contact with the atmosphere for a long time, presumably due to much slower overall horizontal flow at such depths (Warren 1981).

Leeuwin Current impacts

The anomalous condition that is a result of the Leeuwin Current strongly affects the meteorological and climatological responses of the environment in this region. It is clear that the driest terrestrial climates are found on the western sides of the southern continents of the earth. Western Australia's annual coastal rainfall at 32° S is 869.4 mm (data from Bureau of Meteorology website – Mount Lawley annual average rainfall), whereas corresponding locations in Chile and Namibia have annual coastal rainfall of less than 300 mm and 200 mm respectively (Gentilli 1991). This sharply decreases near the latitude 24° S, with Western Australia receiving 233.3 mm (Geraldton airport), Chile nearly nil and Namibia approximately 25 mm (Gentilli 1952). This rainfall differential is unusual considering that Western Australia is an analogue of these other locations (Smith 1989).

Gentilli (1991) indicates that the increased amount of rainfall received in Western Australia (compared to other supposedly analogous climates), is chiefly due to the absence of a cold-water current, and is not due to the presence of the warmer Leeuwin Current. However, this indicates that because of the presence of the Leeuwin Current and the subsequent movement of colder water further from the coast, greater rainfall occurs. On these grounds it is reasonable to attribute higher rainfall to the Leeuwin Current flow.

It can be extrapolated that the heat loss from the warm water of the Leeuwin Current to the atmosphere in the north-western shelf waters may be responsible for driving the poleward gradient and in turn driving the Leeuwin Current flow (Church et al. 1989). This too may be the one of the sources of higher rainfall over Western Australia's south-west when compared to western coastal boundaries of other continents in the southern hemisphere (Telcik 2000).

The effects of the Leeuwin Current on the shelf biology have been studied in depth. It has been documented exhaustively that the presence of the Leeuwin Current is the reason that tropical corals (and associated organisms) can exist as far south as Rottnest Island (32° S). Numerous studies have indicated that many marine species may depend on the Leeuwin Current and similarly on the Capes Current and similar inner-shelf currents for larval dispersal. In particular, studies by Caputi et al. (1996), Hutchins (1991) and Phillips et al. (1991) have analysed the effect of the Leeuwin Current on the dispersal of tropical fish species and the Western Rock Lobster.

The study by Caputi et al. (1996) indicates that due to the presence of the Leeuwin Current (and resulting warmer surface waters), the system is dominated by invertebrate species, rather than finfish – an anomalous condition compared to other eastern boundary flows. Caputi et al. (1991) attributes this to the low productivity of the system as a result of the low nutrient concentration of the contributing Northwest Shelf waters. A study undertaken by Lenanton et al. (1991) supported the study by Caputi et al. (1991) and agreed that the lack of nutrients reduced finfish numbers. For this reason it was indicated that higher numbers of finfish were found in the highly productive estuarine and protected coastal marine systems. The dependence on terrestrial inputs and the limited period of these (winter/spring) in the south-west, indicated a highly competitive environment for finfish development (Lenanton et al. 1991).

Hutchins (1991) indicates that the presence of several species of reef dependent tropical fish and the presence of coral reefs as far south as 32° S (Rottnest Island – and extending to 29° S) are both attributable to the presence of the Leeuwin flow. The coral *Pocillopora damicornis* is the chosen habitat for several tropical fish species, preferring the protected inner lagoon regions, whereas the more exposed regions on the outside reef are typical of temperate reef systems, with corresponding species dominating (Hutchins, 1991).

Phillips et al. (1991) studied the recruitment of rock lobster larvae and its relationship to the strength of the Leeuwin Current. A link between the settlement and the inter-annual variability of the Leeuwin flow is understood to control the dynamics of the fishery (Phillips et al., 1991). It was recorded during the years of 1986 and 1987 (years of uncharacteristically weak Leeuwin Current flow; El Niño – Southern Oscillation years) that no settlement of the larvae occurred (Phillips et al. 1991). This indicates the vital role that the poleward Leeuwin Current plays in recruitment and settlement of the puerulus stage of the rock lobster's life cycle.

2.2 Esperance to Robe

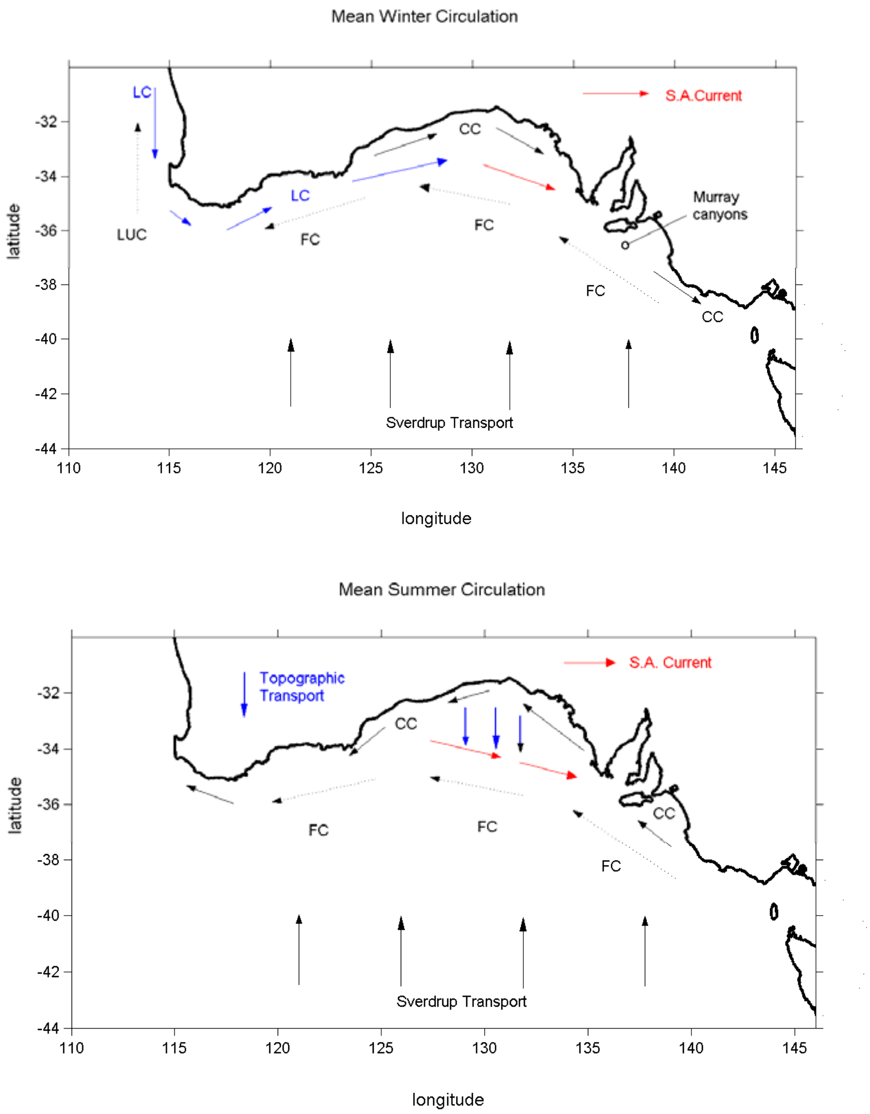

Figure 2.2.1 **Upper panel**: A schematic of some key circulation features for winter, including the Leeuwin Current, the Leeuwin Undercurrent, the Flinders Current and the shelf-edge South Australian Current. Water is downwelled throughout and there is a dense salty outflow from the gulfs. **Lower panel**: Summertime circulation and upwelling occurs off Kangaroo Island and the Bonney Coast. Shelf edge downwelling may occur in the western Great Australian Bight.

Summary

The region between Cape Leeuwin and Portland hosts the world's longest zonal mid-latitude shelf (~2500 km). The topography includes both the very wide shelf of the Great Australian Bight, as well as the very steep and narrow shelves off Esperance, Kangaroo Island and the Bonney Coast (Figure 1.1.1). The shelves are punctuated by the gulfs and promontories of the Eyre Peninsula, Kangaroo Island and the

Bonney Coast. This varied topography, coupled with the forcing by the circulation of the Southern Ocean and local winds, leads to a complex shelf and slope circulation that is highly seasonal and dependent on the local and remote wind forcing and (density driven) thermohaline circulation.

Uniquely, the long, zonal shelf is subject to an equatorward Sverdrup transport from the Southern Ocean (Figure 2.2.1) that is largest in early summer. This transport gives rise to the Flinders Current that is a small sister to the world's major western boundary currents including the Gulf Stream and the East Australian Current. (These western boundary currents arise from the equatorward Sverdrup transport over the entire North Atlantic and South Pacific basins and are typified by strong currents (~50–100 cm/s)). The Flinders Current is thought to be driven mainly by the transport south of Australia. It is trapped to the 600 m isobath where the current speeds can reach 20 cm/s and the bottom boundary layer is upwelling favourable. The Flinders Current is smaller in the east and is likely to be intermittent in both space and time possibly due to opposing winds, thermohaline circulation and the presence of mesoscale eddies along the slope. The Flinders Current may be important to deep upwelling within the ubiquitous canyons of the region.

During winter, the warm inflow of the Leeuwin Current is largely trapped by the shelfbreak and the associated thermohaline circulation may account for around 35% of the total shelf transport off the Eyre Peninsula. The westerly winds drive some 47% of the total transport and the eastward currents average up to 20–30 cm/s. The currents associated with the intense coastal-trapped wave field (6–12 day band) are in order of 25–30 cm/s and can peak at 80–90 cm/s. These winds and wintertime cooling also lead to downwelling to depths of 200 m or so. The net evaporation leads to the outflow of dense salty water from the gulfs and to depths of 300 m on the slope and south-east of Kangaroo Island. The dense water outflow and meanders in the shelf circulation also appear to fix the locations for the growth of mesoscale eddies between the Eyre Peninsula and Portland. Such eddies (~50 km radius) detach from the shelf at the end of winter and may be important to cross-shelf exchange.

During summer, the coastal winds reverse on average and the surface heating leads to the formation of warm water in the western Great Australian Bight and gulfs. No significant exchange of shelf water with the gulfs appears to occur. The winds lead to weak average coastal currents (<10 cm/s) that flow to the north-west (Figure 2.2.1b). In the Great Australian Bight, the wind stress curl can lead to an anticyclonic circulation gyre that can result in shelf-break downwelling in the western Great Australian Bight and an eastward South Australian Current (Figure 2.2.1b). These relatively weak circulation features can be modulated or overwhelmed by variations in the wind and thermohaline circulation.

In the east, upwelling favourable winds and coastal-trapped waves can lead to deep upwelling events off Kangaroo Island and the Bonney Coast that occur over 3–10 days and some 2–4 times a season. The alongshore currents here can be large (~40 cm/s) and the vertical scales of upwelling are of order 150 m (off Kangaroo Island) and 250 m (off the Bonney Coast).

An increasing amount of evidence suggests that El Niño events (4–7 year period) can have a major impact on the winter and summer circulation. These events propagate from the Pacific and around the shelf-slope wave-guide of Western Australia and into the Great Australian Bight. During winter El Niño events, the average shelf currents may be largely shut down. During summer, the thermocline appears to be raised by up to 150 m and impacts on the upwelling off Kangaroo Island and the Bonney Coast.

Surface waves are also important to sediment stirring. The mean (significant) wave height during summer and winter is around 2.3–2.8 m, with dominant periods and wavelengths of 7–9 s and 88–126 m. On average, the wave direction is from the south-west and south. The bottom velocities of these waves can exceed 20 cm/s for 30–60 days of each year, and 40 cm/s for 0–10 days each year. Time averaged currents of these waves can transport surface material and biota by more than 300 km over a one-month period. While tidal velocities are large (~50 cm/s) within the gulfs, they are small (~2–5 cm/s) on the shelves and within the Great Australian Bight.

Shelf slope currents and the Flinders Current: the “mean” seasonal picture

Summary

Limited observations and output from ocean circulation models indicate the existence of a shelf slope Flinders Current that may flow from Tasmania to Cape Leeuwin (Figure 2.2.1). This current has maximum amplitude at depths of 600 m or so and increases in magnitude from 5 cm/s in the east to 20 cm/s in the west, where it forms part of the Leeuwin Undercurrent during winter. The Flinders Current is driven by the equatorward Sverdrup transport in the Southern Ocean and based on wind stress observations, it should be largest in early summer. The bottom boundary layer of the Flinders Current extends some 50 km from the shelf and is necessarily upwelling favourable. The Flinders Current may therefore be important to preconditioning for wind-forced upwelling during summer.

The magnitude of the Flinders Current is, however, affected by cross-shelf density gradients and winds and may vanish or even reverse direction. In addition, the Flinders Current is affected by mesoscale eddy variability that is largest in the west off Albany and off the gulfs region of South Australia. The Flinders Current may well provide a deep westward conveyor belt for the region. More importantly, the cross-shelf pressure gradients associated with the Flinders Current and warm core eddies might be important to upwelling within canyons and might drive nutrients and sediments towards the shelfbreak, where wind-forced upwelling can be important.

The eddy field is strongest during winter, and there is strong evidence for the existence of a sequence of alternating high (warm) and low (cold) eddies along the slope between the Eyre Peninsula and the Bonney Coast: such eddies may detach at the end of winter, when the shelf currents reverse, leading to a significant exchange of water between the shelf slope and deep ocean.

An overview

The existence of the Flinders Current along Australia's southern shelves was first noted in the analysis of hydrographic data of Bye (1972). The dynamics of the current were subsequently explored by Bye (1986) and Godfrey (1989); the latter noted that a north and westward transport for the region should exist in his global analysis of Sverdrup transport. Indeed, the Flinders Current results from the curl of the wind stress that when averaged over the summer and winter periods (figures 2.2.2 and 2.2.3), leads to an equatorward Sverdrup transport in the Southern Ocean as illustrated in Figure 2.2.1.

Along Australia's southern shelves, this transport is deflected to the west leading to the Flinders Current. Middleton and Cirano (2002) have analysed results from the OCCAM global ocean model (Webb et al. 1998) and found the Flinders Current to be trapped along the slope (600 m), largest in the west (20 cm/s) and seasonal in strength (see below). In addition, the bottom boundary layer is necessarily upwelling favourable leading to an upward tilt of isotherms 50 km or so from the slope.

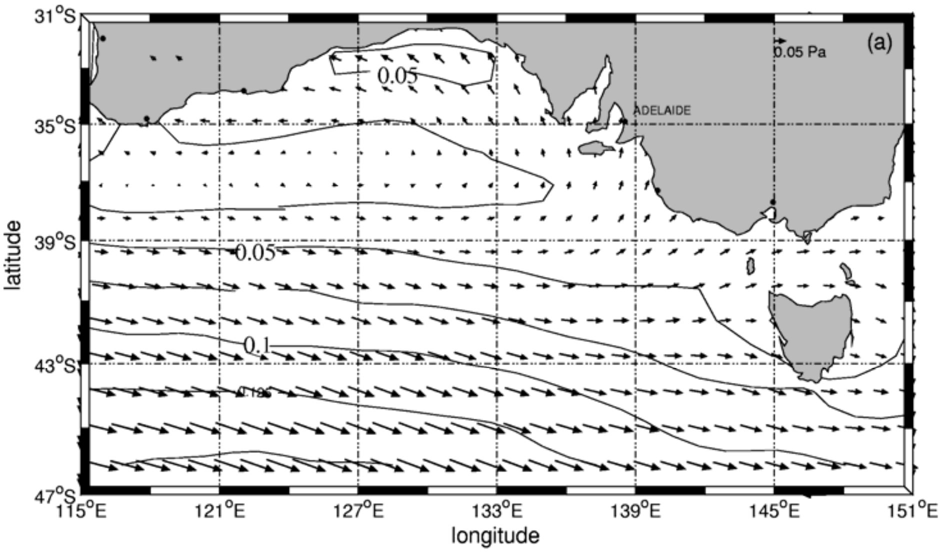

Figure 2.2.2 The mean wind stress field for summer. A legend vector of 0.05 Pa is indicated.

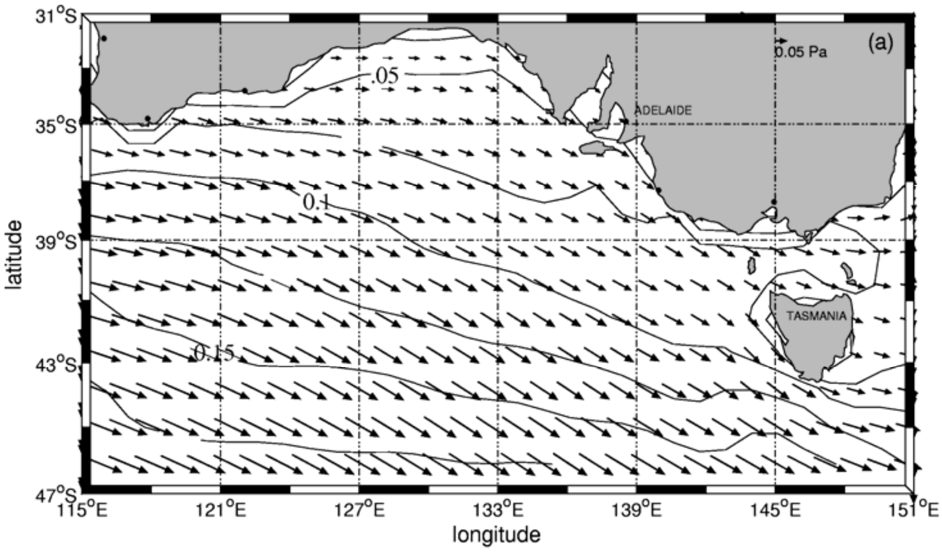

Figure 2.2.3 The mean wind stress field for winter. A legend vector of 0.05 Pa is indicated.

For winter and for a western section off Cliffy Head (~118° E), observations (Figure 2.2.4) show the maximum westward speed to be about 20 cm s^{-1} at a depth of 400–600 m. At and below this depth, the isotherms are upwelled and the associated thermal wind shear acts to reduce the magnitude of the boundary current to near zero at a depth of 1000 m. Above 400 m, the isotherms are downwelled as a result of the wind forcing and cooling. Very warm (>19 °C) water is also found within 50 km of the coast and at depths of 100 m or less. This Leeuwin Current water has speeds of 50–100 cm s^{-1} (see also Church et al. 1989). The Flinders Current also acts to feed the Leeuwin Undercurrent that is observed on the Western Australian slope.

Including the transect shown in Figure 2.2.4, there are but a handful of observations of the Flinders Current and these are summarised by Middleton and Cirano (2002). In summary, the observations are largely indirect but do provide evidence for the Flinders Current as outlined above. An example comes from the hydrographic analysis and data of Schodlok and Tomczak (1997a, b). The latter is presented in Figure 2.2.5 and shows the deep thermocline (500–1000 m) to be upwelled towards the coast and over a distance of 100 km (Figure 2.2.5) – a signature of the Flinders Current.

Seasonal and eddy variability

The magnitude of the Flinders Current is affected by seasonally varying winds (Sverdrup transports), mesoscale eddies and the density field and associated shelf slope currents. The importance of these factors is discussed below.

Winter circulation
In order to determine seasonal variability, the monthly averaged Sverdrup transport along the 39° S zonal section (122–140° E) has been determined using daily winds from a global climatology (NCEP/NCAR). The averaged results in Figure 2.2.6 show the Sverdrup transport, and by implication the Flinders Current, to be generally seasonal, with smallest values (~4 Sv) during winter and largest values (~7 Sv) during early summer.

Using the (smaller) winter Sverdrup transports and mean winter winds (Figure 2.2.3), Cirano and Middleton (2004) obtained numerical results for the circulation of the region that are illustrated by the schematic in Figure 2.2.1. These suggest the existence of a strong (~20 cm/s) eastward flowing coastal current over the shelf (discussed below). Over the slope, an equatorward Flinders Current is found to extend from Tasmania to Cape Leeuwin with maximum amplitudes of 10–15 cm/s and at depths of 600 m or so. In the east, the Flinders Current is forced by a bifurcation of the Tasman Outflow that is in turn forced by the East Australian Current. Off Kangaroo Island and to the west, the Sverdrup transport becomes increasingly important in driving the Flinders Current.

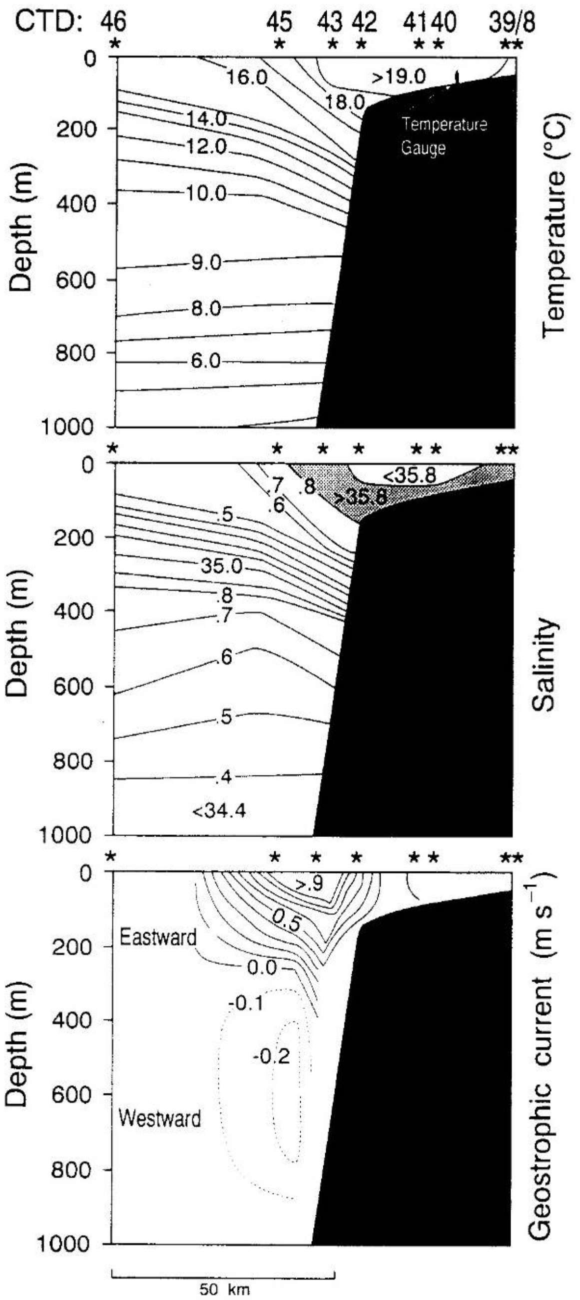

Figure 2.2.4 Cross-shelf ADCP and CTD sections obtained during June by Cresswell and Peterson (1993). Station numbers 38–43 are indicated at the top of the plot.

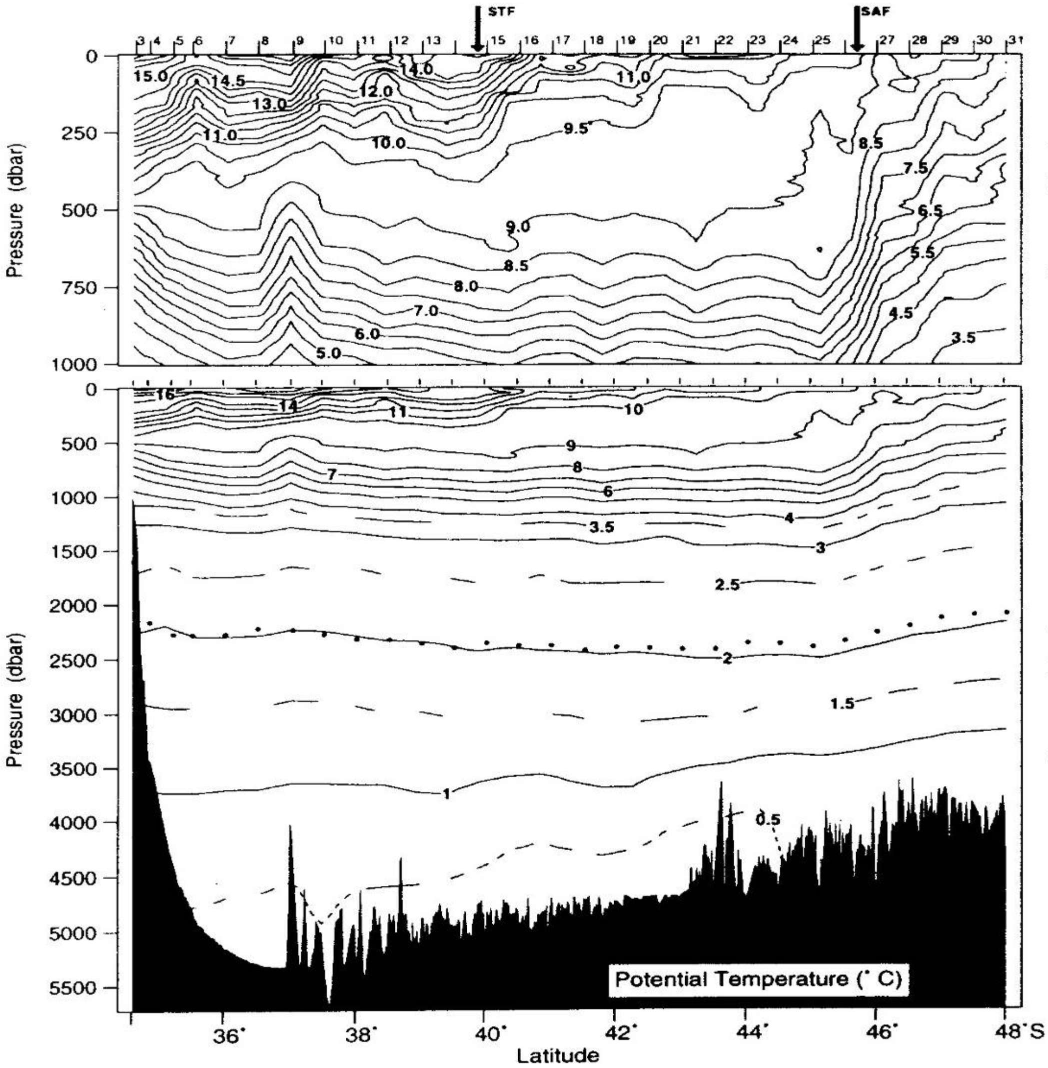

Figure 2.2.5 Isotherms (°C) for a temperature section obtained by Shodlock and Thomczak (1997b) for the November period at 120° E . A detail of the top 100 m is given in the upper panel and illustrates the deep upwelled bottom boundary layer of the Flinders Current. The vertical axis gives depth in terms of pressure where 1 dbar equals 1 m. Station numbers 3–31 are indicated at the top of the plot along with the locations of the Sub-tropical Front (STF) and the Sub-Antarctic Front (SAF).

Winter Eddy variability

Off the Kangaroo Island – Eyre Peninsula region, a sequence of quasi-permanent (wintertime) eddies also seem to be important in modulating the strength of the Flinders Current. Evidence for these eddies is given in the altimeter data analyses of Ridgway and Condie (2004) and their sea surface height anomalies shown in Figure 2.2.7. For the July period, the anomalies indicate the presence of an alternating sequence of high-pressure (warm-core) meanders off the topographic promontories associated with the Eyre Peninsula, Kangaroo Island and the Bonney Coast. Low pressure (cold core) eddies are found between these sites, farther offshore and at locations where the shelf widens (Spencer Gulf and the Coorong).

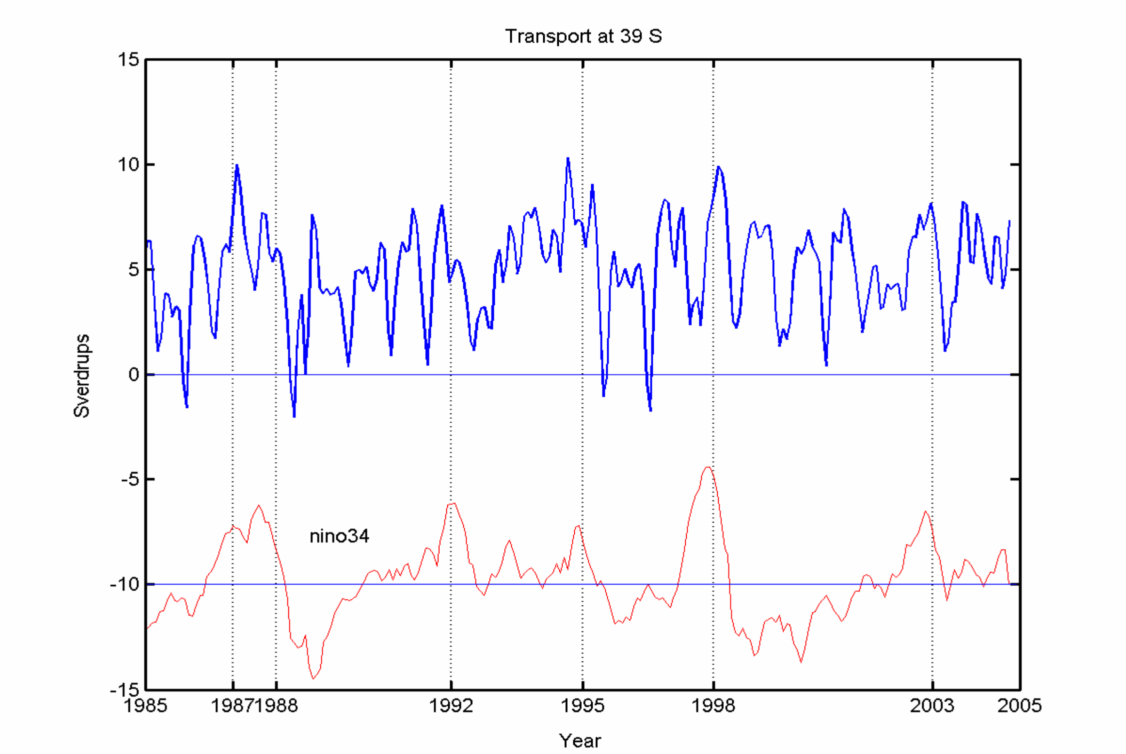

Figure 2.2.6 The monthly averaged Sverdrup transport calculated at 39° S (122–140° E) based upon the NCEP wind stress curl (units Sverdrups). The (non-dimensional) nino34 index is indicated in red: values above -10 indicate El Niño conditions; the vertical dashed lines denote significant El Nino summers.

Similar high and low pressure eddies are found at just these locations in the numerical study of Cirano and Middleton (2004) (see Figure 2.2.12 below); an explanation is given for the growth of the eddies. Further evidence for the formation of a quasi-permanent, low-pressure (anticyclonic) eddy off Kangaroo Island was outlined by Godfrey et al. (1986). Their CTD measurements indicate that salty water flows out from Spencer Gulf during winter and then around to the south of Kangaroo Island at depths of 300 m (Figure 2.2.8). Such an outflow will act to enhance the quasi-permanent (winter) anticyclonic eddy off Kangaroo Island (Cirano & Middleton 2004) that is observed in both altimeter data noted above and also in drifter data (Godfrey et al. 1986; Hahn 1986).

The sea surface height data (Figure 2.2.7) also suggests the eddy variability to be smaller in the mid–Great Australian Bight region, but quite intense in the far west due to instabilities of the Leeuwin Current. Drifter trajectories, CTD surveys and ADCP data all indicate the formation of a large anticyclonic eddy off Albany. The eddy here appears to be quasi-permanent and related to an offshore meander of the Leeuwin Current as it rounds Cape Leeuwin (Ridgway & Condie 2004; Godfrey et al. 1986; Cresswell & Peterson 1993). The radial currents associated with the warm (cold) core eddies over the shelf slope can act to enhance (retard) the Flinders Current and increase upwelling and downwelling through the bottom boundary layer and within canyons (see below).

More recently, Ridgway (pers. comm., 2005) has determined the monthly sea level anomalies for the entire year. An animation of these anomalies shows that the pattern of winter high/low eddies apparent in Figure 2.2.7 becomes detached when the winds and coastal current reverse to be westward. The eddies then detach from the slope region and propagate to the west.

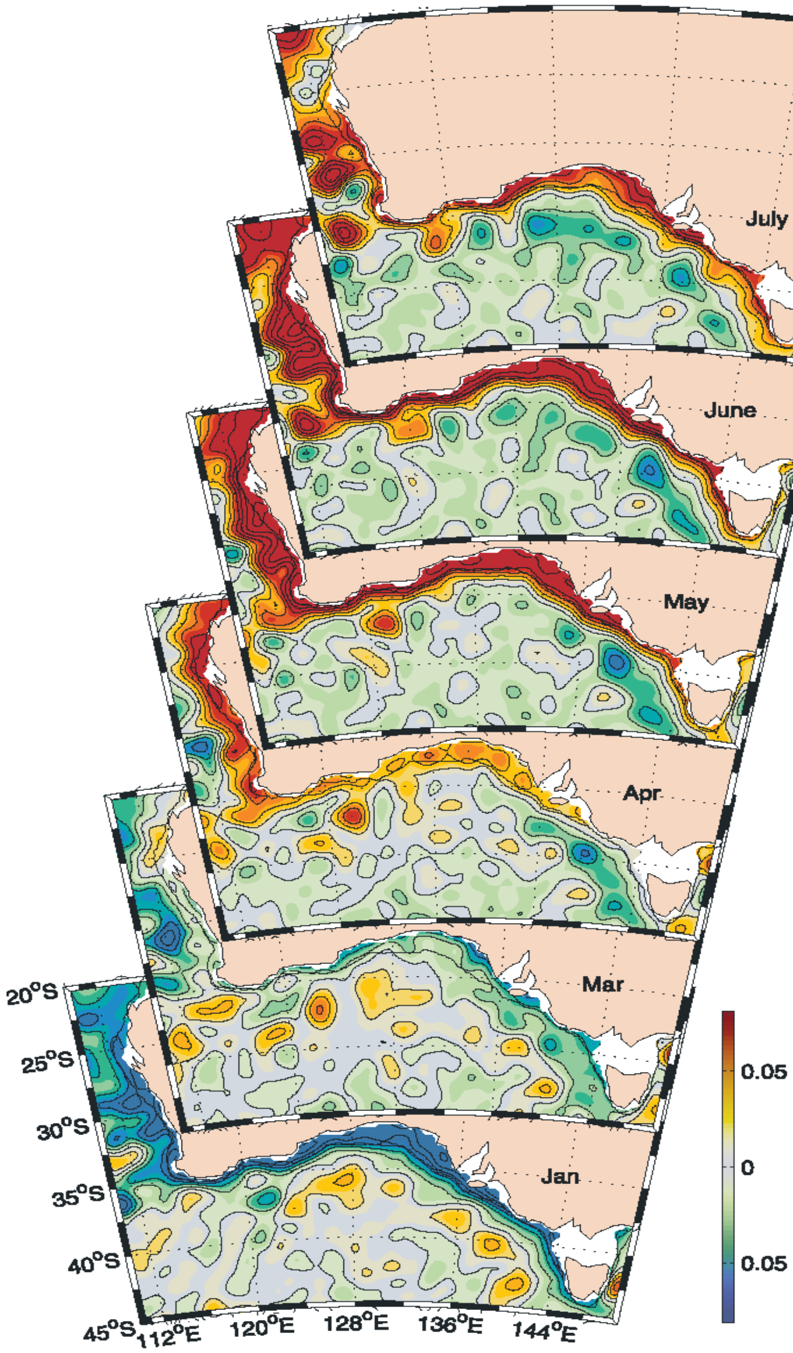

Figure 2.2.7 Sea surface height anomalies inferred from altimeter and coastal sea level data by Ridgway and Condie (2004). The vertical side bar gives height in metres.

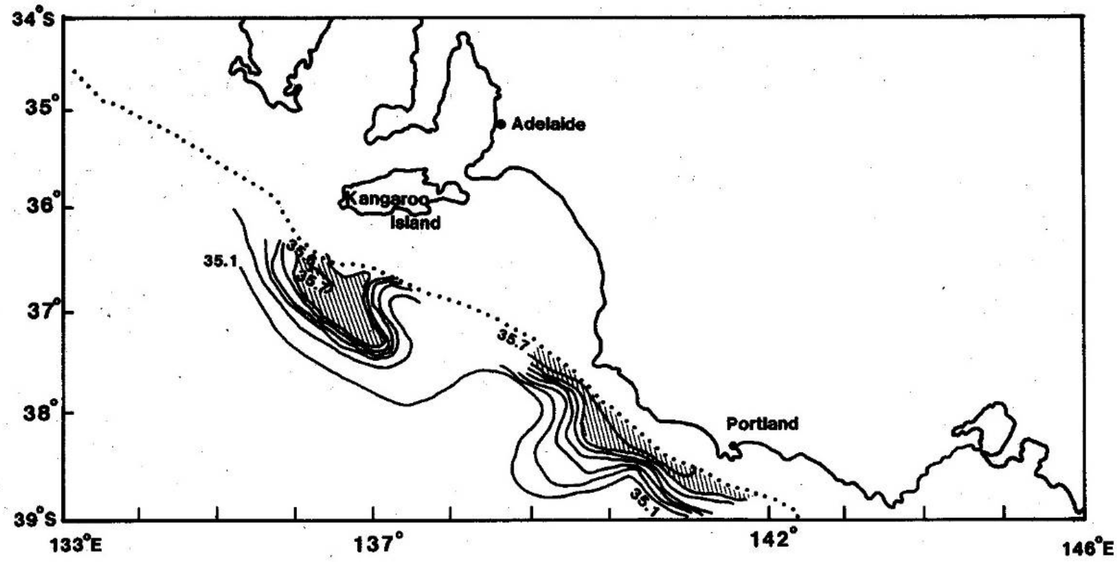

Figure 2.2.8 The salinity (ppt) at a depth of 200 m as determined by Godfrey et al. (1986) during June–July 1982

Summer circulation

As noted, the Sverdup transport is larger in early summer and should drive a stronger Flinders Current than found during winter. Middleton and Platov (2003) have developed a model that is driven by the summer mean winds and (larger) summer Sverdrup transports. The coastal winds reverse during summer, the Leeuwin Current is absent and the shelf-slope circulation is very different to that found during winter. As shown in the schematic (Figure 2.2.1) and numerical results (Figure 2.2.10), the coastal current flows to the west and an anticyclonic (anticlockwise) gyre is found in the Great Australian Bight. The seaward arm of this gyre opposes the underlying Flinders Current. Given the larger Sverdrup transports, the Flinders Current is surprisingly weaker in summer than in winter and is only found in the western half of the Great Australian Bight where the maximum amplitude is in the order of 5–10 cm/s at depths of around 400 m (Figure 2.2.10). We now review the causes of these circulation features.

Wind effects

During summer, the reversal of the winds (to be westward) leads to profound changes in the shelf and slope circulation. An anticyclonic gyre is evident in the Great Australian Bight and shoreward of the 200 m isobath (Figure 2.2.9). This gyre is driven by the positive wind-stress curl in the Great Australian Bight and leads to a poleward (seaward) topographic Sverdrup transport. Herzfeld and Thomczak (1999) found a similar result in their numerical study.

Middleton and Platov (2003) showed that in the western half of the Great Australian Bight, this transport converges with the (deep sea) Sverdrup transport leading to downwelling along the shelfbreak and the raising of sea level. Such downwelling is illustrated by the numerical solutions for a mid–Great Australian Bight section shown in Figure 2.2.10. Middleton and Platov (2003) cited profiles of CARS data as evidence of such summertime downwelling.

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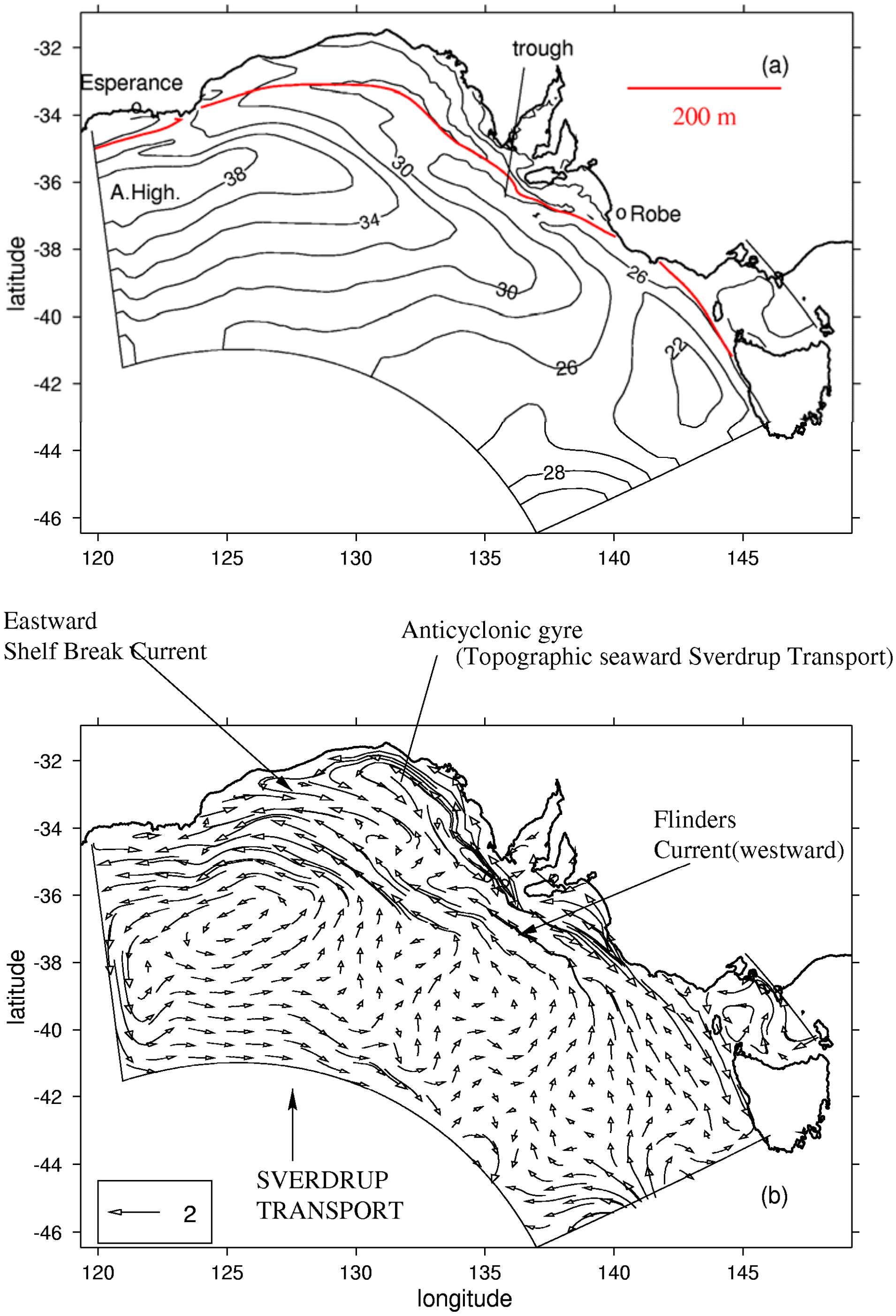


Figure 2.2.9 a) The sea level (units cm) and b) depth-averaged velocity from the numerical model of Middleton and Platov (2003) as driven by summertime mean winds. A vector length of 2 cm/s is indicated in (b) along with some major current systems.

In an analysis of sediment samples, James et al. (2001) also concluded that downwelling must occur along the shelfbreak and in the western half of the Great Australian Bight.

Middleton and Platov (2003) point out that the convergence of the two Sverdrup transport fields also acts to raise sea level leading to an eastward shelfbreak current that opposes the Flinders Current, and which flows as far as the Eyre Peninsula (Figure 2.2.9). This summer (and winter) current has been called the South Australian Current (Black 1853; James et al. 2001; Hahn 1986). Evidence for it is given in the SST images of Herzfeld (1997): see plate 12 in Figure 2.2.11. Indeed, some of the warm water formed in the north-west of the Great Australian Bight during summer is subsequently transported along the shelf edge indicating the existence of both an eastward shelf current and an anticyclonic gyre within the Great Australian Bight. The SST anomalies of Ridgway and Condie (2004) support this scenario.

In contrast to the numerical results cited above, Ridgway and Condie (2004) suggest that the (summer) sea level gradients indicated in Figure 2.2.7 are the surface manifestation of a Flinders Current that flows across the entire Great Australian Bight. However, without further data, the extent of the Flinders Current cannot be determined.

Summer Eddy variability

The summer sea level anomalies presented by Ridgway and Condie (2004) (Figure 2.2.7), also show that the eddy variability is much weaker during summer than winter. A possible reason for this is that the shelf coastal current, now directed to the west is much weaker than during winter so that offshore meanders and the resultant eddies are also weaker.

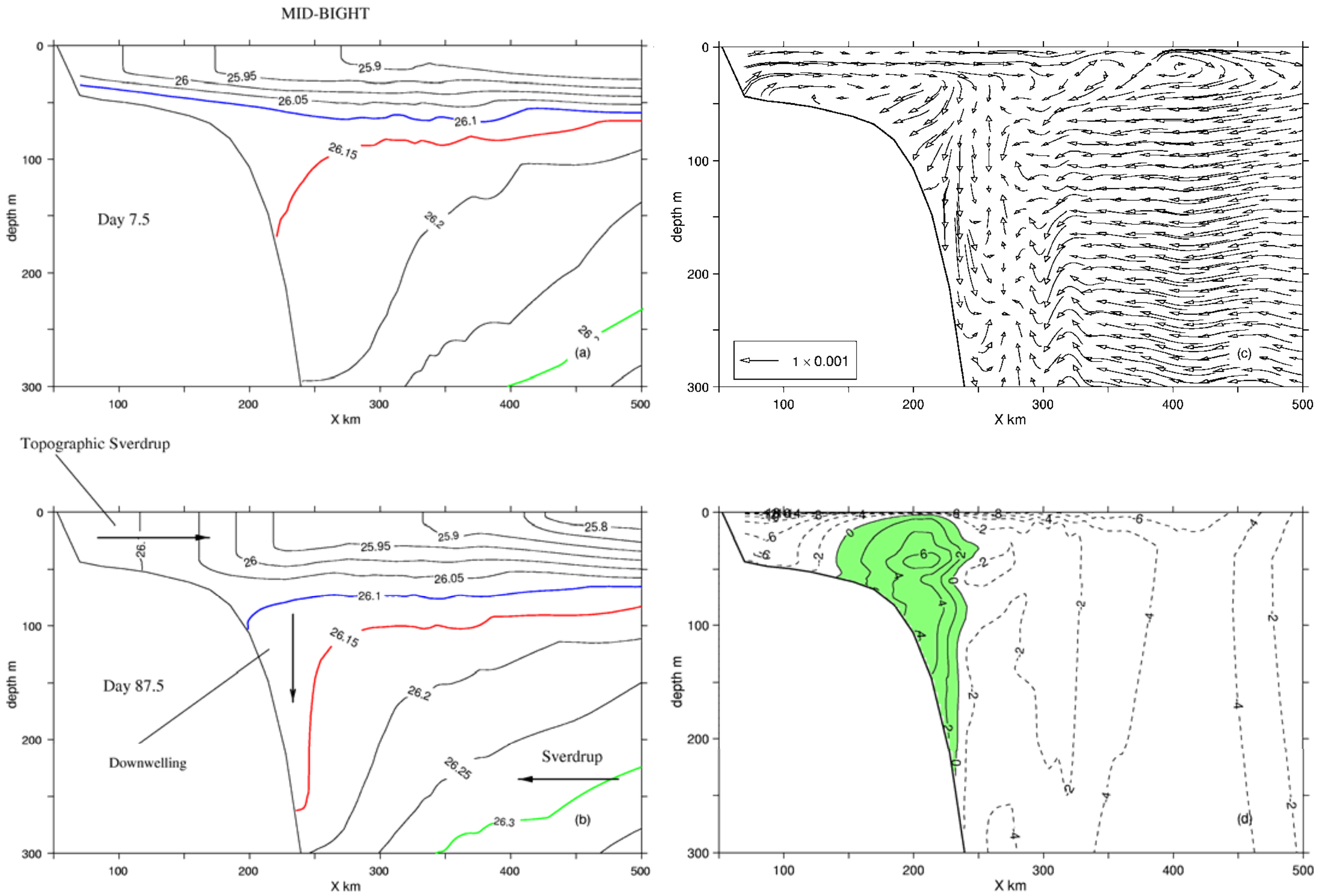


Figure 2.2.10 Numerical simulation of shelf-break downwelling in the western Great Australian Bight (Middleton & Platov 2003); **Top left panel**: The initial density field (interval 0.05 kg/m^3) adopted by Middleton and Platov (2003). Note: following convention, a constant value of 100 kg/m^3 has been subtracted from the density; **Bottom left panel**: The density field at day 87.5 illustrating the shelf-break downwelling of isopycnals; **Top right panel**: The cross-shelf velocity field illustrating the convergence of Sverdrup transports and downwelling over the shelf-break (200 m). The length of the legend vector arrow indicates 1 cm/s in the horizontal and 1 mm/s in the vertical; **Bottom right panel**: The alongshore velocity field (shaded) is positive to the east (units cm/s)

Transport implications of the Flinders Current and eddies

Canyons and upwelling

Through geostrophy, the cross-shelf pressure force associated with the westward Flinders Current is directed shoreward. When these currents flow over the ubiquitous narrow canyons of the region, the geostrophic balance may be disrupted and the pressure force can act to accelerate water, sediments, and nutrients up toward the shelfbreak. In other regions, canyon upwelling is well documented (e.g. Klink 1996). For the Bonney Coast region, the only evidence for this is the presence of neutrally buoyant asphaltites that are associated with sediments at depths of 2000 m or more, but which are found along the Bonney Coast (Peter Boult, PIRSA, pers. comm. 2005). The mechanism may be very important to deep upwelling for the South Australian region during summer, since wind-forced upwelling can then draw the upwelled water much closer to the coast. In the west, and during winter, the shelfbreak currents are downwelling favourable and the mechanism may only be important for cross-shelf exchange at depths of 200 m or more.

Alongshore advection – a deep westward conveyor belt

While the Flinders Current may be intermittent, the shelf slope speeds of 10 cm/s (~9 km/day) imply that fluid and matter can be advected to the west by 810 km over a three-month period. While the Flinders Current is a very deep current, it does provide the only westward means of transport during winter. Wind-forced downwelling during winter provides a means of connecting shelf water to the Flinders Current .

The eddies

The semi-permanent eddies found during winter off South Australia may be implicated in both local shelf slope ecological communities. In addition, the detachment and propagation of these eddies away from the shelf at the end of winter may have implications for cross-shelf exchange of water, nutrients and marine biota.

The “mean” winter shelf circulation and downwelling

Summary

A combination of winds, thermohaline forcing and the Leeuwin Current drive an eastward coastal current from Cape Leeuwin to Kangaroo Island during winter with mean speeds of order 30 cm/s or so. A three-monthly seasonal scale of advection is of order 2000 km. The winds drive an onshore surface Ekman transport and a return subsurface flow to deeper waters lead to downwelling to depths of order 200 m or so. The net cooling and evaporation over winter also leads to dense water formation. Within the gulfs, tidal mixing can lead to the fortnightly flushing of dense water with the lighter shelf waters. Light water is drawn from the Eyre Peninsula and expelled along the west then southern coast of Kangaroo Island and to depths of 300 m. Dense water is also formed along the shallow waters of the Coorong and north-western Great Australian Bight. Over the narrow shelves off Esperance, the Eyre

Peninsula and Kangaroo Island, the alongshore currents can exceed 50 cm/s and may be implicated in both alongshore and offshore sediment transport within the bottom boundary layer.

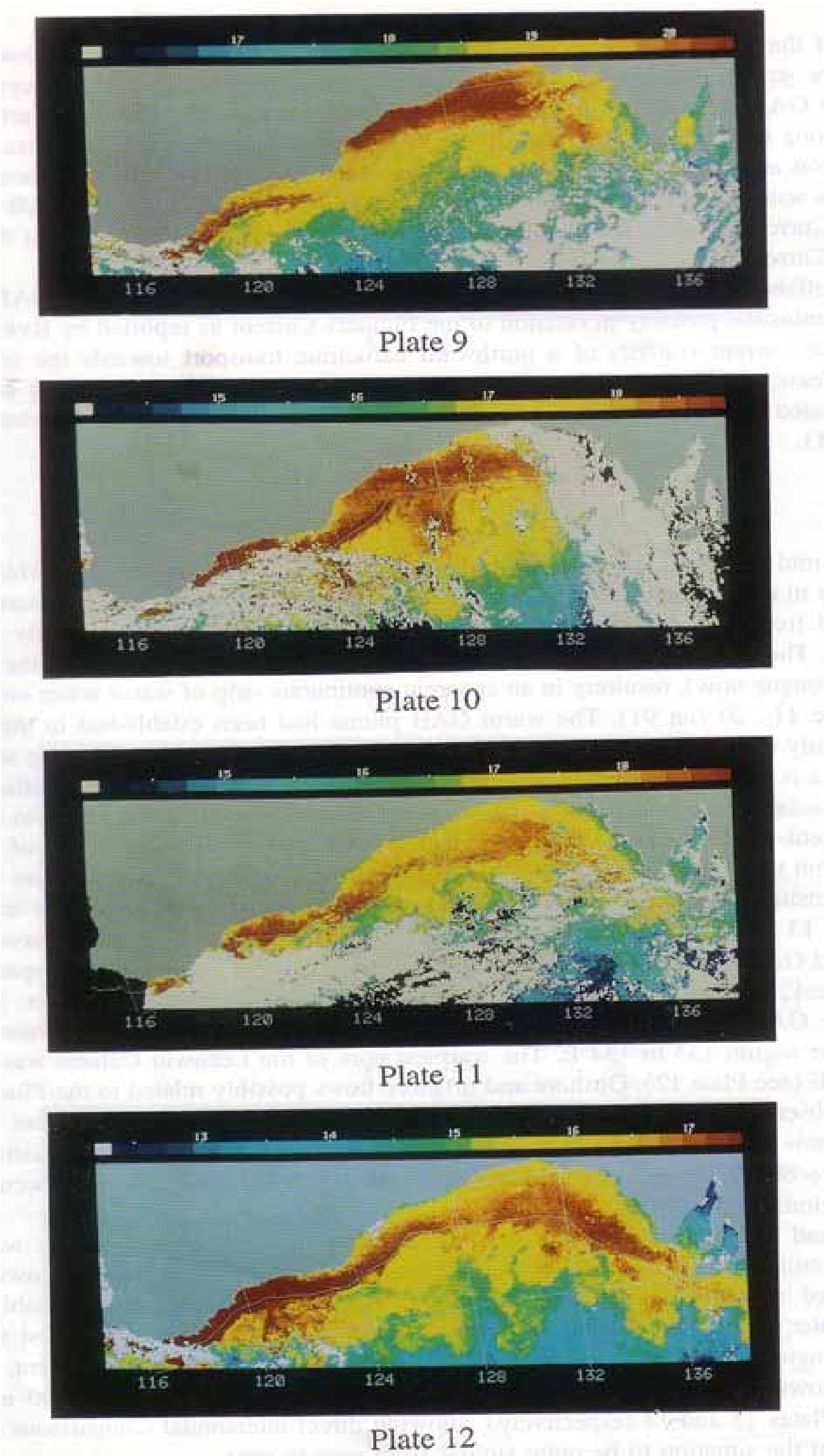


Figure 2.2.11 SST data from Herzfeld (1997) for April (plate 9), May (plate 10), June (plate 11) and July (plate 12) of 1991. The temperature (colour) scale changes in each plate. The data shows the generation of the western Great Australian Bight warm pool during late summer/autumn (plate 9) and the subsequent wintertime intrusion of the Leeuwin Current into the Great Australian Bight and along the shelf-break (plates 11 and 12). The white line in plate 12 indicates the 200 m isobath.

Discussion

Forcing mechanisms

During winter, the wind stress at the coast is directed to the east with an average amplitude of between 0.05 Pa (7 m/s) to 0.1 Pa (9 m/s). These winds drive an Ekman flux onshore that acts to raise sea level near the coast and drive a coastal current from west to east. In the west, the Leeuwin Current enters the region with speeds of up to 90 cm/s as illustrated in the ADCP transect (Figure 2.2.4) off Cliffy Head (Cresswell & Peterson 1993).

The winter period is also one of surface cooling with net heat fluxes of about 60–100 W/m^2 near the coast (Herzfeld 1997; Table 2.2.1 below). The loss of heat leads to the formation of cold (dense) water in the shallow regions of the gulfs, the Coorong and the north-west section of the Great Australian Bight as illustrated by the SST anomalies presented by Ridgway and Condie (2004). Evaporation also exceeds precipitation with a net loss of freshwater of about 1–2 mm/day (NECP/NCAR). This loss of freshwater enhances dense water formation in the regions noted above.

Quantity	Summer	Winter
Mean wind stress (wind)	-0.05 (7)	0.07 (8)
S. dev. wind stress (wind)	0.1 (9.3)	0.12 (10)
Season maxima stress (wind)	0.2 (12)	1.1 (23)
Heat flux (W/m^2)	50 (100)	-100 (-20)

Table 2.2.1 Meteorology for the Region
Typical values of the alongshore components of the mean and standard deviation (S. dev.) February and August wind stress (units Pa). The same statistic is presented in brackets but in m/s: 10 m/s = 36 km/h. A positive mean is directed to the south-east along the shelf. The maximum wind stress most likely to be experienced in any year is also given and was inferred from Trenberth at el. (1989) and Whittington (1964). The heat fluxes are from the NCAR/NCEP climatology for the Great Australian Bight region while those in brackets are for the Head of the Bight (Herzfeld 1997).

An overview of shelf currents – observations and numerical model results

An overview of the net effect of winds, the Leeuwin Current and water mass formation is presented in the results for sea surface height anomalies and SST in figures 2.2.7 and 2.2.11. The positive sea surface height anomaly at the coast ranges from 14 cm to 10 cm between Cape Leeuwin and Kangaroo Island. Ridgway and Condie (2004) point out that the largest cross-shelf sea surface height gradient is located near the shelf edge, indicating the existence of an intensified shelf edge South Australian Current.

As noted, published observations of the South Australian Current are almost non-existent. Black (1853) named the current based on ship-drift reports. Godfrey et al. (1986) indicate (ship-drift) speeds to the east of more than 50 cm/s over the shelfbreak and at 128° E during June 1982. For the gulfs region and Bonney Coast, Cirano and Middleton (2004) have summarised most available current meter data (Provis & Lennon 1981; Hahn 1986; Schahinger 1987). Results typical of the region are presented in Table 2.2.2. While the shelf is much narrower, observed mean winter currents are to the east (poleward), largest near the shelf edge and of order 20–30 cm/s.

The current meter data in Table 2.2.2 also provide support for the numerical results of Cirano and Middleton (2004) and their “mean” winter shelf circulation (Figure 2.2.12). The shelf coastal current can reach values of 50 cm/s off the topographic constrictions of the Eyre Peninsula, Kangaroo Island and Robe. The offshore flow induced here also acts to trigger the sites of the mesoscale eddies discussed above (Cirano & Middleton 2004).

Thermohaline forcing

Relatively cold, salty water (14–15 °C, >36.2 ppt) is produced in the Coorong and north-west section of the Great Australian Bight. The warm anomaly associated with the Leeuwin Current that enters the Great Australian Bight is also evident as a plume along the shelf edge to the mid–Great Australian Bight as shown in the SST data (Figure 2.2.11). The thermohaline circulation and momentum input of the Leeuwin Current may be expected to enhance the coastal current and South Australian Current near the shelfbreak. To resolve the relative importance of these mechanisms (and wind), Cirano and Middleton (2004) determined the net transport due to each for a cross-shelf section off the Eyre Peninsula. The results indicate that of the total transport over the shelf (1.9 Sv shoreward of the 200 m isobath), 47%, 35% and 18% is respectively driven by the alongshore winds, thermohaline effects and the Leeuwin Current. The results confirm that the momentum input by the Leeuwin Current is largely expended at the Eyre Peninsula and that thermohaline effects are important.

Within the gulfs, evaporation leads to water that is denser (>27 kg m^{-3}) than the shelf (26.8 kg m^{-3}) and a plume that flows out of the eastern mouth and then south and east (Figure 2.2.8) along Kangaroo Island (Godfrey et al. 1986). Water is drawn in at the surface at the western mouth of Spencer Gulf and the gulf–shelf exchange is modulated on a fortnightly basis by mixing due to the large tidal signal within the gulfs (Nunes Vaz et al. 1990; Bowers & Lennon 1986; Lennon et al. 1987). The circulation represents a significant mechanism for cross-shelf exchange.

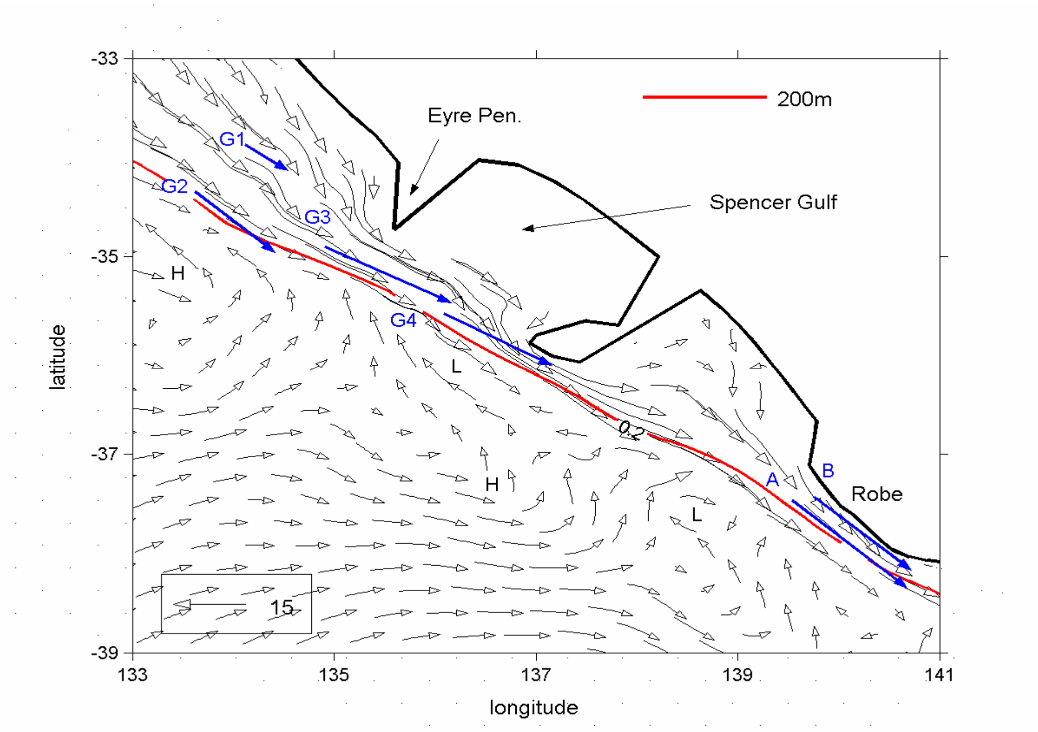


Figure 2.2.12 A numerical simulation of the quasi-steady winter circulation (Cirano & Middleton 2004) and some of the observed mean currents (the dark blue vectors) at sites G1–G4, A and B.

Table 2.2.2 Current meter observations: The tables present mean current speeds and directions obtained from available and published data for summer and winter periods for sites G4, A and B shown in Figure 2.2.12. The first column indicates whether the data is from an El Niño year. Observations from El Niño and non-El Niño years are paired for repeat observation sites (the first being for a non-El Niño year). The second column indicates the mooring site (as shown in Figure 2.2.13), position in the water column by upper (U) or lower (L) and year. The columns labelled "1st record" and "Days" indicate the start time and number of days used to compute the statistics. The magnitude of the vector mean |**U**| is given along with its direction θ in degrees anticlockwise from east. The maximum speed registered for the deployment is given if available: all units are cm/s.

SUMMER

Event	Site and year	1st Rec. dd/mm/yy	Days	Lat.	Long.	Water Depth (m)	Inst. Depth (m)	|U| cm/s	θ	s. dev. cm/s	max
	G4 U 82	**11/11/81**	**78**	**35.70**	**135.78**	**138**	**22**	**2.4**	**289**	**24**	**50**
El Niño	**G4 U 83**	**02/12/82**	**95**	**"**	**"**	**146**	**15**	**2.9**	**267**	**28**	**60**
	G4 L 81	**12/12/80**	**50**	**35.77**	**135.75**	**137**	**115**	**2.0**	**144**	**21**	**45**
	G4 L 82	**11/11/81**	**78**	**"**	**"**	**137**	**133**	**3.5**	**298**	**17**	**45**
El Niño	**G4 L 83**	**02/12/82**	**95**	**"**	**"**	**146**	**125**	**2.9**	**330**	**20**	**45**
	B 84	**021/1/84**	**56**	**37.43**	**139.72**	**50**	**26**	**5.3**	**30**	**24**	**50**
El Niño	**B 83**	**07/02/83**	**60**	**"**	**"**	**52**	**24**	**3.5**	**113**	**23**	**-**
	A 84	**21/01/84**	**56**	**37.53**	**139.52**	**146**	**115**	**4.9**	**332**	**16**	**80**
El Niño	**A 83**	**07/02/83**	**60**	**"**	**"**	**143**	**110**	**2.5**	**7**	**20**	**-**

WINTER

Event	Site and year	1st Rec. dd/mm/yy	Days	Lat.	Long.	Water Depth (m)	Inst. Depth (m)	|U| cm/s	θ	s. dev. cm/s	max
	G4 U 81	**06/04/81**	**78**	**35.77**	**135.75**	**137**	**42**	**20.2**	**-30**	**34**	**100**
El Niño	**G4 U 82**	**26/08/82**	**97**	**"**	**"**	**144**	**31**	**1.4**	**-108**	**25**	**55**
	G4 L 81	**06/04/81**	**78**	**35.77**	**135.75**	**137**	**115**	**19.2**	**-54**	**30**	**90**
El Niño	**G4 L 82**	**26/08/82**	**97**	**"**	**"**	**144**	**124**	**4.6**	**-57**	**21**	**45**
	A 83	**07/07/83**	**57**	**37.53**	**139.52**	**143**	**112**	**28.5**	**-49**	**25**	**80**
El Niño	**A 82**	08/08/82	**59**	**"**	**"**	**"**	**111**	**7.4**	**-60**	**22**	**-**

Transport implications

The wintertime coastal current is on average 15–30 cm/s implying an advective scale of 15–30 km/day or 1300–2700 km over a three-month seasonal period. The mean onshore surface Ekman transport and return offshore transport provide well defined pathways of advection across the entire Great Australian Bight and gulfs region. Nutrients, sediments and toxins formed in the very near-shore zone will be flushed onto the shelf. The regular fortnightly episodic flushing and outflow of dense water of the gulfs with the lighter waters off the Eyre Peninsula and Kangaroo Island may also be important.

The weather-band circulation and coastal-trapped waves

Summary

The weather-band circulation (3–12 days) represents the largest component of the circulation during both summer and winter with rms (root mean square) currents in the order of 25–30 cm/s and seasonal maxima of 50–90 cm/s. The time-varying circulation is often described by coastal-trapped waves. While intense, these quasi-periodic waves act to displace water back and forth along the shelf over short distances of 30 km or so. This ocean weather will be important to the flushing and scouring of benthic communities, but generally not to the transport of marine biota across or along the shelf. However, coastal-trapped waves are elsewhere known to be important for the setup and shutdown of upwelling and may be implicated in the very strong upwelling off the Bonney Coast. Such scattering may also lead to the formation of smaller scale recirculation features near large changes in shelf topography.

Discussion

Superimposed on the prevailing westerlies during winter, passing fronts and low pressure systems lead to an rms along-shelf wind stress of 0.12 Pa and an expected annual extreme of 1.1 Pa (see Table 2.2.1). The frequency of passage of these systems is 3–12 days. The mixing and cooling of these larger amplitude events leads to a very deep (~150 m) wintertime Surface Mixed Layer (SML) (see Figure 2.2.18 below).

In addition, the intense storms within the Great Australian Bight (and on the west Australian shelf) generate a very strong weather-band circulation. From Table 2.2.2, the observations (Hahn 1986; Schahinger 1987) indicate weather-band winter currents near the gulfs region that are typically 20–30 cm/s with seasonal maxima of 50–100 cm/s. The associated sea level changes can reach 50 cm and together with tides can lead to coastal flooding and flushing of coastal bays and estuaries. However, with these exceptions, little has been published detailing the weather-band winter circulation.

More observations are available for the summer weather-band circulation. From Table 2.2.2, the rms weather-band currents are in the order of 23 cm/s with seasonal maxima of 50 cm/s. These are somewhat smaller than the winter currents since the rms wind stress from Table 2.2.1 is also correspondingly smaller (0.1 Pa). Unlike winter, the summer rms current variability generally exceeds the mean so that the summer circulation is largely dominated by weather-band variability. Thus, we will first review aspects of the limited data and analyses of the summer and winter weather-band variability before discussing the summertime circulation more fully below.

Elsewhere, the weather-band circulation has been well characterised by (linear) coastal-trapped wave modes and theories (e.g. Chapman 1987), and is useful in understanding the nature of wind-forced upwelling (Suginohara 1987). The only substantive coastal-trapped wave analysis of data for the shelf region here, however, was made by Church and Freeland (1987). The coastal sea level data they examined (Figure 2.2.13 below) between Esperance and Portland have an energy peak in the 6–12 day band and indicate a phase speed of about 3 m/s which is consistent with a first mode coastal-trapped wave.

For the first coastal-trapped wave mode, the along-shelf velocity is everywhere directed to the east (west) when the coastal sea level anomaly is positive (negative) and the slope velocity is generally very small. However, given an along-shelf current magnitude of 20 cm/s (typical of winter), the coastal-trapped wave can, over a period of 10 days, advect matter 30 km backwards and forwards along the shelf. The cross-shelf velocities and advective scales are an order of magnitude smaller.

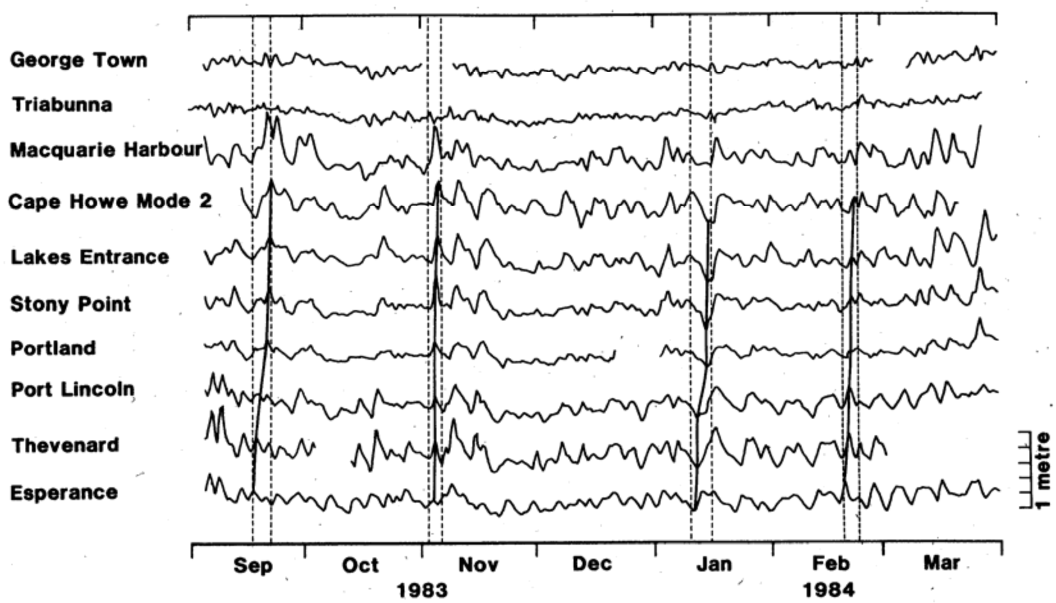


Figure 2.2.13 Adjusted low-passed coastal sea level at the sites indicated (Church & Freeland 1987). The vertical lines allow the phase speed of events between the various coastal sites to be determined. For the shelf between Esperance and Portland, a phase speed of 3 m/s is implied which is consistent with the theoretical first mode speed.

The summer shelf circulation and upwelling

Summary

During summer, the average winds blow in an anticyclonic fashion around the Great Australian Bight (Figure 2.2.2). Unlike winter, the mean circulation associated with these winds is weak (~10 cm/s or less). However, such anticyclonic wind systems are found to reside in the Great Australian Bight for 3–10 days, 2–4 times each summer. The associated coastal wind stresses of 0.05 Pa lead to upwelling of water by 150 m off Kangaroo Island, and 250 m off the Bonney Coast. These two regions appear to be the sites of deep shelfbreak upwelling, and the alongshore velocities of order 25–40 cm/s can transport water up to 215–430 km over a 10-day period. Water is transported as far as the Eyre Peninsula, where local winds during subsequent upwelling events bring it to the surface – a pool of nutrient rich upwelled water is likely to be maintained off Kangaroo Island. The upwelling also results in surface plumes of dense water (Figure 2.2.14) and secondary recirculation features are expected near fronts, islands, bays and headlands. In the western Great Australian Bight, shelf-break downwelling is expected.

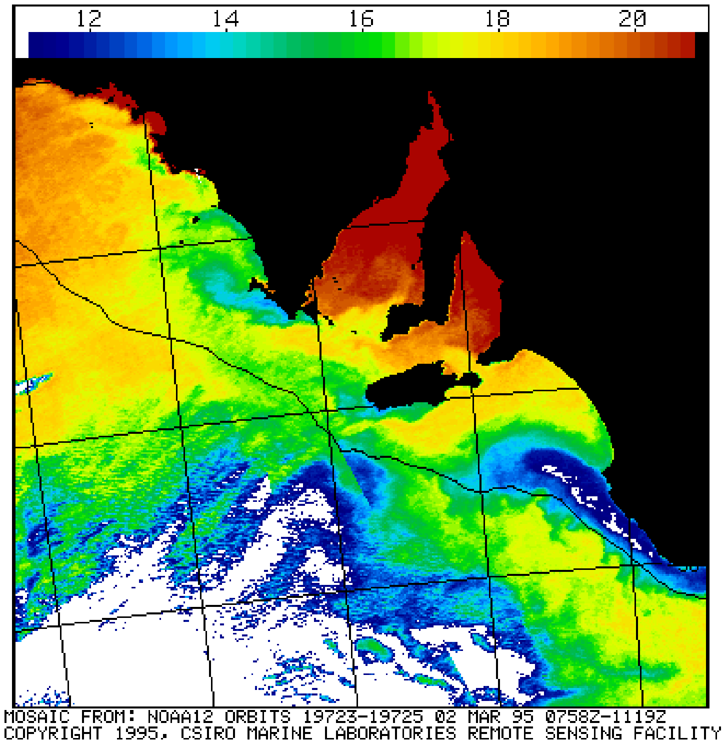


Figure 2.2.14 Satellite derived SST during an upwelling event of March 1995. The black line denotes the 200 m isobath.

Discussion – the large scale

Mean shelf currents in the Great Australian Bight

The inflow of the Leeuwin Current is largely absent during summer (e.g. Church et al. 1989) and on average, the coastal winds will act to lower coastal sea level, drive westward currents and upwell water towards the coast. As noted above, the numerical results of Herzfeld and Thomczak (1999) and Middleton and Platov (2003) suggest that an anticyclonic gyre in the shelf circulation should exist in the Great Australian Bight and shoreward of the 200 m isobath (Figure 2.2.9). This gyre is driven by the positive wind-stress curl in the Great Australian Bight that leads to a poleward (seaward) topographic Sverdrup transport. This transport converges with the (deep sea) Sverdrup transport leading to downwelling (Figure 2.2.10) along the shelfbreak and the raising of sea level and a summer South Australian Current which flows as far as the Eyre Peninsula (Figure 2.2.10). Evidence for these features was cited above. The anticyclonic gyre and South Australian Current are both dependent on there being a curl in the wind stress; that is, the north-westward winds decrease in magnitude away from the coast (e.g. Figure 2.2.2). When the average winds are more nearly constant, the topographic Sverdrup transport, shelf-break downwelling, anticyclonic gyre and the South Australian Current may be absent.

The importance of thermohaline forcing for the summer period was estimated by Middleton and Platov (2003). The warmer lighter waters over the shelf sit higher relative to those in the Southern Ocean leading to eastward alongshore currents of up to 10 cm/s. These currents oppose the westward coastal currents driven by winds and demonstrate the importance and sensitivity of the circulation to the thermohaline forcing and fluxes of heat (and freshwater).

The gulfs region

The likely summer mean circulation at a depth of 35 m is illustrated by numerical models results shown in Figure 2.2.15. The shelf currents are generally to the north-west and largest (up to 10 cm/s) near where the shelf is narrow – the Eyre Peninsula, Kangaroo Island and Robe.

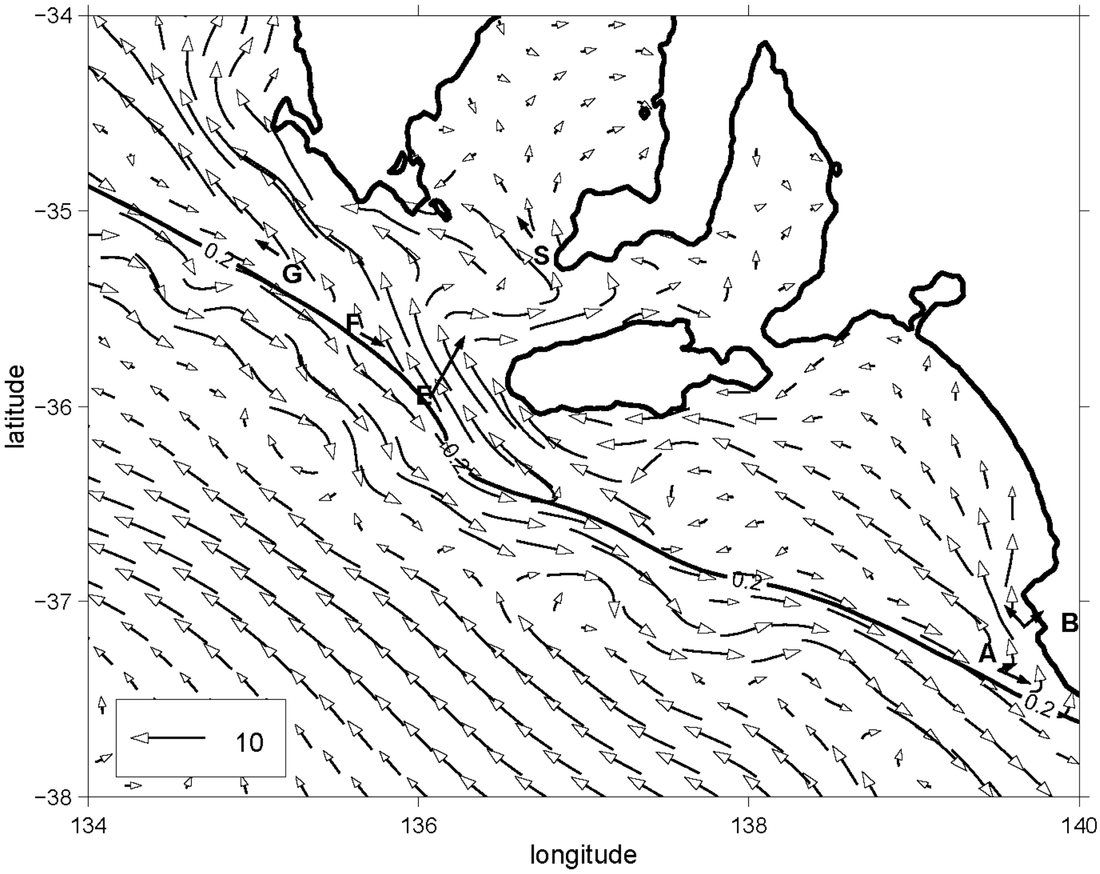


Figure 2.2.15 A detail of the surface flow (depth 35 m), as obtained in the numerical model of Middleton and Platov (2003). A reference vector of 10 cm/s is indicated. The dark arrows represent summer averages from current meters at depths of 10 m or so and at the sites S, G, F, E and A indicated. Note: site F corresponds to G4 in Table 2.2.2. The solid dark line is the 0.2 km or 200 m isobath.

The flow also bifurcates near the western end of Kangaroo Island. Part of the flow is to the north-west towards the Eyre Peninsula while another part moves around to the north of Kangaroo Island and then moves to the west. The latter broadly follows the 100 m isobath (not shown).

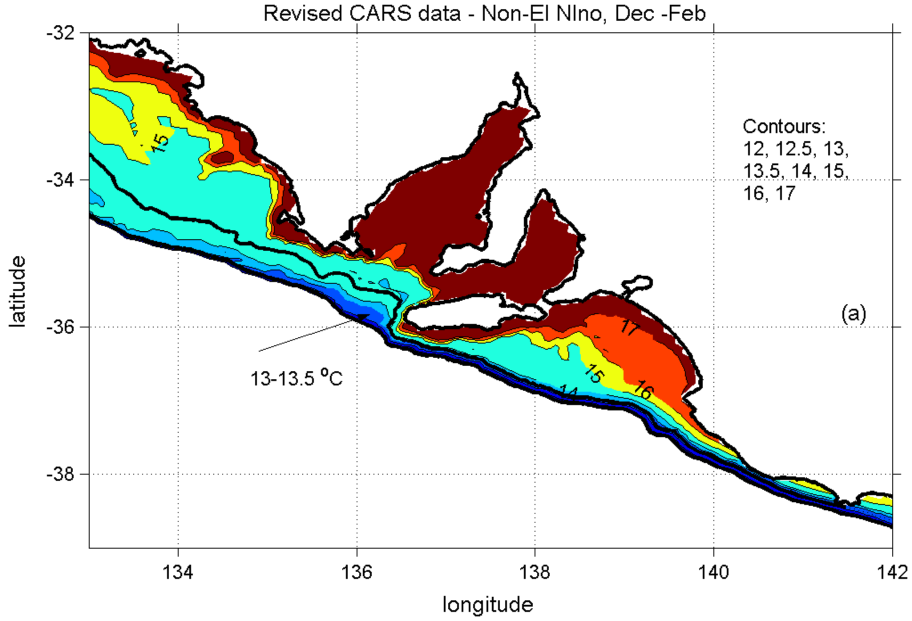
Support for the model shelf circulation comes from two sources. The first is the summer-averaged current meter results (E, F, G) indicated by the solid vectors in Figure 2.2.13: a weak north-westward flow, and onshore flow is indicated. Current meter and model results nearer the surface (see Middleton & Platov 2003) are also in agreement. These indicate a similar circulation pattern that is larger in magnitude, with currents up to 20 cm/s.

The model circulation above is also supported by data obtained from the *CSIRO Atlas of Regional Seas* (CARS, Ridgway et al. 2001). In Figure 2.2.16a the December–February climatology of bottom temperature is presented and the sites for deep upwelling (200 m) are to the south of Kangaroo Island and the Bonney Coast. (The original data used in the CARS climatology (including XBT transects), has been re-interpolated onto the bottom topography to separate out the effects of El Niño events. The results in Figure 2.2.16a and b were obtained using summer data for non-El Niño and El Niño years only.)

Surface upwelling off the Eyre Peninsula also occurs as shown in Figure 2.2.14. However, the model circulation would indicate that this water results from the deep upwelling to the south of Kangaroo Island and subsequent north-westward drift. This scenario is consistent with the bottom temperature data presented in Figure 2.2.16a.

Indeed, McClatchie et al. (2005) concluded that the colder water found to the west of Kangaroo Island in Figure 2.2.16a represents a nutrient-rich pool that acts to feed subsequent upwelling events off the Eyre Peninsula; that is, while cold surface plumes of water can appear simultaneously off the Eyre Peninsula, Kangaroo Island and the Bonney Coast (Figure 2.2.14), the upwelled water off the Eyre Peninsula results from water drawn from the Kangaroo Island pool that was established during a prior upwelling event. This water is transported to the Eyre Peninsula along the path shown in Figure 2.2.15 and little exchange occurs with the very warm waters of the gulf – a result that is also consistent with the studies of Nunes-Vaz et al. (1990).

There is another scenario suggested by Herzfeld and Thomczak (1999). In their numerical study, they found that under conditions of very large wind stress (0.35 Pa) and curl within the Great Australian Bight, bottom boundary layer advection by intense shelf currents (~50 cm/s) could lead to upwelling along the western Eyre Peninsula. The source of the upwelled water here might be a combination of that from Kangaroo Island as well as the Great Australian Bight itself. Griffin et al. (1997) also note that upwelling is indeed found along the western Eyre Peninsula even though the winds are not otherwise upwelling favourable. The climatology of bottom temperatures shown in Figure 2.2.16a does not support the general occurrence of deep shelfbreak upwelling directly off the Eyre Peninsula.



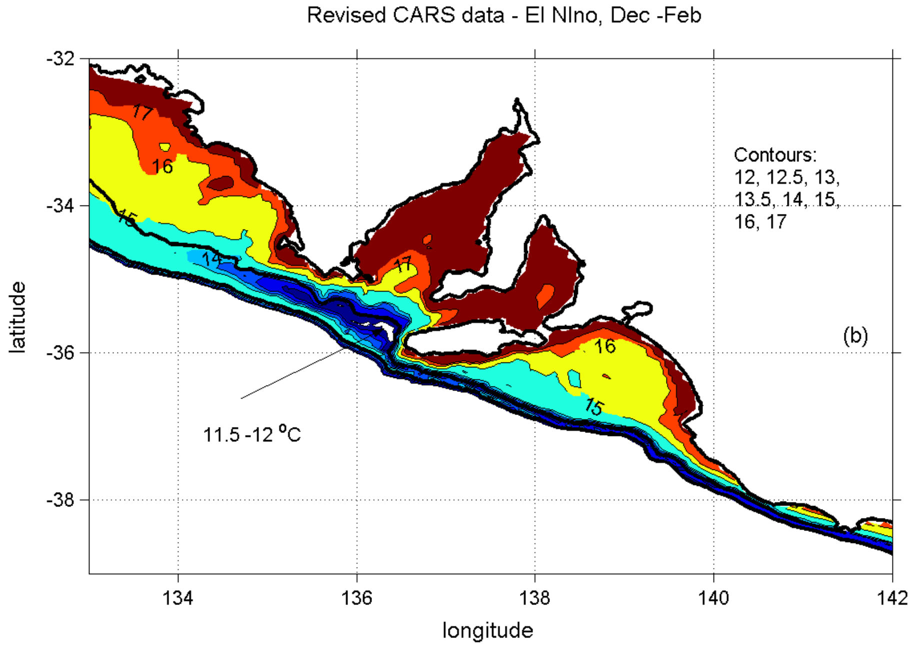


Figure 2.2.16 Top (a): The (revised) CARS climatology for bottom temperature and the December to February period. Only water of temperature 12 °C to 15 °C has been contoured (intervals indicated). For clarity and the 100 m and 200 m isobaths are indicated by the dark lines. El Niño summer years of data have been excluded. Bottom (b): As in (a) but for El Niño years only. (Source: Middleton et al. 2005)

Weather-band circulation and large-scale upwelling

The gulfs and Robe region is one of the few locations along the Australian coastline where a surface signature of upwelling is regularly found (e.g. Figure 2.2.14). The upwelling discussed above does not result from the mean or average flow but rather from 2–4 upwelling events that occur between December and March (Griffin et al. 1997). These events are characterised by the presence of high-pressure systems that sit in the Great Australian Bight for 3–10 days with upwelling favourable wind stresses of order 0.1–0.2 Pa. These stress values are 2–4 times larger than the summer average used to obtain the numerical model results shown in Figure 2.2.15.

The rms and maximum currents for the region are 20–50 cm/s (Table 2.2.2) indicating that the coastal-trapped wave variability can be large. Indeed, this is borne out by the time series of a typical upwelling event off the Bonney Coast (Figure 2.2.17 below). The data (Schahinger 1987) comes from a March 1983 upwelling event and from the two current meter moorings sites (A and B) shown in Figure 2.2.15.The mooring data shown was taken from site B (24 m depth, water depth 50 m) and A (18 m and 110 m in 140 m of water). The wind stress direction is “from” degrees clockwise of true north. Thus from 13–24 March, the wind is about 7 m/s and blows from the south-east – upwelling favourable. The adjusted sea level (labelled Eq. Sea) drops by around 20 cm during this period. As Schahinger (1987) points out, the sea level is highly correlated with the (negative) currents that are in the order of 40 cm/s and directed to the north-west (negative).

The temperatures measured at the inshore site B (depth 24 m) show a general drop in temperature of 2.5 °C to values of around 12 °C. This water has an equilibrium depth of about 200 m (Schahinger 1989) indicating upwelling of 180 m or so. At the offshore site, the thermistor string shows a drop of more than 3 °C to values less than 11 °C at a depth of 110 m. The equilibrium depth of this water is about 250–300 m indicating upwelling of 140–190 m. Recall that the winds here are not strong (~7 m/s) so that upwelling from greater depths might be expected at other times.

It would seem likely that transport within the bottom boundary layer is important given the currents are so large. Indeed, the patch of 11 °C water evident in the thermistor data and for the 19–22 March corresponds to the maximum in the alongshore currents at A110 (around 50 cm/s).

Schahinger (1989) also points out that the alongshore currents off Robe (A110) were found to be highly correlated (r=0.85, 12-hour lag) with those obtained off Neptune Island (site F=G4) and for the same summer 1983 period by Hahn (1986). Indeed, the March 1983 upwelling event was also recorded in the thermistor data of Hahn (1986) that is shown in Figure 2.2.18.

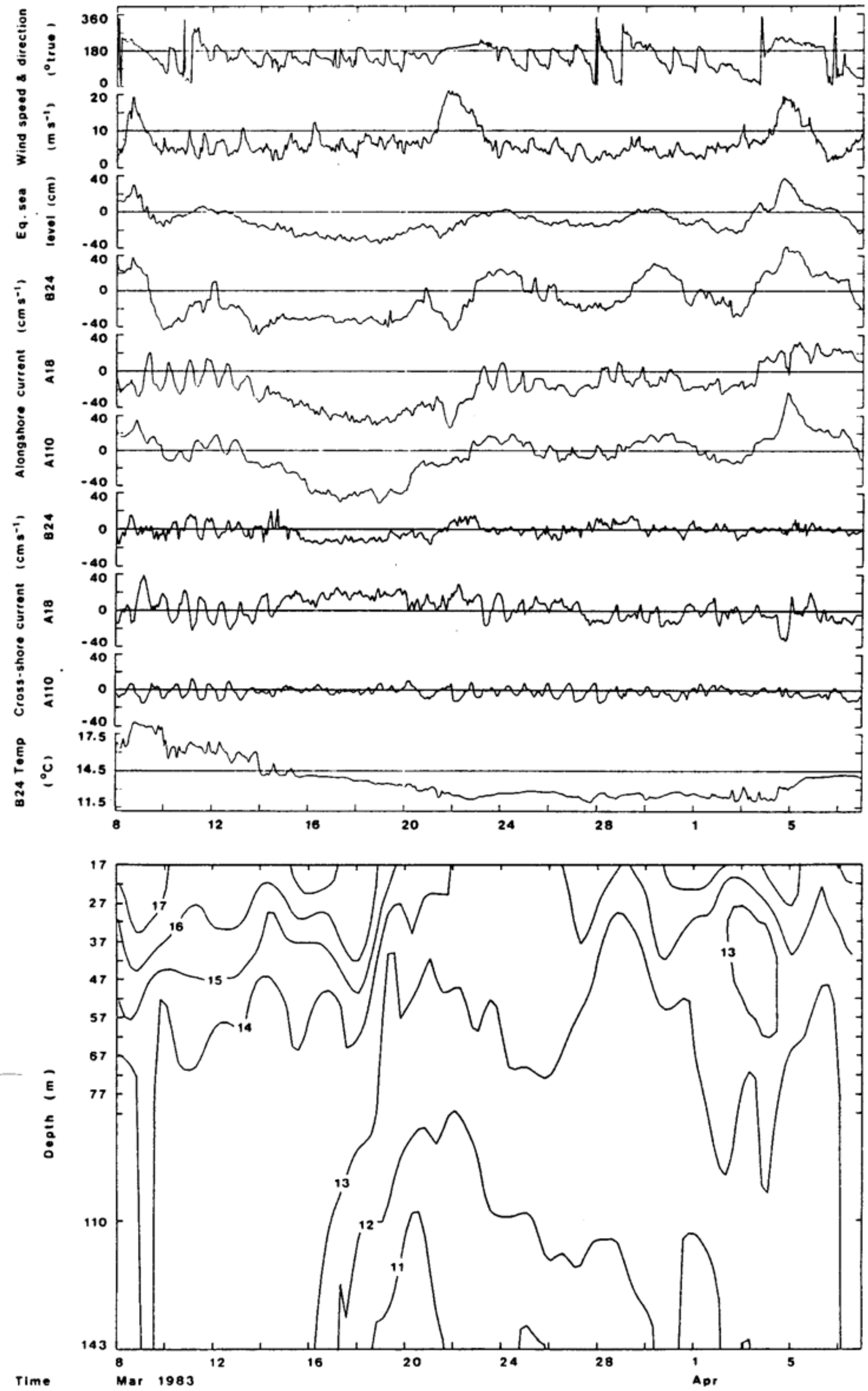


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Figure 2.2.17 **Top panel**: Time series of wind speed and direction (clockwise from north), sea level and currents at sites B and A that were resolved along the axes indicated (Schahinger 1987). **Bottom panel**: A time series of temperature (17–143 m) obtained at offshore site A.

Further insight into the circulation and upwelling is given by the numerical solutions for the weather-band circulation obtained by Middleton and Platov (2004). The solutions were obtained in order to simulate the circulation and upwelling for the summer of 1999. Upwelling favourable winds occurred between 17 January (magnitude 0.07 Pa) and 29 January. The model upwelling associated with this event on 27 January is presented below in a plot of bottom temperature (Figure 2.2.19). Plumes of water (<13 °C) are upwelled to the south of Kangaroo Island and Robe. By 6 February, the upwelling favourable winds have ceased. In agreement with the CARS data, plumes of cold water have moved to the north and the west of Kangaroo Island as well as to the north-west of Robe. The overlying currents are in the order of 25 cm/s. Over 10 days, such currents can advect water by at most 215 km and not as far as the western Eyre Peninsula. The water here must then be brought to the surface by future upwelling events.

While the validity of these results is uncertain, the scales of deep shelf-break upwelling predicted by the model are also of interest. Off Kangaroo Island, 13 °C water is upwelled by 150 m and from depths of 250 m. Off Robe the upwelling is larger, with 13 °C water upwelled by 250 m and from depths of 275 m. The deep upwelling off the Bonney Coast may well supplement the upwelling that should occur in the canyons of the region.

The reason for the very deep upwelling off the Bonney Coast is unknown but may be related to the coastal-trapped wave scattering expected to occur due to the topographic irregularities of the gulfs and Kangaroo Island. Clearly, the observations for the region are few and the results of the numerical studies to date must remain somewhat speculative.

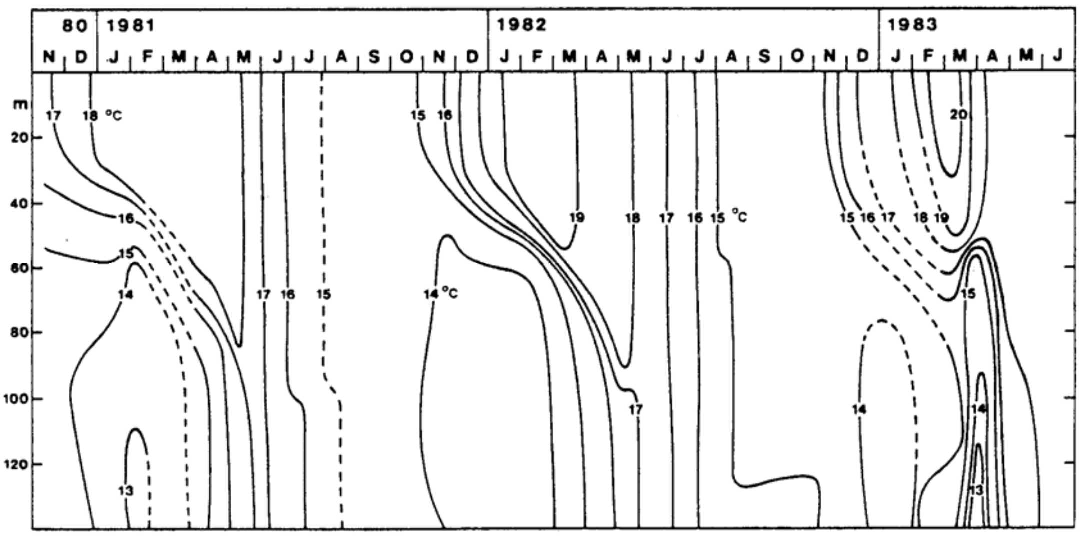


Figure 2.2.18 Thermistor data from the shelf edge site F (seaward of Neptune Island; Figure 2.2.18) obtained by Hahn (1986). Note the 13 °C water upwelled during March 1983.

El Niño events

Summary

El Niño – Southern Oscillation events occur within a 4–7 year period, originate in the Pacific and affect the circulation, upwelling and downwelling of the west and south shelves of Australia. For the Australian region, the depressed sea level and raised thermocline in the west Pacific is transmitted around Papua New Guinea and down the west Australian shelf as a type of shelf slope-trapped wave (Clarke & Van Gorder 1996). Observations show that the wintertime Leeuwin Current and shelf currents are substantially reduced during El Niño events. During summer, limited observations show that the summer thermocline is also raised by 150 m or so during these events.

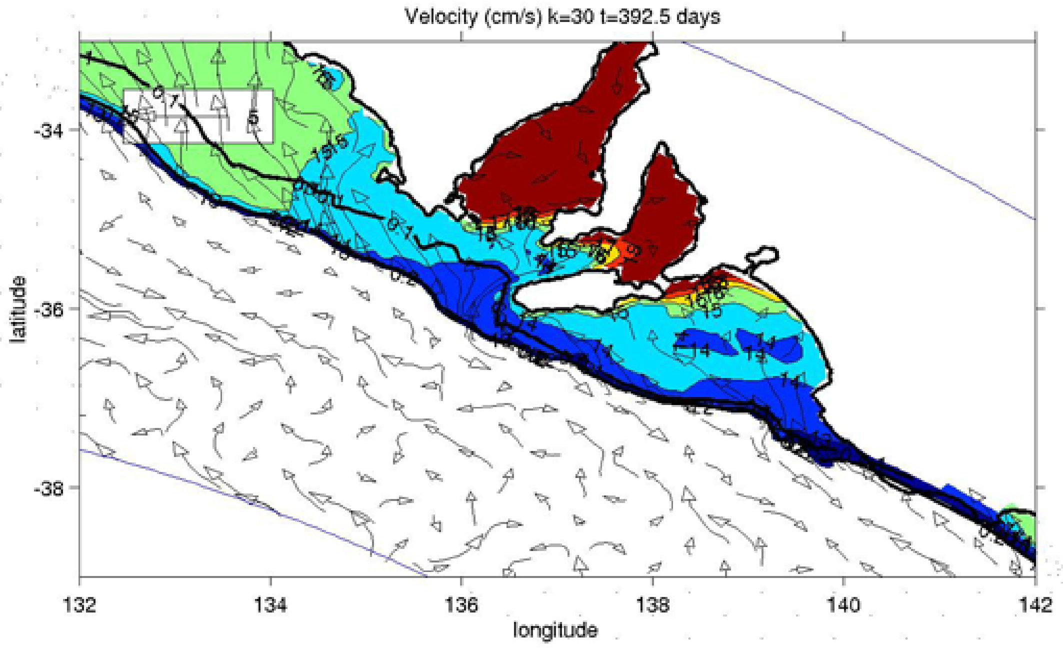
Discussion

Definitive evidence exists for the importance of El Niño events in the western shelf circulation of the Americas (Pizzaro et al. 2001). In the Australian context, the study of Pariwono et al. (1986) was the first to show that anomalously low (high) sea level events along the western and southern shelves are related to El Niño (La Niña) events in the west Pacific. Using observations of temperature and sea level, Feng et al. (2003) and Wijffels and Meyers (2004) have shown that the strength of the Leeuwin Current increases by 25% or 1 Sv between El Niño and La Niña events.

For the South Australian region, the current meter data presented in Table 2.2.2 shows that the mean wintertime currents are largely shut down (from 20 cm/s to 5 cm/s) during El Niño winters. Surprisingly, during El Niño summers, there does not seem to be a corresponding increase in the mean currents. Middleton at el. (2005) suggest that the explanation here involves the thermohaline circulation of the reduced winter inflow of warm Leeuwin Current water and enhanced cold water upwelling during summer.

Li and Clarke (2004) used altimeter and coastal sea level data to show that the eastward shelf slope currents would be enhanced (reduced) during La Niña (El Niño) events. For the South Australian region, the change was estimated to be small – in the order of 4 cm/s – and much smaller than that indicated by the shelf current meter data in Table 2.2.2.

Middleton et al. (2006) have examined all available CTD data from the South Australian region for El Niño effects. They find that during the El Niño summers of 1998 and 2003, the 11.5 °C isotherm is possibly raised by 150 m from its equilibrium depth of 250 m off Kangaroo Island; that is, as expected, colder water lies at shallower (deeper) depths during El Niño (La Niña) events. The 1999 summer was anomalous since it follows a very strong El Niño event and the upwelling favourable winds were amongst the largest for the 1962–2004 period. Middleton et al. (2006) cite data from the Bonney Coast that show similar results.



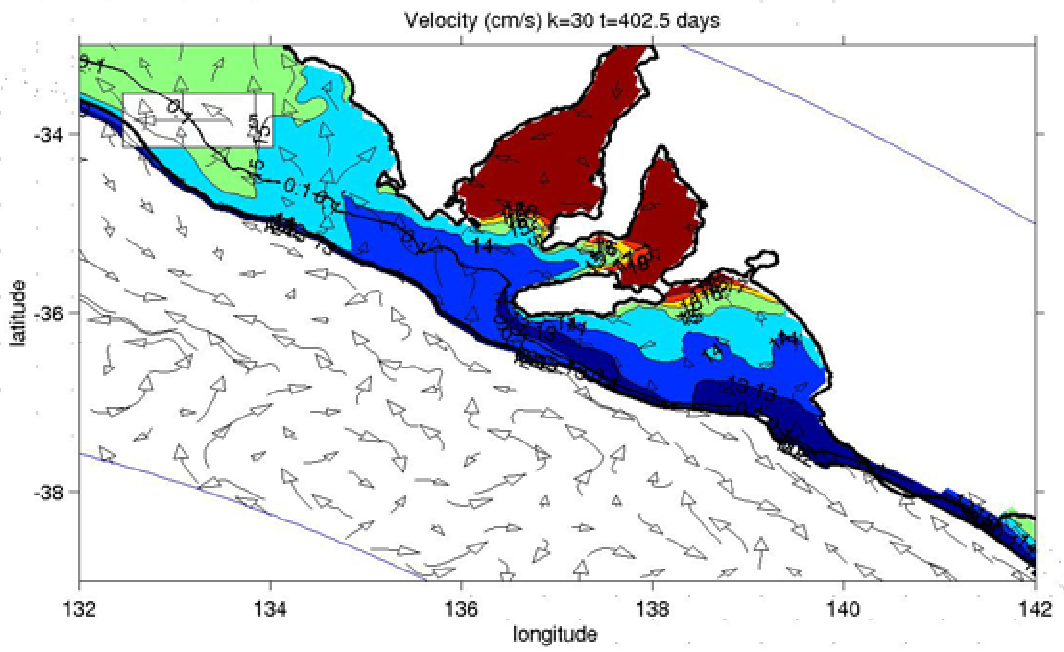


Figure 2.2.19 Bottom temperature and velocity from the numerical model of the weather-band circulation and upwelling (Middleton & Platov 2004). **Top panel**: results for 27 January 1999 (JD 392 1998). **Bottom panel**: results for 6 February 1999 (JD 402 1998). A vector legend of 5 cm/s is indicated. Only water with temperatures between 12 and 18 degrees are colour contoured.

A stunning representation of the enhanced upwelling is shown in Figure 2.2.16 where the bottom temperature for summer is presented for El Niño and non-El Niño summers. During El Niño years, the bottom temperature is typically a degree cooler than normal years. Off Kangaroo Island, a plume of 11.5–12.5 °C water is found close to the 100 m isobath. This water is more typically found at depths of 250–150 m.

Theories for how ENSO events are transmitted to and affect coastal ocean circulation have yet to be developed for this region. For other regions, they are quite idealised (e.g. Pizarro et al. 2001).

Surface waves and tides

Little has been published about surface waves for the region, although they are known to be important to sediment stirring and transport (James et al. 2001). Published data sources include Hemer and Bye (1999), Young and Holland (1996) and the more recent web-based atlas by Caires et al. (2005).

In Table 2.2.3 we present a summary of wave climatology (data from Caires et al. 2005) for February and July. The significant wave height (H_S) is the (monthly) averaged height of the highest one-third of the waves. It is about equal to the average height of the waves as estimated by an experienced observer. The phase speed (c) is the speed of the wave pattern (not the water speed) and the directions of the waves from the south-west and south (Gulev et al. 2005), although these directions are poorly known. The wave period (T) and wavelength (λ) are listed.

Table 2.2.3 Wave climatology for the mid–Great Australian Bight as inferred from Caires et al. (2005) including the significant wave height (H_S), period (T), phase speed (c) and wavelength (λ). The surface and bottom water velocities are denoted by U_o and U_b and the (Stokes) drift velocity by U_d. The standard deviations (σ) of H_S and T are presented.

Month	H_S (m) σ_S	T (s) σ	c (m/s)	λ (m)	U_o(m/s)	U_b(m/s)
Feb	**2.25** **0.45**	**7.5** **1.8**	**11.7**	**88**	**1.9**	**0.05**
July	**2.75** **0.90**	**9.0** **1.8**	**14.0**	**126**	**2.0**	**0.16**

For both summer and winter, the wave climatology is similar, although waves are somewhat larger during winter and of order 2–3.7 m in height with periods of 7–12 s. The wave speed c and wavelength are based on the mean wave period (T) presented.

Using "deep water" wave theory, we have calculated the surface water speed (U_o) as well as the speed (U_b) at a "bottom" depth of 50 m. The surface speeds are large (~2 m/s), while those at the bottom are in the order of 16 cm/s during winter. These are the average velocities and will be exceeded often during a given year. Caires et al. (2005) indicate that the wave height will exceed 3 m for 30–60 days of the year and 6 m for 0–10 days of the year. The bottom velocity will therefore exceed 20 cm/s and 40 cm/s over these periods leading to significant sediment re-suspension. The 100-year wave height is 12.5 m implying a bottom velocity of over 1 m/s. The wave heights and suspension bottom velocities will also be larger in shallower water.

A second feature of the wave field is the time-averaged (Stokes) drift velocity (U_d). This velocity is in the direction of wave propagation (north-east to north) and ultimately towards the shore. The speeds here are in the order of 15 cm/s. Over a one-month period, this drift can advect surface matter and biota by 380 km – a scale that exceeds the shelf width. The role of this wave-drift velocity is unknown, but provides a generally onshore conveyor belt near the surface.

Finally we comment on the tides of the region. While large (~50 cm/s) in the gulfs due to a resonance effect (Easton 1978), they are generally small (2–5 cm/s) on the adjacent shelves and within the Great Australian Bight and likely unimportant to the ecology of the region. Tidal studies of the region include Schahinger (1990), Hahn (1986), Noye et al. (1998) and Platov and Middleton (2000).

3 Ecological integration

3.1 Biodiversity

Principal contributors

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Introduction

The south-western corner of Australia is a region of high species diversity and endemism for many marine organisms; for example, marine macroalgae (Womersley 1990; Phillips 2001), invertebrate taxa such as corals, ascidians, molluscs and echinoderms (Shepherd & Thomas 1982, 1989; Roberts et al. 2002), and nearshore (Hutchins 1994) and continental slope demersal fish (Williams et al. 2001). High species richness in the region is attributed to the lack of mass extinction events associated with unfavourable environmental conditions – such as glaciation – over the recent geological past, and the moderating influence of the Leeuwin Current since the Eocene (McGowran et al. 1997). High endemism is the product of long isolation of the marine flora and fauna as Australia has been separated from other land masses for the past 80 million years (Veevers 1991; Phillips 2001).

Regional geomorphology

Shape and composition of the seafloor

The nature of the seafloor has an important influence on the composition and distribution of marine benthos. Knowledge of the shape and form of the seabed is therefore central to our understanding of patterns in biodiversity. Sediments cover much of the world's seafloor, and provide habitat and refuge for an extraordinary diversity of burrowing organisms. Where the bottom currents are strong, sediments can be eroded and the underlying bedrock exposed to provide secure attachment points for a variety of sessile forms. A range of other factors including water depth, proximity to land, and the types of organisms inhabiting the pelagic realm, also influence substrate type and thereby affect benthic community structure.

The South-west Marine Region covers approximately 1.3 million km^2 of seafloor, 35% of which lies offshore in abyssal depths (>5000 m). The majority of the Region's bedforms (40%) lie between 200 m and 5000 m depth and comprise the continental slope and rise, while the remainder (25%) fringes the coast and constitutes a shallow continental shelf (<200 m). Most of this seafloor is composed of soft unconsolidated sediments, but due to large variations in bathymetry there are marked differences in sedimentary composition and benthic assemblage structure across the Region.

Continental shelf

The crescent-shaped shelf of the Great Australian Bight is a dominant bathymetric feature of the southern margin of the Australian continent (Figure 3.1.1). This immense, relatively flat, submarine plain extends some 1300 km from Cape Pasley (Western Australia) to the Cape Catastrophe (South Australia), and covers an area of almost 200 000 km^2. The shelf is about 260 km wide near the Head of the Bight, but becomes progressively narrower with increasing distance to the east and west, and is approximately 80 km wide at either end. The Great Australian Bight shelf may be divided into a shoreward inner shelf (<50 m depth), a vast middle shelf (50–120 m depth), and an outer shelf that extends to the shelfbreak (150–160 m depth). Along the outer margin, the shelf is 10–30 km wide, but towards the west the shelf narrows to a few kilometres (James et al., 2001).

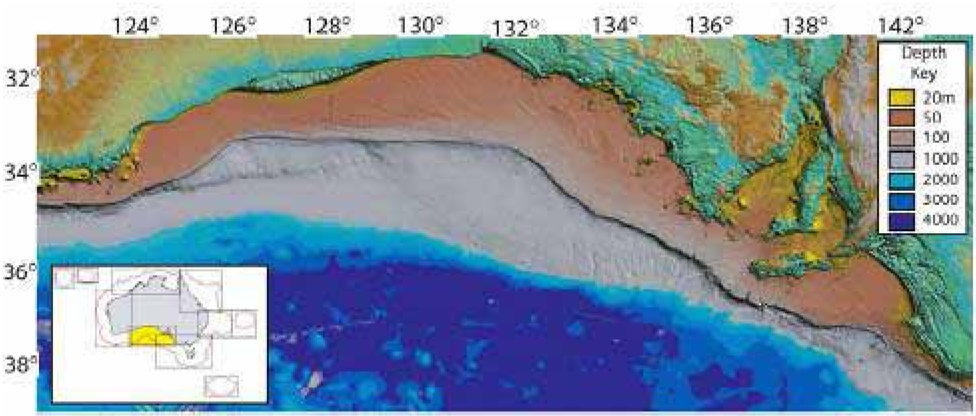


Figure 3.1.1 False-colour bathymetric image of the Great Australian Bight (from Harris et al. 2005; courtesy of Geoscience Australia).

The inland portion of the Great Australian Bight is characterised by very low annual rainfall. There are no major rivers in the region and thus the supply of terrigenous sediments to the marine realm is low. As a consequence, the shelf bedforms of the Great Australian Bight are largely biogenic and form part of the world's largest expanses of temperate carbonate sediments (Connolly & Von Der Borch 1967; Wass, et al. 1969). The Holocene sediments of the shelf are principally composed of fragments of bryozoa, mollusc, foraminifera and coralline algae, with minor amounts of sponge, crustacean and echinoderm (Connolly & Von Der Borch 1967; Wass et al. 1969; Gostin et al. 1988). The inner shelf supports abundant carboniferous macrophytes, and is an area of active sediment production and accumulation. The huge middle shelf is an area of sediment erosion and winnowing, while the outer shelf is a region of sedimentary deposition and variable sediment production (James et al. 2001). As a result, the sediments are generally course-grained and gravelly inshore but become progressively finer and muddier with increasing depth and distance offshore (Connolly & Von Der Borch 1967).

Patterns of Holocene sedimentation on the shelf of the Great Australian Bight are closely linked to the area's modern oceanography. The north-west area of the shelf supports the highest average water temperatures in the Bight and is one of the most prolific sites for rhodolith growth (James et al. 2001). These warm nutrient-depleted waters drift eastwards across the shelf and suppress sediment production on the central and eastern mid-shelf. This arrested production is countered further to the east, off the western Eyre Peninsula, by summer upwelling, which promotes prolific bryozoan growth and sediment production. Upwelling is also thought to play an important role in promoting localised growth of bryozoan communities across the outer shelf, except in the central region. Here, year-round downwelling contributes to off-shelf fine sediment transport and carbonate mud deposition (James et al. 2001).

There is a marked contrast between the flat and gently sloping shelf of the main Great Australian Bight region and the more rugged and uneven topography of the Recherche Shelf off southern Western Australia (Conolly & Von Der Borch 1967). The Recherche Shelf extends from Israelite Bay at the western edge of the Great Australian Bight to Cape Leeuwin, and covers an area of nearly 65 000 km^2 (Carrigy & Fairbridge 1954; Harris et al. 2005). The shelf here is characterised by a 15–50 km-wide plain that slopes gently to a depth of 100 m. Further offshore, the seafloor drops quickly before reaching the shelfbreak at between 100 m and 140 m depth. In the east, the shelf is up to 65 km wide and punctuated by islands of the Recherche Archipelago. These islands are scattered across the entire width of the shelf and extend for more than 160 km along the coast. The shelf varies between 30 km and 65 km in width to the west of the archipelago, but most islands in the western shelf occur within 8 km of the mainland (Conolly & Von Der Borch 1967).

The shelf between Cape Leeuwin and Geraldton is referred to as Rottnest Shelf (Carrigy & Fairbridge 1954). This shelf ranges in width from 45–100 km and covers an area of approximately 52 000 km^2 (Harris et al. 2005) (Figure 3.1.2). The Rottnest Shelf can be divided into a steep shoreface (<30 m depth), a wide, flat inner shelf plain (30–50 m depth), a linear ridge complex that shallows to about 40 m depth, and an outer shelf that slopes seaward to the shelf edge at about 200 m. Rottnest Island in the south and the Abrolhos Reefs in the north are key features of the ridge complex (James et al. 1999).

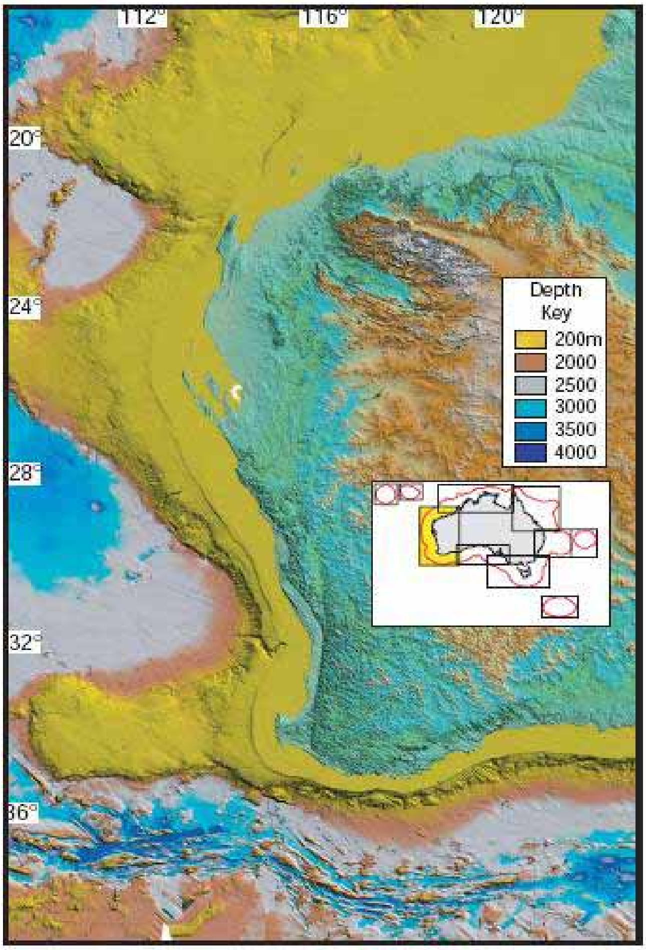


Figure 3.1.2 False-colour bathymetric image of the western Australian margin (from Harris et al. 2005; courtesy of Geoscience Australia).

The shoreface and the adjacent inner plain of the Rottnest Shelf support a variety of benthic habitats including rocky substrates with prolific growths of algae and sponges, rippled sand with clumps of non-calcareous red algae, and open rippled sand (which may be locally modified by burrows and surface traces). Sponges, ascidians, non-calcified red algae and *Ecklonia* are all common here to depths of 65 m, while seagrass such as *Thalassodendron* occurs to depths of 40 m. Encrusting coralline algae form rhodolites around limestone nuclei, and branching forms are present to 60 m depth. The main sedimentary elements identified in this part the shelf are quartzose skeletal sands, and more widespread skeletal gravels and coarse sands containing rhodolites, bryozoans and gastropods (James et al. 1999).

Further offshore, the Rottnest ridge complex is 3–8 km wide and supports a prolific hard substrate biota consisting of bryozoans, ascidians, sponges and algae. The gravel sediments of this region are mainly composed of rhodolites and skeletal sand. In the Houtman Abrolhos region the ridge complex is capped by emergent reef platforms (Pelsaert, Easter and Wallabi reefs). These reefs support rich and diverse coral communities on their leeward sides, and some 184 coral species from 42 genera have been recorded here (Collins et al. 1993a; Collins et al. 1996; Collins et al. 1997; Collins et al. 1998; James et al. 1999).

The outer Rottnest Shelf is a zone of rippled sand and rocky outcrop. The structure of the sediments range from mud to gravel, and are mainly composed of skeletal bryozoan fragments. Sandy substrates are widespread and are intensely burrowed. These sediments support a diverse but generally sparse epifauna composed largely of bryozoans and sponges. Rocky substrates, where present, support prolific bryozoans, sponges and encrusting bivalves (James et al. 1999).

The transition between the Rottnest Shelf and Carnarvon Ramp to the north (formerly known as the Dirk Hartog Shelf) is gradational. The ridge complex and outer shelf become deeper and more subdued northward until both have disappeared and the seafloor is a gently sloping ramp to a subdued shelf edge. These changes in bathymetry are accompanied by changing sedimentary facies, and include the loss of sediment associated with the ridge complex (sands and rhodolite gravel) and loss of the outer shelf bryozoan sands (James et al. 1999).

The inner Carnarvon Ramp is characterised by eolianite cliffs and dunes, with inlets and passes into Shark Bay and Ningaloo Reef. A narrow mid-ramp (50–100 m depth) passes almost without break to the outer ramp, which downlaps onto the Carnarvon Terrace at about 600 m. Key habitat features of the inner ramp include the extensive seagrass banks and tidal flats of Shark Bay, and the fringing coral reefs and lagoons of Ningaloo (Collins 2002; Collins et al. 2003b; Cassata & Collins 2004).

The mid Carnarvon Ramp is an open sand plain with few living benthic organisms. The sparse biota is delicate infaunal bivalves and vagrant bryozoans. Living rhodolites, bryozoans and sponges are present locally on hard substrates, and the calcareous algae *Halimeda* occurs in depths less than 40 m but is absent in sediments. Relict carbonate grains are common in the sediments, which are intraclast skeletal sands, with bryozoans, molluscs and foraminifers present as the most common skeletal constituents. Cemented hard grounds are locally present seaward of Shark Bay and Ningaloo Reef (James et al. 1999).

Like the mid ramp, the outer Carnarvon Ramp has little living material on the seafloor. Bivalves are most abundant, with corals, gastropods and echinoids also present. The outer shelf sediments vary with depth and consist of mainly planktic intraclast sands between 100 m and 150 m. Planktic sand and silt occur between 120 m and 200 m, while a muddy mixture of planktic foraminifers, carbonate silt, and well washed planktic sand extend between 170 m and 500 m (James et al. 1999).

Continental slope

The continental slope drops gradually beyond the shelf of the Great Australian Bight and consists of two marginal terraces: the Ceduna Terrace in the east and the Eyre Terrace in the west (Conolly et al. 1970; Willcox et al. 1988). Both terraces are separated from the continental shelf by an incipient slope between the shelfbreak and the uppermost smooth surface of the terrace (Conolly et al. 1970). The sigmoid-shaped Ceduna Terrace is the larger of the two features and extends for more than 500 km along the southern shelf margin, covering an area of almost 70 000 km^2. This terrace slopes gently to the southwest with an average gradient of 1 in 100, before merging into the continental rise (Conolly et al. 1970; Tilbury & Fraser 1981).

The most striking features of the terrace bathymetry are the numerous submarine valleys that dissect the otherwise gently sloping seafloor. These are mostly broad (<20 km wide) and shallow (<100 m depth) and form a dendritic tributary system feeding submarine canyons on the lower slope (Tilbury & Fraser 1981).

The wedge-shaped Eyre Terrace extends for 240 km along the south-western margin of the shelf, and is 65 km wide in its central portion. Its seaward margin occurs between 1000 m and 1600 m and merges seaward into a fan-valley system consisting of several canyons and fan deposits. The Eyre Canyon forms a broad valley more then 80 km long through the central region of the terrace. Another larger canyon to the east, the Eucla Canyon, delineates the Eyre and Ceduna terraces and extends for over 100 km between the shelf-break and the lower continental slope (Conolly & Von der Borch 1967; Conolly et al. 1970).

The sediments of the southern continental slope off the Great Australian Bight are characterised by muddy foraminiferal, spicule and pteropod oozes. The slope sediments may also contain large quantities of skeletal organic remains derived from the shelf, including bryozoan echinoid and mollusc fragments (Conolly et al. 1970; Harris et al. 2000; James et al. 2001).

Numerous canyons incise the narrow continental slope to the west of the Great Australian Bight. These include the Pasley and Esperance canyons offshore from the Recherche Archipelago, and the Albany Canyon Group (>30 canyons), which cleave the continental slope at regular intervals between Hood Point and Point D'Entrecasteaux (Von der Borch 1968). Recent sonar surveys in the Albany Canyon Group have shown that some individual cannons here may up to 2000 m deep and 90 km long, and extend uninterrupted between the shelf-break and the abyssal plain (Exon et al. 2005).

The slope is variable in width and gradient along the south-western margin of the continent between Cape Leeuwin and Shark Bay. In the south, the Rottnest Shelf slopes gently offshore for some 100 km to the west of Cape Leeuwin before rising to form the Naturaliste Plateau. This submarine table is over 400 km long and 250 km wide, and covers almost 90 000 km^2 of seafloor between 2000 m and 5000 m depth (Borissova 2002; Harris et al. 2005). To the north, the slope narrows and becomes steeply inclined and broken by terraces. The Perth Canyon crosses the slope here, and meanders for more than 160 km between the shelf-break west off Rottnest Island and the abyssal plain to the north of the Naturaliste Plateau (Playford et al. 1976). The slope at the northern-most extent of the South-west Marine Region (known as the Carnarvon Terrace) is relatively gentle and represents a 100 km seaward extension of the gradually sloping outer Carnarvon Ramp. Carbonate silts consisting of bryozoan fragments and sponge spicules blanket the seafloor here, together with planktic forams, pteropods and echinoid fragments (James et al. 1999).

Continental rise and abyssal plain

One of the most notable features of the seafloor in the South-west Marine Region is the development of an extensive and wide continental rise that flanks the foot of the slope and extends towards the abyssal plain (Conolly & Von der Bosch 1967). The rise is delineated by changes in gradient with the slope and the abyss, and forms a largely unbroken apron skirting the complete length of the southern continental slope. In the south-east, the rise extends from about 3000 m depth before merging into the Great Australian Bight Abyssal Plain (5000–5500 m depth) (Conolly & Von der Bosch 1967). The seafloor here is soft and muddy and the surficial sediments are characterised by foraminiferal and coccolith oozes (Conolly & Von der Bosch 1967; Harris et al. 2000).

The abyssal plain to the west of the Great Australian Bight displays considerable topographic relief as a result of continental drift. In the Daimantina Zone, off the south-western continental margin, the abyssal seafloor is heavily folded into a series of east–west tending ridges. Some of these ridges are over 1000 m in height and in excess of 200 km in length (Harris et al. 2000). The bottom topography of the Perth Abyssal Plain is poorly developed by comparison. This plain extends inbound between the Naturaliste Plateau in the south and the Carnarvon Ramp in the north, and forms a relatively flat and featureless bedform below 5500 m depth.

General patterns of biodiversity within the South-west Marine Region

The south-west region's marine flora and fauna are highly diverse. The species section (Section 4 – Part 2) outlines the current knowledge base for each major group (see Table 3.1.1). The following section describes the general knowledge of diversity and abundance of benthic and pelagic groups from inshore and offshore continental shelf and continental slope environments.

Shark Bay to Esperance (nearshore)

Studies of biodiversity of marine flora and fauna have been patchy, focused on key locations on the west and south coasts of Western Australia during the past few decades. Large taxonomic surveys have occurred as part of the International Marine Biological Workshops, convened by Dr Fred Wells (WAM and Fisheries Western Australia). These workshops have been held in the Houtmans Abrolhos and at Rottnest Island on the west coast of Western Australia and in Albany and Esperance on the south coast of Western Australia. Museum researchers have also surveyed areas of coastline as part of their ongoing taxonomic studies. The distribution of nearshore demersal fish has been detailed by Barry Hutchins, and the distribution of molluscs by Dr Fred Wells. The Department of Conservation and Land Management has coordinated baseline surveys in prospective marine parks including Jurien, Marmion, Cape Naturaliste to Cape Leeuwin, and Bremer Bay to Hopetoun. Fisheries Western Australia has also run active programs on the biology and ecology of commercial fish species across much of the Western Australia coastline. The most notable commercial species studied have been western rock lobster and abalone; gillnet and longline fisheries have also been studied. Fisheries Western Australia, in collaboration with the Fisheries Research Group at Murdoch University, has systematically studied the biology, feeding and ecology of nearshore demersal finfish species including the endemic dhufish. The Western Australian Government – CSIRO SRFME program has focused on the Jurien region of the coast, with biodiversity surveys from Geographe Bay, Bunbury, Perth, Jurien and Green Head. University researchers have also moved our knowledge of the biodiversity of marine organisms forward. The most notable recent studies have been the taxonomy of

Western Australian macroalgae by Dr John Huisman (Murdoch University), and the broad spatial studies of fish, sessile invertebrates and macroalgae between capes Leeuwin and Naturaliste, and the Recherche Archipelago by Drs Kendrick, Harvey, and McDonald (University of Western Australia) and others.

This patchy but geographically extensive data has resulted in some broad geographic synthesis papers that help us to define the biodiversity setting. Roberts et al. (2002) in a global study of coral reef biodiversity hotspots found that the west coast of Western Australia from Ningaloo Reef to Rottnest Island had moderate to high species richness, but was one of the global hotspots for endemism. Wernberg et al. (2003) combined quantitative surveys of macroalgal diversity on limestone reefs from Marmion, north of Perth, Hamelin Bay and Hopetoun and concluded that there was a cline in overlapping species distributions from the west coast to the south coast and inferred that this cline indicated mixing of species from north to south. A barrier to eastward species dispersal has been found at the Great Australian Bight. Hutchins (2005) found the nearshore demersal fish fauna of the Recherche Archipelago totalled 263 species, with 53 species only found in Western Australia.

Esperance to Kangaroo Island (nearshore)

Due to the remote and generally inaccessible nature of the coastline, the marine ecosystems of the eastern South-west Marine Region have received considerably less research attention than other areas of temperate Australia. Despite this, a growing body of research suggests that the waters spanning the Great Australian Bight support a rich diversity of organisms, which in some instances is unparalleled both in Australia and overseas (Edyvane 1999a; Ward et al. 2006). Moreover, it is becoming more apparent that the waters of this region are an area of global significance as breeding grounds for a number of rare and endangered marine mammals including the endemic Australian sea lion *Neophoca cinerea* (Gales 1990) and the southern right whale *Eubalaena australis* (Bannister 2001).

The waters of the Great Australian Bight are located at the centre of the Flindersian Biogeographic Province first described by Knox (1963). This region extends across the entire southern coast of the continent and is characterised by a marine benthic flora and fauna with warm to cool-temperate affinities. Within this Flindersian Province over 1000 species of macroalgae, 22 species of seagrass, 600 species of fish, 110 species of echinoderm and 189 species of ascidian have been recorded (Wilson & Allen 1987; Womersley 1990; Shepherd 1991: cited in Edyvane 1999a). Much of this fauna has not been recorded outside the region, and approximately 85% of fish species, 95% of molluscs and 90% of echinoderms are thought to be endemic (Poore 1995). By comparison, it has been estimated that only 13% of fish, 10% of molluscs and 13% of echinoderms are endemic in tropical regions of Australia (Poore 1995). The relatively high levels of biodiversity and apparent endemism for southern Australian waters have been attributed to a range of physical factors. These factors include the continent's long period of geological isolation (> 65 million years), the unusually large width of the continental shelf, and the characteristically low nutrient status of Australia's southern coastal waters (Poore 1995).

Ecological integration: Biodiversity

While temperate marine organisms characterise much of the biota of the Great Australian Bight, a warm Indo-Pacific element is also apparent in both the demersal and pelagic fauna (Maxwell & Cresswell 1981). Seasonal influxes of warm, low salinity water from the Leeuwin Current are thought to be responsible for the dispersal of many pelagic and demersal marine fauna from the warm waters of the northwest of Australia to the southern seaboard including the Bight (Maxwell & Cresswell 1981). The Leeuwin Current is also thought to be responsible for the relatively high representation of tropical phytoplankton in the area (Markina 1976: cited in Edyvane 1999a).

Studies of the regional marine flora and fauna have largely concentrated on shallow nearshore environments, and in particular have considered the taxonomy and general distribution of invertebrates (Shepherd & Thomas 1982, 1989; Shepherd & Davies 1997), algae (Womersley 1984, 1987, 1994, 1996, 1998, 2003) and seagrasses (Shepherd & Womersley 1971, 1976, 1981). More recent studies have integrated results from remote sensing and benthic surveys to map broadscale patterns in species, habitats and ecosystems throughout South Australia’s nearshore waters (Edyvane & Baker 1995, 1996a–d).

A major outcome from the research by Edyvane and Baker (1996) has been the recognition and division of South Australian state waters into a series of spatially explicit marine bioregions. Three of these bioregions (Eucla, Murat and Eyre) are recognised as capturing broadscale patterns in biodiversity in the eastern waters of the Great Australian Bight (Edyvane 1999b). In the west, the subtidal coastal habitats of the Eucla bioregion refect the area’s exposure to strong south-westerly swells. Much of the seafloor here is composed of bare sand with patches of reef supporting low-diversity algal communities (mainly the kelp *Ecklonia radiata* and the fucoid *Scytothalia dorycarpa*) (Edyvane 1999b). The Murat bioregion, to the east, is more variable in nature and offers a greater variety of habitats. Shield-islands of the Nuyts Archipelago protect the mainland coast from south-westerly swells here, and aid the development of several large sheltered embayments. Many of these sandy bays support significant mixed beds of seagrass (*Posidonia sinuosa, Amphibolis Antarctica, Heterozostra tasmanica*) and scattered stands of mangrove (*Avicennia marina*) (Edyvane 1999b). Reefs in this area have strong floral affinities with those in the Eucla bioregion but are typically more diverse, particularly in the lee of offshore islands (Edyvane 1999b). By contrast, the Eyre bioregion, further to the east, is a site of localised upwelling (Wenju et al. 1990). Periodic influxes of cold, nutrient-rich water enhance primary production in this area (Ward et al. 2006), and probably explain the occurrence here of cool-temperate algal species not found on reefs to the west (Edyvane 1999b).

Seabirds

Approximately 1.5 million pairs of seabirds belonging to 16 species breed in South Australia. Of these, more than 75% occur in the eastern Great Australian Bight. Short-tailed shearwaters (*Puffinus tenuirostris*) and white-faced storm petrels (*Pelagodroma marina*) are numerically dominant and collectively account for some 1.3 million pairs (Copley 1996). Other important species represented in the region include the little penguin (*Eudyptula minor*), which is endemic to southern Australia and New Zealand, and the osprey (*Pandion haliaetus*) which nests on cliffs across the Great Australian Bight. Non-breeding migratory seabirds are also known to frequent the coastal and shelf regions of the Great Australian Bight and include albatrosses, petrels and prions (Copley 1996).

Marine mammals

The Great Australian Bight provides critical habitat for two species of marine mammal that are recognised internationally as priorities for conservation: the southern right whale (*Eubalaena australis*), which is listed as endangered under the *Commonwealth Environment Protection and Biodiversity Act 1999*, and the Australian sea lion (*Neophoca cinerea*), which is listed as threatened under the same Act. The Great Australian Bight region is also recognised as an important seasonal habitat for many other species of marine mammals including blue whales, sperm whales, and humpback whales (Kemper & Ling 1991).

Continental shelf and slope

Benthos

Almost all of the seafloor beyond the state water limits (3 nm) out to the edge of the Australian Exclusive Economic Zone (200 nm) is composed of soft sediments but despite the prevalence of this habitat, very little is known about the diversity and distribution of the associated biota. Few systematic surveys of benthic infauna and epifauna have been undertaken in shelf and slope waters anywhere in Australia (Poore 1995). Moreover, there is currently no comprehensive information base for the abundance and distribution of benthic biota in the Australian EEZ (Heap et al. 2005).

In 2002, researchers from SARDI made significant advances in our understanding of the benthic biodiversity of the eastern Great Australian Bight by undertaking the first quantitative epibenthic survey of the region (Ward et al. 2006). This study involved sampling of epifauna throughout the eastern shelf, and was primarily aimed at assessing the effectiveness of the Great Australian Bight Benthic Protection Zone in representing regional biodiversity[1]. A total of 798 species were collected during the survey, including 360 species of sponge, 138 ascidians and 93 bryozoans (many of which are new to science). In comparisons with other similar studies conducted overseas, it appears that the eastern shelf of the Great Australian Bight supports one of the world's most diverse soft-sediment ecosystems.

[1] *The Benthic Protection Zone (BPZ) of the Great Australian Bight (GAB) Marine Park was proclaimed in 1998 to preserve a representative sample of benthic flora and fauna and sediments (Department of Environment and Heritage, 2005). The BPZ consists of a 20 nm-wide strip orientated north to south and extending from 3 nm from the coast to the edge of Australia's Exclusive Economic Zone (EEZ), 20 nm offshore. Within this zone, the benthic assemblages are protected from demersal trawling and other potentially destructive human activities. Before the BPZ was proclaimed, vessels of the GAB Trawl Fishery conducted demersal trawls in depths of 120–160 m (Caton 2001).*

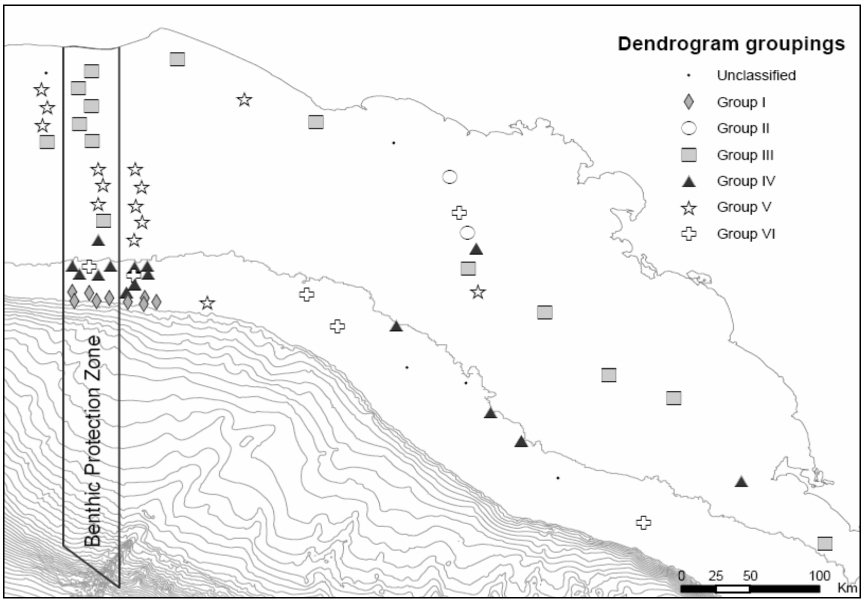


Figure 3.1.3 Map of the eastern Great Australian Bight showing the locations of 65 epifaunal sampling sites and their classification into six groups following cluster analysis of species biomass data (from Ward et al. 2006).

The same epibenthic survey has also provided novel insight into patterns of faunal distributions on the shelf and their relationships to environmental factors (Figure 3.1.3). The study has shown that species richness and biomass generally declines with increasing depth and distance offshore. Large total biomasses and high numbers of species characterise the inner shelf waters off the western Eyre Peninsula (an area of seasonal upwelling and enhanced primary productivity) and inshore waters at the Head of the Bight (a region of year-round elevated water temperatures). By comparison, relatively fewer species and individuals are represented in the outer shelf. This broad-scale environmental gradient is interrupted by regional variations in oceanography that modify the sedimentary characteristics and the associated bottom fauna. As a result, marked differences are evident in the types of species inhabiting different sedimentary facies on the shelf (Ward et al., 2006).

Sessile, suspension-feeding biota dominate the eastern shelf of the Great Australian Bight, but also appear to be conspicuous components of the shelf fauna elsewhere in the South-west Marine Region. Some of the earliest evidence for this comes from the 1962 voyages of *HMAS Gascoyne*, in which grab samples and photographs of the seafloor were collected across southern Australia at depths of about 75 m, 150 m and 300 m (Anonymous 1967). These collections have indicated a shelf fauna dominated by sponges, with bryozoans flourishing between 90 m and 210 m depth (Conolly & Von der Borch 1967; Wass et al. 1970). More recent sampling along the southern and south-western shelfs have highlighted the dominance of filter-feeding organisms, and particularly their importance in generating the carboniferous sediments that blanket the seafloor of the shelf and slope (James et al. 1999, 2001).

No published studies are available on the composition or distribution of benthic biota beyond the shelf-break in the South-west Marine Region. The biodiversity of the slope fauna can therefore only be inferred from studies elsewhere. The most regionally relevant comparison is a study of the crustacean isopod fauna from between 200 m and 3150 m depth off the south-eastern continental slope (Poore et al. 1994). In this study, a total of 359 species belonging to 36 families were identified, of which only 10% had been previously described. The results of this survey support the observation that species diversity at this temperate latitude is higher than at similar latitudes in the northern hemisphere. As the slope waters of the South-west Marine Region span similar latitudes to those sampled by Poore and his co-workers, a rich fauna may be suggested for this region. Benthic surveys recently initiated on the south-western continental margin (RV Southern Surveyor Cruise, No. S10/2005) are likely to prove revealing in this regard.

Fish

Shelf

The marine fish fauna of southern Australia is broadly characterised by a diverse range of species, with high rates of endemism at the specific and generic level (Wilson & Allen 1987). Poore (1995) estimated that some 85% of southern Australia's 600 fishes are endemic to the region; this is in strong contrast to the fauna of northern Australia where only 13% of fish are endemic. Current best estimates suggest that approximately 400 fish species belonging to 86 families are represented on the continental shelf of the South-west Marine Region (Gomon et al. 1994), but levels of endemism for the shelf fish fauna are not well defined. The lack of robust measures of endemism for the shelf is partly due to sporadic influxes of mid-water and pelagic fishes that are typically widespread and often migratory in nature. Little is known about the migratory pathways and distribution patterns of pelagic fishes overall; however, the oceanic pelagic fauna tends to be cosmopolitan and does not exhibit the same zoogeographic patterns of the inshore zone (Wilson & Allen 1987).

Slope

The knowledge base for deep-water fishes from the Australian continental slope has expanded rapidly in recent years following the commercial exploitation of the slope resources (Williams et al. 1996). Much of the commercial fishing on the slope of the South-west marine region has been concentrated in the Great Australian Bight where blue grenadier (*Macruronus novaezelandiae*), gemfish (*Rexea solandri*) and orange roughy (*Hoplostethus atlanticus*) have been targeted (Lynch & Garvey 2003). The first survey of the Bight slope fish resources was conducted in 1988 (Newton and Klaer 1991), and this multi-vessel study remains the most informative guide to the composition and distribution of the regional fauna.

The demersal slope fish fauna of the Great Australian Bight comprises at least 166 species from 125 genera and 71 families (Newton & Klaer 1991). Like other slope faunas in the North Atlantic and New Zealand, grenadiers (Macrouridae) and dogfishes (Squalidae) are the most speciose families, with 26 and 13 species represented respectively. Other families with five or more species represented include the ghost sharks (Chimaeridae), slickheads (Alepocephalidae), morid cods (Moridae) and sawbellies (Trachichthyidae). Whilst apparently large numbers of species and families are represented in the Bight, it is difficult to assess whether the slope fauna is unusually diverse. This is because comparisons between studies are almost always confounded by differences in the types of trawl gear used, and the frequency and geographic coverage of the sampling.

The first regional collection of fishes from the continental slope off the west coast of Australia was taken between 1989 and 1991 during exploratory trawling (Williams et al. 1996). In this study, demersal fish were sampled from 95 locations along the Western Australian slope between Cape Leeuwin (35° S) and North West Cape (20° S) at depths of between 200 m and 1500 m. These collections included 388 species from 108 families, and represent a substantial component of the known Australian fish fauna. In total, the fauna comprise about 9% of the 4100-plus known species (Yearsley et al. 1997) and over 35% of the 300 families currently recognised (Paxton et al., 1989). Due to the relatively low sampling density and large trawl mesh employed in this survey, it is considered likely that many fish species were unsampled. Further sampling with a variety of sampling gears is therefore expected to enlarge the number of species recorded (Williams et al. 1996).

The apparent high diversity of the Western Australian slope fauna is largely attributed to the overlap of tropical and temperate faunas (Williams et al. 2001). This high faunal richness is particularly evident in shallower depths (Hutchins 1994), and appears to be promoted by a complex interaction of oceanic currents at near-surface and intermediate depths. Water circulation patterns are also thought to play a role in the vertical stratification of fish communities on the Western Australian slope. Strong depth-related differences in community structure are evident, and are most pronounced between the shelf-break and upper-slope communities at about 250–350 m, and between upper-slope and mid-slope communities at about 700–800 m (Williams et al. 2001).

Distinct faunal changes with latitude are also apparent on the western slope of the continent, but are less evident in deeper water (Williams et al. 1996). A sharp biotone is recognised in the vicinity of latitudes 32° S and 33° S, and this area appears to be the north-western boundary of a widely distributed benthopelagic slope fish community (Williams et al. 2001). Fish occurring on the mid-slope below this latitude are thought to form part of a larger faunal assemblage that extends across southern Australia to New Zealand (Koslow et al. 1994).

Gaps in knowledge of biodiversity

Inshore

It is difficult to assess biodiversity in the region given the paucity of sampling effort for select organisms across the region. For example, the Terebellidae (Polychaeta) are not well described in depths greater than 30 m, and the distribution of nemerteans along the coast of Western Australia has been largely ”neglected” in terms of sampling (Gibson 1991). Records of the distribution of marine Enchytraeidae and Tubificidae would also benefit from more collections, particularly along the continental shelf (Coates 1991; Erseus 1991). In addition, a range of other groups have been recognised as requiring attention. These include the echinoderms (Marsh 1991), decapod crustaceans (Morgan & Jones 1991), sessile invertebrates

(McDonald 2005), and macroalgae; particularly between the capes region, Albany, offshore from the Fitzgerald biosphere area, and Esperance).

Offshore

The shelf and slope biota of the South-west Marine Region has received relatively little research attention. Of the research that has been conducted, most has concentrated on the fish biota; this is due to the economic importance of some demersal and pelagic fish species. As a result, some good general information on the composition and distribution of the shelf and slope fish fauna is available, but most other taxonomic categories represented on the shelf and slope have received only limited consideration. This is particularly the case for the greater diversity of fauna that typically inhabit the seafloor. Although some benthic surveys have been conducted in the shelf waters of the eastern Great Australian Bight, the benthic biota for most of the shelf and slope in the South-west Marine Region remain largely unexplored.

Table 3.1.1 Summary table of distribution of marine species groups and species numbers in the South-west Marine Region (SWMR). Note inferred presence = (Yes)

Species group	Inshore	Shelf	Slope	Number of species, [Location – note southern or South Australia] (Number of endemic species)	Authority for species numbers, (chapter authors in brackets)
PLANTS					
PHYTOPLANKTON	**Yes**	**Yes**	**Yes**	**148 [in Western Australia]**	**Thompson and Waite 2003 (LTwomey et al)**
MACROALGAE					**Womersley, 1990; Edgar. 2000; Phillips, 2001 (N Goldberg)**
Phaeophyta	**Yes**			**231–240, (57–60%) [in southern Australia]**	
Rhodophyta	**Yes**	**Rhodoliths**		**800, (75–77%) [in southern Australia]**	
Chlorophyta	**Yes**			**124-140, (30–40%) [in southern Australia]**	
SEAGRASSES	**Yes**			**17 [in SWMR]**	**Various, (S Bryars/G Kendrick)**
MANGROVES	**Yes**			**1 [2 var in SWMR]**	**Duke, 1991, (S Bryars)**
PLANKTON					
ZOOPLANKTON	**Yes**	**Yes**	**(Yes)**	**15 [Likely species in SWMR]**	**Dakin and Colefax, 1940; Ritz et al., 2003, (S.McClatchie/D.Gaughan)**
INVERTEBRATES					
SPONGES	**Yes**	**Yes**	**Yes**	**139 [Great Australian Bight] 77 [Houtman Abrolhus, Western Australia] 243 [Marmion, Western Australia] 300 [Recherché Archipelago, Western Australia]**	**Fromont, 1999; Sorokin et al., 2005 (S Sorokin/J Fromont)**
CNIDARIA (not corals) Hydroids Anenomes Octocorals	**Yes**	**Yes**			**(no chapter)**
CNIDARIA: CORALS (stony)	**Yes**		**Yes**	**6 [Western Australia] 39 [South Australia]**	**Veron, 2000 (J Stoddart)**
MOLLUSCS					**Beezley et al., 1988 (M Steer/S Mayfield)**
Gastropoda	**Yes**	**Yes**		**4 [SWMR]**	
Bivalvia	**Yes**	**Yes**		**8 [SWMR]**	
Cephalopoda	**Yes**	**Yes**		**10 [SWMR]**	
Other gastropods Specimen shells (cowries)	**Yes**	**Yes**		**550 [Western Australia]**	
BRYOZOANS	**Yes**	**Yes**	**Yes**	**500 [southern Australia]**	**Bock, 1982 (D Currie)**
ECHINODERMS	**Yes**	**Yes**	**Yes**	**347 [southern Australia] 50 [Great Australian Bight] 83 [from Albany, Western Australia]**	**O'Hara and Poore, 2000 (No chapter) Ward et al., 2006 Marsh, 1990**
Crinoids				**7 [southern Australia] 7 [Albany, Western Australia]**	**Shepherd et al., 1982 Marsh, 1991**
Asteroids				**51 [southern Australia] 25 [Albany, Western Australia]**	**Zeidler and Shepherd, 1982 Marsh, 1991**
Ophiuroids				**73 [southern Australia, 27 [Albany, WA]**	**Baker, 1982a Marsh, 1991**
Echinoids				**49 [southern Australia] 12 [Albany, Western Australia]**	**Baker, 1982b Marsh, 1991**
Holothuroids				**40 [southern Australia] 12 [Albany, Western Australia]**	**Rowe, 1982 Marsh, 1991**
DECAPODS (in general)	**Yes**	**Yes**	**Yes**	**392 [southern Australia]**	**O'Hara and Poore, 2000, (No chapter)**
DECAPODS: PRAWNS (commercial)	**Yes**	**Yes**		**3 [SWMR]**	**(C Dixon et al.)**

Species group	Inshore	Shelf	Slope	Number of species, [Location – note southern or South Australia] (Number of endemic species)	Authority for species numbers, (chapter authors in brackets)
DECAPODS: ROCK LOBSTER **Southern** **Western**	**Yes**			**1 [SWMR]** **1 [SWMR]**	**(A Linnane)** **(N Caputi)**
ASCIDIANS	**Yes**	**Yes**		**300 [southern Australia]** **138 [Great Australian Bight]**	**Edgar, 2000; Kott, 1990, 1992, 2001; Ward et al., 2006 (J McDonald/S Sorokin)**
INFAUNA	**Yes**	**Yes**	**Yes**	**Multi-species**	**(D Currie/S Sorokin)**
FISH					
ELASMOBRANCHS **Sharks** **Rays** **Chimaeras**	 **Yes** **(Yes)** **(Yes)**	 **Yes** **(Yes)** **Yes**	 **Dogfish** **Yes**	152 total [in SWMR] **95 (8)** **51 (14)** **6**	**Shark Advisory Group 2002 (D Trinder)**
DEMERSAL FISH inner	**Yes**			**695 [in SWMR]**	**Compiled from several texts including Gomon et al., 1994 plus Museum data and unpublished records, (J Baker)**
DEMERSAL FISH shelf		**Yes**		**>400 [in SWMR]**	**(L McLeay)**
DEMERSAL FISH slope			**Yes**	**463 [in southern zone of SWMR]** **398 [in south western transit zone]** **480 [in central western zone of SWMR]**	**Last et al., 2005 (D Trinder)**
MACKERELS, TUNA & BILLFISHES **Scrombidae** **Xiphiidae** **Istiophoridae**	 **Mackerels**	 **Mackerels** **Sailfish**	 **Tunas** **Swordfish** **Billfishes**	 **21 [west coast, south of Shark Bay]** **14 [Cape Leeuwin to Kangaroo Island]** **1 [SWMR]** **5 [west coast]**	**Several including Froese and Pauley, 2005 and fishbase (H Kemps/J Totterdell)**
MESOPELAGIC FISH **Myctophids** **Sternoptichidae**			**150-1000m**	 **2 [southern Australia]** **1 [southern Australia]**	**Paxton et al., 1989; May and Blaber, 1989; Blaber and Bulman, 1987 among others (S McClatchie)**
SMALL PELAGIC FISHES	**Yes**	**Yes**		**11**	**Gomon et al., 1994; Kloser et al., 1998 (P Rogers et al.)**
SYNGNATHID FISH	**Yes**			**~40**	**Several includes museum records (J Baker)**
MAMMALS/BIRDS					
SEABIRDS	**(Yes)**			**81 [22 breeding]**	**Surman and Wooler, 2000, (C Surman/L Nicholson)**
PINNIPEDS	**(Yes)**			**3 [in SWMR]**	**Campbell, 2005; Shaughnessy et al., 2005 (S Goldsworthy et al.)**
CETACEANS **Baleen whales** **Toothed whales**	**Yes**	**Yes**	**Yes**	38 total [in SWMR] **10** **28**	**Bannister et al., 1996 (P.Gill et al.)**

3.2 Food webs

Principal contributors

Sam McClatchie

Gary A Kendrick

Overview

The food webs in the South-west Marine Region shelf and slope are not well studied. The lack of information means that inferences need to be made about the food webs in the region based on studies in other areas such as Tasmania and Victoria. Such extrapolation is dangerous, however, as there are distinct differences between dominant feeding guilds of demersal fish between the west coast of Australia and the south and south-east coasts (Williams et al. 2001). There seems to be more similarity between outer shelf and slope fish assemblages on the North-west Shelf and those in the temperate western continental shelf and slope. The current level of knowledge about feeding relationships, which is largely based on gut contents and stable isotope studies, while very useful, is insufficient to quantitatively characterise the pelagic and benthic food webs. At best we can make some general statements about guilds that are likely to be important in the South-west Marine Region.

Diets of benthic invertebrates on the shelf are poorly known in the shelf and slope environment of the South-west Marine Region. In overseas studies, diets of benthic invertebrates tend to be inferred from taxonomic studies that permit species to be assigned to general feeding guilds such as deposit feeders or suspension feeders. As discussed in Section 3.1, the taxonomy of benthic invertebrate communities, especially the infauna, is poorly known in this region, and so little can be specified about the diets of the benthic invertebrates. Biological data for two large invertebrates, the champagne crab *Hypothalassia acerba* and crystal crab *Chaceon bicolor*, have shown that they occupy different depths on the outer continental shelf and slope (Smith et al. 2004). On the west and south coasts, the abundance of champagne crabs was greatest at depths of 200 m and 145 m respectively, with water temperatures of 16.1–17.1 °C. On the west coast, the crystal crab lives in depths of 450–1220 m, where temperatures are only 4–6.5 °C (Smith et al. 2004). Whether this depth differentiation is resource partitioning or driven by the physiological requirements of the crabs is unknown.

Most of the available information on food webs in the South-west Marine Region pertains to the demersal fish, which are discussed below. The situation for plankton and nekton is similar to that for the benthic invertebrates. There is virtually no species-specific information on feeding. A recent large-scale study of the pelagic biophysical dynamics across the continental shelf and slope off Two Rocks, north of Perth, Western Australia found distinct phytoplankton and zooplankton assemblages from on-shelf and offshore areas (Keesing & Heine 2005). The surface waters of the south-western Australian shelf, waters of the Leeuwin Current and surface waters offshore were very low in nitrogen (less than 0.5 μmol) year round and primary productivity was nitrogen limited. (Lourey et al. 2006). Preliminary mesozooplankton feeding studies found a strong negative relationship between large diatoms and mesograzers. A full pelagic trophic model has yet to be produced.

The small pelagic fishes are plankton feeders, and exploit different sizes of plankton. Among the small pelagic fish, sardine and anchovy are omnivorous planktivores, consuming phytoplankton and zooplankton as well as fish eggs and larvae (including their own). The diet of anchovy tends to contain larger particles than that of sardine (van der Lingen 2002). These forage fishes fall prey to a wide size range of epipelagic predators, ranging from the tunas to Australian salmon, pike and barracouta. Mid-size pelagics like the mackerels generally feed on epipelagic nekton. Information on mackerels may be gleaned from Tasmanian studies. Jack mackerel (*Trachurus declivis*) are known to feed on coastal krill (*Nyctiphanes australis*), and their recruitment may be related to fluctuations in krill abundance (Young et al. 1993).

We can use information on Australian salmon (*Arripis truttaceus*) from Victorian waters (Hoedt & Dimmlich 1994) to infer predation further west. The salmon in Victorian waters consumed mainly anchovy of a range of sizes. Juvenile sardine were the second most common prey, and sandy sprat were occasionally common in the stomachs of the salmon. A preliminary sample from the eastern Great Australian Bight indicates that Australian salmon eat bullseyes, small specimens of their own species, sardines, and sandfish (Page et al. 2005). Shortfin pike or snook (*Sphyraena novaehollandiae*) and barracouta (*Thyrsites atun*) were reported to have a diet similar to the Australian salmon (Hoedt & Dimmlich 1994). Longfin pike, swallowtail and snapper prey heavily on krill (Page et al. 2005). Preliminary data from the eastern Great Australian Bight indicate that barracouta consume redbait, pilchards and arrow squid (Page et al. 2005).

The large, migratory predators like tunas are pelagic piscivores. Bluefin tuna (*Thunnus maccoyii*) are known to consume sardines (*Sardinops sagax*), blue mackerel (*Scomber australasicus*) and anchovy (*Engraulis australis*) as well as saury (*Scomberesox saurus*), arrow squid, jack mackerel (*Trachurus* spp.) and several other fish (Ward et al. 2006).

Benthopelagic fish are likely to exploit the vertically migrating mesopelagic fish (myctophids and lightfish) when they descend near the bottom over the shelf, particularly at the shelf edge. The same mesopelagic fishes provide food for tunas and mackerels when their vertical migrations take them into midwater and near the surface at night. The vertically migrating mesopelagic fish, as well as shrimps, squids, and offshore krill species (e.g. *Euphausia* spp.) form an important and almost unstudied link between the pelagic and the epibenthic food webs. Diets of mesopelagic fishes in this region are totally unknown, but from other studies it seems probable that lightfish (*Maurolicus australis*) and the myctophids (*Lampanyctodes hectoris*) eat euphausiids and copepods, compared to Lanternfishes *Diaphus danae* that eats a greater proportion of fish such as the smaller myctophids (*L. hectoris*) (Young & Blaber 1986).

For the demersal shelf fishes (50–200 m depths) there is a surprising lack of information on diet, even in terms of qualitative stomach contents. Diet information is confined to flathead (Burnell & Newton 1989), King George whiting and snapper (Robertson 1977; Jones 1981; Jones et al. 1990) and Westralian dhufish (Western Australian Fisheries, 1992). For other shelf fishes, it is necessary to infer the diets of the species in the South-west Marine Region from more comprehensive studies of the diets of the same species in south-eastern Australia (Bulman et al. 2001; Davenport and Bax 2002). Using this approach, gemfish (*Rexea solandri*), deepwater flathead (Neoplatycephalus conatus) [by analogy with the sand flathead (*Platycephalus bassensis*)] and tiger flathead (*Neoplatycephalus richardsoni*)), can be broadly categorised as benthic or bentho–pelagic piscivores (Bulman et al. 2001). Information on the diets of demersal slope fish is even sparser. Some of the important slope fish like Bight redfish (*Centroberyx affinis*) and orange roughy (*Hoplostethus atlanticus*) feed more on crustacea than on fish, exploiting deepwater shrimps and other midwater nekton, and can be classed as pelagic crustacean feeders and omnivores (Bulman et al. 2001; Williams et al. 2001).

The western continental slope (below 400 m) is characterised by many relatively small benthic-feeding species that are predominantly grenadiers (Macrouridae and Bathygadidae), dogfishes (Squalidae) and cucumberfishes (Chlorophthalmidae) (Williams et al. 2001). These benthic feeders appear not to be dependent on vertically migrating mesopelagic fish. The vertical distribution and relative abundance of mesopelagic micronekton off the west coast of Western Australia is unknown, and the seafloor topography has not been fully surveyed. However, the lack of elevated fish density at depth, as well as the absence of a mid-slope fishery after decades of exploratory commercial fishing, indicates that predation on mesopelagic micronekton does not result in enhanced fish production on the mid-slope off Western Australia (Williams et al. 2001) as demonstrated in south-eastern Australia. This suggests care should be taken when extrapolating tropic dynamics from the east coast to the temperate west coast.

Page et al. (2005) reviewed the diets of the higher predators. New Zealand fur seals take a surprisingly high number of cephalopds and birds. Approximately 28–34% of the fur seals' diet at Pearson and Neptune islands in the eastern Great Australian Bight consisted of cephalopods (mainly arrow squids, *Nototodarus gouldii*, and *Todarodes* spp.) and 18–34% consisted of birds (little penguin, *Eudyptula minor*, and shearwaters, *Puffinus* sp.). Fish constituted 31–54% of the New Zealand fur seal diet at Neptune and Pearson islands, and 55–70% of the fish comprised only three species (Ocean jacket, *Nelusetta ayraudi,* Swallowtail, *Centroberyx lineatus,* and redbait, *Emmelichthys nitidus*).

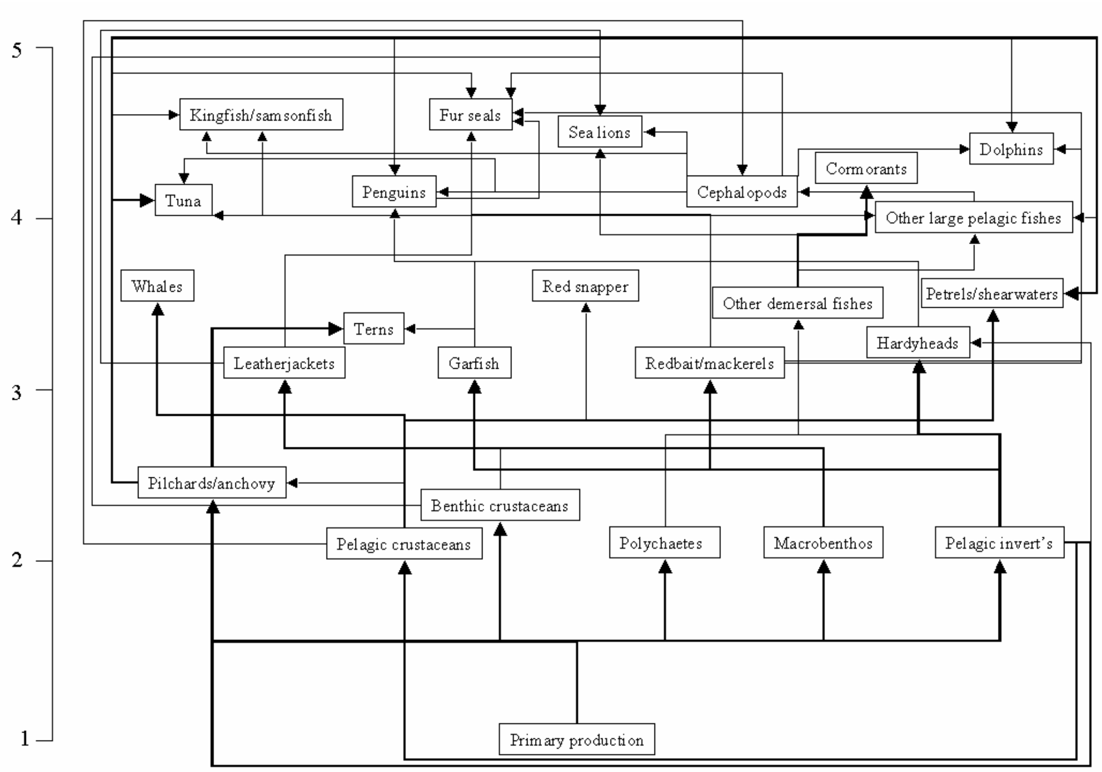


Figure 3.2.1 Simplified food web that summarises the main trophic interactions among species groups in the eastern Great Australian Bight. Species' trophic levels are indicated on the left. To improve clarity, dietary contributions ∫50% are indicated by bold lines, contributions <50% are indicated by fine lines and contributions <10% have been omitted (from Ward et al., 2005)

Little penguin (*Eudyptula minor*) diets seem to be quite variable in the eastern Great Australian Bight. Penguins on Troubridge and Reevsby islands eat mainly fish including hardyheads (*Atherinason esox, Paranesus ogilbyi*), sardine (*Sardinops sagax*), anchovy (*Engraulis australis*), sandy sprats (*Hyperlophus vittatus*), blue sprats (*Spratelloides robustus*), garfish (*Hyporhamphus melanochir*), leatherjackets (various genera), pipefish (various genera), and redbait (*Emmelichthys nitidus*) as well as squid. In contrast, the penguins on Pearson and Greenlie islands had eaten more cephalopods and zooplankton, including arrow squid (*Nototodarus gouldii*), cuttlefish (*Sepioteuthis sp.*), krill (*Nyctiphanes australis*), and crab larvae, as well as anchovies (Page et al. 2005). Shearwaters in the mouth of the Spencer Gulf seem to take mainly krill and copepods, as well as some anchovies; on the other hand, crested terns from Troubridge Island feed more on fish (including sardines, anchovies, garfish and leather jackets).

Of note is a trophic study of the continental shelf of south-eastern Australia where stable isotopes of carbon and nitrogen were used to determine the trophodynamics position of 87 fish species, penguins, marine mammals and invertebrates (Davenport & Bax 2002). The stable isotopes were found to be more useful than gut content analyses. A similar study has not been performed for the southern and western shelfs of Australia, although such a study should treat the western continental shelf separately from the southern shelf. There is a broad tropical–temperate transition north–south along the western continental shelf, with highly diverse but low biomass demersal fish assemblages varying with latitude and depth (Koslow et al. 1997; Williams et al. 2001).

Ecological integration: Food webs

A preliminary food web of the eastern Great Australian Bight developed for ecosystem modelling using EcoPath (Ward et al. 2005) is shown in Figure 3.2.1. This structure can really only be regarded as preliminary since the data that it is based on are sparse. A notable omission is the mesopelagic fish that are likely to be an important component of the shelf food web, especially at the edge of the continental shelf. The mesopelagic fish are omitted because there are very little data available for this group.

Gaps in knowledge of benthic food webs

- Diets of benthic invertebrates are poorly known in the shelf and slope environment of the South-west Marine Region.
- Little is known of the pelagic links to benthic food webs. An ecosystem level approach to the study of trophic connections along a broad latitudinal gradient on the western shelf and southern shelf and slopes is highly recommended.
- Application of existing south-eastern food web models ignore the different physiognomy, sedimentology and habitats available to demersal fish in the south-west region. The spatially explicit fish-habitat approach used by Williams and Bax (2001) should also be extended to food webs.

3.3 Pelagic and benthic production

The south-west of Australia has been commercially fished for decades for a wide range of species including demersal and pelagic invertebrates and finfish. The following analysis of the relative importance of pelagic and demersal fisheries production is based on landings data reported to the FAO by Australia between 1950 and 2002. These data have been spatially reaggregated across Australia's seven recognised large marine ecosystems (<www.seaaroundus.org>) and here we are using the Australian south-west and west coast large marine ecosystems that correspond approximately to the South-west Marine Region. As the west coast large marine ecosystem includes Shark Bay, those species fished exclusively within Shark Bay have been excluded from the analysis.

In the Region, landings have been reported for 144 taxonomic groups including 71 species and 73 higher taxanomic groupings (typically to family). Of these, 18 taxa (or 12%) are found exclusively in the west coast large marine ecosystem and may represent taxa caught in the northern part of the west coast large marine ecosystem which is not part of the planning region. However, these taxa comprise 7.3% of the total landings between 1950 and 2002 with no individual taxa comprising more than 1% of the total landings over the period considered. Thus, it is likely that the incidental inclusion of rare species caught only in the northern area of the west coast large marine ecosystem will not influence the overall analysis of the relative importance of pelagic and demersal fisheries production within the Region.

In the Region, a total of 1.6 million tonnes of fish and invertebrates was landed between 1950 and 2002. These landings included demersal finfish and invertebrates, rays and sharks (considered as demersals in this analysis), and pelagic finfish and invertebrates. Total mean annual landings have increased by 168% in the period between 1950 and 2002, with significant increases across all groups (Table 3.3.1; Figure 3.3.1). In terms of rate of change, the most significant relative increase in mean landings are among the pelagic invertebrates, with greater focus on species such as the teuthid squids. There has also been an increase in landings of demersal rays, sharks and finfish; landings of demersal invertebrates and pelagic finfish have been more modest (184% and 79% respectively).

Between the 1950s and the 1993–2002 period, there have been significant shifts in the relative importance of demersal and pelagic species to the overall catch. Demersal species of invertebrates and finfish comprised 60.2% (±1.5% se) of the total mean annual landings in the 1950s. By the mid 1990s, the proportion of the landings comprised of demersal species had increased to 71.4% (±0.9% se), largely due to the increases in landings of demersal finfish. Indeed, whereas demersal finfish comprised 24.0% (±1.8% se) of the total mean annual finfish landings in the 1950s, this mean had increased to 44.1% (±1.1% se) of the mean annual landings from 1993–2002. With respect to invertebrates, demersal species have consistently comprised more than 98% of the landings.

The significant increase in landings across all major groups plus the shift to increased relative importance of demersal productivity, and in particular demersal finfish, has significant implications for long-term sustainability of fisheries productivity. The marine waters of the Region are relatively nutrient poor and there are thus significant questions as to the total primary production available to support fisheries. It is also likely that benthic primary producers turn over more slowly than water column systems and thus the relative availability of primary production within demersal food webs may be lower.

Additionally, many of the demersal species subject to increasing fishing pressure, such as the sharks and the blue grenadier (*Macruronus novaezelandiae*), have low resilience to fishing given their relatively low reproductive rates and high trophic level. So, although the majority of finfish landed in the Region remain pelagics, demersal finfish are of increased importance in commercial fisheries.

Table 3.3.1 Changes in mean annual total landings (tonnes) between the 1950s and the period 1993–2002 with the percentage increase over that period indicated.

Category	Landings 1950–1959	Landings 1993–2002	% increase
Demersal finfish	1 248	5 153	313
Demersal inverts	7 300	20 727	184
Rays and sharks	608	3 711	511
Pelagic finfish	6 273	11 252	79
Pelagic inverts	4	530	13 160
Total	15 432	41 374	168

Figure 3.3.1 Total landings in tonnes by group from 1950 to 2002

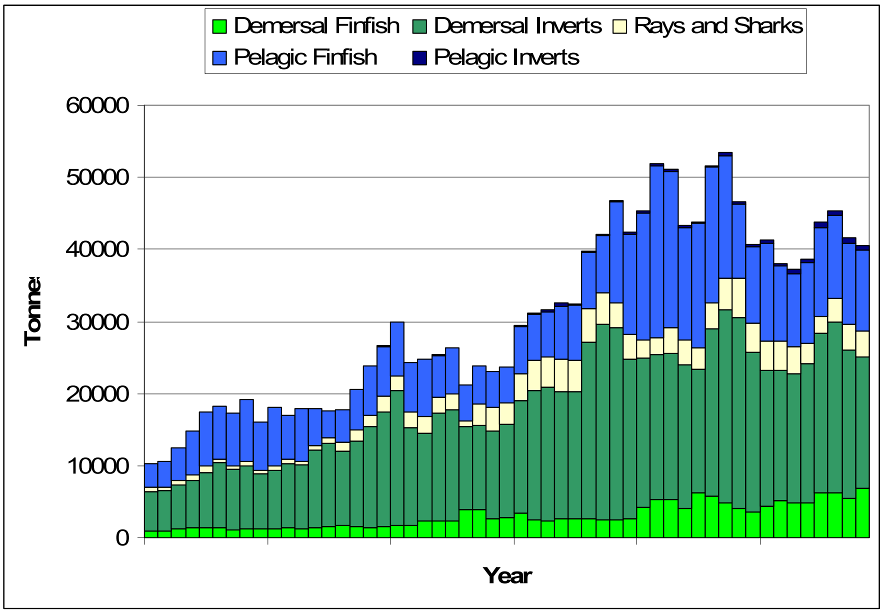
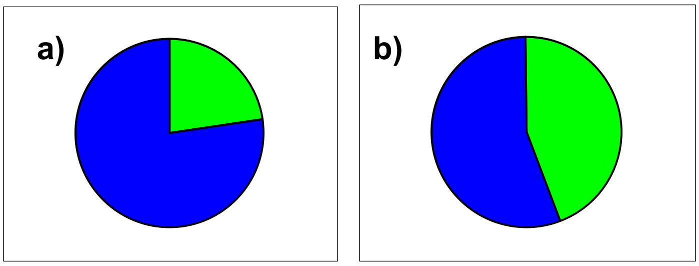


Figure 3.3.2 Relative proportion of demersal (green) and pelagic (blue) finfish between (a) 1950s and (b) 1993–2002.



3.4 Seasonal cycles

3.4.1 Kangaroo Island to Esperance

Principal contributor

Sam McClatchie

Primary production

The seasonal cycle of phytoplankton over the South-west Marine Region can only be inferred from remotely sensed ocean colour because only these data have the spatial coverage over the entire area. Hayes et al. (in press) used monthly composites from the MODIS-Aqua sensor for January, April, July and October to illustrate the annual seasonal cycle (and discussed the limitations of these data in some detail). A consistent feature of the cycle is the low levels of chlorophyll (<1.0 mg Chl a mg^{-3}) over the shelf. Although Hayes et al. refer to chlorophyll levels of 0.75–1.0 mg Chl a mg^{-3} as high, compared to chlorophyll concentrations in shelf seas at comparable latitudes, chlorophyll in the Great Australian Bight is low.

The seasonal snapshots (Hayes et al. in press) show some interesting features over the shelf and slope of the Great Australian Bight between Kangaroo Island and Esperance. In January there is evidence of a connection between higher (0.5–0.75 mg Chl a mg^{-3}) chlorophyll levels on the shelf and higher chlorophyll in offshore waters of the Subtropical Convergence (Figure 3.4.1.1). This feature may be associated with mesoscale eddies in the region evident in the SST imagery (Hayes et al., in press). By April (Figure 3.4.1.2) there is some evidence of propagation of higher chlorophyll (0.75–1.0 mg Chl a mg^{-3}) towards the east over the shelf (Hayes et al. in press). In the winter month of July, there is some evidence for higher chlorophyll in the eastern part of the Great Australian Bight compared to the west (Figure 3.4.1.3). By October, chlorophyll concentrations are low over the shelf (0.25–0.75 mg Chl a mg^{-3}) (Figure 3.4.1.4), although the spring bloom has begun in the Subtropical Convergence offshore (Hayes et al. in press). These remote sensing composites suggest that there may be a seasonal propagation of production from the western area around Esperance towards the eastern Great Australian Bight.

Hayes et al. (in press) also used weekly composites of the SeaWiFS ocean colour sensor to examine spatial and temporal patterns in phytoplankton biomass. They conclude that the Great Australian Bight has a simple seasonal cycle. Chlorophyll is low on the shelf and north of the Subtropical Convergence between November and April. From April, a band of higher chlorophyll develops and spreads across the shelf producing higher chlorophyll in the Head of the Bight. Chlorophyll spreads northward from the Subtropical Convergence at the same time. The higher chlorophyll in the Great Australian Bight persists until late spring, and then recedes back to the Subtropical Convergence (Hayes et al. in press).

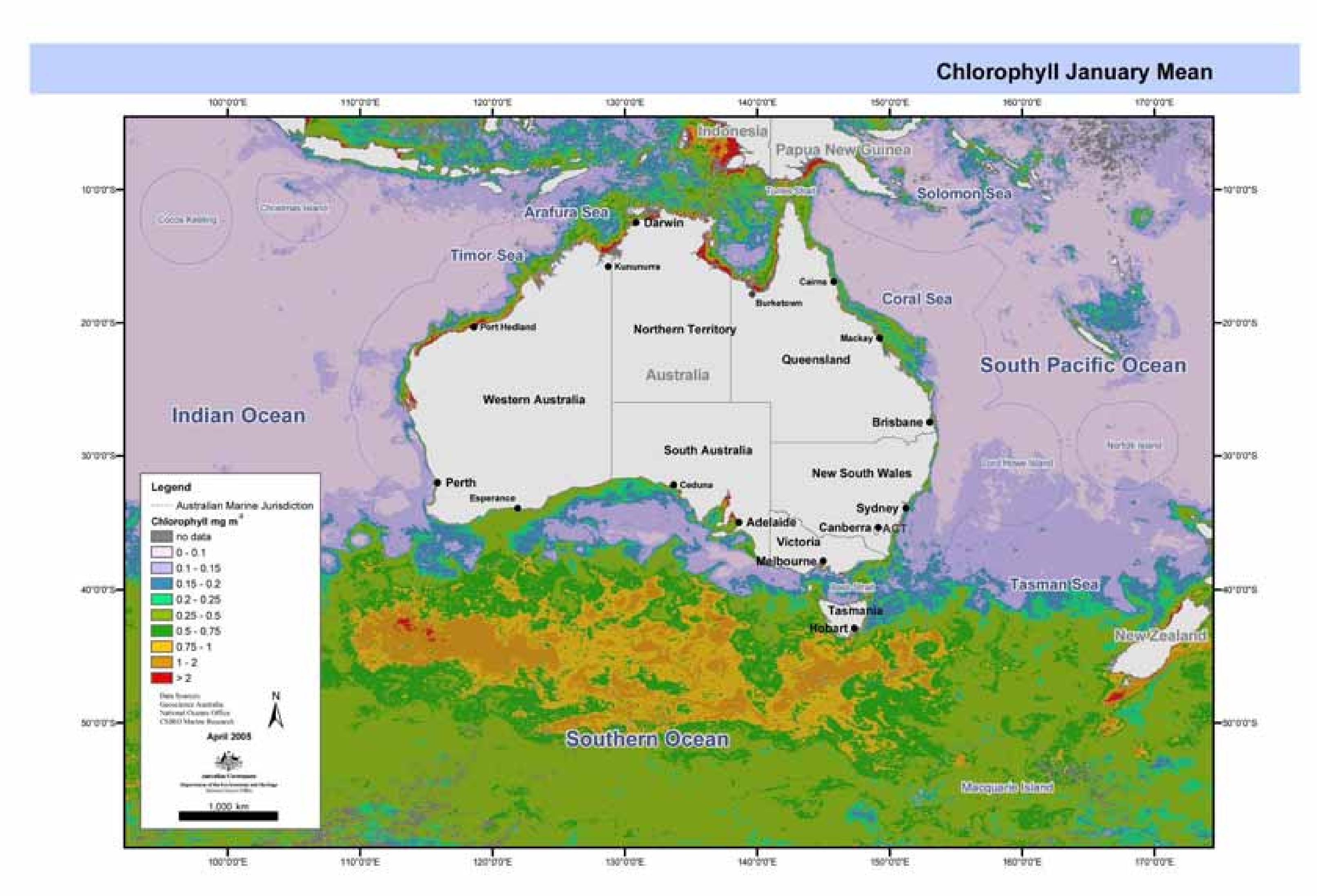


Figure 3.4.1.1 Monthly composites of MODIS ocean colour data showing the seasonal progression of phytoplankton growth – January (from Hayes et al. 2005.)

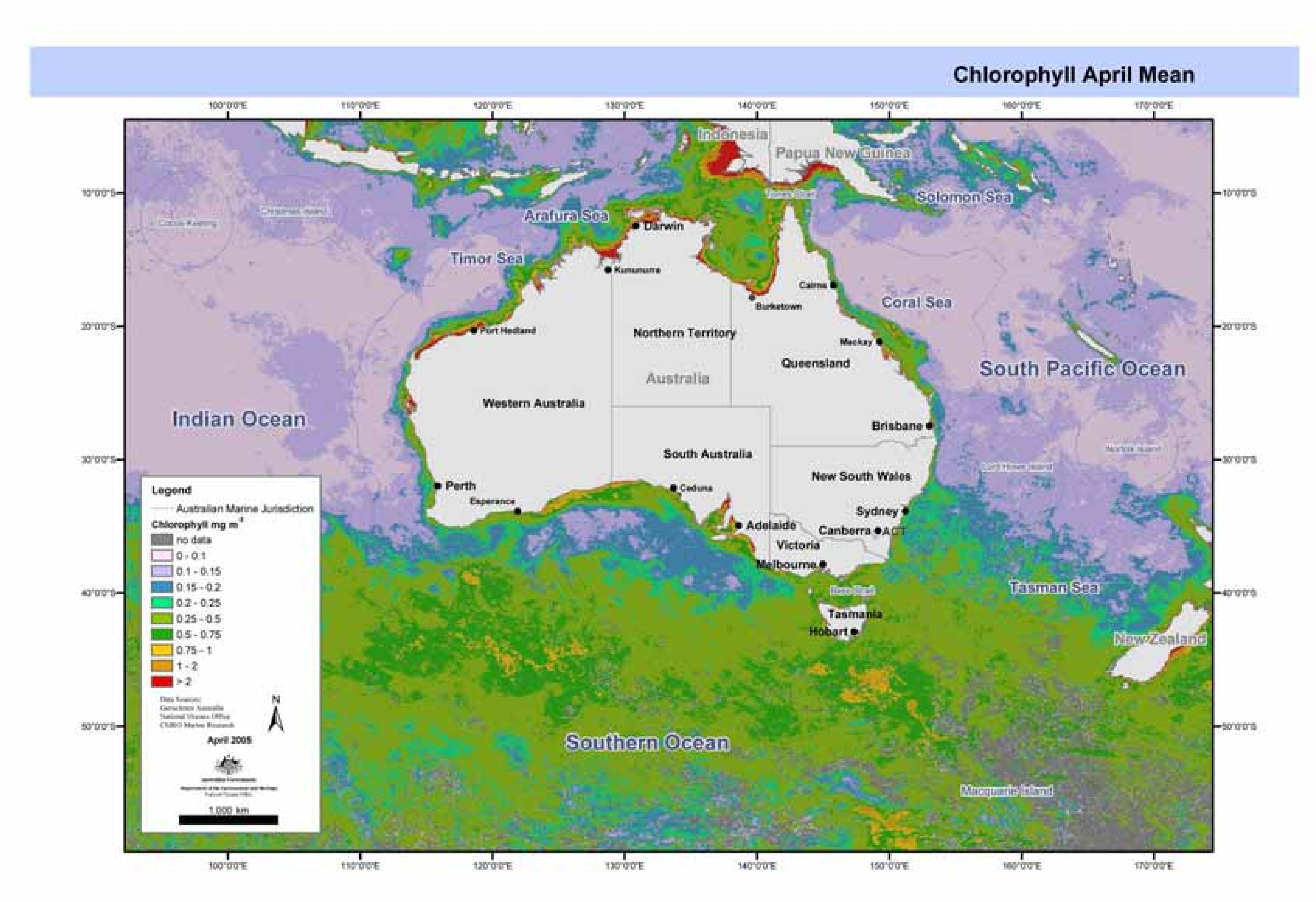


Figure 3.4.1.2: Monthly composites of MODIS ocean colour data showing the seasonal progression of phytoplankton growth – April (from Hayes et al. 2005.)

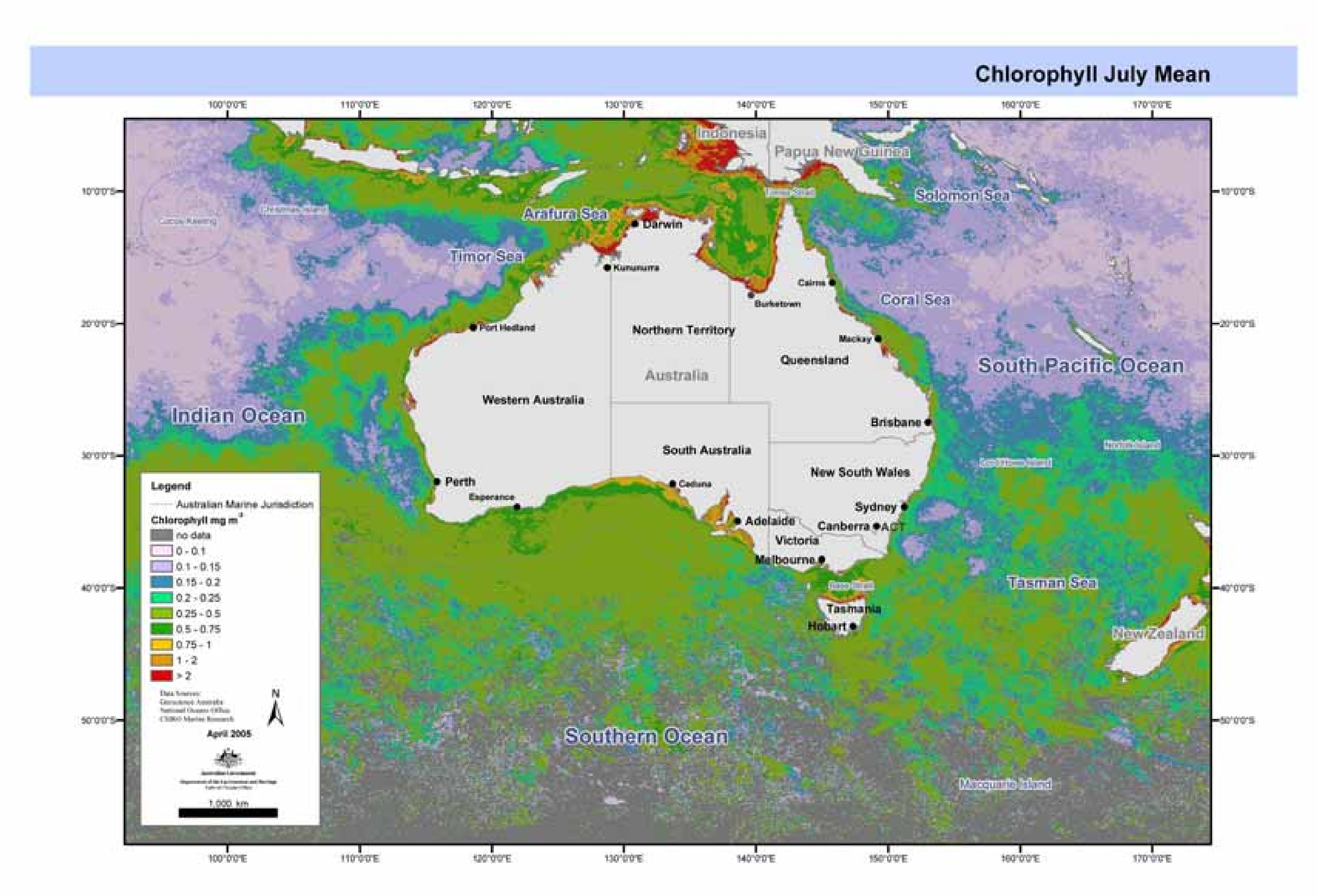


Figure 3.4.1.3 Monthly composites of MODIS ocean colour data showing the seasonal progression of phytoplankton growth – July (from Hayes et al. 2005.)

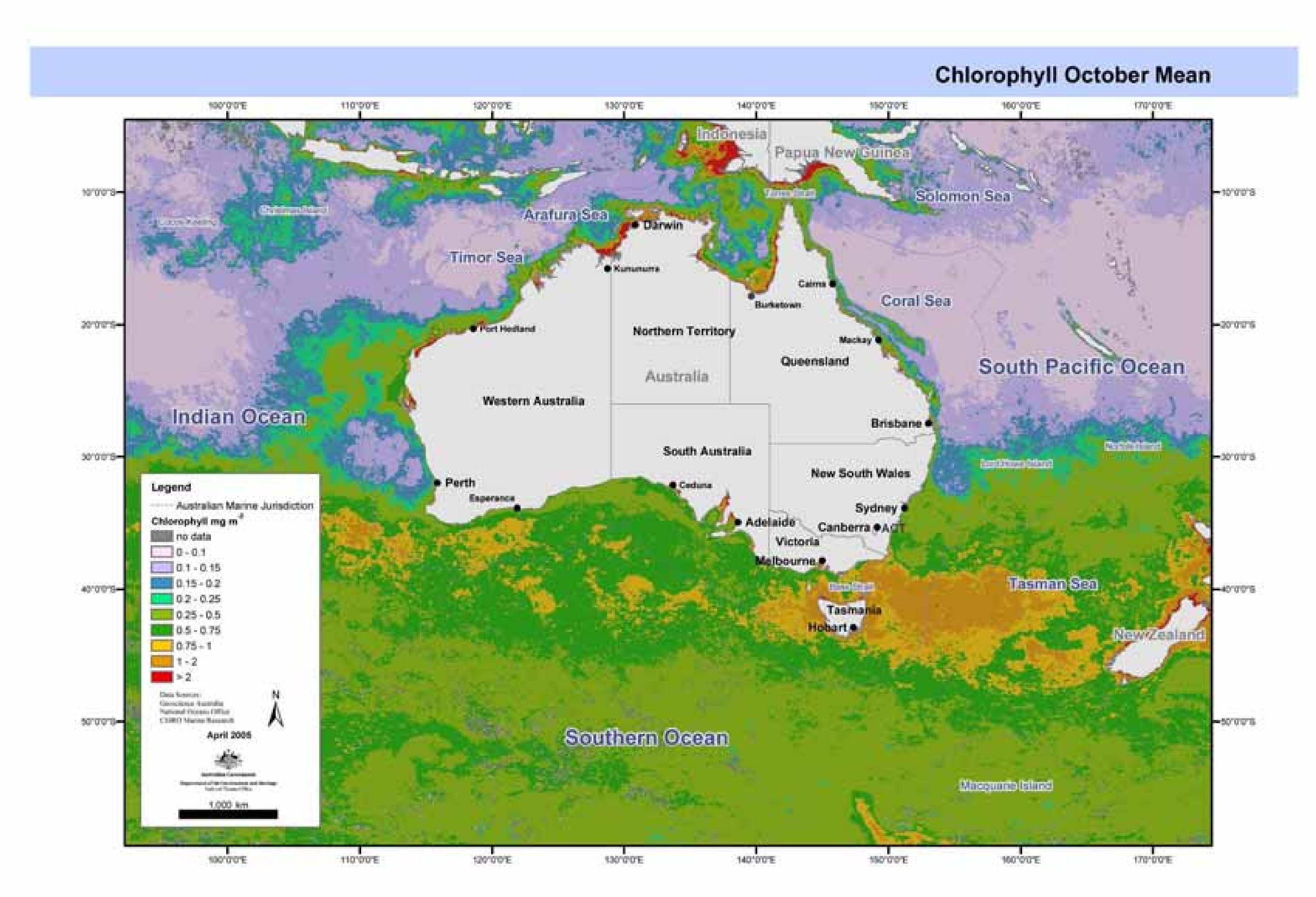


Figure 3.4.1.4 Monthly composites of MODIS ocean colour data showing the seasonal progression of phytoplankton growth – October (from Hayes et al. 2005.)

Primary productivity and seasonal cycle

Measurements of primary productivity in the South-west Marine Region are sparse. Hayes et al. (in press) compiled historical data from 27 naval cruises (1959–1964), but the only measurements in this region were made in the autumn (March–May). Most of these measurements were made either along the shelf edge or further south in the Subtropical Convergence.

Hayes et al. (in press) presented seasonal primary production based on modelled estimates from remote sensing. While there are many problems with the production model, the remote sensing data provide the only regional estimates of the seasonal cycle of primary productivity.

Although there is considerable mesoscale variability, the general pattern of primary production shows a seasonal progression southwards beginning at the end of the winter (July), developing into a major bloom on the shelf and in the Subtropical Convergence in spring (October) then becoming confined to the Subtropical Convergence in mid-summer (January) before retreating northwards again in the autumn (April) (Hayes et al. in press).

Secondary production

The paucity of sampling in the region from Kangaroo Island to Esperance is more serious for zooplankton than for phytoplankton because the distribution of zooplankton cannot be inferred from remote sensing imagery. Historical data from 27 naval cruises (1959–1964) compiled by Hayes et al. (in press) shows that zooplankton biomass estimates were only available for a scattering of stations in winter (June–August) and autumn (March–May). As for the phytoplankton, most of the samples in the historical dataset were on the shelf edge or offshore in the Subtropical Convergence. The historical dataset is insufficient to be informative about seasonality of zooplankton in the Kangaroo Island to Esperance region. An interesting feature of these data is the striking abundance of carnivorous gelatinous zooplankters recorded in autumn (March–May) off Esperance. Remotely sensed chlorophyll imagery suggests advection between the shelf and offshore waters in January off Esperance. The accumulation of predatory zooplankton in autumn may indicate that production on the shelf is being exported and consumed offshore.

3.4.2 Shark Bay to Esperance

Principal contributor

Chari Pattiaratchi

Primary production

The seasonal cycle of phytoplankton biomass (as estimated via chlorophyll a) in the waters off Western Australia can be inferred using satellite-derived data and *in situ* data collected offshore from the Perth metropolitan region (the CSIRO SRFME transect; Haine 2005). The satellite-derived chlorophyll a concentration assessment is limited to near-surface values only. In the South-west Marine Region, the deep chlorophyll maximum is generally present at the base of the euphotic zone, close to the nutricline and represents a significant proportion of the depth integrated productivity (Hansen et al. 2005). The satellite-derived chlorophyll a concentration data represent surface values as the sensors do not penetrate to the base of the euphotic zone. Hence, the analysis presented here is limited mainly to the surface values and does not include the seasonal and spatial variations of the deep chlorophyll maximum.

Two distinct seasonal scenarios characterise the oceanographic conditions along the west and south coasts of Western Australia. During the autumn and winter months, when equatorward wind stress is weakest, the Leeuwin Current flows strongly southwards and can flood much of the continental shelf (Hansen et al. 2005). During this period, the mixed layer is deeper leading to shoaling of the nutricline. During the summer months, southerly winds weaken the Leeuwin Current's flow and generate localised upwelling along the inner continental shelf, forming the source water of the Capes Current (Gersbach et al. 1999). Here, the southerly wind stress overcomes the alongshore pressure gradient which is the driving force of the Leeuwin Current. This results in the surface layers moving offshore and colder water upwelling onto the continental shelf with the result that the Leeuwin Current migrates further offshore.

Data presented by Lourey et al. (2006) have shown that the surface waters of the South-west Marine Region – including the continental shelf, Leeuwin Current and offshore waters – may be considered to be nitrogen limited, with diatom production in shelf waters also limited by the availability of silicate.

In the South-west Marine Region and within the constraints of the *in situ* and satellite data, Leeuwin Current and offshore waters may be characterised as very low surface chlorophyll a environments (<0.25 mg m^{-3}) (Lourey et al. 2006), with slightly elevated concentrations found along the continental shelf (<1.0 mg m^{-3}) (Pearce et al. 2000; Lourey et al. 2006). Higher chlorophyll a values (~2–5 mg m^{-3}) are considered to be representative of shelf waters or estuaries subjected to anthropogenic nutrient inputs (Pearce et al. 2000). Satellite imagery also indicates that the shelf waters are generally higher in chlorophyll a concentrations when compared to Leeuwin Current and offshore waters, in both summer and winter (Figure 3.4.2.1). Interaction between the Leeuwin Current and shelf waters entrains the higher chlorophyll a water into mesoscale eddies which are then advected offshore (Figure 3.4.2.2).

Annual cycles, of temperature, salinity, nitrate, phosphate, silicate and chlorophyll a concentration for the surface waters of the Leeuwin Current and the south-western Australian shelf have been presented by Lourey et al. (2006). In terms of the seasonal cycle, the chlorophyll a concentrations along the continental shelf, Leeuwin Current and offshore waters were higher in winter than in the summer (Figure 3.4.2.3). The summer to winter chlorophyll a increased from ~0.10 mg m^{-3} to 0.25 mg m^{-3} (i.e. a range of ~0.15 mg m^{-3}) in the Leeuwin Current and offshore regions. On the continental shelf, the increase may be larger, possibly up to 0.75 mg m^{-3} (from 0.25 mg m^{-3} to 1 mg m^{-3}) between summer and winter (Lourey et al. 2006). Satellite observations also indicate that the late autumn/early winter bloom is a coherent feature from the Abrolhos Islands to Cape Leeuwin coinciding with intensification of the Leeuwin Current (Figure 3.4.2.4).

The winter increase in chlorophyll a concentration throughout South-west Marine Region is associated with a corresponding increase in the nitrogen concentration which has been attributed to several sources: (1) supply from deeper water through the erosion of the thermocline; (2) regeneration along the continental shelf region through increased storminess; and, (3) through terrestrial sources such river inputs (Hansen et al. 2005; Lourey et al. 2006). However, as the winter chlorophyll a concentration is uniform throughout the whole region (see Figure 3.4.1.4), input from terrestrial sources may only have a minimal impact. It is also important to note that although there is an increase in the chlorophyll a concentrations on the shelf as a result of upwelling and the associated Capes Current, the winter increase in nutrients has a more dominant role in controlling the chlorophyll a concentrations, with the winter values higher than the summer values – although the latter is associated with upwelling.

Primary productivity and the seasonal cycle

In contrast to the chlorophyll a concentrations which were higher in winter than in summer, the primary production rates indicated higher values associated with summer upwelling (Hanson et al. 2005). Here, maximum production rates of 945 mg C m^{-2} d^{-1} were measured during the summer, whilst the maximum winter production rates were 400 mg C m^{-2} d^{-1} (Hanson et al. 2005). This reduction in productivity was attributed to a combination of nutrient availability and the light climate. During the winter, the stronger Leeuwin Current flow leads to increased nutrient levels associated with entrainment of seasonally nutrient-enriched shelf waters. In contrast, lower surface irradiance and increased light attenuation result in lower primary productivity during the winter months.

Secondary production

Seasonal variability in the secondary production is only available from the SRFME transect, offshore Perth (Haine 2005). Measurements undertaken along a cross-shore transect indicated that the secondary production was low in comparison with productive (upwelling dominated) marine environments but were comparable to estimates off Australia's North West Cape (Haine 2005). The seasonal cycle of zooplankton reflected the primary production, with the zooplankton biomass higher in late autumn and winter. The zooplankton assemblages also exhibited differences between nearshore and shelf or offshore waters as well as exhibiting differences with season (Haine 2005).

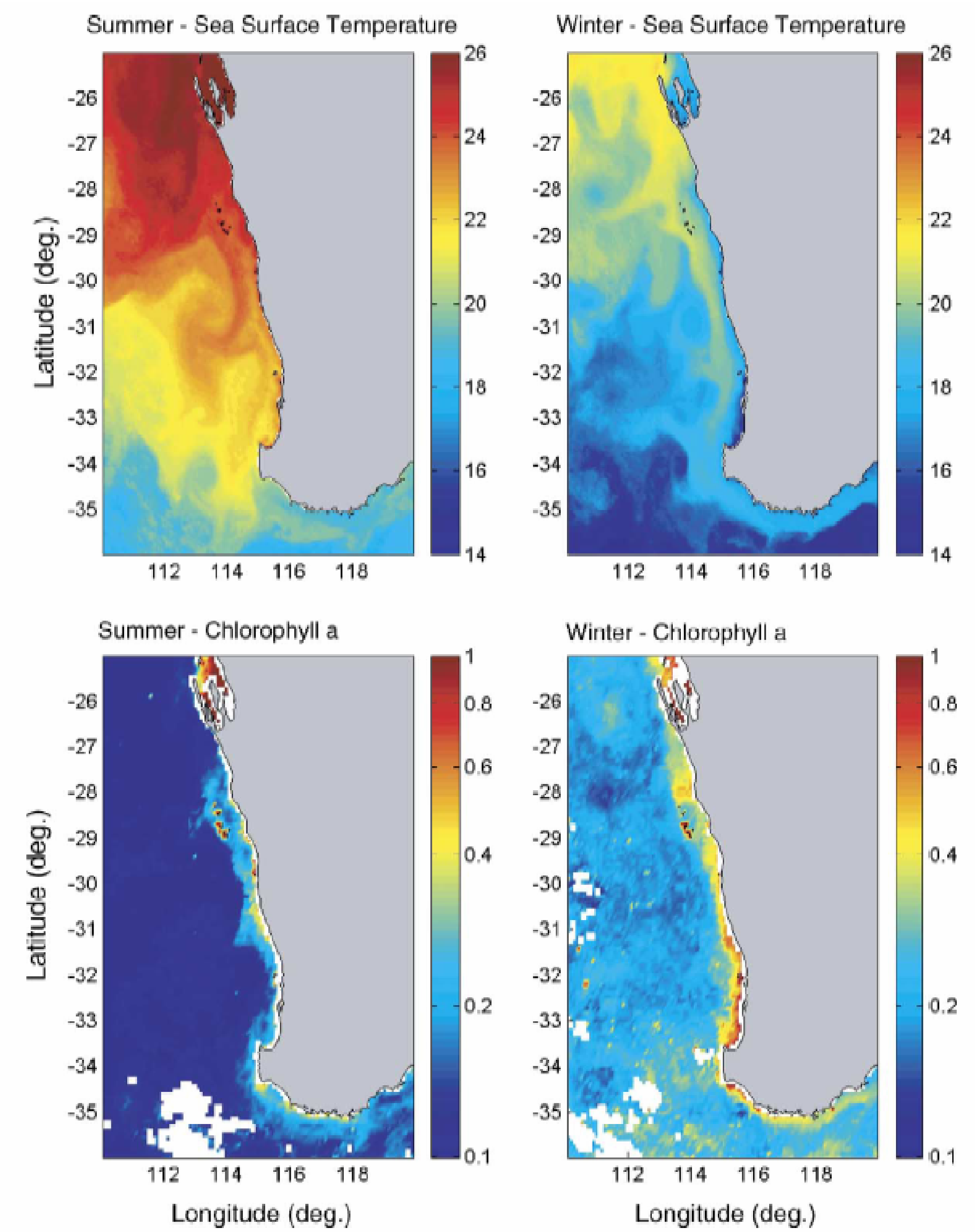


Figure 3.4.2.1: Summer (early February) and winter (mid August) synoptic plots of satellite sea surface temperature (Celsius) and SeaWIFS chlorophyll a concentration (mg m^{-3}) from Lourey et al. (2006).

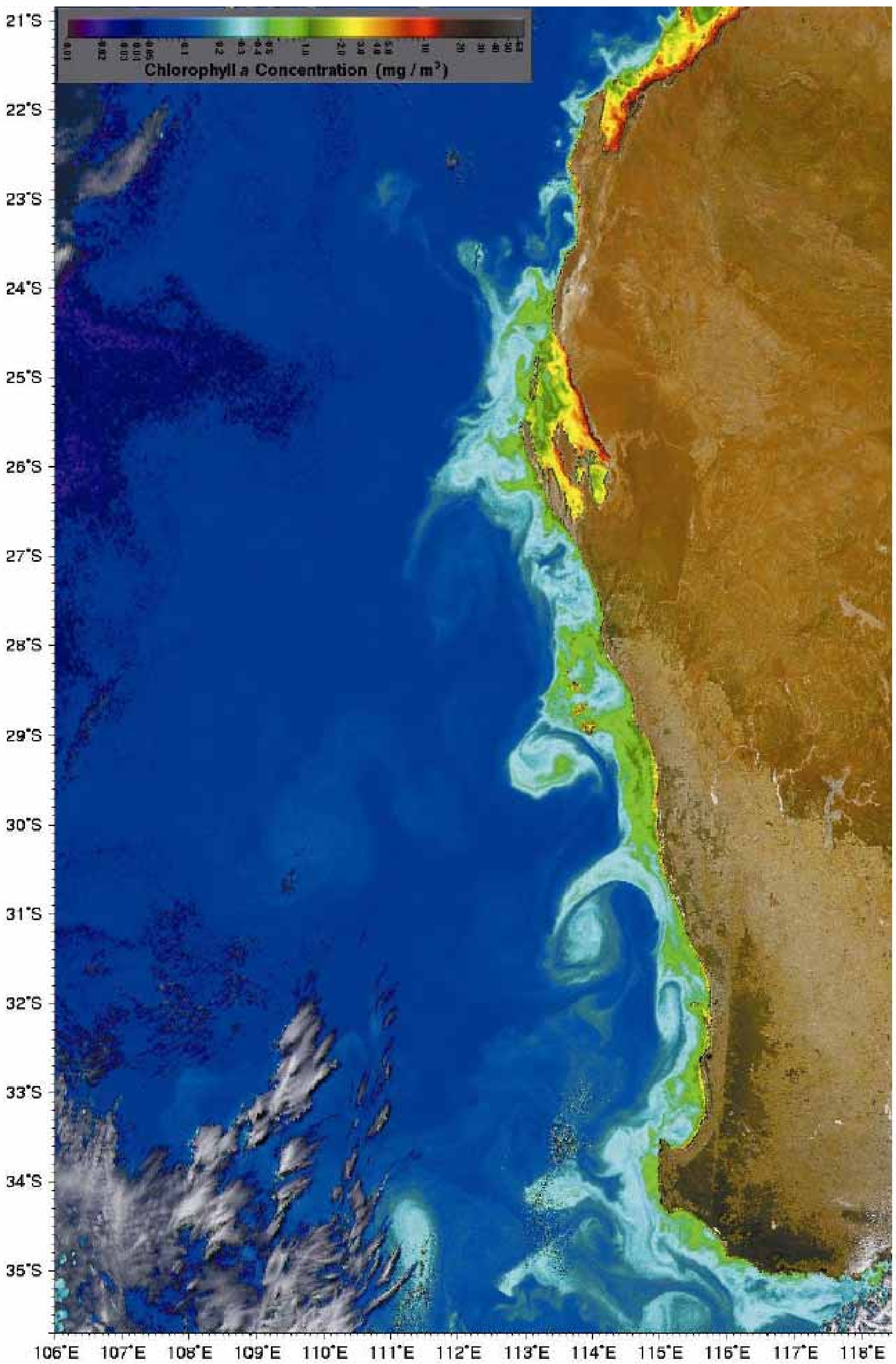


Figure 3.4.2.2 SeaWiFS image from 5 April 2002, illustrating relatively higher chlorophyll a concentrations on the continental shelf and lower concentrations in Leeuwin Current and offshore waters. The two large eddies between 29° S and 32° S show the entrainment of shelf waters into the Leeuwin Current.

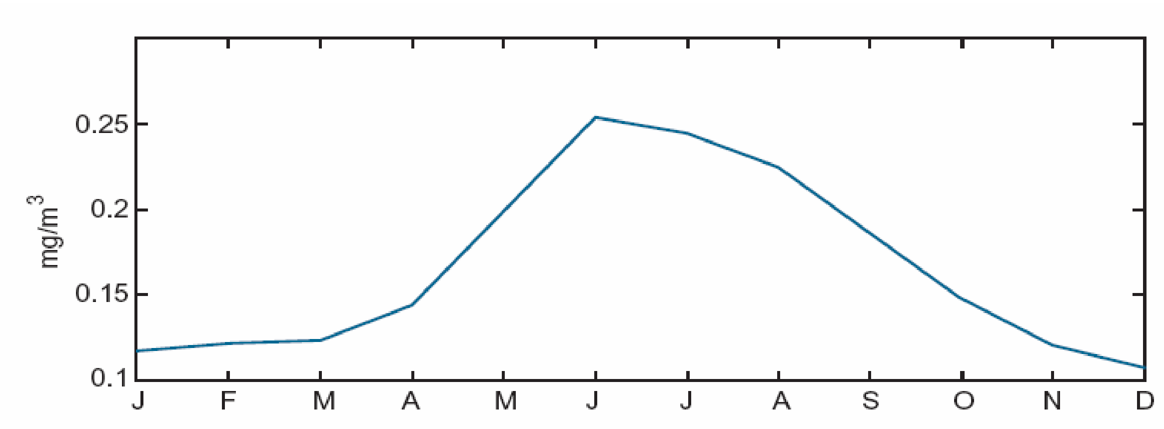


Figure 3.4.2.3 The climatological mean for surface chlorophyll a concentrations off the Western Australian coast (from Feng et al. 2005).

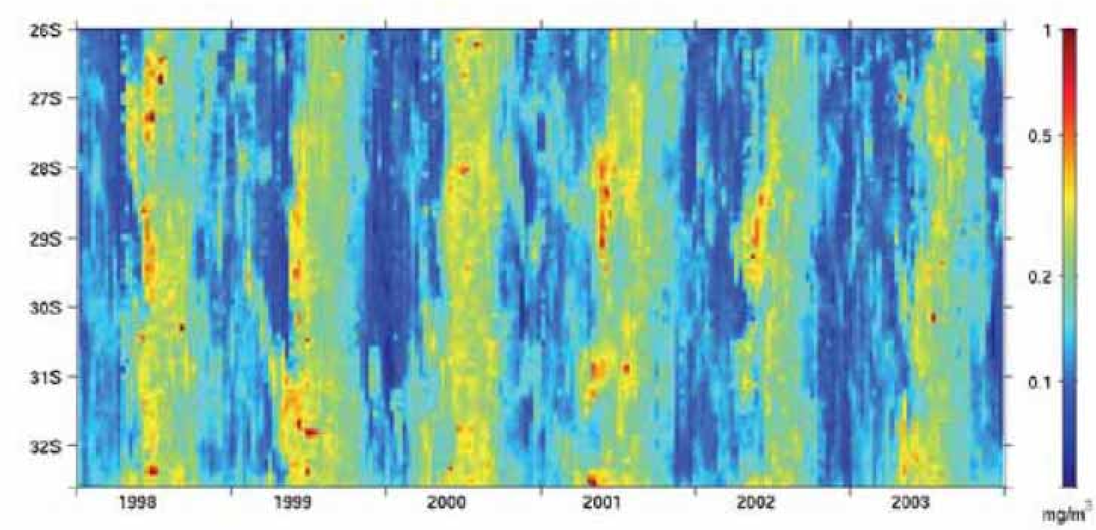


Figure 3.4.2.4 The chlorophyll a distribution estimated using SeaWiFS ocean colour data along the shelfbreak off the west coast of Western Australia from 26° S to 32° S over the period 1998–2003. A late autumn or early winter bloom extends along the coast, with relatively high chlorophyll a levels maintained through much of the winter (from Feng et al. 2005).

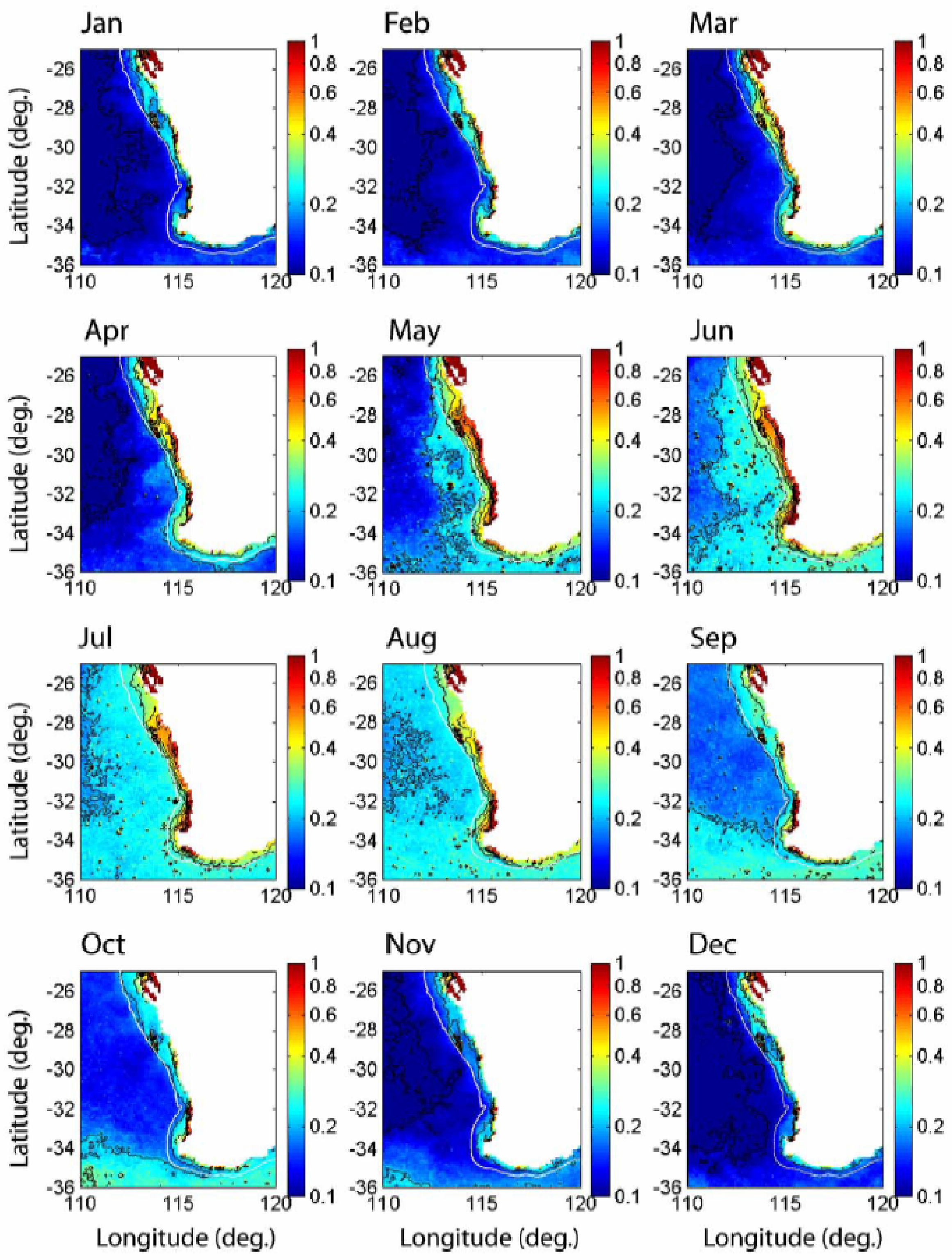


Figure 3.4.6 Monthly mean distribution of surface chlorophyll a (mg m^{-3}) derived from SeaWIFS data (September 1997 – August 2004). The white line marks the shelf break (from Lourey et al. 2006).

3.5 Links to ocean circulation processes

Principal contributors

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John Middleton
Gary A Kendrick

Connectivity

The seasonal progression of phytoplankton production derived from remote sensing indicates that there is zonal and meridional connectivity in the South-west Marine Region. The striking seasonal north–south wave of primary production may be associated with changing Sverdrup transport and seasonal stratification, but may not reflect a connection in the sense of mixing of biological communities between the Subtropical Convergence and the shelf waters. The eastward progression of seasonal phytoplankton production in the Great Australian Bight parallels the path of the Leeuwin Current but is unlikely to be driven by the low nutrient water and is more likely to reflect a breakdown of summer stratification in the warm pool water mass, with associated release of nutrients into the mixed layer. However, the Leeuwin Current water will transport biological communities (e.g. phytoplankton and zooplankton) from west to east in the Great Australian Bight (and may aid movement of Australian salmon as discussed below).

Within these broad north–south and east–west seasonal patterns, there is evidence for connectivity between the shelf and offshore waters off Esperance, where offshore advection may affect the food web and have implications for fisheries recruitment (discussed below). In the eastern Great Australian Bight there is another known connection between 200–300 m deep waters west of Kangaroo Island and the nearshore waters of the Eyre Peninsula, due to the path of Ekman-driven upwelling (McClatchie et al. 2006). In what follows, a range of different oceanographic processes are addressed in terms of how they affect ecological structure and function.

The main oceanographic features of the region between Shark Bay and Esperance are:

- The West Australian Current
- The Leeuwin Current
- The Leeuwin Undercurrent
- The Flinders Current
- Continental shelf current systems: the Ningaloo, Capes and Cresswell currents.

Ecological integration: Links to ocean circulation processes

The west coast of Western Australia was demonstrated by Roberts et al. (2002) to be one of the world's diversity hotspots with high endemism in corals, fish, gastropods and lobsters. The geological long-term stable gradient in ocean climate along the west coast was inferred as being a major driver for both high species richness and high endemism in this region. The predominant pattern of species distributions on the west coast of Australia is a gradient of mixing of tropical and temperate marine fauna and flora, with assemblages dominated by tropical species to the north and temperate species in the south. This pattern is best demonstrated in the corals. There is a decline in species richness of corals in offshore islands from 184 species in the Houtmans Abrolhos, to 23 species 400 km south at Rottnest Island, to five species in the Recherche Archipelago off Esperance. Onshore, there are fewer species over this latitudinal gradient, with 35 species recorded off Kalbarri, 10–15 species on the central west coast, and eight species in Albany (see Part 2, Section 4.4: Corals for greater detail).

Greater mixing and northward movement of waters are related to onshelf counter currents, and the reduced influence of the Leeuwin Current onshelf and nearer to the Western Australian coast. Similarly, macroalgae demonstrate a cline along the west and south coasts of Western Australia. Macroalgal assemblages near Perth, Western Australia are similar to those found near Cape Leeuwin, but the south coast flora recorded from Bremer Bay and the Recherché Archipelago indicate that the dominant canopy of *Ecklonia radiata* and warm-temperate *Sargassum* species are replaced by mixed species canopies of *Ecklonia*, *Cystophora*, *Scytothalia* and cold-temperate *Sargassum* species (Wernberg et al. 2003, Goldberg & Kendrick 2005). This shift is gradual, inferring strong connectivity between warm-temperate west coast and cold-temperate south coast floras.

Influence of the Leeuwin Current

The Leeuwin Current is a shallow (<300 m), narrow band (<100 km wide) of warm, lower salinity, nutrient depleted water of tropical origin that flows poleward from Exmouth to Cape Leeuwin and into the Great Australian Bight (Church et al. 1989; Smith et al. 1991; Ridgway & Condie 2004) and to the North-west Cape of Tasmania. It is the longest boundary current in the World (Ridgway & Condie 2004). The Leeuwin Current has greatest influence on the upper continental slope, and suppresses upwelling on the coast as it is driven in the opposite direction to the equatorial wind stress by an alongshore pressure gradient. The Leeuwin Current is low in nutrients and has a low chlorophyll a signature from satellite remote sensing. Primary and associated secondary production is much greater at the interface between the Leeuwin Current and deeper Undercurrent at approximately 150–200 m depths. Pelagic production appears decoupled from surface primary production measured as chlorophyll a.

The Leeuwin Current also has a major effect on recruitment of the biota of the south-western Australian shelf (Morgan & Wells 1991; Caputi et al. 1996). Strong Leeuwin years correlated to high puerulus settlement for western rock lobster (*Panulirus cygnus*). The Leeuwin Current has a significant negative effect on recruitment of saucer scallops in Shark Bay. The pilchard (*Sardinops sagax neopilchardus*) recruitment is negatively correlated to the strength of Leeuwin flow two years earlier. There is a positive relationship between the strength of the Leeuwin Current and recruitment of the Australian salmon (*Arripis truttaceus*) in South Australia. Intertidal platforms at the western end of Rottnest Island support a number of tropical taxa, the larvae of which are carried southwards on the Leeuwin Current. The Leeuwin Current and its influence on the coastal climate and marine life were the subject of a published symposium (Pearce & Walker 1991).

The Leeuwin Current is predominantly found over the continental slope across Region, but it does meander and has been shown to flood the continental shelf near the Jurien area on the west coast of Western Australia (CSIRO SRFME) and from Albany to Bremer Bay. These meanders influence the recruitment of western rock lobster in the Jurien Bay region and recruitment of tropical taxa in the Bremer Bay area.

The Leeuwin Current is stronger during winter and weaker during the summer months due mainly to changes in the wind stress (Figure 2.1.7; Section 2.1). Coastal counter currents like the Capes Current are stronger during summer months, and their influence on production is predominantly a summer phenomenon.

There is a strong correlation between ENSO events and weakening of the Leeuwin Current. This has demonstrable effects on puerulus settlement of the western rock lobster: higher settlement is recorded when the Leeuwin Current is strongest (Pearce & Phillips 1988). During normal years, the coastal annual mean sea levels are relatively high, indicating that the Leeuwin Current is strong and the settlement of pueruli in coastal reefs is relatively high. During ENSO years, coastal sea levels fall and transport in the Leeuwin Current is weaker (Feng et al. 2003).

Onshelf counter currents

Upwellings associated with onshelf counter currents are restricted to weak onshelf upwelling associated with the Capes Current near Cape Leeuwin, the Ningaloo Current and are also associated with the Abrolhos Islands. Waters associated with these upwelling events affect phytoplankton productivity and composition by shifts from dominant communities of micro- and nano-plankton to more productive communities of larger diatoms in areas of upwelling.

Hansen et al. (2005) studied the seasonal influence of the Capes Current on primary production in south-western Australia and found that although the Capes Current resulted in higher nutrients and higher nearshore primary production in summer between Cape Leeuwin and Cape Naturaliste, during winter the nutrient levels associated with the Leeuwin Current were also higher than expected; Hansen et al. (2005) invoked entrainment of nutrient-rich shelf waters at the base of the Leeuwin Current as an explanation. The interactions between the Leeuwin Current and onshelf counter currents is an area that requires further investigation.

Deep westward conveyor belt

The Flinders Current is a deep (~600 m) flowing current moving from east to west. It is too deep to influence epipelagic communities in summer but in winter, wind-forced downwelling may entrain epipelagic organisms into the deep Flinders Current. Whether these organisms can survive at depth long enough to undergo significant westward transport by the Flinders Current is unknown. The connection provided by the Flinders Current may be one reason why the slope demersal fish communities are relatively homogeneous in terms of species composition all along the southern Australian continental shelf margin (Last et al. 2005). A similar homogeneity of mesopelagic communities might be expected as a result of this flow pattern but there are no data to confirm this.

Upwelling system

The narrow south-east shelf to the east of the South-west Marine Region underlies a large summertime upwelling plume (called the Bonney Upwelling) that extends to the north-west as a series of discrete upwelling centres off western Kangaroo Island (Kitani 1977) and along the Eyre Peninsula (Anonymous 2001; Kampf et al. 2004) (see Figure 3.5.1). The eastern boundary of the South-west Marine Region is artificial in the sense that it transects the upwelling system that underpins the productivity of the eastern part of the South-west Marine Region. For that reason, this report includes some discussion of the broader upwelling system here.

Early work on upwelling off South Australia focused on the narrow shelf area off Robe, south-east of the two gulfs, where upwelling of sub-Antarctic water (following terminology of Newell (1974)) comes to the surface in the summer months, forming the Bonney Upwelling (Rochford 1977; Lewis 1981; Bye 1983; Provis & Lennon 1981). Rochford (1977) measured moderate nitrate enrichment in surface waters off Port MacDonnell and speculated that Ekman flux driven by south-east winds (upwelling-favourable in the southern hemisphere) contributed to upwelling in the area. Using a more extensive set of cross-shelf transects, and five years of monthly samples of temperature, salinity, nitrate and silicate at Port MacDonnell, Lewis (1981) measured nitrate concentrations six times higher in the lower layer of sub-Antarctic water compared to the upper layer of sub-tropical water in summer. He described three summer upwelling centres where sub-Antarctic water reaches the surface in the Bonney Upwelling (south-east of Port MacDonnell, south of Southend, and south of Robe). Lewis (1981) made a qualitative link between upwelling intensity and the occurrence of south-east winds, and speculated that the canyons at the shelf edge might play a role in focusing the upwelling.

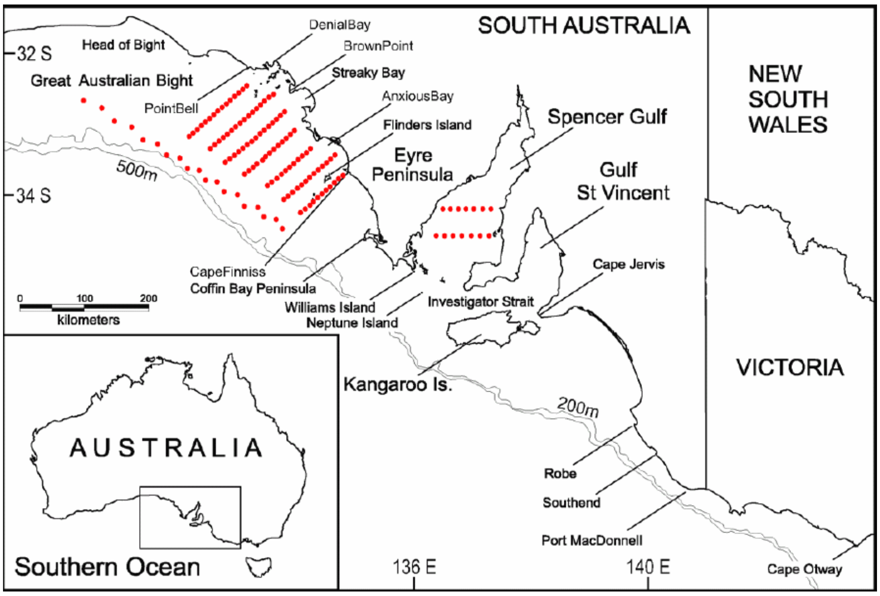

Figure 3.5.1 Map of the eastern Great Australian Bight showing locations mentioned in the text.

Schahinger (1997) used time-series measurements of wind stress, currents from three current meters, and bottom temperatures combined with CTD sections to examine the dynamics of the Bonney Upwelling. He calculated the internal Rossby radius to give the subsurface scale of thermocline uplift, discussed the strengthening effect of the daily sea breeze, and examined the timing and duration of two upwelling events. He related cross-shelf gradients in density to vertical differences in alongshore velocity using the thermal wind equation, and estimated the thickness of the surface Ekman layer and mixed layer which was used to compare the calculated mean flows with the measured flows. Schahinger (1997) speculated that the spatial scale of the upwelling was on the order of 20 km, and agreed with Lewis (1981) that the upwelling centres were localised while the spatial effect of the upwelling was broadened by advection.

Later modelling work (Wenju et al. 1990) simulated the onset of upwelling along the Bonney Coast and tested the effects of wind direction, bottom topography and interfacial stress. Wenju's three layer and two layer models were able to simulate wind-driven upwelling, and predicted uplift of interfaces beginning a day after the onset of favourable winds. The effect of bottom topography rather than coastal curvature was shown to be significant, and the most favourable areas for upwelling were in an approximately 20–30 km wide band adjacent to the coast between Portland and Cape Jaffa, near Robe (see Figure 3.5.1), as well as on the western edge of Kangaroo Island (Wenju et al. 1990). The model also predicted a westward-flowing jet of up to 70 cm s^{-1} adjacent to the coast. Another researcher (Anonymous 2001) made extensive use of remote sensing imagery of the south-east region, clearly showing the Bonney Upwelling, as well as upwelling off western Kangaroo Island and Coffin Bay Peninsula (see Figure 3.5.1) between December and March. The eastern Great Australian Bight along the western coast of the Eyre Peninsula (Figure 3.5.1) is also an upwelling region (Middleton & Platov 2003; Middleton & Cirano 2002; Baird 2003; Kampf et al. 2004) and it is assumed that the upwelling-driven enhancement of primary and secondary production supports the large pelagic fish resource.

Exactly how the enrichment occurs, its spatial and temporal scales and its variability are poorly understood, although the seasonal shelf circulation has been modelled (Middleton & Platov 2003; Middleton & Cirano 2002). Recent work showed that there are on average two to three wind-driven upwelling events during the austral summer (Kampf et al. 2004). These events are associated with south-easterly winds that prevail between December and April (Bye 1983). The coastal upwelling was shown to produce surface phytoplankton patches within a week of the upwelling event (Kampf et al. 2004), that may sink and form the observed subsurface chlorophyll a maxima (Kampf et al. 2004).

Two-dimensional modelling studies predict that upwelling in the eastern Great Australian Bight is strongly influenced by bathymetry (Baird 2003). Where the shelf is narrow and bathymetry is steep, modelling suggests that upwelling occurs within 10 km of the coast, raising cool water and nutrients to the surface where phytoplankton concentrations then develop. Zooplankton patches lag the development of phytoplankton concentrations and generally occur downstream (Baird, 2003). In contrast, where the shelf is broad and relatively shallow out to 200 km offshore, modelling predicts that upwelling of cooler water will occur more slowly and be located at the shelf break rather than inshore. Here the model suggests that nutrients are utilised by phytoplankton before reaching the surface, a subsurface phytoplankton peak develops, and the phytoplankton and zooplankton patches are spatially and temporally co-located (Baird 2003).

For the mid to western end of the Great Australian Bight, the study of Middleton and Platov (2003) indicates that downwelling and not upwelling should occur along the shelfbreak. The downwelling results from convergence of deep ocean and shelf slope Sverdrup transports that are both driven by the generally positive wind stress curl. In the region separating the Bonney Coast upwelling and the western Eyre Peninsula upwellings, Hahn (1986) conducted an extensive seasonal study at the mouth of the Spencer Gulf by repeating CTD transects in the axis, and across the mouth, of the Spencer Gulf combined with a moored current meter and thermistor array on the shelf. His work showed the development of strong stratification on the shelf in summer, outflow of high salinity water from the Spencer Gulf in the autumn, and well mixed water on the shelf and in the mouth of the Spencer Gulf in the winter. The inverse estuary characteristics of the Spencer Gulf and the high salinity autumn outflow into shelf waters were described by Lennon et al. (1987) and Nunes Vaz et al. (1990). The interface between Spencer Gulf and shelf water creates a front in summer (Hahn 1986), where larval fish have been shown to aggregate (Bruce & Short 1990), possibly as a result of convergent flows, although convergence was not demonstrated.

Both numerical model results (Middleton & Platov 2003) and the CARS climatology of bottom temperature (December–January) provide strong evidence that shelf break upwelling is confined to the Kangaroo Island region and does not occur further to the west off the Eyre Peninsula. Rather, the upwelled water is likely to remain in the Kangaroo Island "pool" until subsequent upwelling events draw the water to the shallower and surface coastal regions of the eastern Great Australian Bight. In this manner, the surface upwelling apparent off the Bonney Coast, Kangaroo Island and the eastern Great Australian Bight can appear to be simultaneous. Moreover, it appears likely that the water within the Kangaroo Island pool remains nutrient rich.

Support for this model comes from the CTD sections collected during March 2004 for the eastern Great Australian Bight. In particular, the data show that the upwelled signal (cool <17 °C, fresher <35.6 ppt, dense σT >26 kg m^{-3}) diminishes in width and intensity with increasing distance from Kangaroo Island. The pattern of fluorescence is similar to that for temperature and indicates that the Kangaroo Island pool remains nutrient rich.

The warmest water is found near the shelf break along with very low values of fluorescence and relatively higher levels of oxygen, suggesting nutrient-limited growth of phytoplankton. These data support the notion that the upwelled nutrient-rich water is supplied from the Kangaroo Island pool and not by shelf break upwelling in the eastern Great Australian Bight. The coldest water lies nearest the Kangaroo Island pool and has high values of fluorescence and low values of oxygen. The data also indicates anomalously fresh water due to groundwater discharge (aquifiers) at depths of 40 m or more. In addition, the coastal bays are sources of anomalously salty water – a likely result of evaporation. The eastern Great Australian Bight upwelling signal near the coast is also most evident as two distinct patches of cool water centred on Brown Point (separating Streaky Bay and Denial Bay), and the southern side of Cape Finnis and Flinders Island. Upwelling around headlands and bays is known to occur elsewhere due to local wind effects (e.g. Roughan et al. 2005) as well as advection by headland eddies (e.g. Leth & Middleton 2004; Oey 1996; Penven et al. 2000). Unfortunately, without further ocean current data, we cannot determine the mechanisms for the localised upwelling

Headlands

The area around Flinders Island (34° 45' S 134° 30' E) shows evidence of localised enrichment of phytoplankton in remote sensing imagery, with strong indications that a filament may be generated along a ledge and the inner edge of the island (Figure 3.5.2), forming a cyclonic eddy in Anxious Bay (McClatchie et al. 2006). This feature may be associated with the local bathymetry; in particular, the shallow ridge that extends normally to the shore and the enriched phytoplankton may indicate an upwelling centre (i.e. an intensified coastal upwelling with comparable along-shore and cross-shore spatial scales (Brink 1983)). Roughan et al. (in press) described a small-scale, isolated upwelling associated with a headland in the lee of Point Loma, California. This upwelling was not associated with wind stress (currently thought to be the primary driver of upwelling on the western Eyre Peninsula), but was driven by divergence of the prevailing flow as it passes the headland (Roughan et al. in press). A similar phenomenon may be occurring at Flinders Island. The enriched phytoplankton produced in the area by the proposed upwelling mechanism may attract concentrations of zooplankton and micronekton that in turn could be eaten by pelagic fish. Pelagic fish (sardines, mackerels) are known to aggregate on the northern side of the island, but little is known about the temporal variability in their distribution.

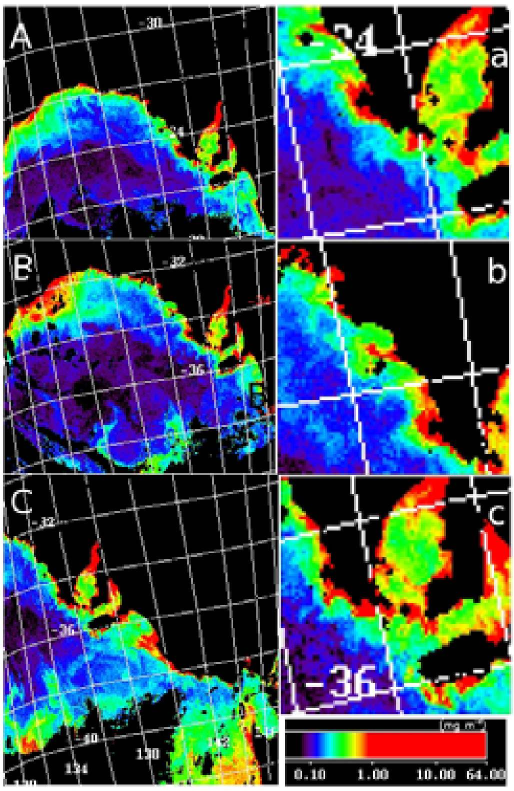

Figure 3.5.2 SeaWIFS imagery of the eastern Great Australian Bight (left panel) in March 2004 with enlargements of the western Eyre Peninsula (right panel). Chlorophyll concentrations should be regarded as relative near shore (in Case 2 waters where the scattering may be from material other than chlorophyll). A: a = 2 March 2004; B: b = 19 March 2004; C: c = 28 March 2004.

The South Australian gulfs

Deep salinity outflow from Spencer Gulf

For most of the year, there is relatively little circulation between the shelf and the warm and salty Spencer Gulf waters (see Chapter 2 of this report). A temperature front is present in the mouth of the Spencer Gulf and is known to be an area rich in ichthyoplankton (Bruce & Short 1990). Although the frontal dynamics of this area have not been studied in detail, it is likely that the strong daily sea breezes in the area will produce coupled bands of upwelling (where the sea breeze is strong) and downwelling (where the sea breeze dies out further offshore)(see physical review). The recirculation cell produced by sea breeze forcing may retain plankton in the frontal zone, and explain why Bruce and Short (1990) found concentrations of fish larvae in the area. The link between physical dynamics and the biota has not yet been verified by observations.

Although the Spencer Gulf is largely isolated from the shelf, there is a mass flux of salt from the Spencer Gulf onto the shelf in the autumn (Lennon et al. 1987; Nunes Vaz et al. 1990). This efflux of warm, salty water must transport plankton and particulate organic matter from the gulf into the continental shelf waters. In addition, such a large flux of denser water may have an effect on mixing at the mouth of the Spencer Gulf, and such mixing may affect local productivity. The effect on productivity may be to enhance nutrients and increase primary production, but it may also remove some phytoplankton production from well-lit surface waters, thereby reducing primary production.

Links between the gulfs, coastal embayments and the shelf

Prawns

There is little published information on the recruitment and movement of juvenile prawns in the Spencer Gulf, Gulf of St Vincent and west coast (Eyre Peninsula) fisheries (see Carrick & Ostendorf 1999; Carrick & Williams 2000; Svane 2003; Svane & Johnson 2003). At present juvenile prawns in these three fisheries are thought to be separate stocks, with limited exchange of adults between them (Cameron Dixon, pers. comm.). The size structure of prawns in the mouth of the Spencer Gulf suggests that any movement between the gulfs and the shelf would be by adult rather than juvenile prawns. Any exchange would be limited to the region near Kangaroo Island, but is difficult to verify because population structure data come from commercial catches that do not extend below ~60 m (Cameron Dixon, pers. comm.).

The Spencer Gulf stock does not rely upon coastal embayments for recruitment, but rather serves as a single, large hyper-saline body of water. Larvae of western king prawns (*Melicertus latisulcatus*) are concentrated in the northern part of the Spencer Gulf (north of 34° S) (Carrick & Ostendorf, 1999). The distribution of western king prawn juveniles indicates that the shallow, inshore nursery areas are north of Cowell in the west and Wardang Island in the east of Spencer Gulf (summarised in Carrick & Ostendorf 1999). These boundaries correspond with the part of the Spencer Gulf that is shallower than 17 m (except for the central channel which extends to 25 m deep). Juveniles were denser on the western side compared to the eastern side of the gulf. The prawns from these nursery areas recruit to the whole of the Spencer Gulf (see map of principal trawl grounds in Carrick & Ostendorf 1999).

The west coast prawn fishery relies upon the hypersaline lagoons, such as Venus Bay, for recruitment, with the estuary in Venus Bay being the main source for larvae (Carrick & Ostendorf 1999). Although there are no tagging data to verify movements, based on what is known of prawn ecology, it is likely that juvenile prawns move out from the west coast lagoons (that may include Baird Bay and the inlets off Ceduna) and mangrove areas onto the shelf as they increase in size and become less tolerant of salinity changes.

Marine scalefish

There is relatively little exchange of fish between the South Australian gulfs and the shelf waters, although there is a seasonal migration of yellow-tailed Kingfish (*Seriola lalandii*) from the islands at the mouth of the Spencer Gulf into the upper reaches of the gulf (McGlennon 1997; Fowler et al. 2003). These are large fish (>10 kg), in contrast to escaped 1.5–3.5 kg Kingfish from the farms now established in the gulf. Spencer Gulf has not previously been exposed to smaller Kingfish and there is currently a lack of understanding about the influence of escaped cultured Kingfish on the Spencer Gulf ecosystem (Fowler et al. 2003). Small escaped Kingfish may prey on fish, squid and crustaceans (Fowler et al. 2003), including King George whiting, garfish, western king prawns and trevally (McGlennon 1997).

The multi-species fisheries in Spencer Gulf and Gulf of St Vincent (collectively termed marine scalefish) largely exist in isolation within the gulfs. The key species in the marine scalefish fishery are snapper (*Pagrus auratus*), King George whiting (*Sillaginodes punctata*), garfish (*Hyporhamphus melanochir*), and squid (*Sepioteuthis australis*).

Snapper

It was originally thought that snapper moved between the Spencer Gulf and the shelf waters on an annual basis (McGlennon & Jones 1997). Snapper spawn in the shallow upper reaches of the Spencer Gulf, and McGlennon and Jones (1997) suggested that a proportion of recruits were resident in these waters throughout the year. They suggested that as snapper age, a greater proportion of them move out into the shelf waters and return annually to the gulf waters to spawn. McGlennon and Jones (1997) proposed that fish older than nine years tend more often to remain in the Spencer Gulf rather than pursue an annual movement onto the shelf.

Pre-recruit snapper (year 0+) are found in the upper reaches of the Spencer Gulf (north of ~33° 30' S) in association with muddy sediments and an essentially featureless bottom terrain (Fowler & Jennings 2003). An analysis of the age-related elemental composition of snapper otoliths collected thr0oughout state waters showed that composition was similar in the first three years of life, although with some indication of separation between the northern Spencer Gulf and the northern Gulf of St Vincent. This indicates that all of the snapper come from a single stock, or at most from two stocks in the two gulfs (Fowler et al. 2005). For older fish, the elemental composition diverges with age for snapper of 3–5 years old. After age 5+, the divergence in elemental composition of the otoliths ceased. This indicates that snapper dispersed and then became resident in different parts of South Australian coastal waters (Fowler et al. 2005). The otolith chemistry data show that there is no support for seasonal migration into and out of the Spencer Gulf, but despite the lack of evidence from this method, some seasonal exchange of snapper between gulf and shelf waters cannot be discounted (AJ Fowler, pers. comm.). Otolith chemistry data also show that there is most likely a single stock of fish that disperses throughout the gulf and shelf waters (as deep as 200 m) with age (Fowler et al. 2005).

King George whiting

The recruitment dynamics, relationships to ocean circulation and spatial scale of the stocks of King George whiting (*Sillaginodes punctata*) are quite different in the South-west Marine Region off South Australia compared to the South-east Marine Region off Victoria. Off Victoria the population of King George whiting is a single stock and recruitment is driven by larval advection from the west. The larvae are transported several hundred kilometres by strong currents over the continental shelf during the winter and spring from a single region to the west (Jenkins et al. 2000). In South Australian waters, the King George whiting spawn on offshore reefs from where the larvae are transported up the gulfs and finally settle out in inshore shallow bays (Fowler et al. 1999). The bays may be vegetated with seagrass or have a bare, sandy bottom (Fowler & Short 1996). The juveniles tend to move into deeper parts of the bays and eventually into open water as they grow (Jones et al. 1996).

The more complex size structure of the populations in the southern parts of the Gulf of St Vincent and Spencer Gulf compared to the northern parts of these gulfs indicates movement of fish down the gulfs with age (Fowler et al. 2000). In contrast with Victoria, the movement of larvae in South Australia is more restricted. There is minimal exchange of larvae between discrete populations, and movement is restricted to less than 100–200 km (Fowler et al. 2000). There appears to be no evidence for exchange between discrete stocks in the Spencer Gulf and the Gulf of St Vincent. What transport there is appears to be driven by relatively weak coastal currents, and the front at the mouth of the Spencer Gulf is thought to act as a barrier to movement (Fowler et al. 2000). The scale of these discrete stocks is smaller than the unit stock in Victoria.

Eddies

Mesoscale eddies and their influence on production

The Leeuwin Current is associated with mesoscale eddies and meanders (Pearce & Griffiths 1991; Fang & Morrow 2003; Morrow et al. 2003; Feng et al. 2005; Fieux et al. 2005). Eddies form at the shelfbreak and eventually separate from the current and drift westward. These eddies are apparent in sea surface temperature satellite imagery (Griffin et al. 2001) and in altimeter data (Fang & Morrow 2003) (Figure 2.1.5, Section 2.1). Eddies are associated with changes in the bathymetry and offshore water of different densities and their generation and offshore transport occur off Shark Bay, the Abrolhos Islands, Jurien Bay, Rottnest Island and Cape Leeuwin.

Eddies west of Rottnest were recently studied as part of a Southern Surveyor Cruise and the Western Australian Government – CSIRO SFRME joint venture. Results of the cruise will be published as a single issue of *Deep Sea Research* in 2006. Studies of the cruise's results have found that while there was no demonstrable nutrient upwelling between interacting cyclonic (anticlockwise rotating) eddies and anti-cyclonic (clockwise rotating) eddies these eddy systems may drive offshore pelagic production but do so in unexpected ways; further research is required.

Cresswell and Griffin (2004) describe the propagation of westward-moving anti-cyclonic eddies south of the Leeuwin Current on the south coast of Western Australia. Weak eddies drift westward from south of Victoria and first encounter the continental slope near the Recherche Archipelago where they take on warm water from the Leeuwin Current and strengthen, moving westward for up to 18 months. They also described effects on the Leeuwin Current of encounters with cyclonic and anti-cyclonic eddies, the former accelerating flow and the latter decelerating Leeuwin Current flow and diverting it out to sea. The effects of these structures on pelagic production may be profound but as yet these effects have not been studied in detail.

Significant anti-cyclonic eddies are visible in remote sensing data of sea surface height along the south coast of Australia (Anonymous 2001). These eddies initially propagate eastward, partially influenced by the Leeuwin Current, and then move away from the shelf to the west (see Chapter 2 of this report). Eddies are known to have a significant effect on shelf plankton communities including larval fish (Govoni 2005), when shelf water becomes entrained in an eddy (Richards et al. 1989; Nishimoto & Washburn 2002). The development of an entrained community depends upon whether eddies are upwelling (cold core) or downwelling (warm core). Generally warm-core eddies lead to reduced production within the eddy (Brandt, 1981) and decay of the plankton community over time, in contrast to cold-core eddies where an enriched community may flourish until nutrients are depleted (McGillicuddy & Robinson 1997). In both cases the eddy community tends to be distinct from the surrounding water, and shows considerable horizontal structure in terms of species composition, both across the eddy filaments and with depth (Muhling et al. submitted). The enclosed communities tend to be successional in nature, as previously mentioned.

In the eastern Great Australian Bight, eddies induce upwelling and so nutrient enrichment is predicted, with possible subsequent phytoplankton growth. If such eddies stay on the shelf and retain larval fish, enhanced recruitment may result (Dickey-Collas et al. 1996; Kimura et al. 2000; Nakata et al. 2000; Logerwell et al. 2001). Where eddies entrain larval fish off the shelf (Fang and Morrow 2003; Morrow et al. 2003), they may advect them away either from suitable feeding areas or from suitable settlement areas (Heath 1992), which can negatively affect recruitment. Fish eggs and larvae may also be exposed to enhanced predation within the eddy community. In the cold-core eddies, located off the shelf, that are described here, the feeding environment for larval fish in the eddy may be adequate due to the expected enriched production. Transport of plankton into other water masses by an eddy can also result in the death of larval fish due to temperature stress (Colton, 1959). That eddies can have a significant effect on fish recruitment was demonstrated by Myers and Drinkwater (1989) who showed that recruitment in 15 of 17 groundfish stocks was negatively influenced by greater numbers of Gulf Stream rings near the continental shelf of North America. In the South Australian case, the effect of advection by eddies may be mainly due to transport of larvae away from suitable settlement areas on the shelf. It is predicted that the impact of the off-shelf eddies would be more severe for demersal and semi-demersal fish than for pelagic species in this case, but there are no studies in the eastern Great Australian Bight that substantiate this speculation. The topic is the subject of active research in the western part of the South-west Marine Region (Muhling, unpublished manuscript).

Topographic influences

Canyons and seamounts

The south-western continental margin of Australia is transitional (Morgan & Wells 1991) between the cool water carbonate shelf of southern Australia and the warm water North-west Shelf. Submarine canyons are distinctive features of the continental slope with the Rottnest Canyon on the west coast, and the Bremer Canyon on the south coast being the most distinctive. The canyons influence movement of both the Leeuwin Current and the Leeuwin Undercurrent.

The Rottnest Canyon has been the focus of study as part of the Western Australian Government – CSIRO SRFME joint partnership. Rottnest Canyon influences the volume of water moving southward in the Leeuwin Current and the number and scale of eddy formations and propagations west of Rottnest Island. In strong Leeuwin flow years, more eddies are propagated than in low-flow years. The canyons on the south coast of Western Australia have been studied less, although similar effects on surface and midwater circulation and currents would be expected.

The edge of the continental shelf south of Kangaroo Island is incised by spectacular canyon complexes. The processes that affect upwelling within canyons are known to include tidal mixing and rectification as well as large-scale along-slope currents (Huthnance 1995; Hickey 1995). In the context of large-scale along-slope currents, Klink (1996) showed that the shoreward pressure gradient that is normally balanced by geostrophy is ruptured over a “narrow” canyon and can drive fluid, sediments and nutrients up-slope ("narrow" in this context means relative to the internal deformation radius, about 30–50 km for the Bonney Coast – Kangaroo Island region). For this region, there are two sources of westward current needed for upwelling. The first source is the Flinders Current (Middleton & Cirano, 2001) that flows from east to west at depths of 400–800 m with speeds 5–10 cm/s and is driven by the onshore Sverdrup transport from the Southern Ocean. The Flinders Current appears to be strongest during summer, although it appears that it can be non-existent or reversed by currents forced by winds and the thermohaline circulation. In addition, the numerical simulations of upwelling during 1999 (Middleton & Platov 2004) show that the Flinders Current, and shelf slope currents can be influenced by mesoscale eddies that are common during the summer months (see Figure 3.5.3 below). This second source of westward slope currents associated with warm-core eddies may well also lead to upwelling within the canyons of the region.

Closer to shore, wind-forced upwelling can raise water and nutrients from depths of 150 m or so to near the coasts of Kangaroo Island and Robe (Lewis 1981; Middleton & Platov 2003, 2004; Schahinger 1987; Griffin et al. 1997). The paths of nutrient and sediment upwelling between the deep slope and coast remain to be determined, although notably tar balls have been found on the Bonney Coast and may well have come from oil-bearing sediments located on the adjacent shelf slope (200–600 m depth) (see below).

In addition, it has recently been shown that upwelling is almost certainly enhanced by the El Niño signal that propagates from the equatorial Pacific and into the Bonney Coast – Kangaroo Island region (Li and Clarke 2004; Middleton et al. 2005). The data available suggest that 11.5 °C water can be raised from depths of ~250 m and onto the shelf (60 m) during these signals. More data on deep-slope upwelling are needed both during normal and ENSO years.

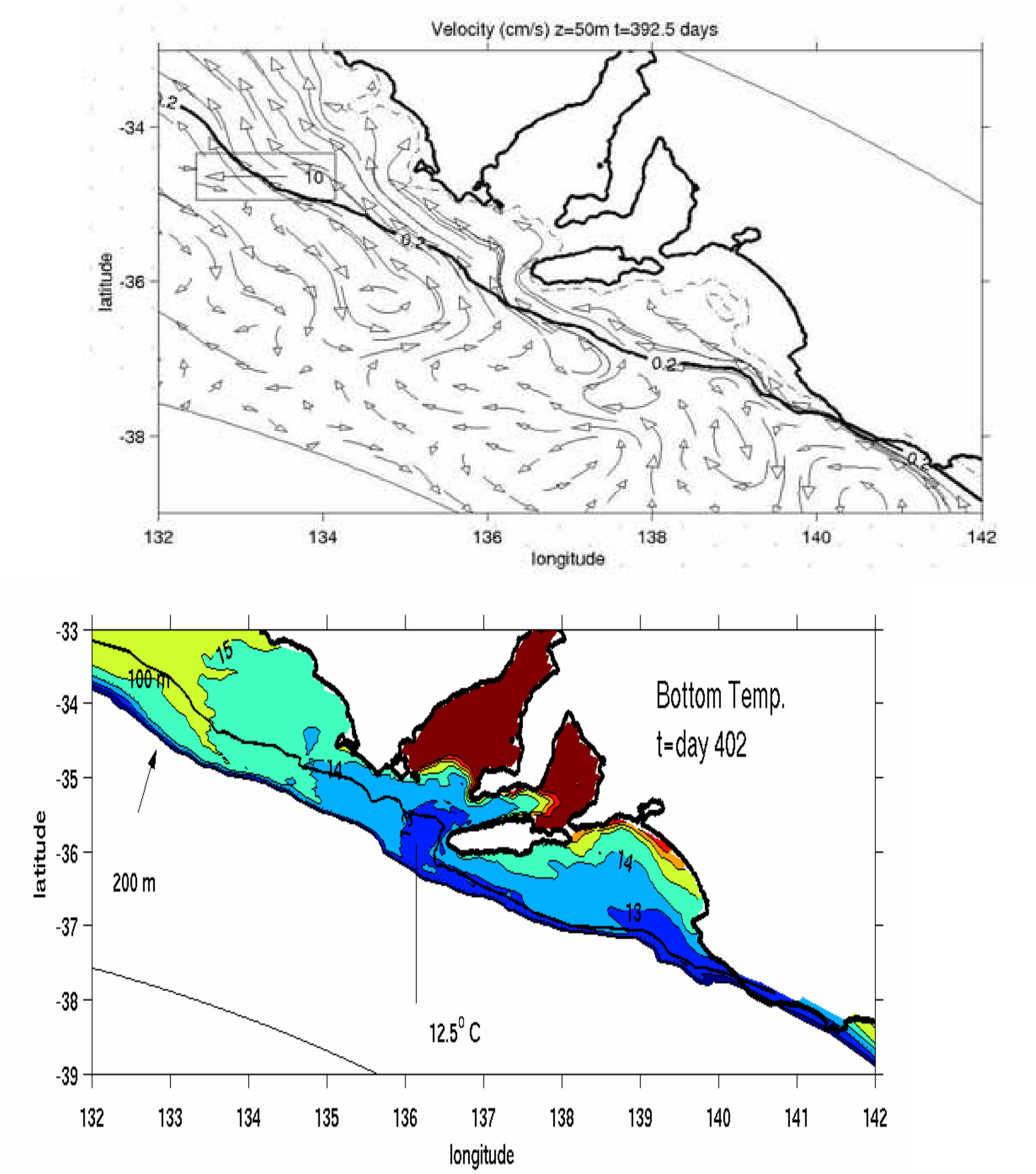

Figure 3.5.3 Results from the SA Regional Ocean Model. **Top panel**: The velocity field at a depth of 50 m at 27 January 1999 ,with active coastal upwelling. A vector of 10 cm/s is indicated. The dark line is the 200 m isobath and the presence of warm (cold) core eddies, that extend to depths of >300 m, will drive deep upwelling (downwelling) in the canyons. **Bottom panel**: The bottom temperature 10 days later (6 Feb 1999) when the winds have vanished. Only water of temperatures between 11 °C and 18 °C is contoured. Upwelling has occurred as indicated by the plumes of 13 °C water off Kangaroo Island and the Bonney Coast. This water was initially at a depth of 250 m.

Significance of the canyons to marine productivity hotspots

Abrupt topography and the biophysical mechanisms of prey aggregation are becoming more recognised as creating key hotspots of productivity in the oceans (Genin 2004); these hotspots are vitally important to sustaining fish production. Overseas studies in the Mediterranean, Georges Bank, and off the Oregon and Canadian west coasts have shown that canyons generate complex flows, the net result of which can be higher regional productivity. As such, they form important hotspots of biological production. Dense krill concentrations accumulate in the heads of the canyons off Georges Bank (Greene 1988), providing a "prey subsidy" that helps to sustain high fish production on the banks. While smaller zooplankton and phytoplankton are advected by the deep and temporally variable flows generated around canyons, swimming and vertically migrating micronekton such as krill and mesopelagic fish can maintain position by behavioural interaction with the flow field (Macquart-Moulin & Patriti 1996; Mackas et al. 1997; Allen et al. 2001). These aggregations of micronekton are preyed upon by commercial species such as *Sebastes* on the North American west coast (Pereyra et al., 1969), and provide a rich food source for cetaceans (Bosley et al. 2004). Astoria canyon off Oregon is an important fishery area with extensive groundfish dependent upon the rich prey field of the canyon (Pereyra et al. 1969). Work on the South Australian canyons, scheduled for 2007, will be the first effort to expand these findings into the South-west Marine Region and to investigate the importance of the canyons as key habitats underpinning the fisheries within the Region.

Benthic communities

Water circulation patterns can influence benthic communities in several ways. Most importantly, they modify other water column processes, such as near-bottom flow, that bring food and new recruits to the community (e.g. Snelgrove & Butman 1994). Moreover, bottom currents largely determine sediment type and food supply to the benthos, which in turn influence benthic patterns (Gray 1981). Circulation also affects larval supply to benthic habitats because larval supply is thought to be primarily passive over broad scales (Bradbury & Snelgrove 2001). Circulation is closely linked to wind as well as to topographic features such islands, banks and canyons which can create enhanced larval retention through eddies (Lobel & Robinson 1986; Tremblay et al. 1994) and also produce highly productive areas associated with upwelling that may influence larval transport and survival (e.g. Shanks 1995). All of these processes act in concert with post-settlement processes such as disturbance (Barry & Dayton 1991), predation (Thrush 1999) and competition (Peterson 1977), to influence benthic patterns of distribution and abundance.

Most soft-bottom communities at depths below the photic zone are dependent on sinking water column production as the major food source, and thus the quality and quantity of organic matter reaching the seabed is likely to be an important influence on benthic community structure and biomass (Smetacek 1984). Horizontal advection can complicate this linkage through transport of sinking particles (detritus, larvae) to a bottom area that is distant from the surface waters where they were abundant (Lampitt et al. 1995). In addition, decoupling between herbivory and primary production can result in greater export of production to the bottom as a result of lowered zooplankton grazing rates (Ambrose & Renaud 1995).

Previous macrofaunal studies have typically found a positive relationship between benthic abundance and biomass and enhanced flux of organic carbon to the seabed (Davies & Payne 1984). For example, Grebmeier et al. (1988) found a significantly greater benthic biomass in the Bering Shelf region where water column primary production was much higher, and Ambrose and Renaud (1995) found water column and benthic chlorophyll concentration were the most important predictors of infaunal density and biomass. In spite of such findings, linkages between the pelagic realm and the benthic community pattern are not well understood, especially in cold ocean systems (Snelgrove et al. 2000). This is especially true of the South-west Marine Region.

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Part 2 – Key Species Groups

4 Species groups

4.1 Phytoplankton

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Species group name and description

The term phytoplankton usually refers to autotrophic planktonic organisms in the euphotic zone (surface lit waters) of an aquatic ecosystem. Phytoplankton communities are largely comprised of protists from a diverse range of taxonomic classes including; glaucophytes, green algae, cryptomonads, chrysophytes, haptophytes, diatoms, dinoflagellates, apicomplexa, euglenoids and cerozoa. Prokaryotic Cyanobacteria are also included in the phytoplankton.

The definition of phytoplankton however, is not straight forward, complicated by the ability of some taxa to change their modes of nutrition. Many dinoflagellates for example, are heterotrophic able to obtain nutrients through phagocytosis. Additionally, mixotrophs have the ability to combine heterotrophy and autotrophy (Jansson et al. 1996). Generally the decision whether on not to include particular organisms within the phytoplankton is subjective, typically left to the individual researcher to determine whether or not the organism is autotrophic or not. More often than not, the whole protist community are included as phytoplankton if they are filterable on a glass fibre filter or equivalent.

Traditionally taxonomists have identified phytoplankton using light microscopy and in more recent decades electron microscopy. Modern techniques enable resolution of individual cells down to about 5 μm. Phytoplankton are generally defined by three size classes, microplankton (20-200μm), nanoplankton (2-20μm) and picoplankton (0.2-2μm) (Sieburth et al. 1978). Diatoms and dinoflagellates are the most abundant of the micro and nanoplankton size classes (Jeffrey and Vesk 1997), and were for many years thought to be responsible for the majority of oceanic primary production. More recent studies have suggested that photosynthetic picoplankton may also play an important role in carbon fixation in the ocean, especially in oligotrophic waters where they may be responsible for up to 90% of primary production (Stockner 1988).

In more recent years High Performance Liquid Chromatography (HPLC) has been used to supplement traditional light microscopy by evaluating the relative concentration of photosynthetic pigments (chlorophylls, carotenoids etc.) in the phytoplankton community, which can be used as markers of phytoplankton taxa (Mantoura and Llewellyn 1983). HPLC methods are very useful in regions where there are large proportions of nano- and pico-plankton that would otherwise go undetected. Recent data from shelf, slope and open-ocean off Western Australia suggest that the phytoplankton are dominated by nano- and pico-plankton, which comprise ca. 90% of the biomass (Thompson, unpublished data). While measurements of phytoplankton photo-pigments would appear to be a more accurate method to evaluate phytoplankton community composition and relative biomass, there are still serious issues regarding the conversion of pigments to phytoplankton species groups. Primarily, software such as the well-developed CHEMTAX program depend on initial ratios between pigments and cell counts to initialize their analysis. Studies have shown that proper initialization is crucial for accurate estimation, but that ratios are highly variable between water masses and need to be determined separately for different oceanographic regions.

Phytoplankton are the start of the food chain in the ocean, and provide the organic compounds required for the survival of higher trophic levels through photosynthesis. As micro-organisms in a dynamic environment, phytoplankton are dependent on oceanographic processes like upwelling and vertical mixing to bring nutrients from great depths to levels where they may be utilized for photosynthesis. The dynamic nature of these processes means both nutrients and phytoplankton are distributed randomly through the water column, and phytoplankton are exposed to constantly fluctuating nutrient supplies and light intensities.

The following report is divided into two separate sections which describe the phytoplankton of (1) the Western Australian and (2) South Australian regions.

Western Australia

Data available

A detailed guide to dominant dinoflagellate species throughout Australia is provided by (Wood 1954). The dominant dinoflagellate flora of SW planning area is outlined in this publication.

Early Russian cruises documented phytoplankton community composition in the oceanic waters off the coast of Western Australia (Markina 1974; Markina 1976).

A comprehensive study of phytoplankton and zooplankton dynamics were conducted in Cockburn Sound and Warnbro Sound, adjacent to Perth from 1991-1994 (Helleren and John 1997). This study presents the most comprehensive and taxonomically sound list of phytoplankton taxa for the coastal waters of Western Australia.

The 1995 mass mortality of pilchards (*Sardinops sagax*) prompted an investigation of the water quality and phytoplankton community composition in the waters of Rottnest Island off the coast of Perth, and Dongara and Geraldton north of the SW planning area in June 1995 (Griffin et al. 1997a).

In their recent report on phytoplankton biomass levels of Western Australian coastal and estuarine waters, (Pearce et al. 2000) clearly demonstrate that there is a paucity of near-shore, coastal and oceanic data in south-west Australia. However, in the past 5 years there has been an increased focus on continental shelf, shelf-break and deep water phytoplankton dynamics off the coast of Western Australia, led by research teams from CSIRO Marine Research and the University of Western Australia, Centre from Water Research.

A four year study of phytoplankton response to wastewater discharge on inshore shelf-waters was conducted near Perth provided a detailed phytoplankton taxonomy of integrated water column samples from 8 sites, including sites near waste-water outfalls and distal control sites (Figure 4.1.1) (Thompson and Waite 2003). A detailed phytoplankton species list was generated using light microscopy of preserved samples collected from 1996-2000 (Table 4.1.1).

An honours dissertation by Congdon (2003) from the Centre for Water Research at the University of Western Australia investigated nitrogen fixation along a transect from Fremantle to Rottnest in May and August 2003. The study reported the presence several organisms capable of N fixation including the ubiquitous non-heterocystous cyanobacteria *Trichodesmium* genus. Importantly the pico-planktonic size fraction was responsible for the majority of N-fixation off the WA coast (Congdon 2003).

(Fearns et al. 2005) conducted a study to validate ocean colour products derived from SeaWiFS satellite data along a 40 km offshore transect located 20 km north of Perth at Hillarys Marina (31°49.9' S, 115°19.0' E). Physical, chemical and biological measurements were take at a total of nine sampling stations at 5 km intervals along the transect from October 1996 to December 1998. A limited phytoplankton data set was generated from this study, which included the spatial and temporal dynamics of diatoms, dinoflagellates and cyanobacteria.

A preliminary one-year study on phytoplankton diversity and production off Bunbury was conducted as part of a baseline survey for the Water Corporation (Waite and Alexander 2000). This showed that production rates were overall 2-3 times higher off Bunbury than off Perth, and that there was a very diverse phytoplankton assemblage present.

In 2002 – 2004, a detailed study across the continental shelf north of Perth was conducted in a collaborative project led by Tony Koslow (CSIRO Marine Research) (Keesing and Heine 2005). The aim of the project was to characterise the continental shelf/slope pelagic ecosystem off southwestern Australia. Monthly sampling was conducted from inshore to the outer continental shelf (100 m water depth), extended quarterly to offshore waters (1000 m depth). Taxonomic analysis was conducted with light microscopy and supplemented with High Performance Liquid Chromatography (HPLC).

An expedition by the research vessel Southern Surveyor (SS0803) was conducted in 2003 to assess the physical, chemical and biological dynamics associated with 2 eddies off the coast of south-west Australia (Figure 4.1.1). A series of transects were established across the two eddies which included collection of surface and water column phytoplankton samples. Phytoplankton taxonomy was provided by light microscopy (Table 4.1.2) and supplemented with diagnostic pigment analysis via HPLC (Thompson et. al *in preparation*).

Immediately following the Eddy's cruise, the RV Southern Surveyor (SS0903) was employed to sample a series of cross-shelf transects from the Houtman Abrolhos Islands to Cape Leeuwin. Several sites were sampled at the surface and deep chlorophyll maximum (DCM) depth for phytoplankton taxonomy via light microscopy (Figure 4.1.1, Table 4.1.2) and via HPLC photopigment analysis (Twomey, Pez & Waite *in preparation*)

The Southern Surveyor cruise details and data sets from cruises SS0803 and SS0903 are accessible through the CSIRO Division of Marine Research MarLIN data base www.marine.csiro.au/marlin/

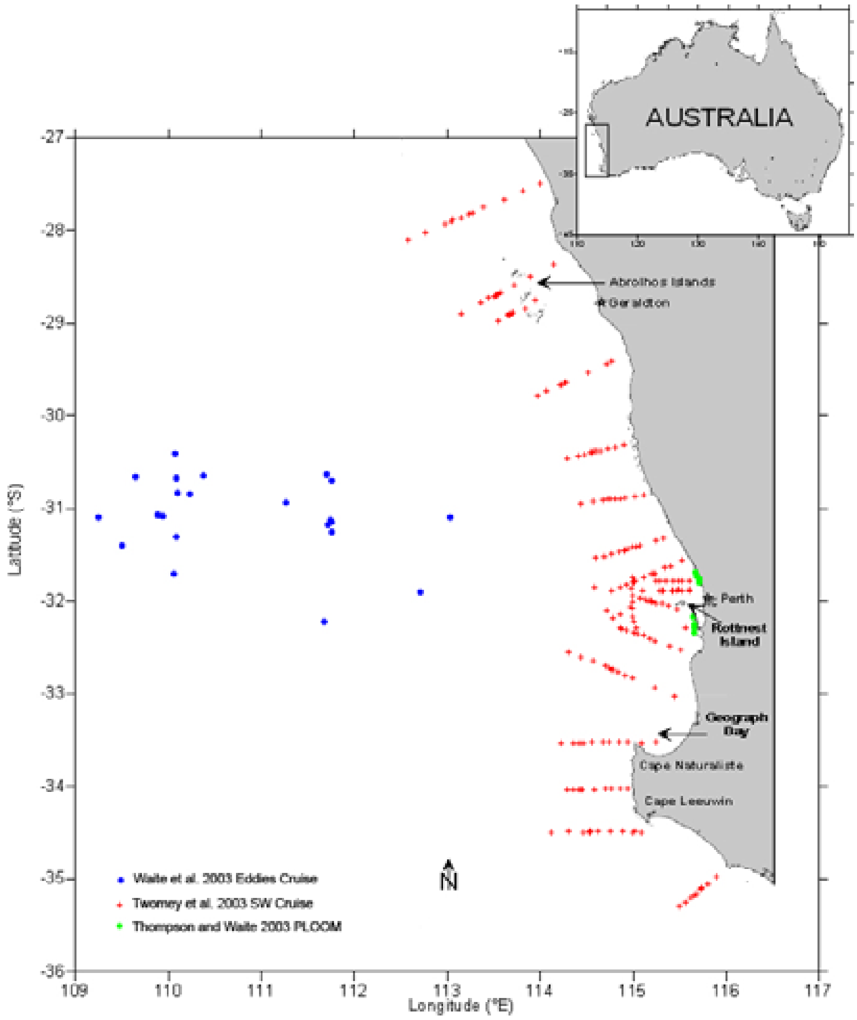

Figure 4.1.1. Location of phytoplankton sampling stations for Table 4.1.2
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Table 4.1.2 Phytoplankton taxa observed during 3 separate cruises off the coast of Western Australia. Source represents data publication; (1) Waite et al. 2003, Eddies cruise (SS0803), (2) Thompson and Waite 2003, PLOOM, and (3) Twomey et al. 2005, SW coast cruise (SS0903). Refer to Figure 4.1.1. * Trichodesmium is the synonym of Oscillatoria.

Group	Genus (species when known)	Source
chlorophyta	*Oltmannsiellopsis sp.*	1
	Pyramimonas sp.	1 & 3
chrysophyta	*Apedinella sp.*	1 & 3
	Chromulina sp.	1 & 3
	Meringosphaera sp.	2
	Pseudopedinella sp.	1 & 3
	Ebria tripartita	2
cryptophytes	*Plagioselmis sp.*	1 & 3
	Rhodomonas sp.	1
cyanobacteria	**Oscillatoria erythraea*	2 & 3
	Spirulina sp.	2
	Richelia intracellularis	2
diatoms	*Achnanthes oblongella*	2
	Achnanthidium sp.	2
	Actinoptychus sp.	2
	Amphora decussata	2
	Amphora sp.	2
	Asterionellopsis glacialis	2
	Asteromphallus sp.	2
	Bacillaria paradoxa	2
	Bacillaria sp.	2
	Bacteriastrum sp.	1 & 3
	Bacteriastrum hyalinium	2
	Biddulphia sinensis	2
	Campylodiscus sp.	2
	Cerataulina sp.	1 & 3
diatoms cont.	*Cerataulina pelagica*	2
	Chaetoceros socialis	2
	Chaetoceros sp.	2
	Climacodium sp.	2 & 3
	Climacosphenia moniligera	2
	Cocconeis heteroideae	2
	Cocconeis scutellum	2
	Corethron sp.	2 & 3
	Coscinodiscus sp.	1 & 3
	Coscinodiscus centralis	2
	Coscinodiscus normanii	2
	Coscinodiscus sp2.	2
	Cyclotella	1 & 3
	Cylindrotheca closterium	2
	Detonula sp.	2
	Dimerogramma sp.	2
	Diploneis bombus	2
	Diploneis chersonensis	2
	Diploneis ovalis	2
	Diploneis vacillans	2
	Ditylum brightwellii	2
	Druridgia compressa	2
	Entomoeoneis sp.	2
	Entomoeoneis tenuistriata	2
diatoms cont.	*Eucampia sp.*	1 & 3
	Eucampia cornuta	2
	Falcula sp.	2
	Gramatophora marina	2
	Gramatophora oceanica	2
	Guinardia sp.	1
	Guinardia flaccida	2 & 3
	Guinardia striata	3
	Gyrosigma balticum	2
	Hantzschia sp.	2
	Hemiaulus sp.	2
	Hyalodiscus sp.	2
	Leptocylindrus sp.	1 & 3
	Leptocylindrus danicus	2
	Leptocylindrus minimus	2
	Licmophora flabellata	2
	Licmophora gracilis	2
	Licmophora lyngbyei	2
	Lithodesmium undulatum	2
	Mastogloia cocconeiformis	2
	Navicula sp.	1, 2 & 3
	Navicula punctulata	2
	Navicula robertsiana	2

Group	Genus (species when known)	Source
	Navicula salinarum	2
	Nitzschia sp.	1, 2 & 3
diatoms cont.	*Nitzschia fasciculata*	2
	Nitzschia longissima	2
	Nitzschia punctata	2
	Nitzschia seriata	2
	Nitzschia tryblionella	2
	Odontella sp.	1
	Odontella aurita	2
	Paralia sulcata	2
	Planktoniella sp.	2
	Pleurosigma salinarum	2
	Pleurosigma sp.	1 & 2
	Podocystis sp.	2
	Pseudonitzschia	1 & 3
	Rhizosolenia sp.	1 & 3
	Rhizosolenia clevei	2
	Rhizosolenia setigera	2
	Rhizosolenia shrubsolei	2
	Rhizosolenia stolterfothii	2
	Skeletonema costatum	2
	Helocotheca sp.	2
	Striatella unipunctata	2
	Surirella ovalis	2
	Synedra fasciculata	2
	Synedra undulata	2
	Thalassionema sp.	1, 2 & 3
	Thalassionema frauenfeldii	2
	Thalassionema nitzschiodes	2
diatoms cont.	*Thalassiosira sp.*	1
	Thalassiosira pseudonana	2
	Thalassiothrix sp.	2
	Triceratium alternans	2
	Ceratium declinatum	2
dinoflagellates	*Ceratium furca*	1, 2 & 3
	Ceratium lineatum	2
	Dinophysis accuminata	2
	Dinophysis caudata	2
	Dinophysis rotundatum	2
	Gymnodinium sp.	1 & 3
	Gyrodinium sp1.	1 & 3
	Gyrodinium sp2.	2
	Heterocapsa sp.	1 & 3
	Katodinium sp	2 & 3
	Katodinium rotundatum	2
	Mesoporos perforatus	2
	Oxyphysis sp.	1 & 3
	Oxytoxum sp.	1
	Peridinium sp.	1 & 3
	Prorocentrum sp.	1, 2 & 3
	Prorocentrum lima	2
	Prorocentrum micans	2
	Protoperidinium sp.	1
	Protoperidinium bipes	2
	Protoperidinium claudicans	2
	Protoperidinium roseum	2
dinos. cont.	*Protoperidinium sp.*	2
	Protoperidinium steinii	2
	Pyrocystis lunula	2
	Scrippsiella sp.	1 & 3
	Scrippsiella trochoidea	2
	Torodinium sp.	1
eugleonphytes	*Eutreptiella sp.*	1
haptophytes	*Phaeocystis sp.*	1
prasinophytes	*Pyramimonas sp.*	2
	Tetraselmis sp.	2
silicoflagellates	*Dictyocha sp.*	1
	Dictyocha fibula	2
	Dictyocha octonaria	2
	Octactis sp.	1

Habitat and distribution

Emerging research has indicated that the distribution of the phytoplankton community is largely dependent on the physical oceanography of the region (Hanson et al. 2005). The western coast of Australia is dominated by the Leeuwin Current, which transports nutrient poor, tropical water towards the south-pole adjacent to the coastline (Pearce 1991). The phytoplankton community in the Leeuwin Current is dominated by cryptophyte and haptophyte flagellates and very low rates of primary productivity (Hanson et al. 2005). The phytoplankton of the Leeuwin Current are most likely nitrogen limited and derive their nutrition from regenerated nutrients within the water column, though low rates of nitrogen fixation is detectable at sites on the coast where it has been measured (Pez, 2004; Waite et al., unpublished data). Opposing the Leeuwin Current is the Capes Current, which flows northward and is generated from the region near Cape Leeuwin and Cape Naturaliste (Pearce and Pattiaratchi 1999). The Capes Current has been associated with coastal upwelling of deep waters onto the continental shelf (Gersbach et al. 1999). The relatively higher concentration of nitrate in newly upwelled waters stimulates phytoplankton productivity and appears to increase the relative proportion of diatoms (Hanson et al. 2005).

Significance of the species group in the southwest planning area

Phytoplankton are dominant primary producers in shelf and oceanic waters. The productivity and biomass distribution of phytoplankton will therefore largely dictate the level of secondary and tertiary production in an ecosystem. This has important ramifications in terms of the distribution and biomass of recreational and commercial fisheries. An understanding of the underlying processes of nutrient delivery and the spatial and temporal response of the phytoplankton community are essential in determining the carrying capacity of higher order organisms. It is becoming increasingly more likely that the phytoplankton community are responding to pulsed nutrient inputs, either via coastal drainage or upwelling of nutrient rich waters. Elucidating the seasonal and spatial distribution of phytoplankton on the shelf and shelf-break waters along the SWPA may provide clues on finfish and mesofaunal distribution and biomass.

The limited research that has been conducted suggests that the Western Australian coastal waters are nutrient poor in comparison to the western margins of other continents. This is due to large-scale upwelling in south and western regions of Africa, the USA, Europe and South America, which brings nutrient laden waters to the surface where there is enough light to stimulate primary production. The west coast of Australia however is dominated on the continental shelf by the Leeuwin Current, which suppresses upwelling and restricts the mixed depth to the base of the euphotic zone.

In the past decade there has been an increased focus on the role of pico- and nano-plankton in biogeochemical cycles of the world's oceans. Recent research suggests that phytoplankton in the < 5 μm size range are extremely important N-fixers, primary producers and nutrient sources and sinks (Arrigo 2005). Emerging research (refer to the special edition of Deep Sea Research II in preparation, Thompson et al. and Twomey et al.) has demonstrated that the < 5μm size fraction plays a significant role in the coastal waters of the SW planning area contributing around 90% of the biomass N uptake and N fixation. Considering the previous studies have largely neglected these organisms, future research should focus on the examination of N flux attributable to these organisms.

Impact/threats

In general an increase in nutrient loading to an aquatic ecosystem will result in an increase of phytoplankton biomass. In many cases this may be beneficial by encouraging trophic transfer of nutrients to commercially important higher order organisms. However in some cases, increased phytoplankton biomass may have negative impacts (c.f. Hallegraeff 1993). Algal blooms have the ability to increase light attenuation etc.

There are no records of major environmental disturbance by phytoplankton off the south west coast of Australia. However there is always potential for increased phytoplankton biomass or changes in species composition, should the dominant sources of nutrients in the ecosystem change. There is sufficient research to suggest that the coastal waters of the SWPA region are strongly oligotrophic and that the phytoplankton community are most likely nitrogen limited. Should nitrogen inputs increase or change significantly we could expect to see changes in phytoplankton biomass and species composition. For example, recent research determined that sites near wastewater discharge off the coast near Perth had elevated nutrient loading, and phytoplankton biomass was greater than twice the level at relevant control sites (Thompson and Waite 2003). Helleren and John (1997) identified that high nitrogen loading associated with industry in Cockburn Sound was the primary cause of higher biomass than comparative sites.

Potential threats therefore may include: the discharge of nutrient laden (particularly nitrogen) waters from industry etc; increased nutrient loading from commercial fishery operations such as sea-cages; dispersal of non-indigenous phytoplankton via ships' ballast waters; large scale environmental perturbations such as freak storm events and long-term environmental change. The presence of potentially toxic algal species in the SWPA region are cause for concern, particularly if their frequencies increase. Regular monitoring is therefore recommended.

Information gaps

Although there are several independent data sets collected by different individuals and agencies from various regions of south-west Australia, there is a lack of integration of work undertaken. Needed is a database of phytoplankton in the SWPA, which could include fields such as; biomass, productivity, nutrient uptake and taxonomy.

There are large spatial and temporal gaps in our knowledge of phytoplankton in the SW planning area. The majority of data presented here has been collected from areas on the continental shelf near Perth. There is an obvious lack of cross-shelf and open-ocean phytoplankton data and paucity of data extending east from Albany along the south coast of Western Australia. Some of these gaps will be addressed in planned Southern Surveyor cruises led by Dr. Charithra Pattiaratchi in April-May 2006 which will extend from Albany to Esperance, and by Dr. Anya Waite in May 2006 which will follow the path of eddies generated in south-west Australia.

Key references and current research

Current research

Special edition of Deep Sea Research II, in preparation, a collection of 15 papers on the physical and biological dynamics of the Leeuwin Current and its eddies, Guest Editors Anya Waite (CWR/UWA) , Peter A. Thompson (CSIRO Hobart), and Lynnath Beckley (Murdoch University). Papers to be submitted in final form in December 2005, for publication in 2006.

Waite, Thompson and Twomey, 2003-2006. Interaction of coastal currents, phytoplankton dynamics and trophic transfer in the coastal waters of Western Australia. Current project funded by the CSIRO Strategic Research Fund for the Marine Environment (SRFME). Documents phytoplankton response to physico-chemical variability across the continental shelf adjacent to Albany WA. Phytoplankton taxonomy includes light microscopy and HPLC.

Waite et al. 2006. Southern Surveyor Eddy's 2. A detailed multidisciplinary study designed to illuminate cross-shelf transport of nutrients, production and fish larvae effected by eddies / filaments at the shelf break.

Pattiaratchi et al. 2006. Southern Surveyor South Coast Cruise. Series of cross shelf transects from Esperance to Albany WA. Phytoplankton taxonomy to include light microscopy and HPLC.

South Australia

Data available

To date there have been few published studies concerning phytoplankton in the eastern Great Australian Bight (32-36˚ S, 132-138.5˚ E, hereafter referred to as EGAB). Information for the region consists mainly of estimations of phytoplankton standing stock via chlorophyll a measurements. There is little or no published data available regarding phytoplankton abundance or community structure.

A study by (Motoda et al. 1978) examined depth integrated chlorophyll concentrations and phytoplankton productivity at three stations in the western Great Australian Bight.

Annual sardine spawning biomass surveys conducted by researchers at SARDI Aquatic Sciences have provided chlorophyll data for the EGAB. Chlorophyll concentrations have been measured during February –March of 2001 and 2002, using a CTD equipped with a fluorometer deployed at 250+ stations across the region, to within 10m metres of the bottom, or to 70m at stations greater than 80m depth. In 2004, surface concentrations were measured as extracted chlorophyll due to the unavailability of a CTD with a fluorometer (Ward et al. 2004; Ward et al. 2001; Ward et al. 2003; Ward et al. 2002).

The most comprehensive information on the abundance, composition, and spatial and temporal distribution of the phytoplankton community in the EGAB, and the processes affecting these factors comes from unpublished data from a PhD project undertaken through SARDI Aquatic Sciences and the University of Adelaide that is yet to be completed (Van Ruth, PhD thesis in prep). This study includes taxonomic descriptions of the phytoplankton community in the region, together with measurements of bio-oceanographic parameters and phytoplankton productivity during the study period. Potential limiting nutrients and the underwater light regime are also being investigated in this study.

Habitat and distribution

For many years the EGAB was thought to be a region of low phytoplankton productivity due to a lack of nutrient enrichment processes. In the absence of any other data, chlorophyll concentrations and primary productivity measurements reported by Motoda *et al.* (1978) were assumed to reflect phytoplankton productivity across the whole Great Australian Bight. However, this is not a valid assumption, since the size of the Great Australian Bight region means there is significant potential for spatial and temporal variations in productivity levels.

More recently, several studies have reported the occurrence of coastal upwelling in the eastern Great Australian Bight during summer/autumn. This upwelling is focussed off southwestern Kangaroo Island and southwestern Eyre Peninsula during summer and autumn and is driven by prevailing southeasterly winds and bottom topography (Griffin et al. 1997; Herzfeld and Tomczak 1997; Herzfeld and Tomczak 1999; Kampf et al. 2004; Middleton and Platov 2003). Upwelling areas are associated with elevated chlorophyll concentrations in surface waters (Ward et al. 2004; Ward et al. 2001; Ward et al. 2003; Ward et al. 2002); Van Ruth, PhD thesis in prep).

Current research indicates that the phytoplankton community of the EGAB is strongly influenced by the oceanography of the region. Phytoplankton abundances are an order of magnitude higher in inshore regions than offshore regions of the EGAB during summer/autumn, with highest abundances observed in the upwelling regions (Van Ruth, PhD thesis in prep). During the upwelling season, concentrations of nitrogen and phosphorus are higher in inshore waters than the offshore shelf waters of the EGAB (Van Ruth, PhD thesis in prep). However, research to date suggests nitrogen and phosphorus are not likely to limit phytoplankton productivity in the EGAB. Latest results suggest the diatom community is most likely limited by the availability of silica, and that iron limitation also plays a factor in shaping community structure (Van Ruth, PhD thesis in prep). The summer/autumn phytoplankton community is dominated by diatoms (>90% of total community), which is a surprising result given the likelihood of silica limitation, and is a further indication of possible iron limitation of the rest of the phytoplankton community in the region (Van Ruth, PhD thesis in prep).

Significance of the species group in the southwest planning area

The EGAB is one of South Australia’s most significant marine regions. It is habitat for several commercially important species of fish, which implicitly rely on the health and productivity of the phytoplankton for their survival. The area is also highly important ecologically as it supports a large number of endemic species. Knowledge of the patterns and processes of phytoplankton productivity in the area may assist in the management and conservation of these species, and the sustainability of these fisheries in the future.

Impacts/threats

As mentioned above in the Western Australian section, there is always potential for increased phytoplankton biomass or changes in species composition, should the dominant sources of nutrients in the ecosystem change. These changes may have beneficial impacts on the ecosystem through an increase in productivity of commercially important species of fish, but there may also be detrimental effects if there is an increase in the presence of toxic algal species in the community. In the South Australian sector of the south-west planning region, potential impacts/threats to phytoplankton biomass and community composition may include anthropogenic effects such as the discharge of domestic and industrial waste-water and storm water run-off, increased nutrient inputs in coastal areas from commercial fishery and aquaculture operations, large scale meteorological and oceanographical variations including El Nĩno events, and long-term environmental change.

Information gaps

The study of the phytoplankton community in the EGAB is still in its embryonic stages. On going investigations are required to fully understand the processes underpinning spatial and temporal patterns in primary productivity observed in the EGAB. Research so far has been focussed on seasonal changes to the phytoplankton community over large spatial scales. The highly variable nature of the upwelling in the region will necessitate finer scale studies in future, focussing on the upwelling hotspots in the area, and investigating changes in the phytoplankton community on the scale of weeks and days. It will also be important to examine spatial and temporal differences in the size distribution of the phytoplankton community to attempt to uncover any variations in the contribution of different size components (especially picoplankton) to primary productivity in the EGAB.

Key references and current research

SARDI researchers continue to collect fluorescence data for the region during annual sardine spawning biomass surveys, conducted during February and March (Ward et al. 2004; Ward et al. 2001; Ward et al. 2003; Ward et al. 2002).

Current research is proceeding in the form of a PhD project undertaken through SARDI Aquatic Sciences and the University of Adelaide, with an expected completion date of November 2006 (Van Ruth, PhD thesis in prep).

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4.2 Macroalgae

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Species and species groups

Macroalgae are photosynthetic organisms that form three-dimensional structures attached to intertidal and subtidal rocky substrata that in turn, are habitat to a variety of organisms. In addition, macroalgae are home and a source of food for animals, bacteria, and other organisms in the form of unattached drift rolling along the seafloor (i.e. *Ecklonia*) or floating on the sea surface (i.e. *Sargassum*), and as wrack on coastal beaches (Kirkman & Kendrick 1997, Walker & Kendrick 1998). Wrack has been identified as a food source for the Hooded Plover and Bridled Tern (Walker & Kendrick 1998, Kendrick 1999a). Drifting *Sargassum* is habitat for juvenile fish (Lenanton et al. 1982) and contributes seasonally to beach wrack (Hansen 1984). Grazing has not been found to significantly reduce biomass of attached macroalgae along the south and southwest coast of Australia. Instead, the abalone *Haliotis roei* and sea urchins feed primarily on drift algae (Wells & Keesing 1989, Vanderklift & Kendrick 2004, 2005). Drift is also a food resource for fish and organisms that fish prey upon (Lenanton et al. 1982, Robertson & Lenanton 1984).

Macroalgae along the southwestern and southern coasts of Australia are highly diverse with 62% of macroalgal species endemic to the south coast (Phillips 2001, Table 1). The distributions of macroalgal species range from cold temperate, warm temperate, tropical, and cosmopolitan (Phillips 2001). There is a gradual transition from a subtropical flora of the Houtman Abrolhos and north of Geraldton, to a cold-temperate flora found in the Flindersian province along the southwestern corner of Western Australia and the south coast of Australia (Womersley 1990). Along the south coast, the distributions of tropical species can be patchy and relegated to sheltered bays and other habitats with microclimates, where water temperatures are higher than along the open coast (Womersley 1990, Phillips 2001).

Macroalgae are divided into three main groups: Phaeophyceae or brown algae, Rhodophyta or red algae, and Chlorophyta or green algae (Table 4.2.1). These three groups are found worldwide and a large number of species are found endemic to temperate Australian waters (Womersley 1990, Table 1). Species diversity has been catalogued within the southwest marine region (Table 4.2.2). Members of the brown algae are typically the most visually dominant and form canopy layers. The red and green algae are found as understory beneath the canopy layer or in gaps where the canopy species are not present.

The canopy layers of the southern and southwestern coast of Australia tend to be dominated by brown algae, typically from the orders Laminariales and Fucales. The common kelp, *Ecklonia radiata*, is the sole member of the Laminariales found in these waters, but often represents a large proportion of the biomass. Fucalean genera commonly represented in the canopy are *Cystophora*, *Acrocarpia* and *Platythalia* (Cystoseiraceae), *Sargassum* (Sargassaceae), *Seirococcus* and *Scytothalia* (Seirococcaceae). Currents and water temperature influence species distributions on a large scale, as do other factors such as water movement, depth and biotic interactions at smaller spatial scales.

Ecklonia radiata is distributed in temperate waters of Australia from Kalbarri to Caloundra in Queensland. Throughout this region, the species is often a dominant member of the canopy. Despite its diminutive size (generally <2m) relative to many other Laminarian species, it is large in comparison to other (fucalean) canopy species of the region. Also, it is often found at densities greater than 20 plants m^{-2}, resulting in high biomass. In Western Australia, Kirkman (1981a) estimated that this species was responsible for 95% of algal biomass in depths between 6 and 10 m along northern Perth (Kirkman 1981a). Similarly, Walker et al. (1988b) reported that the kelp covered approximately 30% of subtidal reef at Rottnest Island. *Ecklonia* is particularly common on exposed oceanic shores in South Australia, where biomasses between of 1 and 10 kg fwt m^{-2} have been recorded (e.g.Shepherd & Womersley 1970, 1971, 1976, 1981, Collings 1996). The kelp is important as a source of nitrogen in coastal waters (Hansen 1984, Paling 1988, 1991, WAWA 1991), and contributes to the detrital food chain when cast ashore as wrack (Robertson & Hanson 1982, Robertson & Lucas 1983, Hansen 1984, Robertson & Lenanton 1984)

Where *Ecklonia* is absent or found in low densities, fucalean species may dominate the canopy. Patches of monospecific stands may be present, but often stands are represented with a great diversity of coexisting species. Some fucalean taxa are widely distributed across the southern coast and others have narrower distributions that are consistent with biogeographical factors. For instance, *Cystophora* and *Sargassum* species are well represented across both the southern and southwestern coats. In contrast, *Platythalia* has a largely western distribution. The genus *Acrocarpia* contains two species – *A. robusta*, found only in Western Australia, and *A. paniculata*, with a more easterly distribution, restricted to the region west of the Great Australian Bight (Womersley 1987). Similarly, the family Seirococcaceae is represented in this region by two morphologically similar species: to the west of Pt Lincoln (South Australia), *Scytothalia dorycarpa* is recorded, and to the east, *Seirococcus axillaris* is present.

The distributions of some fucalean taxa are associated with particular water movement regimes and depths. The terrestrial equivalent of the hydrodynamic forces involved in oceanic environments at the sublittoral fringe would see windspeeds of over 1400 km hr^{-1} which reverse direction repeatedly across the course of every minute. The massive bull kelp, *Durvillaea potatorum* dominates the sublittoral fringe of rough water shores of southeastern Australia and *Cystophora intermedia* is abundant from Victor Harbor west to Point Sinclair (South Australia) (Shepherd & Womersley 1970, 1971, 1976, 1981, Womersley 1987). Few other canopy species can exist in this high energy environment, but *Acrocarpia paniculata* may be found here in addition to slightly the more moderate conditions found at greater depth (Shepherd & Womersley 1970, 1971, 1981, Collings 1996, Collings & Cheshire 1998).

Other conspicuous canopy species found in moderate to rough conditions are *Seirococcus axillaris* and *Scytothalia dorycarpa. Seirococcus* has an eastern distribution and *Scytothalia* is found to the west (Womersley 1987). Where they overlap in distribution, *Seirococcus* tends to be found in areas of lesser water movement than *Scytothalia* (Shepherd & Womersley 1970, Shepherd & Sprigg 1976, Collings 1996).

Species restricted to calmer waters must overcome the effects of sedimentation (Devinny & Volse 1978) and the inhibition of nutrient uptake because of boundary layers and reduced turbulence (Cousens 1982). Two canopy taxa commonly associated with these lower levels of water movement are *Caulocystis uvifera* and *Scaberia agardhii* (Shepherd & Sprigg 1976, Shepherd & Womersley 1981, Collings 1996).

Sargassum and *Cystophora* represent two of the major canopy forming genera in southern Australia, represented with 15 and 23 species, respectively. Their distributions cross a range of geographic, depth and exposure spectra. For example, at Rottnest Island, *Sargassum* can cover 20% of the substrata to depths of 10 m. In addition, *Sargassum* can contribute to 20% of annual production and 27% of algal biomass (in Steinberg & Kendrick 1999). In South Australia, Collings and Cheshire (1998) observed that *Cystophora* species were well-represented in higher energy environments and *Sargassum* in areas with reduced water movement (but see Shepherd & Sprigg 1976). *Sargassum* dispersal and recruitment has been studied by Kendrick and Walker (1991, 1995) and Kendrick (1994), among others.

The understory layer consists of encrusting, foliose, filamentous, and fleshy macroalgae that are up to tens of centimeters in length (Steinberg & Kendrick 1999). Coralline macroalgae commonly found in the understory layer are *Corallina*, *Metamastophora*, *Jania*, *Amphiroa*, and *Metagoniolithon*. In Victoria and South Australia, common understory genera are *Plocamium* and *Corallina*. In Western Australia, *Pterocladia*, Rhodymenia, *Amphiroa*, *Dictyomenia* are common in the understory layer (Steinberg & Kendrick 1999).

Status

No macroalgal species has been designated as threatened. However, macroalgae are protected in South Australian waters under the South Australian Fisheries Act 1982 , the South Australian National Parks and Wildlife Act 1972, and the Native Vegetation Act 1991. Marine protected areas and conservation parks that include macroalgae occur in several locations, including the Great Australian Bight, Point Labatt on western Eyre Peninsula, Goose Island in Spencer Gulf, Troubridge Hill on southern Yorke Peninsula, Port Noarlunga and Aldinga reefs in Gulf St Vincent, West Island in Encounter Bay, and Seal Bay on Kangaroo Island. In Western Australia, macroalgae are protected under the *Conservation and Land Management Act 1984* in the existing marine parks: Shark Bay, Ningaloo, Marmion and Shoalwater Islands Marine Parks, and in the future planned marine parks in Geographe and Flinders Bays and Dampier Archipelago. They are also included in the definition of fish in the *Fisheries Resources Management Act 1994* and are protected under fisheries closures and the Fish Habitat Protected Area program. Under this legislation, macroalgae are protected in Fish Habitat Protection Areas such as in Cottesloe, Western Australia.

Habitat and distributions

Macroalgal assemblages along the southwest and southern coasts of Australia are characterized with widespread distributions and species turnover at the metres-scale. The flora is rich along relatively small stretches of the coastline (Bolton 1996), indicating that small-scale processes contribute to high species richness at the local scale. However, large-scale geographical changes influence algal distributions. For example, *Ecklonia radiata* is the dominant canopy species along both the western and southern coasts of Australia and directly influences species distribution, but only a few species are predictably associated with the kelp beds (Wernberg et al. 2003). Instead, species distributions are a function of process acting at a range of spatial scales and include large-scale geographical clines, exposure to wave energy, and interspecific interactions with *Ecklonia* (Wernberg et al. 2003).

Reefs along the southwest and southern coasts are composed of granite, metamorphosed schists, greenstones, and limestone (Kendrick 1999). Areal estimates of reef were published for the Houtman Abrolhos Islands, Perth Metropolitan area, Rottnest Island and that of the Recherche Archipelago has recently been recorded (Table 4.2.3). The Recherche Archipelago areal estimate of reef habitat is substantially larger than that of the Houtman Abrolhos Islands, Perth, and Rottnest, on account of the greater extent of the archipelago (Table 4.2.3). Limestone reefs are prevalent between Shark Bay and Cape Leeuwin, and then intermix with granite reefs from Cape Leeuwin to Esperance (Walker 1991). At Marmion Lagoon, *Ecklonia* is the dominant canopy species on the limestone reefs and can contribute 95% of biomass of algae (Kendrick 1999). At Hamelin Bay where both granite and limestone reefs are found, *Ecklonia*, *Sargassum*, and *Rhodymenia* are common on limestone reefs and *Scytothalia*, *Platythalia*, *Phacelocarpus*, and *Zonaria* are representative species in macroalgal assemblages on granite reefs (Harman et al. 2003). Along the south coast at the Fitzgerald National Park, *Cystophora*, *Sargassum*, *Ecklonia*, and *Scytothalia* are common on the subtidal schists reefs (in Bancroft & Davidson 2000).

The Leeuwin Current and Capes Current influence the distribution of macroalgae along the southwestern and southern coasts of Australia. The Leeuwin Current is a southerly-flowing, warm-water current that contributes to transport of tropical species down the coast of Western Australia (Pearce 1991). The strength of the current varies annually and may be responsible for the tropical species *Penicillus nodolosus* that had once been present at Rottnest Island to now only be found at higher latitudes (i.e. Houtman Abrolhos) (Walker 1991). The Capes Current flows northward and may impede southward dispersal of macroalgae (Walker 1991).

In Shark Bay, macroalgal species richness decreases with increasing salinity (35-60%) (Kendrick et al.1990).

Significance of species group in the southwest planning area

Algal assemblages are important as a food source, nursery grounds, and three-dimensional shelter for a variety of organisms. Macroalgae contribute to marine nutrient and carbon cycling. In addition, the macroalgae (endemic, tropical, temperate, and cosmopolitan components) have distributions encompassing the southwest marine region, with high species turnover at the scale of metres.

Impacts and threats

Human populations along Australian coastlines are increasing and this growth has the potential to add to large-scale degradation of macroalgal habitats and altering of species composition and relative abundance. For example, in eutrophic waters, abundance of dominant canopy species have been shown to decrease, species diversity to decrease, and ephemeral species to increase (Walker & Kendrick 1988, Worm 2001). Walker and Kendrick (1998) outlined the following impacts and threats to coastal macroalgal habitats. A decrease in water quality will reduce the depth of the photic zone thereby restricting macroalgal distributions with depth. Sedimentation from coastal developments (ports, marinas, groynes, housing developments, and canal estates), dredging, and sediment infill can impact macroalgal recruitment due to smothering of algal propagules and recruits. Local hydrodynamics from coastal developments can alter local hydrodynamics resulting in fragmented algal distributions. Pollution (point or diffuse sources) sources from sewage, mariculture, and agriculture runoff can alter algal diversity. Ballast waters and importing of marine organisms for mariculture and aquarium industries can result in the introduction of invasive species such as *Undaria pinnatifida*, *Caulerpa taxifolia*, and *Caulerpa racemosa*.

Information gaps

Surveys of macroalgae in Australia have been a function of biases of the researcher and access of the collector (Huisman et al. 1998). New collections often result in substantial extensions of known distributional ranges (Phillips 2001, Goldberg & Kendrick, in press). Of the species that have been identified, there is little information available on species-level density, growth, reproduction, and seasonal abundance (Entwisle & Huisman 1998) and associated physical parameters (i.e. seawater temperatures, nutrients, water clarity, and exposure to wave energy). In addition, numerous species have low relative abundance or are found infrequently, but no study has conclusively identified the spatial abundance of these rare species, or if they are threatened (Entwisle & Huisman 1998). The spatial distributions of algal-dominated reefs need to be mapped along with associated physical (depth and seafloor topographic features) and oceanographic parameters (i.e. exposure to wave energy and current patterns), as has been surveyed in the Recherche Archipelago, Rottnest Island, and Marmion Lagoon. Distributions of deep-water algal assemblages (>30 m), including rhodolith beds, need to also be explored.

Proposed actions

Knowledge of macroalgal assemblages would benefit from mapping of macroalgal habitats; investigations into ecological/processes studies; investigations into the maintenance of species diversity; investigations into the effects of diffuse sources of pollution on macroalgal diversity and species distributions; and surveys of invasive species.

Current research groups

Current research on macroalgae is being carried out at universities and government institutions in Perth, Western Australia. The marine and estuarine group from the University of Western Australia (www.plants.uwa.edu.au/home/research; Principal investigators: Di Walker, Gary Kendrick) investigates macroalgal ecology, and

mapping of macroalgal assemblages on subtidal reefs. The Marine and Estuarine Ecology research group at Edith Cowan University focuses on process-oriented studies to understand and ultimately manage degradation due to urban development (cem.ecu.edu.au/marine-estuarine; Principal investigators: Paul Lavary, Glenn Hyndes, Ian Bennett, Matt Vanderklift). Macroalgal research at the School of Biological Sciences and Biotechnology at Murdoch University is led by Michael Borowitzka (www.bsb.murdoch.edu.au/research/interests). Macroalgal taxonomy is investigated by John Huisman (Research Fellow at Murdoch University).
The project entitled Coastal Ecosystem and Biodiversity in Western Australia (CSIRO-Strategic Research for the Marine Environment) aims to investigate biodiversity, including benthic macroalgal diversity, biogeochemical processes and environmental quality (www.srfme.org.au/coreres/project3.htm; Team leader: Russ Babcock).

In South Australia, macroalgal research is carried out by both the University of Adelaide and state government institutions. The University of Adelaide has a strong research group under the leadership of Assoc. Prof. Sean Connell and Dr Bronwyn Gillanders (www.marinebiology.adelaide.edu.au/). Their work focuses on a range of broad ecological questions, with an emphasis on an understanding of southern Australian marine macroalgal systems at a variety of scales. SARDI Aquatic Sciences (www.sardi.sa.gov.au/aquatic/) conducts research in a wide variety of marine fields, with Dr David Turner conducting the “Reef Health” program which is a broad scale investigation of the state of South Australia’s reef ecosystems, with a strong emphasis on the macroalgal component. Professor Bryan Womersley and Dr Bob Baldock maintain the macroalgal herbarium at the State Herbarium, provide taxonomic expertise and are involved in the revision of macroalgal systematics.

Key datasets and contacts

Descriptions of macroalgal assemblages attached to subtidal reefs have been compiled for Geraldton, Houtmans Abrolhos, Quinns Rock, Marmion Lagoon, Rottnest Island, Cape Peron area, Hamelin Bay, and the Recherche Archipelago (Table 4.2.4).

Table 4.2.1 Approximate numbers of genera and species of macroalgae worldwide, in southwestern and southern Australia, and percent of endemic species to the southern Australia (data from Womersley 1990, Edgar 2000, Phillips 2001)

	Phaeophyceae (brown algae)	Rhodophyta (red algae)	Chlorophyta (green algae)
Worldwide	900-1500 species	4000-6000 species	1040 species
Southern Australia	104 genera 231-240 species	284 genera 800 species	39 genera 124-140 species
Proportion of endemic genera and species to southern Australia	19% genera 57-60% species	30% genera 75-77% species	5% genera 30-40% species
Taxonomic orders with species endemic to southern coast of Australia	Chordariales, Dictyotales, Fucales	Gigartinales, Rhodymeniales, Corallinales, Ceramiales	Caulerpales

Table 4.2.2 Species richness at various locations along the southwestern and southern coats of Australia

Location	Phaeophyceae	Rhodophyta	Chlorophyta	Total species
Rottnest Island[1]	71	222	54	355
Recherche Archipelago[2]	65	148	29	242
Houtman Abrolhos[3]	50	178	32	260
West Island[4]	9	93	30	132
Pearson Island[5]	21	99	40	160
Waterloo Bay[6]	31	262	71	364
St Francis Island[7]	10	82	47	139

[1]Huisman & Walker 1990, [2]Goldberg & Kendrick, in press, [3]Huisman 1997, [4]Shepherd & Womersley 1970, [5]Shepherd & Womersley 1971, [6]Shepherd & Womersley 1981 [7]Shepherd & Womersley 1976

Table 4.2.3 Areal coverage of reef habitats.

Location	Marine Habitats (km^2)	Reference
Abrolhos Islands	502	Hatcher et al. 1988
Perth Metropolitan:		
Quinns Rock* (depths <10 m)	13.3	Walker et al. 1991c
Marmion Marine Park	9.6	Ottaway & Simpson 1986
Marmion Lagoon	9.7	Kirkman 1981a
Two Rocks to Trigg Island	23	Johannes & Hearn 1985
Trigg to Success Bank*	4.6	Paling 1991
Cockburn Sound	50.5	Paling 1991
Shoalwater Bay	9.89	Paling 1991
Warnbro Sound	10.15	
Rottnest Island*	15.4 km^2	Paling 1991
Recherche Archipelago	35203 km^2	Kendrick et al. 2005

*depths <10 m

Table 4.2.4 Descriptions of subtidal macroalgal assemblages

Location	Description of data set	References
Shark Bay	Benthic algae (Presence/absence)	Kendrick 1983, Kendrick et al. 1990
Geraldton	Benthic algae (% cover and/or density of dominant species)	Walker 1989, Walker et al. 1991a, 1992
Houtmans Abrolhos	Biological communities (mapping)	Hatcher et al. 1998
	Demography of *Ecklonia*	Hatcher et al. 1987
Quinns Rock	Benthic algae (Presence/absence)	Walker et al. 1991c
Beenyup sewage outfall	Benthic algae (Presence/absence)	CALM 1990
	Nutrient enrichment experiments on kelps	WAWA 1991
Marmion Lagoon	Shading effects on Ecklonia	Kirkman 1989
	Benthic algae	Phillips et al. 1997, Kendrick et al. 1999, Wernberg 2003, Wernberg et al. 2003
Rottnest Island	Catalogue of species of marine algae	Huisman & Walker 1990
	Demography of *Sargassum*	Kendrick 1991, Kendrick & Walker 1991, 1995
Sepia Depression, Cape Peron, Warnbro Sound, and Shoalwater Bay	Benthic algae (Presence/absence)	LeProvost et al. 1981, Gordon 1986
Hamelin Bay	Diversity of benthic algae	Kendrick 1999b, Harman et al. 2003
	Algal assemblages associated with *Ecklonia*	Wernberg et al. 2003, Kendrick et al. 2004
Recherche Archipelago	Diversity of benthic algae	Goldberg & Kendrick, 2004, in press
Fitzgerald River	Diversity of benthic algae	Kendrick in Bancroft & Davison 2000
West Island	Benthic algae (diversity and biomass)	Shepherd & Womersley 1970
Pearson Island	Benthic algae (diversity and biomass)	Shepherd & Womersley 1971
Waterloo Bay	Benthic algae (diversity and biomass)	Shepherd & Womersley 1981
St Francis Island	Benthic algae (diversity and biomass)	Shepherd & Womersley 1976

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4.3 Seagrasses

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Photo: G. Kendrick

Species group name and description

The seagrasses are flowering vascular plants that live submerged in seawater or estuarine brackish water. They are neither macroalgae nor freshwater vascular plants. Seagrasses are specialised to being fully submerged and many flower submerged, although there is one species that requires exposure during low tides for successful fertilization of flowers. Seagrasses in temperate Australia persist on sand habitats in shallow coastal environments by recruitment from seedlings and lateral spread of rhizomes from existing meadows. Colonisation also takes place by detached rhizomes or stems with adventitious roots attaching to sand areas. These colonizing processes, combined with seagrass loss from physical disturbance, result in a mosaic of sand and seagrass meadows and patches that create a distinctive landscape in shallow nearshore waters.

Worldwide, they are found in the nearshore marine and estuarine environments of most coastal areas (Green and Short 2003). In Australia, they are well documented from tropical and temperate coasts. The diversity of seagrasses in temperate south western Australia is the highest for any temperate region in the world and this reflects the broad distribution of seagrasses in estuaries, coastal embayments and nearshore sheltered environments, through to exposed coastal nearshore and offshore areas that are buffeted by ocean swells.

The seagrasses found in the SW marine region demonstrate a range of specializations in size, reproduction, morphology, productivity and growth dynamics due to the range of environments they are found in. For example, the genus *Posidonia* is represented by three species from the *Posidonia australis* complex (*P. australis, P. angustifolia*, and *P. sinuosa*) (Cambridge and Kuo 1979) and four species of the *P. ostenfeldii* complex (*P. ostenfeldii, P. coriacea, P. denhartogii* and *P. kirkmanii*) (five species - Kuo and Cambridge 1984, reduced to four species - Campey et al. 2000).

Some seagrasses, especially the *Posidonia* spp., are slow colonisers, demonstrating poor recruitment from seeds and seedlings (Kirkman & Kuo, 1990; Kuo & Kirkman, 1996) and slow horizontal spread from rhizomes (Clarke & Kirkman, 1989). Once these seagrasses are disturbed, they generally do not recover (Cambridge & McComb, 1984; Kirkman, 1985; Shepherd *et al*., 1989). Kirkman and Kirkman (2000) documented little change in the distribution of meadow-forming *Posidonia* and *Amphibolis* species over a 17-year period near Perth, Western Australia. Similarly across Australia, little recolonisation of *Posidonia* spp. or *Amphibolis* spp. has occurred in areas where seagrasses have been lost following eutrophication (e.g. Cockburn Sound (Western Australia), Cambridge & McComb, 1984; Cambridge *et al.*, 1986; Kendrick *et al.* 2002; Albany Harbours (Western Australia), Wells *et al.*, 1991; Eastern Gulf St Vincent (South Australia) and Western Port (Victoria), Shepherd *et al*., 1989).

Within the SW marine region there are 17 species across four families:

Family Cymodoceaceae Taylor
Amphibolis antarctica (Labill.) Sonder et Aschers.
Amphibolis griffithii (J.M. Black) den Hartog
Syringodium isoetifolium (Aschers.) Dandy
Thalassodendron pachyrhizum den Hartog

Family Hydrocharitaceae Jussieu
Halophila australis Doty and Stone
Halophila decipiens Ostenfeld

Family Posidoniaceae Lotsy
Posidonia angustifolia Cambridge and Kuo
Posidonia australis Hook.*f*.
Posidonia coriacea Cambridge and Kuo
Posidonia denhartogii Kuo and Cambridge
Posidonia kirkmanii Kuo and Cambridge
Posidonia ostenfeldii den Hartog
Posidonia sinuosa Cambridge and Kuo

Family Zosteraceae Drummortier
Heterozostera nigricaulis J. Kuo
Heterozostera polychlamys J. Kuo
Zostera mucronata den Hartog
Zostera muelleri Irmisch ex Aschers.

Recent taxonomic work

Les *et al.* (2002) sank the genus *Heterozostera* into *Zostera*. Kuo (2005) does not support this move despite the morphological and genetic similarities between *Zostera* and *Heterozostera* presented by Les *et al.* (2002). There is some confusion in the literature because of this nomenclatural disagreement (e.g. Walker *et al.* 2004 describe the nutrient dynamics of *Zostera tasmanica*). Kuo (2005) presents two new species of *Heterozostera* in the SW marine region (*H. nigricaulis* J. Kuo, *H. polychlamys* J. Kuo) and states that the more historically described *H. tasmanica* does not occur there. Previously described *H. tasmanica* is now *H. nigricaulis* or *H. polychlamys*. Campey *et al.* (2000) suggest that there is considerable taxonomic confusion within the *P. ostenfeldii* complex and that the whole group should be reanalysed. They wrote that *P. robertsonii* is synonymous with *P. coriacea*, from vegetative morphological and genetic data. The genera of *Ruppia* and *Lepilaena* were not considered to be seagrasses for the purposes of the present review.

Common names of seagrasses include, tapeweed (*Posidonia*), wireweed (*Amphibolis*), paddleweed (*Halophila*), and garweed (*Zostera* and *Heterozostera*). *Posidonia* and *Amphibolis* often grow in extensive monospecific meadows in subtidal waters (Figures 4.3.1 and 4.3.2), with smaller patches of *Heterozostera* interspersed and *Halophila* as an understorey species. *Zostera* also grows in large monospecific meadows on tidal flats. *P. angustifolia* and *P. sinuosa* often grow sympatrically.

Status

None of the species in the planning area is listed as threatened or endangered. *Amphibolis griffithii* is endemic to the SW marine region with a western limit at Shark Bay in Western Australia and an eastern limit at Encounter Bay in South Australia.

Seagrasses are protected in South Australian waters under the *South Australian Fisheries Act 1982* and the *Native Vegetation Act 1991*. They are also protected in coastal conservation parks (under the *South Australian National Parks and Wildlife Act 1972*) and aquatic reserves (under the *South Australian Fisheries Act 1982*) in several locations, including the west coast of Eyre Peninsula, Spencer Gulf, Gulf St Vincent, Encounter Bay, and Kangaroo Island.

Seagrasses are specifically protected in Western Australian waters under the *Wildlife Conservation Act 1950*. They are also protected under the *Conservation and Land Management Act 1984* in the existing marine parks: Shark Bay, Ningaloo, Marmion and Shoalwater Islands Marine Parks, and in the future planned marine parks in Geographe and Flinders Bays and Dampier Archipelago. Throughout the rest of the State, seagrasses are offered some protection from coastal and marine development through the *Environmental Protection Act 1986*. They are also included in the definition of fish in the *Fisheries Resources Management Act 1994* and are protected under fisheries closures and the Fish Habitat Protected Area program.

Habitat and distribution

Seagrasses grow on sediments in intertidal and shallow subtidal waters wherever there is sufficient light and favourable hydrodynamic conditions. Seagrasses are common in the sheltered coastal areas of South Australia, including bays, lees of islands and fringing coastal reefs, and the two major gulfs (Figure 4.3.3). Edyvane (1999) estimated that there are 9 620 km^2 of seagrasses in South Australia. The majority of this coverage occurs in Spencer Gulf (5 520 km^2) and Gulf St Vincent (2 440 km^2, Edyvane 1999, Figure 4.3.3). Major regions of seagrass meadows within central South Australia are located along the west coast of Eyre Peninsula in Fowlers Bay, Tourville Bay, Murat Bay, Smoky Bay, Streaky Bay, Baird Bay, Venus Bay, Waterloo Bay, and Coffin Bay; in much of Spencer Gulf; along the northern part of Investigator Strait in Marion Bay, Foul Bay, and Sturt Bay; in much of Gulf St Vincent; around northern Kangaroo Island in Nepean Bay, Antechamber Bay, D'Estrees Bay, and Emu Bay; and in Encounter Bay at the eastern boundary of the SW region (Figure 4.3.3, Bryars 2003a).

Species distributions are broadly known in South Australia (see Shepherd and Robertson 1989; Kirkman 1997). *Posidonia* is the dominant genus in terms of spatial coverage, with *P. angustifolia*, *P. australis*, and *P. sinuosa* being the most abundant species within the genus. The upper parts of both Spencer Gulf and Gulf St Vincent have extensive tidal flats that are dominated by *P. australis* and *Zostera* species. Within the Gulfs and bays around South Australia, seagrasses are generally restricted to depths of <20m (Shepherd and Robertson 1989, Edyvane 1999b). However, in the clearer waters of Investigator Strait, some offshore islands, and at the base of cliffs on the west coast of Eyre Peninsula, seagrasses grow to depths of 30m or more (Shepherd and Robertson 1989).

In temperate Western Australia, seagrasses occupy approximately 20,000 km^2 of shallow coastal habitat (Walker, 1991) in water depths ranging from the intertidal to >50 m. Seagrasses occur in a range of habitats from wave-exposed sandbanks to sheltered bays, lagoons and estuaries. They grow predominantly on sand from 1-35 m depth (Cambridge & Kuo, 1979), but also on deep rock to over 50 m deep (e.g. *Thalassodendron pachyrhizum*), and shallow estuarine mud and sand flats.

Along the southwest coast of Australia, seagrass habitats are heavily influenced by exposure to ocean swells and large-scale sand movement. *Amphibolis griffithii* has higher water baffling capacity than *Posidonia australis*, *P. sinuosa* or mixed *Posidonia* meadows (van Keulen and Borowitzka 2002, 2003). *Amphibolis antarctica* meadows have been shown to reduce water flows from 50 to 2-5 cm s^{-1} (Verduin and Backhaus 2000).
The *P. ostenfeldii* group of species typically form patchy meadows with mixed species in open-ocean or rough water sublittoral habitats (Campey et al. 2000). They are characterised by their long, thick, leathery leaves and long leaf sheaths that are deeply buried. Their ability to withstand ocean swell is because, unlike the *Posidonia australis* group, their rhizomes grow vertically instead of horizontally. These characters appear to be associated with strong wave movement and mobile sand substratum typical of the environments in which they are found (Kuo and Cambridge, 1984).

Significance of species group

Seagrass meadows in the SW marine region play important roles in:

- Providing habitat for many fish and crustaceans, including commercially and recreationally important species such as King George whiting (Connolly 1994, Connolly and Jones 1996, Connolly *et al.* 1999, Hyndes *et al.* 1999, Bryars 2003a, Bloomfield and Gillanders 2005).
- Stabilising coastal sediments, trapping sediments, and preventing coastal erosion (Keough and Jenkins 1995, Edgar 2001, Westphalen *et al.* 2004).
- Supporting a large range of biodiversity, including molluscs, and epiphytic plants and algae (Keough and Jenkins 1995, Edgar 2001).
- Primary production (Keough and Jenkins 1995, Edgar 2001), including carbon export to adjacent habitats (Connolly *et al.* 2005, Hyndes and Lavery 2005).
- Nutrient cycling (Walker et al. 1999, 2004, Edgar 2001, Smit et al. 2005).

Impacts/threats

The major threat to seagrasses is coastal development. Over the last two decades, the loss of seagrass from direct and indirect human impacts amounts to 18% of the documented global seagrass area (Green and Short 2003). Seagrass losses occur as development pressure on coastlines and coastal catchments increases. Known key threatening processes include:

- Eutrophication
- Sedimentation
- Increased turbidity
- Shading
- Scouring
- Toxicants

South Australia

Over the past 70 years, at least 5000 ha of seagrasses have been lost from the metropolitan Adelaide coastline in eastern Gulf St Vincent. Initial losses have been linked to wastewater treatment plant outfalls and stormwater discharges, with subsequent physical erosion in some places (Westphalen *et al.* 2004). A small area of loss and degradation (ca. 40 ha) was reported by Shepherd *et al.* (1989) at Proper Bay in southwestern Spencer Gulf due to discharge wastes from fish processing factories in Port Lincoln. The significant losses of subtidal seagrasses reported in Western Cove on Kangaroo Island (Edyvane 1997) appear to be linked to eutrophication due to land-based inputs (Bryars *et al.* 2003). Tanner (2005) documented the disappearance of large areas of deepwater *Heterozostera* over a 30-year period in Investigator Strait/Gulf St Vincent, and suggested that the losses may have been due to land-based discharges and prawn trawling. Numerous other smaller areas of loss have been associated with a range of activities, including mining and seismic operations, construction works, aquaculture structures, and moorings (Shepherd *et al.* 1989, Madigan *et al.* 2000, Bryars 2003 a, b). Large-scale natural losses of intertidal and shallow subtidal seagrasses (up to 13, 000 ha) in northern Spencer Gulf were linked to extreme weather conditions (Seddon *et al.* 2000). Losses of *Posidonia* and *Amphibolis* can take decades to recover (Shepherd *et al.* 1989, Kirkman 1997, Bryars and Neverauskas 2004).

Western Australia

In Western Australia, significant areas of seagrass have been lost following eutrophication in protected coastal embayments (e.g. Cockburn Sound (Western Australia), Cambridge & McComb, 1984, Cambridge *et al.*, 1986, Kendrick *et al.* 2002; Albany Harbours (Western Australia), Wells *et al.*, 1991) (Table 4.3.1). In Cockburn Sound, the seagrass species *Posidonia sinuosa*, *P. angustifolia* and *P. australis* once formed an almost continuous meadow between 1–6 m depth that fringed the eastern, southern and western flanks. Between 1967 and 1972, seagrasses had been lost or fragmented along the eastern and south-eastern shores of the Sound (Table 4.3.2). This 5-year time interval was effectively instantaneous for long-lived and slow growing species like *Posidonia sinuosa* and *P. australis*. The decline in area of seagrass cover on the shallow shelfs (<10 m depths) that border Cockburn Sound was dramatic (Cambridge et al. 1986, Kendrick et al. 2000, 2002).

The quantity of dead seagrass leaf and rhizome material that entered detrital pathways over the 5 year interval, over extensive areas of the eastern and southern fringing shelves, was immense, and probably fuelled the conversion of the inshore ecosystem from net autotrophic to net heterotrophic. Large losses of seagrasses continued into the 1980s and early 1990s.

Table 4.3.1 Survey of seagrass mapping exercises from SW Australia published in international journals from the last decade showing either landscape scale recovery (expansion) or losses of seagrasses.

Authors	Location	Remote sensing type	Spatial extent	Method of mapping	Comments
Hastings *et al.* 1995	Rottnest Island, Western Australia	Colour and B/W aerial photographs unrectified	Approx 81 ha	Because of the small area of bays 1-2 aerial photographs were used in each bay. Seagrass was manually drawn onto mylar sheets which were scanned and polygon cover determined in ARC-INFO	50 years of aerial photography was used Rocky Bay loss of seagrasses total 31% from mooring damage 18% 1941-1981 13% 1981-1992 Thomson Bay 1941-92 <5% Fragmentation occurring
Kendrick *et al.* 2000	Success and Parmelia Banks, West. Australia	Colour and B/W aerial photographs rectified and mosaicked	3,974 ha	Control rules were: isolated patches less than 30 m^2 not mapped; isolated patches 30 – 100 m^2 mapped as separate meadows when distance between patches was greater than diameter of patches; seagrass patches 30 – 100 m^2 were mapped together when they are not isolated by sand > diameter of seagrass patch; seagrass patches >100 m^2 were mapped as separate meadows. Spatial errors varied from 2.5 to 13.9 m between years mapped	Changes in area of seagrass coverage were recorded between 1965, 1972, 1982 and 1995 21% increase in seagrass cover on Success Bank. On Parmelia Bank %cover of seagrasses has remained constant at approx 45% Seagrasses responsible for gains are *Amphibolis griffithii* and *Posidonia coriacea*
Seddon et al. 2000	Spencer Gulf, South Australia	Colour aerial photographs	70 – 80 km of coastline	Eight habitat categories including density of shoots and level of dieback Estimate of spatial area was 31 ± 30 ha	Historical dieback between 1987 and 1994 in the intertidal and shallow subtidal Over 8269 ha showed dieback attributed to climate change associated with El Niño.

Kendrick et al. 2002	Cockburn Sound, Western Australia	Colour and B/W aerial photographs rectified and mosaicked	3667 ha	As for Kendrick et al. 2000	Historical decline in seagrass area by 77% since 1967. 1967-72: 1587 ha lost. 1972:1981: 602 ha lost. 1981-1999: 79 ha lost. Species of seagrass lost were predominantly *Posidonia sinuosa* and *P. angustifolia.*

Table 4.3.2 Loss of seagrass area and % cover in Cockburn Sound between 1967 and 1999. (After Kendrick et al. 2002)

REGION	MAPPING AREA (ha)	1967		1972		1981		1994		1999	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(%)	(ha)
Cockburn East	2138.7	1750.3	81.80%	309.8	14.50%	13.5	0.60%	26	1.20%	13.5	0.60%
Cockburn South	817.8	633.7	77.50%	528	64.60%	283.1	34.60%	291.2	35.60%	290.4	35.50%
Cockburn West	710	545.4	76.80%	504	71.00%	442.8	62.40%	372.3	52.40%	356.1	50.20%
TOTAL	**3666.5**	**2929.4**	**79.90%**	**1341.7**	**36.60%**	**739.5**	**20.20%**	**689.6**	**18.80%**	**660**	**18.00%**

Possible major threats

- Invasive pest species, including *Caulerpa taxifolia* and *C. racemosa* that are already established in the Port River region of eastern Gulf St Vincent, South Australia.
- Seagrasses exposed at low tide may be threatened by climate change (c.f. Seddon *et al.* 2000) and sea-level rises. Climate change also will bring changes in the frequency, seasonal timing and severity of storms and storm surges that threaten to physically remove seagrasses from shallow subtidal coastal areas.
- Increasing impact from increased human development of the coastal zone and associated effects of overfishing, physical destruction, and seagrass loss from eutrophication, increased turbidity, and other pollutants.

Information gaps

South Australia

There is a lack of information on basic biology, mechanisms of seagrass loss, and early indicators of seagrass decline, as well as detailed species distributions, spatial coverage and associated aspects of the physical environment. Standardised techniques of seagrass mapping and surveying are required. Further work is also required on indirect food chain links between seagrass production and fisheries production. For example, recent work by Connolly *et al.* (2005) indicated that subtidal seagrasses are extremely important in supporting a commercial fish species (*Sillago schomburgkii*) that lives on tidal flats that are physically isolated from the seagrass meadows. Little is known about the spatial coverage, habitat use and food chain links of deepwater seagrasses.

Western Australia

Gaps in seagrass knowledge have recently been outlined in the Strategic review and R&D plan for Seagrass developed for the Fisheries Research and Development Corporation by the CSIRO (Butler and Jernakoff 1999). These gaps have not been completely addressed over the six years since this report. The major gaps identified in seagrass knowledge include:

1. Large-scale mapping of seagrass species distributions and correlating their distribution to fisheries data for commercial species that either spend part of their life cycle or consume the exported products of seagrass meadows.
2. Studies of dispersal and recruitment ecology of different seagrass species in an attempt to understand recruitment bottlenecks for seagrasses.
3. Influence of recruitment from seedlings versus clonal growth in the recovery of seagrass meadows.
4. Optimization of seagrass replanting programs for both maximum increase in seagrass cover and return of ecological function
5. Links between seagrass meadows, unvegetated sand and reef in shallow subtidal landscapes and their importance in trophodynamics, spatial subsidies of primary production to distant ecosystem, and fisheries dynamics
6. Linking local scale mapping to landscape scale seagrass dynamics

Current research

South Australia

Researchers from SARDI, SA Water (formerly Engineering and Water Supply Department), DEH, and the University of Adelaide have undertaken much of the previous work on seagrasses. The broad-scale distribution of seagrasses was previously mapped by CSIRO with the assistance of SARDI, PIRSA and DEHAA, but the maps require revision (see Figure 4.3.3). Major projects currently underway include the Adelaide Coastal Waters Study that aims to determine possible causes of seagrass loss off Adelaide (SARDI), a study investigating the health of seagrass meadows adjacent to freshwater drains in the south-east of South Australia (SARDI and DEH), and an investigation of potential seagrass rehabilitation techniques off Adelaide (SARDI and DEH).

Western Australia

Researchers from the University of Western Australia, Murdoch University and Edith Cowan University working with the State Departments of Fisheries, Environment and Conservation and Land Management and the CSIRO Marine Research Division are responsible for most previous seagrass research in Western Australia. Many multi-disciplinary studies have been generated from the threat of seagrass loss in coastal waters. Examples of these studies include the 1970s Cockburn Sound Study, the 1990s Albany Harbours Study, and the Southern Metropolitan Coastal Waters Study; all initiated by what is now called the WA Department of Environment. EPA requirements also led to multiple seagrass environmental studies and restoration programmes in the State. These included a multi-year study during the 1990s of the ecological significance of seagrasses combined with seagrass transplanting in the Owen Anchorage Region funded by a shellsands mining firm (Cockburn Cement), assessment of the impact of ocean sewage outfalls in the Perth metropolitan area funded by WaterCorp WA, and more recently, studies of the long term health of seagrass meadows in Cockburn Sound funded by the Kwinana Industries Council through the Cockburn Sound Management Authority. CSIRO and Dr Hugh Kirkman has worked on long term change in seagrass meadows, seagrass restoration and transplanting and seagrass mapping in the Western Australia between 1975 and 1995. Recent harbour expansions in Esperance, Geraldton and Dampier have resulted in a switch in the focus of research from nutrient dynamics and pollution to turbidity and its effects on seagrass meadows. Through FRDC funding (FRDC program 2001/060) the fish habitats of the Recherche Archipelago have recently been studied, including the distribution of deep-water seagrass habitats and their associated fish fauna.

Present research into seagrass transplantation is active at Murdoch University (Drs Paling, VanKeulen and Verduin), University of Western Australia (Prof. Walker, Drs Cambridge and Kendrick) and Edith Cowan University (Assoc. Prof. Lavery and Dr Hyndes) through ARC Linkage grants, and industry contracts. Through the Coastal CRC, innovative seagrass species mapping is occurring in Owen Anchorage, using geostatistical techniques (Drs Van Neil, Holmes, Radford and Kendrick). Studies of the effect of turbidity and shading of seagrasses is a major program funded through the WA State Government/CSIRO Strategic Fund for Research into the Marine Environment being led by Assoc Prof. Lavery from ECU. Coastal Fisheries and seagrass habitats have also received a major boost with the appointment of Prof. Neil Loneragan to lead the Fisheries Research Group at Murdoch University, to replace Prof. Potter.

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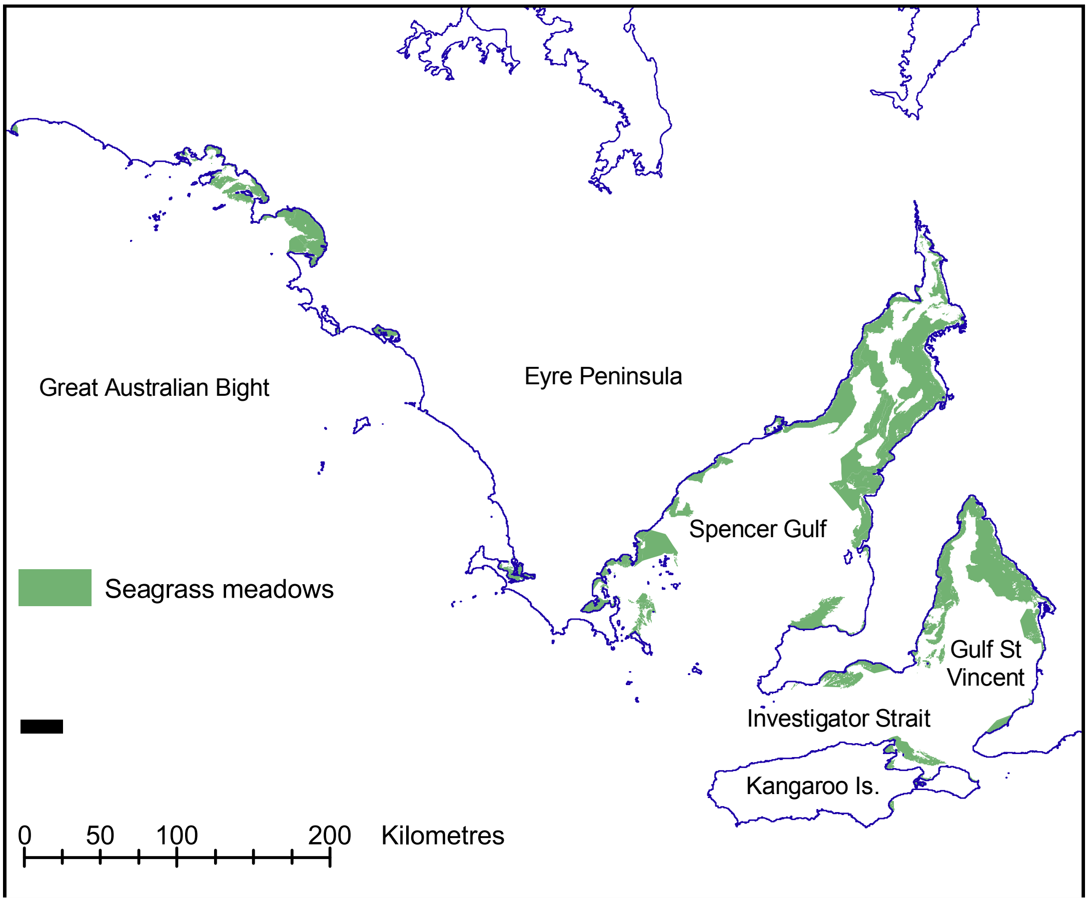
Figure 4.3.1 Meadow of *Amphibolis antarctica*. Source: Greg Collings, SARDI.

Figure 4.3.2 Meadow of *Posidonia australis*. Source: Keith Rowling, SARDI.

Figure 4.3.3. Distribution of seagrass meadows in central South Australia. Data source: SARDI Aquatic Sciences (Components of the information are owned by SARDI, CSIRO, DEHAA and PIRSA). Note: while errors are known to occur in the data, they do indicate the general distribution of shallow water seagrasses in the region.



4.4 Mangroves

Principal contributor
Simon Bryars

Species group name and description

Mangroves are true flowering plants that have roots, stems and leaves. Mangroves evolved from land-based plants to become tolerant to saltwater. Unlike tropical regions of Australia where numerous mangrove species occur, the grey or white mangrove, *Avicennia marina* (Forsk.) Vierh., Verbenaceae (Avicenniaceae), is the only species of mangrove found in the SW marine region. Duke (1991) presents evidence that three varieties of *A. marina* exist around Australia, with two of the varieties occurring in the SW marine region.

The grey mangrove grows in intertidal mud and sand, and has specially-adapted aerial peg roots (pneumatophores) that allow gas exchange at low tide (Figure 4.4.1). In the SW marine region, mature plants may exist as shrubs or small trees reaching a height of ca. 5 m in South Australia (Edyvane 1999a) and forming mono-specific stands that may be referred to as mangrove forests (Figure 4.4.2). Mangroves in South Australia are usually associated with areas of saltmarsh or samphire to landward and tidal flats to seaward (Butler *et al.* 1977a). Tidal creeks are also an important feature of many mangrove forests in South Australia (Figure 4.4.3). *Avicennia marina* occurs in a range of salinities from brackish to hypersaline (Semeniuk et al. 2000a), and is viviparous, i.e. its seeds germinate while still attached to the parent (Semeniuk et al. 1978).

Status

Avicennia marina is not listed as threatened or endangered, and is common and widespread in both the SW marine region and Australasia.

Mangroves are specifically protected in South Australian waters under the *South Australian Fisheries Act 1982*, the *Harbours Act 1936*, and the *Native Vegetation Act 1991*. They are also protected in coastal conservation parks (under the *South Australian National Parks and Wildlife Act 1972*) and aquatic reserves (under the *South Australian Fisheries Act 1982*) in several locations, including the west coast of Eyre Peninsula, northern Spencer Gulf, and Gulf St Vincent. According to Edyvane (1999a), ca. 56% of South Australia's mangroves are protected in seven separate reserves. No formal protection appears to be afforded mangroves in Western Australia.

Habitat and distribution

Avicennia marina has a cosmopolitan distribution across Australasia, including much of northern Australia from northwest Western Australia to southern New South Wales (Duke 1991, Chapman and Underwood 1995). Isolated populations are also found in southwest Western Australia, Victoria, and South Australia. Within South Australia, mangroves are common in the warmer and more sheltered coastal areas, including bays, island lees, and the two major gulfs (Figure 4.4.4). Mangroves in South Australia form the largest temperate mangrove forests in Australia, with an estimated

230 km^2 of coverage (Edyvane 1999a). Key regions of mangrove forests are located along the west coast of Eyre Peninsula at Tourville Bay, Murat Bay, St Peters Island, Laura Bay, Smoky Bay, Streaky Bay, and Venus Bay; in Spencer Gulf at Tumby Bay, Arno Bay, Franklin Harbour, northern Spencer Gulf, Port Broughton, and Wallaroo; and in northern and eastern Gulf St Vincent (Edyvane 1999b, Bryars 2003, Figure 4.4.4). Mangroves in the Port River/Barker Inlet estuary in eastern Gulf St Vincent represent the most southerly mangroves in the SW marine region. In the Western Australian section of the SW marine region, the only significant stands of mangroves occur in the Leschenault Inlet estuary at Bunbury (Semeniuk et al. 1978), covering an area of 3 ha (Pedretti and Paling 2000).

Significance of species group

Mangrove forests in the SW marine region play important roles in:

- Providing habitat for many fish and crustaceans, including commercially and recreationally important species (Butler *et al.* 1977a, b, Kenneally 1982, Connolly and Jones 1996, Bryars 2003, Bloomfield and Gillanders 2005).
- Stabilising coastal sediments, trapping pollutants, and preventing coastal erosion (Chapman and Underwood 1995, Edgar 2001).
- Supporting a large range of biodiversity, including birds, molluscs, plants, insects, spiders, and polychaete worms (Butler *et al.* 1977a, b, Kenneally 1982, Chapman and Underwood 1995, Edgar 2001).
- Primary production, including delivery of leaf litter and other plant material to the seabed (Chapman and Underwood 1995, Edgar 2001).

Impacts/threats

Mangrove losses have occurred in several locations around South Australia, including northern Spencer Gulf, Franklin Harbour, and eastern Gulf St Vincent (Burton 1984, Bayard 1992, Edyvane 1995, see Figure 4.4.3). Causes of losses and ongoing threats to mangroves include clearing, land reclamation, alteration of tidal flows (due to construction of bridges and causeways across tidal creeks), removal of tidal flows (due to construction of dam walls and levee banks, see Figure 4.4.3), rubbish dumping, human trampling, eutrophication, wave erosion, smothering, and oil spills (e.g. the *Era* spill in upper Spencer Gulf) (Butler et al. 1975, Burton 1984, Edyvane 1995, Fairhead 1995, Edyvane 1999a, Bryars 2003). In contrast to human-induced losses, there have also been natural seaward and landward increases in areal coverage of mangroves in eastern Gulf St Vincent during the 20th century (Burton 1982, Coleman 1998). In Western Australia, previous impacts on the Leschenault Inlet estuary have occurred from land reclamation, dredging, harbour reconstruction and urbanisation (Semeniuk et al. 2000b). As with South Australia, mangroves also increased their distribution during the 20th century in some parts of the Leschenault Inlet estuary in Western Australia (Semeniuk et al. 2000a). Global warming and sea-level rises may present a future threat to mangrove forests.

Information gaps

Biological

Within the SW marine region, further research is required on the contribution of mangroves to coastal food chains, including those supporting commercially and recreationally important species. Recent research suggests that mangroves contribute little production to habitats seaward of the mangroves (Connolly et al. 2005). Research is also needed on the real effects of coastal pollutants on mangroves. While mangroves often live in heavily urbanised and polluted waters, little is known about the impacts of potential toxicants on mangrove ecosystems.

Key references and current research

The Department for Environment and Heritage SA recently completed a comprehensive and detailed mapping program of mangroves and saltmarshes in South Australia. The DEH data are available in GIS format and were used for creating Figure 4.4.4. Researchers from Adelaide University and SARDI have undertaken most of the biological research previously conducted in South Australia. Little research is currently underway in South Australia.

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Figure 4.4.1 The grey or white mangrove, *Avicennia marina*, displaying aerial peg roots (pneumatophores) at low tide. Source: Simon Bryars, SARDI

Figure 4.4.2 Mangrove forest at Wills Creek, Gulf St Vincent, South Australia. Source: Simon Bryars, SARDI

Figure 4.4.3 Aerial view of a mangrove forest and tidal creek (Chapman Creek) in eastern Gulf St Vincent. Note the areas of mangrove dieback and the dam wall that has altered tidal flows. Source: Simon Bryars, SARDI

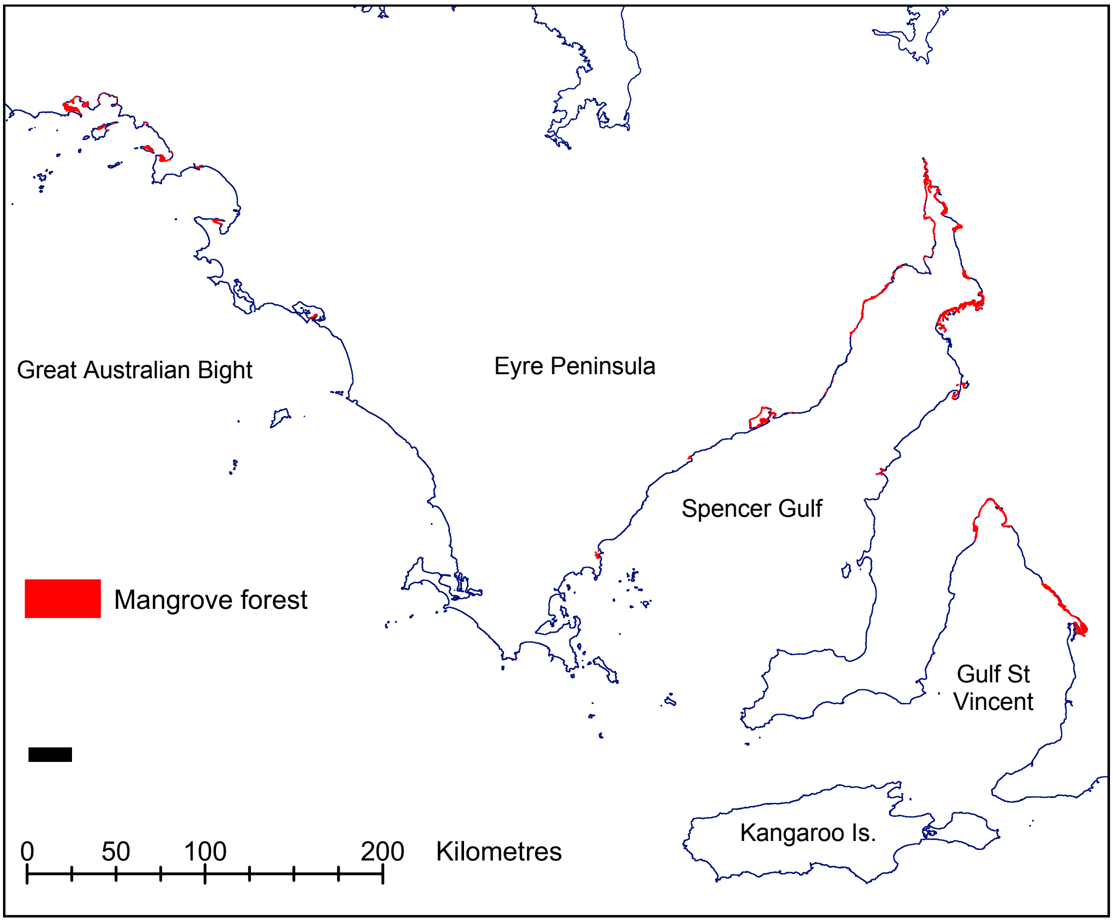


Figure 4.4.4 Distribution of mangrove forests in central South Australia. Data source: The Department for Environment and Heritage SA.

4.5 Sponges

Contributors
Shirley Sorokin
Dr Jane Fromont

Spirastrella papillosa grazed by the cowrie *Zoila frendii*, near Esperance. Photo courtesy of Peter Clarkson

Species group name and description

Sponges (Phylum Porifera) are the simplest multicellular animals that fall, developmentally, between the Protozoa, where individuals consist of independent cells, and the higher Metazoans, where cells are arranged in tissues and organs that have particular functions (Hooper et al. 2002). The phylum is united by the possession of choanocyte chambers, a system of inhalant and exhalent canals, a mobile population of totipotent (capable of forming any cell type) cells, and the possession, for many species, of silicious or calcareous spicules (Hooper et al. 2002). Flagellated cells (choanocytes) in the choanocyte chambers pump water, from which food particles and oxygen are filtered.

Sponges are sessile and occur in many different forms from boring to encrusting to massive. They occur in all oceans from the intertidal zone to the deep sea. There are estimated to be more than 15 000 species of living sponges (Hooper and Van Soest, 2002). The phylum is divided into three classes: Demospongiae, possessing siliceous spicules and/or spongin fibres; Calcarea, possessing calcareous spicules; and Hexactinellida 'glass sponges' usually found in deep water and possessing siliceous spicules (Hooper et al. 2002).

Sponge species can be distinguished from each other by their spicule morphology, skeletal layout, cell type (Boury-Esnault and Rutzler 1997; Vos et al. 1991), and in some groups, by their chemical compounds (Soest and Braekman, 1999).

The collection and identification of sponges in Australia in the past 10-20 years has been accelerated by marine bio-prospecting studies (eg Quinn et al, 2002), including collections in the SW marine region (eg. in the Great Australian Bight, Capon et al, 1993), ecological and biodiversity studies, (eg. Fromont 1999, Fromont et al. 2006), and taxonomic revisions (eg Hooper 1996). A review of the status of sponge collections in Australia, their geographic strengths and gaps, and the major contributors up until 1994 can be found in Hooper & Wiedenmayer (1994, plus subsequent updates).

Status

No sponges in the SW marine region are officially listed as threatened, endangered or rare. All benthic fauna within the Great Australian Bight Marine Park Benthic Protection Zone are protected from bottom trawling (Department of Environment and Heritage, 2005). Throughout the rest of the SW marine region sponges are not currently protected in commonwealth waters. Some marine parks (Jurien Bay Marine Park) and fish habitat protection areas (Cottesloe Reef Habitat Protection Area) have been established in this region in State waters.

Habitat and distribution

In southern Australia sponges are more significant space occupiers where seaweeds are less dominant, which includes areas out of the euphotic zone such as water deeper than 30 metres and caves (Edgar, 2000). As they are sessile filter feeders they also flourish in areas of high current, although large upright sponges that cannot withstand strong currents are found in calmer deeper waters. Sponges are attached to firm substrates, or weld shell fragments into their base in soft sediments, or have anchoring spicules; they can also bore into calcareous material and are acknowledged for being significant contributors to bioerosion and calcium recycling (see review in Hooper, 2005).

Class: Demospongiae

The Australian Biological Resources Study (ABRS) lists only 119 named species of Demosponge from South Australia and 12 from the Great Australian Bight, although many more unnamed species were known to exist in museum collections. By comparison, a recent study by Sorokin et al. (submitted) reported 109 Demosponges from the Great Australian Bight shelf, from 40 to 200m depth. One third of the sponges were in the order Poecilosclerida. The most common sponge collected, the massive *Spirastrella papillosa* (order Hadromerida) was found at 21 out of 26 sites sampled across the shelf, although it did not occur on the shelf edge. Wilson and Clarkson (2004) also noted this species as being widespread in the SW marine region, in addition to *Trachycladus laevispirulifer*, *Caulospongia biflabellata* and two unspecified *Geodia* (their observations were within diving depths, ≤ 60m). Sponges common around islands off the Western side of the Eyre Peninsula include species of the genera *Tethya*, *Sycon* and *Neofibularia* (Edyvane and Baker 1999).

To date one expedition has been undertaken on sponge species occurrence and distribution in the SW marine region slope and deep shelf environments. The 'Voyage of Discovery' by the RV *Southern Surveyor* late 2005 documented sponge diversity between Barrow Island and Albany at depths of 100-1000 metres (A. Williams, pers.comm.) Transects where collections occurred in the planning region were off the Houtman Abrolhos, Jurien Marine Park, the Perth Canyon and Albany.

Some previous work has been undertaken on the distribution of sponge species in deep waters in north western Australia, 400 km north of the SW marine region, (Fromont 2001, Fromont et al. 2002). The first of these surveys found a total of 22 species of Demospongiae collected at depths greater than 200 metres, and 75 species collected at depths less than 200 metres on the shelf and slope off North West Cape, WA. In the second survey 24 Demosponge species were collected from depths greater than 200 metres, and 12 of these species (50% of the second collection) differed from the first study. Therefore a total of 34 species of Demosponges were found at depths greater than 200 metres in this area. These Demosponge species were all collected on hard substrata and sponge individuals were small or encrusting. Deepwater species spanned a number of families, with the Astrophorida, Hadromerida, Haplosclerida and Lithistids best represented in terms of species diversity. The most common genera included *Geodia*, *Stelletta*, *Polymastia*, *Xestospongia*, and *Strongylophora*. Identifications have not yet been made to species level. There is also a present focus on the sponge fauna between depths of 20-100 metres off Ningaloo reef, which has been collected by the Australian Institute of Marine Science and will be identified at the WA Museum (Fromont, pers.comm.).

Shallow-water studies (<20m depth) in the SW marine region have found very high diversity of Demosponge species. Fromont (1999) reported 77 species from two surveys at the Houtman Abrolhos bringing the total number of species recorded from the area to 109. Work undertaken in the Marmion Lagoon reported 243 species from 6 sites within a 20km stretch of coast (McQuillan, 2006), while recent work in the Recherche Archipelago indicates a species diversity of approximately 300 species (McDonald et al. 2005).

Class: Calcarea

Six of the ten Calcarea species recorded from the Great Australian Bight were very small and were only collected from softer sediment at the edge of the continental shelf in 200m of water (Sorokin et al. 2005). The distribution of calcareous sponges in offshore and shelf areas in south Western Australia is unknown. Fromont 2001, 2002 did not find any calcareous sponges in surveys conducted on the slope off North West Cape, WA.

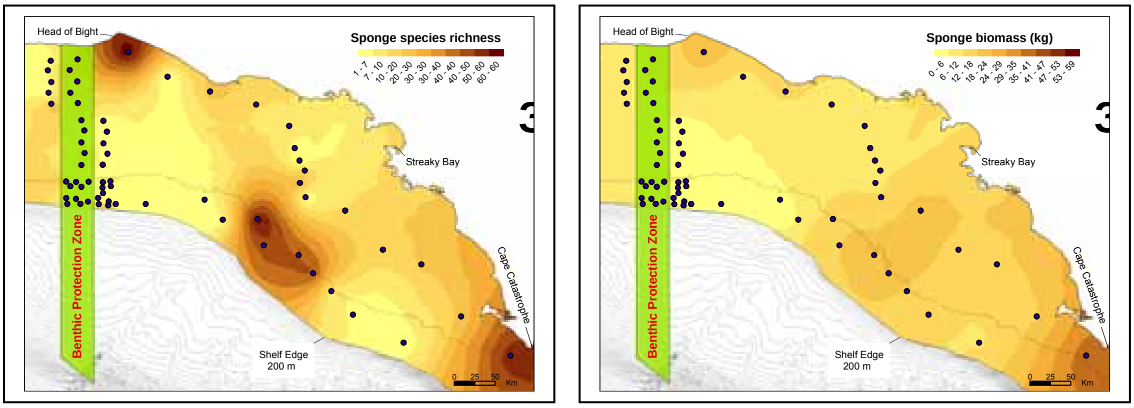
Class: Hexactinellida

The only glass sponge described from the shelf of South Australia belongs to the species *Pheronema amphorae* (Reiswig, 1992). Reiswig also reported *Regadrella okinoseana* from the continental slope off South Australia and *Farrea occa occa* and *Euplectella regalis* from the continental slope off Western Australia; all four sponges were in the Great Australian Bight bioregion.

The distribution of glass sponges in other offshore and shelf areas of the SW marine region is unknown. The 2005 *Southern Surveyor* expedition was the first work to address this knowledge gap. Work in preparation by Tabachnick has included the collections of glass sponges held in the Western Australian Museum which are all to the north of this bioregion. This work has found 20 species of Hexactinellids, 12 of which are known species while 6 species are indicated as being new and 2 are new sub species (Tabachnick, pers. comm.). This work includes the five species of

Hexactinellids found recently in deep soft sediments on the shelf and slope off North West Cape, WA (Fromont, 2001).

Figure. 4.5.1 Maps of total sponge richness (number species.tow^{-1}) and biomass (kg.tow^{-1}) collected from 65 epibenthic sled shots in the eastern Great Australian Bight (see Ward et al., 2006 for further details.).



Significance of species group in the South West Marine Region

In the absence of reef building corals, sponges function as large epibenthos that form the three-dimensional structure of subtidal reefs. They provide shelter for other organisms such as worms, crustaceans, echinoderms, molluscs and fishes and provide a substrate for zooanthids, hydroids and other sessile invertebrates. Within the planning area they have been shown to be an important food source for cowries (Wilson and Clarkson, 2004). They filter organic matter and bacteria from the water column and are also host to microorganisms including cyanobacteria, bacteria and zooxanthellae from which they obtain nutrients.

The Great Australian Bight shelf is rich in sponges that may yield marine metabolites with potential therapeutic applications (Capon, 2001). This resource has been under-explored to date. This same situation is applicable to the whole of the SW marine region.

Impacts/threats

Epibenthic sponges are easily damaged and can be completely removed by bottom trawling. Large sponges have become rare or absent from the continental shelf in some areas of Australia due to trawling (Ponder et al. 2002). It is unknown whether these ecosystems are recoverable. On coral reefs sponge populations are generally constant and unchanging (Wilkinson, 1998), but very little is known about their basic biology, rates of mortality and recruitment, reproduction, growth and age. In general sponges are thought to be slow growing and long lived. For example, a study in the Caribbean found no marked changes in size in the barrel sponge, *Xestospongia muta*, (called the "redwood of the deep"), and believe that sponge growth in medium to large-sized sponges may be very gradual or episodic (Pawlik, people.uncw.edu/pawlikj/xmuta.html). Studies on its Indo Pacific counterpart, *X. testudinaria*, also did not detect significant changes in circumference of individuals over 5 years of monitoring (Fromont and Bergquist, 1994)

Information gaps

There have been several historical and recent expeditions to the Great Australian Bight and coastal areas of South Australia, but the extent of knowledge gathered is difficult to assess due to the lack of a collective electronic database of work undertaken. Compared to other studies of sponges on the Southern Australian coast, for example Bass Strait, there is a lack of published information on shelf sponges in South Australia. Aside from the recent data collected on sponges of the Great Australian Bight and the Southern Surveyor expedition, there is no information about the shelf sponges in the rest of the SW marine region. Shallow water sponges have been collected and identified for some restricted regions, eg. Recherche Archipelago, Marmion Lagoon, Houtman Abrolhos, but the knowledge of the shallow fauna of SW Australia is still very patchy and incomplete.

Key references and current research

- The Australian Biological Resources Study publications (Hooper & Wiedenmayer, 1994 and the ABRS website - updated by Hooper in 1999 and 2005) contain a list of sponge species described in Australian territorial waters, including the SW marine region, including an assessment of their synonymy/ validity.
- Fromont, 1999, documents the shallow water sponge fauna at the Houtman Abrolhos.
- Sorokin et al. 2005 provides a catalogue of 139 sponges (identified to genus level) in the Great Australian Bight Marine Park Benthic Protection Zone; it also lists GAB sponges held at Museum Victoria.
- *Systema Porifera* (Hooper and Van Soest, 2002) is the major sponge text that provides information for the identification of sponges to genus level.

❖ A further 212 different species collected by SARDI in the GAB require identification and funding is currently being sought.
❖ A review of Australian Calcarea, currently funded, will include sponges from the planning area (G. Worheide pers comm.)
❖ A review of the Australian Hexactinellida is currently in preparation (K. Tabachnick pers comm.), although few specimens of this class have been collected from the SW planning area to date.
❖ The sponge biota collected on the Southern Surveyor expedition is being identified by Fromont.
❖ Shallow water sponge fauna of the Jurien Bay Marine Park is presently being documented.

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4.6 Corals

Contributor
Jim Stoddart

Species group name and description

Scleractinia – stony corals

"Coral" is a widely used term in the public arena that applies to a variety of distantly related animal groups in the Phylum Coelenterata (jellyfish, hydroids, anemones, corals). In the scientific community it is generally applied to the Hexacorallia (hard corals) and the Octocorallia (soft corals). Here, the term is restricted to the members of the Order Scleractinia, which include those species that are the primary constructors of the physical component of coral reef habitats.

All coelenterates have the same general body plan, having a sac-like body cavity with one opening that serves as both mouth and anus. Corals are anemone-like animals that secrete a skeleton. Some corals are solitary, most seen on coral reefs are colonial. More information on corals can be found in Veron (2000) and Veron and Stafford-Smith (2002). For further reading on the relationships of coelenterates see Mather and Bennett (1993).

Status

All Scleractinia are listed by the Convention on International Trade in Endangered Species (CITES) as threatened by international trade under CITES Appendix II. This means that the import or export of corals and coral products is subject to permitting under Australia's *Environment and Biodiversity Conservation Act 1999.*

There is no state legislation in Western Australia or South Australia that specifically references corals. Under Western Australian legislation, corals within state waters are given protection through the *Wildlife Conservation Act 1950* (which generally prohibits the taking of fauna) and the *Fish Resources Management Act 1994* (which regulates the management and conservation of aquatic organisms and their habitat). No corals are declared as fauna in need of special protection under the *WA Wildlife Conservation Act*. Within South Australia the collection of intertidal organisms from reefs is prohibited under the Fisheries Act 1982.

Coral reef areas are given special consideration within guidelines issued under Part IV of the WA *Environmental Protection Act 1986* for environmental impact assessments. In particular, the EPA's Guidance Note 29 sets out criteria for the desired level of protection of Benthic Primary Producer Habitats, which include coral communities.

Marine protected areas declared in Western Australian under the *Conservation and Land Management Act 1984* or the *Fish Resources Management Act 1994* or in South Australia under the *National Parks &*

Wildlife Act 1972 or the *Fisheries Act 1982* can provide additional levels of protection to corals in specific areas.

Within Commonwealth waters of the SW marine region, the Great Australian Bight Marine Park Benthic Protection Zone provides a further capacity to manage the status of the group, although the area probably contains relatively few Scleractinia.

Habitat and distribution

Corals can be broadly divided into those growing on coral reefs or non-coral reefs.

- Coral Reefs: areas where coral is the current or past dominant benthic cover and has constructed the habitat;
- Non-coral Reefs: corals growing on hard bottom not derived from recent or past coral growth where they may be a sub-dominant part of the community (usually inferred from their sparse cover of the bottom).

In some situations, corals growing in the second habitat type may become sufficiently abundant that the physical and biological processes within local areas of the ecosystem become very similar to true coral reefs. In these areas, corals create and maintain a substantial amount of the habitat complexity and primary production.

Corals are extremely rare in estuarine waters or coastal waters influenced by riverine outflows – due to their inability to tolerate lowered salinity or terrigenous sediments.

Geographically, corals are predominantly tropical species, with a centre of biodiversity for the Indo-Pacific species typifying Australia contained within the tropics immediately to Australia's north. However, coral species can occur in colder climates and are spread around the entire Australian mainland coast, although with much lesser biodiversity below the Tropic of Capricorn. Coral reefs are rare below that Tropic, with some notable exceptions around islands like Western Australia's Houtman Abrolhos or New South Wales' Lord Howe. The former site is of great interest to studies investigating what physical or biological factors are most important in restricting the latitudinal limit of coral reefs (Johannes et al. 1983).

For a general discussion of the distribution, evolution, biology and habitat requirements of corals, see Veron (2000) or (1995).

Significance of the species group in the SW Marine Region

The northern extent of the SW marine region coincides loosely with the disappearance of abundant and diverse coral from coastal habitats. To the South of Shark Bay, abundant corals occur predominantly around offshore islands, with corals at inshore sites occurring in very isolated patches, usually of only a few species. Figure 4.6.1 provides a pictorial representation of the decrease in coral diversity (both inshore and offshore) with increasing latitude in the planning area.

The corals and coral reefs of the Houtman Abrolhos Islands (28°S – 29°S) and Rottnest Island (32°S) have been relatively well studied, but corals in other parts of the SW marine region are known only from limited studies of specific species. The most comprehensive overview of the distribution of corals off the Western Australian component of the SW marine region may be found in Veron and Marsh (1988) and a discussion of the influence of the Leeuwin Current in maintaining the distribution of reefs in this area in Hatcher (1991).

To date, studies and understanding of the corals of this area concentrate on the shallow water areas in State Waters. Within the much deeper Commonwealth waters of the SW marine region little is known of the distribution of corals. Some surveys of these deeper communities have commenced as part of studies for permits for oil and gas leases and as part of a CSIRO study undertaken to support planning for this Regional Marine Plan but published studies are lacking thus far.

Corals form a very minor localised component of the benthic fauna of the SW marine region or the adjacent State waters, outside of the island habitats mentioned. Within the planning area, corals are not known to provide any significant ecological value. Their potential to provide recruits to the shallower areas where corals are more at risk (see Impacts/Threats) is unknown.

Within adjacent State waters, corals are significant in small areas in providing coral reef habitat, in wider areas for divers to enjoy and to some extent provide an economic benefit through the Marine Aquarium Fishery. The latter is a small but statewide fishery managed by the Western Australian Department of Fisheries which landed around 3.3 tonnes of coral in 2003-4 in addition to many other species targeted for the aquarium trade (Penn et al. 2005).

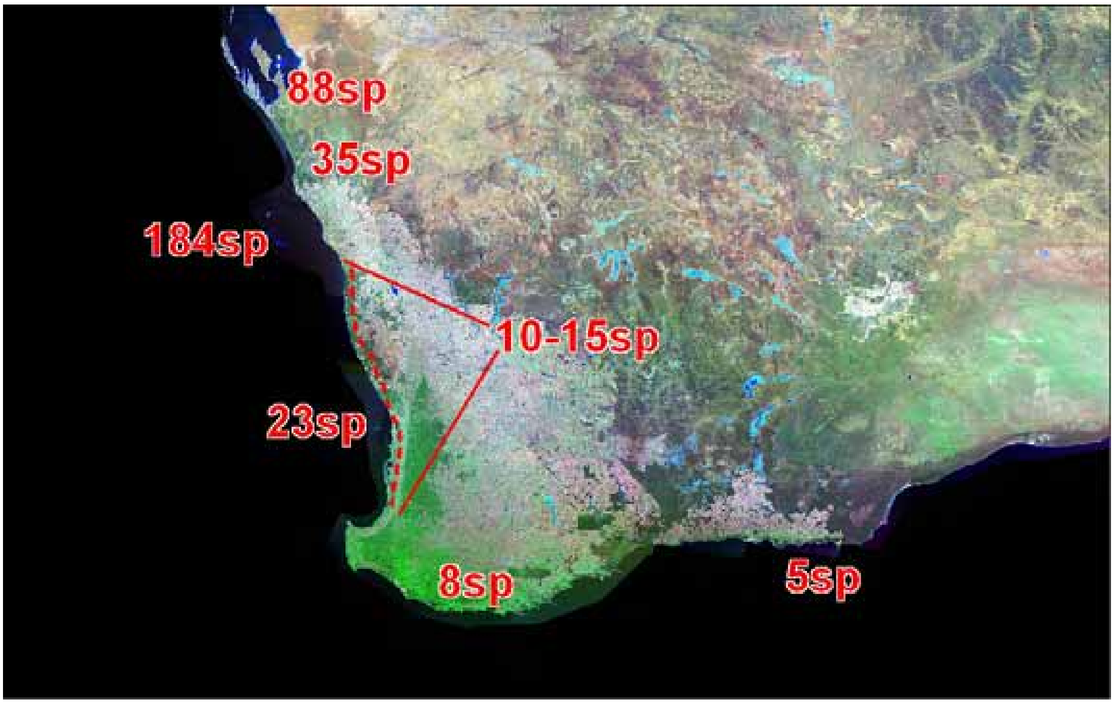

Figure 4.6.1 Decreasing numbers of coral species with increasing latitude. Data from Veron & Marsh 1988. Offshore sites represent (from north to south) the Abrolhos Islands, Rottnest Island and the Recherche Archipelago.

Impacts/threats

There is no current knowledge of the form or level of threat that may be present for corals in this area. The only potential impacting processes would be deep-water trawls or physical impacts of oil or gas developments and neither are likely to be significant at present. Although deepwater trawling has largely been focussed in the SE Marine Region, there are small deepwater trawl fisheries spread across the SW Marine Region. Their impact on deepwater corals appears to be small but has not yet been clearly determined. Given the vulnerability of deepwater corals to trawl damage, it is too early to conclude that there is little or no credible threat to deepwater corals in the SWMR

Within the adjacent State waters, threats to corals would include nearshore coastal development (although corals are rare in the nearshore areas), bottom-trawling, land-based pollution sources and global warming. The greatest interaction of human activity with corals in this area probably occurs with lobster fishing activity around the Houtman Abrolhos Islands (Webster et al. 2002).

Current indications are that the take of coral by the Marine Aquarium Fishery is sustainable and has not led to perceptible impacts (Penn et al. 2005).

Information gaps

The inventory of coral species present in the SW marine region is likely to be incomplete at present. There have been few surveys for corals in this area and the actual distribution of coral species here is speculative at present. The potential role of deep water coral communities or populations to act as genetic reservoirs for their relatives in shallower waters which may be prone to the impacts of global warming is intriguing but without any factual evidence for this area.

In general any studies of the distribution, abundance and taxonomy of these deep-water corals will provide rapid advancement in our ability to assess their importance.

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4.7 Infauna

Principal contributors
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Species group name and description

Infauna is the collective name given to the invertebrate fauna that exist within, or are closely associated with, marine sediments (Petersen, 1913). Infauna are generally classified into three nominal size groups using graded geological sieves. Macrofauna are those organisms that do not pass through a 0.5 mm screen; meiofauna (also called interstitial fauna) are those organisms that pass through a 0.5 mm screen, but do not pass through a 0.062 mm screen; while microfauna refer to any fauna that pass through a 0.062mm screen (Mare, 1942). Common macrofauna include polychaete worms, bivalves, amphipods and decapods. Meiofauna typically include nematodes, copepods, and turbellarians, while the majority of microfauna are ciliate protozoans (Gray, 1981).

Infauna are thought to form one of the richest species pools in the oceans, and perhaps earth, however accurate estimates of species numbers are difficult because few sedimentary habitats have been well sampled (Snelgrove, 1999). Presently the number of described macrofauna is about 87,000, but it has been estimated that the total global number of species is approximately 725,000. The number of described meiofauna is 7000, with 100 million species the estimated total (Snelgrove et al., 1997).

Most infauna are sedentary or have limited movement and are therefore reliant on organic matter sinking down from surface waters for nutrition. Two primary feeding guilds (suspension and deposit feeders) are represented within the group (Sanders, 1958). Suspension-feeding infauna such as fan-worms and clams are able to trap food particles close to the bottom, whilst deposit-feeding infauna like heart urchins rely on particles that have already settled (Levinton, 1972).

Status

It is difficult to assess the conservation status of marine infaunal species because only a small proportion of the fauna has described, and very little is known about their distributions. Presently, no infaunal species are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as threatened, endangered or rare. In addition, none are listed by the *Convention on International Trade in Endangered Species* (CITES) as threatened by international trade. All benthic fauna, including infauna, are protected from human impacts within the Great Australian Bight Marine Park (DEH, 2005), but infuana are unprotected in those commonwealth waters comprising the rest of the SW marine region.

Habitat and distribution

Most infauna live between sand gains in the top few centimetres of the seafloor (within the oxygenated sediment), but some may inhabit burrows and tubes that extend more than 2.5 m below the sediment surface (Pemberton et al., 1976). A number of macrofauna (eg crabs and shrimps) have the ability to move in and out of the sediments to forage, but most meiofauna and micofauna reside in the interstices of the sediment grains for much of their adult lives (Gray, 1981).

Sediment structure is an important influence on the distribution, abundance and community composition of benthic infauna. Strong correlations between sediment grain size and biotic composition have been previously demonstrated in many estuarine and shallow coastal environments (Sanders, 1958; Dayton, 1984; Coleman et al., 1997; Snelgrove, 1999) although grain size may be positively or negatively correlated with species diversity. In part, this may reflect differences in the range and diversity of sediments examined, but may also reflect the effects of other factors, in particular hydrodynamic processes, which affect the distribution of both sediments and fauna (Snelgrove and Butman, 1994). Other factors known to affect the distribution of infauna include depth (Gray, 1981), food availability (Pearson and Rosenberg, 1987) larval supply (Ramey and Snelgrove, 2003), disturbance (Hall, 1994), predation (Thrush, 1999) and competition (Peterson and Andre, 1980).

Several generalisations explaining distribution patterns in marine sedimentary diversity have been proposed in recent years following comparative studies in different habitats. A number of studies have observed latitudinal gradients in shallow water infauna, with decreasing diversity towards the poles (Sanders, 1968; Roy et al., 1998; Attrill et al., 2001). It has also been suggested that tropical continental slope environments are more diverse than their temperate and polar counterparts (Poore and Wilson, 1993; Rex et al. 1993). Other studies have found that species diversity is lowest in physically extreme environments, such as estuaries (Sanders, 1968) or in areas that are subject to organic enrichment and pollution (Pearson and Rosenberg, 1978).

Significance of infauna in the southwest planning area

Approximately 70% of the earth's seafloor, and almost all of the seabed in the SW marine region, is composed of soft unconsolidated sediments (Snelgrove, 1999; Heap et al., 2005). Despite the prevalence of these habitats in the SW region, virtually nothing is known about the composition or distribution of the regions sedimentary infauna (Gary Poore, MoV, *pers. comm.*). This is largely because most of Australia's offshore benthic collecting efforts have been biased towards sampling organisms inhabiting the sediment surface (ie epifauna species such as corals, sponges and ascidians) and have not employed methods that capture the greater diversity of organisms living within the sediments (CoML, 2005).

Infaunal organisms play an important functional role in many marine ecosystem processes. They contribute to the biochemical cycling of nutrients (Rosenberg, 2001; Levin et al., 2001), provide habitat structures for other organisms (Thrush et al., 2001; Reise, 2002) and serve as an important food source for demersal fish (Parry et al., 1995; Bulman et al., 2001) and other tertiary consumers including seabirds (Ambrose, 1985; Skagen and Oman, 1996), whales (Oliver and Slattery, 1985) and seals (Pauly et al., 1998). Ecosystem changes resulting from shifts in the composition and distribution of sedimentary infauna are therefore predicted, but are rarely reported in the literature (Pinnegar et al., 2000).

One of the largest infaunal organisms represented in the SW region, the giant crab *Pseudocarcinus gigas*, is the basis of a significant commercial fishery. In 2002/03, 18.5 tonnes of this crab were harvested in the South Australian Fishery at an estimated value of $0.45 million; with most of the catch being exported live to southeast Asian markets (DEH, 2004). Giant crabs (*Pseudocarcinus gigas*) are endemic to southern Australian waters and are distributed throughout much of the SW planning region (Kailola et al, 1993). While they occur at depths ranging from 20m to 600m, the highest population densities are found at the edge of the continental shelf in depths of approximately 200m. The shelf break is also where they are actively targeted by commercial fishers using baited pots. The direct and indirect effects of giant crab fishing on the ecology of the SW planning region are largely undetermined (DEH, 2004). Potential impacts may include direct disturbances to benthos, the removal of non-target species, and entrapment and entanglement of seals, whales, dolphins and turtles. Indirect effects may include changes to the population structure of motile invertebrates and fish that scavenge on discarded baits or depend on giant crabs as a source of food.

Impacts/threats

Measurements of change in infaunal communities have been widely used in identifying and monitoring man-made impacts on the sea. Macrofauna, for example, have proven to be useful in assessing the environmental impacts of coastal discharges (Poore and Kudenov, 1978; Anderlini and Wear, 1995; Ashton and Richardson, 1995) and chemical contamination of sediments (Coleman, 1993; Ward and Hutchings, 1996). This is largely because infaunal organisms are relatively non-mobile and tend to integrate the effects of pollutants over time (Warwick, 1993). This lack of mobility make infauna particularly vulnerable to direct physical disturbances, such as those from trawls and dredges, that alter sedimentary structure (Hall, 1994).

The impacts of trawls and dredges are often considered to be similar as both are towed across the surface sediments where they are likely to damage organisms near the surface. Several studies (Caddy, 1973; de Groot 1984) have described changes to the topography of the seabed caused by fishing gear, and these suggest that fishing gear penetrates 10 to 30 mm into the sediment depending upon the weight of the gear and the softness of the sediments. Typically, trawls and dredges dislodge attached epifauna and flatten existing topographical features (Jennings and Kaiser, 1998). This action disrupts sediment stratification, destroys burrows and other structures and reduces the amount of suitable niches for infauna (Ponder *et al*. 2002). Significant mortalities of infaunal species and modifications to the benthic community structure are widely reported direct results of trawling and dredging impacts (Jennings and Kaiser, 1998). Such changes may, in turn, have important effects on ecosystem function (Thrush and Dayton, 2002). Fisheries with the potential to impact infauna in the SW planning region include; in south Australia - the Great Australian Bight Trawl Fishery (GABTF), and the West Coast Prawn Fishery; in Western Australia – the South West Trawl, Abrolhos Islands and Mid-west, and South Coast Trawl Fisheries which target western king prawns and scallops (see McLeay this publication).

Work on benthic communities in the Minerva gas field, Port Campbell, Victoria, has shown that drilling operations can affect community structure of infauna, reducing abundance of some species by 88% for a few months, with modified communities persisting near the well head up to 11 months after exploratory drilling (Currie and Isaacs, 2005). In the SW marine region, the Great Australian Bight has a history of petroleum exploration and further exploration of the GAB is anticipated in the near future (McLeay et al., 2003). Although the GAB Benthic Protection Zone is protected from bottom trawling, mining and exploration may be approved on a case-by-case basis by the Governor General (DEH, 2005).

A range of other factors have the potential to modify the marine sedimentary biodiversity of the SW marine region. Coastal pollution such as agricultural runoff, sewage outfalls and industrial waste are widely understood to affect benthic infauna and typically lead to reduced biodiversity in the impacted area (Pearson and Rosenberg, 1978). Toxins produced by harmful algae can bioaccumulate to lethal levels in molluscs, crustaceans, polychaetes and echinoderms, and cause the loss of herbivorous and predatory species (Williamson et al, 2002). Global warming and associated changes in ocean circulation represent another more pervasive threat, as this process the capacity to affect productivity, larval transport, and the community structure of infauna throughout the world's oceans.

Information gaps

Large gaps in the knowledge of infauna worldwide arguably reflect preferential marine research interests in fish, a shortage of taxonomic expertise and a lack of funding. Regardless of cause, it is clear that the state of knowledge is poor for much of the SW region of Australia (Ocean Biogeographic Information System query). A recent review of marine invertebrates by Ponder et al. (2002) highlights this fact, and notes that most of our taxonomic understanding stems from shallow coastal waters near the large population centres of the SE Australia. In contrast, most other parts of the Australian marine environment are poorly sampled for infauna, especially the deep-sea.

Key references and current research

- The shelf off Western Australia is presently being investigated by the RV *Southern Surveyor* (voyage SS10/2005), with collection of infauna one of the voyage objectives (Williams and Kloser, 2005).
- The South Australian Research and Development Institute (SARDI) is engaged in ongoing research into the performance of the Great Australian Bight Marine Park. A cross-shelf survey scheduled for June 2006 will include an assessment of the composition and distribution of sedimentary infauna.
- Other studies in South Australian coastal waters are addressing infaunal biodiversity patterns and processes in tidal flats (Sabine Dittmann, Flinders University), and the use of infauna in monitoring impacts effects of marine aquaculture on benthos (Sharon Drabsch, SARDI)
- Many museums and universities have collections that can be viewed to help in the identification of infaunal organisms. The Australian Museum website (www.austmus.gov.au/index.cfm?) has numerous links to current research and literature, and is a good place to start.
- Other useful gateways to infaunal research in southern Australia include the Museum of Victoria website (www.museum.vic.gov.au/collections/sciences/marine.asp), the South Australian Museum website (www.samuseum.sa.gov.au/orig/science.htm), and the Western Australian Museum (museum.wa.gov.au/collections/natscience/naturalscience.asp).

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4.8 Zooplankton

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Species group name and description

Zooplankton cover a diverse range of drifting planktonic animals, some of which spend their entire lives in the plankton (termed holoplankton) and some which are planktonic only in their larval stages (meroplankton). Most marine invertebrate taxa include zooplanktonic representatives. Zooplankton above approximately 20 microns in size are numerically dominated by crustaceans (mainly copepods, cladocerans and decapods), but gelatinous zooplankton (salps, ctenophores, medusae and siphonophores) may also be extremely abundant at times. Other groups include pteropods, bryozoans, chaetognaths, appendicularians, and the larvae of molluscs, echinoderms and many other benthic organisms. Euphausiids (and other schooling crustaceans are sometimes grouped with zooplankton (see Ritz et al. 2003) but are more often classed as micronekton because of their stronger swimming abilities. We have included the euphausiids here.

Data available

The major zooplankton taxonomic groups likely to be found in the eastern GAB can be inferred from the more broadly distributed or cosmopolitan species in Dakin & Colefax (1940), Nyan Taw (1978), and Ritz et al (2003). This is necessary because there is no census of the zooplankton species of the eastern GAB or of the SW marine region as a whole. There is little information on distribution, abundance, community structure, species or measures of biodiversity in the Great Australian Bight (GAB) (133-138E, 31.5-37S) (see summary of existing data in Table 4.8.1). Zooplankton vertical tow samples from the annual February-March sardine surveys from 1995 to 2005 have been collected and analysed for displacement volumes. The most detailed information on distribution, abundance, broad taxonomic composition and seasonality of zooplankton is available from analyses of vertical net tows collected from the 1999 and 2000 annual sardine surveys (van Ruth and Ward, unpublished manuscript and Figure 4.8.1). Summaries of zooplankton and micronekton samples collected on a CSIRO cruise to the Bluefin Tuna fishing grounds of the eastern GAB in 1998 using a fine mesh zooplankton net, bongo net, and the opening-closing MIDOC trawl are available (Kloser et al. 1998), but the results have not been fully published. A less detailed summary of 8 zooplankton samples (collected with bongo net) and 3 micronekton samples (collected with Isaacs- Kidd midwater trawl) from a Japanese cruise in 1998 was presented by Young et al. (1996) for a cross-shelf transect in the same area as sampled by Kloser et al. (1998).

The following summary includes excerpts from material provided by Alan Pearce (CSIRO Marine and Atmospheric Research) during collaborative investigations with the Western Australian Department of Fisheries (Gaughan et al., submitted). Little is known about the distribution, abundance or species diversity of zooplankton in the southeastern Indian Ocean or along the Western Australian continental shelf. In an early review of zooplankton surveys in Australian waters, Tranter (1962) reported that there were only 17 observations off Western Australia, all taken in July-August 1961, and 45 open-ocean observations in the "south-East Indian" oceanic region (which he defined as from 30°S to Tasmania, and so included the south coast of Australia. Zooplankton coverage was greatly improved during the International Indian Ocean Expedition (IIOE) in the early 1960s (Zeitzschel 1973), but again little work was undertaken directly off the Western Australian coast. The Australian contribution to the IIOE focused on repeated sampling along the 110°E meridian between 10° and 32°S; Tranter and Kerr (1969) and Tranter (1973) showed that there were large variations in zooplankton biomass (*inter alia*) in the top 200 m of water both seasonally and by latitude, with the overall trend decreasing southwards and biomass peaks occurred in spring and late summer (Tranter 1973). However, there was no analysis of particular species. Distribution of certain species of amphipods along the 110°E meridian were later linked to water mass distribution (Tranter 1977).

More recently, zooplankton sampling has been carried out along the southwestern Australian continental shelf but has been somewhat sporadic and largely designed to support studies of specific areas related to coastal management. Particular interest has focused on the coastal embayments of Cockburn and Warnbro Sounds, just south of Fremantle (Environmental Resources of Australia 1971, Department of Environmental Protection 1996, Helleren and John 1997) and in nearshore waters for habitats at different levels of exposure by wind and waves (Seidel 2000). Estuarine zooplankton has been described in various levels of detail for several systems in southwestern WA (e.g. Lukatelich 1987, Rippingale 1987, Hodgkin and Clark 1988, Gaughan and Potter 1994, 1995).

Fletcher et al. (1996) provides displacement volumes of zooplankton sampled vertically from 0-70 m depth with 500 µm mesh nets at stations on the shelf between Kangaroo Island and Perth in July and December 1994 . Vertical sampling in the early to mid-1990s has also provided unpublished displacement volumes of zooplankton for shelf waters from inshore waters (~20 m depth) to the shelf break in the regions of Albany, Bremer Bay and Esperance off southern WA coast and along the lower west coast between approximately Perth and Cape Leeuwin (Fletcher et al. 1996). This data set continued from the mid-1990s to present (2005), but with 300 µm mesh nets (see Table 4.8.1b). Limited vertical and depth-stratified horizontal plankton tows have been taken from north of Perth to the northern limit of the SW marine region during ichthyoplankton surveys. Multiple surveys have thus been undertaken in several areas off the southwestern WA coast with a focus on collecting ichthyoplankton data, but the taxonomic composition of zooplankton for only few of these samples has been investigated. Gaughan and Fletcher (1997) examined the carnivorous macrozooplankton taxa (mainly siphonophores and chaetognaths) of some of the earlier winter and summer samples from southern WA. Gaughan et al. (submitted) sampled macrozooplankton along an inshore-offshore transect near Perth so as to objectively investigate which of several biological and physical factors were influencing the zooplankton communities.

Figure 4.8.1 Map showing distribution of summer and winter zooplankton displacement volumes from selected sardine surveys (from Ward et al., unpublished manuscript). There are no comparable dry weight data.

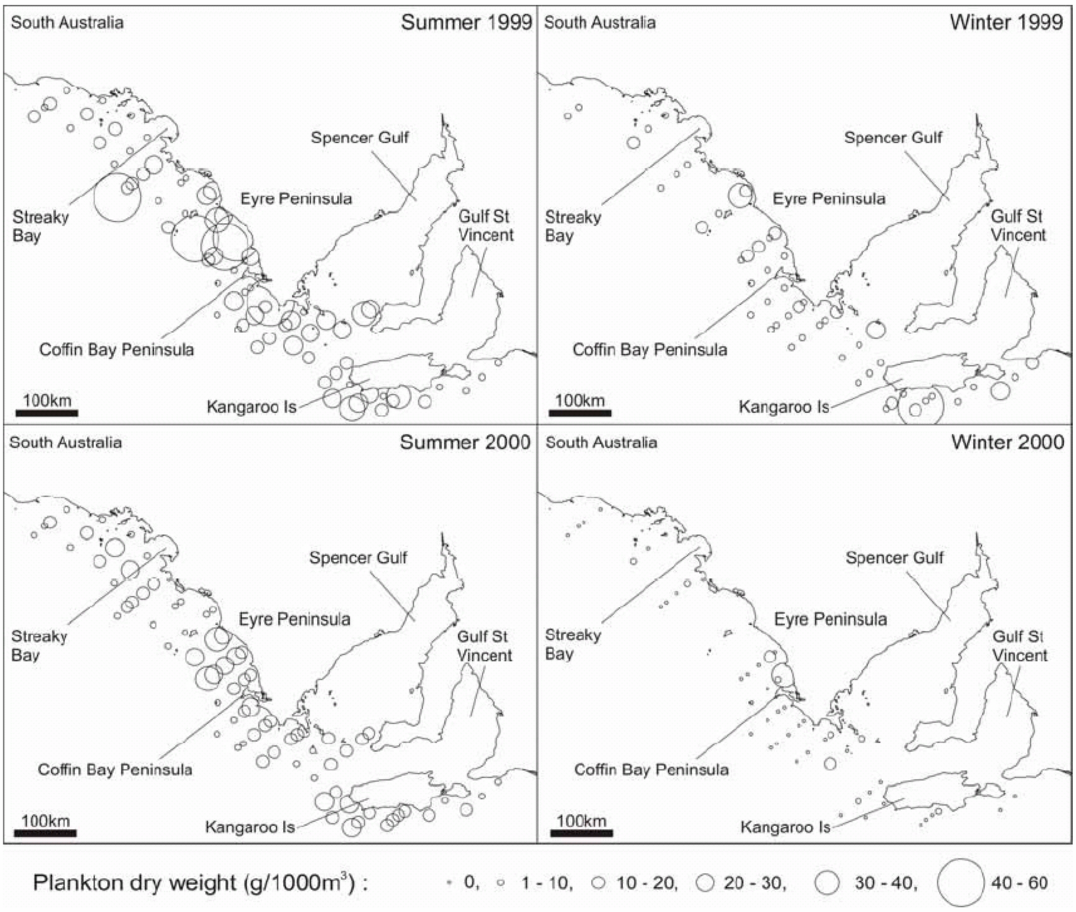

Table 4.8.1a: Summary of zooplankton and micronekton data available for the Great Australian Bight (GAB) and eastern GAB. See areas column for the latitudes and longitudes.

Area	Dates/ cruise	Gear	Depths	Number of samples	Analyses	Reference
Central GAB (124.5-127.8°E)	Dec. 1965	Norpac net 350 µm	Near bottom (50-144 m) to surface	4 @ 0-50 m, 8 @ 51-100 m, 3 @ 101-150 m bottom depth	Bulk biomass (wet weight per m-^{3})	Motoda et al. (1978)
Central & eastern GAB (130-134°E)	Feb. 1999	Bongo net 333 µm	200 m or near bottom horizontal tow	3 inshore 1 shelf 4 offshore	Biomass (wet weight by coarse taxonomic groups)	Young et al. (2000)
Central & eastern GAB (130-134°E)	Feb. 1999	Isaacs-Kidd midwater trawl	Not stated	1 inshore 1 shelf 1 offshore	Biomass (wet weight by coarse taxonomic groups)	Young et al. (2000)
Eastern GAB (134-138.5°E)	Feb/ Mar & July1999 Feb/ Mar & July 2000	0.255 m diameter Calvet nets 300 µm	10m above bottom, or 70 m to surface in 20 to 120 m depths.	77 summer 1999, 77 summer 2000, 48 winter 1999, 48 winter 2000	Seasonal biomass (volume m^{-2} by coarse taxonomic groups)	van Ruth & Ward, unpublished manuscript
Eastern GAB (132-138.5°E)	Feb/ Mar 1995-2005	0.255 m diameter Calvet nets 300 µm	10m above bottom, or 70 m to surface in 20 to 120 m depths.	200+ stations in each year	Bulk biomass (volume m^{-2})	Ward et al. sardine spawning biomass reports

Table 4.8.1b: Summary of oceanic plankton sampling conducted by the WA Department of Fisheries. Vertical tows are to a depth of 70 m, or to within 2 m the bottom in water shallower than 70 m. Zooplankton analyses are limited to bulk biomass (displacement volume). Inshore marine and estuarine plankton samples are not included.

Area	**Date**	**Gear**	**Depths**	**n**
Albany	All months 1989	500µm	Surface	116
WA south coast 117.93, 35.03	December 1991	500µm	Oblique	47, 27
WA south coast 116.75, 34.97 – 119.43. 34.40	July 1992	500µm	Vertical	110
WA south coast 117.43, 35.08 - 122.45, 33.42	January 1993	500µm	Vertical	115
WA south coast 114.68, 35.00 - 123.15, 34.00	July 1993	500µm	Vertical	248
Albany 117.93, 35.03	**JULY 1993**	Vertical 300µm & 500µm	Vertical	89
WA south – west coast 121.96, 34.85 – 115.75, 32.05	January/February 1994	500µm	Vertical	175
Esperance 121.96, 34.85	April 1995	300µm bongo	Vertical	105
WA west coast 115.34, 31.73 – 115.55, 33.5	August 1996	300µm bongo	Vertical	96
Adelaide – Fremantle 138.6, 34.9 - 115.75, 32.05	July 1994	1000µm, 300/500µm bongo	Surface & depth stratified. Vertical	583
Adelaide – Fremantle 138.60, 34.92 - 115.75, 32.05	December 1994	1000µm, 300/500µm bongo	Surface & depth stratified. Vertical	233
WA mid-west coast 28 – 29 S	Jan. – March 1996, February 1997	500µm bongo	Vertical	450
WA west coast 22, 114 – 115, 31.5	March 1996	500µm bongo	Vertical	65
WA lower west coast 115.68, 31.55 - 115.75, 32.05	March 1996	300µm bongo	Vertical	96
WA south coast 115.15, 34.30 – 119.43, 34.40	June/July 1997	300µm bongo	Vertical	188
WA lower west coast 115.00, 33.99 – 114.97, 30.32	July/August 1998	300µm bongo	Vertical	247
WA south – lower west coast 123.15, 34.00 - 115.68, 31.55	May, June, July, August 1999	300µm bongo	Vertical	1195
WA lower west coast 115.00, 33.52 - 115.68,	July 2000	300µm bongo	Vertical	458

31.55				
WA south coast 117.88, 35.02- 119.43, 34.40	July 2001	300µm bongo	Vertical	425
WA south coast 120.12, 33.85 – 124.13, 33.83	January 2002	300µm bongo	Vertical	215
WA lower west coast 115.03, 33.68 – 115.43, 31.27	July/August 2002	300µm bongo	Vertical	454
WA south coast 117.6, 35.13 – 120.12, 33.85	July 2003	300µm bongo	Vertical	275
WA south coast 120.12, 33.85 – 124.13, 33.83	February/March 2004	300µm bongo	Vertical	181
WA lower west coast 115.03, 33.68 – 115.68, 31.55	July 2004	300µm bongo	Vertical	409
WA south coast 120.12, 33.85 –117.6, 35.13	July 2005	300µm bongo	Vertical	220

Assumptions and uncertainties

The paucity of basic structural information on zooplankton communities in the eastern GAB means that inferences about function need to be drawn from studies in adjacent areas, like the SE region, that are better studied. A basic understanding can also be gained by gleaning relevant information from the substantial international literature devoted to the biology and ecology of zooplankton.

The biophysical studies of the pelagic environment off southwestern Australia (see below) will contribute to a better understanding of zooplankton across the entire SW marine region. Due to changes in the biophysical environment through the marine region it is not clear if, and to what extent, localized studies can be extrapolated to the entire region. For example, Ward et al. (2005) have demonstrated that higher productivity associated with upwelling off South Australia leads to higher growth rates of larval pilchard, *Sardinops sagax*, than was found by Gaughan et al. (2001a) for the broader region between Kangaroo Island and Albany. Thus, although similarities can be inferred for some aspects of zooplankton ecology across broad regions (e.g. species composition, energy flow paths), care must be taken when attempting to generalize or extrapolate results (e.g. zooplankton abundance, energy flow rates).

Status

Zooplankton are not currently exploited in any way and can be regarded as virgin biomass.

Habitat and distribution

From a study of southeastern Australian zooplankton (Ritz et al. 2003) we can safely assume that a number of the cosmopolitan copepod species will be found in this region. These can further be divided into species that are more likely to be found on the shelf as opposed to in estuaries. Species likely to occur in the SW marine region are listed in Table 4.8.2. Note that this table is indicative only and scores of other species, particularly of copepods, will also occur.

The studies of Cockburn and Warnbro Sounds (and nearby inner shelf waters) showed that the zooplankton communities were dominated by calanoid copepods, cladocerans and protozoa (mainly radiolaria), and that densities were higher within the nearshore Sounds than on the continental shelf (DEP 1996). This study concluded that the zooplankton succession off Perth is generally characterised by low abundances in winter, a rapid increase in cladoceran numbers during summer; and abundant cladocerans and copepods in autumn (DEP 1996). A study of zooplankton adjacent to the shore near and south of Fremantle found that densities were also highest in summer, declined in autumn and were lowest in winter; the number of taxa, however, displayed a reverse trend with highest diversity in autumn and least in summer (Siedel 2000).

Zooplankton concentrations in estuaries can far exceed those found in marine waters. As for the eastern GAB, estuarine zooplankton is less diverse then for marine waters and contains a mix of estuarine and marine species. The dominant estuarine calanoids in southwestern WA are *Gladioferens imparipes* and *Sulcanus* *conflictus*. In the lower Swan River (Perth), sampling with 500 μm nets indicated that similar groups to those found in Cockburn Sound (above) dominated the zooplankton; concentrations were highest in summer and autumn, when the zooplankton community was dominated by marine species (Gaughan and Potter 1994). Other abundant groups included *Acartia (Acartiura)* sp., *Oikopleura dioica*, *Lucifer* sp. and the zoea of estuarine crabs. The only comprehensive study of estuarine zooplankton which included sampling throughout out the system and using net of sufficiently fine mesh (53 μm) was undertaken in Wilson Inlet, where densities of copepods, tintinnid protozoans, rotifers, polychaete larvae and mollusc each exceeded 100,000 m^{-3} in the autumn-summer period (Gaughan and Potter 1995).

Gaughan and Fletcher (1997) found substantial seasonal changes in the community composition (abundance and diversity) of macrozooplankton off southern WA between Albany and Esperance. They suggested that the Leeuwin Current may play an important role in transporting warm-water species to the south coast of WA, supporting Markina's (1976) finding that zooplankton in the GAB were mainly of tropical origin. Gaughan et al. (submitted) have more recently reached a similar conclusion for shelf waters off Perth. Importantly, this study has demonstrated some strong similarities in the seasonality of the shelf zooplankton between Perth and the Albany-Esperance region, a distance of over 700 km. Gaughan et al. (submitted) provides the first attempt to relate zooplankton variability to environmental variables (salinity, temperature, chlorophyll concentration, strength of Leeuwin Current, location on shelf) in shelf waters off southwestern WA. Statistical modeling generally found a combination of factors, frequently with non-linear relationships, influenced zooplankton variability. However, the dominant factors were location on the shelf (distance offshore) and the strength of the Leeuwin Current. Given the broad similarity in seasonal behaviour of the zooplankton community between Perth and Albany-Esperance, the results of the study off Perth indicates that the Leeuwin Current imposes a major effect on zooplankton through a significant part of the SW marine region. However, the mechanism of this influence has not been determined. Nonetheless, as Ridgway and Condie (2004) have now established that water originating in the Leeuwin Current reaches eastward to western Tasmania, and thus flows through the entire SW study region, this mesoscale current may also influence zooplankton communities through the entire SW marine region. The ability for the eastward flowing current to passively transport larval pilchard from Esperance to the eastern GAB (Gaughan et al. 2001b) implies that zooplankton taxa communities may at times have relatively direct links across the entire GAB; differences through the SW marine region can, however, be expected to reflect localised biophysical dynamics including the gradual eastward weakening of the Leeuwin Current and the presence of periodic upwelling off the Eyre Peninsula.

Table 4.8.2 More abundant zooplankton likely to occur or known to occur in the SW marine region from Kangaroo Is. to the central GAB. References given are those most relevant to distribution in the SW marine region.

Taxonomic group	Species	Habitat	Known occurence	Selected references
Copepods	*Calanus australis*	Epipelagic, inshore, shelf and oceanic	SE Australia, Tasmania, NZ, subantarctic	Dakin & Colefax 1940
	Nanocalanus minor	Epipelagic, inshore, shelf and oceanic tropical & subtropical	SE Australia, Tasmania, NZ	Dakin & Colefax 1940
	Acartia danae	Epipelagic, inshore, shelf and oceanic	SE Australia, Tasmania, NZ,	Dakin & Colefax 1940
	Acartia tranteri	Estuarine, inshore, shelf and oceanic	SE Australia, Tasmania, NZ,	Dakin & Colefax 1940
	Centropages australiensis	Epipelagic, inshore, shelf and oceanic	SE Australia, Tasmania, WA	Dakin & Colefax 1940, Gaughan & Potter 1994
	Temora turbinata	Estuarine, epipelagic to mesopelagic tropical to temperate	Indian and Pacific Oceans, Tasmania, WA, NZ	Nyan Taw 1978, Gaughan & Potter 1994
	Clausocalanus ingens		Cosmopolitan	Nyan Taw 1978
	Paracalanus indicus (also reported as parvus)	Estuarine, inshore, shelf	WA	Dakin & Colefax 1940, Gaughan & Potter 1994
	Gladioferens pectinatus *Gladioferens imparipes*	Estuarine and inshore	SE Australia, Tasmania WA	Dakin & Colefax 1940 Gaughan & Potter 1994
	Sulcanus conflictus	Estuarine	SE Australia, Tasmania, WA	Dakin & Colefax 1940 Gaughan & Potter 1994
	Labidocera cervi	Epipelagic inshore and coastal	SE Australia, Tasmania, WA, NZ	Dakin & Colefax 1940 Gaughan & Potter 1994
Decapods	*Lucifer hanseni*	Coastal	SE Australia, Tasmania, WA	Nyan Taw 1978 Gaughan & Potter 1994
Cladocerans	*Evadne* spp.	Coastal & oceanic	Cosmopolitan	Ritz and Hosie 1982

	Podon spp.	Coastal	Cosmopolitan	Gaughan & Potter 1994
	Penilia spp.	Coastal & estuarine	Cosmopolitan	
Euphausiids	*Nyctiphanes australis*	Coastal	SE Australia, central SA, Tasmania, NZ	Ritz and Hosie 1982
Scyphozoans	*Aurelia* spp.	Coastal & estuarine	Temperate	Ritz and Hosie 1982
Ctenophores	*Beroe* spp.	Coastal	-	Ritz and Hosie 1982
Annelid, mollusc & echinoderm larvae	Various	Coastal	-	Ritz and Hosie 1982
Chaetognaths	*Sagitta* spp.	Estuarine, inshore, coastal & oceanic	Cosmopolitan	Ritz and Hosie 1982
Salps	*Thalia democratica*	Coastal	Comopolitan	Ritz and Hosie 1982
Appendicularians	*Oikopleura* spp., *Fritillaria* spp.	Coastal & estuarine	Cosmoploitan	Ritz and Hosie 1982

Basic zooplankton distribution data for the eastern GAB (132-138.5E, shelf waters in the upper 70 m, out to ~200 m contour) based on displacement volume is provided in van Ruth and Ward (unpublished manuscript). Zooplankton volumes were up to 4 times higher in summer than in winter. Higher densities were found to the west of the Eyre Peninsula, adjacent to areas with cooler temperatures and higher chlorophyll, suggesting that the zooplankton were more abundant on the margins of the regional upwelling centres (Kämpf et al. 2004, McClatchie and Ward, in press) in this part of the GAB (van Ruth and Ward, unpublished manuscript). Current data suggests that zooplankton (collected with a 300 μm net) are dominated by copepods and cladocerans, but that there are marked seasonal differences in the relative composition of the community between summer and winter (Table 4.8.2).

Table 4.8.2 Relative abundance of broad taxonomic groups of zooplankton in the eastern GAB based on summer and winter samples from sardine surveys in 1999 and 2000 (compiled from van Ruth and Ward, unpublished manuscript)

Taxa	**Summer**	**Winter**
Copepods	39%	60%
Cladocerans	34%	24%
Chaetognaths, Appendicularians, Echinoderms, Gastropds, Decapods, Mysids & Thaliacians	26%	15%
Scyphozoans, Hydrozoans, Amphipods & Polychaetes	1%	1%

Significance of the species group in the southwest planning area

Since there are few studies of zooplankton in the SW marine region, we must infer their significance from studies in the SE region, and it is reasonable to assume that we expect some similarities with the SW marine region if the same species occur there. Often relatively few species numerically dominate the coastal or estuarine environments. *Calanus australis* may be very abundant in SE Australian coastal and oceanic waters. In estuaries, *Gladioferus pectinatus* can reach very high densities in

Victoria and Tasmania (10,000-90,000 m^{-3}), or *Acartia tranteri* and *Paracalanus indicus* may be numerically dominant.

While the ecological position of zooplankton in the SW marine region can be gleaned from the literature dealing with zooplankton communities elsewhere, such an approach would remain qualitative; a true understanding of the pelagic ecosystem of the SW marine region thus requires some quantitative assessments of the abundance of zooplankton and the rates at which zooplankton interact within the nutrient-phytoplankton-zooplankton (NPZ) cycle. Studies aimed at gaining a better understand the NPZ cycle in shelf waters of WA and how shelf waters interact with the Leeuwin Current and oceanic waters off WA are currently underway. Pearce et al. (submitted) has documented cross-shelf biophysical properties in the Perth region. This approach has now been expanded in a current study off Two Rocks, 50 km north of Perth, as part of the WA Strategic Research Fund for the Marine Environment (SRFME) (Keesing and Heine 2005). This study employs a transect running from 50 - 2000 m depth and includes what will be the most comprehensive documentation of copepod community structure (including species identification) in SW Australian shelf waters. Besides examination of the copepod fauna and other mesoplankton, spatial and temporal variability of the microzooplankton (e.g. the protozoan groups radiolarians and ciliates) is also under investigation.

Other studies relevant to investigating the NPZ cycle in shelf waters are currently underway off Albany and Esperance on the southern WA coastline. The NPZ cycle and copepod communities are also being investigated in the eddies that form from meanders of the Leeuwin Current off the west Australian coast. This work will be extended by further planned investigations of the NPZ cycle during the actual period of formation of these eddies.

Besides constituting a broad role in ecosystem functioning, zooplankton is crucial to fisheries production through providing food for larvae of all teleost species (e.g. Gaughan 1992) and many invertebrates and for a variety of planktivorous fish (juveniles and adults stages). The role of zooplankton in the diets of planktivorous fish in southwestern WA has received little direct study. Nonetheless, frequent unpublished observations indicate that copepods and diatoms form a key part of the diet of small pelagic fish including pilchards *Sardinops sagax*, anchovies *Engraulis australis* and the tropical sardine *Sardinella lemuru*. The proportions of zooplankton and phytoplankton in the diets of small pelagic fish appears to reflect the relative availability of these groups, although these fish can apparently also select larger prey, with *S. sagax* sometimes feeding exclusively on krill. Malseed (2004) undertook stable isotope analysis of *S. sagax* and co-occurring zooplankton in the Esperance region to establish the biochemical link and also found that the original source of nitrogen (nitrate verus N fixation or ammonium) for *S. sagax* can vary over relatively short distances (<100 km). Goh (1992) found that sandy sprat (*Hyperlophus vittatus*), an inshore small pelagic fish species, were planktivorous, but could switch between filter feeding and particulate feeding.

The cladoceran *Penilia* spp, which is very abundant in coastal waters over summer (Gaughan and Potter 1994, DEP 1996) is a seasonally important prey type for *H. vittatus* (Goh 1992) and is likely also important for *S. sagax* and *S. lemuru* when these species are present in inshore waters.

Zooplankton are also a primary source of food for baleen whales and whale sharks. Pygmy blue whales feed on deepwater schools of krill in the Rottenest Trench off Perth (Chris Burton, pers. Comm.) and may occasionally also do so off Cape Naturalist to the south. (see the description of Cetaceans in this report).

Effect of zooplankton on primary production

Copepods are important consumers of primary production (phytoplankton) and in some cases also detrital material (*Acartia tranteri*) in both estuarine and shelf waters (see Table 4.8.1). They may have a significant effect on primary production because of their abundance (*Calanus australis, Acartia tranteri, Paracalanus indicus*), coincidence of their breeding with the spring bloom of phytoplankton (*Calanus australis*), or by producing multiple broods year-round (*Acartia tranteri*). Observations made during the SA sardine surveys indicate that in summer, high densities of salps can occur at inshore stations in the eastern GAB. Although no measurements have been made, it is likely that the very high filtering rates of these gelatinous zooplankters will have a very significant effect on reducing primary production in the areas where they bloom.

Effect of zooplankton as predators

Invertebrate predation is an important source of mortality for larval fish, including sardines in other regions, and predatory copepods probably contribute to such mortality. In the region from KI to Esperance, some copepods are predatory (*Labidocera cervi*), but we do not know if they take larval fish. What is more likely is that some of the gelatinous zooplankters such as hydroids and ctenophores consume both fish eggs and fish larvae. This potential source of mortality on larval fish may influence recruitment success of pelagic fish, including sardine, but this has not been quantified at all in the region. Krill (*N. australis*) are omnivorous, and chaetognaths are voracious predators, so that both would contribute to mortality of larval fish.

Significance of zooplankton as food

Certain species (e.g. *Paracalanus indicus* and *Acartia tranteri*) are known to be important prey for small planktonic fishes (Kimmerer & McKinnon, 1985).
We do not at this time know which copepod species are exploited by which fish, although it is known that both sardines and anchovy eat zooplankton (and more likely are indiscriminate filter feeders on zooplankton where their selectivity is determined by their gill rakers).

Krill (*N.australis*) are known to be important prey for mackerel in the SE region (Young et al. 1993), and the abundance of krill appears to affect recruitment success of the jack mackerel (*Trachurus declivis*). This trophic link may also be important in the SW marine region, but we have no information. A similar trophic link might be expected for Australian salmon (*Arripes truttaceus*). Recruitment of salmon is related to environmental variability (see the section on climate variation in this report) but the mechanism could be mediated by the abundance of krill and other prey. *N.australis* are an important food source for blue whales in the SE region, and these whales move into the area around Kangaroo Is (see the Cetacean section, this report), so that krill resources in this area may also be exploited during those visits.

Impacts/threats

A feasibility study for exploring the possibility of exploiting the coastal krill, *Nyctiphanes australis*, which is the most likely target for a "zooplankton" fishery, in Tasmanian waters, concluded that exploitation was unlikely to be economically viable (Johnannes & Young1999). It seems reasonable to extrapolate Johannes and Young's (1999) conclusion to other southern Australian waters at this time.

Zooplankton communities will be affected by climate change. Changes in the distribution of water masses are expected to affect the distribution, abundance and species composition of zooplankton communities. El Niño impacts the southern shelf of Australia, and recent modelling work suggests that increased upwelling intensity occurs in the summer following an El Niño event (Middleton et al. submitted). This effect would influence the upwelling region off the western coast of Kangaroo Island. The models suggest that upwelled water appearing on the west coast of the Eyre Peninsula has its origin at 250-350 m off Kangaroo Island (McClatchie et al. 2006, Middleton et al. submitted) and so changes in upwelling at source would also be expected to impact the Eyre peninsula area. A preliminary analysis of zooplankton data from the sardine surveys indicates that El Niño may increase the biomass of zooplankton in the summer following the event, presumably by increasing the regional productivity mediated by upwelling. However, the evidence for this effect is very limited at present (see Section on climate variation, this report).

Given that (1) the strength of the Leeuwin Current is related to the SOI (e.g. Fang and Morrow, 2003) and therefore to El Nino and La Nina events (2) variability in the strength of the current influences the behaviour of meanders and eddies that interact with coastal waters, and (3) the Leeuwin Current affects nutrient and phytoplankton dynamics when associated with the shelf (Hanson et al. 2005 a, b, Twomey et al. submitted), any longer-term climactic changes may result in mesoscale changes in the NPZ cycle in the SW marine region. It is unrealistic to expect that such changes could be adequately quantified given the lack of current baseline data. Nevertheless, the propensity for change can be considered as a distinct possibility in the event of ongoing climate change. The development of alternative hypothetical scenarios would allow a better understanding of the potential impacts.

Information gaps

- There is very little information on zooplankton communities between Kangaroo Island and Esperance. Samples have been collected for the summer sardine survey covering the shelf of the eastern GAB (see Table 4.8.1), but little detailed analysis of species composition of no estimates of size structure was done. These samples currently represent an archived but unexploited scientific resource on the zooplankton of the region.
- There is very poor understanding of the distribution and abundance of important zooplankton groups (e.g. copepods, krill, gelatinous zooplankton) across the region. Broadscale knowledge of spatio-temporal variability in abundance of zooplankton is sparse, although some is currently being collected. Further data could be collected through examination of currently

available ichthyoplankton samples in both SA and WA. Knowledge of ecological flow within the NPZ cycle of the SW marine region has until recently been non-existent. Some research is currently focussing on the NPZ cycle in WA.

- The significance of zooplankton, including krill (nekton) in shelf and slope food webs has not been quantified in the SW marine region. There are no studies that address the implications of seasonal fluctuations in the abundance of krill on fish, seabirds, or cetaceans for example.
- There is poor understanding of the frequency, drivers, and significance of outbreaks of gelatinous zooplankton in the shelf waters of the GAB. These organisms include salps that have a huge influence on primary production because they effectively filter a wide range of phytoplankton, have high filtering rates and increase at extraordinary rates through vegetative budding. Carnivorous gelatinous zooplankton (including hydromedusae and ctenophores) may also be extremely important through their predation on other zooplankton, and may exert a significant impact on recruitment of pelagic fish (including sardines) by consuming both fish eggs and fish larvae.

Key references and current research

Research

Apart from the annual sardine surveys described above, there is almost no current research being conducted on zooplankton in the region between KI and Esperance.

Research on zooplankton in WA is being undertaken within the SRFME program's Biophysical Oceanography project and ancillary collaborative projects involving CSIRO Marine and Atmospheric Research, the WA Department of Fisheries and the universities (Curtin, Edith Cowan, Murdoch, UWA).

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4.9 Prawns

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Species group name and description

Whilst many species of prawns, all from the family Penaeidae, are found within the South-west Marine Region (SWMR), only the western king prawn (*Penaeus (Melicertus) latisulcatus*) is targeted commercially. Other species that are found within the region include the recreationally harvested western school prawn (*Metapenaeus dalli*) and the group of small prawn species collectively termed coral prawns (*Metapenaeopsis spp.*). It is generally accepted that the southern distribution of other important commercial prawns including endeavour, tiger and banana prawns ends at Shark Bay. Whilst it is likely that these species may occur incidentally in northern areas of the SWMR, they will not be addressed in this report.

Western king prawn

Western king prawn, *Penaeus (Melicertus) latisulcatus* Kishinouye, 1896
Other names: Blue-legged king prawn
FAO name: Western king prawn

The western king prawn, *Penaeus (Melicertus) latisulcatus*, is distributed broadly throughout the Indo-West Pacific region and Australia. The body colour is generally light yellow to brown, with dark brown rostrum and ridges, with shades of light blue on the legs and yellow pleopods.

Females may grow up to 200 mm in total length (TL), with males reaching 140 mm TL. The species can live for up to 4 years, and become mature at 6 to 7 months of age at around a size of 25 mm carapace length. It feeds primarily on meiofauna and decayed organic matter (detritus) and is a prey item to a large variety of fishes and molluscs.

Figure 4.9.1 The western king prawn, *Penaeus (Melicertus) latisulcatus* in the laboratory.

Coral prawns

Coral prawns, *Metapenaeopsis spp.* Bouvier*,* 1905

Little is known of the group of species collectively termed ‘coral prawns’ in the commercial prawn fisheries of the SWMR. It is believed that these prawns are from the Genus *Metapenaeopsis,* a Genus whose species are distributed in the Indo-Pacific region and throughout Australian waters. Distinguishable taxonomic features include a rostrum lacking ventral teeth and a telson that has a pair of fixed spines near the tip (Jones and Morgan, 2002).

Most *Metapenaeopsis* species grow to a maximum total length of 125 mm and inhabit depths up to 50 m, though some species inhabit depths up to 200 m. Due to their smaller size they are of lesser economic value than most *Penaeus* species.

Western school prawn

Western school prawn, *Metapenaeus dalli* Racek, 1957
Other names: school prawn, river prawn
FAO name: western school shrimp

The western school prawn, *Metapenaeus dalli*, is found in the Indo-West Pacific region and Australia. The body is semi-translucent pale green to brown with numerous dark brownish green pigment spots and the tips of the uropods are green to reddish. Its distinguishable taxonomic features include a telson without obvious spines and sides of the abdomen almost without fine hairs (Grey *et al.*, 1983).

Female western school prawns grow to a total length of 85 mm and males to 65 mm TL. Whilst this prawn most commonly inhabits estuaries and rivers it is also found in inshore marine environments up to 33 m in depth.

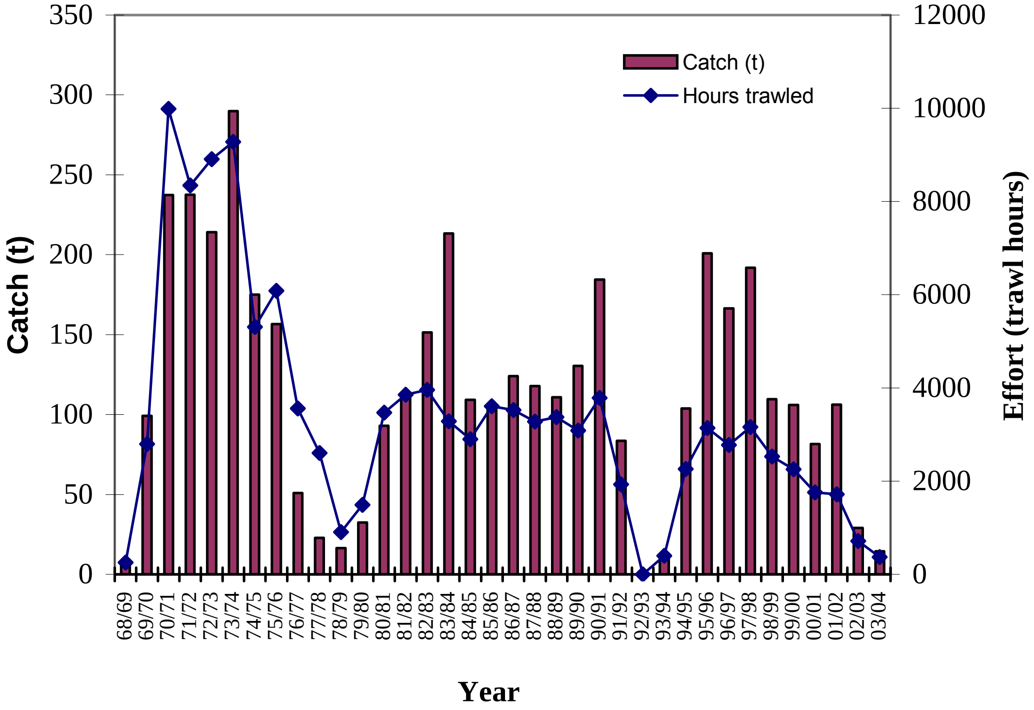
Status

Western king prawn

Western king prawns in the SWMR are harvested commercially from the West Coast Prawn Fishery (WCPF) of South Australia and the Southern Prawn Fisheries of Western Australia that include the Abrolhos Island and Mid West Trawl Fishery (AIMWTF) and South West Trawl Fishery (SWTF) off Fremantle and Geographe Bay. They used to be harvested commercially form the Peel-Harvey estuary on a small scale.

The WCPF is an oceanic fishery with 3 licensed fishers and is highly dependent upon favourable oceanic conditions for successful recruitment. Since its inception in 1967 the fishery has suffered stock collapse on three occasions: 1977–79, 1992–94 and 2002–today (Figure 4.9.1). On the first two occasions these collapses were followed by equally rapid recoveries, however signs of a similar recovery from the most recent collapse are not yet evident. There is some limited evidence to suggest that these declines are associated with environmental effects, in particular sea level height (Carrick and Ostendorf, 2005).

Figure 4.9.2 Commercial catch (t) and effort (hours) of western king prawns from the West Coast Prawn Fishery of South Australia since the 1968/69 financial year (Svane and Roberts, 2004).



The AIMWTF fishery targets the southern saucer scallop *Amusium balloti*, with a small harvest of western king prawns taken off Port Gregory using otter trawls. The Port Gregory area is open for prawn trawling between 1 March and 31 October annually, and fishers operate under gear restrictions that include minimum mesh sizes, by-catch reduction devices and a vessel monitoring system (VMS). Over the last 10 years the average annual catch of western king prawns is 600 kilograms by an average of two boats. In 2002, 1.1 t of king prawns were reported as landed in the Port Gregory area. A risk assessment for the AIMWTF conducted by the Department of Fisheries, Western Australia, stated that, in terms of consequence, fishing for western king prawns in the Port Gregory area has only a ‘negligible’ impact on the breeding population level as only sporadic fishing (by only a few boats) occurs in a limited area. This consequence was considered ‘likely’ to occur however the overall risk rating was ‘negligible’.

The SWTF is also a multi-species demersal otter trawl fishery with saucer scallops (*Amusium balloti*) being the main target species. The fishery includes grounds off Fremantle and Geographe Bay that are divided into four management zones and it operates under input controls on vessel number, gear type and spatial and temporal closures. The annual harvest of western king prawns was 20 t during 2003, representing a 27% increase on the average catch levels for the previous five years (14.3 t). A risk assessment for this fishery has not been conducted.

Western king prawns are also harvested recreationally from most of the rivers and estuaries of West Australia that fall within the SWMR. There are two recreational methods of king prawn harvest allowed: 1) the use of lights and dip nets at night during the annual ‘prawn run’, and 2) hand capture by divers in the deeper sections of the rivers (year round). Fishers are entitled to harvest up to 9 litres of prawns per person per day. Results from the National Recreational and Indigenous Fishing Survey (NRIFS, Henry and Lyle 2003) suggest that the number of prawns (western king and western school) captured annually in Western Australia is 943,458 ± 304,208 (s.e.). Whilst no size information is available for the recreational harvest, captured prawns are generally new recruits. The NRIFS figure would equate to approximately 5 t of prawns at a size of 20 mm CL. The status of this fishery has not been determined.

Coral prawns

Coral prawns are captured in all commercial fisheries of the SWMR. In the WCPF of South Australia, coral prawns are discarded as by-catch, however in the AIMWTF they are harvested as by-product with annual catches generally <1 t. In the risk assessment for the AIMWTF conducted by the Department of Fisheries, Western Australia, the consequence and risk rating for coral prawns were the same as that for western king prawns i.e. consequence was ‘likely’ yet the risk of significant impact on the breeding population level was ‘negligible’.

Western school prawn

Almost all the West Australian rivers and estuaries within the SWMR are important habitats for the western school prawn. These prawns are harvested by recreational fishers along with western king prawns (see above). Neither the proportion of western school prawns in the recreational catch nor the status of western school prawn stocks has been determined.

Habitat and distribution

Western king prawn

The western king prawn is distributed broadly throughout the Indo-West Pacific region. Its known locations include the Red Sea and south-east Africa to Korea, Japan, Malaysia, Indonesia, New Guinea and Australia (Grey *et al.*, 1983). Within Australia they are found in waters of SA, WA, NT, QLD and northern NSW.

Juvenile and adult western king prawns reside in distinct habitats. Adult prawns generally inhabit marine environments up to 50 m in depth that may constitute a sand, mud or gravely texture. However adults may also remain in the estuary or river systems in which they inhabited as juveniles, particularly during years of low rainfall. Juvenile prawns inhabit shallow, sand/mudflat, estuarine habitats that are often associated with mangroves. In South Australia, the timing of their recruitment to adult stocks varies according to the time of settlement. In Western Australia, juveniles migrate from estuaries between March and July.

The waters of the SWMR are predominately temperate and are at the lower end of the temperature tolerance for the species. This is particularly the case in South Australia where minimum annual temperatures often fall below 13°C. These conditions lead to highly seasonal effects on growth and fecundity compared to their tropical counterparts. Adult females spawn on multiple occasions during months of elevated temperature (November-March) and the larvae undergo metamorphosis through four main larval stages; nauplii, zoea, mysis and post-larvae. The larval phase may take up to 5 weeks in the temperate waters of the SWMR and thus settlement to suitable habitats is a chance event. These life history traits mean that commercial densities of *P. latisulcatus* are generally associated with hyper-saline marine embayments (Kailola *et al.*, 1993). As such commercial fisheries are often based on populations of discreet stocks with minimal genetic mixing. Electrophoretic studies found genetic differences among the populations sampled from WA, SA and the Gulf of Carpentaria (Richardson, 1982).

Coral prawns

In the SWMR, little is known of the group of species commonly termed coral prawns. It is believed that these species are from the Genus *Metapenaeopsis,* a Genus distributed throughout the Indo-Pacific and Australia.

As with western king prawns, juvenile and adult coral prawns reside in distinct habitats with adults residing in marine environments and juveniles residing in estuarine habitats. Prawns of the Genus *Metapenaeopsis* have been trawled in high densities in the shallow waters of Spencer Gulf, South Australia, during targeted surveys of juvenile western king prawns (Roberts *et al*. 2005).

Western school prawn

The western school prawn is found in the Indo-West Pacific from South Eastern Java to north-west and western Australia. In Australia it is abundant from Mandurah to Broome and reported further north to Darwin.

The western school prawn spends its entire life cycle in the confines of rivers or estuaries in south-western West Australia. It attains a harvestable size of around 50 mm TL at nine to ten months of age, in spring. As with most prawns, this species is nocturnal and buries itself in the sand or mud during the day, coming out to feed during the night.

Spawning usually occurs at one year of age during summer, with individual females able to produce up to 300,000 eggs. Recruitment success is highly variable, although it appears that consecutive dry winters provide the best conditions. Due to fishing pressure and predation in the first year of their life, few western school prawns reach two years of age in the SWMR.

Significance of the group in the south west marine region

Prawns are a significant commercial and recreational species group in the SWMR but are not targeted by Indigenous peoples. Prawns are a significant prey species in both estuarine and marine environments.

Western king prawn

There are three commercial fisheries that harvest western king prawns in the SWMR. In the last five years, the combined catch of western king prawns from the region has varied between 30–120 t and would not have exceeded at total value of $2 million in the peak years. Whilst these catches are important for a number of fishers and fisheries, this catch only represents ~0.8–3.3% of Australia’s total catch for the species and ~0.1–0.5% of Australia’s total wild caught prawn production.

Western king prawns are also harvested recreationally in the rivers and estuaries of West Australia. They are captured in significant numbers, along with western school prawns, during the annual ‘prawn run’ during the late autumn and winter months. Recreational divers may also harvest western king prawns in river systems throughout the year. The economic importance of western king prawns as a recreational species is not well understood, though combined catches of both prawn species by recreational fishers may well exceed 5 t.

Western king prawns are an important prey item in both estuarine and marine environments.

Figure 4.9.3 A cod-end being emptied on a vessel from the West Coast Prawn Fishery of South Australia.

Coral prawns

Coral prawns are harvested as by-product in the AIMWTF, although annual catches are generally <1t. The value of coral prawns is considerably less than other penaeids due to their small size, thus the economic value of this fishery is insubstantial in both a regional and national context. The importance of these species in an ecosystem context is not well understood.

Western school prawn

The western school prawn is an important recreational species (see western king prawn above). It is harvested by fishers during the annual 'prawn run'. The proportion of western school prawns in the recreational catch and their economic significance as a recreational species is unknown.

Western school prawns are an important prey item in estuarine environments, including important recreational fish species such as black bream, mulloway, tailor and cobbler.

Impacts/threats

The life history of many prawn species involves a nursery phase in shallow estuarine or coastal waters, which makes them susceptible to a variety of impacts. The juvenile phase is associated with intertidal estuarine environments that can be extremely fragile e.g. mangroves and seagrass. These environments are often subjected to the threats and pressures from increasing urbanisation. The high economic value of adult prawns makes them a prized target of commercial fishers. Given they are short-lived animals with highly variable recruitment, prawn stocks face some threat from overfishing.

Western king prawn

The WCPF of South Australia has suffered several stock collapses throughout its history. These declines appear to correlate with sea level height more so than overfishing (Carrick and Ostendorf 2005). As sea level height is influenced by long-term trends such as the El Nino Southern Oscillation, a significant threat to the sustainability of this population may be long-term and large-scale environmental shifts driven by factors such as the theorised ‘greenhouse effect’. Clearly commercial fishing on top of such environmentally driven recruitment increases the likelihood of stock collapse by reducing the spawning biomass of the stock.

Other threats to the WCPF include the degradation of important estuarine nursery habitats. Currently the human population base in these areas is very small. However in recent years there has been a rapid increase in the development of aquaculture in the important nursery habitats, particularly with the burgeoning oyster industry. The impact of these aquaculture developments on prawn recruitment is largely unknown.

In Western Australia, western king prawns are a secondary target species in two multi-species fisheries. Whilst these fisheries are small and annual catches of prawns are modest, managing multi-species fisheries provides a number of challenges that can increase the risk of overfishing. These risks generally result from insufficient funds through which to adequately monitor individual populations. A risk assessment has been conducted for the AIMWTF in which the threat of overfishing to western king prawns stocks was assessed as ‘negligible’ because fishing effort was limited spatially and temporally. A risk assessment has not been conducted for the SWTF. In the SWTF, fishing pressure associated with a recreational catch in its pre-recruit phase is additional to the fairly low commercial effort on these stocks. .

Coral prawns

As previously discussed, little is known of coral prawns stocks in the SWMR. This lack of historic knowledge itself poses a substantial risk to the species this group represents. As with other species that have a marine and estuarine existence they face the associated risks of urbanisation and overfishing.

The low commercial value of coral prawns in the SWMR is likely to ensure that minimal research and monitoring will be conducted on these species in the future. Factors in their favour are that they are often numerous, they are highly fecund and are not a targeted species. Further, with Australian Government requirements for ecological sustainable fishing there will continue to be increased research focus on by-catch and by-product species for each of the commercial prawn fisheries in the SWMR.

Western school prawn

The western school prawn spends its entire life-cycle within the confines of river systems. As such they are particularly vulnerable to the threats associated with urbanisation. There appears to be a clear relationship between recruitment success and salinity, with increasing recruitment after consecutive years of low annual rainfall. Thus western school prawns stocks may be vulnerable to long-term environmental shifts.

A further threat to these prawn stocks is overfishing. Recreational effort is limited by bag limits and seasonal closures, however annual catches are not monitored. Significant increases in recreational effort under current management arrangements may pose a substantial threat to localised stocks.

Information gaps

Western king prawn

The general biology of western king prawns is well understood. Less well understood is the effects of large-scale environmental processes on the recruitment dynamics and productivity of these oceanic fisheries in the SWMR. It appears that such effects drive recruitment in the WCPF of South Australia such that it is a boom/bust fishery. Knowledge of the environmental processes that affect recruitment are essential for the sustainable management of this fishery, and the results of such studies would increase the knowledge base for prawn fisheries world-wide.

In recent years, the Australian Government has driven fishery research and management in a direction toward Ecologically Based Fishery Management. Such an approach requires integrated multi-species research and management underpinned by knowledge of the effects of fishing on marine communities. Whilst considerable research has been conducted on the effects of fishing in other western king prawn fisheries, and an FRDC project was completed in 1993 for trawl fisheries of south-west West Australia, there is no on-going monitoring of trawl by-catch from the prawn fisheries in the SWMR.

Coral prawns

Whilst there is considerable knowledge of the biology of the Genus *Metapenaeopsis,* little is known of the species present in the SWMR despite the fact that they are harvested commercially in the AIMWTF and are captured as by-product in the other two fisheries. Mapping the distribution, abundance and species diversity of this species group should be a priority for prawn research in this region.

Western school prawn

The general biology of western school prawns is well understood. As with western king prawns, a greater understanding of the effect of the environment on recruitment and production of this important recreational fishery is needed. Further quantification of the recreational catch including determining the proportion of each species and the size structure of the catch would aid management.

Key references and current research

Whilst considerable research has been conducted on the species that are harvested within the SWMR, most of these studies have been conducted on the more lucrative fisheries outside this region, such as Spencer's Gulf and the Gulf of St Vincent. Scientific research on the biology of the prawn species within the SWMR has been conducted since the 1970's, and is generally well understood. In recent years, prawn research has focused on strategies to optimise prawn harvest and minimise the impact of prawn fishing on the environment e.g. by-catch reduction devices. Limited studies have been conducted on the effect of trawling on the environment within the SWMR and the effect of the environment on recruitment and production of these fisheries.

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4.10 Rock lobster – southern (*Jasus edwardsii*)

Principal contributor
Adrian Linnane

Species group name and description

Common names: southern rock lobster, spiny lobster, crayfish
Scientific name: superfamily Palinuroidea,
family Palinuridae
genus Jasus
species edwardsii

The southern rock lobster (*Jasus edwardsii*) belongs to the family Palinuridae, which comprises 49 species worldwide. This family consists of decapod crustaceans in the superfamily Palinuroidea, which encompasses both palinurids and the Scyllaridae – or slipper lobsters. The Palinuroidea (spiny lobsters), along with the two other lobster superfamilies, the Nephropoidea (clawed lobsters) and the Galatheoidea (galatheids) consist of reptant (i.e. crawling) decapods, in contrast to the natant (i.e. swimming) decapods such as shrimp. The major morphological features distinguishing spiny lobsters from clawed are: lack of claws on the first pair of legs, lack of a distinctive intromittent organ on the underside of the first abdominal segment, a horn over each eye as opposed to a single rostrum between the eyes and larger antennae.

First described in 1837, the southern rock lobster was originally thought to be same species as the South African lobster (*Jasus lalandii*). Since then it has undergone numerous taxonomic changes. In 1963, the southern rock lobster was identified as a separate species and given the name *Jasus novaehollandiae*. At the same time, the New Zealand lobster was renamed *Jasus edwardsii*. Subsequent genetic profiling of Australian and New Zealand lobsters could not separate the species, so the name *Jasus edwardsii* is now applied to both populations. Southern rock lobsters are easily distinguished from the western rock lobster (*Panulirus cygnus*) by their shorter antennae and sculptured shell surface.

Status

The southern rock lobster, has been fished in South Australian waters since the 1890s, but the commercial fishery did not develop until the late 1940s and early 1950s when overseas markets for frozen tails were first established. The South West Region incorporates the Northern Zone Rock Lobster Fishery (NZRLF) which itself includes all South Australian marine waters between the mouth of the Murray River and the Western Australian border and covers an area of 207,000 km^2 (Figure 4.10.1). The NZRLF is comprised of 42 Marine Fishing Areas (MFAs), but the majority of fishing is conducted in ten MFAs (7, 8, 15, 27, 28, 39, 40, 48, 49 and 50). Southern rock lobsters are also taken as part of the South Coast Crustacean Fishery (SCCF) in Western Australia.

Management arrangements have evolved since the inception of the fishery. The major management milestones for the NZRLF are shown in Table 4.10.1. Stock Assessment Reports prepared by the South Australian Research and Development Institute (SARDI) are delivered annually to the Primary Industry and Resources, South Australia (PIRSA) Fishery Policy Group. Recent catch and effort statistics, combined with fishery model outputs indicate that the biomass of southern rock lobster in the NZRLF is declining. A stock-rebuilding strategy is currently being developed to ensure increases in biomass, egg production and yield are achieved in the NZRLF, within a reasonable timeframe. In response, the total allowable commercial catch (TACC) was reduced from 625 tonnes in the 2003/04 fishing season to 520 tonnes in 2004/05 of which 446 tonnes were landed (Linnane et al., 2005). Annual landing of southern rock lobster in the SCCF of Western Australia have ranged between 40 – 105 tonnes over the last decade and represent approximately 2% of the total landings for Australia (Anon, 2004)

There is an also an important recreational fishery for lobsters within the boundaries of the NZRLF with the most recent survey of the sector undertaken during the 2004/05 season. Based on data from registered pot fishers only, the estimated State recreational catch in the 2004/05 season was 83.17 tonnes of which 8.56 tonnes came from the NZRLF.

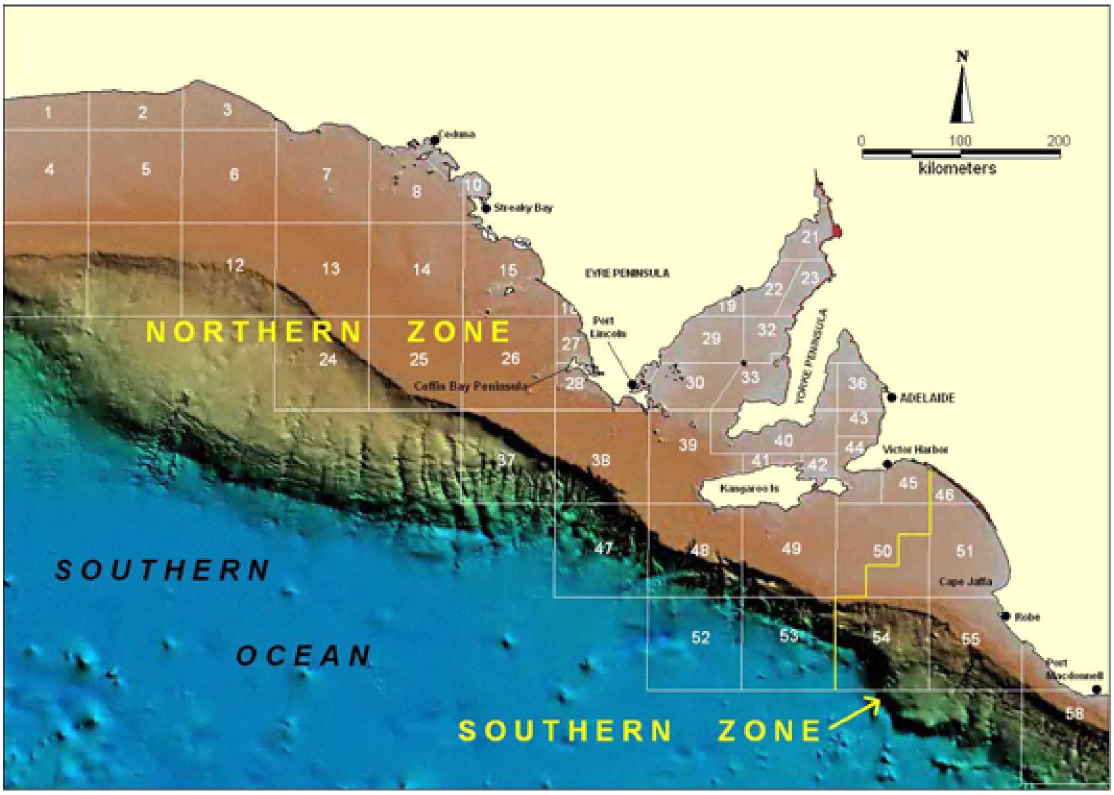

Figure 4.10.1 Northern and Southern zones of the South Australia rock lobster fishery with numbered Marine Fishing Areas (MFAs).

Table 4.10.1. Major management milestones for the South Australian Northern Zone Southern Rock Lobster Fishery (Zacharin 1997).

Date	Management milestone
1968	Limited entry declared
1985	10% pot reduction; max number of pots 65
1992	10% pot reduction; max number of pots 60
1993	1 week closure during season
1994	LML increased from 98.5 to 102mm CL; further "1 week" closure
1995	Further "1 week" closure added
1997	Flexible closures introduced
1999	Extra 3 days of fixed closure added Ballot held to determine if size should increase to 105 mm – affirmed for 2000 season
2000	LML increased from 102 to 105 mm CL
2001	7% effort reduction
2002	8% effort reduction
2003	TACC implemented for the 2003/04 season at 625 tonnes; VMS introduced.
2004	TACC reduced to 520 tonnes for the 2004/05 season; vessel length and power restrictions removed.

Habitat and distribution

Southern rock lobster inhabit crevices in rocky reef habitat from the intertidal zone to depths of 200 m. Geologically, the NZRLF can be divided into two subregions. From the Gulf of St Vincent to the South Australia/Western Australia border, the marine substrate is comprised mainly of a vast basement of granitic rocks (Lewis 1981). Reef communities and habitats for lobsters are confined to relatively small patches where this basement of granite projects through the overlying sands. Some additional areas of limestone reef occur off Elliston. The remainder of the NZRLF (i.e. from Gulf St Vincent to the Murray Mouth) is comprised of a metamorphosed basement with intrusions of igneous rocks, particularly granites. These intrusive granites produce peaked reefs that provide discrete localised habitats for lobsters that are interspersed by large expanses of sand. Granite does not erode as easily as the limestone reefs in the Southern Zone Rock Lobster Fishery (SZRLF) and granite reefs thus lack the numerous ledges, crevices and undercuts which provide ideal habitats for lobsters. Densities of lobsters on the granitic reefs of the NZRLF are generally lower than those on the limestone reefs of the SZRLF.

Southern rock lobsters are distributed around southern mainland Australia, Tasmania and New Zealand (Smith et al. 1980; Booth et al. 1990). In Australia, the northerly limits of distribution are Geraldton in Western Australia and Coffs harbour in northern New South Wales, however the bulk of the population can be found in South Australia, Victoria, and Tasmania (Brown and Phillips 1994).

Lifecycle and reproduction

Southern rock lobster mate from April to July. Fertilisation is external, with the male depositing a spermatophore on the female’s sternal plates (MacDiarmid 1988). The eggs are extruded shortly afterwards and are brooded over the winter for about 3-4 months (MacDiarmid 1989).

The larvae hatch in early spring, pass through a brief (10-14 days) nauplius phase into a planktonic, leaf-like phase called phyllosoma. Phyllosoma have been found down to depths of 60 m, tens to hundreds of kilometres offshore from the New Zealand coast (Booth et al. 1991; Booth and Stewart 1992; Booth 1994; Booth et al. 1999; Booth et al. 2002). They develop through a series of 11 stages over 12-23 months before metamorphosing into the puerulus (Figure 4.10.2) stage near the continental shelf break). The puerulus actively swims inshore to settle on to reef habitat in depths from 50 m to the intertidal zone

Geographic variation in larval production may be marked. In New Zealand, it has been suggested that this may be due to variations in: (i) size at first maturity, (ii) breeding female abundance and/or (iii) egg production per recruit (Booth and Stewart 1992). Additionally, phyllosoma are thought to drift passively which, coupled with the long offshore larval period, means that oceanographic conditions, particularly currents and eddies, may play an important part in their dispersal (Booth and Stewart 1992).

Geographic patterns in the abundance of phyllosoma may also be consistent with those in puerulus settlement (Booth and Stewart 1992; Booth 1994). Correlations between levels of settlement and juvenile abundance have been found at two sites in New Zealand (Breen and Booth 1989). In South Australia, it has been suggested that the strength of westerly winds, during late winter and early spring, may play a role in the inter-annual variation in recruitment to the NZRLF (McGarvey and Matthews 2001). In their study, both winds and recruitment were shown to exhibit a 10-12 year periodicity, with significant correlations between recruitment and westerly winds lagged by 5-7 years.

Figure 4.10.2 Puerulus stage of the southern rock lobster.

Feeding and growth

Adult lobsters are omnivorous and feed on a wide variety of organisms: crabs and other crustaceans, sea urchins, molluscs including bivalves, chitons and gastropods and a wide variety of algal species.

Lobsters grow through a cycle of moulting and thus increase their size incrementally (Musgrove 2000). Male and female moult cycles are out of phase by 6 months, with males undergoing moulting between October and November, and females during April to June (MacDiarmid 1989).

A tagging study undertaken between 1993 and 1996, in which over 61,000 lobsters were tagged and 16,000 recaptured, demonstrated that there was substantial variation in growth rates among locations in South Australia (McGarvey et al. 1999) with a general trend of higher growth rates in the NZRLF compared to the SZRLF. Growth rates also varied throughout the life of individuals and the mean annual growth for lobsters at 100 mm carapace length (CL) ranged from 7-20 and 5-15 mm per year for males and females respectively. Growth rates tended to increase along the South Australian coast from south-east to north-west and were highest in areas of low lobster density and high water temperature (McGarvey et al. 1999). Growth rates also appeared to be related to depth of habitat and declined at the rate of 1 mm per year for each 20 m increase in depth. The size at which 50% of females are sexually mature is spatially variable, ranging between 90 and 115 mm CL (Prescott et al. 1996).

Movement

In South Australia, movement patterns of the southern rock lobster Jasus edwardsii were determined from 14,280 tag-recapture events from across the state between 1993 and 2003 (Linnane et al. 2005) In total, 68% of lobsters were recaptured within 1 km of their release site and 85% within 5 km. Movement rates were noticeably high in the south-east of the state and at Gleesons Landing lobster sanctuary off the Yorke Peninsula in the NZRLF but patterns of movement differed spatially. In the south-east, lobsters moved distances of <20 km from inshore waters to nearby offshore reefs whereas off the Yorke Peninsula individuals moved distances >100 km from within the sanctuary to sites located on the north-western coast of Kangaroo Island and the southern end of Eyre Peninsula.

These results support findings from an earlier tag–recapture study where most recaptured lobsters had moved short distances with only a small proportion having moved distances greater than a few kilometres, up to 28 km (Lewis 1981). All the above studies indicated that immature lobsters moved greater distances than mature individuals.

Significance of the species group in the Southwest planning area

Southern rock lobster have been found in the regurgitates of Australian Sea Lions (*Neophoca cinerea*) at Kangaroo Island (Rebecca R. McIntosh, Sea Mammal Ecology Group La Trobe University, Melbourne, pers comm.) but the overall importance of lobsters in the diets of these and other marine mammals remains largely unquantified.

In terms of socio-economic importance to the region, the southern rock lobster is South Australia's most valuable fisheries resource. The annual landed value to the NZRLF alone in 2003/04 was ~$AUS13 million with 95% of the catch subsequently exported at a considerably higher price (Anon. 2002). The economic benefits of the recreational fishery flows into many sectors although exact figures in financial terms for the rock lobster fishery are not available.

Impacts/threats

The prolonged larval stages of spiny lobsters exposes them to changing environmental conditions in oceanic waters, principally large scale events such as El Nino. The impacts of El Nino events on larval transport within the South West Region are not well understood but El Nino years are known to correspond with low puerulus settlement in *Palinurus cygnus* in Western Australia (Griffin et al. 2001).

Information gaps

The southern rock lobster Fishery Management Committee (Research Sub-committee) have identified the following biological research areas as currently having "high priority" for the NZRLF:
Relationship between rock lobster recruitment characteristics with oceanographic and environmental conditions
Development of a robust performance assessment framework to monitor the direct and indirect ecosystem impacts of rock lobster fishing operations on temperate reef communities in the region
Assessment of risks to by-product, by-catch, threatened, endangered and protected species, from rock lobster fishing
Review monitoring requirements, to incorporate fishery-independent estimation of rock lobster abundance

Key references and current research

Research

SARDI Aquatic Sciences produces annual stock assessment reports for the South Australian rock lobster fishery. Reports include outputs on:

- A range of fishery statistics as determined from both commercial logbook and voluntary catch sampling data
- A puerulus monitoring programme that describes the emerging relationship between settlement indices and subsequent recruitment to the fishable biomass
- A range of fishery model outputs that provide assessment information to management based on biological performance indicators

A Fishery Independent Monitoring Survey (FIMS) has been developed for trial in the fishery for the 2005/06 season. Data will be used as input for fishery independent models with outputs used in the determination of a fishery independent estimate of lobster abundance.

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4.11 Rock lobster – western

Principal contributor
Nick Caputi

Species group name and description

Common name: western rock lobster, spiny lobster

Scientific name: superfamily Palinuroidea,
family Palinuridae
genus Panulirus
species cygnus

Western rock lobsters are spiny lobsters with long antennular flagella. The anterodorsal aspect of the carapace bears 2 distinct, smooth supraorbital spines and behind them are 2 rows of 4–8 smaller spines. Each abdominal segment has a transverse groove. The older juveniles and adult lobsters (except 'whites') assume a reddish-purple colour with each moult. The carapace is uniformly coloured without obvious spots and markings, although the abdomen is spotted dorsally and laterally. Each walking leg has a broad, pale longitudinal stripe on its dorsal surface. The migrating 'white' phase lobsters are light coloured.

Status

No spiny lobsters in the SWPA are listed as endangered under international, Australian (Commonwealth), Western Australia (WA) or South Australian environmental legislation and management arrangements are in place under state and Commonwealth fisheries legislation.

Latest figures indicate full exploitation, and indications are that under current management rules, egg production has improved to levels considered safe for the fishery. Fluctuations in puerulus settlement will be due entirely to environmental factors.

Despite increasing coastal development and resulting pollution, WA's coastal waters (including nursery grounds), remain clean, ensuring western rock lobsters of extremely high quality.

Environmental factors such as the Leeuwin Current, water temperature and storms affect the puerulus settlement rates. Fisheries researchers have used oceanographic modeling to better understand how larvae move with currents and are distributed.

The commercial fishery for western rock lobster is the most valuable single-species fishery in Australia (worth between $A200 and $A400 million annually) and usually represents about twenty per cent of the total value of Australia's fisheries.

As one of the first managed fisheries in Western Australia, data have been kept on the western rock lobster fishery since the early 1950s. The rock lobster fishery was declared limited entry in March 1963 when licence and pot numbers were frozen. Since 1963, boat numbers have declined from 836 to 491 (January 2007). The commercial catch has varied between 8,000t and 14,500t over the last 20 years mostly due to natural fluctuations in annual recruitment. The settlement of pueruli, that stage in the life cycle which settles in inshore areas after the larval phase, is used to predict reliably recruitment levels and therefore catches three to four years ahead.

The current management package employs several measures to pursue the legislative objectives – at the heart of which is resource sustainability. The rock lobster management package is widely recognised as meeting this objective.

This fishery is managed using a total allowable effort (TAE) system and associated input controls. The primary control mechanism is the number of pots licensed for the fishery, together with a proportional usage rate which creates the TAE in pot days. Unitisation in the fishery and transferability provisions allow market forces to determine what is the most efficient use of licences and pot entitlements. This is known as an individually transferable effort (ITE) management system. The number of pots allowed in the fishery was set at 76,623 in the late 1980s, and since 1993/94 a usage rate of 82% has operated to keep the TAE at a sustainable level. Further effort reductions were implemented for the 2005/06 season.

The fishery is divided into three zones which distributes effort across the entire fishery, reducing concentration of effort and the potential for higher exploitation rates (Figure 4.11.1). This also permits the implementation of management controls aimed at addressing zone-specific issues, including different maximum size restrictions in the northern and southern regions of the fishery.

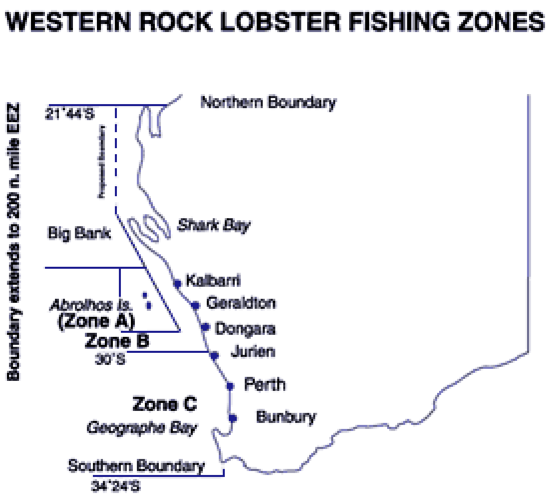

Figure 4.11.1. Map showing the locations of the main fishing zones of the Western Rock Lobster fishery.

The management arrangements also include the protection of females in breeding condition, a variable minimum carapace length and a maximum female carapace length. Gear controls, including escape gaps and a limit on the size of pots, also play a significant role in controlling exploitation rates. The season is open from 15 November to 30 June annually, with the Abrolhos Islands zone operating from 15 March to 30 June.

In 1999/2000, the West Coast Rock Lobster Managed Fishery became the world's first fishery to receive Marine Stewardship Council (MSC) certification. The ongoing requirements of maintaining this certification continue to require a high level of research and management input.

During 2002/03, the Australian Government Department of Environment and Heritage (DEH) certified the fishery as environmentally sustainable under the provisions of the *Environment Protection and Biodiversity Conservation Act 1999*. While subject to a number of conditions, certification allows product from the fishery to be exported from Australia for a period of five years before reassessment.

The Windy Harbour/Augusta Rock Lobster Managed Fishery, the Esperance Rock Lobster Managed Fishery (ERLF), the rock lobster pot fishery (a Regulation fishery) operating in the Albany and Great Australian Bight (GAB) sectors, are managed under the 'south coast crustacean fisheries'. The fisheries are multi-species and take southern rock lobsters (*Jasus edwardsii*) and western rock lobsters (*Panulirus cygnus*) as well as deep sea crab species. Southern rock lobsters comprise the majority of the catch in the eastern areas of the fishery. Western rock lobsters are a significant component of the catch in the Windy Harbour fishery (not reported here due to confidentiality provisions relating to the small number of licensees).

These fisheries are managed primarily through input controls in the form of limited entry, pot numbers, size limits and seasonal closures. In 2002/03, two vessels were licensed to fish for rock lobsters in the Windy Harbour/Augusta Rock Lobster Managed Fishery, 11 were licensed to fish in the Esperance Rock Lobster Managed Fishery and 31 vessels were endorsed to fish in the GAB and Albany zones. The season for fishing for rock lobsters throughout the south coast crustacean fisheries mirrors the Western Rock Lobster Managed Fishery season (15 November to 30 June).

Habitat and Distribution

The western rock lobster is only found in Western Australia, from Albany to the North West Cape (Figure 4.11.2). It is also present in the Houtman Abrolhos, about 80 km off Geraldton.

Lobsters inhabit the continental shelf in water from 1 m to approximately 200 m deep, although most live in waters shallower than 60 m. Juveniles live in caves and under ledges of limestone patch reefs surrounded by seagrass beds (eg *Halophila* species, *Amphibolis* species) in water generally 10–30 m deep. Adults can be found in similar habitats in deeper water. At the Houtman Abrolhos islands, lobsters shelter in holes and under clumps of coral.

Figure 4.11.2. Distribution of the Western Rock Lobster.

Life cycle and reproduction

The species can live for over 20 years and reach sizes of up to 5.5 kg, although animals over 3 kg are rarely caught under current harvesting practices. In the southern areas of its distribution, the lobsters become mature at about 6-7 years old at a carapace length of about 90 mm. In the northern waters near Kalbarri and at the Abrolhos Islands, they mature at smaller sizes, usually at about 70 mm carapace length.

When lobsters mate, the male attaches a package of sperm, which resembles a blob of tar, to the underside of the female. This “spermatophore” is generally called a tarspot and remains there until the female is ready to spawn her eggs. At spawning, the female releases eggs from small pores at the base of the third pair of walking legs, sperm is released at the same time by the female scratching the spermatophore and the eggs are fertilised as they are swept backwards and become attached to the sticky setae on the pleopods. Females with eggs attached under their abdomen are known as “berried” females. The eggs hatch in about 5-8 weeks (depending upon water temperature), releasing tiny larvae called phyllosoma into the water currents.

The phyllosoma larvae spend 9-11 months in a planktonic state, carried by ocean currents where they feed on other plankton before the last phyllosoma stage moults into what is called the puerulus stage. This stage is now capable of settling out of the plankton into suitable habitats which are mostly shallow inshore reefs where they can begin life as a tiny juvenile rock lobster.

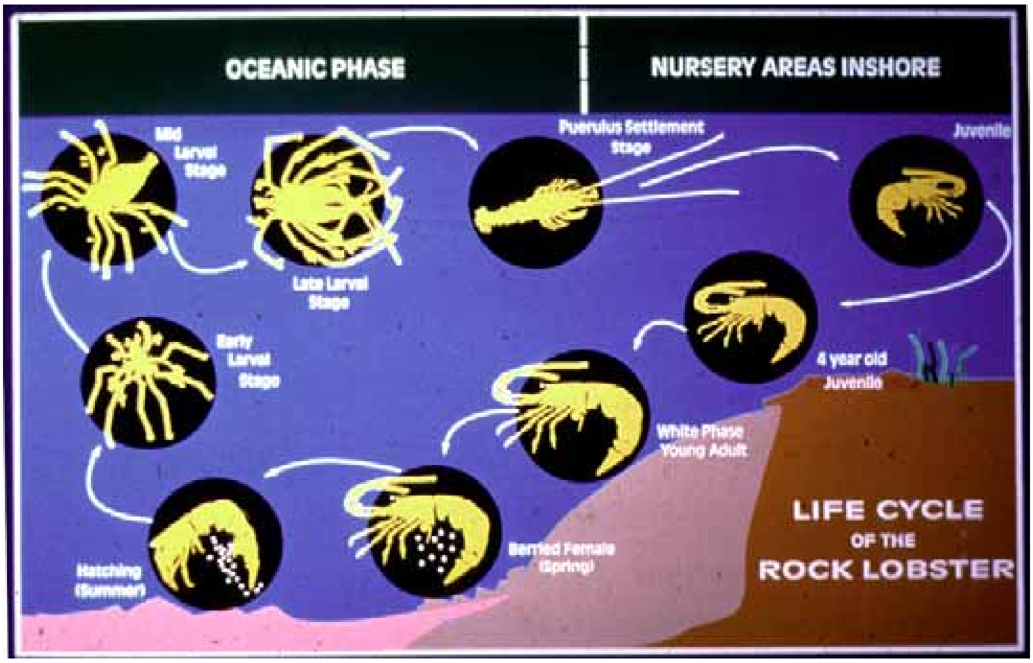

Figure 4.11.3. Life cycle of the Western Rock Lobster

Recruitment and movement

Most lobster larvae do not survive their long oceanic journey. Many are eaten by predators or are not carried close enough to the shallow reefs by the ocean currents to allow them to settle. Therefore, the number settling can vary greatly from year to year largely as a result of changes in environmental factors. When the Leeuwin Current is flowing strongly, a higher number of the larval lobsters return to the coast. Westerly winds at the time of year when the puerulus are ready to settle may also help more to reach the shallow reefs along the coast. The south–flowing Leeuwin Current also affects the spatial distribution of the puerulus settlement.

Pueruli that successfully return to the coast, moult to become juveniles which look like miniature adults. These juveniles feed and grow on the shallow inshore reefs for the next three or four years. About four years after settlement, the lobsters undergo a synchronised moult in late spring when they change from their normal red shell colour into a paler colour. They are then known as “white” lobsters until they return to their normal red colour at the next moult a few months later. The white phase of a rock lobster’s life is the migratory phase. At this time (summer) they leave the coastal reefs and undergo a mass migration into deeper water where they become sedentary again on deeper reefs. A small percentage make longer migrations, usually following the continental shelf in a northerly direction.

Ecology

Growth rates of rock lobster vary from place to place and also between individuals. In the central west coast region (the middle of the species distribution), most lobsters reach 76 mm carapace length (the legal size for most of the fishery) either in their third year after settlement before they moult into the white phase, or in their fourth year after they have moulted into the white phase.

The western rock lobster is an opportunistic omnivore feeding on a wide range of food items from coralline algae to molluscan and crustacean fauna (Joll and Phillips 1984; Edgar 1990a), the populations of which probably have high productivity, high turnover rates and short life cycles. Studies have found that juvenile rock lobsters show a range of diets and feeding strategies, varying greatly between seasons and between different habitats in the same season (Edgar 1990a). Edgar (1990a) reported that the diet of *P. cygnus* reflected the abundance and size distribution of benthic macrofauna available on all sampling occasions.

As juveniles, *P. cygnus* are eaten by a number of fish species whilst at large sizes they are one of a number of prey items for octopus and a variety of larger finfish. There are no predators that rely on western rock lobster as their only prey item.

Significance of the species group in the SW Marine Park Plan

In terms of socio-economic importance to the region, the commercial fishery for western rock lobster is the most valuable single-species fishery in Australia (worth between $A200 and $A400 million annually) and usually represents about twenty per cent of the total value of Australia's fisheries. An average catch of 11,000 t is achieved each year.

Impacts/threats

The table below provides a listing of "moderate" hazards/issues identified at a recent (February 2005) ecological risk assessment workshop. No risk hazards/issues were identified at a level above a "moderate" ranking. For some of the hazards, the participants developed a conceptual model or component tree to describe better the nature of the hazard. Stakeholders developed these diagrams for risks they considered to be the most important. An environmental management strategy has been developed to deal with the key issues arising from the risk assessment process.

Table 4.11.1. Moderate risk hazards identified during the recent ecological risk assessment workshop. (To view the full list of hazards and rankings, refer to the following web site: www.fish.wa.gov.au/docs/mp/mp203/fmp203.pdf)

Moderate Risk Hazards
• Possibility that estimate of egg production is incorrect (effect on spawning biomass) • Increase in fishing efficiency - shift to campaign fishing (effect on spawning biomass) • Whale entanglements in pot ropes (social impact) • Sea lion mortality in pots (without management) • Effect of fishing on the Central west coast shallow environment (including coastal development) • Effect of fishing on the Central west coast deep environment

Information gaps

The points mentioned below are not information gaps as such, but are areas in need of continual research in the face of changes in the fishery, resulting from changes in fishing pressure.

i. Changes to regional contributions to egg production. Need for ongoing research to continually monitor the state of egg production in the fishery.

ii. Changes to the impact of commercial and recreational fishing pressure due to improvements in fishing technology. Measures that increase fishing efficiency and its impact on fishing pressure will need to be monitored in the future.

iii. There is a possibility, given the promising results that have been obtained to date from growing out pueruli to a marketable size under experimental conditions, that WRL pueruli will be harvested from the wild fishery for commercial sale, for grow-out at sea or ashore. A modeling study of the impact of removing different numbers of pueruli on the subsequent catch in the wild fishery has estimated that effects are likely to be slight unless many millions of pueruli are removed, but this will need to be empirically validated in the future if rock lobster pueruli on growing becomes a commercial reality.

Current research

Core research into:

- commercial and recreational catch and catch predictions
- status of the breeding stock
- biology (growth, movement patterns etc.)

also several on-going FRDC funded projects dealing with:

- enhancement of the fishery (2002/045)
- reproductive biology (2003/005)
- effects of lobster fishing on deep water ecosystems (2004/049)
- ecological interactions on coastal ecosystems (SRFME Mid West Coast Collaborative projects)

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4.12 Molluscs of commercial, recreational, cultural and ecological significance

Contributors
Dr Mike Steer
Dr Stephen Mayfield

Species group name and description

Molluscs are a diverse group of animals, all of which have bodies structured on the same basic pattern. They are typically unsegmented, have an anterior head, a ventral muscular foot, and a dorsal visceral mass enveloped by a fleshy mantle. The space between the mantle and the viscera, known as the mantle cavity, contains paired gills. A calcareous shell secreted by the mantle is often present, although in many species groups it is reduced, internal or absent.

There are at least 80,000 known molluscan species worldwide, making it one of the largest phyla in the animal kingdom (Purves *et al*. 1995, Edgar 2000). Seven distinct classes are currently recognised: Aplocophora, Monoplacophora, Polyplacophora (e.g. chitons), Gastropoda (e.g. snails, slugs), Bivalvia (e.g. mussels, scallops), Scaphopoda (e.g. tusk shells) and Cephalopoda (e.g. squid, octopus) (Fig. 4.12.1). The three largest classes are the gastropods, bivalves and cephalopods and have the widest geographical distribution. Gastropods are characterised by their large muscular foot and the anterior location of the anus and gills. A two-part shell connected by a flexible hinge defines the bivalves. In cephalopods, the mantle is present as a tube-like structure and the sensory organs, particularly the eyes, are relatively well advanced.

It is estimated that more than 15,000 species of marine molluscs inhabit Australian waters (Beesley et al. 1998). Many of these species are likely to inhabit the Southwest Region. Many of these are currently known to be of commercial, recreational, cultural or ecological significance within the Southwest Region (Table 4.12.1).

Figure 4.12.1 Representatives from five of the seven distinct molluscan classes (source: Branch & Branch 1981)

Table 4.12.1 Molluscs of commercial, recreational, cultural or ecological significance within the Southwest Region.

Class	Family	Species	Common name
GASTROPODA	Haliotidae	*Haliotis rubra*	Blacklip abalone
		Haliotis conicopora	Brownlip abalone
		Haliotis laevigata	Greenlip abalone
		Haliotis roei	Roe's abalone
	Cypraeidae		Cowries
	Volutidae		Volutes
	Conidae		Cone shells
	Muricidae		Murexes
BIVALVIA	Ostreidae	*Ostrea angasi*	Mud oyster
		Crassostrea gigas	Pacific oyster
	Mytilidae	*Mytilus edulis*	Blue mussel
	Pectinidae	*Amusium balloti*	Western saucer scallop
		Pecten fumatus	Southern scallop
	Donacidae	*Donax deltoides*	Pipi, Goolwa cockle
	Arcidae	*Anadara* sp.	Ark shells
	Veneridae	*Katelysia* sp.	Venus shells, mud cockles
CEPHALOPODA	Loliginidae	*Sepioteuthis australis*	Southern calamary
		Sepioteuthis lessoniana	Northern calamary
	Ommastrephidae	*Nototodarus gouldi*	Arrow squid
		Ommastrephes bartrami	Red ocean squid
		Todarodes fillapovae	Southern Ocean squid
	Sepiidae	*Sepia apama*	Giant cuttlefish
	Octopodidae	*Octopus maorum*	Maori octopus
		Octopus cf tetricus	Common Perth octopus
		Octopus australis	Southern octopus
		Octopus pallidus	Pale octopus

Status

The existence of shell middens around coastal southern Australia reveals that molluscs were exploited by indigenous people prior to colonisation, and were clearly an important component of their diet and culture (Bailey 1975). Abalone, cockles, mussels and oysters predominantly collected from shallow, inshore waters, were consistently identified in midden debris (Bailey 1975). These species have retained their importance, and along with scallops and various cephalopods are currently commercially and recreationally exploited.

Gastropoda

Abalone

Abalone (genus *Haliotis*) (Fig 4.12.2) form the basis of valuable commercial fisheries in South Australia (SA) and Western Australia (WA). In both States, the bulk of the catch is exported (canned/frozen), primarily to Hong Kong. A small amount is exported live.

Blacklip abalone (*H. rubra*) populations located on south-western Kangaroo Island form the basis for the fishery on this species in the Central Zone of the SA abalone fishery. Recent stock assessment reports (Mayfield et al. 2004, 2005, 2006) concluded that the stocks were declining and total allowable commercial catches (TACC) were reduced between 2004 (42.3 t) and 2005 (29.7 t), and again between 2005 and 2006 (24.3 t).. Both blacklip and greenlip (*H. laevigata*) abalone are commercially exploited in the Western Zone of the SA fishery. TACC have been stable for >10 years. Blacklip abalone comprise ~60% (293 t) and greenlip abalone ~40% (207 t) of the TACC. The most recent stock assessment reports suggest that greenlip abalone populations are increasing, whilst those of blacklip abalone are probably stable.

Three other abalone species are found in SA. These are *H. roei*, *H. scalaris* and *H. cyclobates*. None of these are commercially exploited. However, the potential for exploitation of *H. roei* was assessed in the WZ between 2000 and 2003. That study concluded that sustainable catches were unlikely to exceed 20 $t.yr^{-1}$ (Preece et al. 2004).

In SA, abalone are also harvested by recreational and indigenous fishers. Estimates of the catch obtained by these sectors are rare, but all suggest that catches are small (~2% of the commercial TACC). Levels of illegal fishing are also suggested to be negligible.

There are 11 abalone species in WA waters, of which three are commercially fished. Roe’s abalone, *H. roei*, is the most common species, whilst greenlip and brownlip (*H. conicopora*) are larger, more rare and more valuable.

Greenlip and brownlip abalone form the basis of the commercial fishery along the lower south-west and south coasts of WA, while Roe’s abalone occur in commercial quantities between the SA/WA border and Shark Bay. The commercial catch in 2004 totalled 312.3 t and comprised 107.6 t of Roe’s abalone, 170.5 t of greenlip, and 34.2 t of brownlip abalone. These fisheries are considered ‘fully exploited’.

The recreational abalone harvest in WA is substantial, particularly on *H. roei* around the Perth metropolitan area (Area 7 of the commercial fishery), which has a TACC of 35 t. Total recreational catch of roe’s abalone in the Perth metropolitan area in 2004 was estimated at 25 - 30 t, which is around 80% of the commercial catch.

Specimen shells

Many gastropod species, particularly within the families Cypridae, Volutidae, Conidea and Muricidae, are collected for their shells. These shells are either retained by enthusiasts for their private collections or commercially sold as ornaments, decorations or collectibles. In WA, the collection of these shells is controlled under the specimen shell managed fishery. In 2003, an estimated 550 species of molluscs have been collected, each in very low numbers (Hart & Wells 2004). Although some cowry and volute species are considered rare and potentially vulnerable, current levels of shell collection appear sustainable (Hart & Wells 2004). Recreational shell collecting is considered substantial, however, the majority consists of dead shells washed up on beaches.

The Muricid *Dicathais orbita* is one of the most abundant gastropods of the southern Australian intertidal and subtidal coast. It is edible and is currently underappreciated as a resource in Australia (Benkendorff, pers comm.). Muricids are heavily fished overseas as a source of food and also for purple dye secretion, which forms the basis of a homeopathic remedy called Murex. Murex is listed on the homeopathic Materia Medica for treating a range of women's problems (Influenca 2002; Boericke 2005). Benkendorff *et* al. (2000) have also demonstrated that *D.* orbita produces a potent antibiotic. Consequently, this species holds good potential for future development and there is a precedent for utilising the Muricidae as medicinal molluscs.

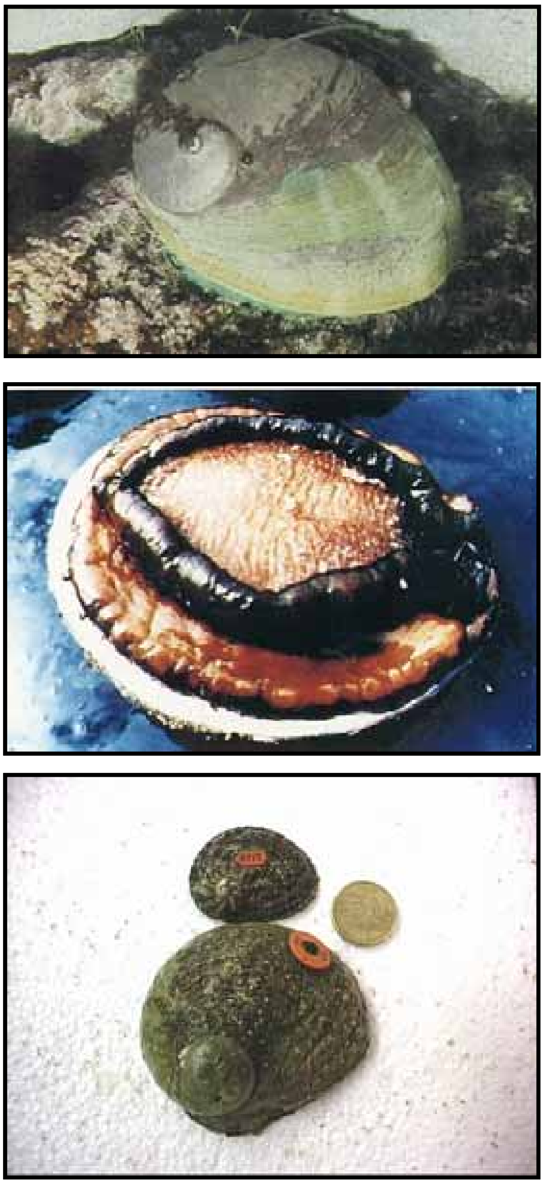

Figure 4.12.2 Top picture: greenlip abalone, *H. laevigata*; Middle picture: blacklip abalone, *H. rubra*, showing its muscular foot; Bottom picture: Roe's abalone, *H. roei*, both specimens have been tagged. (photo credits: SARDI Aquatic Sciences)

Bivalves

Blue mussels

Existing Western Australian wild stocks of blue mussels (*M. edulis*) appear fully exploited (Kailola et al. 1993). Blue mussels are also farmed at several locations within the Southwest Region, using spat which settles naturally on suspended ropes (Kailola et al. 1993). South Australian mussel farming is still in its infancy, but is developing strongly and expected to contribute significantly to the aquaculture industry in the near future.

Scallops

Unlike southeastern Australia, the southern scallop (*P. fumatus*) is not heavily targeted in the Southwest Region, whereas the Western saucer scallop (*A. balloti*) supports a relatively small (<12 t) fishery in waters adjacent to Fremantle and Geographe Bay. The status of this fishery is yet to be assessed.

Oysters

Mud oysters, *O. angasi*, were once harvested in large numbers, particularly by European settlers, but the population crashed in the 19th century, possibly because of an epidemic caused by a parasitic protozoan *Bonamia* sp (Edgar 2000). The commercial and recreational fisheries for this species are currently small. Attempts to culture the mud oyster had limited success and the emphasis shifted towards the Pacific oyster, *C. gigas*, as it is considered a superior commercial species. Today, the oyster farming industry is a major economic contributor of seafood in SA. There is no commercial harvesting of wild Pacific oysters.

Cockles

Although Goolwa cockles, *Donax deltoides* (Fig. 4.12.3), are found on the surf beaches on the west coast of SA, they are not present in commercial quantities. The commercial Goolwa cockle fishery primarily operates east of the Murray River mouth, outside of the Southwest Region. A variety of cockles, including the Goolwa cockles, the arc shells and venus shells are recreationally harvested throughout southern Australia either for food or bait. Recreational bag limits apply in both SA and WA.

The brooch shell, *Neotrigonia bednalli,* is endemic to the Australian continental shelf of the Southwest region. This species, as well as other members of the *Neotrigonia* genus, are considered 'living fossils' as the oldest known representative occurred in the middle Miocene (~ 200 million years ago). This subclass was presumed to be extinct until the discovery of live animals in the early nineteenth century (Beesley et al. 1998). Consequently, these relic populations have considerable evolutionary significance.

Figure 4.12.3 Goolwa cockles, *Donax deltoides.* (photo: SARDI Aquatic Sciences)

Cephalopods

Arrow squid, calamary (predominantly *Sepioteuthis australis*) and the giant Australian cuttlefish are the only cephalopods commercially targeted within the Southwest Region. Initially these species were exclusively retained as by-catch from various commercial trawlers and sold as bait, but have since developed into important fisheries. Calamary, and to a lesser extent cuttlefish, are recreationally harvested in both SA and WA. Recreational harvest of arrow squid is negligible.

Arrow squid

The arrow squid fishery is the largest squid fishery in Australia landing approximated 2,000 tonnes annually (Lynch 2005). The area of the fishery includes Commonwealth waters from Fraser Island in Queensland, south to the South Australian and Western Australian border, including waters around Tasmania. The majority of squid are jigged in fishing grounds off Portland, Queenscliff and Lakes Entrance in Victoria. Demersal trawl vessels operating in the South East Trawl and Great Australian Bight Trawl fisheries also catch arrow squid as a by-product when targeting finfish on shelf grounds. Other by-product squid species that exist within the Southwest Region include the offshore red ocean squid (*Ommastrephes bartrami*) and the Southern Ocean arrow squid (*Todarodes fillappovae*). Currently Australia's arrow squid fishery is considered under fished and there is potential for further expansion (Lynch 2005).

Calamary

In the last 20 years, southern calamary (Fig. 4.12.4) has increased in commercial significance and contributes to multi-species marine fisheries in all southern Australian states, particularly SA and Tasmania. SA's calamary fishery is the largest with an estimated annual commercial catch of 450 t (Steer et al. 2006). There is insufficient biological information to estimate total biomass or sustainable yield for calamary and cephalopods in general. Consequently, stock assessments are difficult, particularly because these animals have a short, sub-annual, lifespan and there is considerable inter-annual variability in the population size. As such, the status of the population is poorly understood.

Cuttlefish

The main fishery targeting cuttlefish in SA has historically been based on the annual spawning aggregation of *Sepia apama* (Fig. 4.12.4.) in northern Spencer Gulf, SA. Only small catches of cuttlefish are taken in other areas of the State and WA, generally as by-catch when targeting calamary, and in haul nets and rock lobster pots (Hall 2002). Until 1998, there were no specific management restrictions on harvesting cuttlefish. As the fishery rapidly expanded between 1994 and 1997, concerns were raised over exploitation levels, particularly due to concentration of effort on the annual spawning aggregation. This prompted the introduction of a spatial closure in 1998 to protect the spawning stock. Over the years, this closure had been re-viewed and amended. Currently, the spawning area is protected by a permanent (effective until December 31st 2006) area closure that protects all cephalopods. As a result, the commercial cuttlefish catch in SA has reduced significantly.

Octopus

Despite a small developing octopus fishery in WA, that targets the common Perth octopus, *Octopus* cf *tetricus*, interest in the commercial harvesting of octopus in the Southwest Region is based on reducing predation within the valuable rock lobster fisheries (Kailola et al. 1993). The Maori octopus and the common Perth octopus are the major predators of rock lobsters in SA and WA, respectively. There is no information on the stock structure or status of these species.

Figure 4.12.4 Top picture: southern calamary, *Sepioteuthis australis*; Middle picture: Female *S. australis* laying eggs; Bottom picture: the giant Australian cuttlefish, *Sepia apama.* (photo credits: Top and middle – Dr Troy Jantzen, Bottom – SARDI Aquatic Sciences)

Habitat and distribution

Gastropods

Abalone

Abalone are ubiquitous throughout the SW Region. Greenlip and blacklip/brownlip abalone are distributed between Kangaroo Island (SA) and Cape Naturaliste (WA) and between Kangaroo Island (SA) and Rottnest Island (WA), respectively (Fig. 4.12.5). Despite substantial genetic evidence, that suggests blacklip and brownlip abalone are conspecific, there are many life history features that render them separate species. Roe’s abalone have a comparatively broader distribution within this Region, being abundant between Kangaroo Island (SA) and Shark Bay (WA). Depth distribution differs among species. Roe’s abalone are typically found on shallow (<5 m) reef platforms. Greenlip, blacklip and brownlip abalone are found between 5 and 50 m.

Shells
There is limited information of the distribution of species targeted by shell collectors. However, species within the families Cypridae, Volutidae, Conidea and Muricidae, typically occur over wide geographic (range: 100's to 1000's of km) and broad depth (range: 0 to 200 m) ranges.

Bivalves

Mussels
Blue mussels inhabit a wide range of estuarine and marine habitats on the southern coast of Australia, from Cape Hawke on the east coast to Fremantle, WA, including the waters around Tasmania (Fig. 4.12.5). They are sessile and can be found attached to hard substrates from the low tide level to a depth of 10 m. They sometimes form dense beds on low relief sandy substrates and prefer exposed sites subjected to significant water movement. Their distribution is limited by high water temperatures and low salinities (lower limit 15 ‰).

Scallops
The southern scallop extents from Tuncurry, New South Wales, through Bass Strait and the northern coasts of Tasmania, to Shark Bay, WA (Fig. 4.12.5). The Western saucer scallop is distributed along the Western Australian coast from Esperance to Broome. Both species live in discrete beds over bare, soft sand or mud. The southern scallop inhabits waters of at least 120 m, whereas the Western saucer scallop is predominantly found in waters less than 75 m deep.

Cockles
Donacid cockles are adapted for life on high-energy sandy beaches. Only six species of the family Donacidae are found in Australia, and of these *Donax deltoides* is the largest (Murray-Jones & Johnson 2003). Cockles are widely distributed and locally common, typically inhabiting the wash zone at high tide (Fig. 4.12.5). They are most abundant from approximately 10 cm below the surface. The genus is known for its tidal migrations where cockles actively emerge from the sand and use the surf to relocate up or down the beach as the tide changes (Murray-Jones 1999). The mud cockles, ark shells and venus shells, prefer lower energy environments and are most common in estuaries and on mud flats and seagrass beds to depths of approximately 5 m.

Oysters
Oysters inhabit coastal marine and estuarine environments. They typically attach to hard substrates, however some species break free and settle on soft mud, or sand. The mud oyster, *Ostrea angasi,* is native to southern Australia extending from the New South Wales coast to Fremantle, WA, including Tasmania (Fig. 4.12.5). This species is virtually indistinguishable from the renowned European gourmet oyster, *O. edulis*. The Pacific oyster, *Crassostrea gigas*, is native to Japan, but has been introduced to a variety of countries, including Australia, for aquaculture purposes. This species has since colonised brackish waters and sheltered estuaries around Tasmania and parts of SA (Fig. 4.12.5).

Cephalopods

Calamary
The southern calamary is a neritic species endemic to southern Australian and northern New Zealand waters. In southern Australia, it ranges from Moreton Bay, Queensland, to Dampier in WA, including Tasmania (Fig. 4.12.5). For most of its distribution, it inhabits coastal waters and protected bays usually in depths of less than 70 m. Adult calamary are typically associated with shallow (<20 m) seagrass meadows, where they form large spawning aggregations and are subsequently targeted by commercial and recreational fishers. Spawning occurs year-round and, once hatched, juveniles migrate offshore.

Cuttlefish
The giant Australian cuttlefish are also found in coastal waters across southern Australia from Brisbane, Queensland, to Shark Bay, WA including Tasmania (Fig. 4.12.5). This species is the largest in the world with males measuring up to one metre in total length. Each winter tens of thousands of cuttlefish aggregate on a discrete area of rocky reef in northern Spencer Gulf, South Australia, to spawn. This is the only known dense aggregation of spawning cuttlefish in the world and as such has been identified as an area of national significance (Steer & Hall 2005).

Arrow squid
The arrow squid is a continental shelf species that inhabits waters surrounding Australia from latitude 27°S in southern Queensland to Geraldton in WA, including Bass Strait and Tasmania (Fig 4.12.5.). They are predominantly found in waters 50 – 200 m, but are known to voraciously feed on schooling fish in surface waters at night. Unlike many other commercially exploited ommastrephids, limited tagging studies have indicated that the arrow squid does not undertake large-scale migrations and does not seem to be associated with large oceanic current systems (Dunning 1998; O'Dor 1998).

Octopus
The southern octopus, Maori octopus and pale octopus are distributed in the temperate waters around south eastern Australia (Fig. 4.12.5). The common Perth octopus is distributed from Albany to Exmouth Gulf on the west coast (Fig. 4.12.5). This species is similar to the common Sydney octopus, *O. tetricus*, found on the east coast. All of these species, with the exception of the pale octopus, inhabits seagrass beds in bays and coastal waters as well as coastal rocky reefs. The pale octopus is typically found on sand and mud habitats from shallow water to depths of almost 600 m (Norman 2000).

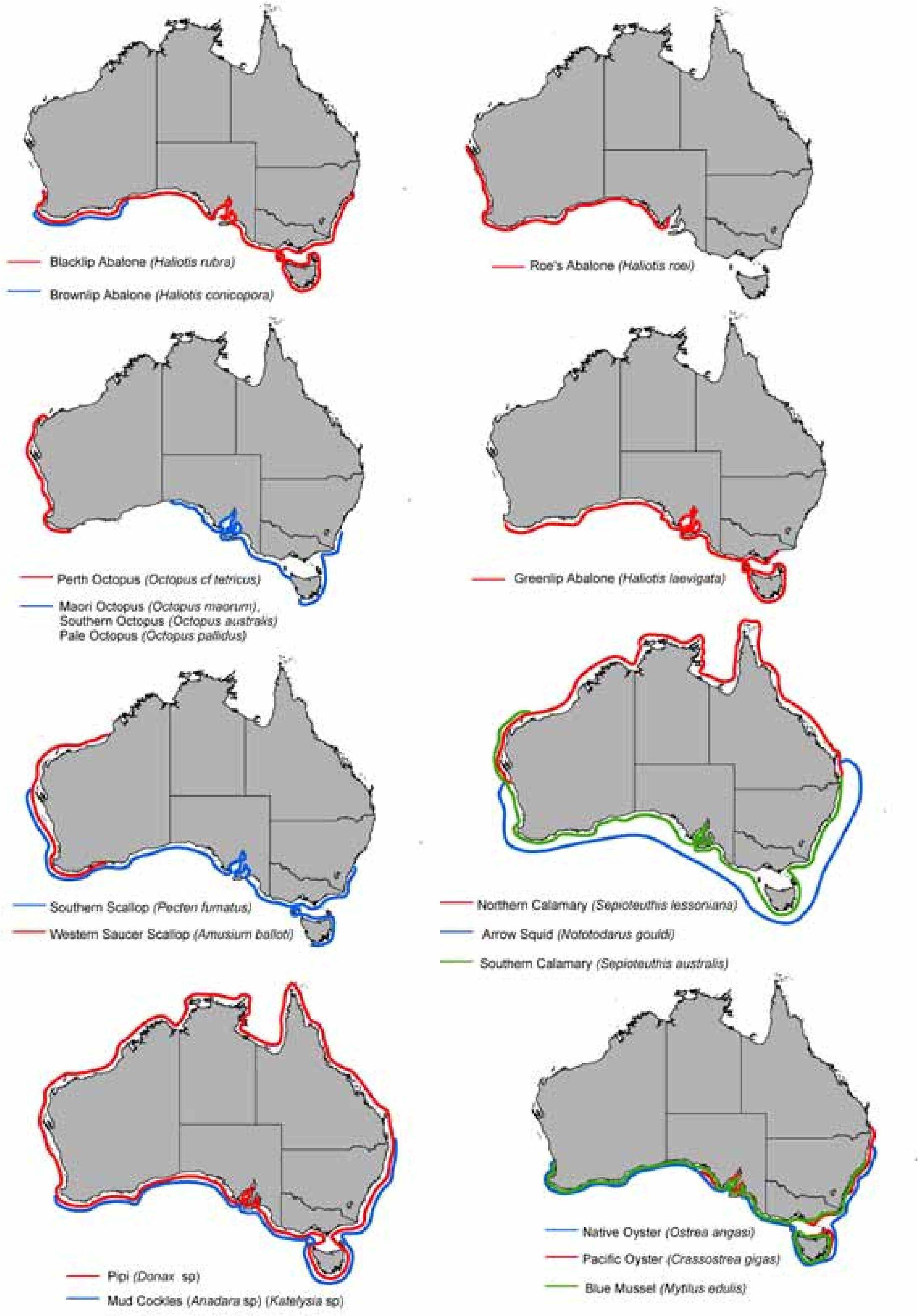

Figure 4.12.5 Distribution of molluscs of commercial significance.

Significance of the species group in the southwest planning area

Gastropods

Little is known about the role of abalone in structuring marine ecosystems. However, small abalone are preyed upon by a range of predators, including fish, crabs, starfish and octopus. Shells are frequently bored by whelks that then feed on the foot muscle. Boring polycheates may also erode the shells (Shepherd 1973). Recently settled abalone eat coralline algae (Shepherd & Turner 1985, Shepherd & Daume 1996). Diet shifts with age to a wide range of drift algae.

Bivalves

In general, bivalves are considered to have an important ecological role as cleansers of coastal waters and providing physical structure to stabilise the substrate. In addition, the structural complexity of bivalve communities creates a heterogeneous environment, providing numerous species with food and shelter and thus increasing the biodiversity of coastal ecosystems.

Suspension-feeding bivalves, such as blue mussels and oysters, are considered excellent indicators of water quality in coastal waters. The blue mussel is used extensively as a bioindicator in southern Australia. The Western Australian Environmental Protection Authority and Health Department regularly use this species to monitor bacterial and heavy metal pollutants in Perth's metropolitan waters (Beesley et al. 1998).

Cephalopods

Cephalopods are key components of the marine ecosystem as primary consumers of crustaceans and fish, as well as being a food source for numerous predators of commercial and conservational significance. Known predators include seabirds, teleosts and sharks, whales, dolphins and seals (Coleman 1984; Gales et al. 1993).

Impacts/threats

Gastropods

The greatest threats to abalone in SA are illegal fishing and disease. While the level of illegal fishing is putatively low, anecdotal reports of recent increases coupled to the high value of the product suggest that it could increase substantially in coming years.

With the exception of *Perkinsus*, little is known about the diseases that may affect abalone. *Perkinsus olseni* is a protozoan parasite that infects abalone, and other molluscs. Infections are typically visible as brown nodules, <1 cm in diameter, on the foot, mantle or as internal pustules (Lester & Hayward 2005). This parasite has the ability to spread rapidly among and decimate abalone populations. A large-scale die-off of greenlip abalone occurred in Gulf St Vincent in the early 1990s (Goggin & Lester 1995) and more recently, for blacklip abalone, along much of the coastline of NSW.

There is limited information on the distribution of *Perkinsus* in either abalone, or other molluscan reservoir hosts in SA. Spatially limited surveys conducted over 10 years ago (O'Donoghue et al. 1991) identified high infection rates (up to 56%) in blacklip abalone around Cape Catastrophe. More recent opportunistic surveys between Pt Labatt and Wedge Island suggest that the infection rate in populations north and west of Cape Catastrophe were low to zero.

Bivalves

Habitat loss, or destruction, and environmental pollution are serious threats to coastal bivalve communities. The impacts of industrial pollutants, specifically trace metals and organochlorides heavily impact on mussel and oyster populations, especially those cultivated in sheltered bays and estuaries. Diatom blooms are an additional concern, as they may have serious detrimental effects on the marketability of commercially important bivalves.

The introduction of the Pacific oyster, *C. gigas*, has lead to the partial displacement of native rock oysters around Australia. This is particularly evident in New South Wales, where the Pacific oyster is out-competing the endemic Sydney rock oyster, *Saccostrea commercialis*. This species has subsequently been declared noxious in New South Wales and farmers are required to remove them from their leases (except in Port Stephens). Culture of Pacific oysters in Victorian coastal waters is not currently permitted.

Local waterways are also vulnerable to foreign bivalves, such as the prolific Asian estuarine mussel, *Musculista senhousia*, that appears to have been introduced to Western Australia's Swan River via ship ballast water.

Cephalopods

One of the major concerns with cephalopods is that there is little, to no, generational overlap. Therefore, the strength of one generation critically depends on the strength and spawning success of the previous generation. This represents an extremely risky strategy, where if one generation fails to spawn, recruitment failure and population collapse are likely. Such collapses have occurred in squid fisheries worldwide, such as the shortfin squid (*Illex illecebrosus*) and the Japanese flying squid (*Todarodes pacificus*), which have largely been attributed to aggressive fishing pressure at a time when stocks had fallen to naturally low levels (Dawe and Warren 1993). Fishers, who target spawning aggregations, thus removing animals before they successfully breed, further exacerbate the risk of collapse.

Information gaps

Gastropods

In SA there is no information on the distribution and abundance of *H. cyclobates* or *H. scalaris*. Information on the distribution and abundance of *H. roei* is limited to the area between the WA/SA border and Spencer Gulf (Preece et al. 2004).

There is also limited information on the direct and indirect effects on the ecosystem arising from the harvest of abalone. Although the selective nature of the fishery indicates direct impacts of fishing on the ecosystem are almost certainly negligible, knowledge of the flow-on effects resulting from the annual commercial harvest are required.

Bivalves

Harmoniously balancing the ecological benefits and sustainable harvests of bivalves requires successful recruitment. Bivalve research thus far has mainly focused on the more descriptive aspects of recruitment, such as reproductive cycles, fecundity, larval development and morphology and dispersion patterns. Although this information is important, a greater understanding of the recruitment process can be gained by understanding the factors that influence each component.

Cephalopods

There is a pressing need to improve methods of population assessment for cephalopods in general, and to gain a better understanding of the interactions between various life-cycle stages and the factors of the physical and biological environment the lead to natural mortality (Boyle & Rodhouse 2005).

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4.13 Bryozoans

Principal Contributor
David Currie

Species group name and description

Bryozoans are colonial, mainly marine animals that are usually found attached to solid substrates such as shells, rocks or other biota. Although there are about 6000 living species, with several times that number of fossil species, the Bryozoa remain largely unknown to most people. Colonies vary in height or diameter from less than one millimetre to over one metre, and occur as flat sheets, plant-like tufts, fleshy lobes or coral-like growths. The individuals (zooids) that comprise the colonies are usually less than 0.5 mm in length and are enclosed in calcium carbonate and/or a protective organic cuticle. This exoskeleton has an opening, through which a lophophore (a tentacular food catching organ) is extended into the water column for feeding (Ryland, 1970). All bryozoans are filter-feeders and rely on small plankton and organic particles suspended in the waters column as a source of food. Bryozoans therefore tend to flourish in waters rich in micro-plankton (Bock, 1982).

Bryozoan morphology is highly variable and systematic work requires detailed microscopic study. Under the current classification system three classes are recognised; the Phylactolaemata, the Gymnolaemata and the Stenolaemata. The class Stenolaemata contains some living marine species and over 500 fossil genera. The class Gymnolaemata is almost entirely marine and includes the great majority of living bryozoans, as well as many fossil species. The class Phylactolaemata, on the other hand, is restricted to fresh water and contains approximately 50 species (Barnes, 1982).

Status

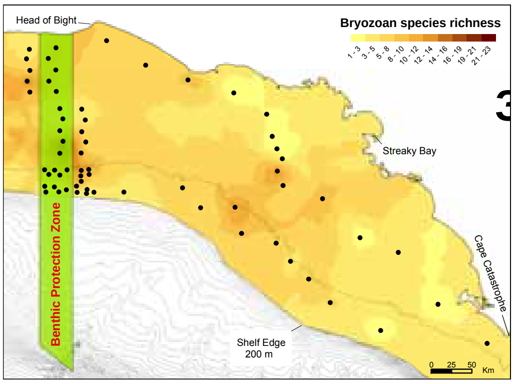
Bock (1982) reported that there are over 500 species of bryozoans in southern Australia, suggesting that the region supports one of the most diverse bryozoan faunas of the world. However the number and identities of a large proportion of the SW marine region fauna is poorly understood. There are more than 100 potentially undescribed species of bryozoan from the Great Australian Bight (GAB) in the Victorian Museum (Phil Bock, personal communication). The South Australian Museum also has a large collection of unidentified bryozoans from the same area (Thierry Laparousaz, personal communication).

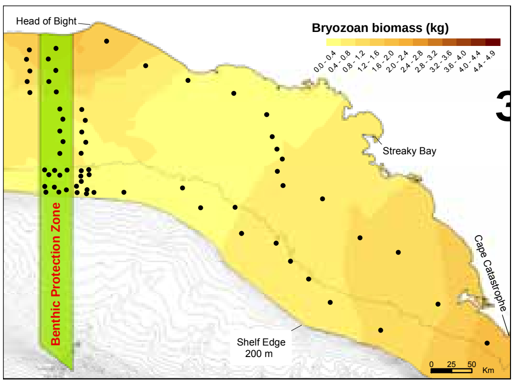
No Bryozoans are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as threatened, endangered or rare. In addition, none are listed by the *Convention on International Trade in Endangered Species* (CITES) as threatened by international trade. All benthic fauna, including bryozoans, are protected from bottom trawling within the Great Australian Bight Marine Park (DEH, 2005). Throughout the rest of the SW marine region bryozoans are not currently protected in commonwealth waters.

Habitat and distribution

While some bryozoans may live as epiphytes on the surface of motile animals (including turtles and sea snakes), most bryozoans prefer a more stable substrate on which to settle and grow. The nature of the seafloor is therefore considered a major factor governing the distribution and structural form of bryozoan colonies (Hageman et al., 1997, 2000). Almost all of the seabed in the SW marine region is composed of soft unconsolidated sediments (Heap et al., 2005). These sediments vary in grain-size structure with depth and local hydrology but are typically coarsest in shallow inshore waters and become progressively finer with increasing depth and distance offshore (Heap et al., 2005; Ward et al., 2006). The most comprehensive regional studies to date (James et al., 1992, 1994, 1997, 2000, 2001) demonstrate strong relationships between sediment grain-size structure and bryozoan abundance. In particular, these studies show that bryozoan bio-fragments are the dominant feature of the fine-sediments skirting the margin of the continental shelf. Results from more recent research in the eastern GAB (Ward et al., 2006) appear to contradict these findings. In the Ward study, bryozoan biomass was found to be greatest in coarse, inner-shelf sediments at the Head of the Bight and off the tip of the Eyre Peninsula (Figure 4.13.1). The same study also found that bryozoan diversity was typically highest in areas where bryozoan biomass was low (eg. in the outer shelf south of the Head of the Bight, and southwest of Streaky Bay).

Figure. 4.13.1 Maps of total bryozoan richness (number species.tow^{-1}) and biomass (kg.tow^{-1}) collected from 65 epibenthic sled shots in the eastern Great Australian Bight (see Ward et al., 2006 for further details.).





Significance of the species group in the sw planning area

Bryozoans perform a similar function to corals. They form erect growths that provide structure to seafloor habitats, which increases three-dimensionality and biodiversity, and supports the life-history stages of economically significant species. In New Zealand, studies have shown that the surfaces and interstices of some bryozoan colonies can support extremely high numbers of other taxa (~100 spp.) including polychaetes, molluscs, crustaceans and ascidians (Bradstock and Gordon, 1983). Because many of these taxa are significant component in the diets of fish, bryozoan colonies are thought to play an important role in sustaining fish populations. Whilst no trophic linkages have been demonstrated between bryozoans and fish in the SW marine region, it is considered likely that such interdependencies exist.

Where bryozoans grow abundantly they are important contributors to carbonate sediments. Because the sediments that bryozoans generate provides habitat for animals residing in or on the sediments, the group indirectly contributes to biodiversity. Most of the diversity in marine ecosystems consists of invertebrates living on or in sediments (Snelgrove, 1999). These invertebrates can include large animals such as scallops and crabs, however most species are small such as polychaetes and amphipods. In the SW marine region, bryozoan biofragments are one of the most conspicuous and abundant components of the shelf sediments and may contribute up to 75% of the sediment volume (James et al., 2001). Accordingly, it may be inferred that bryozoans in the SWMP play a central role in the maintenance of the regions biodiversity.

Bryozoans are considered a nuisance by some, as many species grow on the bottoms of ships, causing drag and reducing the efficiency and manoeuvrability of the fouled vessel (Berntsson and Jonsson, 2003). Bryozoans may also foul offshore structures, including oil and gas platforms, resulting in several problems that are of concern for their safe operation (Currie and Jenkins, 1994). In Western Australia, the foundations of offshore petroleum drilling and production platforms have had to be significantly altered to cope with sediment instability generated by unusually high proportions of open framed bryozoans (Phil Bock, personal communication). Yet bryozoans produce a remarkable variety of chemical compounds, some of which may find uses in medicine. One compound, the drug Bryostatin 1, produced by the cosmopolitan bryozoan *Bugula neritina* (also known to occur in the SW marine region) is currently under testing as an anti-cancer drug (Haefner, 2003).

Impacts/threats

A number of reviews highlight the fact that fishing gears such as beam trawls, otter trawls and dredges modify benthic habitats and fauna (Dayton et al., 1995; Jennings and Kaiser, 1998; Thrush and Dayton, 2002). Due to their fragile structure, bryozoan communities are particularly vulnerable to direct damage by fishing gear that is dragged across the seafloor (Bradstock and Gordon, 1983). Moreover, because emergent benthos provide habitat for other fauna, the removal of bryozoan structure during fishing may reduce the suitability of an area for species of commercial importance (Sainsbury et al.1998; Kaiser et al., 2000). In the SW marine region, most trawling effort is concentrated on the edge and upper slope of the continental shelf (Caton and McLaughlin, 2004). It would therefore appear that bryozoan communities occurring within this area are potentially at greatest risk.

In recent years, marine natural product bioprospecting has yielded a considerable number of drug candidates. Marine invertebrates such as bryozoans, whose immense genetic and biochemical diversity is only beginning to be appreciated, look likely to become a rich source for the discovery of more effective drugs (Haefner, 2003). To date, little is known about the status of many marine medicinal populations or indeed the size and biological significance of the medicinal component of mortality. In 1988, 13 metric tonnes of the Bryozoan *Bugula neritina* were collected in southern California by a pharmaceutical company to yield 18g of Bryostatin 1 for use in clinical trials (Cragg, 1998). The ecological consequences of such levels of harvesting are unclear. In terrestrial ecosystems bioprospecting has directly caused declines in plant species (Pinheiro, 1997), and it would appear that impacts are likely to be most pronounced if an organisms is rare or has a restricted distribution. In view of the high diversity and biomass of bryozoans in the SW marine region, it is clear that the area has the potential to be a future locus for medicinal compounds. However, because little is known about the ecology or distribution of bryozoans in the SW marine region, it is currently impossible to assess potential impacts on, or conservation status of, all species that may be collected.

Given that temperature is a key delimiter of benthic distribution, it is likely that sedimentary faunal shifts have occurred, or will occur, as a result of global warming (Snelgrove, 1999). Ultimately, global warming will compress or eliminate habitats as the fauna are shifted. Another concern is that global warming may change ocean circulation (Manabe et al., 1994), thus affecting productivity, larval transport, and ultimately the community structure of bryozoans and other benthos.

Information gaps

A considerable amount of literature has been published on the systematics and taxonomy of bryozoans from the SW marine region (Bock and Cook 1993, 1998a, 1998b, 1999, 2001a, 2001b; Conroy, et al., 2001; Cook and Bock 2001; Hayward and Parker 1994; Parker and Cook 1994), however virtually no detailed information is available on their ecology or distribution. This is partially due to the relatively unexplored state of Australia's marine environment and the cost and operational difficulty of survey work offshore. More directly however, it is thought to be a reflection of the limited importance placed by government agencies on invertebrate research in general (Ponder et al., 2002).

Key references and current research

- The International Bryozoology Association (IBA) brings together research on everything bryozoan from over 40 countries across the globe. Their web site is a resource for information on current research and literature. The site is hosted by the Natural History Museum, London (www.nhm.ac.uk/hosted_sites/iba).
- The web site Recent and Fossil Bryozoa (maintained by Dr. Phil Bock) provides an Australian gateway to bryozoan research. This site includes detailed descriptions and photographs of over 1000 species, electronic copies of research papers and links to other published works. The site is hosted by the RMIT University, Melbourne (www.civgeo.rmit.edu.au/bryozoa/default.html).

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4.14 Ascidians

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Species group name and description

Phylum: Chordata
Sub-phylum: Tunicata
Class: Ascidiacea

The Ascidiacea commonly known as ascidians or sea squirts are sessile filter-feeding animals – either in solitary or colonial forms that are found from intertidal to hadal depths. Ascidian larvae are tadpole-like and possess a notochord relating them to other members of the phylum Chordata.

Adult sea squirts are found attached to rocks, shells, pilings, boat bottoms or lying on, or rooted in, sediments of the sea floor. An opaque, transparent or translucent tunic that varies in consistency from gelatinous to leathery surrounds their soft body. The tunic, which is secreted by the ectoderm of the adult animal is composed of ‘tunicin’ related chemically to plant cellulose; this is unique in the animal kingdom. The tunic gives the basic shape to the ascidian and has a branchial (incurrent) opening, its ‘mouth’, which is sometimes on a funnel-like projection of the body wall (a siphon) and an atrial (excurrent) opening that may also be on a siphon. Neatly embedded within this tunic, and connected at the openings, is a muscular body, possessing a perforated pharynx, nerve ganglion, gut, heart, liver and gonads. The mouth leads into the large perforated pharynx. Cilia line the perforated pharynx and drive a current of water through the body, from which food is caught on a mucous sheet. This food-laden mucous moves into and through an oesophagus, a small stomach and an intestine and rectum. Faecal pellets, which are released through the anus are expelled through the exhalent siphon with the spent water and gametes. In colonial ascidians many small bodies ‘zooids’ are embedded in a common tunic and are connected - with different taxonomic groups having different degrees of organisation (Kott, 1997).

All ascidians are hermaphrodites: fertilisation can be external with development in the water column (usually solitary species) or internal with embryos brooded in the body (colonial species). Larvae do not need to feed and attach within a few hours. Ascidians secrete a substance that attaches their test to a hard substrate, or have hair-like extensions of their test that can attach to looser particles (Kott, 1997).

Ascidians have evolved along two main lines: the Aplousobranchia that have a mainly colonial habit and vegetative replication, and the Stolidobranchia and Phlebobranchia that have larger and better developed organs (such as increased filtering area) that enhance their efficiency as solitary animals. Ascidians from Australian waters have been documented in monographs by Kott (1985, 1990a, 1990b, 1992a, 1992b, 2001).

Identification of ascidians is a specialised task requiring a rigorous collecting methodology and dissections of specimens required to assess the internal organisation of gut and other organs.

Status

No ascidians in the South West marine region are designated as threatened, endangered or rare. However, as many marine environments, have not been studied in detail, the SW marine region in particular, we do not know how much biodiversity has been lost, nor the importance of loss to small and large-scale environmental processes.

All benthic fauna within the Great Australian Bight Marine Park Benthic Protection Zone are protected from bottom trawling (DEH website, 2005). Throughout the rest of the SW marine region ascidians are not currently protected in commonwealth waters. Some marine parks (Jurien Bay Marine Park) and fish habitat protection areas (Cottesloe Reef Habitat Protection Area) have been established in this region in State waters.

Habitat and distribution

Habitat

Ascidians are a conspicuous component of most benthic communities, and in southern Australia have been reported to depths of 600 m (*Ascidia challengeri* in Tasmania, Kott, 1985). There are deep-water species that live on or are rooted in, soft, muddy substratum and are known to occur at depths exceeding 2000 m. However, the majority of ascidians inhabit shallower waters where they attach themselves to hard structures such as rocks, the bottoms of ships, coral rubble, encrusted on other organisms, lying on the sea floor or rooted in its sediments.

The conditions that could affect ascidian distribution include light and water flow. Studies have demonstrated correlations between these variables and ascidian distributions over small spatial scales. For example, Bingham and Reynes, (1999) identify ultraviolet light as a major constraint associated with shallow water distributions of *Corella inflata*. As ascidians are sessile filter feeders they also flourish in areas of high current, and thrive in areas with increased nutrient content. Water flow can, however, limit the species that can persist. Animals inhabiting regions of high flow have to be sufficiently robust to withstand the associated turbulence and scouring from algal fronds. Species without a toughened test tend to inhabit more protected waters or have a preference for deep sheltered habitats near the base of vertical substrata, away from areas of high water flow and any algal canopy (McDonald pers. obs).

One of the more conspicuous species is *Pyura spinifera*. This species is encrusted by the sponge *Halisarca* sp. and ranges in colour from vibrant yellow to dusky pink and purple, the colour changes often associated with changes in depth (McDonald pers. obs). It has a large fleshy head that is supported by a long thick stalk that has been recorded up to 1m in length. The large size of these animals effectively restricts them to less turbulent deeper waters where they are less influenced by the ocean swells.

Distribution

There are an estimated 3000 species of ascidians known worldwide with 700 in Australia (Kott 2005b) and 300 recorded from southern Australia (Edgar, 2000).

Australia's tropical ascidian fauna has a range into the Indo-West paciic coralline region. The temperate fauna contains species that appear to have use the Australian continental shelf as a bridge to extend their range from the tropics. It also contains indigenous species and a very few species that may be relicts of a Gondwana fauna, having been recoded also from New Zealand (Kott 2005).

Kott (1972a, 1972b and 1975) examined ascidian fauna from the South Australian Gulfs and west coast of South Australia, where she found evidence of 'a marine faunal boundary at the eastern end of the Great Australian Bight'. A high degree of endemism was noted for the northern GAB (Kott, 1975). The SW region is likely to have elements of temperate and tropical species as summarised by Kott (1997). These elements include indigenous species known from the central to eastern southern Australia, Flindersian fauna from SW Australia to the Bass Strait, and a wider Flindersian fauna extending up the western coast (Kott 1997).

Ward *et al* 2006, collected sessile benthos from 65 sites across the eastern GAB; ascidians were collected from 53 of these sites. In the Ward study, an estimated 138 nominal species of ascidian were collected (17 percent of the total number of macro – invertebrate sessile species collected). The ascidians are lodged at the South Australian Museum but have yet to be identified, during the sorting of these specimens similar specimens were 'split' rather than 'lumped' until identification can be performed, so the species number is likely to be lower than the original estimate.

Significance of the Species Group in the SW Marine Region

Ascidians, like all filter feeders, are an important link between the benthic and pelagic system, as they actively filter plankton and organic detritus from the seawater. These organisms are an important and integral component of the marine system important in their use of space, cycling of nutrients, maintaining water clarity, and in providing food, shelter and recruitment structures for many organisms, including many commercial fish, crustacean and mollusc species.

Results from a recently completed expedition by the Southern Surveyor (late 2005) may add to our knowledge of ascidian diversity at depths of 100-1000 metres.

Ascidians, along with other sessile marine organisms, are targeted by biochemists in the search for marine natural products for medicinal purposes the most notable of these was the discovery in 1981 of an anti-cancer drug called didemnin B (Reinhardt et al. 1981) from the Caribbean ascidian, *Trididemnum solidum*. Scientists from the University of Melbourne have investigated the chemistry of some benthos from the Great Australian Bight including isolating new Chromenols (Rochfort et al. 1996) from the tunicate *Aplidium solidium*.

Impacts/threats

The most obvious threat to ascidian communities in this region is trawling. As with most sessile benthos, ascidians are easily damaged as very little is known about the basic biology, rates of mortality and recruitment, reproduction, growth and age of ascidians. As such it is difficult to determine how anthropogenic disturbance may impact upon these animals.

Ascidians can thrive in areas with increased nutrient content, which are often associated with anthropogenic activity. This activity may cause stress in natural communities and lead to alterations in community structure. The 'natural' communities can then be susceptible to the introduction of introduced ascidian species, such as *Ciona intestinalis* (see McDonald, 2004). Introduced pests including *Ciona intestinalis,* are known to rapidly cover the substratum, smothering and eventually excluding native species (Lambert & Lambert, 1998). Spread of introduced species increases the risk that habitats of high conservation and/or economic value (marine parks, aquaculture sites) will be impacted.

Information gaps

To date most studies on ascidians in the target region have been taxonomic, often limited to areas easily accessible to the collector. Aside from brief statements about collection points made in the taxonomic literature (see Kott references), and a recent study in the Great Australian Bight there is very little ecological data on species within the South West marine region slope or deep shelf environments.

Shallow water ascidians have been identified in specific regions, e.g. the Recherche Archipelago (McDonald, 2005; McDonald *et al,* 2005), Marmion Marine Park (Lemmens *et al,* 1995), Cockburn Sound (Clapin, 1994 Clapin *et al,* 1997) but in comparison to many parts of Australia there is a paucity of information on the Ascidiacea in the SW marine region.

Ascidian growth, reproduction and recruitment, are perhaps the most important processes regulating the population dynamics of these organisms. Despite this, neither of these areas been widely researched for any species.

Although Kott's specimens are registered in Museums along with habitat and depth information, the enormous task of collating of data from different museum registers is prohibitive to quickly assessing the data available in Australia. For example the South Australian Museum has no electronic database, and even the number of ascidians held there cannot easily be obtained.

Key references and current research

The ABRS Fauna Online website is a source of taxonomic and biological information being compiled for all animal species known to occur in Australia, the ascidian database (Kott, 2005) includes a full list of references on the biology and taxonomy of Australian ascidians.

Apart from the studies by Kott (1985-2001), ascidian research in South Australia has been restricted to inshore species in the SA gulfs eg: recruitment (Davis 1987), larval dispersion (Davis and Butler 1989) population dynamics (Davis 1989), and community composition (Butler and Connolly, 1999). The main body of research on ascidians in Western Australia is conducted at the University of Western Australia (UWA) and government institutions, such as the Western Australian Museum (WAM). The aquatic ecology group at WAM (Principal investigator: Jane Fromont) and the marine ecology group from the University of Western Australia (Principal investigators: Justin McDonald, Gary Kendrick) are investigating the ecology of benthic invertebrates. Previous research by CSIRO and Curtin University documented the "Clearance rates of four ascidians from Marmion Lagoon, Western Australia" (Lemmens, *et al*., 1995).

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4.15 Elasmobranchs

Sharks, rays and chimaeras

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Species group name and description

Sharks, Rays and Chimaeras are cartilaginous fishes belonging to the class Chondrichthyes, subclass Elasmobranchii (Compagno 1973). The most recent Australian review suggests that Australia is particularly rich in chondrichthyan diversity with at least 297 of an estimated worldwide total of 1025 species found within our territorial waters (Shark Advisory Group 2002).

This review estimates that at least 152 chondrichthyan species (95 sharks, 51 rays, 6 chimaeras) may be found in the South West Marine Region (SW marine region). The region possesses an equally high level of endemism with 22 species (8 sharks, 14 rays) thought to be endemic to the bioregion (Last & Stevens 1994). The diversity and level endemism found in the region would suggest that it may be of global significance with regard to the conservation and status of chondrichthyan fishes.

Status

The status for most sharks in the SW marine region is presently unknown however the the following species are known to have significant populations and / or aggregation sites within the SW marine region and have been listed by the World Conservation Union (IUCN) as Vulnerable [Criteria in brackets]; White Shark, (*Carcharodon carcharias*) - [Global: A1cd+2cd], the Whale Shark, (*Rhincodon typus*) – [Global: A1bd+2d], and the Grey Nurse (*Carcharias taurus*) – [Australia: A1abcd], (Cavanagh et al 2003). All are fully protected by Australian state and federal laws.

Grey nurse sharks became the first protected shark in the world when the NSW government declared it a protected species in 1984 (Pollard et al. 1996). The species was listed nationally as Vulnerable in 1999, under the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act) and is now also protected under the Western Australian Wildlife Conservation Act (1950) and by State fisheries regulations in Queensland and Tasmania. A recent review indicates that the west coast population of grey nurse sharks is relatively large and stable (McAuley 2004b) and the IUCN assessment for the west coast population has subsequently been downgraded from Vulnerable to Near Threatened.

The white shark is a wide-ranging species across temperate Australia however a recent review of white shark biology in Australia (Malcolm et al 2001) suggests that white sharks may be more abundant in the SW marine region than other parts of Australia and that a number of locations in the region are important for white sharks at different life-stages. This information may imply that the SW marine region is an area of significance to the conservation and management of white sharks not only in Australian terms, but possibly in a global context.

At least 8 shark species appear to be endemic to the bioregion; all are typically demersal and occur in inshore waters and on the shelf.

Common name	*Scientific name*
Ornate angel shark	*Squatina tergocellata*
Cobbler wobbegong	*Sutorectus tentaculatus*
Ginger carpet shark	*Parascyllium sparsimaculatum*
Blotched catshark	*Asymbolus funebris*
Bighead catshark	*Apristurus sp* F
Western spotted catshark	*Asymbolus occidus*
Variegated catshark	*Asymbolus submaculatus*
Black-spotted catshark	*Aulohalaelurus labiosus*

Table 4.15.1 Shark species endemic to the South West Marine Bioregion

With the exception of the ornate angel shark little is known of the biology of these species.

A number of sharks are commercially exploited in the SW marine region, the most important species being the dusky shark (*Carcharhinus obscurus)*, gummy shark (*Mustelus antarcticus*), whiskery shark (*Furgaleus macki*), school shark (*galeorhinus galeus*) and sandbar shark (*Carcharhinus plumbeus*). Recent stock assessments (McAuley 2004a, Walker et al 2003) for these species indicate the following:

- the breeding stock of dusky sharks (*Carcharhinus obscurus*) is overexploited and recruitment of neonate dusky sharks has decreased in recent years
- mortality of larger dusky sharks from capture in the Commonwealth-managed pelagic longline fisheries, by WA-managed 'wetline' methods and from entanglement in plastic packing straps has likely contributed to depletion of the dusky shark breeding stock
- whiskery shark (*Furgaleus macki*) biomass is higher than previously estimated and appears to be stabilising only slightly below the target biomass level
- the biomass of mature female whiskery sharks has been increasing marginally for three years
- effort creep in the temperate gillnet fisheries is reducing the probability of achieving the whiskery shark biomass target
- gummy shark (*Mustelus antarcticus*) biomass is apparently increasing
- allowable catches of sandbar sharks (*C. plumbeus*) has recently been reduced due to sustainability concerns
- school shark are currently overexploited with current total biomass between 20-59% of the total virgin biomass, or between 19-43% of mature virgin biomass

At least 49 species of skates and rays may be found in the SW marine region (Last & Stevens 1994) of which up to 19 may be endemic. Age, growth, diet, distribution and reproductive biology have variously been documented for a small number of commonly occurring species including the lobed stingaree (*Urolophus lobatus*), sparsely-spotted stingaree (*U. paucimaculatus*), masked stingaree (*Trygonoptera personata*) and western shovelnosed stingaree (*T. mucosa*) (Platell et al 1998, White et al 2001, 2002). However, for most of the skate and ray species found in the SW marine region little is known of basic biological parameters such as fecundity, age of maturity, and litter size, while similarly geographical distribution and stock status within the region is also often poorly described.

The IUCN has assessed the status of only a handful of non-shark chondricthyans of which, the following may occasionally occur within the bioregion; the Manta Ray, *(Manta birostris,* Smooth Stingray, *(Dasyatis brevicaudata),* Coffin Ray, *(Hypnos monopterygius),* Western Shovelnose Ray, *(Aptychotrema vicentiana),* Southern Fiddler Ray, *(Trygonorrhina fasciata),* Elephant Fish, *(Callorhinchus milii),* and White-spotted guitarfish, *(Rhynchobatus djiddensis).* Only the white-spotted guitar fish is considered at risk being listed Globally as Vulnerable (A2bd+3bd+4bd) and as Near Threatened in Australia.

Common Name	*Scientific name*
Abyssal Skate	*Bathyraja sp* **A**
Oscellate Skate	*Dipturus sp E*
Pygmy Thornback Skate	*Dipturus sp M*
Southern Round Skate	*Irolita waitii*
Blotched Skate	*Notoraja sp* **D**
Sandy Skate	*Pavoraja sp* **C**
Magpie Fiddler Ray	*Trygonorrhina melaleuca*
Western Shovelnose Stingaree	*Trygonoptera mucosa*
Striped Stingaree	*Trygonoptera ovalis*
Masked Stingaree	*Trygonoptera personata*
Circular Stinagaree	*Urolophus circularis*
Wide Stinagaree	*Urolophus expansus*
Lobed Stingaree	*Urolophus lobatus*
Coastal Stingaree	*Urolophus orarius*

Table 4.15.2 Ray and skate species endemic to the South West Marine Bioregion

Habitat and distribution

Sharks inhabit a wide range of coastal and offshore habitats and depths and while typically marine in distribution may also inhabit estuarine and freshwater systems (Last & Stevens 1994). The distribution, biology and ecology of the pelagic and demersal shark species found in the shelf and inshore waters of the SW marine region are highly varied.

Some of the pelagic species that inhabit the offshore waters of the SW marine region include blue (*Prionacae glauca*) and oceanic whitetip (*Carcharhinus longimanus*) and whale sharks (*Rhincodon typus*). These species are quite diverse in there ecological function; whale sharks are plankton feeders which migrate long distances throughout the Indo-Pacific while the apparently ubiquitous blue and oceanic whitetip sharks are predominantly fish and cephalopod predators.

Deep sea demersal shark stocks are typically dominated by dogfishes (Squalidae), of which there are two distinct ecological groupings: the first occupy the upper-slope region in depths between 200 and 650 m, the second group occur mid-slope between 650 and 1200 m depth. Both groups have different habitats, species compositions, reproductive biology and subsequent vulnerability to capture. Fishery, market and independent survey data indicate that some upper-slope species have been depleted (Daley et al. 2002).

Dusky sharks are common in temperate and tropical waters around the world and in Western Australia occur in the greatest abundance between the Pilbara and a line of longitude of about 120° E on the south coast. The species has also been recorded in South Australia, but is less common in southern waters, where the similar looking copper shark (*Carcharhinus brachyurus*) is more abundant (McAuley 2004a).

The gummy shark inhabits shallow southern continental shelf waters between Geraldton and northern New South Wales. A CSIRO study has found that while gummy sharks caught along the south coast of WA are from the same genetic population as those caught in south-eastern Australia, the results of microchemical analysis of jaw cartilage and differences in their reproductive biology suggest there is limited mixing between regions (McAuley 2004a).

The whiskery shark is found in southern continental shelf waters between North West Cape in Western Australia and Bass Strait, although is most common in the southern half of WA. This species typically inhabits rocky reef areas and forages almost exclusively for octopus and other cephalopods (Simpfendorfer et al 2001a)

The sandbar shark (*Carcharhinus plumbeus*), also known locally as the thickskin shark, is a medium sized whaler shark that is widespread around the world in temperate and tropical continental shelf and adjacent oceanic waters. Its range in Australia is similar to that of the dusky shark but does not extend as far into the southern latitudes. In WA, *C. plumbeus* is mainly found between the Kimberley and Albany on the south coast. The stock is largely segregated by size, with juveniles apparently preferring deeper continental shelf waters (>100m) south of Shark Bay but moving into shallower waters (50m-100m) between summer and early winter. Adults are most commonly found in depths greater than 40m between the Eighty Mile Beach in the Pilbara and the Abrolhos Islands. Adults can also be found in deeper water (>100m) south of the Abrolhos Islands during summer and autumn. (McAuley 2004a)

School shark have a global temperate distribution and are found in Australia and New Zealand as well as the western Pacific and Atlantic oceans. School sharks are typically demersal and can inhabit shallow coastal waters as well as occurring across the continental shelf and down to 800m depth along the continental slope. The species appears to have fairly discreet pupping and nursery areas, which are often in shallow protected bays and estuaries (Walker et al 2003).

Rays generally inhabit marine waters (coastal and offshore) and are typically demersal or epibenthic in nature, though a handful of species can be said to be truly pelagic. Rays are carnivorous and given their predominantly demersal distribution are typically benthic feeders. Most have crushing teeth and feed primarily on invertebrates such as molluscs, worms and crustaceans.

A number of stingaree species inhabit shallow coastal waters in the region including *Urolophus lobatus, U. paucimaculatus, Trygonoptera personata* and *T. mucosa*. The geographic distribution of these four species appear to be strongly overlapping but studies by researchers at Murdoch University (Platell et al 1998) have shown that these species segregate by habitat, diet, feeding strategy and depth thereby reducing the potential for inter-specific competition.

Significance of the species group in the SW planning area

Nearly every part of a shark carcass can be utilised by humans either for food or in the production of other products, making sharks one of the most versatile fish species for exploitation. The fins, skin, meat, internal organs and cartilage can all be used either as food or in natural health and medicinal products while shark liver oils are also used in the production of lubricants (Musik 2004, Trinder et al 2005). Despite this versatility within the region sharks have historically been targeted primarily for their flesh, with fins providing additional product in recent years due to increased demand from eastern Asian markets. The predominant use for most shark species caught in the SW marine is for human consumption though some species such as dusky and sandbar sharks also produce fins suitable for export. In Australia some common market names used for sharks and shark meat include; flake, monkfish & dogfish. Though many rays and skates are also edible these species are not utilized to the same degree as sharks.

Indigenous fishing

Coastal indigenous people were the traditional custodians of Australia's fishery resources and many indigenous communities continue to maintain an active interest in the use, conservation, and management of fish resources. Fish, including sharks and rays, crustaceans and molluscs are of significant nutritional, economic and cultural importance for many coastal indigenous communities. The Western Australian Department of Fisheries released a management paper- the Aboriginal Fishing Strategy (Franklyn 2003) – aimed at addressing the issues surrounding the cultural rights of aboriginal communities in WA south west to the fish resources found in the region.

While such general information is available on indigenous use and attitudes towards fish resources there is little quantitative information available on indigenous fishing activities in the SW marine region. The only significant study in recent times to address the issue of indigenous fishing practices in Australia – The National Recreational and Indigenous Fishing Surveys (Henry and Lyle 2003) focused on northern Australian aboriginal communities only and therefore only inferences can be made regarding indigenous customary fishing of shark stocks within the SW marine region.

Commercial Fishing

Demersal gillnet fishing

Sharks are targeted by a number of commercial fisheries in the region.

(The following information is adapted from Penn et al. 2005)

Two managed commercial shark fisheries operate in the Western Australian area of the SW marine region. These are the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery (JASDGDLF) and the West Coast Demersal Gillnet and Demersal Longline (Interim) Managed Fishery (WCDGDLF). The majority of operators in these fisheries use demersal gillnets and primarily target shark though scalefish comprise a significant component in the catch. The three main shark species targeted by fishers in WA are the dusky whaler shark (*Carcharhinus obscurus*), whiskery shark (*Furgaleus macki*) and gummy shark (*Mustelus antarcticus*) although the sandbar or thickskin shark (*Carcharhinus plumbeus*) is also targeted by commercial fishers on the west coast.

The south and west coast fisheries are controlled through two similar management plans.

The JASDGDLF covers waters from latitude 33° S to the WA/SA border. For the purposes of management, the fishery is composed of two zones. Zone 1 extends from latitude 33° S around the coast as far as longitude 116°30' E, and Zone 2 from 116°30' E to the WA/SA border (129° E). The WCDGDLF extends north from latitude 33° S along the WA coastline to latitude 26° S.

The JASDGDLF was declared a limited entry fishery in 1988 and is managed under a joint authority with the Australian Government. This fishery is managed primarily through effort controls in the form of time/gear units. One unit allows a fisher to use one 'net' for one month. This management strategy was introduced in 1992 and net length has been modified to reduce effort in a series of stages through to 2000/01 (see State of the Fisheries Report 2000/01). All JASDGDLF units now permit the use of either 270 m of demersal gillnet (15 or 20 mesh-drop) or 90 demersal longline hooks for one month.

The WCDGDLF is currently managed as a limited entry fishery, under an interim management plan introduced in 1997. Under the interim plan, the fishery is managed using effort controls in the form of time/gear units, with each unit allowing a net length of 540 m. Implementation of the full management plan is currently awaiting the outcomes of legal challenges to the proposed unit allocation.

Estimated value of the shark and scalefish catch from the JASDGDLF is $3.3 million with shark fins providing an estimated additional $875,000 in revenue. In the WCDGDLF the sale of sharks and scalefish provided $950,000 in product with an estimated additional $350,000 coming from shark fins.

Species		JASDGDLF	WCDGDLF	Total
Gummy	*Mustelus antarcticus*	380	27	407
Dusky	*Carcharhinus obscurus*	182	95	277
Sandbar (thickskin)	*Carcharhinus plumbeus*	30	134	164
Whiskery	*Furgaleus macki*	133	30	163
Hammerhead	Sphyrnidae	36	21	57
Wobbegong	Orectolobidae	32	22	54
Blacktip.	*Carcharhinus* spp	7	27	34
School	*Galeorhinus galeus*	14	0	14
Shovelnose rays	Rhinobatidae, Rhynchobatidae	0	6	6
Skates and rays		4	0	4
Copper	*Carcharhinus brachyurus*	0	4	4
Pencil	*Hypogaleus hyugaensis*	2	0	0
Other sharks		54	4	58
	TOTAL	**875**	**369**	**1244**

Table 4.15.3 Commercial shark and ray catches from WA's demersal gillnet fisheries in 2002/03 (adapted from Penn et al 2005)

In South Australia sharks are targeted in the Southern Shark Fishery (SSF) sector of the Commonwealth managed Southern and Eastern Scalefish and Shark Fishery (SESSF). The SESSF is an amalgamation of 4 fisheries – the South East Trawl (SET), South East Non-Trawl (SENT), Southern Shark (SS) and Great Australian Bight Trawl (GABT) fisheries (DEH 2003).

The SESSF is one of the major Commonwealth managed fisheries, landing over 35,000 tonnes annually and with a value of around $95 million. The SESSF is a complex multi species fishery that targets scalefish and shark stocks of various size, distribution and composition. Overall the SESSF covers nearly half the waters of the Australian Fishing Zone of mainland Australia and Tasmania, extending from 80 nautical miles off the coast near Fraser Island to Cape Leeuwin in Western Australia. The fishery operates in both Commonwealth and State waters under complex jurisdictional arrangements due to different Offshore Constitutional Settlements (OCS) with State Governments (DEH 2003).

The Australian endemic gummy shark is the main target species in the SSF and represented approximately 80% by weight of the total catch in the fishery in 2002/03 (Caton 2003). School shark are taken as byproduct in the fishery and comprise approximately 10% of the total catch, by weight. A recent assessment of school shark stocks suggests that at current exploitation levels the species is unlikely to rebuild to its target level by 2011 (Caton 2003). Some relief from fishing pressure on school sharks may occur in coming years as industry reports that fishers are directing their effort away from this species, both because of the need for the stock to recover and because processors are paying less for school shark than previously (Caton 2003). While this may produce a positive outcome for school shark, it is also likely to lead to increased pressure on gummy shark stocks. Sawsharks and elephant fish are minor components of the SSF with the take of both regulated through the allocation of annual quota. Annual catches are reported to be relatively stable over recent years and there is unlikely to be any significant impact on these stocks as a result of commercial fishing pressure.

Species		Catch (tonnes)
School	*Galeorhinus galeus*	196.8
Gummy	*Mustelus antarcticus*	1512.4
Elephantfish	*Callorhincus milli*	33.5
Sawshark	Pristiophoriidae	163.9
	TOTAL	1906.6

Table 4.15.4 South Australian shark catches in the SSF (adapted from Caton 2003)

Rays, skates and chimaeras make up only a small component of the JASDGDLF, WCDGDLF and SSF and detailed information regarding species composition, level of discards and likely survival of released fish is not available.

Thickskin (sandbar) shark, *Carcharhinus plumbeus*. (image courtesy of Rory McAuley, WA Fisheries)

Large dusky shark, *Carcharhinus obscurus* (image courtesy of Rory McAuley, WA Fisheries)

Pelagic longlining

Sharks make up a significant proportion of the catch in tuna and billfish longline fisheries operating within the SW marine region but due to a landing limitation of 20 sharks per trip imposed by the Australian Fisheries Management Authority the commercial significance of sharks in these fisheries are relatively small. Pelagic species regularly taken by longline fisheries in the region include; the blue shark (*Prionacae glauca*), the crocodile shark (*Pseudocarcharias kamoharai*), the shortfin mako (*Isurus oxyrhyncus*) and the oceanic whitetip shark (*Carcharhinus longimanus*). Blue and oceanic whitetips are typically retained within the 20 trunk limit as they provide excellent fins suitable for export, mako sharks are often retained for the meat, particularly sub-adult and juvenile fish, yet, despite markets existing overseas, crocodile sharks are invariably discarded even when fishing trip shark quotas are not met by other species.

Species		Number Discarded	Number Retained	Weight Retained
Blue	*Prionacae glauca*	21,517	1,859	39,430
Crocodile	*Psuedocarcharias kamoharai*	10,036	0	0
Shortfin mako	*Isurus oxyrhincus*	1,217	85	1,397
Blacktip	*Carcharhinus spp*	70	8	60
Oceanic whitetip	**C. longimanus**	664	84	1,045
Bronze	*C..brachyurus*	470	30	400
Dusky	*C. obscurus*	44	10	665
Silky	*C. falciformis*	0	1	60
Tiger	*Galeocerdo cuvier*	48	2	60
Porbeagle	*Lamna nasus*	23	0	0
Hammerhead	*Sphyrnidae*	613	59	833
Thresher	*Alopiidae*	67	6	130
Shark unspecified		7	0	0
	TOTAL	34,776	2144	44,080

Table 4.15.5 Shark catches in the Southern and Western Tuna and Billfish Fisheries in 2003 (adapted from Lynch 2004)

Though not listed in the table above the pelagic stingray (*Dasyiatis violacae*) and manta ray (*Manta birostris*) are also occasionally caught by longline fishers operating in the SW marine region. Both species are usually discarded alive.

Bottom trawling

The ornate angel shark (*Squatina tergocellata*) forms an important component of the multispecies catch of demersal trawlers in the Great Australian Bight Trawl Fishery (GABTF) and is also taken in the Western Australian Deepwater Trawl Fishery (WADTF). The GABTF began in 1988, and since then *S. tergocellata* has risen from the seventh to the third most important commercial species, by weight (Bridge et al 1998).

About 14 species of dogfish (*Squalidae*) are taken in bottom trawl fisheries operating in southern Australian waters, including the GABTF and the WADTF. Dogfish were historically targeted for their liver oil but are now mainly retained as byproduct for flesh. The total catch in the year 2000 was estimated to be approximately 1500 tonnes (whole weight) with a landed value of approximately $1.5 million. This figure represents a mix of dogfish species and the catch weight for the group exceeds any single species of shark in Australia, with the exception of the gummy shark, yet catches of dogfish are essentially unregulated. [Taken from Daley et al 2002].

Being predominantly demersal in nature skates, rays and chimaeras commonly occur in the bycatch of bottom trawl fisheries, including the WADTF and the GABTF. The following table lists the main recorded chondrichthyan catch landed (in tones) in the GABTF between 1995 and 2002

Common name	1995	1996	1997	1998	1999	2000	2001	2002	Total
Angel Shark	97	105	140	99	109	73	88	125	**836**
Saw Sharks	24	30	28	26	23	24	34	31	**218**
Gummy Shark	15	18	20	13	12	11	22	28	**139**
Dogfish	1	3	12	14	13	7	9	6	**65**
Wobbegong	3	3	5	2	2	4	4	11	**33**
School Shark	2	7	5	4	2	4	2	1	**26**
Shark "Other"	1	2	3	3	4	0	1	0	**14**
Rays	0	0	0	5	0	0	1	-	**6**

Table 4.15.6 Catch of sharks and rays in the GABTF between 1995 and 2002 (adapted from Lynch and Garvey 2003).

In addition, Brown and Knuckey (2002) report the following species as being taken but not usually landed in the GABTF; Ogilby's ghost shark, Bight ghost shark, wide stingaree, fiddler ray, whitley's skate, smooth stingray, eagle rays, electric rays, shovelnose rays (Rhinobatidae) and numbfish (*Narcine sp*). Accurate data on the WADTF catch composition are not available.

Recreational Fishing

There is generally little detailed information concerning recreational shark catches in Australia and the SW marine region is no exception, despite the fact that recreational fishing is a highly popular activity in Australia. The most recent and comprehensive review of recreational fishing estimates that the national participation rate of the population above the age of 5 years is 19.5%, which equates to an estimated 3.36 million Australian residents (Henry and Lyle 2003). Rates of fishing participation recorded in both Western Australia (28.5%), and South Australia (24.1%) were above the national average in 2000 (Henry & Lyle 2003) and given that almost 88%, of the WA's recreational fishing effort occurs along the west and south coasts (Penn et al 2004), it would seem that the SW marine region is a significant area for recreational fishers. The bioregion also supports a high number of licensed tour operators, particularly in WA.

Henry and Lyle (2003) estimated that over 55, 000 individual sharks and rays were caught in SA (30,722) and WA (24,432) in 2000 by recreational fisherman, but that more than 81% of the catch was discarded. Shark captures were also recorded from a number of marine zones being; coastal (50%), estuarine (40%) and offshore (10%) habitats. Given the diverse range of species and sizes in the region any estimation of the chondrichthyan biomass removed from the region by recreational fishers is likely to be highly variable, particularly given the lack of detailed data on size and species composition of the catch. While the estimated number of shark and ray captures each year appear quite high, the high level of discards and the general resilience of sharks and rays in relation to capture by hook and line methods (pers comm. D Gaughan, WA Fisheries) would suggest that recreational fishing is unlikely to place significant pressure on most stocks. Exceptions to this may be those species with local populations that are already depleted and that are more likely to be retained than discarded, either because they have high quality flesh, such as school shark, or are of significant trophy value to sports fishermen, such as tiger sharks (Lowry and Murphy 2003).

Impacts/threats

In general, sharks are known to be particularly susceptible to fishing pressure because of their generally slow growth, late sexual maturity, and low fecundity (Stevens et al. 2000, Malcolm et al. 2001) and fishing is by far the greatest threat to the status of sharks in the SW marine region. Within the region there are a number of commercial and recreational fisheries, which take sharks either as target species, or as byproduct and bycatch. Some species that may be at risk due to fishing efforts include grey nurse, white shark, sandbar shark, school shark and the southern and endeavour dogfishes.

As a direct result of management actions, fishing effort in the WA demersal gillnet and longline fishery has been reduced to 42% of its historical peak. Recent research by the WA Department of Fisheries has also shown that a significant proportion of the seabed within the functional area of the WA demersal gillnet fishery is unsuitable or rarely used for commercial fishing operations and thus provides significant natural refugia for many demersal shark species. Despite this western Australian dusky and sandbar (thickskin) shark stocks are currently over exploited and are at risk of serious depletion. The main reasons for this is that both species are taken in WA's demersal gillnet and longline fisheries. Some spatial relief from fishing pressure is provided by the closure of marine waters north of Latitude 26º 09' S (Steep Point) and west of Longitude 114°06' E (North West Cape) to shark fishing methods and recent changes to the boundaries of the northern WA shark fisheries should further extend the area available as refugia to these species. However, both species are capable of long distance travel and consequently individuals are capable of traversing the entire length of protected coastline and beyond into legally fishable grounds. (pers comm R. McAuley, WA Department of Fisheries).

Spatial closures in the SESSF, between Eyre Bluff and the WA / SA border are designed to protect the breeding school shark populations whilst also allowing operators access to the known gummy shark areas (AFMA 2004). This closure is intended to relieve some of the fishing pressure on the currently overexploited school shark populations.

Unlike in NSW and Queensland, grey nurse sharks have never been subject to targeted fishing in Western Australia, subsequently the only significant source of *C. taurus* mortality has been through incidental capture by the demersal gillnet fishery. Given the decrease in effort in this fishery and the presence of natural refugia from fishing pressure, the risk to grey nurse sharks is currently relatively low and this is the main reason behind the IUCNs recent decision to downgrade the status of the Western Australian population (Cavanagh et al 2003).

It is estimated that approximately 200 white sharks are caught in Australian waters each year with the largest proportion of these taken within the SW marine region. Most of these are either juveniles or sub-adults and while about 40% are released alive, post-release survival rates are unknown (Malcolm et al 2001). White sharks are also targeted (under permit) by shark control programs in NSW and Qld and given a recent spate of lethal shark attacks on humans in both WA and SA, there may be public pressure to see similar programs introduced around swimming beaches in heavily populated areas with in the region. Based on studies in South Africa, NSW and Qld (Dudley 1997, Dudley et al 1998), the establishment of a shark control program in WA or SA could have significant impacts on great white sharks and a number of other coastal shark species.

A number of dogfish species appear to be impacted by commercial bottom trawling in Australia, while some have been specifically targeted using demersal gillnets and longlines. Species of *Centrophorus* particularly appear to be vulnerable to over-fishing as they produce small litters (1-2), are long lived (at least 46 years) and are fished throughout their full vertical distribution. *Centrophorus harrissoni* has a small endemic distribution and is not only at risk of extirpation but may even be at risk of extinction. It appears unlikely that catch restrictions alone would enable threatened *Centrophorus spp* to recover, consequently additional measures such as seasonal closures or closed areas may be considered as part of recovery programs. Other dogfish species taken by bottom trawl fisheries operating on the slope within the SW marine region include *Deania calcea* and *Centroscymnus coelolepis*.

Interactions between sharks and aquaculture pens holding tuna, salmon and other finfish have been recorded in SA and Tasmania. These interactions hold the potential to cause injury and death to the sharks involved either through entanglement and drowning or through the unavoidable destruction of the animal due to safety concerns for farm staff. White sharks are one species which has been recorded in and around tuna pens in SA and any mortality to this species has the potential for posing a significant impact on the SA population. Other species attracted to aquaculture pens include whalers such as duskies, bronzies and blue sharks. A workshop was recently held by the South Australian Research and Development Institute (SARDI) to look at ways of removing entangled or entrapped sharks from tuna pens in a manner which is safe for both farm staff and the shark itself (Murray Jones 2004). Recent advances in shark handling and removal techniques should greatly alleviate the risk posed to large sharks by entanglement and entrapment in aquaculture pens or infrastructure.

Pollution and habitat loss or degradation may also pose minor threats to some populations. School shark pupping and nursery areas are often found in shallow embayments and estuaries and the loss or degradation of these areas through trawling activity, coastal development or industrial pollution could have potential impacts on recruitment and survival rates of juveniles (Walker et al 2003).

Information gaps

There are still many gaps in our knowledge on the biology and ecology of sharks and rays in the SW marine region. Currently only four species of shark, the dusky, sandbar, school and gummy sharks, have been sufficiently studied to provide reliable pictures of their respective current stock status, and not surprisingly these four species comprise the main target species in the WASF and SSF. Detailed information on basic biological parameters, movements and stock status of pelagic oceanic sharks are still required. Species such as blue, crocodile and oceanic whitetip sharks are regularly taken by pelagic longline fisheries yet little is know about the reproductive biology, movements and stock status of these species. Likewise, detailed population information on deepwater dogfish such as *Centrophorus spp* is required. Dogfishes are targeted and taken as bycatch in eastern Australian commercial fisheries and while not targeted at the same levels within the SW marine region, knowledge concerning this group of sharks is needed for effective management.

Given the presence of major shark fisheries within the region, there is also a current and urgent need for research into the ecosystem effects of the removal of apex predators such as sharks within the region. While there is still very little known about white shark growth, reproductive biology and movements, it appears evident that the SW marine region is of importance to the species and consequently more work is required to elucidate the life history of this species if conservation efforts are to be successful.

As can be seen from the biological data tables, there is even less knowledge regarding the biology and ecology of rays and skates than sharks. The life history of most ray species found within the region has not yet been documented and the stock status of even fewer species has been assessed to date. While the need to gain further knowledge on most rays is possibly not as urgent as it is for some shark species, the fact remains that significant gaps exist in our knowledge on this broad group of elasmobranchs.

Key references and current research

Research

Recent research on sharks has focused on the biology and movement of key species including; the western Australian population of grey nurse sharks (WA Fisheries), great whites in the GAB (CSIRO) and school and gummy sharks in the SSF (CSIRO, MAFRI). Other work has focused on the utilization of shark carcasses (i.e. meat, internal organs, skin and cartilage) that are taken in various commercial fisheries around Australia and on mercury levels in shark meat destined for human consumption. Projects just completed by the WA Fisheries Department Research Laboratories include; biology and stock assessment for the thickskin (sandbar) shark, *Carcharhinus plumbeus*; Shark DNA database for compliance and management purposes, and population biology and movements of grey nurse sharks, as already mentioned.

Researchers at Murdoch University are currently conducting a number of studies on the biology of selected shark and ray species on the lower west coast of Australia. In particular studies on the biology of the Port Jackson shark *Heterodontus portusjacksoni,* and the levels of shark and ray bycatch in demersal trawl fisheries in the region and their impacts are currently underway. This work will be expanded in the coming years to investigate the trophic effects of removing sharks from coastal marine ecosystems within the region.

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4.16 Demersal fish – inshore

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Species group name & description

The planning area known as the South-West Marine Region (SWMR) spans the warm, subtropical waters of Shark Bay, through to the temperate waters of southern Kangaroo Island off the central coast of South Australia. Within this large area, the inshore demersal fish fauna is diverse, with at least 830 currently recognised species within 433 genera, in waters between the shore and 50m deep[1]. Demersal fish in the SWMR are supported by a variety of habitat types, such as estuaries, subtidal seagrass beds, many types of reef, and a variety of muddy, sandy and rubbly habitats.

Some inshore demersal fishes are completely habitat dependent, and do not move away from their "home" reef, seagrass bed or sand patch. Others are more wide ranging, or live in several different habitats throughout the stages of the lifecycle. The juveniles of many inshore demersal species utilise inshore, seagrass-lined estuaries, or sandy / muddy bay habitats for feeding and protection, and then migrate offshore as adults, to reefs or other habitats. Examples of species with such segregated life stages include King George Whiting, Pink Snapper, Ocean Leatherjacket, Spangled Emperor, Western Smooth Boxfish, Rock Ling, some of the leatherjacket species (Monacanthidae), and many others.

The inshore demersal fishes have many feeding strategies. Some, particularly the larger reef fish, are purely carnivorous, eating smaller fish, and/or benthic invertebrates. Some examples include emperors (Lethrinidae), groupers, Harlequin Fish and other serranids, adult Dhufish, and Pink Snapper. A few groups of demersal fish are "ambush predators", such as anglerfish and stargazers, whose large,

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[1] A complete species list is available from the author

trapdoor-shaped mouths are capable of rapidly seizing larger fish that fall prey to their feeding approach.

Some carnivorous fish eat only invertebrate prey, which differs according to the size and age of the fish (e.g. Blue-throated Wrasse - Shepherd and Clarkson, 2001). As adults, many inshore demersal fishes prey upon invertebrates, such as amphipods, isopods, polychaetes and other worms, small crabs, sea urchins, chitons, and small gastropods. In a given area, various benthic carnivorous fishes (such as whitings, trevallies, flatheads, goatfish, silverbelly, gurnard perches, and bullseyes) can co-exist, by each eating a largely different set of invertebrate prey (Platell and Potter, 2001). Even within a single family (e.g. Sillaginidae), a comparatively large number of species can co-exist together in a given area, by differing in their foraging behaviour, food preferences, and age-related movements (Hyndes et al., 1997). A number of inshore fish have planktivorous juveniles, and carnivorous adults (e.g. Silver Trevally) (Kailola et al., 1993). Some species are omnivorous, and feed on macroalgae or seagrass, as well as small crustaceans and other invertebrates. Examples include Dusky Morwong (May and Maxwell, 1986), and Sea Garfish (Noell, 2004). The SWMR, which contains areas of high algal biomass, supports numerous herbivorous fishes. Examples in southern waters include Silver Drummer, Zebra Fish, Southern and Western Sea Carp, Herring Cale, and Victorian Scalyfin, and studies in S.A. have shown that herbivores typically comprise 8-10% of the total numbers of fish in a community (Shepherd and Baker, in press). A few species, notably the lampreys[2], are parasitic on other fishes as adults. Other specialised feeders include the group of cleaner fish species, which pick parasites off larger “client” fish at “cleaning stations” (usually reefs). Examples of cleaners recently observed within the SWMR include Western Cleaner Clingfish, Moonlighter, and Pencil Weed Whiting (Shepherd et al., 2005).

Reproduction is varied in nearshore fishes. Some reproduce throughout the year (e.g. Silverbelly *Parequula melbournensis*, Sarre et al., 1997), and some have a distinct seasonal spawning period (e.g. Silver Trevally, Estuary Catfish, Jackass Morwong, and many others). A number of groups, notably the Labridae and Serranidae, contain members that are protogynous hermaphrodites, whereby individuals start life as a female and then change sex to reproduce as a male. Some inshore fish have wide-ranging larvae (e.g. West Australian Dhufish, King George Whiting, Silver Trevally) and others reproduce locally and have limited dispersal ability, including live-bearing fishes (e.g. Clinidae weedfishes and snake-blennies); mouth-brooding groups (e.g. Apogonidae cardinalfishes, and the tropical Opistognathidae jawfishes); nesting species (Gobiesocidae clingfishes, many of the Gobiidae gobies, and also the Estuary Catfish); cave-dwelling species; and groups such as the syngnathids and the frogfishes, that exhibit specialised forms of parental care.

Status

As in other countries, it is difficult to adequately assess the conservation status of marine fish species in southern Australia. For many species, there is poor knowledge of the distribution, relative abundance, critical habitats and threatening processes (e.g. Pogonoski et al., 2002), compared with that for terrestrial and freshwater fauna.

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[2] Lampreys are a primitive group of jawless fish, whose members have a cartilaginous skeleton and a notochord, and are thus not classed with bony fish (Hardisty, 1986).

For a small number of fish species, the geographic distribution appears to be extremely limited, making populations of such fishes potentially vulnerable to decline from site-specific impacts. Examples include (i) Braun's Wrasse *Pictilabrus brauni*, which has been found only in one small reef area off a beach in south-western Australia; only a few specimens have even been recorded, despite 25 years of surveying, including a number of searches in the area from where the type was collected (Hutchins and Morrison 1996, and B. Hutchins, pers. comm., cited by Pogonoski et al., 2002), and (ii) the Golden Roughy *Paratrachichthys pulsator*, a small, cave-dwelling, light-emitting reef fish known to date from only one island off the west coast of Eyre Peninsula, South Australia (Gomon and Kuiter, 1987).

However, for other species, the apparent, limited distributions and uncommonness are likely an artefact of inadequate sampling (particularly of small, cryptic reef fish, and also species in habitats beyond diving range, or not subject to fishing), and the opportunistic, rather than systematic, nature of existing collections. Other limitations include ongoing uncertainty about the taxonomic identities of some marine fishes (particularly suites of species of very similar appearance), which in some cases have been confused, rather than aided, by the advent of genetic studies.

Nevertheless, there are doubtless threats faced by populations of many inshore fish species, principally decline in habitat quality and available area, and, for some of the more common and edible species, over-fishing.

In recent years, a national overview of the conservation status of some families of marine and estuarine fish has been produced, with a strong emphasis on large reef fish (in the Labridae and Serranidae), and syngnathids (Pogonoski et al., 2002). Further, a comprehensive publication is being produced on the status of approximately 320 marine fish in continental shelf waters of southern Australia (particularly South Australia), including detailed information on the known distribution, habitats, biology, current conservation status at international, national and state levels, vulnerable population characteristics, threatening processes, current research and management, and recommendations (Baker, in press).

Currently, the majority of marine fish species that are formally protected under legislation in southern Australia are in the Syngnathidae family, comprising the seahorses, seadragons, pipehorses and pipefishes. In both S.A. and W.A., the Leafy Seadragon *Phycodurus eques* is a protected species, and a permit is required for its capture. As of January 2006, all other syngnathids in South Australia are also protected under legislation. The conservation status of syngnathids at international, Commonwealth, and State levels is discussed in detail in a companion chapter (Baker, this volume). Within the SWMR, fishes other than the syngnathids that are formally protected under legislation include the following:

- *Achoerodus gouldii* Western Blue Groper: Protected from capture, under the *South Australian Fisheries Act*
- *Epinephelus lanceolatus* Queensland Grouper: Protected from capture under legislation in W.A. and New South Wales);
- All members of the Serranidae (e.g. groupers, estuary cod) over 120cm: Protected from capture under legislation in W.A.

Two tropical species, rarely occurring as far south as the mid-west W.A. coast, are also protected under legislation in W.A.:

- *Cheilinus undulatus* Humphead Maori Wrasse (found on offshore atolls)
- *Epinephelus tukula* Potato Cod.

Species for which a national conservation status was recommended in a report for the Australian Government Department for the Environment and Heritage (AGDEH) report *Conservation Overview and Action Plan for Australian Threatened and Potentially Threatened Marine and Estuarine Fishes* (Pogonoski et al., 2002), include the following. As yet, only two of these are formally protected under legislation (see above). For most of these species, the Australian Society for Fish Biology (2001) recommended the same status as appeared in the AGDEH report:

- *Pictilabrus brauni* Braun's Wrasse: *Lower Risk – Near Threatened*
- *Choerodon rubescens* Baldchin Groper: *Lower Risk – Least Concern*
- *Cheilinus undulatus* Humphead Maori Wrasse: *Lower Risk – Conservation Dependent*
- *Cromileptes altivelis* Barramundi Cod: *Lower Risk – Conservation Dependent*
- *Achoerodus gouldii* Western Blue Groper: *Lower Risk – Conservation Dependent*
- *Epinephelus lanceolatus* Queensland Grouper: *Lower Risk – Conservation Dependent*
- *Brachionichthys* sp. Australian Handfish / Common Handfish: *Lower Risk – Least Concern*
- *Pegasus* (= *Acanthopegasus*) *lancifer* Sculptured Seamoth: *Lower Risk – Least Concern*
- *Ophiclinops hutchinsi* Ear-spot Snake-blenny: (*Data Deficient*)
- *Sympterichthys* (= *Brachionichthys*) *verrucosus* Warty Handfish / Verrucose Handfish: *Data Deficient*
- *Peronedys anguillaris* Eelblenny: *Data Deficient*

A number of fish species within the SWMR are listed internationally in the *IUCN Red List of Threatened Species*. In addition to several syngnathid fish (see Baker, this volume), others within the SWMR that are listed by IUCN include:

- *Epinephelus lanceolatus* Queensland Grouper: *Vulnerable* (A2d)
- *Epinephelus coioides* Estuary Cod*: Near Threatened*
- *Plectropomus leopardus* Leopard Coralgrouper (Coral Trout): *Near Threatened*
- *Epinephelides armatus* Breaksea Cod: *Near Threatened*
- *Choerodon rubescens* Baldchin Groper: *Least Concern*
- *Cheilinus undulatus* Humphead Maori Wrasse: *Endangered* (A2bd+3bd)
- *Cromileptes altivelis* Barramundi Cod*: Data Deficient*
- *Pegasus lancifer* Sculptured Seamoth: *Data Deficient*

In South Australia, a recent review of threatened species listings for terrestrial and freshwater biota (NPWC and DEH, 2003), also included recommendations for formal protection of a number of estuarine fish. Such species that occur in the SWMR, for which recommendations were made, include:

- *Geotria australis* Wide-mouthed Lamprey / Pouched Lamprey: *Endangered*
- *Mordacia mordax* Short-headed Lamprey: *Endangered*
- *Anguilla australis* Short-finned Eel Shortfin Eel: *Rare*
- *Pseudaphritis urvillii* Congolli / Tupong: *Rare*

Habitat and distribution

Distribution

IMCRA Technical Group (1996, 1998) divided the coastal marine environment of Australia into biogeographic provinces, with transitional "biotones" in between. Each province and biotone has specific oceanographic and biophysical characteristics, and a set of "indicator" fish, usually species of restricted range, has been devised for each province. Within the SWMR, biogeographic provinces and biotones include:

- Gulfs Province: Area 67,350 km^2, comprising the Spencer Gulf and Gulf St Vincent, and enclosing Kangaroo Island. The province extends out to the shelf break with a western boundary at Port Lincoln and an eastern edge just east of Kangaroo Island. "*A weak but unique province with a small endemic element and a relict element of sub-tropical species. Exhibits a strong disjunction and acts as a biotone for cool temperate species from Bass Strait and Tasmania, and for a large suite of species from the South Western Province (SWP). The hypersaline and sub-tropical temperature conditions in the gulfs are unique to temperate Australia and probably enable this region to act as refugia for species further north*" (IMCRA Technical Group, 1996). Indicator species include the syngnathids *Vanacampus vercoi*, *Filicampus tigris* and *Acentronura australe*, and the Crested Triplefin *Trinorfolkia cristata.*
- Great Australian Bight Biotone: Area 200,000 km^2, from Esperance in the west to Port Lincoln in the east. "*A weak biotone dominated by SWP species and embedded between this province and the Gulfs Province. A major disjunction exists near the Recherche Archipelago resulting from the western limit of a suite of wide ranging species from the Central Eastern Province and the Tasmanian Province, and the eastern limits of the South Western Province (SWP). The biotone is also traversed by a large suite of wide ranging western warm temperate species that extend along the southern Australian coast to the Gulfs Province, Bass Strait Province and the South Eastern Biotone, and a suite of ubiquitous temperate Australian species that originate in the Central Eastern bioregions".*
- South Western Province: Area: 52,040 km^2, in the south-west W.A., from Perth to about Esperance. "*A major provincial region forming part of Whitley's (1937) Flindersian Province and part of Hutchins' (1994) Leeuwin Province which extends from Coral Bay in the north to the Recherche Archipelago, with a "core" region extending from Shark Bay to Albany. The South Western Province (SWP) is defined by two primary distribution types: western warm temperate species that emerge from the South Western Biotone and extend into the Great Australian Bight Biotone and the Gulf Province; and more widely distributed elements that extend from the South Western Biotone eastward into Bass Strait. A smaller suite of eurythermal species extend northward into the Central Western Biotone. Major disjunctions exist at its western and eastern boundaries. Some species from the Central Western Province (CWP) extend southward to this region*". Indicator Species include the snake-blennies *Ophiclinops hutchinsi* and *O. pectoralis*, the W.A. endemic scalyfin species *Parma bicolor* and *P. mccullochi,* Orange-spotted Pufferfish *Torquigener vicinus*, Large-toothed Flathead *Platycephalus chauliodous*, the clingfishes *Cochleoceps viridis* and *Aspasmogaster occidentalis*, the Western Hardyhead *Leptatherina wallacei.*

- <u>South Western Biotone</u>: Area: 23,120 km^2, from Perth in the south to approximately Geraldton in the north. Described as "*a most extraordinary marine biotone characterised by strong disjunctions occurring throughout its range. An extensive region over which a range of western warm temperate species emanating from the South Western Province (SWP), Great Australian Bight Biotone, the Gulfs Province, and the Bass Strait Province, and more widespread species from eastern regions (e.g. Central Eastern Province) terminate. It is also the southern limit of a suite of western sub-tropical (Central Western Biotone) and tropical elements. Hutchins (1994) notes this region to be dominated by tropical elements at the northern end of the biotone with one category of tropical species (D) extending to the southern limit. Hutchins found that warm-temperate species dominate the bulk of the region, with a lesser and more even spread of sub-tropical elements throughout the biotone*".
- <u>Central Western Province</u>: Area 40,250 km2, from approximately Geraldton in the south to Carnarvon at the head of Shark Bay in the north. Defined by "*a suite of subtropical species that extend from the South Western Biotone and western sector of the South Western Province (SWP) to the Central Western Biotone and southern limits of the North Western Province (NWP). This faunal unit has been recognised by Hutchins (1994). Represents the southern part of Whitley's (1937) Damperian Province*". Indicator species include Western School Whiting *Sillago vittata*, Prophet's Pipefish *Lissocampus fatiloquus* and Ladder Pipefish *Festucalex scalaris*, Paxman's Leatherjacket *Colurodontis paxmani*, Paxton's Toadfish *Torquigener paxtoni*, Spiky Bass *Hypopterus macropterus* (Gunther, 1859), Bigeye Gurnard Perch *Maxillicosta lopholepis,* and the Western Frogfish *Batrachomoeus occidentalis.*
- <u>Central Western Biotone</u>: Area: 27,370 km2, from the mouth of Shark Bay to just north of North West Cape in the north. The north-western limit of eurythermal southern temperate and SWP species, subtropical CWP species, and southern limits of NWP species and a suite of wider ranging tropical species.

At the eastern end of the SWMR, Kangaroo Island is a transitional region between south-eastern and south-western Australian fish faunas (Wilson and Allen 1987, cited by Shepherd and Baker, in press). For a number of south-eastern Australian fish species, Kangaroo Island and the central South Australia coast is the western geographic limit. Such species include *Latridopsis forsteri* (Bastard Trumpeter), *Histiogamphelus briggsii* (Brigg's Crested Pipefish), *Tasmanogobius gloveri* (Marine Goby), *Heteroclinus* sp. 4 (Coleman's Weedfish), the estuarine goby species *Tasmanogobius lasti* (Lagoon Goby), and the eel species *Conger verreauxi* (Southern Conger Eel), and *Anguilla australis* (Short-finned Eel), a freshwater species that spawns in the sea. Further west, the Eyre Peninsula / eastern Great Australian Bight area is the western geographic limit for a number of the south-eastern Australian weedfish species, such as *Heteroclinus johnstoni* (Johnston's Weedfish), *H. perspicillatus* (Common Weedfish) and *H. wilsoni* (Wilson's Weedfish).

In W.A., based on an analysis of 18 families, Hutchins (1994, 2001) divided the fish fauna of the W.A. coast into 4 groups: South-west (Recherche to Pt Dennison and Kalbarri); North-west (Abrolhos and Shark Bay to Dampier); Offshore Atolls; and Kimberleys. A considerable number (at least 68 species) of inshore fish, especially reef-dwelling species, are considered to be endemic within that State. In particular, the south-western region (Augusta through to the Great Australian Bight), and the central west coast (e.g. Shark Bay area) support a large proportion of W.A.'s endemic fish species.

The Shark Bay / Houtman Abrolhos region, at the northern end of the SWMR, is a transitional zone between major marine biogeographic provinces (see above), thereby also functioning as a transitional region for temperate and tropical marine fauna (IMCRA Technical Group, 1998; Australian Government DEH, 2005a). At least 350 scalefish fish species, of which more than 80% are tropical, have been recorded in the Shark Bay area alone (Hutchins, 1990a; Hutchins et al., 1995, cited by DEP, 2001) and about 372 from the Houtman Abrolhos (Hutchins, 1997a). The Shark Bay / Houtman Abrolhos region, at the northern end of the SWMR, is the southern limit in W.A. for many widespread Indo-Pacific tropical fish, including large species such as Bonefish, some of the emperors (Lethrinidae), various *Epinephelus* coral cods and rock cods, 7 of the tropical reef snappers (*Lutjanus*), several maori wrasses, as well as smaller fish, such as some of the damsels, pullers, butterflyfish and numerous species of cardinalfish[3]. Some of the tropical species do not spawn in the area, but their larvae travel southwards on the Leeuwin current from more northerly breeding populations (Hutchins, 1997b; B. Hutchins, pers. comm.., 2006), particularly during March-April, when the current strengthens (Hutchins and Pearce, 1994).

A number of widespread tropical and sub-tropical reef fish species also extend southwards towards the south-western W.A. coast (Hutchins, 1991; Hutchins and Pearce, 1994), partly due to the Leeuwin Current, which has an important influence on the climate and marine ecosystems of Western Australia (Pearce and Walker, 1991; Pearce and Pattiaratchi, 1999). Many such tropical species were recorded recently during a survey in the Jurien Bay Marine Park (data by G. Edgar, N. Barrett and colleagues, reported in Bancroft, 2003).

Further south, Rottnest Island is the published southern limit for the tropical species *Epinephelus lanceolatus* (Queensland Grouper) and *E. rivulatus* Chinaman Rockcod, *Gomphosus varius* (Bird Wrasse), *Platax teira* (Teira Batfish), *Upeneus tragula* (Bar-tailed Goatfish), and *Plagiotremus tapeinosoma* (Yellow Sabretooth Blenny), amongst others.

Within the SWMR, there are several taxa that are the western representatives of a “species pair”, each with a counterpart in south-eastern Australia (Wilson and Allen, 1987; Hutchins, 1994; Burridge, 2000). Some examples include the Queen Snapper *Nemadactylus valenciennesi*, the Striped Perch *Pelates octolineatus*, the Western Blue Devil *Paraplesiops meleagris*, and the Western Cleaner Clingfish *Cochleoceps bicolor*.

Habitats

Within the SWMR, common habitats for nearshore fish include, very broadly, estuaries (many with supratidal saltmarsh and intertidal mangroves), intertidal and subtidal seagrass beds; intertidal and subtidal sand, mud and rubble habitats; intertidal and subtidal reefs; and mixed habitats (e.g. patch reef in seagrass or in sand). Less commonly occurring habitats for inshore fish include bottoms dominated by rhodoliths, and sponge “gardens” (Howard, 1989; Harvey, 2002a; Bryars, 2003; Baker, 2004).

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[3] A list of species for which Shark Bay or Abrolhos Is. is the southern limit, is available from the author.

Estuaries: Estuarine habitats, of which there are few in western South Australia but many in south-western Australia, have important feeding and sheltering functions for many nearshore marine fish species, and are critically important as “nursery areas” for juveniles of many coastal fish species. For example, many juvenile fish feed on the epifauna in estuarine Eelgrass (*Zostera*) beds (Connolly, 1994a). Recent work in W.A. has shown that for inshore fish species with a low dispersal capability, populations of fish species that live in estuaries either permanently or temporarily, have greater genetic subdivision, compared with populations of fish species that are restricted to marine habitats (Watts and Johnson, 2004).

Examples of species for which estuaries provide important ecological functions, particularly as “nurseries” for juveniles, are given below. Many of them are of major commercial and/or recreational significance in the SWMR: King George Whiting, Yellowfin Whiting, Western School Whiting and Western Trumpeter Whiting, mullets (Yellow-eye, Jumping, and Sea), Mulloway, Southern Sea Garfish and Western River Garfish, species of flathead and flounder, Estuary Catfish (Cobbler), Black Bream, Striped Trumpeter, Yellowtail Trumpeter, Tarwhine (in W.A. estuaries as juveniles, prior to their migration into marine waters when larger), Australian Herring, Perth Herring (in W.A.), Tommy Ruff, West Australian Salmon, and the pelagic schooling fish Australian Anchovy (Lenanton, 1982; Jones, 1979, 1980, 1984; Loneragan et al., 1986; Connolly, 1994a, 1994b; Potter and Hyndes, 1994; Jones et al., 1996; Hyndes et al., 1996; Connolly et al., 1997; Valesini et al., 1997; Kanandjembo et al., 2000; Bloomfield and Gillanders, 2005)

In addition to feeding and sheltering functions, estuaries are also used as spawning areas for both estuarine-dependent species (e.g. Black Bream, Western River Garfish) and for nearshore marine species that inhabit estuaries for only part of the life cycle (e.g. Yellowfin Whiting, Yellow-eye Mullet, Yellowtail Trumpeter, Jumping Mullet, and Perth Herring) (Jones, 1984; Loneragan et al., 1986; Potter and Hyndes, 1994, 1999; Kanandjembo et al., 2000; Bryars, 2003). Estuaries that are only open intermittently support a greater number of estuary-spawning fish species than permanently open estuaries (Potter and Hyndes, 1999). A study of seasonal changes in the fish fauna of the hydrologically-variable Swan-Canning Estuary near Perth, showed that 17 of 34 species sampled during the survey, spawn in the upper estuary (Kanandjembo et al. 2000).

Large numbers of smaller fish, such as species of hardyhead and goby, can be very abundant in the saltmarsh, seagrass, sand and muddy habitats of estuaries in the SWMR (Prince et al., 1982; Potter et al., 1986; Gaughan et al. 1990; Neira et al., 1992; Humphries and Potter, 1993; Jones et al., 1996; Connolly et al., 1997; Jackson and Jones, 1999; Potter and Hyndes, 1999; Kanandjembo et al. 2000). Such species are a food source for larger estuarine and marine fauna. Other common smaller fish in estuaries include species of weedfish (Clinidae), pipefish (Syngnathidae) and the Weeping Toado (known as “Blowies” in W.A.).

Of particular note in estuaries of South Australia are the juveniles (“Salmon Trout”) of the West Australian Salmon, a species which exhibits environmentally-driven “pulses” of strong recruitment into sheltered estuaries such as Barker Inlet, following current-mediated spawning events in south-western Australia, and subsequent transport of eggs, larvae and post-larvae across the Great Australian Bight (Lenanton et al., 1991; Jones, 1999). In W.A., the life cycle of this species is strongly influenced by both the tropical Leeuwin Current (flowing southwards along the W.A.

coast, and eastwards into the GAB) and the cool, inner shelf Capes Current (flowing northwards from Cape Leeuwin, up the central W.A. coast) (Gersbach et al. 1999; Pearce and Pattiaratchi, 1999).

Seagrass: Nearshore seagrass beds are a major feature within the SWMR, particularly Shark Bay on the mid-west coast, and along parts of the south-western coast of W.A. (e.g. Cockburn Sound); and in Gulf St Vincent, Spencer Gulf, and the bays of the eastern Great Australian Bight of South Australia. Common seagrass-dwelling fish include various weedy whiting (e.g. species of *Siphonognathus*), Striped Perch *Pelates octolineatus*, the leatherjackets *Monacanthus chinensis* and *Acanthaluteres spinomelanurus,* numerous species of cardinalfish, including the Western Gobbleguts *Apogon rueppellii,* various species of weedfish (Clinidae), clingfish (Gobiesocidae) and pipefish (Syngnathidae), amongst many others (Scott, 1981; Gomon et al., 1994; McDonald, 2000; Travers and Potter, 2002; Browne, 2004).

Reefs: "Reef habitat" is a very broad category, because the SWMR comprises reefs of various forms (topography, shape and orientation), compositions, exposures and covers. Reef forms include intertidal and subtidal platforms, ledges, blocks, boulders, and cobble/rubble reefs. Reef in various parts of the SWMR are composed of granite, metamorphic rocks, calcareous (e.g. limestone) rocks or biogenic materials (e.g. shelly material in upper Spencer Gulf in S.A., and coral along parts of the central W.A. coast). In parts of the south-western and central coast of W.A., extensive limestone reefs are a characteristic feature, and represent a major habitat feature influencing the structure of the coastal fish assemblages (Howard, 1989; Ayvazian and Hyndes, 1995). In S.A. and south-western W.A., shallow subtidal reefs are often dominated by one or more species of large brown macroalgae (some of many examples include *Ecklonia radiata*, *Scytothalia dorycarpa*, *Acrocarpia paniculata*, species of *Cystophora* and species of *Sargassum*, and *Scaberia agardhii*) and/or mixed red, brown and/or green macroalgae of various sizes and forms. Some reefs are covered mainly with calcareous red algae. Deeper reefs are often dominated by invertebrates and red macroalgae where light still penetrates, and by larger sessile invertebrates in deeper or darker water. Coastal reefs in areas of fast current flow and/or with steep depth gradients can contain invertebrate-dominated assemblages that are similar to those on reefs usually found in much deeper water, as occurs on north-eastern Kangaroo Island (Backstairs Passage area). There are hundreds of reef fishes in the SWMR, and a full list is available from the author. Many occur over the reef canopy (e.g. Magpie Perch, Zebra Fish, Dusky Morwong, and many of the Wrasses and Leatherjackets); within the cover of the canopy (e.g. Sea Carps, Herring Cale and Rainbow Cale, Senator Wrasse, some of the Weed Whiting species), or in the shelter of caves and crevices within reefs (e.g. Western Blue Devil, Rock Ling, Golden Roughy, Western Upsidedown Pipefish, Green Moray, and various species of Bullseye) (Shepherd and Brook 2003b; Shepherd and Baker, in press). At the northern end of the SWMR, some of the commonly seen fishes on coral reefs include the angelfishes (Pomacanthidae), butterflyfishes (Chaetodontidae), damselfishes (Pomacentridae), emperors (Lethrinidae), tropical snappers / seaperches (Lutjanidae), parrotfishes (Labridae) and members of the Serranidae (a diverse family that includes "rockcods", seaperches and "coral trouts").

<u>*Artificial "Reefs":*</u> The three-dimensional structure and attached epibiota of shipwrecks, jetties and tyre reefs have important roles in aggregating fish and providing feeding, sheltering and, in some cases, breeding habitat, at localised scales. A few examples of jetty structures in S.A. that attract (I) specific site-associated fish species, and/or (ii) large numbers of fish, and/or (iii) high species richness of inshore fish, include those at Rapid Bay (Shepherd and Baker, in press), Edithburgh, Stenhouse Bay, Point Turton, Wool Bay, Port Giles, Port Hughes, Wallaroo, and Tumby Bay (DIASA, undated; Baker, 2004, and references therein; Dive-Oz, 2005a) In WA, some of the jetties recognised for their fish fauna include those at Esperance, Albany, Busselton, Rockingham, Woodman Point and Fremantle (Dive-Oz, 2005e, and recreational diving reports, 2004)

Artificial reefs made of tyres, concrete blocks or other materials also serve as additional habitat for nearshore fish. Examples of tyre reefs that attract nearshore fish include those at Noarlunga, Glenelg and Coobowie in Gulf St Vincent, Point Lowly in Spencer Gulf, and Geographe Bay in W.A. (Branden et al., 1994; DIASA, undated).

In S.A., some of the wrecks (both historical and recent) of variable importance as habitat for nearshore fish include: the Barge and Dredge at Glenelg, which are popular dive sites that support a wide variety of fish (e.g. MLSSA, 1997; 1999); the *Zanoni*, the *Norma* and the *John Robb* in northern Gulf St Vincent; the Stanvac barges and the *Lumb* off the southern metropolitan area; the recently sunk *Hobart* off the Fleurieu Peninsula; the *Clan Ranald,* and *Willyama* wrecks off southern Yorke Peninsula and the *Glenpark* wreck off Wedge Island; the *Songvaar*, *Australian* and the *Investigator* wrecks in the Port Victoria / Wardang I. area of Spencer Gulf; the *Portland Maru* off north-western Kangaroo I., and the *Degei* tuna boat wreck south of off Port Lincoln (DIASA, undated; Baker, 2004; Dive-Oz, 2005b).

In W.A., examples of wrecks that provide habitat for various types of nearshore fish include the *Gudrun* in Shark Bay Marine Park; the navy ships HMAS *Swan* (at Dunsborough) and HMAS *Perth* (Albany); the Bell Park wrecks off Rockingham; the *Gareenup* (North Mole) wreck off Fremantle; seven vessels at Rottnest I. (some also in the vicinity of natural reefs which are species-rich in fish); the screw steamer *SS Orizaba* off Point Peron; the *Lena* off Bunbury; the *Cheynes III* at King George Sound (Albany); the *Sanko Harvest* near Esperance; as well as the Key Biscayne oil rig structure off Lancelin (Aquanaut, undated; Dive-Oz, 2005f).

<u>*Unvegetated Habitats*</u>: Nearshore sand and gravel habitats, even if apparently "bare", provide important feeding, sheltering and/or other living functions, for numerous fish species. Nearshore "surf-zones" adjacent to beaches provide important habitat for a variety of nearshore fishes, particularly members of the Atherinidae (hardyheads), Mugilidae (mullets), Tetraodontidae (toadfishes), Clupeidae (sprats) and Pomatomidae (Tailor) (Ayvazian and Hyndes, 1995). Examples of species in the SWMR found in the vicinity of unvegetated habitats include school whitings (*Sillago* species), Yellow-eye Mullet and Sea Mullet, Silverbelly / Silver Biddy, Blue-spotted Goatfish, Common Stinkfish, Warty Handfish, Common Stargazer, Sculptured Seamoth, Little Scorpionfish, several species of Gurnard, flounder species (e.g. Small-toothed Flounder *Pseudorhombus jenynsii*, Large-scale Flounder *Engyprosopon grandisquama*, Long-snouted, Spotted, Elongate, and Greenback), flathead species (e.g. Sand Flathead, Yank Flathead),

Southern Sole and Southern Tongue Sole, various species of Hardyhead, toadfish (e.g. Smooth, Whitley's and Prickly), Orange-barred Pufferfish, many of the goby species, and burrowing species such as Beaked Salmon, Serpent Eels, and Worm-eels (Hutchins and Swainston, 1986; Edgar, 2000; Travers and Potter, 2002; Baker, 2004).

Significance of the species group in the south-west planning area

Commercial Fishing

<u>*South Australia*</u>***:*** The South Australian Marine Scalefish Fishery is a multi-gear, multi-species fishery, and has been operating in various forms for at least 160 years (PISA, undated; Noell et al., 2005). A new management plan has recently been devised for this fishery (Noell et al., 2005), following a number of developments during the 1990s and early 2000s, such as licence amalgamation, licence buy-back, increased netting restrictions, various closed areas and seasons, and changes to minimum legal sizes (Noell, 2005, Table 3.2). There were 371 MSF licence holders in 2005 (down from 464 in 1998). Traditionally, fishing effort shifts temporally and spatially between species, depending on their relative abundance and value (SARDI, 2005). The fishery utilises a variety of lines (handlines, longlines), nets (e.g. gill, hauling, beach seine) and traps to catch scalefish. Collectively, in the gulf waters (Spencer Gulf and Gulf St Vincent), and in the shallow waters of the eastern Great Australian Bight (west coast of S.A.), major activities of the MSF include the following (Knight et al., 2004; Noell et al., 2005):

- netting (haul and gill) for juvenile Australian Salmon ("Salmon Trout"), Yellow-eye Mullet, Australian Herring, Snook, Yellowfin Whiting (in the upper gulfs), King George Whiting, and Southern Sea Garfish (the latter also caught by dab netting, with most catches coming from the gulfs region)
- handline fishing for larger King George Whiting, over reefs and sand habitats in the gulfs, and in bays on the West Coast of S.A.
- trolling for Snook and Australian Salmon
- hand-line and long-line fishing for Pink Snapper: larger fish are targetted over natural and artificial reefs, and the majority of the S.A. Pink Snapper catch comes from Spencer Gulf
- hand-line fishing for Sweep and Wrasses, over reefs
- off high energy beaches: 'salmon' and beach seine netting and rod-and-line fishing for Australian Salmon, and rod-and-line fishing for Mulloway

Catch and effort statistics show that between 45 and 50 inshore demersal scalefish species are reported in the annual catch, but only about one dozen of these are caught in quantities considered significant enough for data to be collated and reported. The table below shows the annual MSF catches of major scalefish species, between 1996 and 2005.

Species	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05
Yellow-Eye Mullet	86	106	68	74	72	57	47	45	50
Australian Salmon	555	632	524	457	581	455	576	158	133
Tommy Ruff	204	284	322	302	231	262	197	152	183
Snapper	305	394	447	576	577	648	533	411	504
Yellowfin Whiting	102	74	84	112	152	148	181	163	138
King George whiting	586	552	594	517	453	390	398	355	347
Snook	120	113	117	94	106	99	112	81	
Garfish	513	504	421	476	532	470	332	321	364
Trevally	11	5	5	8	22	5	4	4	10
Wrasses ("Parrotfish")	26	47	47	40	20	24	27	22	24
Flounder species	16	11	28	40	19	*	*	21	27

Table 4.16.1 Catches (tonnes) of the main inshore scalefishes in South Australia (from Knight et al., 2002 and SARDI, 2005) N.B. Excludes figures from the Inland Waters Fishery, which is not within the SWMR boundary, and catches of Ocean Leatherjackets, which are mostly taken in deeper waters (> 60m). * = confidential figures, due to less than 5 fishers.

Knight et al. (2004) provided examples of regional catch statistics, and Baker (2004) detailed some of the locations along the central and western coasts of S.A. in which inshore fish are caught commercially, and the species composition taken.

In addition to MSF licence holders, there is currently also a single separate licence for taking Australian Salmon in S.A. (Noell, 2005). The Rock Lobster fishery in S.A. also has some level of access to the Marine Scalefish Fishery. The main marine scalefish species taken by Northern Zone Rock Lobster fishers include Ocean Leatherjacket, Australian Salmon, Southern Blue Morwong, Pink Snapper, and wrasse species. Southern Zone Rock Lobster fishers (mainly east of the SWMR) take Southern Rock Cod, Australian Salmon and Yellow-eye Mullet (mostly for bait), and Conger Eel (Noell et al., 2005).

Western Australia: Unlike the situation in S.A., commercial fisheries that catch scalefish in W.A. have traditionally been managed as numerous separate fisheries (requiring a Managed Fishery Licence – MFL) in each region of the State. Added to these is the "wetlining" sector, which refers to fisheries that are not under formal management arrangements. The term usually describes the catching of scalefish, using handlines or droplines, and to date, wetlining has been the only commercial fishing activity available to commercial fishers in WA who do not hold an MFL (Department of Fisheries, W.A., 2005k,l). However, during the early 2000s, there was a move towards Integrated Fisheries Management (IFM), which involves the estimation and setting of a total sustainable harvest level for each fish species, and the allocation of explicit catch "shares" for use by each of the principle user groups – commercial, recreational (including charter), indigenous and "passive users" (Department of Fisheries, W.A., 2005k). For simplicity, commercial fisheries in W.A. will be described here on the existing fishery-specific basis, from south to north:

Along the South Coast and South West Coast, West Australian Salmon *Arripis truttaceus* are caught commercially, mainly using beach seines, but also as a byproduct of commercial netting activities in estuarine fisheries (Department of Fisheries, W.A., 2004h; Australian Government DEH, 2004b). The fisheries (comprising about 18 licences in the South Coast, and 15 in the South West Coast) target a westward spawning migration in February-May, and in some years a eastward "back run" in May-August. The commercial harvest in 2001/02 was 2,623 tonnes, of which 1995t was taken in the south coast fishery, and about 627.5t was taken in the south west fishery. In 2003, the total catch was 1,892t, of which 1,157t came from the South Coast (Department of Fisheries, W.A., 2005a). Catches in the past 25 years have fluctuated between 900t and 4,000t, the variation considered largely due to fluctuations in environmental factors and market demand (but see section below on **Impacts / Threats**). Both the Leeuwin Current and the Cape Current are considered important influences on the annual relative abundance and movements of West Australian Salmon (Pearce and Walker, 1991; Lenanton et al., 1991; Pearce et al., 1996; Pearce and Pattiaratchi, 1999), and therefore the number of fish available to the South West sector of the fishery fluctuates, depending upon migration patterns of the salmon. Scalefish byproduct in this fishery is minor (mostly less than 500kg per species group per annum), and includes small quantities of Australian Herring, Sea Mullet and Yellow-eye Mullet (Department of Fisheries, W.A., 2004h; Australian Government DEH, 2004b).

There is a seasonal fishery for Australian Herring along 10 South Coast beaches, using herring (“G”) trap nets. To date, holders of an unrestricted fishing boat licence have been permitted to take Herring throughout the range of their distribution along the lower West and South coasts. Small quantities of Herring are also taken by some estuarine-licensed vessels, and by “wetline” vessels (Nowara and Lenanton, in Department of Fisheries W.A., 2005a). In 2003, 79% (415t) of the State catch (527t) was taken on the South Coast, mostly from the ocean, using trap nets and other gear. The annual catch has continued to decrease since 2000, and has followed a general downward trend since 1991 (Herring Figure 1, in Department of Fisheries W.A., 2005a). Since the mid-1990s, the level of effort has been reduced by 47% through a series of Government buy-back initiatives; however recent catches have declined in excess of that expected from the buy-back. The reported status of the fishery is outlined below, in the section on **Threats / Impacts**.

Between Cape Beaufort and the W.A. / S.A. border, 13 estuaries and inlets are open to commercial fishing as part of the South Coast Estuarine Fishery (SCEF). The SCEF targets finfish species, mainly using gillnet and haul net. The main target species, with catches for 2003, are:

- Cobbler (94t taken in 2003)
- Black Bream (~44t)
- Sea Mullet (~36t)
- leatherjackets (20t)
- Australian Herring (~19t)
- flathead species (~11t)
- Tarwhine or Silver Bream (8.5t)
- King George Whiting (7.5t)
- Pink Snapper (6.6t)
- Yellow-eye Mullet (6t)

(Nowara and Lenanton, in Department of Fisheries, W.A., 2005a). In previous years, Estuary Catfish, Sea Mullet and Yellow-eye Mullet were reported to have constituted between 70% - 90% of the catch from the South Coast estuaries (Kailola et al., 1993). In most years during the past 2 decades, the total annual catch has been within the range of ~ 250t to 400t. Abundance of some of the major species is heavily influenced by environmental variables, hence catches of some of the major species in this fishery fluctuate significantly from year to year.

Between Cape Leeuwin and the W.A. / S.A. border is the South Coast Trawl Fishery, a small fishery for scallops which operates mainly in Bremer Bay, the Recherche Archipelago and Israelite Bay. In years of low scallop catches, licensees may use other gear to target scalefish species (Department of Fisheries, W.A., 2005d). Scalefish byproduct includes flatheads, Footballer Sweep, Queen Snapper, Gurnards (Triglidae), Leatherjackets (Monacanthidae), Blue Mackerel, Redfish (*Centroberyx* sp.) and Trevallies (Carangidae). Between 1990 and 2002, the average catches per annum were 24t of leatherjackets; 9t of Bight Redfish, and nearly 8t of Queen Snapper. The average annual catch of all scalefish taken by fish trawl between 1990 and 2002 was 61t, with a significant range of total catch in this period - including a high of nearly 197t in 1992 and a low of 1.5t in 1996 (Department of Fisheries W.A., 2005c). Some of the scalefish are caught in waters deeper than 50m (i.e. reportedly 100m – 200m) (R. Lenanton, pers. comm., cited in Department of Fisheries, W.A., 2005d), and thus catches will not be discussed further here.

Also on the South Coast, the South-West Beach Seine Fishery targets the pelagic species Whitebait (Sandy Sprat *Hyperlophus vittatus*), with catches of between 150t – 200t per annum during the early 2000s. This fishery is discussed in more detail in the chapter on pelagic fish. Bycatch consists mainly of Sea Mullet, Western Sand Whiting (= Yellowfin Whiting) and the pelagic species Blue Sprat (*Spratelloides robustus*), with a total scalefish bycatch of 73.7 tonnes in 2002 (Department of Fisheries, Western Australia, 2005b).

A small proportion (7%) of the State “wetline” catch in 2002/03 was reported from the South Coast region. Half of the top 10 species were from the shallower part of the continental shelf, and are thus detailed here: Pink Snapper (20t), Samson Fish (15t), Australian Herring (10t), Queen Snapper (6t) and leatherjackets (4t). Fisheries along the south coast are concentrated around Albany, Bremer Bay and Esperance (Department of Fisheries, Western Australia, 2005a).

The Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery (JASDGDLF) operates in continental shelf waters along the south coast of W.A., between Eucla at S.A. / W.A. border and approximately Mandurah on the south-west coast (McAuley and Simpfendorfer, 2003, Figure 2). The demersal gillnet and demersal longline fisheries target various shark species, but finfish are also targetted. Catches along the South Coast in 2003 included: Queen Snapper (33t), Western Blue Groper (24t), Dhufish (8t), Pink Snapper (7t), Redfish (4t), Samson Fish (3t), leatherjackets (4t) boarfishes (3t), and 43t of unspecified scalefish (Gaughan and Chidlow, in Department of Fisheries, W.A., 2005a).

On the West Coast of W.A., the Demersal Gillnet and Demersal Longline Fishery (WCDGDLF), operates from the Mandurah area northwards to approximately Kalbarri (McAuley and Simpfendorfer, 2003, Figure 2). The demersal gillnet and demersal longline fisheries target various shark species, but finfish are also taken. Scalefish catches in 2003 included the following: Queen Snapper (6t), Western Blue Groper (4t), Dhufish (14t), Pink Snapper (13t), Samson Fish (11t), Sweetlip Emperor (11t), Mulloway (8t), plus 20t of unspecified scalefish species (Gaughan and Chidlow, in Department of Fisheries, W.A., 2005a).

A study of the catch composition in the demersal gillnet and demersal longline fisheries during 1994 and 1999, using both data reported by fishers, and fishery-independent research surveys, showed that scalefish comprised between 5% and

17% of the total demersal gillnet and longline catch. Due to discarding, the species composition and abundance differed between fishers' data and research data. Buffalo Bream, *Kyphosus cornelii* and Dusky Morwong, *Dactylophora nigricans* are significant components of the discarded scalefish catch in the demersal gillnet and demersal longline fisheries (McAuley and Simpfendorfer, 2003).

The 'West Coast Demersal Scalefish Fishery' (WCDSF) is a term used to describe commercial access to species or fishing methods not previously subject to a management plan, however formal integrated fisheries management arrangements were being developed in 2005-2006. It has been recommended that the West Coast region be divided into four zones (Kalbarri, Mid-West, Metro and South West), for management of the wetline fleet (Department of Fisheries, W.A., 2005l). The wetline fleet comprises both 'wetline only' vessels and the 'wetline' activities of vessels with other managed fishery licences. The main fishing methods used in demersal wetline fishing are handlines and droplines, and the major fishing areas are the Abrolhos Islands, Perth metropolitan area and the south-west coast. The WCDSF focuses primarily on West Australian Dhufish and Pink Snapper, but also targets a number of emperors (*Lethrinus* species), Baldchin Groper, and Coral trout (*Plectropomus leopardus*), amongst other species (St John and King, in Department of Fisheries, W.A., 2005a). In 2002/03 the catch of the entire fishery was 1,154t, an increase of 60t from the previous year. The main scalefish species landed during 2002/03 included:

- Pink Snapper: 272t, an increase of 22t over the previous year, and although the catch in 2002/03 was above the 10-year average of 204t, it remained well below the last peak in catch of 309t in 1995/96
- Dhufish: 232t, representing the highest reported catch over the last decade, and 50% above the average over the past 10 years (155t), with a current trend of escalating catch approaching the historical peak of 295t in the mid-1980s. Fremantle and Geraldton are two of the West Coast areas in which Dhufish are specifically targeted (Kailola et al., 1993; St John and King, in Department of Fisheries W.A., 2005a)
- two Emperor species (*Lethrinus nebulosus* and *L. miniatus*): 151t caught by 100 boats, mainly from the Abrolhos Is.
- Samson Fish: 75t
- Bight Redfish: 52t
- Baldchin Groper: 41t, an increase of 7t over the previous year, and the highest reported catch for this species since 1993/94
- Sweetlip (Haemulidae): 26t
- Goldband Snapper: 22t (caught in waters deeper than 40m, in the northern part of the West Coast region, off Geraldton)
- Skipjack Trevally: 17t
- Mulloway: 16t
- Coral Trout: 12t, caught by 58 boats in 2003. Geraldton / Abrolhos Is. is one of the main areas where Coral Trout are taken.

About 80 species of scalefish were part of the remainder of the catch. In 2002/03, the six major targeted demersal species comprised 61% of the total catch of all species caught by handline and dropline in the fishery (St John and King, in Department of Fisheries, W.A., 2005a). During 2002/03, 262 licensed fishing boats in the West Coast region line-fished for demersal scalefish, totalling 12,254 fishing days. Over half the catch (50.4% or 582 t), however, was caught by just 20 vessels during 1,087 days (or 8.9% of the total effort). Overall 252 boats reported catching

Dhufish, 243 boats caught Pink Snapper and 164 boats caught Baldchin Groper (St John and King, in Department of Fisheries, W.A., 2005a).

Other fisheries that catch finfish in the West Coast region include the West Coast Estuarine Managed Fishery (WCEF), which operates in the Swan / Canning and Peel / Harvey Estuaries. The Hardy Inlet fishery also shares the characteristics of the west coast estuaries. The main fishing methods used are gillnets and haul nets, but crab pots are also used in the Peel / Harvey Estuary. During the past two decades, some of the key scalefish species taken from the west coast estuaries, have included Black Bream, Cobbler, King George Whiting, Sea Mullet, Yellow-eye Mullet and Western Sand Whiting (Smith and Nowara, in Department of Fisheries, W.A., 2005a). Both catch and effort have declined over a 20 year period in this fishery (e.g. West Coast Estuarine Figure 1, in Department of Fisheries, W.A., 2005). Total catches of scalefish from the West Coast estuarine fisheries in 2003 were:

- Sea Mullet 68.7 t
- Yellow-eye Mullet: 33.8t
- Yellowfin Whiting: 18.2t
- Perth Herring: 11.2t
- Australian Herring: 6.5t
- King George Whiting: 6.2t
- Tailor: 2.6t
- Cobbler: 1.6t
- Other species: 8.9 t

The estuarine fishery in the Hardy Inlet / Blackwood river area takes Yellowfin Whiting and other whiting species, Black Bream, Sea Mullet and Yelloweye Mullet, and Australian Herring. The total annual catch of all species has ranged between 10t and 34t during the past 25 years to 2002 (Department of Fisheries W.A., 2004e).
The West Coast Beach Bait Managed Fishery, which catches the pelagic species Whitebait, is discussed in the chapter on Pelagic Fish.

Also on the West Coast, the Cockburn Sound (Fish Net) Managed Fishery captures scalefish, mainly Australian Herring and Sea Garfish, with opportunistic catches of whiting and mullet (Nowara and Lenanton, in Department of Fisheries, 2005a). The Cockburn Sound (Line and Pot) Managed Fishery takes Sea Garfish, Australian Herring and Pink Snapper. In 2003, about 52t of scalefish were taken in these two fisheries, coupled with the Cockburn Sound component catch from the West Coast Beach Bait and the West Coast Purse Seine Managed Fisheries. The annual finfish catch has generally declined since the peak catch of 165t in 1992. In 2003, the catch of 52t of finfish is a decrease of almost 10t from the previous year's catch. The catch composition in 2003 included about 15 finfish and elasmobranch species. Around 95% of the total catch consisted of Australian Herring, Sea Garfish, Pink Snapper (mainly taken with long-lines), Maray (*Etrumeus teres*) and skates and rays. Catch and effort have both declined since 1999 (Nowara and Lenanton, in Department of Fisheries, 2005a). Small quantities of Australian Herring are also taken by "wetline" vessels, and by some estuarine licensed fishers on both the south and west coasts. In 2003, the west coast "wetline" catch was 111.8t, and included 18.4t from the ocean, 6.5t from estuaries and 86.9t from embayments (Geographe Bay and Cockburn Sound) (Nowara and Lenanton, in Department of Fisheries, 2005a).

Scalefish byproduct is also recorded in the South West Trawl Managed Fishery, which includes two of the State's smaller scallop fishing grounds (Fremantle and

Geographe Bay). In 2003, 7t of Yellowfin Whiting were recorded in this fishery (Kangas, in Department of Fisheries, W.A., 2005a).

Scalefish are a minor byproduct in the Abrolhos Islands and Mid West Trawl Managed Fishery (AIMWTMF), which comprises scallop fishing grounds around some of the Abrolhos Is., and further inshore at the “South Kidney Patch” (seaward of Coronation Beach), as well as prawn fishing grounds off Port Gregory. According to Department of Fisheries W.A. (2004b), less than 1t per annum of mixed scalefish species are recorded in the AIMWTMF. Syngnathids are reported to be a very minor component of the bycatch, and are discarded, dead (Department of Fisheries W.A., 2004b). The composition of scalefish species in the bycatch is purportedly recorded in fishery logbooks.

At the northern end of the SWMR (Gascoyne region), fisheries which take scalefish mainly include the Shark Bay Beach Seine and Mesh Net Managed Fishery (SBBSMNMF); the Shark Bay Snapper Managed Fishery; and the Shark Bay “Wetline Fishery” (in which species such as Samson Fish and Mulloway are caught as byproduct, by fishers licensed for other fisheries, such as Prawn) (Bunting, 2002).

The Shark Bay Beach Seine and Mesh Net Managed Fishery (SBBSMNMF) takes a mixed catch of whiting (*Sillago schomburgkii* and *S. analis*), Sea Mullet, Tailor and Western Yellowfin Bream, using a combination of beach seines and haul nets (Smith, in Department of Fisheries W.A., 2005a). The 2003 total catch for the SBBSMNMF was 324t, an increase of 24t compared to the 2002 reported catch. Since 1990, the total annual landings from the fishery have been stable, with catches averaging 277 t per year. The total landings during 2003 included 106.7t of whiting, 149.2t of Sea Mullet, 27.8t of Tailor and 23.6t of Yellowfin Bream. The remaining reported landings of 16.3t comprised over 18 different species of scalefish. Whitings (95% of which is *S. schomburgkii*) are the main target species in the fishery, and comprised about one-third of the total catch quantity and about 40% of the total catch value in 2003 (Smith, in Department of Fisheries W.A., 2005a).

The Shark Bay Snapper Managed Fishery (SBSMF) uses mechanised handlines to target the oceanic Pink Snapper stock, which is genetically distinct from the inner gulf stocks[4]. The peak season for Pink Snapper in Shark Bay is in the winter months, when the fish form spawning aggregations over the rocky reefs near the islands. After peaking at around 600t during 1959 and 1960, catches declined for a decade until interest picked up in the late 1970s and early 1980s. In 1985, the catch reached an all-time high of 1,300t and concern about over-exploitation resulted in management measures being established, including limited-entry status, and the introduction of quotas, limiting the Total Allowable Catch (TAC) to 550t (Department of Fisheries, W.A., 2004d). Since 2000, the SBSMF fishery has been quota-managed on a year-round basis. A minimum holding of 100 quota units applies and all units are transferable. For the quota period September 2002 – August 2003, the annual total allowable catch of Pink Snapper was set at 563,750 kg (i.e. the same as the previous season). The commercial catch of Pink Snapper was 450t in 1999, 488t in 2000, 467 in 2001, 487t in 2002 (Australian Government Department of DEH, 2004a), and 429t in 2003. Concerns over the level of Pink Snapper spawning

[4] In the inner gulfs of Shark Bay, nine licensed beach seine fishers are permitted to supplement their main catch of whiting and mullet by taking small quantities of snapper (Department of Fisheries, W.A., 2004d).

biomass in 2003 (see section on **Threats/Impacts**), resulted in a TAC reduction to 338t for the 2004/05 season (Department of Fisheries, W.A., 2004d). In recent years, the offshore SBSMF fishery has increasingly targeted a number of other species in addition to snapper, such as the deeper continental shelf species Goldband Snapper and Rosy Jobfish (two *Pristipomoides* spp., of which Goldband Snapper now comprises about 50% of the non-snapper catch by weight); emperors (Lethrinidae) and cods (Serranidae). The collective catch of species other than snapper was 245t in 2003, 158t in 2002, and 105t in 2001 (Moran and Jackson, in Department of Fisheries, 2005a). Discarded bycatch include North-west Blowfish (*Lagocephalus sceleratus*) and Bludger Trevally (*Carangoides gymnostethus*) Australian Government Department of DEH, 2004a). It has been recommended that the SBSMF should be integrated into a wider Gascoyne Demersal Scalefish Fishery (Department of Fisheries, W.A., 2005l).

In 2002/03, the “wetline” sector catch in the Gascoyne region was about 14% of the State total (Department of Fisheries W.A., 2005a). Several of the top 12 species are demersal fishes from the shallower continental shelf waters, with catches in 2003 as follows: 44t of Pink Snapper (caught outside of the Shark Bay Snapper Managed Fishery); 12t of Sea Mullet (the majority of which was reported from the area between the northern boundary of the beach seine fishery and Carnarvon); and 6t of Red Emperor. The wetline sector also catches deeper water continental shelf species such as Goldband Snapper *Pristipomoides multidens* (144t), Rosy Jobfish *Pristipomoides filamentosus* (36t in 2003), Ruby Snapper *Etelis carbunculus* (9t), Grey-banded Rockcod *Epinephelus octofasciatus* (9t), the migratory Cobia *Rachycentron canadum* (7t) and a ”pearl perch” species of *Glaucosoma* (possibly *G. buergeri*, the Deepsea Jewfish). Deeper water continental shelf species are assuming a greater prominence in the catches in recent years, as fishers move from the inner to outer continental shelf (Department of Fisheries W.A., 2005a).

Scalefish species are a minor bycatch in the Shark Bay Prawn Managed fishery (Sporer and Kangas, in Department of Fisheries W.A., 2005a), with scalefish byproduct landings in 2003 consisting 21t of pelagic tuna (not discussed here), 5t of Mulloway, and small quantities of other scalefish species. Due to ongoing concern about the depleted biomass of Pink Snapper in Shark Bay, the Shark Bay Prawn and Scallop trawler fishers volunteered not to take their portion of the Pink Snapper quota for the 2004/05 year (Department of Fisheries, W.A., 2004d).

Recreational Fishing

Recreational fishing for coastal fish species is a significant activity throughout the SWMR, particularly close to population centres. For example, during the National Recreational and Indigenous Fishing Survey (NRIFS) in 2000-01, an estimated 72% of all households in SA with occupants who fished in the 12 months prior to the survey, came from the combined Adelaide and Outer Adelaide statistical divisions, with small proportions from other areas (e.g. 7% from the Northern region; 4% from Yorke Peninsula and Lower North; 4% from Eyre Peninsula) (Henry and Lyle, 2003). Similarly in W.A., the largest proportion of the fishing households came from the metropolitan area (Perth region = 65% of total); with smaller numbers away from the metro area (e.g. 15% in the South West region; 5% in the Upper and Lower Great Southern region, 4% in the Central region, and 3% each in the South Eastern and the Midlands regions) (Henry and Lyle, 2003, Appendix 5.4).

The NRIFS showed that in S.A. and W.A., fishing in coastal waters accounted for 74% and 66% respectively of the total recreational fishing effort (number of events). There was a relatively higher proportion of estuarine fishing (19% of total events) in W.A. compared with S.A. (6%), due to the large number of estuaries in W.A., and their relative accessibility. Offshore fishing in S.A. accounted for a low percentage (3%) of fishing events throughout the survey, compared with nearly 11% in W.A. (Henry and Lyle, 2003).

The following sections discuss some of the main species taken by recreational fishers in the SWMR, according to State-based statistics.

South Australia: Recreational fishing in S.A. is managed mainly using minimum size limits, and bag and boat limts for many of the popular species. During the NRIFS, conducted between May 2000 and April 2001, the combined catch (numbers) of King George Whiting, Australian Herring (Tommy Ruff) and Garfish comprised just over 66% of the total marine and estuarine fish harvest in S.A. (Jones and Doonan, 2005). During that survey, the biomass of King George Whiting, Pink Snapper, Australian Salmon and Australian Herring were higher than that of any other finfish species caught (Jones and Doonan, 2005, Table 12). Some of the other significant species in terms of numbers and/or biomass caught by recreational fishers include whitings other than King George (e.g. Southern School Whiting, Yellowfin Whiting), Garfish, Trevally, Snook, mullets (particularly Yellow-eye), Blue-spotted Goatfish (“Red Mullet”), Mulloway and *Seriola* species (Kingfish and Samson Fish). For most of the major species taken by recreational fishers in S.A., line fishing accounts for the majority of the catch, with nets accounting for a proportion of the garfish and mullet catches (Jones and Doonan, 2005, Table 17). During the NRIF survey, boat fishers took the largest percentage of King George whiting (91% of total catch), Pink Snapper (92%), Garfish (81%), and Snook (96%). Fishing effort to catch King George Whiting is very high, with 1.7 million fishing hours recorded during the survey period. In contrast, fishing effort to catch Snapper during the period May 2000 – April 2001 was estimated to be ~359,000 hours. Spencer Gulf is one of the most important recreational fishing area for Snapper, and regular fishing competitions are held to catch “trophy-sized” Snapper specimens. Gulf St Vincent and southern Spencer Gulf are important areas for recreational fishing of Garfish. Jetty and shore fishers rely more heavily on the migrating schools of Australian Herring and West Australian Salmon (for both species, shore catch = 63%, boat catch = 37%), and local populations of Yellow-eye Mullet (shore catch = 76%), and other mullet species (shore catch = 87%) (DAFF, 2004; Jones and Doonan, 2005, Table 17). A large proportion of the Australian Herring catch comes from the gulfs region of S.A. (e.g. combined catch from Gulf St Vincent and Spencer Gulf was ~ 2.36 million in 2000/01 (Jones and Doonan, 2005).

The following table (4.16.2) shows the regions of S.A. in which the highest catches of each of the major nearshore scalefish species were caught during the NRIFS (from Jones and Doonan, 2005). For some species (e.g. Pink Snapper, Mulloway), the numbers released after capture were higher than the retained catch in most regions.

Table 4.16.2 Regional recreational catches of the major inshore fish species in S.A., according to the results of the National Recreational and Indigenous Fishing Survey, 2000-01 (from appendices in Jones and Doonan, 2005). CB = Coffin Bay; FP = Fleurieu Peninsula; FWC = Far West Coast; L & C = Lakes and Coorong; MWC = Mid West Coast; NGSV = Northern Gulf St Vincent; NSG = Northern Spencer Gulf; SE SA = South East South Australia; SGSV = Southern Gulf St Vincent; SSG = Southern Spencer Gulf. For all species, regions with the lowest catches are excluded. Unless significant for a particular species, catches from the SE SA and from L & C, are not shown because those regions are not part of the SWMR

Species	***Regional Catches (No. + No. Released) In Rank Order***
King George Whiting	• Combined SG (955,571 + 373,861) • Coffin Bay (425,942 + 148,369) • NGSV (338,753 + 96,501) • SGSV and FP (158,237 + 53,447) • MWC (120,010 + 59,001) • FWC (107,857 + 57,595) • KI (91,950 + 19,292)
Pink Snapper	• NSG (74,900 + 213,221) • SSG (22,203 + 48,054) • SE SA (5,922 + 2,998) • SGSV and FP (3,593 + 18,691) • NGSV (3,127 + 26,947) • FWC (2,093 + 1,966) • KI (1,753 + 11,397) • CB (1,704 + 1,600)
Garfish (mainly Southern Sea Garfish)	• NGSV (552,683 + 93,951) • SSG (328,640 + 34,864) • SGSV + FP (165, 592 + 9,603) • SE SA (148,698 + 16,147) • CB (137,083 + 18,273) • NSG (132,350 + 19,671)
Australian Salmon	• SGSV + FP (246,148 + 73,338) • CB (105,175 + 14,984) • SSG (89,846 + 10,428) • NGSV (70,794 + 25,034) • SE SA (62,802 + 28,395) • MWC (52,295 + 18,848) • NSG (49,547 + 11,693) • FWC (28,675 + 34,322)
Australian Herring (Tommy Ruff)	• NGSV (951,565 + 194,517) • SSG (548,899 + 142,258) • NSG (433,743 + 44,308) • SGSV + FP (422,327 + 186,299) • MWC (197,414 + 54,225) • CB (164,118 + 24,466) • SE SA (141,656 + 82,015)
Snook	• NSG (51,639 + 1,216) • SSG (48,723 + 5,661) • SGSV + FP (45,804 + 1,101) • NGSV (15,014 + 226) • FWC (8,251 + 1,081) • SE SA (6,298 + 323)
Yellowfin Whiting	• Both gulfs (NSG + NGSV) (~300,000+)
School Whiting	• KI (33,200)
Yellow-eye Mullet	• SGSV + FP (149,634 + 119,143) • NGSV (93,133 + 33,634) • L & C (81,142 + 30,129) • SSG (41, 330 + 10,098) • NSG (30, 358 + 6,611)
Unspecified mullets (Yellow-eye, Jumping and Sea mullets)	• SGSV + FP (200,543 + 50,706) • SE SA (72,785 + 27,368) • NGSV (16,054 + 9,267)
Mulloway	• SE SA (16,565 + 44,748) • SGSV and FP (3,264 + 6,377) • NSG (1,938 + 3,343) • NGSV (1,267 + 3,604) • FWC (1,319 + 2,290) • L & C (1,231 + 3,902)

Some of the other nearshore scalefish species taken by recreational fishers in S.A. are shown in the table below. Figures are total numbers harvested during the NRIFS, with standard errors, and the total S.A. catch numbers as a proportion of the national total, from all States combined (collated from Henry and Lyle, 2003, and Jones and Doonan, 2005, Table 12). For several of these species, the total catches from S.A. waters represent a significant proportion of the national total, with examples including Snook (~78% of national notal), Yellow-eye Mullet (~80%), Blue-spotted Goatfish (Red “Mullet”) (~78%), and Striped Perch (~ 90%) (Henry and Lyle, 2003; SARDI data, sited by Shepherd and Baker, in press). According to the results of the NRIFS, large numbers of unspecified wrasses are taken by recreational fishers in S.A. (e.g. ~64,000 during the survey period).

Species	Total SA Catch (No’s)	SE (+/-) SA Catch (No’s)	Percentage of National Total
Black Bream	81,088	16,777	~10%
Estuary Catfish	2,480	5,107	~14%
Dusky Morwong	1,693		~ 20%
Flatheads (Platycephalidae)	72,105	9,785	< 5%
Harlequin Fish	157		~3%
Trumpeters (mainly “Striped Perch”)	268,366	50,613	> 90%
Leatherjackets (Monacanthidae)	155,168	19,369	~23%
Luderick	3,563	2,085	~1%
Morwongs, unspecified	561		~2%
Queen Snapper (Southern Blue Morwong)	3,208		~12%
Red “Mullet”	113,077	29,535	~78%
Redfish	45,310	9,236	
Silver Drummer	720		
Snook	185,947	34,482	~ 78%
Sweep (Sea + Banded Sweep)	57,864	16,430	~28%
Trevally species (Silver + unspecified)	80,620	18,292	
Wrasse – unspecified (various species in Labridae)	64,199		~ 21%
Western Blue Devil	1099		~64%
Western Blue Groper	394		~13%

Table 4.16.3 Examples of other scalefish species taken by recreational fishers in South Australia during the NRIF survey period 2000-01 (Henry and Lyle, 2003; Jones and Doonan, 2005; SARDI data, sited by Shepherd and Baker, in press).

Despite the use of different survey methods, the results of the NRIFS generally accord with the conclusions from an earlier boat ramp survey (McGlennon and Kinloch, 1997), which showed that King George Whiting (KGW), is one of the most important target species for recreational fishers in S.A., in terms of catch numbers. Metropolitan Gulf St Vincent, Spencer Gulf and several, large, sheltered bays along the west coast are important recreational fishing locations for this species (DAFF, 2004). The boat survey showed that in GSV, the recreational take of KGW equals the commercial catch, and is also high in Spencer Gulf (e.g. nearly 40% of the combined commercial and recreational catch, during the 2 year survey period) (McGlennon and Kinloch, 1997).

Western Australia: Recreational fishing in W.A. managed within four broad biological regions, three of which (South Coast, West Coast, and part of the Gascoyne) are included in the SWMR. Recreational fishing effort is estimated to have doubled during the past decade, and an estimated 600,000 people fish in that State (DAFF, 2005). The development of Integrated Fishery Management (IFM) in W.A. has resulted in new recreational management arrangements for the bioregions, including a reduction in recreational bag limits for vulnerable species, and the introduction of a Statewide possession limit applying to recreational fishers (Department of Fisheries, W.A., 2005k). Each region has specific fishing rules in accordance with the regional ecology, mix of species and fishing pressure (Department of Fisheries, W.A., 2004a). There are size limits, bag limits and possession limits for most of the popular species.

Collectively, some of the nearshore species that are important to recreational fishers in south-western and central W.A. include the following (from Potter et al., 1996; Hyndes et al., 1998; Sumner and Williamson, 1999; Dibden et al., 2000; Moran et al., 2003; Henry and Lyle, 2003; Department of Fisheries W.A., 2004a,d; Australian Government DEH, 2004b; Fishing WA web site, 2005; Stagles, 2005):

- Australian Herring (Tommy Ruff): about 3.9 million fish (523t) taken by recreational fishers in 2000/01
- West Australian Salmon: 41,000 fish (~136t) taken in 2000/01, mostly from the South Coast region
- Species of *Sillago*: Yellowfin Whiting, and school and trumpeter whitings, of which there are several species in the SWMR - collectively, about 2.45 million fish taken in 2000/01
- King George Whiting: about 400,000 fish taken in 2000/01
- Pink Snapper: highly prized for sport and eating, and widely fished throughout WA, with about 126,000 taken in 2000/01. Major areas for recreational fishing include Shark Bay, and the West Coast region
- Tailor : more than 600,000 fish taken in 2000/01
- Southern Sea Garfish: ~ 304,000 fish taken in 2000/01
- Silver / Skipjack Trevally: ~370,000 fish taken in 2000/01
- Dhufish: a species which has been described as “the icon of the southern recreational boat fishery”, and for which a total catch of at least 102,000 fish was recorded during the NRIFS in 2000/01. According to St John and King (in Department of Fisheries W.A., 2005a) the recreational catch may be well over 250t per annum.
- Baldchin Groper: highly prized as a food species, with ~60,000 fish take in 2000/01
- Western Blue Groper: more than 2,600 individuals caught during the NRIFS in 2000/01
- Breaksea Cod: ~51,000 taken in 2000/01, and, according to Stagles (2005), reported to be mainly a valued incidental catch when other reef fish are being targetted)
- Tarwhine: ~195,000 taken in 2000/01
- various species of mullet: ~ 297,000 taken in 2000/01
- various leatherjackets (Monacanthidae): ~ 34,400 taken in 2000/01
- Sea Sweep: ~21,000 taken in 2000/01
- Sergeant Baker: ~6,300 taken in 2000/01
- Harlequin Fish: nearly 4,800 fish caught in 2000/01
- Western Foxfish: ~8,100 fish caught during 2000/01
- Flatheads (Platycephalidae): ~80,000 were caught during 2000/01. Commonly targeted species inshore include the Bar-tailed Flathead – mainly north of the Swan/Canning estuary system; Southern Blue-spotted Flathead – mainly south of

Fremantle (e.g. Wilson Inlet); and the Long-spined, Rock and Long-headed flatheads (Stagles, 2005)
- Estuary Catfish (“Cobbler”): a heavily targeted species in metropolitan and southern estuaries and coastal rivers (about 8,150 taken in 2000/01); and
- Black Bream: more than 200,000 fish caught in 2000/01; another popular and heavily targeted estuarine species, particularly around the metropolitan area and the southern coast

Other demersal fish species of interest to recreational fishers in W.A. (particularly in the Gascoyne bioregion, of which Shark Bay forms the southern limit) include Golden Trevally, Leopard Coral Trout (e.g. Abrolhos Is.), Western Yellowfin Bream, *Lethrinus* species such as Spangled Emperor, Blue-lined Emperor and Sweetlip Emperor, Chinaman Cod, Rankin Cod, Butterfish (Western Whiptail), and Tripletail (an estuarine species highly regarded for eating) (Sumner et al., 2002; Stagles, 2005; Department of Fisheries, Western Australia, 2005a).

It is noted that many of the species of interest to spearfishers in Australia, occur in the SWMR. Examples include Mulloway, Dhufish, Western Blue Groper and Baldchin Groper and other wrasses, parrotfishes (W.A.), leatherjackets, sweeps, boarfishes, snappers, emperors (W.A.), morwongs, Luderick and drummers (Johnson, 1985a,b; Smith, 2000; International Freediving and Spearfishing News, undated). In W.A., Cobbler (Estuary Catfish) is also taken, using hand spears.

About 20% of the State’s fishing effort (an estimated 1.7 million fishing days in 2003-2004 is recorded in the South Coast region (Baharthah, 2004, cited by Department of Fisheries, W.A., 2005a). The major estuaries of Walpole-Nornalup, Wilson Inlet, the Albany Harbours, Bremer Bay, Hopetoun and Stokes Inlet are popular fishing areas (Department of Fisheries, W.A., 2004f). Some of the key species taken in estuaries and nearshore waters along the South Coast of W.A. include Black Bream (heavily targetted), Cobbler (Estuary Catfish), Yellowfin Whiting, King George Whiting and other whiting species, Australian Herring, Tarwhine, Tailor, trevally and flathead species (Department of Fisheries, W.A., 2004e, 2005a,c). Beach fishes target mainly West Australian Salmon and Australian Herring, with other species including Garfish, Skipjack Trevally, Yellowfin Whiting, Southern School Whiting and King George Whiting. A shore-based recreational fishing survey in 1994-1995 showed that West Australian Salmon and Australian Herring are the two most common and most frequently targeted species of finfish in the South Coast region (Ayvazian et al., 1997). The estimated catch of Australian Salmon along the South Coast was 64.3t in 1994 and 103t in 1995 (Ayvazian et al., 1997), and 117t in 2000/01 (Henry and Lyle, 2003, cited in Department of Fisheries, 2005a). In 2000/01, the Australian Herring catch along the south Coast was about 84.5t (=81t from the ocean and 3.5t from the estuaries) (Nowara and Lenanton, in Department of Fisheries, W.A., 2005a). Further offshore, boat fishers catch finfish species such as Breaksea Cod, Harlequin Fish, Western Blue Groper, King George Whiting, Dhufish, Pink Snapper, Queen Snapper, Red Snapper, Trevally, and Samson Fish (Department of Fisheries, W.A., 2005a,c). On the South Coast, recreational fishing effort has increased during the past decade, and fishing regulations were being revised in 2005, in consultation with communities (Department of Fisheries, W.A., 2005a and 2005m).

About 70% of W.A.'s recreational fishers fish on the West Coast (between Black Point, east of Augusta and the Zuytdorp Cliffs, north of Kalbarri), and target about 100 species (Department of Fisheries, W.A., 2004a). In the West Coast region, fishing effort is high (e.g. between 2.4 million and 5.6 million fisher days per year, between 1997 and 2004). On the West Coast, a survey in 1997 of recreational boat-based fishing from Augusta to Kalbarri (Sumner and Williamson, 1999 - also cited by Department of Fisheries W.A., 2005a), showed that the main scalefish species caught by boat-based fishers were as follows, in order of number caught:

- whiting species (Sillaginidae) other than King George Whiting: 564,000
- Australian Herring: 425,000
- Trevallies (mainly Skipjack): 123,000
- King George Whiting: 94,000
- Southern Sea Garfish: 79,000
- various species of Wrasse and Groper (Labridae): 66,000
- Western Australian Dhufish: 29,000 (equivalent to 132 tonnes reported and retained. A further 65 tonnes were released as undersize, or in excess of the bag limit (Sumner and Williamson, 1999, reported by Stagles, 2005))
- Snook: 28,000
- Tailor: 27,000
- Pink Snapper: 18,000 (N.B. a "poor year" for snapper, hence catch was less than in some other recent years)
- Breaksea Cod: 16,000
- Baldchin Groper: ~8,500 (= about 23t, a substantial proportion of which came from the Jurien Bay area, according to Fairclough and Cornish, 2004)
- Flathead species: ~8,200
- Tarwhine: ~6,100
- Western Blue Groper: 557

For some of the main species (e.g. Western Australian Dhufish, Baldchin Groper and Southern Sea Garfish), the recreational catch in the West Coast region was of similar magnitude to the commercial catch, and in the case of Skipjack Trevally, the recreational catch was higher.

As is the case along the South Coast, Australian Salmon is an important species for shore-based anglers along the West Coast region, with estimated catches of 64.3t in 1994 and 55.4t in 1995 (Ayvazian et al., 1997). Other significant species for shore-based fishers along the West coast include Australian Herring, several whiting species, Tailor, Cobbler (Estuary Catfish), and Black Bream (Department of Fisheries, 2005a). In the Peel-Harvey Estuary and Swan-Canning Estuary, the recreational catch of scalefish is relatively small, compared to the recreational crab catch. The most common fish species kept by anglers (in order of number kept) are (i) for the Swan-Canning Estuary: Tailor, whiting other than King George, Black Bream, flathead species, Australian Herring, Weeping Toado (Common Blowfish), flounder species, and West Australian Butterfish (Malseed and Sumner, 2001a); and (ii) for the Peel-Harvey Estuary: Australian Herring, whiting other than King George (*Sillago* spp.), Tailor, Skipjack Trevally, trumpeters, King George Whiting, Tarwhine and Black Bream (Malseed and Sumner, 2001b). Similarly, at the southern end of the West Coast Region, data from a previous recreational fishing survey in the Blackwood River Estuary / Hardy Inlet area near Augusta (Caputi, 1976, cited by Department of Fisheries W.A., 2004e), showed that the most common species kept by recreational fishers were, in order of estimated total weight: Black Bream, Yellowfin Whiting, Australian Herring, King George Whiting, Silver Bream (Tarwhine), Tailor and Skipjack Trevally.

Further north is the Gascoyne region (between the Zuytdorp Cliffs, north of Kalbarri and the Ashburton River, south of Onslow), the southern end of which forms the northern edge of the SWMR. In the Gascoyne region, fishing effort is classed as moderate (e.g. accounting for 4% - 7% of the State's recreational fishers between 1998 and 2004, and about 243,000 fisher days – 348,000 fishing days during that period) (Department of Fisheries, W.A., 2003a, Sumner et al., 2002 and Baharthah 2004, cited by Department of Fisheries 2005a). About 350t of demersal and pelagic finfish were taken in 1998/99 (Sumner et al, 2002 cited by Department of Fisheries, W.A., 2003a, 2005a). At least one third of the fishing effort comes from Shark Bay (e.g. 89,000 fisher days were recorded within the Shark Bay Marine Park in 1998/99). Nearly half of the recreational fishers in the Gascoyne region come from Perth area, and visit for fishing holidays, for up to two weeks (Department of Fisheries, W.A., 2005a). A study in 1998/99 (Sumner et al., 2002, cited by Department of Fisheries, W.A., 2005a) showed that the most important recreational fish catches in the Gascoyne region were as follows in order of weight caught:

- Spangled Emperor: 30,000 fish kept, or 79t;
- Pink Snapper: 28,000 fish or 79t;
- Mackerel (*Scomberomorus* spp.) (Spanish Mackerel 8,000 fish or 47t, other mackerel 8t);
- Blue-lined Emperor / Black Snapper / Grass Emperor: 33,000 fish or 34t;
- Golden Trevally: 6,000 fish or 20t;
- Sweetlip Emperor: 13,00 fish or 16t;
- Chinaman Cod: 23,000 fish or 10t gilled and gutted;
- Western Yellowfin Bream: 10,000 fish or 5t;
- Tailor: 7,000 fish (or 5t); and
- whiting species (Sillaginidae): 34,000 fish (or 5t).

An earlier study in 1996 (Sumner and Steckis, 1999) showed that Pink Snapper was the primary species caught by boat fishers in the Gascoyne region, with lesser numbers of Spangled Emperor, and insignificant numbers of other fish species. Shore-based anglers mainly caught various species of whiting. In Shark Bay, recreational fishers seeking Pink Snapper generally target the inner gulf stocks in the Freycinet Estuary and east of the Peron Peninsula (Sumner and Steckis, 1999).

Collecting and trade

The trade in syngnathids for the aquarium industry is discussed in a companion chapter (Baker, this volume). In W.A., a large number (about 320 – 330 species per year) of other finfish are taken, mostly in small quantities, to serve the aquarium industry. For management purposes, the species taken in the dive-based aquarium fish fishery, are divided into species for which less than 2000 (Group A) and more than 2000 (Group B) individuals per year are collected (Department of Fisheries, Western Australia, 2004c). Most group B species are taken in tropical north-west W.A., north of the SWMR boundary. However a number of species in that group occur further south, such as *Chromis atripectoralis*, *Amniataba caudavittata*, and *Atherinomorus vaigiensis* (= *A. ogilbyi*), for which an average of 4514, 2466 and 7113 individuals per year, respectively, were taken in the fishery between 2000 and

2003, from all fishing areas combined). Although the fishery is permitted to operate in waters along the entire W.A. coastline, the areas of high effort include Albany; the south-west coast between Margaret River and Two Rocks (north of Perth); the Houtman Abrolhos, and Shark Bay (Department of Fisheries, Western Australia, 2004c, Figure 2).

Examples of species that occur in the SWMR, that are taken in the Marine Aquarium Fish Managed Fishery in numbers greater than 100 specimens per year, include those in the following table.

Scientific Name	**Common Names**	**Mean No./Yr (2000- 2003)**
Pomacentridae	(specified species: damselfish family)	1066
Mullidae	(unspecified species: goatfish family)	1035
Apogon rueppellii	Western Gobbleguts	615
Mugil cephalus	Sea Mullet	496
Anoplocapros lenticularis	Humpback Boxfish / White-barred Boxfish	465
Chaetodontidae / Pomacanthidae	(unspecified species: butterflyfish & angelfish families)	457
Trachinops noarlungae	Yellow-headed Hulafish / Noarlunga Hulafish	455
Blenniidae	(unspecified species: blenny family)	448
Sillaginidae	(unspecified species: whiting family)	395
Coris auricularis	Western King Wrasse / Blushing Wrasse	392
Lactoria cornuta	Longhorn Cowfish	360
Terapon jarbua	Crescent Perch	350
Carangidae	(unspecified species: trevally and dart family)	340
Chromis klunzingeri	Black-headed Puller / Black-headed Chromis	309
Enoplosus armatus	Old Wife	296
Pomacentrus coelestis	Blue Damsel / Neon Damsel	284
Trachinops brauni	Braun's Hulafish	242
Thalassoma lunare	Moon Wrasse / Lunare Wrasse	239
Chaetodontoplus duboulayi	Scribbled Angelfish	220
Tilodon sexfasciatum	Moonlighter / Six-banded Coralfish	205
Halichoeres brownfieldi	Brownfield's Wrasse	184
Rhabdosargus sarba	Tarwhine / Silver Bream	172
Epinephelus coioides	Estuary Cod / Estuary Grouper	172
Apogon victoriae	Red-striped Cardinalfish / Western Striped Cardinalfish	158
Pomacentrus milleri	Miller's Damselfish	149
Petroscirtes breviceps	Short-headed Sabretooth Blenny	142
Neatypus obliquus	Western Footballer / Footballer Sweep	141
Aracana aurita	Shaw's Cowfish / Striped Cowfish	141
Parupeneus signatus (= *P. spilurus*)	Black-spot Goatfish	139
Labridae	(unspecified species: wrasse family)	139
Microcanthus strigatus	Stripey	129
Pterois volitans	Red Firefish / Common Lionfish	125
Pempheris analis	Bronze Bullseye	123
Labroides dimidiatus	Blue-streak Cleaner Wrasse / Cleaner Fish	117
Hemiramphidae	(unspecified species: garfish family)	111
Amblygobius phalaena	Banded Goby / Dusky Barred Goby	109
Parachaetodon ocellatus	Ocellate Coralfish / Six-spine Butterflyfish	106
Abudefduf vaigiensis	Sergeant Major / Indo-Pacific Sergeant	104
Valenciennea muralis	Striped Goby	101

Table 4.16.4 "Group A" species in the W.A. Marine Aquarium Fish fishery, that occur in the South-west Marine Region. Average catches for the period 2000-2003 are totals for all of W.A., and may include specimens from locations north of the SWMR (adapted from Department of Fisheries, W.A., 2004c)

Charter boat fishing

During the past 15 years, charter boat fishing has increased significantly in both S.A. and W.A. (Presser and Mavrakis, 2005; Department of Fisheries, W.A., 2005h), with dozens of charter companies now conducting regular fishing trips in both States. For example, in 1990 there were about 40 fishing charters operating in W.A. (Department of Fisheries, W.A., 1998), and by 2003 this number had increased to at least 240, with about 140 of those working in the West Coast region (Department of Fisheries, W.A., 2005a).

Fishing charter operations enable recreational fishers and tourists to visit otherwise inaccessible or less accessible fishing areas, and to catch large or "prized" fish (in many cases more reliably than would otherwise be the case, due to the experience and professional guidance of the charter staff). The increasing significance of charter boat catches as a proportion of the total recreational fishing catch, particularly for some of the most popular and heavily fished table species, has prompted the recent development of specific management arrangements for the fishery in W.A. (in 2001) and in S.A. (in 2004-2005). Charter boat operators in both States must now be registered, have a specific charter boat licence, and provide catch return forms to the regulatory body - Department of Fisheries in W.A. or PIRSA in S.A.. In both States, the charter boat industry now has limited entry. In S.A., transferable licences are granted following assessment of eligibility. All charters during which fishing occurs must now be licensed. For example, a dive charter operator or a shark / whale viewing charter operator will require a charter boat fishery licence if passengers participate in recreational fishing and/or take fish during the charter trip (Presser and Mavrakis, 2005).

In S.A., size limits, bag limits and boat limits for charters and their passengers now exist for the following species: whitings (King George, Yellowfin and School), adult and juvenile Pink Snapper, Black Bream, Australian Salmon, Australian Herring (Tommy Ruff), Samson Fish, Yellowtail Kingfish, Silver Trevally, Snook, Swallowtail, Mulloway, Queen Snapper (Southern Blue Morwong), Sweep, Redfish, Sea Garfish, all mullet species, flathead and flounder species (PIRSA, 2005b). At the time of writing, catches of Western Blue Groper in South Australia were also subject to bag and boat limits outside of gulf waters, however the species is soon to be fully protected in S.A., and will be removed from the list of permitted catches in the charter boat industry.

In W.A. there are 3 types of charter boat activity, two of which ("fishing tours" and "restricted fishing tours") are relevant here. Charter boat companies off the central and south-western coast of W.A. promote the catching of large Pink Snapper, Sweetlip Emperor, Red Emperor (which occurs in the northern part of SWMR), Baldchin Groper, Blue Groper and Dhufish, amongst other demersal fishes. Total catches of scalefishes by charter boats in recent years are shown in the table below. In 2003, there were 2,751 "fishing only" tours (= approx. 28,715 fisher days) in the West Coast region; 1,287 fishing only tours (~ 10,448 fisher days) in the Gascoyne region; and 692 fishing only tours (~ 2,386 fisher days) in the South Coast[5] region (Department of Fisheries, W.A., 2005a). The figures for "fishing only" tours do not include those charters during which diving and other activities were undertaken in

[5] (For the South Coast latter region, the fishing effort in 2003 was 21% lower than that recorded in 2002)

addition to fishing, hence total effort for the charter boat industry is higher than that presented here (e.g. in 2003, the total number of charter tours in the West Coast region was 5,395).

Species	Mean Estimated Catch (t) for 2002-2003		
	Gascoyne	***West Coast***	***South Coast***
Dhufish		24	
Baldchin Groper		7.5	
Bight Redfish			5
Swallowtail			1
Queen Snapper		10.5	6.5
Breaksea Cod		4.5	1
Skipjack Trevally		5.5	1
Samson Fish		16.5	4.5
Pink Snapper	26.5	17	1.5
Sea Sweep			0.5
Spangled Emperor	16		
Sweetlip Emperor	6.5	3.5	
Red Emperor	8.5		
Black Snapper	2		
Rankin Cod	4		
Emperors, unspecified (*Lethrinus* sp.)	3 (= 1t in 2002 and 5t in 2003)		
Chinaman Cod	0.75		
Other Scalefish	19	25	4.5

Table 4.16.5 Estimated average fishing effort from “fishing only” charter tours in W.A., for the period 20002-2003 (adapted from tables in Department of Fisheries W.A., 2005a).

Indigenous fishing

South Australia: In S.A., coastal Aboriginal communities have fished for thousands of years, using fishing nets made from fibres; fish spears, stone or wooden fish traps and/or snares. Within the South Australian component of the SWMR, examples of coastal peoples for which fishing has traditionally been a significant practice, and continues to be to the present day, include the Kaurna community along the eastern Gulf St Vincent coastline, the Narungga on Yorke Peninsula, and the Nauo, Barngarla and Wirangu on Eyre Peninsula and West Coast of S.A. (Mountford, 1939; Ellis, 1976; Berndt, 1985, cited by Noell et al, 2005; Martin, 1988[6]; Nicholson, 1991; NNTT, 2000, 2003; District Council of Yorke Peninsula, 2005). Along the central and western South Australia coast, recent Native Title claims and some of the coastal sites of Aboriginal Heritage significance (many of which relate to fishing), are discussed in Baker (2004).

The West Coast of S.A. falls within the consideration of the Wangka Wilurrara Regional Council, whose Regional Land Strategy (1995, cited by Ellis, 1999) aimed at addressing the land and sea needs of aboriginal communities in the region. Ellis (1999) reported that Aboriginal communities continue to have a significant presence and influence along parts of the West Coast, and that there is a need to acknowledge and protect the cultural needs of current resident Aboriginal populations and communities. On mid and far western Eyre Peninsula through to the

[6] Archaeologically, some of the most significant Aboriginal fish trap remains in southern Australia occur in western S.A. (e.g. Martin, 1988).

Great Australian Bight, the Wirangu coastal people both historically and presently inhabit the area, and maintain a physical connection with that area, including fishing (NNTT, 2000; National Native Title Tribunal database, 2003). Southern Eyre Peninsula is a significant area for the coastal Nauo and Barngarla people, and the Yorke Peninsula coast, particularly the western side, is part of the traditional (and current) fishing grounds of the Narungga. Fish such as Dusky Morwong ("butterfish", which is a popular traditional food for Aboriginal groups, especially on western Yorke Peninsula), Australian Salmon, Yellow-eye Mullet, Pink Snapper, whitings (King George, Yellowfin and Sand), and Sea Garfish and some of the nearshore scalefish species that are utilised by coastal Aboriginal groups in S.A..

Previously in S.A., the *Fisheries Act 1982* made no statement regarding Aboriginal cultural fishing, and all non-licensed fishers were recognised as recreational fishers under the *Act* (Noell et al., 2005). Traditional or customary fishing of scalefish is a significant activity for some coastal Aboriginal groups. More formal recognition (under legislation and fisheries management) of this practice is being developed as part of the current review of the *Fisheries Act*. Furthermore, the State is currently engaging with Native Title claimant representative bodies and the commercial fishing industry, to negotiate agreements in relation to Native Title claims. The review of the Act, and the agreement negotiation process, will both help to clarify the means by which Aboriginal community access to fisheries resources is defined and implemented in the South Australian Marine Scalefish Fishery (Noell et al., 2005). There is also provision for Aboriginal corporations to engage in the charter boat industry, if they are signatory to, or associated with, an indigenous land use agreement (ILUA) that includes provisions about entering the Charter Boat Fishery (Presser and Mavrakis, 2005).

Western Australia: In W.A, there is now an Aboriginal Fishery Strategy (Department of Fisheries, W.A., Aboriginal and Torres Strait Islander Commission, Fisheries Research and Development Corporation, and Department of Indigenous Affairs, 2003), to better recognise the interests of Aboriginal people in the protection and use of fish in Western Australia, as part of the Integrated Fisheries Management Strategy for W.A.'s fish resources. Some of the recommendations include formalised Customary Fishing Rights (fishing for the purpose of satisfying personal, domestic, ceremonial, educational or non-commercial communal needs), designated Aboriginal Fishing Areas (in northern W.A.), possession limits, and educational programs, promoting and raising awareness in the broader community about customary fishing rights and significance, and the responsibilities, rules and practices that accompany changes to the management of customary fishing. Recommendations were also made for more formal and satisfactory engagement of Aboriginal fishing groups in commercial fishing, aquaculture ventures, and fisheries management. The Aboriginal Fishing strategy builds upon some of the previous recommendations in a report on integration of Native Title interests in fishing and coastal management in Western Australia (Wright and Sparkes, 2002), as well as a number of national reports (Appendix 1 in Department of Fisheries, W.A., Aboriginal and Torres Strait Islander Commission, Fisheries Research and Development Corporation, and Department of Indigenous Affairs, 2003).

Conservation interest

Western Australia

The conservation interest in nearshore fish and their habitats is reflected in the non-fishing (sanctuary) zones of the various marine parks of Western Australia. Within the SWMR, Marine Parks in W.A. include, from north to south: Shark Bay (includes Hamelin Pool Marine Nature Reserve), Jurien, Marmion, Swan Estuary, Shoalwater Is., the proposed Capes (Geographe Bay, Leeuwin – Naturaliste coast, and Hardy Inlet), and proposed Walpole / Nornalup Inlets MP (between Augusta and Albany) (CALM, 2005b,c). Some of the no-take sanctuary zones include South Passage (southern end of Dirk Hartog Island) and Mary Anne Island (Shark Bay). In 2003, during a proposal period for "The Capes" Marine Park, the Department of Conservation and Land Management in W.A. reported that priority species of conservation concern included residents such as Western Blue Groper, Dhufish, Harlequin Fish, King George Whiting in Geographe Bay, and Black Bream in Hardy Inlet. Other inshore fish of conservation concern, for which status could not be determined due to insufficient information, included Queen Snapper, Pink Snapper, Skipjack Trevally, Cobbler, Breaksea Cod, and Mulloway (CALM, 2005b)

In W.A., various Fish Habitat Protection Areas (FHPAs) have been declared, to assist in the "conservation and protection of fish, fish breeding areas, fish fossils or the aquatic ecosystem"[7] (Department of Fisheries, W.A., 2001b, 2003d, 2004g). FHPAs aid in the protection of populations of large, site-associated reef fish species, such as Baldchin Groper, Breaksea Cod, Western Blue Groper, Harlequin Fish, emperors, parrotfishes, Pink Snapper, Queen Snapper, and Dhufish (CALM, 2005a). Examples include the Lancelin Island FHPA, reportedly declared following extensive line fishing and spearfishing, which resulted in the local extirpation of many larger edible species, followed by targeting of smaller fish (Department of Fisheries WA, Australian Marine Conservation Society, and Friends of Lancelin Island, 2001). FHPAs in WA include, from north to south: Point Quobba (northern Shark Bay), Miaboolya Beach, the Kalbarri Blue Holes, Abrolhos Is., Lancelin Island, and Cottesloe Reef (Department of Fisheries WA, Australian Marine Conservation Society, and Friends of Lancelin Island, 2001; Department of Fisheries, W.A., 2001b, 2003d, 2004g).

Also in W.A., Reef Protection Areas (RPAs) and Reef Observation Areas (ROAs) have been declared around recreationally significant natural and artificial reefs. Some, but not all, of these also serve as a conservation measure for site-associated nearshore fish. Examples of RPAs on the South Coast include the *Sanko Harvest* wreck, Esperance Jetty, and the *HMAS Perth* wreck. There are several RPAs in the West Coast bioregion, such as Cowaramup Bay, Yallingup Reef, the *HMAS Swan* Wreck, and the Quindalup artificial reef (Department of Fisheries, WA, 2005a). However not of these RPAs all are fully protected, and line fishing is permitted in some (e.g. Cowaramup Bay). In Marmion Marine Park, Waterman's Reef is an ROA, and fishing is prohibited. At the Abrolhos Islands, there are 4 Reef Observation

[7] Secondary objectives of FHPAs include "the culture and propagation of fish and experimental purposes related to that culture and propagation"; and/or "the management of fish and activities relating to the appreciation or observation of fish" (Department of Fisheries, W.A., 2001b, 2003d, 2004g).

Areas, in which fishing is completely prohibited. These are situated at Leo's Island, Coral Patches, Beacon Island and North Island. Te ROAs at the Abrolhos Islands were introduced in the mid-1990s, (Nardi, 1998), but have apparently had little impact on the size or abundance of potentially thretened species such as Baldchin Groper (K. Nardi, Department of Fisheries, Western Australia, pers. comm., cited by Fairclough and Cornish, 2004). On the Gascoyne coast further north, the *Gudrun* wreck in Shark Bay is a Reef Protection Area.

A considerable portion of the inshore coast within the SWMR is closed to trawling. These closures are of some relevance here, due to their role in protecting the benthos from physical and ecological damage, and also helping to reduce the total number of fish taken in trawl bycatch. Examples of trawling closures include the inner parts of Shark Bay; much of the area between Dongara and Yanchep (out to 200m); the innermost coastal waters from Perth to Augusta, and a narrow coastal strip in the W.A. portion of the Great Australian bight, eastwards to Eucla (Department of Fisheries, WA, 2005a).

There are also seasonal closures on the taking of fish in some areas (e.g. spawning season prohibition on fishing Baldchin Groper at the Houtman Abrolhos, and seasonal closures in parts of Shark Bay and Cockburn Sound, to protect spawning aggregations of Pink Snapper (Department of Fisheries, W.A., 2004d). There are also various spearfishing and netting prohibitions in some areas (e.g. at Rottnest Island, spearfishing is prohibited within 200m from shore, and netting is prohibited within 500m from shore).

South Australia:

The ongoing success and expansion of the Reef Watch program in South Australia (see section on **Education**, below), well illustrates the conservation interest that marine community members in S.A. have in protecting nearshore fish populations and their habitats.

In South Australia, there are 14 Aquatic Reserves (Ivanovici, 1984; Johnson, 1988a; Neverauskas and Edyvane, 1993; Baker, 2000; PIRSA 2005a). Many of the Aquatic Reserves were declared by the former S.A. Department of Fisheries, to assist in the conservation of fish species and their associated habitats that are significant to commercial and/or recreational Fisheries. Examples include American River on northern Kangaroo I.; Onkaparinga Estuary, Barker Inlet-St Kilda, and St Kilda-Chapman Creek in Gulf St Vincent; and Whyalla-Cowleds Landing, Blanche Harbour-Douglas Bank, and Yatala Harbour in Spencer Gulf. A few reef areas (Aldinga Reef, Port Noarlunga Reef and Troubridge Hill) were declared mainly due to their significance for diving and recreational, but only one of these serves to protect site-associated nearshore fish populations in the area from fishing impacts (Troubridge Hill, and part of Port Noarlunga reserve, are both open to line fishing). The very small (54ha) Aquatic Reserve at Goose I. in Spencer Gulf also offers protection for site-associated fish species in that area. It is noted that although the only marine park in S.A., the Great Australian Bight Marine Park, has a benthic protection zone in which trawling is prohibited, inshore fishing (for species such as Snapper, King George Whiting and Snapper), is permitted in the park (see DEHAA, 1998; Ward et al., 2003).

During past decades, various marine community groups and individuals have lobbied for the increased conservation of marine areas of significance to nearshore fish. Some examples include the following, in approximate chronological order:

- In 1974, the Althorpe Islands and surrounding waters were nominated by the former S.A. Department of Fisheries and Fauna Conservation, as a reserve to protect Blue Groper populations (Wynne, 1980);
- In 1980, a report to government by two marine researchers, and representatives of the S.A. SCUBA Divers Association and S.A. Underwater Photographic Society (Ottaway et al., 1980), recommended that all offshore islands controlled by National Parks in S.A., should have their reserve boundaries extended seawards, either to the 20m contour, or 600m seaward. The authors also recommended a number of nearshore areas that should be protected from fishing, particularly spear-fishing.
- In 1980, the former South Australian Department of Fisheries, nominated the reefs at Cape Elizabeth as a conservation reserve;
- The lack of marine protected areas on Eyre Peninsula was highlighted as an important issue in a study report of the marine biota of the Eyre Coast (Buckley, AMDL consultancy to Department of Environment and Planning, 1986). In 1986, declaration of marine reserves was considered by Dr B. Lever, Director of SA National Parks and Wildlife Service, to be one of the two most urgent issues for conservation in South Australia. The Buckley report recommended that marine reserves be declared to protect and conserve representative examples of each major subtidal community, and to protect and conserve spawning, nursery and feeding grounds for commercial and other fish and crustaceans (Buckley, 1986);
- Several submissions were received by the Department of Fisheries in 1991, stating that additional “non-fishing areas” should be introduced in the Barker Inlet area (GSV), to protect juvenile fish and vulnerable adult fish stocks. Such areas included Angas Inlet, where the habitat (mangroves and tidal banks) was purportedly being degraded by human activity in the area (Rohan *et al.,* 1991);
- In 1992, a senior research officer of National Parks and Wildlife Service South Australia considered proclamation of a marine park and reserve network around the Innes National Park area on southern Yorke Peninsula to be a very high priority (Robinson, recommendation to S.A. Department of Fisheries, 1992);
- Since the declaration of the Troubridge Hill Aquatic Reserve in 1983, there have been regular requests to government from dive groups seeking increased protection for the fish fauna in the Troubridge area from all forms of fishing;
- During the 1990s, individuals from the 30-member South Australian Marine Protected Areas Technical Working Group of scientists, provided recommendations to the former S.A. Department of Fisheries, as part of a Commonwealth-funded process to collate background information on areas of high conservation value that may contribute to a representative system of MPAs in South Australia. These recommendations, supplemented by additional information collated during the South Australian Benthic Surveys Program (1992-1997), and by additional nominations received during a public consultation period, were summarised in Edyvane (1999);
- Reports by Caton (1997) and Brook (2000) recommended increased protection for part of the Southern Fleurieu area, through the use of MPAs, including high-protection zones;

- During the mid 1990s, members of marine-affiliated conservation groups in South Australia, including the Conservation Council of South Australia, Australian Marine Conservation Society, Wilderness Society, Australian Conservation Foundation, and Nature Conservation Society, jointly submitted to government a nomination for 8 areas to be declared Wilderness Areas under the *Wilderness Protection Act 1992* CCSA/AMCS/Wilderness Society/ACF/NCSSA Media Release, December, 1998);
- A dive report from the Marine Life Society of South Australia suggested that Wardang Island and its surrounding islands should be Heritage listed or declared a Marine Park, and that the inner Port Victoria area should also be formally protected due to the large amount of seagrass in the area, and its role as a fish nursery for a large number of juvenile fish (Bellchambers, 1999).
- McGarvey *et al.* (2000) stated that seasonal closures or area closures should be considered as one of several options for protecting the spawning stock of King George Whiting (N.B. another option included the introduction of a maximum legal length for caught fish).
- The north-eastern Kangaroo Island area (Dudley Peninsula) has recently (1999-2003) been the subject of a community-based MPA proposal developed by the Kangaroo Island Branch of the Australian Marine Conservation Society (KI-AMCS 2000 and 2001), and associated with the on-going Coastcare-funded monitoring project and register of values of the area.
- Shepherd and Brook (2002) suggested that no-take fishing areas along the south-western coast of Yorke Peninsula would provide better protection for Blue Groper populations that have been depleted by fishing over several decades, because the prohibition (under the *Fisheries Act 1982*) on fishing Western Blue Groper in Investigator Strait waters appears not to have been effective.

In recent years, the South Australian Government (2002, and DEH, 2004) has committed to declaring 19 new marine protected areas (MPAs) in S.A. over the coming decade, as part of South Australia's contribution to the National Representative System of Marine Protected Areas (ANZECC, 1999). Baker (2004) discussed in detail the numerous ecological values of these 19 large areas, and the contribution that protected zones in these MPAs could make to preserving those values (including, of relevance here, the protection of site-associated nearshore fish populations and their habitats).

Non-extractive recreation and eco-tourism

The high popularity of syngnathids, particularly seadragons, for marine dive and snorkel tourism / recreation, and in marine education, is discussed in a companion chapter (Baker, this volume). Apart from syngnathids, also of interest to recreational divers and tourists are many of the other inshore fishes, especially those are large, colourful and/or brightly patterned. Examples of such popular species and families, of which there are very many within the SWMR, include the following (from DIASA, undated; Aquanaut, undated; Baker, 2004; Dive-Oz, 2005d,e,f; Reef Watch, 2003; CALM, 2005c):

- In both W.A. and S.A.: Banded Sweep, blennies (Blenniidae), Blue-lined Leatherjacket, bullseyes (Pempherididae), cardinalfishes (Apogonidae), Dusky Morwong, Globefish, Harlequin Fish, Herring Cale, Horseshoe Leatherjacket and other leatherjackets (Monacanthidae), Long-snouted Boarfish, Magpie Perch,

Moonlighter, Old Wife, Ornate Cowfish and Shaw's Cowfish and other boxfishes in the Aracanidae, Queen Snapper, Rainbow Cale, Red Snapper, Sea Sweep, Senator Wrasse, Six-spined Leatherjacket, Victorian Scalyfin, Western Blue Devilfish, Western Blue Groper, Western Foxfish, Western Talma, wrasses (Labridae), Yellow-headed Hulafish, and Zebra Fish.
- In W.A.: Angelfishes (Pomacanthidae), Buffalo Bream, butterflyfishes (Chaetodontidae), Common Lionfish, Crested Morwong, damselfishes (Pomacentridae), Dhufish, Estuary Cod, Green Moon Wrasse, Moon Wrasse, parrotfishes (Scaridae), Red-stripe Cardinalfish, Scissortail Sergeant, Sergeant Major, Spangled Emperor, surgeonfishes (Acanthuridae), and Teira Batfish.
- In S.A.: Blue-throated Wrasse, Southern Hulafish.

Various dive sites across the central and western coasts of S.A. that are popular for recreation due to their fish assemblages, and examples of the fishes they support, are discussed in Baker (2004) and DIASA (undated). Examples of natural reefs in S.A. that attract divers due to the fish assemblages include those along the north coast of Kangaroo I. (e.g. Western River Cove, Stokes Bay and other locations); various sites in GSV (such as Glenelg, Seacliff, Noarlunga and Aldinga – the latter two of which are Aquatic Reserves, Carrickalinga, Rapid Head, and Second Valley); many sites along southern Yorke Peninsula (such as Troubridge Point and Troubridge Hill, Foul Bay, Cable Hut Bay, Stenhouse Bay, Chinaman's Hat I., Haystack I., the Althorpe Is., Reef Head, Emmes Reef, Pondalowie Bay, Brown's Beach and Corny Point); various locations in Spencer Gulf (Wardang I.; Lipson Cove; the Sir Joseph Banks group); the Gambier group islands south of Spencer Gulf; islands in Thorny Passage; various sites off southern Eyre Peninsula (e.g. Donnington Rocks, Memory Cove, Redbanks, Wanna), and locations in the eastern Great Australian Bight (e.g. Frenchmans, Coles Point, Smooth Pool, Pearson I. and Waldegrave I.).

In W.A., some of the popular dive sites, and the fishes they support, are listed by Aquanaut (undated), Marine Domain Diving (2005) and Dive-Oz (2005d,e,f). Examples of such locations include Shark Bay, Houtman Abrolhos Is., Dongara, Jurien, Ocean Reef, Marmion Marine Park (including the very popular reef near Hillarys Boat Harbour), Rottnest Island, Carnac I., Rockingham area (e.g. Shoalwater Bay and islands, Cape Peron, and Warnbro Sound), Bunbury, Busselton (including the jetty, which is widely promoted as for dive tourism), Dunsborough, Augusta, Albany (including Torbay, Michaelmas I., Two Peoples Bay and many other locations), Bremer Bay, Hopetoun, and Esperance (including Cape le Grande area and some of the islands in the Recherche Archipelago).

Marine Parks in W.A. are also popular dive sites, many of these due to the protected populations of reef fish. Examples include the marine parks at Shark Bay, Marmion, and Shoalwater Islands (near Rockingham) (Aquanaut, undated; CALM, 2005c). Also in W.A., the various Fish Habitat Protection Areas (FHPAs) that have been declared (partly to protect large, site-associated reef fish species – see section above on **Conservation Interest**), are also popular for diving, snorkelling, marine photography, and other non-extractive recreation. The FHPAs also have a role in marine education, particularly accessible areas like Cottesloe Reef (Department of Fisheries, W.A., 2001b).

Education

Western Australia

The section below, on **Current Research**, discusses examples of university research projects on fish and fish habitats that have been undertaken in W.A. (particularly in Marine Parks). A number of the protected areas in W.A. have also served a role in community education about nearshore fish and their habitats. For example, Australian Marine Conservation Society (AMCS) in W.A., in conjunction with Department of Conservation and Land Management and a number of other project partners, has worked to develop community-based monitoring methods in protected areas (including FHPAs such as Cottesloe); a marine community monitoring manual (which includes fish survey methods); and an educational CD-ROM (*The Marine Life of Western Australia*), which provides information about the habitat and identification of various nearshore fish species in W.A.'s protected areas (e.g. see Department of Fisheries, W.A., 2001b; Wheeler, 2004; University of Western Australia, 2005).

In W.A., the Aquarium of Western Australia (Hillarys) assists community education about the variety of nearshore marine fishes in W.A.. Also at Hillarys is the Naturaliste Marine Discovery Centre, an education centre attached to a new marine research facility. The Discovery Centre has viewing windows into scientific research areas and aquariums, school training areas, and an interactive exhibition hall. Various education programs for adults and schools are also planned. The Centre aims to promote the marine biology and ecology of WA's coastal and inland waterways; the impact of recreational and commercial fishing on communities; and the importance of knowledge-based fisheries management to ensure fish population sustainability (Department of Fisheries, W.A., 2005f). Further south, at Busselton, there is an underwater observatory and interpretive centre the end of the jetty. The Busselton facility explains the diversity of marine life in the local area, and is a popular eco-tourism destination.

Also in W.A., the Department of Fisheries Research Angler Program (RAP) has an educational function, by assisting volunteers to contribute to scientific research projects (Department of Fisheries, W.A., 2005g).

South Australia

A community monitoring program in S.A., Reef Watch, has a major role in community education about the marine environment. With regard to nearshore fish, divers record and help to monitor populations of common species on various reefs along the central S.A. coast, as well as reporting sightings of potentially threatened species, such as Western Blue Groper and Harlequin Fish. Reef Watch also organises annual "marathon dive" fish counts at the Port Noarlunga Aquatic Reserve, and various educational activities, such as reef species identification workshops (Reef Watch, 2005). Several of the Aquatic Reserves in S.A. have a role in marine education. For example, Barker Inlet has been the site of a number of university-based studies on fish species composition, diets, and spatial and temporal distribution in estuarine habitats (see section on **Research**) Port Noarlunga is regularly used by community groups for monitoring, and is also the site of an underwater trail of markers that explain the local marine life. At Goose I., in Spencer Gulf, marine education courses for school groups are held.

Aquaculture

South Australia
Since the early 1990s in South Australia, Southern Bluefin Tuna (not discussed in this chapter) has been a very significant marine scalefish species for grow-out in cages, and remains the most important scalefish species in terms of production volume and value. However, during the early 2000s, interest increased in the culture of other scalefishes, particularly Yellowfin Kingfish and Mulloway. There are commercial hatcheries and grow-out facilities for Yellowtail Kingfish in northern and western Spencer Gulf, and the culture of Kingfish has replaced that of slower growing species such as Pink Snapper. The increasing importance of Mulloway was supported by the first mass culture and high survival of juveniles in 2001. Initial grow-out trials in cages showed that Mulloway is a hardy species, fast growing, and accepting of artificial feeds, all factors which are considered to auger well for continued growth of Mulloway aquaculture in S.A. (PIRSA Aquaculture web site, December, 2005). During the past decade, licences have also been granted for the culture (mainly in Spencer Gulf) of Pink Snapper, King George Whiting, Australian Herring, Silver Trevally, Black Bream, and a few other scalefish species. Primary Industries and Resources South Australia Aquaculture's Public Register (PIRSA, 2005c) provides details of current leases, and species cultured. During the past decade, PIRSA has developed various aquaculture management policy, planning and zoning reports for each region of the State, and the government's planning agency (Planning S.A.) has produced corresponding development plans and plan amendment reports for some of these areas, to further accommodate aquaculture development.

Western Australia
Compared with shellfish and freshwater fish, nearshore marine scalefish species are currently not a significant part of aquaculture production in W.A. However, in the West Coast region, there has been some research into the culture of Yellowtail Kingfish, including production of broodstock from hatchery-reared fish in an intensive system (Department of Fisheries, W.A., 2005a). In W.A. there is a breeding and hatchery facility for Black Bream (using Swan River stock), and as part of a trial to provide stock for recreational fishing, fry have been released into approximately 300 fresh and saline private water bodies on land in the south-west, from Carnarvon to Esperance. The successful breeding and rearing Black Bream in recent years at the Fremantle Maritime Centre has generated further interest in the use of this species for restocking coastal waterways, and for commercial aquaculture (Department of Fisheries, Western Australia, 2004j). On the West Coast and also near Esperance on the South Coast, there have been proposals during the early 2000s, to ranch tuna in pens. Tuna are pelagic species, and therefore are not discussed in this chapter. Also in W.A., an indigenous group is currently engaged in trials to culture several marine aquarium fish species (Australian Government DEH, 2005c). Maps of currently designated aquaculture sites in W.A. are shown in W.A.'s State of the Fisheries reports (e.g. Department of Fisheries W.A., 2005a), and a number of aquaculture plan reports have suggested guidelines, standards, potential sites and potential species of scalefish for culture (e.g. Department of Fisheries W.A., 2000b) (see also section on **Threats / Impacts**). Examples of inshore species suggested for culture in W.A. include Pink Snapper, Black Bream, Yellowtail Kingfish, Bar-cheeked Coral Trout and other coral trout species, Estuary Cod, Breaksea Cod, Baldchin

Groper, West Australian Dhufish, various tropical snappers (Lutjanidae) and a number of parrotfishes (Family Labridae) (Department of Fisheries W.A., 2000b).

Impacts/threats

Some of the nearshore demersal fish species have life history characteristics that make them susceptible to impacts, and vulnerable to population decline. Such characteristics include low population densities; strong habitat association in nearshore areas; small home range sizes and low mobility; possible low rates of natural adult mortality (due to low levels of predation, hence human-induced mortality may disrupt population dynamics); localised reproduction; aggregation (in some species) for feeding and/or breeding; and small brood sizes. Natural vulnerability, as outlined above, is exacerbated by a number of human-induced threats, the combined effects of which deplete populations of many nearshore fishes. Some examples of impacts and/or threats within the SWMR, are provided below.

Nearshore habitat damage

Populations of some inshore fishes may be naturally small and fragmented (e.g. due to the patchy nature of suitable habitat), however habitat decline poses a significant additional threat to populations, particularly to inshore fishes with limited dispersal ability, and a small depth range. Many inshore fish in southern Australia, including the South-west Marine Region, are strongly site-associated with estuaries, shallow subtidal seagrass beds, or macroalgal- dominated reefs, and examples are given in other sections of this chapter. Long-term degradation of these nearshore habitats is especially prevalent in highly urbanised areas such as the around Perth, Fremantle (Cockburn Sound, for which there have been some remedial management measures in recent years - e.g. see Pearce et al., 2000), the Peel-Harvey estuary area (south of Mandurah), and Albany Harbour in Western Australia; the metropolitan coast of Gulf St Vincent, and the industrialised north of Spencer Gulf in South Australia (for summary of impacts in S.A. nearshore habitats, see Baker, 2004, and **Syngnathid Fish**, this volume). Physical damage to nearshore nursery areas, and habitat degradation due to shoreline development, trawling (which reduces available habitat by modifying benthic composition and structure), aquaculture, and catchment-based activities (e.g. run-off of sewage nutrients, urban stormwater, industrial chemicals, agricultural wastes, and sediments) are considered to be some of the main threats to inshore fish populations.

Estuarine species within the SWMR, such as Estuary Cod, Mulloway, Black Bream, Cobbler, and Bar-tailed Flathead are especially vulnerable to decline, due to the long term degradation of estuarine habitats. *Mulloway*, for example are ocean spawners, but require freshwater outflow from rivers/estuaries for successful recruitment. In the Murray Mouth area (east of the SWMR), population levels of Mulloway are considered to be now reduced, principally due to altered flow regime and diminished flow (PIRSA, 1999) and modified estuarine habitat, although over-fishing (both commercial and recreational) is a contributing factor. The decline in catch of *Cobbler* in W.A. estuaries (Swan / Canning and Peel / Harvey) appears to be the result of both fishery and fishery-independent factors, including loss of estuarine breeding habitats, which has resulted in very low breeding stock levels (Smith and Nowara, in Department of Fisheries, W.A.,2005a). *Black Bream* occur in some of the most polluted estuaries in the SWMR, such as the Port River / Barker Inlet in S.A., Swan / Canning and the Peel / Harvey. For example, in April–June 2003, a bloom of the toxic dinoflagellate *Karlodinium micrum* killed numerous Black Bream and other species in the Swan/Canning Estuary (Smith and Nowara, in Department of Fisheries, W.A., 2005a). Stagles (2005) reported that 200,000 Black Bream were killed during this episode, however the Department of Fisheries (2005a) stated that commercial and recreational fisheries for Black Bream were not affected by the fish kill. Fish kills have occurred in a number of other SWMR estuaries during the past two decades. In some estuaries, such as the Peel-Harvey system in W.A. (Pearce et al., 2000), and Barker Inlet in S.A., toxic phytoplankton species are regularly present. It is reported that estuarine degradation has also been a contributing factor the very poor recruitment exhibited by juvenile Black Bream in the Blackwood River in recent years, and run-off from acid sulphate soils is considered to be an additional problem for Black Bream (Stagles, 2005). Black Bream populations are genetically unique within each west coast estuary, indicating the need for cautious management (Smith and Nowara, in Department of Fisheries, W.A.,2005a).

Fishing

The combined impact of fishing by all sectors is taking an increasingly heavy toll on the populations of many inshore fish species in South Australia and Western Australia. Increasing evidence during the past two decades has shown that some of the most popular food fish in the SWMR are over-exploited, fully-exploited or at risk, at local and/or regional scales. During recent decades, recreational fishing and charter boat fishing have both increased in popularity and effort; and the increased technology in both commercial and recreational fisheries (e.g. bigger and faster boats, GPS, coloured echo-sounders and echo-integrators etc) have enabled fishers to search wider, further, and deeper for scalefish. Over-fishing by commercial and recreational fishers, and the rapid growth of charter boat fishing, are together considered to be one of the main pressures facing scalefish populations in south-western W.A. (CALM, 2005b). Within the SWMR, commonly cited examples of fishing-induced depletions include Pink Snapper, King George Whiting, Australian Herring, Australian Salmon, Southern Sea Garfish, Black Bream, Cobbler, Baldchin Groper, Breaksea Cod, Dhufish, Estuary Cod, and the Coral Trout species, to name a few. Species classified by W.A. Fisheries as being at “high risk” of over-exploitation and consequent population impacts, include those that are generally large, long-lived, slow-growing, mature later in life (e.g. 4 years plus), form semi-resident populations, are vulnerable to localised depletion due to their life history, and/or are of relatively low abundance and are highly targeted. Fish in this category, or which many are larger reef fish species, have a low resilience to exploitation, in terms of minimum population doubling time (Froese and Pauly, 2005). Examples of classified “high risk” species in W.A. include Coral Trout (*Plectropomus leopardus* and other *Plectropomus* species), Estuary Cod (*Epinephelus suillus*) and other species in the Serranidae (including Harlequin Fish *Othos dentex*, and Breaksea Cod *Epinephelides armatus*), Dhufish *Glaucosoma hebraicum*, Cobbler *Cnidoglanis macrocephalus*, Emperors (species of *Lethrinus*), Red Emperor *Lutjanus sebae* and other tropical snappers and sea perches in the Lutjanidae (including Mangrove Jack); wrasses such as Baldchin Groper *Choerodon rubescens* and Western Blue Groper *Achoerodus gouldii*, Boarfish (in the Pentacerotidae), Mulloway *Argyrosomus japonicus*, Red Snapper (*Centroberyx* species), Parrotfish species (in the Scaridae), Pink Snapper *Pagrus auratus*, Queen Snapper *Nemadactylus valenciennesi*, West Australian Salmon *Arripis truttaceus* (N.B. included in the category due to the high rate of exploitation by fishers, and the vulnerability of migrating schools), species in the genus *Seriola* (Samson Fish, Amberjack and Yellowtail Kingfish), Giant Trevally *Caranx ignobilis*, and Golden Trevally *Gnathanodon speciosus* (Department of Fisheries, W.A., 2004a).

Relatively more abundant species than those above, particularly species from estuarine and nearshore sand and seagrass habitats, have been ranked by W.A. Fisheries as "medium risk" of over-exploitation. These include Bream (*Acanthopagrus* species); species of flathead (Platycephalidae) and flounder (Bothidae, Pleuronectidae), Goatfish (Mullidae), Leatherjackets (Monacanthidae), Snook (species of *Sphyraena*), Pike (*Dinolestes*), Tailor *Pomatomus saltatrix*, Tarwhine *Rhabdosargus sarba*, trevallies (Carangidae), King George Whiting *Sillaginodes punctata*, and Yellowfin Whiting *Sillago schomburgkii* (Department of Fisheries, W.A., 2004a).

Tropical species such as Rankin Cod and Red Emperor (both considered at risk – Department of Fisheries W.A., 2000a) are not discussed here, because the main part of their distribution is north of the SWMR boundary. Within the main part of the SWMR, a few examples of species at risk from over-fishing include the following:

West Australian Salmon: fully exploited by the commercial fishery in W.A. (Australian Government DEH, 2004), and at risk of being over-fished in S.A. (Noell et al., 2005). In S.A., the species is classified as fully fished (MSFMC, 2003). The commercial catch quota that has been set in S.A., reportedly allows sufficient escapement of adult fish to the spawning area, however data to support this are not available. The recreational sector catch in S.A. is high (according to Henry and Lyle, 2003, more than 800,000 fish were estimated to be caught in S.A. in 2000/01, equivalent to hundreds of tonnes of smaller "salmon trout" or more than 2000t of larger Salmon). The recreational catch in S.A. was estimated at 39% of the total catch in 2000/01, indicating that the total catch is now close to the annual TAC of 1000 tonnes for Salmon in S.A.. In W.A., although recreational sector catches along the south coast have increased during the past decade, they are still an order of magnitude lower than the annual commercial yield, and considerably lower than the recreational catch in South Australia. In S.A. a legal minimum length (21cm) is set to try to ensure that smaller Salmon will have a chance to pass the "gautlet" of the commercial and recreational fisheries, and travel to W.A. to spawn (PIRSA, undated). Baitfish such as pilchards and anchovies , one of the main food sources for Australian Salmon, are taken commercially in S.A. and W.A., and the tonnage of pilchards taken commercially in S.A. has increasing significantly in recent years. In W.A., age composition data, maximum yield modelling and egg-per-recruit analysis indicate that the commercial exploitation rate is high, and schools of pre-spawning, migratory Salmon are highly vulnerable, as they must pass each of the fishing beaches in turn and may be taken. In W.A., the accepted upper catch limit in 2004 was 3,350t, but this could be considered too high, as evidenced by long term catch data. Any substantial increase in harvest, or significant reduction in recruitment (for example through environmentally-mediated events) is considered to be detrimental to the sustainability of the spawning stock, the biomass of which would fall below an acceptable biological reference point of 30% of virgin egg biomass (Penn et al., 2003; Australian Government DEH, 2004; Nowara and Lenanton, in Department of Fisheries, W.A., 2005a).

Australian Herring: The population is classified as fully-exploited in W.A.. There are declining trends in fishery-independent estimates of recruitment since 2000, declining commercial catches over the same period (in excess of the reduction to be expected due to licence buy-backs), and high recreational catches on the lower West Coast. As is the case with Australian Salmon, virtually the entire commercial Herring catch consists of mature individuals with peak seasonal catches being taken during the annual autumn spawning migration. These factors together suggest that a serious review of the status of Australian Herring, particularly the breeding stock, is now needed (Nowara and Lenaton, in Department of Fisheries, W.A., 2005a).

King George Whiting (KGW): In recent years, there has been concern amongst both scientists and fishers about a decrease in the King George Whiting population as a whole, and also regional decreases in abundance. Generally, KGW is classified as over-fished in South Australia (Noell et al., 2005); more specifically, over-fished in Spencer Gulf and Gulf St Vincent (GSV), and fully fished on the West Coast of S.A. (MSFMC, 2003). Despite a large, 20 year research effort directed towards the KGW in S.A.(see **References**, below), stocks continue to decline in S.A., where it has traditionally been the most sought after scalefish species in both commercial and recreational scalefish fisheries, and more recently, in the burgeoning charter boat sector. Recreational fishers take more than half of the total catch in S.A. (McGarvey et al., 2003; Henry and Lyle, 2003; Jones and Doonan, 2005). The fishable biomass and annual recruitment in West Coast and Spencer Gulf waters has declined during the late 1990s and early 2000s (MSFMC, 2003). In GSV, where variation in biomass and recruitment is more variable than the other regions, biomass and recruitment in 2002 dropped by 18-21% compared with the 5 year averages. During the past decade, there has been a substantial drop in the commercial catch and effort (McGarvey et al., 2003), with many scalefish fishers now targetting other species instead of KGW. Whilst some of the reduced effort may be due to changes in the fishery structure (such as a smaller number of licences in the fishery), it is clear that reduced abundance of KGW has prompted some fishers to stop fishing the species commercially, and in some cases target other species. Traditionally in S.A., smaller whiting have been targetted when they leave the nursery areas (Jones et al., 1990) in shallow gulf and west coast waters, and the majority of each year class is fished heavily by commercial and recreational fishers when the whiting reach legal size. Smaller King George Whiting are also caught in the bycatch from prawn trawling. During the past decade, increased technology in commercial, recreational and charter boat sectors has enabled fishers to more easily target the offshore spawning stock of larger, older whiting in deeper water, which adds further pressure to sustainability. The larger, older KGW may be important contributors to spawning potential of the stock. There has been some evidence for declining recruitment to the fishery, at least since 1999 (McGarvey et al., 2003), and possibly much longer. It is also noted that heavy fishing since the middle of the 20th century may have affected whiting population dynamics, as suggested by Cockrum and Jones (1992), who reported that the average size of whiting at first spawning has decreased by several centimetres since the 1950's, believed to be due to fishery-induced selection pressure for fish to become fecund earlier in life. Fowler and McGarvey (1997) recommended that there be sufficient escapement of immature fish, and the main targeted age class (2 to 3 year olds) from heavily fished inshore areas, to enable sufficient numbers to annually replenish spawning populations, which appear to be restricted to a few specific locations in South Australia, such as lower Spencer Gulf and northern Kangaroo Island waters (see Fowler and McGarvey, 1997; McGarvey et al., 2000, 2003). McGarvey et al. (2000) recommended additional regulatory measures to protect the spawning stock of larger King George Whiting in deeper waters. The MSF Management Committee (MSFMC, 2003) agreed that more precautionary management of each sector's catch is required, in addition to protection of spawning areas).

Yellow-fin Whiting (YFW): Classified as fully fished in South Australia (MSFMC, 2003), and being at "medium risk" of over-exploitation in W.A. (Department of Fisheries, W.A., 2004a). YFW is fished commercially in S.A.(Spencer Gulf and GSV) and W.A. (Shark Bay, amongst other areas), and is also one of the popular, highly targetted inshore species taken by recreational fishers. Due to steadily increasing market value of Yellow-fin Whiting since the 1980s, annual commercial catches in S.A. have been increasing in most years throughout the 1990s and early 2000s (compared with yields from the 1980s). In S.A., targetted effort on this species by commercial netters increased by about 100% during the late 1990s and early 2000s, in response to netting bans in some areas where King George whiting were previously netted, and the consequent shift towards targetting Yellowfin Whiting rather than King George whiting (McGarvey et al., 2003). In S.A., where the species occurs mainly in the warmer, upper gulf waters, Ferguson (1999 and 2000) advised cautious management of the fishery for Yellow-fin Whiting, based on the following factors: (i) older age classes are not common, and in S.A., have been found mainly in parts of Spencer Gulf. In that gulf, fishing in the commercial grounds is considered to be responsible for a reduction in the relative abundance of older age classes; (ii) recruitment and year class strength are highly variable over space and time, likely due to oceanographic factors; (iii) the contraction of the size range in the fishery may indicate smaller numbers of the major egg producers in the population (i.e. the older females), and ultimately a decline in egg production; (iv) fisheries which target young fish (as occurs in Gulf St Vincent, where 2-year old Yellow-fin Whiting dominate the catch) are dependent upon continued high annual recruitment levels, and recruitment levels and subsequent year class strength are likely to strongly influence the biomass available to the fishery; and (v) the recreational fishery for Yellow-fin Whiting is active at a time when these fish are reproductive. The status of the species in W.A. has not been fully assessed, however moves towards integrated fisheries management in that State may assist in determining population status of YFW, which is caught in numerous fisheries.

Pink Snapper: A species that is long-lived, slow-growing, and aggregative in nature (especially during the spawning period). Snapper populations are subject to sporadic "boom" recruitments, which results in irregular "pulses" in year class strength, and these irregular large recruitments (which may be only 1 or 2 years in 10) are required to sustain the fishery for a number of years. Although "strong" and "weak" years tend to even out to ensure sustainability of the stock, an extended period of weak years (low recruitment) can deplete the stocks, if fishing levels remain high during that period. Understanding of the stocks is complicated by the fact that some Pink Snapper appear to remain resident in inshore areas for long periods, whereas other stocks may travel relatively long distances (e.g. 300km, for the outer Shark Bay stock - Department of Fisheries, W.A., 2004dJuvenile snapper in inshore waters and adult snapper on reefs and other structures are vulnerable to line, net and trap fishing. The species is fully exploited in South Australia (commercially and recreationally) (MSFMC, 2003; Noell et al., 2005), and in W.A., including the West Coast Demersal Scalefish fishery, and the Shark Bay Snapper fishery (for which there is a annual quota), amongst others (see Department of Fisheries, W.A., 2004d and 2004l, for details of snapper fisheries in W.A.). Various recreational fishing regulations throughout the SWMR - including a suite of minimum size limits (according to the size at which each stock reaches maturity), bag and boat limits, and a number of seasonal closures - have not been sufficient to prevent stock declines in both S.A. and W.A.. Catch rates, previously used as an indication of abundance, are a poor measure (as is the case for other aggregating species), because total stock numbers can decline whilst catch rates remain high. Fishers can predict spawning aggregations over time and space, and target accordingly (St John and King, in Department of Fisheries WA, 2005a). Separate and specific management measures are required for Pink Snapper “stocks” in various regions of each State. In Shark Bay, for example, there are three separate stocks of Pink Snapper in the inshore waters, plus an oceanic stock. The stocks do not interbreed and are vulnerable to over-fishing (Department of Fisheries, W.A., 2005i). In Shark Bay, Pink Snapper have been fished since the 1950s, and the fully exploited nature of the fishery was known at least 15 years ago (e.g. Moran and Jenke, 1989). The species is now considered to be over-fished in that area (Department of Fisheries, 2005a,i), largely due to a high levels of commercial and recreational fishing during the past two decades (including increasing recreational fishing effort), combined with an extended period of poor recruitment since the mid-late 1990s (Moran and Jackson, in Department of Fisheries, W.A., 2005a). The Shark Bay snapper spawning stock biomass is now well below the 30% reference level (N.B. 40% of virgin biomass is considered by some researchers to be the minimum safe level for long-lived species such as Pink Snapper), and tighter control on commercial and recreational fishing is now occurring (such as a cap on the recreational fishing harvest, and a vessel monitoring system for commercial fishers, to reduce discarding), to prevent further declines (e.g. see Moran and Jackson, in Department of Fisheries, W.A.,2005a). In the West Coast demersal fishery in W.A., recent (e.g. 2002/03) increases in the total catch of Pink Snapper appear to relate more to increased fishing effort than total abundance. In that fishery, the continuing high level of latent fishing effort available to target Pink Snapper, especially the northern stocks, is of concern (St John and King, in Dept Fisheries WA, 2005a). Similarly in S.A., there are concerns about the decline of snapper populations in Spencer Gulf and Gulf St Vincent (GSV). Some researchers and fishers consider that the Snapper fishery is over-exploited, due to decline in the number of large (older), high-fecundity fish available in the fishery, amongst other indicators. Larger, older Snapper are easily captured due to their strong association with natural and artificial reefs, such as those in northern Spencer Gulf. There is some evidence from tagging to show that adult Snapper return to “home reefs” annually to spawn (Fowler et al., 2003), and thus would be particularly vulnerable to capture at that time. In some areas of the state, populations apparently declined throughout the 1980s and 1990s, which prompted a more recent (early 2000s) state-wide fishing ban in November each year. Previously, the decline in the fishery was particularly evident in southern Gulf St Vincent and Investigator Strait (McGlennon and Jones, 1997). According to PIRSA (Anon, 2000c), the fishery for Snapper in southern GSV declined significantly during the 1980s, and did not recover by the turn of the century, which prompted the call for a “rebuilding strategy”. The fishery in GSV is reported to be showing signs of “slow recovery” (Fowler et al., 2003). In 2001/02, the State-wide snapper catch (647.6t) was the highest ever recorded, and the majority of the commercial catch was taken with handlines (Fowler et al., 2003). The state commercial harvest and effort has increased by 64.5% and 6.1%, respectively over the last 5 years. The recreational harvest was estimated at 39.1% of the total harvest in 2000/01, and the charter boat sector harvested 61.4 tonnes, or 13% of the recreational harvest (MSFMC, 2003). It is noted that the commercial catches of Pink Snapper in S.A. in the early to mid-2000s were the highest ever recorded, despite the November closure. Over-fishing of snapper populations may also have ecological impacts. Because Snapper are wide-ranging, relatively long lived, and have age / size classes that occupy different habitats and ecological niches, they may have considerable ecological significance in the habitats in which they occur.

Southern Sea Garfish: Classified by government as either as over-fished (Noell et al., 2005) or fully fished (DEHAA and EPA, 1998; Ye, 1999; MSFMC, 2003) in South Australia, according to available biological performance indicators (BPIs) (e.g. Ye, 1999; Ye, cited by Anonymous 2001b; Jones et al., 2002). In addition to the commercial catch, the species is one of the most popular recreational fishes in some parts of S.A.. Garfish is a schooling species, particularly over shallow seagrass beds, and is therefore readily captured by line fishing and netting methods. Garfish now mature at a smaller size than was observed 40 years ago, believed to be a response to heavy fishing levels (Ye, 1999; Ye, cited by Anonymous, 2001b; and see also Jones et al., 2002 for the most recent *publicly available* assessment of the stocks and the fishery).

Snook: Classified as fully fished in S.A. The commercial harvest does not reflect targeted effort for this species, as non-targeted effort (by net fishers) is significant. The commercial harvest in 2001/02 was 12% lower than the 5 yr average, prompting increasing interest in the status of this species. The catch by the recreational sector in S.A. is high (e.g. about 46% of the total catch in 2000/01) (MSFMC, 2003). Snook is one of the “secondary species” in S.A. Marine Scalefish Fishery for which research is due to be undertaken (Noell et al., 2005).

Cobbler: In Western Australia, Cobbler (Estuary Catfish) have been exploited commercially since the inception of the inshore, estuarine fishery, but targeted only since the 1970s (Kailola et al., 1993). The commercial fishery for Estuary Catfish is concentrated in southern waters between Perth and Albany. The Swan-Avon and Peel-Harvey estuaries and Wilson Inlet are three of the main areas in which Cobbler have been taken commercially during the past 30 years, and the annual catch and CPUE fluctuate widely between years (Kailola et al., 1993). The live weight of the Cobbler catch in W.A. has ranged between 58t and 121t per annum, between 1994 and 2003, and the landed weight is about 71% of those figures (W.A. Fisheries Research Services Division statistics 1994-2003). About 94t of the catch in 2003 was taken from the South Coast estuaries, but only 1.6t were taken from the West Coast estuaries. The species is heavily targeted by recreational fishers in metropolitan and southern estuaries and coastal rivers (with about 8,150 specimens taken from the West Coast region alone in 2000/01). Cobbler has traditionally been one of the main estuarine species taken in the South Coast and West Coast regions of W.A.(Nowara and Lenanton, in Department of Fisheries, W.A., 2005a), and although commercial fishing effort in the West Coast estuarine fishery has decreased in recent years, the low catches in that region are indications of long-term over-exploitation by commercial and recreational fishing, and reduced abundance due to decline in habitat quality.

Baldchin Groper: A large (reaching 70cm), long-lived, slow-growing, site-associated wrasse, found on shallow and deeper reefs in W.A. (Fairclough in prep., cited by Fairclough and Cornish, 2004). Baldchin Groper is highly sought after for its fighting abilities and palatable flesh (Crowe et al., 1999; Last et al., 1999; Stagles 2005). The Abrolhos Islands, Jurien Bay, and Shark Bay, are three of the heavily fished areas for Baldchin Groper. There is increasing commercial effort at the Abrolhos, but catches are not reflecting this, which suggests that over-exploitation is occurring in that area (Penn et al., 2003, cited by Fairclough and Cornish, 2004; St John and King, in Dept Fisheries WA, 2005a). Since 1999, fishing effort in the West Coast Demersal fishery has increased by 25%, reaching a record level in 2003 (5,835 fishing days). The increased effort, coupled with a downward trend in catch rates indicates that more detailed assessments, and close monitoring are required to ensure that over-exploitation does not occur (St John and King, in Dept Fisheries WA, 2005a). Recreational and commercial fishing can impact on Baldchin Groper stocks very quickly, with the average size of fish caught in some areas dropping to just above the legal minimum size in a very short time (Stagles, 2005). Like many other wrasses, the species is a protogynous hermaphrodite (changes sex), and the males maintain harems of females. Heavy fishing of larger individuals may skew the sex ratio, by removing larger males from the population. While sex ratios of adult Baldchin Groper are naturally biased towards females (Fairclough, in prep.), ratios in *commercial* catches of fish above the minimum size limit, are approximately 1:1, suggesting that many males are being removed from the population by this sector (at least in the Abrolhos Islands). The lower length at which 50% of females change sex in the Abrolhos Islands (479 mm) versus Shark Bay (545 mm), may indicate that fishing pressure is having an impact on social structure in the former region (Fairclough, in prep., cited by Fairclough and Cornish, 2004). Furthermore, the recent increase in legal minimum size may further skew the sex ratio, by promoting the capture of larger individuals (males). Fish at the minimum legal length for capture of 40 cm range from 4 to 14 years of age (Nardi, 1999; Fairclough, in prep.). There are several closed areas (see section on **Conservation Interest**), and a number of recreational fishing regulations (bag and possession limits). Fairclough and Cornish (2004) assessed the species for IUCN, and Baldchin Groper is currently rated as *Least Concern* on the IUCN Red List, due to management actions being in place, and provided that commercial and recreational catches are continually monitored and controlled; that fishing regulations are enforced; and that the species status is regularly re-assessed (e.g. through monitoring of relative abundance and sex ratio of Baldchin Groper populations in both closed and fished areas, and monitoring of fishing effort and yields).

Blue-throated Wrasse: Blue-throated Wrasse (BTW) is caught by commercial fishers (MSF catch, and also by-catch in rock lobster fishery), and also by recreational line fishers, spear fishers, and charter boat fishers in South Australia. In S.A, the commercial catches offshore (most of which was BTW) increased rapidly during the late 1990s, to peak at 47t per annum in 1997/98 and 1998/99 (see Knight et al., 2002). Commercial catches declined to ~ 20t per annum during the early 2000s. Prescott (2001), reported that wrasses (principally BTW) was the second largest proportion of bycatch in the Northern Zone Rock Lobster Fishery as a whole, according to a sampling of 32,000 pots in 1991 – 1992. Recreational catches are high (about 52% of the total catch in 2000/01, according to MSFMC, 2003), and recreational and charter boat catches are currently not subject to bag or boat limits, and are thus inadequately controlled. In S.A., wrasses, including BTW, are classified as being at high risk of localised depletion (MSFMC, 2003). Near-shore populations of Blue-throated Wrasse may be potentially vulnerable to over-exploitation by line fishing and spearfishing, due to behaviours such as strong site association with macroalgal-covered reefs and other nearshore reefs; territoriality (particularly during breeding season) and inquisitive nature. Blue-throated wrasse may be a keystone marine species (see Shepherd and Clarkson, 2001), hence fishing impacts on the species itself may have wider ecological ramifications. Shepherd et al. (2002) and Shepherd and Brook (2003) discussed some of the issues associated with the recreational fishing of Blue-throated Wrasse in parts of South Australia. Baker (in prep.) provides a summary of the conservation status of (and risks to) Blue-throated Wrasse in South Australia.

Other Wrasse Species: There are numerous wrasse (Labridae) species within the SWMR, and the sections on **Commercial Fishing, Recreational Fishing** and **Collecting and Trade** list some of the wrasse species taken within the SWMR. Due to behaviours such as strong site association with macroalgal-covered reefs (and coral reefs, in the northern part of the SWMR); territoriality (particularly during breeding season); protogynous hermaphroditism (i.e. in which the terminal phase is a large male), and inquisitive nature, wrasses may be potentially vulnerable to over-exploitation by commercial fishing (targetted fishing, also live collecting, and by-catch in other fisheries, such as lobster), and recreational fishing (line, and spearfishing). In W.A., populations of many of the wrasses taken incidentally in line fisheries are not assessed, nor are populations of those species targetted by collectors for the aquarium industry. In S.A., wrasses are classified as being at high risk of localised depletion (MSFMC, 2003). Baker (in prep.) provides a summary of the conservation status of (and risks to) various wrasse species in South Australia, such as Western Foxfish, Brown-spotted Wrasse, Maori Wrasse, and Rosy Wrasse.

Harlequin Fish: The species, which is endemic to S.A. and W.A., occurs on shallow reefs over a small depth range (Edgar, 2000). W.A. is the main part of the range, and considerable numbers are caught there (e.g. ~ 4,800 specimens in 2000/01, according to Henry and Lyle, 2003). Small numbers of large adults are targeted by recreational line fishers and charter boat operations in various parts of South Australia, and the species is also promoted for spearfishing to catch in S.A. (Smith, 2000; International Freediving and Spearfishing News, undated)[8]. Harlequin Fish are also caught in small numbers, as bycatch in the South Australian Rock Lobster Fishery (Sloan, 2003). Near-shore populations may be potentially vulnerable to decline, due to this species solitary nature, strong site association with reefs and caves, relatively slow growth, and inquisitive nature / attraction to divers. These characteristics are known to have made the species populations susceptible to impacts from spear fishing, and Harlequin Fish numbers are reported to have been reduced in accessible areas of S.A. and W.A. due to “heavy spear-fishing pressures” (Hutchins and Swainston, 1986). Currently in S.A., there are no bag or boat limits for Harlequin Fish taken in the charter boat industry, despite this species being promoted by some charter companies one of the “prized” catches available. There is a paucity of information about population sizes, and the effects of fishing on the population dynamics of this species. Harlequin Fish is currently one subject of a community-based Reefwatch *In Peril* program in SA, which aims to monitor the

[8] In the past, Harlequin Fish was one of the targeted species in spearfishing competitions in South Australia during the 1970s and 1980s (e.g. Ottway et al., 1980; Johnson, 1985a, b)

distribution and abundance of a number of potentially threatened species at various diving and snorkelling locations around the State

Western Blue Devil: Strong site-association with shallow, inshore reefs and caves; territoriality; possibly naturally low population numbers, localised reproduction, and the solitary and inquisitive nature of this species, make populations of Western Blue Devil vulnerable to population decline. The flesh is considered quite palatable, and thus the species is captured within the SWMR by line fishers and spearfishers (Ottaway et al., 1980; Capel, 1994; Baker, in prep.). In S.A., about 1100 specimens were reported to have been taken in 2000/01 (NRIFS data, cited by Jones and Doonan, 2005), and a similar number was taken in W.A. during that period (NRIFS data, 2000/01). Collection for the aquarium trade in W.A. (about 90 per year) is an additional threat. Complete protection from spear-fishing was first suggested for S.A. populations of Western Blue Devil back in 1967, by Dr S. Shepherd, and again by Otway et al. in 1980, and this has not occurred to date, nor has there been any formal controls on recreational line fishing and collecting.

Spangled Emperor: Vulnerable due to its life history (large, long-lived, protogynous hermaphroditic species), habit (site-associated), and habitat (adults occur on reefs in relatively shallow waters of the upper continental shelf), coupled with its popularity as a table fish. Spangled Emperor is taken by both commercial and recreational fishers in W.A. In the Gascoyne region, about 30,000 fish (or 79t) were taken by recreational fishers in 1998/99 ((Sumner et al., 2002), and the species is also popular for charter boat fishing (16t in 2002/03).

Bream species: *Acanthopagrus* species such as Black Bream and Western Yellowfin Bream have variable recruitment, and following years of low recruitment, ongoing heavy fishing can deplete the populations. Bream species, particularly juveniles, rely upon nearshore habitats (including mangroves and other estuarine habitats), and long term degradation of many nearshore habitats within the SWMR may have had an adverse impact on bream populations (see section above). Both bream species are heavily targetted in W.A. (see sections on **Commercial Fishing** and **Recreational Fishing**). In some estuaries, Black Bream stocks are genetically isolated, which supports the need for a higher level of site-specific protection than would be required for more migratory species (Department of Fisheries WA, 2004e). In the Harvey Estuary in W.A., recreational bag limits have recently been reduced from 20 fish per day to 4, in recognition of the vulnerability of this species. A study in Shark Bay showed that Yellowfin Bream is long-lived (to at least 24 years), and a protandrous hermaphrodite. According to Fairclough et al. (2004), although catch numbers of Yellowfin Bream W.A appear to have been sustainable to date, if fishing pressure was to increase markedly, the females of this species would presumably become severely depleted (Fairclough et al., 2004).

Tailor: The species is heavily targetted by recreational fishers in W.A. (Young et al., 1999), with 0.6 million fish taken in 2000/01 (Henry and Lyle, 2003). Tailor are also caught in commercial fisheries, such as the Shark Bay Beach Seine and Mesh Net Managed Fishery (28t taken in 2003). Management of Tailor fishing on the west coast of W.A. should consider the migratory nature of the species (Edmonds et al., 1999), and the variable abundance of Tailor, likely due to the influence of the Cape Current on movements of Tailor larvae spawning in coastal waters on the south-western coast (Lenanton et al., 1996; Pearce and Pattiaratchi, 1999). There is also an issue of under-reporting of recreational catches, and discarding of undersized specimens caught recreationally (Young et al., 1999). The species is considered vulnerable to localised depletion, if not exploitation, over the long term (Department of Fisheries, W.A., 2000a).

Leopard Coral Trout: The species is vulnerable to overfishing, in areas such as the Abrolhos Is. (Department of Fisheries, W.A., 2000a). Leopard Coral Trout are taken by commercial line, trawl and trap fishers, and also by recreational line fishers and spearfishers. According to Stagles (2005) Leopard Coral Trout are very vulnerable to spearfishing, because they make no attempt to evade the speargun. Although there are recreational size limits and bag limits, it is considered easy to take the larger resident specimens on reefs. Stagles (2005) reported that both commercial and recreational over-fishing is undoubtedly the biggest threat to Leopard Coral Trout populations There is evidence that depleted populations of this reef fish species respond to the protection offered by sanctuary (no-fishing) zones (Nardi et al., 2002).

Breaksea Cod: A large (> 50 cm), slow to mature (3–4 years), long-lived (> 20 years), reef-associated grouper from inshore waters in W.A.. Breaksea Cod is taken by commercial and (especially) recreational fishers in W.A., with the commercial harvest poorly documented until recently (J. St John pers. comm., cited by Cornish, 2004). Breaksea Cod is a common component of mixed catches from hook-and-line over inshore reefs (Prokop, 2002, cited by Cornish, 2004), and there is a bag limit for recreational fishing. Larger individuals have apparently been depleted in inshore areas (particularly the metropolitan area), and fishers are consequently moving further offshore to target the larger specimens (Stagles, 2005). Vulnerable population characteristics include the limited spatial distribution, association with nearshore habitats, large size, inquisitive nature, ease of capture, vulnerability of all age classes to capture (ranging from young, sexually immature fish, to the largest, oldest adults), low reproductive potential, and probable low survival rate of released specimens that are under legal size (Eastman, 2001; J. St John, W.A. Fisheries, pers. comm. 2003, cited by Cornish, 2004; Stagles, 2005). IUCN has classified the species as being *Near Threatened* (Cornish, 2004), and recommended that the status be re-assessed at regular intervals, in light of the vulnerable population characteristics, the significant increase in recreational fishing in W.A. in recent years, and the inadequate controls on the take by commercial fishers.

Dhufish: The species is vulnerable due to its limited distribution (mainly from Recherche Archipelago to Shark Bay, and rarely northwards), large size, relatively slow growth, long life span, seasonal migration of adults into inshore waters (Cusack and Roennfeldt, 1987), and association with structures for most of the year, such as nearshore reefs. There is some evidence that the species schools to spawn (St John and King, in Dept Fisheries WA, 2005a), which increases vulnerability of Dhufish to fishing pressure, however there is currently inadequate information about spawning behaviour over space and time. The species is classified as fully fished in W.A. (St John and King, in Department of Fisheries W.A., 2005a), and for at least 13 years, there has been a suggestion of over-fishing, based on decreases in the average size of Dhufish in catches (Department of Fisheries W.A. data, 1992, cited by Kailola et al., 1993). The high (and increasing) recreational and targetted commercial catches (see sections on **Commercial Fishing** and **Recreational Fishing**), have together been identified as the single biggest threat to Dhufish populations. Recent escalation in commercial “wetline” sector catches are considered to be due to an increase in effective effort, rather than an increase in stock abundance. Over the same period, declining catches and catch rates in the demersal gillnet and demersal longline fishery (which does not specifically target Dhufish, and for which effort has been stable over the period), likely indicate lower abundance of Dhufish (Hesp et al., 2002; St John and King, in Department of Fisheries W.A., 2005a). The recreational catch has traditionally been very high, including targetting of the larger individuals that migrate inshore (Kailola et al., 1993), and in recent year recreational fishers have also noted the depletion of large, older Dhufish catches (Stagles, 2005). Fishing technology improvements during the past decade, coupled with the decline in other heavily targetted reef fish species (e.g. Pink Snapper) may prompt fishers to move further offshore to target Dhufish in deeper water areas that were previously *de facto* “refuges”. Preliminary estimates of age structure in the population (Hesp et al., 2002), coupled with the high fishing mortality rate (which is estimated to be higher than the rate of natural mortality), indicate that Dhufish in W.A. cannot sustain current catch levels (St John and King, in Department of Fisheries W.A., 2005a). In addition to the permitted catch, there is an issue with high mortality of undersized Dhufish that are pulled up from deeper water and released (Department of Fisheries W.A., 2000a, also cited in Stagles, 2005).

Dusky Morwong: This fish species is vulnerable to over-exploitation due to its large size, strong habitat association (both adults and juveniles), and the ease of capture using a number of fishing methods (e.g. spear, line, trap). Juveniles usually occur in shallow waters, on macroalgae-covered reefs or in shallow seagrass beds, and are easily targetted by spearfishers and line fishers. Adults often occur in seagrass beds or sand near seagrass, or around rocky outcrops, to around 30m (Kuiter, 1993; Edgar, 2000). Dusky Morwong can grow to 1m long in areas where fishing pressures are minimal, however large fish are not often seen in nearshore areas, in populated parts of South Australia, due to fishing pressures. In S.A., spearfishing-induced depletions of Dusky Morwong populations over the past few decades are likely to have occurred in eastern Gulf St Vincent and the Fleurieu, and Yorke Peninsula. Dusky Morwong was first recommended for formal protection against spearfishing by S.A. Shepherd in 1967, and again in 1980 (Ottway et al., 1980). In S.A., between 1,700 and 2,100 specimens were reported to have been taken by recreational fishers in 2000/01 (Henry and Lyle, 2003; Jones and Doonan, 2005), with a higher number in Victoria, and a lower number (about 400) in W.A.. There are currently no bag limits, boat limits or minimum sizes for Dusky Morwong taken by recreational fishers or charter boats in South Australia. The species is also caught as bycatch in Commonwealth-managed fisheries (for which bycatch action plans have recently been developed), and in the demersal gillnet and demersal longline fisheries of W.A., in which Dusky Morwong is a significant component of the discarded scalefish catch (McAuley and Simpfendorfer, 2003).

Mulloway: Considered to be of uncertain status in S.A., and the subject of current research (MSFMC, 2003). The species is popular with recreational / sports fishers in some areas of S.A., such as the Coorong / Murray Mouth, and the Far West coast, particularly the surf beaches (PIRSA, 1999), and there is heavy fishing pressure from this sector. Commercial fishers in S.A. also catch Mulloway in these areas, using rod-and-line (Noell et al., 2005), with low and variable catches. In W.A., the species is taken commercially by the West Coast Demersal Scalefish Fishery (16t in 2002/03) and Mulloway is a byproduct of the West Coast Demersal Gillnet and Demersal Longline Fishery (8t in 2003), and some of the fisheries in Shark Bay. In

S.A., the recreational sector takes the majority of the catch (MSFMC, 2003), and a large number of undersized specimens are released. Catches from the Murray Mouth, Lakes and Coorong and South East of S.A. are not discussed here, however within the S.A. portion of the SWMR (Spencer Gulf, Gulf St Vincent and S.A. West Coast), about 7,800 specimens were reported to have been taken in 2000/01, with a further 15,600 released (NRIFS data, cited by Jones and Doonan, 2005). The species is estuarine dependent, and the condition of estuaries, especially adequate water flow, are crucial to the survival of populations in some areas (see section on **Habitat Damage**). Concern for Mulloway populations in S.A. was expressed at least 15 years ago, when a number of submission received by the S.A. Department of Fisheries (Rohan et al., 1991) requested additional protection measures for Mulloway due to adverse changes in critical habitat. There is recent evidence of a small, genetically unique, geographically isolated population of Mulloway at the Head of Great Australian Bight (GAB). The population is believed to aggregate in the area due to outflow of subterranean fresh water (and it is notable that there are no coastal estuaries with freshwater input in the eastern GAB). During the late 1990s, the GAB population, which is highly localised, was considered to be over-fished to the extent that it became uneconomically viable to exploit (Jones, SARDI, pers comm. to K. Evans; 2000). During the past decade, Mulloway in this far west coast area of S.A. have been increasing targetted by offshore charter boats, and the species is promoted as one of the “prized” catches from areas such as Fowlers Bay, in the eastern GAB. Recreational bag and boat limits for Mulloway caches in S.A. have recently been revised in light of the high fishing pressure from the recreational sector, and the depleted status of Mulloway populations. The status of Mulloway in W.A. is not known for this report.

Leatherjackets: Within the SWMR, some of the shallow water, reef-associated species may be vulnerable to over-exploitation, due to their large size, aggregative nature, strong site association with reefs, and apparent population structure (possibly haremic in some species, or composed of small “family” groups). Leatherjackets are a significant bycatch in a number of commercial fisheries in the SWMR, and are heavily targeted by recreational fishers, particularly in S.A. where 155,168 (+/- 9,369) leatherjackets (unspecified species) were caught by anglers in 2000/01 (Henry and Lyle, 2003; Jones and Doonan, 2005). There are no recreational catch limits for recreational fishers or charter boats in S.A., and catch monitoring appears to be similarly inadequate in W.A..

Cobbler (*Estuary Catfish*)*:* Vulnerable to depletion due to its association with estuaries (many of which are polluted, low fecundity, and over-exploitation by recreational and commercial fishers. Within each estuary on the West Coast of W.A., Cobbler populations are genetically unique and exhibit different growth rates. In 2003, catches of cobbler in the Swan/Canning and Peel/Harvey Estuaries remained very low relative to historic levels, despite continued market demand for this species. The decline in catch of this previously abundant species appears to be the result of both fishery and fishery-independent factors (see above, on **Habitat Damage**) (Smith and Nowara, in Department of Fisheries, W.A., 2005a). Although the size at maturity is less than the legal minimum length (which would normally afford protection to the breeding stock), breeding stock levels in the three west coast estuaries are likely to be very low (Smith and Nowara, in Department of Fisheries, W.A.,2005a) due to the low reproductive potential of Cobbler, coupled with degradation of the estuaries, and the heavy fishing of this species.

Collecting

A number of nearshore fishes taken for the aquarium industry in W.A., such as those in the Apogonidae and Gobiesocidae, have vulnerable population characteristics, such as strong site association, limited dispersal ability and localised reproduction. Others, such as reef fish in the Labridae and Serranidae (amongst other targetted reef fish families), are also vulnerable due to their site-association and ease of capture. N.B. It is noted that the Estuary Cod *Epinephelus coioides*, listed as taken in the W.A. Aquarium Fish Managed Fishery, is on the IUCN's threatened species list. In the W.A. aquarium fishery, there has been inadequate assessment of the sustainability of fishing many of the groups of inshore fishes. Issues associated with collection of syngnathids is discussed in a companion chapter (Baker, this volume).

Bycatch and fish discarding

Most of the fisheries within the SWMR in which nets, traps, or longlines are used, record multiple inshore fish species in the bycatch, and many of those species are discarded. Fish discarding occurs for many reasons, including the following (from Noell et al., 2005)

- undersized fish / catch (i.e. for species managed by minimum legal lengths)
- legal-sized fish that are legislatively required to be returned to water (includes species managed by catch limits – commercial trip limits, recreational bag and boat limits, and also species inadvertently taken by devices that are prohibited for capture of that species, or during a closed season)
- protected species (e.g. Western Blue Groper in Spencer Gulf, Gulf St Vincent and Investigator Strait in S.A.);
- "catch-and-release" fish by recreational fishers (e.g. sport species including Australian Salmon, Mulloway, Yellowtail Kingfish, Pink Snapper)
- Unwanted catch (e.g. fish regarded by commercial and recreational fishers to have low value and/or poor eating qualities)

The demersal gillnet and longline fisheries in southern and south-western W.A. discards species such as Buffalo Bream, Dusky Morwong, Red-lipped Morwong; Giant Toado; gurnards in the Triglidae; gurnard perches (e.g. *Neosebastes* species); Western Sea Carp; boxfishes in the Ostraciidae; scorpionfishes (Scorpaenidae) and stargazers (Uranoscopidae) (McAuley and Simpfendorfer, 2003). A bycatch survey between 1994 and 1999 showed that discarded Buffalo Bream and Dusky Morwong accounted for 19.6% and 12.4% of the weight of the scalefish catch, respectively, in the demersal gillnet and demersal longline fisheries of south-western W.A. (McAuley and Simpfendorfer, 2003). During the survey period, the mean annual catch of Buffalo Bream was 44 tonnes, and all of this was discarded.
In general, scalefish bycatch is considered to be poorly documented in some of the nearshore trawl fisheries in W.A. (e.g. see Australian Government DEH, 2005b). In the Shark Bay Prawn Managed Fishery, concerns relating to bycatch and discarding include mortality of protected species, wastage / collection of large numbers of small fish, local depletion of resources, potential adverse effects of bycatch on ecological processes of Shark Bay, and inadequate information about levels of bycatch (Bunting, 2002).

Research completed in 2003 identified an impact from prawn trawling on juvenile Pink Snapper recruitment in Denham Sound (Moran and Kangas, 2003). Modifications to the fishery boundary have been implemented to reduce this interaction. Also in the Abrolhos Islands and Mid West Trawl Managed Fishery (AIMWTMF), Bycatch Reduction Devices (BRDs) were to be introduced in 2002/03, to reduce the amount of scalefish taken by trawls (Department of Fisheries W.A., 2004b).

In S.A., byproduct of in the Rock Lobster fishery includes nearshore species such as Barracouta, Bream, “cod” species, flathead species, flounder species, Sea Garfish, Australian Salmon, Australian Herring, Whiting species, Mackerel, Horse Mackerel, Leatherjacket species, Morwong species, Mullet species, Mulloway, Sweep, Trevally, Red Snapper, Swallowtail, Red “Mullet”, Pink Snapper, Snook, and Sole species. In addition to the byproduct, a number of other bycatch species are recorded, and many of these are discarded: Horseshoe Leatherjacket, Blue Groper (small quantities, according to Prescott, 2001), Blue-throated Wrasse, Six-spine Leatherjacket, Velvet Leatherjacket, Barber Perch, Yellow-striped Leatherjacket, Orange-spotted Wrasse, Blue-lined Leatherjacket, Largetooth Beardie, Moonlighter, Ocean Perch, Red Snapper, Bearded Rock Cod, Conger Eel, Jackass Morwong, Maori Wrasse, Harlequin Fish, Silver Spot, Knifejaw, Rosy Wrasse, Black-Banded Seaperch, Red Cod, Spinytail Leatherjacket, and Blue-spotted Goatfish (Sloan, 2003).

In the Spencer Gulf Prawn Trawl Fishery, studies by Carrick (1997) found that about 15 fish species from 10 families dominated (97%) the bycatch, with the most abundant being Sand Trevally *Pseudocaranx wrightii* (average 38% of catch) and Degen’s Leatherjacket (average 32%), with other abundant species in the bycatch including Stinkfish, Southern Silverbelly, Southern School Whiting, Spiny Gurnard, Soldierfish, Blue-spotted Goatfish, Southern Sand Flathead, and Slender Bullseye. More than 70 inshore scalefish species were recorded in the bycatch. Capture of leatherjackets was sometimes so high that it affected the efficiency of trawling. A significant impact of trawling on Small-toothed Flounder (a sandy mud/muddy sand habit fish species) was detected, with the fleet having the capacity to “reduce local populations by at least 60% over 14 days of intensive fishing” and “generally, regions more intensively fished had fewer large individuals (of flounder) than areas not fished, and densities of flounder were significantly lower”. King George Whiting, juvenile Snapper and Sand Whiting were “sometimes caught in large quantities by prawn trawls”, although “there was substantial spatial and inter-annual variation in catches”. However, Carrick (1997) suggested that there was little evidence that the Spencer Gulf prawn fishery was affecting commercial fisheries for Snapper or Whiting. More recent studies (e.g. Svane, 2002, 2004) have been further documenting the bycatch in this fishery, and the fate of the discards in the ecosystem. In addition to traditional management measures such as limited entry to the fishery, and vessel and gear restrictions, it is noted that a large number of measures have been taken during the past decades to minimise the environmental effects of prawn trawling in Spencer Gulf and Gulf St Vincent (e.g. MacDonald, 1998; Carrick, 1997; Broadhurst et al., 1999; South Australian Prawn Industry Association web site, 2000; PIRSA 2003).

Examples include (i) seasonal closures (ii) the closure of some shallow water nursery areas and spawning areas to prawn trawling; (iii) rotation of trawling grounds; (iv) the spatial and temporal organisation and “real time” management of the fishing fleet in some areas (e.g. Spencer Gulf) to minimise capture of undersized prawns and bycatch species, and (v) developments in gear design to reduce bycatch, such as square-mesh cod-ends, bycatch chutes, and the fitting of exclusion devices.

Concerns regarding bycatch and discarding of syngnathid fish in the SWMR are discussed in a companion chapter (Baker, this volume).

Other issues

- Inadequate number and size of "no-take" protected areas, particularly for larger, site-associated species that are highly vulnerable to over-exploitation.
- Food depletion for nearshore carnivorous fish, due to increased bait fishing harvest levels in recent decades.
- Degradation of nearshore habitats due to aquaculture developments, such as fish ranching, and shellfish leases.
- Unregulated diving and snorkelling access to some of the more popular nearshore habitats can result in harassment of some site-associated fish species, as well as physical damage to the habitat, particularly reefs. Recreational boating can have similar impacts (e.g. see Webster et al., 2002, for discussion of this issue at Abrolhos Is.)
- The use of jet skis near areas that support territorial, site-associated inshore fish is seen as incompatible with the conservation of populations of such species (Department of Fisheries, WA, 2004g).
- Introduced species (e.g. from bilge water) can compete with coastal fishes for food sources or space. One examples of an introduced marine fish is the Japanese Goby *Tridentiger trigonocephalus*, found in a number of port and harbour areas, and now common in the lower reaches of the Swan River in W.A. (Hutchins and Thompson, 2001).

Current research

Single species research

In both S.A. and W.A., much of the research effort on inshore fish relates to species taken in commercial and / or recreational fisheries. Examples of research projects during the past decade include the following, listed in order of species:

King George Whiting: Studies of (i) of the age composition, growth, reproductive biology, and recruitment in coastal waters of south-western Australia (Hyndes et al., 1998); (ii) biological data for the management of competing commercial and recreational fisheries (Potter et al., 1997); (iii) methods to estimate spawning biomass (Fowler, 2000); (iv) spawning areas and larval advection pathways for King George whiting (Fowler et al., 2000); (v) spatial variation in size and age structures and reproductive characteristics (Fowler et al., 2000); (vi) seasonal growth estimation, from length-at-age samples (McGarvey and Fowler, 2002); (vii) movement patterns over space and time in S.A., and implications for management (Fowler et al., 2002); (viii) development of an integrated fisheries management model in S.A. (Fowler ad McGarvey, 2000); (ix) spatial and temporal distributions of size /age composition harvested by the commercial fishery, and size /age composition of spawning KGW in southern gulfs and west coast waters of S.A. (SARDI research, cited in MSFMC, 2004); (x) spawning and larval rearing research relevant to aquaculture and fisheries biology (Ham and Hutchinson, 2003).

Yellowfin Whiting: (i) Age structure, growth rate, age and length at first sexual maturity, and spawning period, of *S. schomburgkii* in south-western W.A., and comparison with several other *Sillago* species in the area (Hyndes and Potter, 1997); (ii) age structure, growth, recruitment and stock status of Yellowfin Whiting in the S.A. gulfs (Ferguson 1999, 2000).

Pink Snapper: (i) In S.A., a biological sampling program to collect information on the reproductive biology and growth (age determination) in Spencer Gulf and Gulf St. Vincent waters (SARDI web site, 2005); (ii) study of the inter-annual variation in distribution and abundance of 0+ age snapper in northern Spencer Gulf, according to otolith microchemistry, implications for movements and stock structure, and relation of recruitment to environmental variables (Fowler and Jennings, 2003; Fowler et al., 2005); (iii) determination of biological requirements and yield- and egg-per-recruit estimates for management Snapper fishery in S.A. (McGarvey and Jones, 2000); (iv) development of an age-structured management model for the S.A. snapper fishery, based upon 20 years of data (e.g. McGarvey, 2004); (v) delineation of stocks in Shark Bay W.A., by analysis of stable isotope and strontium/calcium ratios in otoliths (Edmonds et al., 1999); (vi) tagging study of long-term movement patterns of inshore and offshore snapper stocks in the Shark Bay region, to aid fishery management (Moran et al., 2003); (vii) study of the spawning locations, and dispersal of snapper eggs and larvae in Shark Bay, using ichthyoplankton data, combined with hydrodynamic modelling (Nahas et al., 2003); (viii) study of the effects of the trawl fishery on the stock in Denham Sound, Shark Bay (Moran and Kangas, 2003); (ix) development of a management model for the sapper stocks in Shark Bay (FRDC project, cited in Department of Fisheries, W.A., 2002); (x) estimates of regional age structures in the West Coast region of W.A., to enable more sophisticated age-based stock assessment techniques to be used in the future (reported by St John and King, in Dept Fisheries W.A., 2005a).

Australian Salmon: (i) estimation of rates of migration, exploitation and survival using tag recovery data (Cappo et al., 2000); (ii) development of a juvenile index of recruitment in Western Australian waters; (iii) recruitment and juvenile growth in Barker Inlet, S.A. (Jones and Dimmlich, SARDI); (iv) a time-series analysis to examine historic commercial catches, to assist prediction of future commercial catches in W.A.; and (v) effects of seasonal and inter-annual variability of the ocean environment on recruitment to the fishery in W.A. (FRDC projects, reported in Department of Fisheries, W.A., 2005a, and Fisheries Research and Development Corporation web site, December, 2005).

Australian Herring: (i) Reproductive biology (Fairclough et al., 2000a); (ii) Length and age compositions and growth rates in different regions (Fairclough et al., 2000b); (iii) stock identification using three techniques (Ayvazian et al., 2000, 2004); (iii) development of a juvenile index of recruitment in Western Australian waters; (iv) recruitment and juvenile growth in Barker Inlet, S.A. (Jones and Dimmlich, SARDI); (v) a time-series analysis to examine historic commercial catches, to assist prediction of future commercial catches in W.A.; (vi) effects of seasonal and inter-annual variability of the ocean environment on recruitment to the fishery in W.A.; and (vii) development of an age-structured stock assessment model, which explicitly considers the spatial distribution of the stock on the west coast of W.A. and the south coast of W.A. and S.A., using historic information and data gathered during a three-year research project (Department of Fisheries, W.A., 2005a).

<u>*Sea Garfish:*</u> (i) In S.A., study of the species biology (Ye, 1999; Ye and Short, 2000; Noell, 2004); the habitat ecology of larval and juvenile garfish; and linkages between the distribution of seagrass and garfish larvae in Gulf St. Vincent (Jones et al, 2002; Noell, 2004); (ii) genetic discrimination between stocks in the southern States (Donnellan et al., 2002); (iii) a study of larval development of Sea Garfish and River Garfish in S.A. (Noell, 2003); (iv) molecular discrimination of garfish larvae in southern Australian waters (Noell et al., 2001); (v) development of an age-structured management model for the Sea Garfish fishery in S.A., based on the data collected on all fishery biology parameters (growth, age composition, reproductive biology) (SARDI web site, December, 2005).

<u>*Snook:*</u> Applications of geographical information systems and spatial analysis to assess temporal variations in the South Australian snook fishery (Doonan, 2002).

<u>*Dhufish*</u>: (i) Age and size composition, growth rate, reproductive biology, and study of habitats, and the relevance to management (Hesp et al., 2002; Hesp and Potter, 2003); (ii) estimates of regional age structures in the West Coast region, to enable more sophisticated age-based stock assessment techniques to be used in the future (reported by St John and King, in Dept Fisheries W.A., 2005a).

<u>*Tarwhine*</u>: In Shark Bay and also the Swan River estuary, and adjacent marine waters, study of the reproductive biology and implications of hermaphroditism (e.g. Hesp and Potter, 2003).

<u>*Baldchin Groper*</u>: (i) life history, and the effect of protected areas, at the Houtman Abrolhos Is. (Nardi, 1999); (ii) in Shark Bay, study of the habitats, age and growth, reproductive biology, and implications of hermaphroditism, of *Choerodon rubescens* and three other species in the Labridae (Fairclough et al., 2004).

<u>*Tailor:*</u> (i) Spawning and larval distribution (Lenanton et al., 1996); (ii) tagging study in W.A. waers, to determine movement, exploitation, growth and mortality (Young et al., 1999); (iii) Delineation of stocks by analysis of stable isotope and strontium/calcium ratios in otoliths (Edmonds et al., 1999).

<u>*Black Bream*</u>: (i) study of the genetic differentiation between estuarine populations (Chaplin et al., 1997); (ii) biological data for the management of competing commercial and recreational fisheries (Potter et al., 1997); (iii) age composition, growth rates, reproductive biology and diets of Black Bream in four estuaries and a coastal saline lake in south-western Australia (Sarre, 1999); (iv) the dietary compositions of estuarine populations, according to body size and season (Sarre et al., 2000); (v) evaluation of a stock enhancement trial of Black Bream in the Swan River (Dibden et al., 2000); (vi) development of an age-based population model for the Swan River stock, to assist in future stock assessments, including the assessment of any future fish kill impacts (Murdoch University and W.A. Fisheries collaborative research, reported by Smith and Nowara, in Department of Fisheires, W.A., 2005a).

<u>*Breaksea Cod*</u>: Studies of age, growth and reproductive biology, including a Curtin University project (Eastman, 2001), and a Department of Fisheries project (Anonymous, 2001a).

Black Snapper (Blue-lined Emperor): study of the stocks and fishery in Shark Bay, and implications for management (cited by Department of Fisheries W.A., 2005a).

Other: Examples include (i) study the spatial and temporal factors (including environmental effects) affecting abundance of King George and Yellowfin whiting, Australian Herring, Australian Salmon, Yellow-eye Mullet, Sea Mullet and Tailor, along the south-western Australian coast (Ayvazian and Cheng, 2002); (ii) reproductive biology and larval development of the Yellowtail Trumpeter *Amniataba caudavittata* in the Swan River estuary (Potter et al., 1994); (iii) methods of discriminating between cultured and wild Yellowtail Kingfish in S.A. (Fowler et al., 2003); (iv) study of the habitats, age composition, growth, reproductive biology, and hermaphroditism in the Western Yellowfin Bream *Acanthopagrus latus*, and in three species of Tuskfish (*Choerodon*), and implications for fisheries management (e.g. Fairclough et al., 2004; A. Hesp and colleagues, Murdoch University, cited by Department of Fisheries W.A., 2005a).

In W.A., the Department of Fisheries has a program to engage anglers in fisheries research projects, including estimation of trends in the abundance of key fished species, also studies of health, size / rates of growth, age of maturity, reproduction, etc. Tagging is a major activity undertaken by the research anglers (Department of Fisheries, W.A., 2005g).

Multi-species research

Recent research on syngnathid fish in southern Australia is discussed in a companion chapter (Baker, this volume). For other nearshore fish, recent studies include the following:

SOUTH AUSTRALIA

Much research has been undertaken in the saltmarsh, mangrove, seagrass and sand / mud habitats of the Port River-Barker Inlet system, the most significant estuarine area for nearshore fish in Gulf St Vincent (e.g. Jones, 1984; Jones et al., 1996; Connolly, 1994a, 1994b; Connolly et al., 1997; Jackson and Jones, 1999; Bloomfield and Gillanders, 2005).

A spatial model has been developed to quantitatively assess the economic value of seagrass habitats, particularly for fisheries production. The project investigated the functional relationship of some economically important fish species to seagrass habitats, and developed a seagrass residency index (SRI), to indicate the species most likely to be affected by changes in health and abundance of the seagrass beds in the coastal waters of South Australia (Scott et al., 2000; McArthur et al., 2003). Also in the gulfs region of S.A., a project examined the relationships between seagrass habitat patterns and fragmentation, and the abundance and species composition of seagrass fauna, including small fishes (McDonald, 2000; McDonald and Tanner, 2002)

On rocky coasts, reef fish assemblages are being studied by Shepherd and colleagues (e.g. Shepherd and Brook, 2003; Shepherd et al., 2005; Shepherd and Baker, in press). In recent years, Reef Watch (see section above, on **Education**) has played a major role in assisting ongoing surveys across South Australia to record the distribution and relative abundance of Western Blue Groper and other reef fish. Feeding behaviour of Western Blue Groper has also been studied during this program (Shepherd, 2005; Shepherd and Brook, 2005). An ongoing program (supervised by D. Turner, SARDI) to assess the "health" of nearshore reefs in S.A. has documented the fish fauna on various coastal reefs, particularly in the southern metropolitan area of Gulf St vincent (e.g. Cheshire et al., 1998; Cheshire and Westphalen, 2000).

WESTERN AUSTRALIA

At the north-western end of the SWMR (Shark Bay and Abrolhos Is.), recent studies of fish in reef habitats include (i) a study of the differences in inshore fish assemblages on granite reefs and limestone reefs of various relief, at Hamelin Bay (Harman et al., 2004); (ii) a critical analysis of stereo-video and diver-based survey techniques for studies of multi-species fish assemblages, and a performance evaluation of Marine Protected Areas for fish replenishment at the Houtman Abrolhos Islands, using stereo-video techniques (Watson et al., in prep.); (iv) a study of the effectiveness of protected areas for restoring populations of Baldchin Groper *Choerodon rubescens* and Coral Trout *Plectropomus leopardus*, using a before-after-control-impact monitoring design (Nardi et al., 2002). Also of relevance to demersal scalefish is work that has been undertaken in the use of bycatch reduction devices (BRDs) in the Shark Bay Prawn Managed Fishery, to reduce the collection and mortality of fish (Bunting, 2002).

Further south, in the Marmion Marine Park, the diversity and abundance of fish species are being documented as part of a study on the differences in communities within sanctuary zones compared with fished (general use) zones (Ryan, 2003; Ryan et al., in prep.). The fish fauna of Jurien Bay Marine Park has also been documented recently by scientists from Tasmanian Aquaculture and Fisheries Institute (TAFI), University of Tasmania and the Marine Conservation Branch of CALM in W.A. (reported in Bancroft, 2003). Jurien Bay is part of a baseline study of the habitats, biodiversity, and ecological values of marine parks in southern Australia. Other fish-related studies in marine parks include a PhD project at the University of W.A., that aims to identify and understand selection and use of microhabitats by fish assemblages in the rocky infralittoral zones of two marine parks with similar ecosystems and species, but in separate geographical areas.

In south-western W.A., a number of recent studies have documented the inshore fish fauna of various coastal estuaries, including the Swan-Canning (Kanandjembo et al., 2000), Peel-Harvey (Young and Potter, 2003), Wellstead (Bremer Bay) (Young and Potter, 2002), and Leschenault estuaries (e.g. several papers by Platell et al., 2001; Potter et al., 2001). Recent work has also been undertaken on genetic subdivision in estuarine fish populations compared with nearshore marine fish populations (Watts and Johnson, 2004). It is noted that many other estuarine studies (some biological, some ecological and others related to fisheries), were undertaken in south-western W.A. during the 1980s and 1990s (Prince et al., 1982; Lenanton and Hodgkin, 1985; Potter et al., 1986; Lenanton and Potter, 1987; Lonegeran et al., 1986; Potter and Hyndes, 1994; Valesini et al., 1997). Potter and Hyndes (1999) collated data on the species compositions and the ages, sizes, reproductive biology, habitats and diets of the main fish species in seven estuaries in south-western W.A.. A major survey has also been undertaken to estimate the impact of recreational fishing on key species in the south coast estuaries (Department of Fisheries, Western Australia, 2005a). The

Department of Fisheries in W.A. has recently commissioned work from Emeritus Professor Ian Potter, Director of the Centre for Fish and Fisheries at Murdoch University, relating to the health of the Swan River. Data will be gathered on fish populations and fish habitats, contaminants, the deaths of large number of fish through disease or algae blooms, the impact of recreational activities on the river, the potential to lose fish species, and reductions in the numbers of estuarine fish such as Cobbler (Department of Fisheries W.A. Annual Report to Parliament, 2004).

Fish species composition and habitat use has also been studied in various seagrass habitats; for example (i) as part of a study during the 1990s by researchers at Edith Cowan University of the species diversity and functional ecology of seagrass beds of Cockburn Sound; (ii) study of the daily, seasonal and spatial variations in fish species composition and densities in seagrass beds of differing structure, and in bare sand habitat (Travers and Potter, 2002); (iii) study of the differences in the fish species composition between *Amphibolis* and *Posidonia* seagrass beds of differing “architecture” and density (Hyndes et al., 2003); (iv) sudy of the fish communities of seagrass meadows and associated habitats in Shark Bay (Heithaus, 2004). Research in nearshore sand habitats in south-western W.A., includes a study of spatial and seasonal differences in inshore demersal fish fauna, according to depth and distance from shore (Hyndes et al., 1999).

A number of studies in W.A. have documented the dietary preferences of various nearshore fish species, including:

- differences in the diets of 18 abundant benthic carnivorous fish species (with teleosts including members of Scorpaenidae, Triglidae, Platycephalidae, Sillaginidae, Carangidae, Gerreidae, Mullidae and Pempherididae) on the lower west coast of Australia (Platell and Potter, 2001);
- dietary compositions of 6 abundant fish species that utilise seagrass and/or sand habitat (Western Gobbleguts, Sand Bass, Red-striped Cardinalfish, Silver Biddy, Bar-tailed Goatfish, and a scorpionfish species) (Linke et al., 2001);
- differences in dietary compositions and feeding behaviour of four abundant fish (Flathead Sandfish, Ogilby’s Hardyhead, Yellowfin Whiting and Elongate Flounder) in three nearshore habitats that varied in wave exposure and sea grass content (Hourston et al., 2004);
- the differences in diet and feeding behaviour between the 6 whiting (Sillaginidae) species in south-western W.A., according to mouth morphology, age-related movements and habitat preferences (Hyndes et al., 1997);
- seasonal differences in the diets of the Western School Whiting, Silver Whiting, Blue Sprat, and Small-toothed Flounder, at sites of variable wave exposure (Schafer et al., 2002);
- the diets of Silverbelly *Parequula melbournensis* and Sand Trevally *Pseudocaranx wrighti*, according to body size, season and location (Platell et al., 1997);
- the habitats and diet of two species of *Upeneichthys* goatfish (Platell et al., 1998);
- distribution, size compositions and diets of Long-spined Flathead *Platycephalus longispinis* and Little Scorpionfish *Maxillicosta scabriceps* in south-western Australia (Platell and Potter, 1998);

During the past decade, much work has been undertaken to develop stereo video for use in fisheries stock assessment, and also for identifying and censusing non-target fishes, and studying fish behaviour (e.g. Harvey and Cappo, 2001). Related to this are the reef fish studies in south-western W.A., part of the 2002-2004 research program in the Recherche Archipelago. During this study the fish fauna of the Esperance Bay, Duke of Orleans and Cape Arid areas was recorded, using baited remote underwater videos (BRUV's) (Shortis et al., 2001; Cappo et al., 2002), which attract many of the demersal fishes (Harvey, 2002a). Diver-operated stereo video was also used to survey the distribution of reef fish at islands throughout Esperance Bay (Harvey, 2002b). The study investigated differences in the fish assemblages according to combinations of variables such as wave exposure, depth (between 5m and 22m), distance from shore (e.g. bay sites versus islands), and also in relation to habitat types (e.g. Harvey, 2002b; Harvey et al., 2004; Kendrick et al., 2004). During the study, 5287 fish were recorded, comprising 50 species and 22 families, with significant differences recorded in reef fishassemblages between inshore, offshore and island habitats (Kendrick et al., 2004).

Another recent project in W.A., funded by Fisheries Research and Development Corporation and undertaken by I. Potter and colleagues, at Murdoch University, aimed to (i) develop a quantitative scheme that can be used to readily identify the different habitat types found in nearshore marine waters along the lower west coast of Australia; (ii) to determine the compositions of the fish faunas in representative examples of the different habitat types (and thereby determine which habitat types are used most extensively by main commercial and recreational fish species); and (iii) establish the suite of environmental characteristics that can be readily used to determine the habitat type of any site in the nearshore region and thus predict the fish species that are likely to be found at that site.

At the West Australian Museum, there is ongoing taxonomic work to determine the identity and distribution of nearshore fish species in W.A., and other parts of southern Australia. Much of this work during the past two decades has been undertaken by J.B. Hutchins (see **References**). Recent work includes description of new species and genera of clingfishes (including a paper in preparation, that describes five new *Parvicrepis* species (B. Hutchins, pers. comm., November, 2005). There is also a recent publication on the fishes of the Recherche Archipelago (Hutchins, 2005), including a checklist of 263 species recorded by during three surveys in the 1970s – 1980s (B. Hutchins, pers. comm., November, 2005). Previous survey of the fish diversity in south-western W.A. showed that 28% of W.A.'s endemic fish species occur in the Recherche Archipelago (Hutchins, 2001). The W.A. Museum engages in ongoing survey work in various parts of the State, including the Shark Bay region, Abrolhos Is., and Rottnest I. The publication of a 25-year study of the fish fauna of Rottnest I. is currently in preparation, and a separate study on tropical fish recruitment at the island is also nearing completion (B. Hutchins, pers. comm., June, 2006).

Throughout the world, many colleagues of the W.A. Museum are working on the taxonomy and systematics of the inshore fishes found in W.A., or have published accounts during the past three decades. There is a good knowledge of the inshore fauna of W.A., compared with most other Australian States, and surveys are still being undertaken (B. Hutchins.., pers. comm., June, 2006).

M. Gomon (Museum of Victoria), and R. Kuiter are preparing a revised edition of the *Fishes of Australia's South Coast* (previous edition: Gomon et al., 1994) which will include updates of the taxonomic identity and distribution of fishes within the SWMR.

Some of the recent work of taxonomists from U.S.A. and other countries relates to species in the SWMR (e.g. Smith-Vaniz, 2004, who described a new species of jawfish from the Houtman Abrolhos).

Information gaps

- For many of the commercially and recreationally significant inshore fish species, there is inadequate research on the population status and fisheries assessment (including estimates of population abundance, breeding stock size, age structure, movement patterns, recruitment strength, total fishing mortality, total and regional catch and effort from all sources etc). In W.A., some of these inshore species (e.g. Dhufish, Baldchin Groper) are currently caught as target or bycatch by numerous, separately managed and assessed fisheries, which makes stock assessment very complex and difficult. Presumably, assessing population status will become easier during the next decade in W.A. as that State moves towards Integrated Fisheries Management. In S.A., other than Pink Snapper, King George Whiting and Garfish, most other inshore scalefish species that are targetted, are classified as “secondary” species (Noell et al., 2005) due to their lower value, hence the research effort for such species is not as large or sustained, despite the fact that several of these species re classified as being either over-fished or fully-fished. Some of the nearshore commercial species in S.A. for which further research effort is over-due, include Australian Herring, Australian Salmon, Snook, Mulloway, Blue Groper and other wrasses (Labridae), Yellowfin Whiting, leatherjackets (Monacanthidae), Black Bream, mullet, trevally, Blue-spotted Goatfish, Striped Trumpeter, Sweep, weedy whiting species, flathead species, Samson Fish, and Yellowtail Kingfish. For most of these species, a rank-order priority for future research effort has been established (Noell et al., 2005).
- Spawning stock biomass estimates are required for some of the populations of reef species that form spawning aggregations.
- For many of the heavily targetted species, more regular monitoring of recreational catches is required in areas where there is high fishing pressure.
- For some commercially and recreationally significant species, such as Pink Snapper and Dhufish, the relationship of recruitment to environmental factors is likely to significantly influence the productivity of the fisheries, and further research is required to better understand the environment – recruitment relationship (St John and King, in Department of Fisheries, W.A., 2005a).
- Documentation of scalefish bycatch is poor in some fisheries, and non-existent in others (e.g. West Coast Prawn Trawl Fishery in S.A.).
- Performance measures are lacking in terms of monitoring the sustainability of targetting inshore fish populations in number of fisheries.
- For various inshore species, particularly non-targetted taxa in the eastern part of the SWMR, there is inadequate information on the taxonomy and systematics (e.g. to determine species richness within a family, and distribution). For many of these inshore fishes, further research is also needed on the geographical distribution, depth range, relative abundance over space and time, habitat requirements, and biology and population dynamics. Such research is significantly impeded by a paucity of funding.
- Research should be undertaken to determine the appropriate size and placement of protected areas for the replenishment of populations of site-associated nearshore fish species, and monitoring programs are required to determine their effectiveness.

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4.17 Demersal fish – shelf

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Bight redfish (*Centroberyx gerrardi*)

Species group name and description

The species group demersal fish (shelf) are here defined as those bony fish living on or near the sea floor in continental shelf waters down to 200 m. There are over 400 species belonging to 86 families inhabiting waters of the South Western Marine Bioregion (SWMB) (Table 4.17.1), and new species continue to be identified (Gomon *et al* 1994). The species and families included comprise only a selection of those present within the SWMB. They exhibit many forms and inhabit a diverse range of habitats in a variety of depths, from shallow coastal waters to deeper waters of the outer shelf. Deeper living species also inhabit continental slope waters down to 1500m (Table 4.17.1). Current information suggests shallower coastal regions exhibit greater species richness and that diversity is highest within the families Labridae, Syngnathidae, Gobiesocidae, Gobiidae, Clinidae and Monocanthidae (Gomon *et al* 1994). Deeper waters are dominated by species from the families Moridae, Antennariidae, Macrouridae, Scorpaenidae and Trachichthyidae (Table 4.17.1).

Status

There are few data relating to stock structure, life history, distribution and abundance of most demersal fish species within the SWMB. There is also a lack of information on how environmental conditions may affect the organisation and composition of demersal fish assemblages. Currently no demersal fish occurring within the SWMB are listed as threatened or endangered on any International, Commonwealth or State lists, however species from the family Syngnathidae (pipefishes, seahorses and seadragons) are protected throughout Australia (see Syngnathid section). The absence of other species from any list most likely reflects the lack of biological information available within the region.

Some information relating to aspects of life history is available for species taken in Commonwealth and State managed fisheries within the SWMB. Deepwater flathead (*Neoplatycephalus conatus*), Bight redfish (*Centroberyx gerrardi*), oceanjackets (*Nelusetta ayraudi*), King George whiting (*Sillaginodes punctata*), West Australian dhufish (*Glaucosoma herbracium*), mulloway (*Argyrosomus japonicus*) and snapper (*Pagrus auratus*) have received particular attention (Burnell and Newton 1989; Fowler and McGarvey 1995; Fowler *et al* 2003; Grove Jones and Burnell 1991; Hall 1986; Rowling 1990; Smale 1985; West Australian Fisheries 1992).

The first surveys of demersal fauna in the Great Australian Bight (GAB) were undertaken in 1912 by the *FRV Endeavour*. A number of surveys since this time used demersal trawls to sample fish fauna in the GAB with the view to establishing commercial fishing ventures (Burnell and Newton 1989, Collins and Baron 1981, Garry and Maxwell 1981, Houston 1954, Kesteven and Stark 1967, Newton and Klaer 1991; Walker and Clarke 1990; Walker *et al.* 1982; Walker *et al.* 1989). A similar suit of species to those present in trawl fisheries in eastern Australia and New Zealand was revealed, nonetheless the biomass of demersal fish stocks within the region was thought insufficient to support large commercial fisheries. Despite this finding, demersal fisheries within the SWMB now form some of the most high value finfish fisheries of the region. Fishers use demersal trawl, trap, handline, dropline and longline methods to target species distributed across the shelf.

Commonwealth fisheries

The Great Australian Bight Trawl (GABTS), Gillnet Hook and Trap (GHTS) sectors are the only Commonwealth managed fisheries that target demersal teleost fishes on the continental slope within the SWMB.

The GABTS now forms a division of the Southern and Eastern Scalefish and Shark Fishery (SESSF). It is a multispecies fishery comprised of 10 vessels that use demersal trawls in continental shelf and slope waters between Kangaroo Island and Cape Leeuwin in Western Australia. Deepwater flathead and Bight redfish are targeted at depths of 120-160 m on the shelf. Deepwater flathead comprise 40-50 % of landings (Kailola *et al* 1993). Other species taken as bycatch include oceanjackets, jackass morwong (*Nemadactylus macropterus*), knifejaw (*Oplegnathus woodwardi*), latchet (*Pterygotrigla polyomata*) and Queen snapper (*Nemadactylus valenciennesi*). A detailed history of the GABTS is provided in Caton (2003). A recent study of the fishery collected spatial and temporal data relating to the quantity and species composition of catch retained and discarded (Knuckey and Brown 2002).

The GHTS also forms part of the SESSF. Only a few operators within this fishery target demersal teleost fish. Small quantities of blue-eye trevalla (*Hyperoglyphe antarctica*), gemfish (*Rexea solandri*) and hapuku (*Polyprion oxygeneios*) are taken by demersal longlines and droplines in the eastern GAB.

State fisheries

South Australia
Demersal fisheries operate in state waters under regulations imposed for the Marine Scalefish Fishery (MSF). The MSF has been operating since 1904 and is the oldest commercial fishery in South Australia. Commercial fishers use handlines and longlines to target snapper and King George whiting in inshore waters of the eastern GAB. Oceanjackets are caught in fish traps in offshore locations of the GAB.

Western Australia
Demersal fisheries of Western Australia operate within Fish Management Resources Regulations imposed in 1995. Most demersal fish species taken within this fishery are caught by ‘wetline’ methods (handline and dropline). At depths <100 m fishers primarily focus on West Australian dhufish and pink snapper (*Pagrus auratus*) but

also commonly target a number of other species including baldchin groper (*Choerodon rubescens*) and emporers (*Lethrinus sp*). Species of current or increasing importance from the outer shelf (>100 m) include jobfish (*Pristipomoides* spp), ruby snapper (*Etelis carbunculus*) and grey-banded cod (*Epinephelus octofasciatus*). Blue-eye trevalla, hapuku and bight redfish are also taken by droplines in outer shelf waters off southern WA. Some of these species are caught in other commercial sectors by demersal gillnet and longline methods (Penn *et al*, 2005). Demersal fish species are also taken in the South West Trawl, Abrolhos Islands and Mid-west, and South Coast Trawl Fisheries which target western king prawns and scallops (see Molluscs section), however research indicated negligible impact on bycatch (Laurenson *et al* 1993). The Department of Fisheries is currently undertaking a major initiative to bring the commercial exploitation of all demersal teleosts under formal management arrangements by integrating the management of commercial and recreational fisheries.

Recreational Fisheries

There are few data relating to the take of demersal fish by recreational fishers in the SWMB. Some data exists for South Australia and Western Australia from the NRIFS (Henry and Lyle 2003) however the information presented does not refer to bioregions.

Access to waters of the GAB is limited for small vessels (< 8m) by inaccessible coastline and exposed waters. In the eastern GAB, fishers target King George whiting and snapper (*Pagrus auratus*) from small trailer boats in shallow coastal embayments or near islands. Land based fishers target King George whiting and mulloway (*Argyrosomus japonicus*) near surf beaches and from rock platforms.

In Western Australia most demersal species are taken by offshore boat anglers using line methods. Fishers target West Australian dhufish (*Glaucosoma herbracium*), pink snapper (*Pagrus auratus*), King George whiting (*Sillaginodes punctata*), serranids, lethrinids and gropers (various species) (Penn *et al*, 2005). Participation in boat fishing appears to be increasing and along with advances in both vessels and affordable accessory-fishing equipment (e.g. GPS), recreational fishers are now fishing across much of the continental shelf including the upper slope.

Habitat and distribution

Demersal fish utilise a wide range of habitats associated with different substrate types. In the SWMB they are found in shallow coastal embayments (<20m) dominated by seagrass, sand and reef, and midwater depths (50-100 m) where they live among sediments. Sediments are dominated by carbonate deposits formed from relict bryozoa, coralline algae, sponges, molluscs, asteroids and foraminiferans (Wass *et al.* 1970; James *et al.* 1992). Many species (eg families Monocanthidae, Berycidae, Sparidae) form large aggregations on rocky granite and limestone reefs out to depths of >100m.

The continental shelf of the GAB has been described as a featureless plain that slopes gently out to the shelf break at a depth of approximately 125-165 m (Edyvane

1998). It is approximately 260 km wide at the Head of Bight. To the east and west the shelf is generally narrower and flanked by steep continental slopes that are incised by canyons (Conolly and Von der Borch 1967; Tilbury and Fraser 1981; www.environment.gov.au). In Western Australia the continental shelf is narrow in the south-west and broadens towards Shark Bay in the north.

The wide ranging distribution of demersal fish species along the Western Australian coast into the western Bight is caused by the warm Leeuwin current extending southwards from the tropical waters of Western Australia. Within this region exists a network of limestone and granite reefs where fish aggregate. By contrast there is an absence of shallow reef habitat in the GAB**.** Migration of demersal teleost species to south-eastern Australia is inhibited by a combination of biological, oceanographic and bathymetric processes which are poorly understood. The reef free "dead zone" of sand-mud substratum at the Murray River outflow between Kangaroo Island and Robe further maintains a biogeographic barrier between species found in the SWMB and south-eastern Australia (Wilson and Allen 1987).

Poore (1985) estimated that 85% of southern Australia's fishes are endemic to the region, nonetheless the degree of endemism in the SWMB is unknown. There are also few data describing how bottom topography, oceanographic processes, sediment type and benthic community structure affect the distribution and abundance of demersal fish species at finer spatial scales within the SWMB. Harman *et al* (2003) and Watson *et al* (2005) compared fish assemblages found on limestone and granite reefs at Hamelin Bay in Western Australia using different techniques and found significant differences in the presence and abundance of demersal fish species.

Significance of the species group in the southwest planning area

The ecological significance of the demersal fish on the shelf of the SWMB is difficult to assess. A recent study validated national demersal fish datasets for the regionalisation of the Australian continental slope and outer shelf (> 40 m depth) (Last *et al* 2005). Few data are available for demersal fishes on the inner continental shelf off south-west Australia and in the GAB.

Proclamation of a 20 mile wide Benthic Protection Zone (BPZ) in the Great Australian Bight Marine Park (GABMP) in 1998 aimed to (1) protect the ecological integrity of a large, representative sample of the Great Australian Bight's unique and diverse benthic flora and fauna and (2) provide an undisturbed sample of the Great Australian Bight's benthic habitat that can be used as a reference point for comparison with neighbouring zones that may have been disturbed by trawling or mineral exploration. The extent to which the BPZ achieves these goals in relation to demersal fish species of the area is currently unknown and requires assessment.

Trophic relationships for most demersal species within the region have not been studied. Diet is likely to differ between species, life history stage and depending on the substrate with which they are associated. Analysis of the diet of deepwater flathead in the Great Australian Bight indicated diets contained up to 60% fish, 20% crustaceans, and 10% squid (Burnell and Newton 1989). King George whiting and snapper are known to feed on polychaetes, crustaceans, molluscs and fish (Jones *et* *al* 1990; Robertson 1977; Jones 1981). West Australian dhufish feed primarily on small fish but also feed on crustaceans and molluscs (WA Fisheries 1992).

The species group within the SWMB is of significant economic value through commercial fisheries production. No socioeconomic impact assessment has been undertaken for the region's fisheries. Fisheries production for the Commonwealth GABTS increased from approximately A$8.5 to nearly A$14.1 million between 2002/03 and 2003/04 (ABARE 2005). Deepwater flathead and Bight redfish had a production value of A$6.3 million and A$2.1 million respectively within the GABTS in 2003/04.During 2003/04 snapper and King George whiting had a combined production value of A$7 million (ABARE 2005) in South Australia. In Western Australia during the same period West Australian dhufish and pink snapper had a production value of A$2.1 and A$3.7 million, respectively.

Fishing-based tourism generates significant revenue within the SWMB. During 1999 and 2000 recreational fishers spent over A$480 million in South Australia and Western Australia. The proportion of money spent on targeting demersal shelf species within the SWMB is unknown.

The socioeconomic and cultural significance of demersal fish species to indigenous communities located within the SWMB is poorly understood. Snapper and mulloway are occasionally targeted from the shore by the Anagu Pitjanjatjara people on Yalata lands in the GAB.

Impacts/threats

The main threats to demersal fish species of the shelf of the SWMB include overfishing and habitat degradation by fishing practices. Apart from the Benthic protection Zone in the GABMP there are no protected areas for reef dwelling and resident species. Levels of discarded bycatch for most fisheries within the region are also unquantified (Green 2003).

Overfishing by the GABTS of species such as orange roughy on the continental slope caused fishing effort to shift to other species such as deepwater flathead and bight redfish on the shelf (Ward *et al* 2003a). The impact of this change in effort is not yet known. Previous estimates of sustainable yield for deepwater flathead indicated the resource was underexploited in the GAB, nonetheless increased targeting of deepwater flathead may have affected sustainable yields of other species caught as bycatch (eg Bight redfish) (Kailola 1993).

The effects of demersal trawling on benthic and demersal community composition in tropical regions are well documented (Hall 1996, 1999). However, the potential environmental and ecological effects of demersal trawling in the SWMB are unknown. Despite the declaration of the Benthic Protection Zone in the Great Australian Bight Marine Park, between 10.4% and 2% of trawling still occurred within the protected area between 1998 and 2002 (Ward *et al* 2003). A recent study by SARDI Aquatic Sciences showed sessile benthic communities were significantly different between areas inside and outside the Benthic Protection Zone suggesting the zone is achieving its aim of protecting invertebrate biodiversity (Ward *et al* 2003b). However the degree to which the Benthic Protection Zone is protecting biodiversity and abundance of demersal fish remains unquantified.

Line fishing is highly selective and is generally classed as negligible in terms of habitat impact. However, the status of many fish stocks targeted by line fishing remains unknown. Some species have been classed as fully exploited (eg King George whiting, Fowler *et al* 2003). There is also a threat of localised depletion of reef-associated species such as West Australian dhufish, snapper, queen snapper and blue groper, particularly in areas in close proximity to coastal towns (Fisheries WA 2000). Incidental bycatch and discarding of non-target species also occurs and post-release survival (PRS) is environment (eg depth) related and species specific. PRS is also dependent on the fishing method and gear type used (McLeay *et al* 2003).

Information gaps

Much remains unknown about the demersal fish assemblage inhabiting the SWMB continental shelf. The large number of species and wide range of habitats means research of this species group is inherently difficult. Few surveys have focused on species living on the inner shelf and more information is required for regional planning in the area (Last *et al* 2005). The degree of endemism is unknown and given the lack of research in the region new species are likely to be discovered (Gomon *et al* 1994). It is not known how the organisation and distribution of demersal fish assemblages changes in response to longitudinal and cross shelf environmental gradients, or how oceanographic processes within the region affect secondary production and the dispersal of demersal fish. Trophic relationships for most species also remain unquantified.

Some life history information is available for species exploited in demersal fisheries of the SWMB. There are few data relating to stock structure, distribution and abundance of most species. Some research on snapper has been undertaken (see Edmonds et al 1999, Fowler *et al* 2005). There is also little known about how environmental conditions affect levels of production and recruitment in demersal fish assemblages targeted by fisheries. Commercial and recreational line fishers often target a similar suit of species yet the level of catch and effort within the recreational sector in coastal regions of the SWMB is unknown. Some data may be available from the recent National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) and from fishing surveys undertaken for parts of Western Australia (Gaughan pers. comm.).

No data is available for the effects of demersal trawling on demersal fish within the SWMB. Trawling may impact on species richness and the structure of benthic communities. Abundance of non-target species can also be affected by trawl operations and trawl discards may influence the abundance of higher order predators. The extent to which the Benthic Protection Zone is protecting the biodiversity of demersal fish assemblages within the region remains unquantified.

Little is known about the factors affecting PRS of many species targeted in line fisheries. Discard mortality is not accounted for in stock assessment models and few data exist for fish caught by line within the SWMB (McLeay *et al* 2002).

Current research

Research of demersal fishes of the continental shelf SWMB is largely restricted to species targeted in commercial and recreational line fisheries. King George whiting and snapper are the ongoing focus of stock assessment research in South Australia at SARDI Aquatic Sciences. A recent study used otolith microchemistry to investigate movement and stock structure of snapper (Fowler *et al* 2005). Current PhD studies at SARDI Aquatic Sciences are researching recruitment processes in snapper and documenting aspects of life history for mulloway. However, mulloway research is mainly focussed on the fishery within the Coorong estuarine system.

Researchers in Western Australia at the Department of Fisheries conduct stock assessments of demersal fish taken in commercial and recreational fisheries. Life history information and catch and effort data is collated for West Australian dhufish, pink snapper and baldchin grouper (Penn *et al* 2005). A major creel survey of boat anglers on the west coast recently began and catch estimates in the charter boat sector are being validated.

Current FRDC funded projects are researching cost-effective techniques to monitor recreational catch and effort in Western Australian demersal finfish fisheries (Project 2005/034), researching the importance of snapper and West Australian dhufish spawning aggregations (Project 2004/051), and assessing management implications for different spatial scales of exploitation among populations of demersal scalefish. Other research has focussed on PRS in West Australian dhufish, pink snapper, baldchin grouper and breaksea cod (Moran and St John 2000; St John and Moran 2001; St John and Syers in press).

Murdoch University has recently completed studies on the biology of several shelf species within the SWMB including mulloway, two species of trevally (*Pseudocaranx* spp.) and several wrasse species (e.g. *Achoerodus gouldii*, *Bodianus frenchii*, *Coris aurocularis*) (Centre for Fish and Fisheries Research, Annual Report 2004). Murdoch University is also investigating the development of an ecosystem model that can better utilise the typical fisheries data available in Australia.

Work on the marine environment is being undertaken as part of the Western Australian Strategic Research Fund for the Marine Environment (SRFME). Much of the SRFME research represents the first consolidated examination of pelagic and benthic biophysical processes in southern WA and has established the baseline for our understanding of shelf biological processes. Linking the findings of the baseline SRFME work to population dynamics for shelf demersal fish remains a challenge that will require focussed research in the future.

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Table 4.17.1 Species list (adapted from Gomon *et al* 1994). TR = Trawl, L = Line. GN = Gillnet

Biological data – demersal fish

Names	Number of species in			Habitat				
Family	SWMB	Common	Max size (mm)	Substrate	Max Depth (m)	SHELF/SLOPE	Commercial target	Fishing method
Callorhynchidae	1	Elephantfish	1500	Sand/Mud	120	SH		
Ophichththidae	3	Worm/Snake eel	2500	Sand/Mud		SH		
Muraenidae	1	Moray eel	1500	Rock		SH		
Congridae	3	Conger/Ladder eels	450	Mud/Silt	130	SH		
Gonorhynchidae	1	Beaked salmon	500	Sand		SH		
Argentinidae	1	Silverside	190	Sand/mud	400	SH/SL		
Aulopodidae	1	Sergeant Baker	680	Rock	250	SH/SL		
Harpadontidae	1	Largescale saury	630	Sand/Mud	100	SH		
Batrachoididae	1	Pinkhead frogfish	310		<50	SH		
Lophiidae	1	Goosefish	250			SH		
Brachionichthyidae	1	Handfish	80		92	SH		
Antennariidae	9	Anglerfish	190		>145	SH		
Gobiesocidae	16	Clingfish	120	Rock/Seagrass/Sponge	<20	SH		
Moridae	10	Beardies/Rockcod	800	Rock/Sand	1000	SH/SL		
Merlucciidae	1	Blue grenadier	1100	Sand	700	SH/SL	Y	TR
Macrouridae	11	Whiptails	500	Sand/Mud	1200	SH/SL		
Ophidiidae	3	Ling	2000	Sand/Mud	700	SH/SL		
Bythitidae	4	Blindfish	500	Rock	1000	SH/SL		
Berycidae	3	Nannygai/Swallowtail/Red snapper	510	Rock/Sand	300	SH/SL	Y	TR

Species list

Biological data – demersal fish

Names	Number of species in			Habitat				
Family	SWMB	Common	Max size (mm)	Substrate	Max Depth (m)	SHELF/SLOPE	Commercial target	Fishing method
Trachchthyidae	10	Roughy	520	Rock/Sand/Mud	1000	SH/SL		
Monocentridae	1	Pineapplefish	280	Sand/Mud	150	SH		
Zeidae	4	Dory	700	Sand/Mud/Rock	800	SH/SL	Y	TR
Veliferidae	1	Veilfin	490		240	SH		
Lophotidae	1	Crested bandfish	2000			SH		
Fistulariidae	1	Flutemouth	1600	Rock/Coral		SH		
Macroramphosidae	3	Bellowsfish/Snipefish	280	Sand/Mud/Rock	1000	SH		
Syngnathidae	30	Pipefish/Seadragons	460	Seagrass/Algae/Sand/Rock	<20	SH		
Pegasidae	1	Sculptured seamoth	105	Sand/Mud	55	SH		
Scorpaenidae	13	Scorpionfish/Gurnards	470	Seagrass/Mud/Rock	800	SH/SL		
Triglidae	8	Gurnard/Latchet	570	Sand/Mud	450	SH/SL	Y	TR
Aploactinidae	3	Velvetfish	200	Rock/Algae		SH		
Pataecidae	3	Prowfish/Indianfish	350	Sand/Mud/Rock/Sponge	25	SH		
Gnathanacanthidae	1	Red velvetfish	300	Rock	30	SH		
Platycephalidae	8	Flathead	900	Rock/Sand/Mud	360	SH	Y	TR
Congiopodidae	1	Whitenose pigfish	160	Rock		SH		
Serranidae	11	Western wirrah	750	Rock	220	SH		
Callanthiidae	1	Splendid perch	480	Rock	180	SH		
Percichthyidae	3	Cardinalfishes/Hapuku	1500	Rock/Sand/Mud	1500	SH/SL	Y	L
Plesiopidae	6	Bluedevils/hulas	330	Rock	45	SH		
Acanthoclinidae	1	Southern longfin	26	Rock	15	SH		
Terapontidae	2	Trumpeter	380	Seagrass	<20	SH		
Apogonidae	8	Cardinalfish	550	Seagrass/Sand/Rock/Mud	1225	SH/SL		

Species list
Biological data – demersal fish

Names	Number of species in			Habitat				
Family	SWMB	Common	Max size (mm)	Substrate	Max Depth (m)	SHELF/SLOPE	Commercial target	Fishing method
Dinolestidae	1	Pike	900	Seagrass/Rock	64	SH		
Sillaginidae	3	Whiting	720	Seagrass/Rock	70	SH	Y	L
Gerreidae	1	Silverbelly	210	Seagrass/Mud/Rock	100	SH		
Sparidae	2	Snapper/Bream	1300	Reef/Sand	35	SH	Y	L
Sciaenidae	1	Mulloway	2000	Reef/Sand	30	SH	Y	L/GN
Mullidae	1	Red Mullet	300	Reef/Sand	40	SH		
Monodactylidae	1	Pomfret	240		<20	SH		
Pempherididae	4	Bullseye	200	Reef	60	SH		
Kyphosidae	1	Drummer	800	Reef	30	SH		
Girellidae	3	Drummer/Zebrafish	620	Reef	25	SH		
Scorpididae	5	Sweep/Moonlighter	560	Reef	200	SH		
Chaetodontidae	2	Butterflyfish	200	Reef	40	SH		
Enoplosidae	1	Old Wife	250	Reef/Seagrass	100	SH		
Pentacerotidae	5	Boarfish	600	Reef	550	SH/SL		
Oplegnathidae	1	Knifejaw	480		400	SH/SL		
Chironemidae	2	Kelpfish	330	Rock	10	SH		
Aplodactylidae	1	Seacarp	450	Rock/Algae	<20	SH		
Cheilodactylidae	6	Morwong	1200	Rock	100	SH		
Latrididae	1	Trumpeter	650	Rock	60	SH		
Cepolidae	1	Bandfish	380	Sand/Mud	76	SH		
Mugilidae	4	Mullet	800	Sand	<20	SH		
Pomacentridae	3	Damselfish	280	Rock	40	SH		
Labridae	15	Wrasses	1750	Rock/Algae	100	SH		
Odacidae	9	Weedy whiting/Cale	520	Rock/Algae	35	SH		
Pinguipedidae	3	Grubfish	330	Sand/Mud	200	SH		
Percophidae	1	Sandfish	90	Rock	130	SH		
Creediidae	2	Sanddiver	75	Sand	55	SH		
Leptoscopidae	1	Sandfish	110	Sand	<20	SH		

Species list

Biological data – demersal fish

Names				Habitat				
Family	Number of species in SW Marine Bioregion	Common	Max size (mm)	Substrate	Max Depth (m)	SHELF/SLOPE	Commercial target	Fishing method
Uranoscopidae	4	Stargazer	750	Sand	900	SH/SL		
Bovichtidae	2	Congolli/Dragonet	280	Rock/Sand	<20	SH		
Blennidae	2	Blenny	130	Sand/Algae/Rock	<21	SH		
Tripterygiidae	5	Threefin	110	Seagrass/Algae/Rock	<20	SH		
Clinidae	29	Weedfish/Snakeblenny	400	Seagrass/Algae/Rock	<21	SH		
Callionymidae	5	Stinkfish	350	Sand/Mud	60	SH		
Gobiidae	19	Goby	150	Seagrass/Algae/Rock/Mud/Sand	<20	SH		
Eleotrididae	2	Gudgeon	110		<20	SH		
Centrolophidae	6	Rudderfish/Trevalla	1400	Rock/Sand/Mud	800	SH/SL		
Bothidae	5	Flounder	400	Sand	200	SH/SL	Y	TR
Pleuronectidae	11	Flounder/Sole	380	Sand/Mud	900	SH/SL	Y	TR
Cynoglossidae	1	Sole	270	Sand/Mud	45	SH		
Monocanthidae	19	Leatherjacket	600	Rock/Sand	350	SH/SL		
Aracanidae	6	Boxfish	350	Rock	200	SH		
Tetraodontidae	10	Toadfish	970	Rock/Sand/Algae	180	SH		
Diodontidae	2	Burrfish/Globefish	500	Rock/Sand/Algae	320	SH		
Glaucosomatidae	1	Pearl Perch	1220	Rock	200	SH	Y	L

4.18 Demersal fish – slope

Principal contributor
Damien Trinder

Species group name and description

The species grouping ‘demersal fish - continental slope’ (demersal slope fish) refers to fish species that occur on or near the seabed along the continental slope (and around submerged seamounts) in depths between 200 and 2000m, and as such includes a diverse range of families, genera and species.

Few surveys have been conducted of the demersal fish fauna from within the SW marine region, but results from these studies suggest the following families dominate the biome in terms of species diversity; Macrouridae, Squalidae, alepocephalidae, Ophidiidae, Moridae, Triglidae, Scyliorhinidae and Scorpaenidae (Williams et al.. 1996, Newton & Klaer 1991). While the following families appear to be the most abundant in terms of numbers of individuals; upper slope (200 – 600m) Acropomatidae, Trachichthydiae, Chlorophthalmidae and Scorpaenidae; middle slope (600-800m) Macrouridae, Bathyclupeidae, Chaunacidae and Neoscopelidae; and lower slope (below 800m) Macrouridae, al.epocephalidae, Oreosomatidae and Synaphobranchidae.

Status

Recent analysis of the distribution of demersal fishes of the continental slope and outer shelf by Last et al.. (2005) found that 463 species occur in the southern zone of the SW marine region, of which 26 are endemic to the province. A total of 398 species were found in the south western transition zone and 480 species in the Central Western Province of which 31 are endemic to that province. These figures reflect a high level of species diversity and suggest that a total of 57 species are endemic to the SW marine region, however, the status of many demersal slope fish stocks with in the region is presently unknown.

A number of demersal slope fish species in Australia have experienced significant population declines in recent decades as a direct result of commercial fishing. Orange Roughy (*Hoplostethus atlanticus*), Harrison’s dogfish (*Centrophorus harrisoni*) and Endeavour dogfish (*C. moluccensis*) populations have been reduced by 95% of the original stock in some cases. Harrison’s dogfish is listed as Critically Endangered (A2bd+3d+4bd) on the IUCN redlist (Cavanagh et al.. 2003), while *C. moluccensis* is listed as Endangered (A2bd+3d+4bd). Both species are thought to occur within the region al.though some questions exist as to wether the west coast form of *C. harrisoni* is in fact a separate taxon.

Habitat and distribution

The Australian continental slope has gone virtually unexplored until recently and detailed habitat identification and description of much of the slope within the SW marine region is still to be undertaken. While limited information exists describing the topography of the Western Australian continental slope in detail, broad scale topographic features within the region vary from vast undulating muddy areas to rough limestone substrates and steep-sided canyons and pinnacles (Williams 1992).

By definition the continental slope extends from the edge of the continental shelf, at a depth of approximately 200 m, to approximately 2000 m where it meets the continental rise, which in turn continues down to the abyssal seafloor at 4000 – 5000 m. Continental slopes are dynamic environments and can vary dramatically across small distances. Water parameters and properties at the seafloor can also vary considerably with depth, creating seabed habitats that are rich in species and support large biomasses. Seabed features on the slope can include many features such as canyons, seamounts and deep fractures, which influence local hydrodynamics and support diverse biological communities.

Sediments along the shelf and upper slopes vary between southern and western zones. Sediments on the continental slope, in the southern province, are primarily sandy mud changing to finer mud at greater depths. In the Central Western province sediment structure is a little more varied but typically shows higher gravel contents than the southern province (Paslow et al. 2005). These differences in sediment structure can have profound effects on sediment infauna, which in turn can affect the distribution and abundance of demersal fish stocks, which rely either directly or indirectly on this biota as a source of food.

Demersal fish communities of the continental slope off Western Australia include a diverse range of tropical and temperate fauna. Major near surface and several intermediate flows adjacent to the slope influence the community composition. Species distribution of demersal slope fishes with in the SW marine region appears to change with latitude and depth but not with longitude (Williams et al. 1991, Last et al.. 2005).

Latitudinal species variation appears to occur primarily in the upper slope regions, possibly indicating the presence of shelf species and the subsequent influence of surface waters on this part of the slope. Warm sub-tropical waters occur in the northern parts of the central west zone but cooler temperate waters are found in the southern part of this zone and this transition from warm to cool waters is evident in the overlap of warm and cool water species in this part of the SW marine region.

Last et al. (2005) suggest that the slope fish of southern Australia form part of a larger fish faunal assemblage that extends across the Tasman Sea to New Zealand. Despite this, commercial catches in the region show some variation between the western and eastern ends of the southern zone (Newton & Klaer 1991).

Last et al. (2005) indicate the species richness declines as depth increases (500 species on the continental shelf compared with less than 20 species at 2000m depth). Four distinct depth biomes were evident from their study, which they labelled as: outer shelf (40-220m); upper slope (275-500); mid upper slope (630-775m); and mid slope (870-1100). These depth boundaries were seen to vary al.ong the coast being generally shallower on the east coast of Australia then elsewhere. A fifth biome for the lower slope (ca 1500+ m) probably al.so exists for the entire outer continental slope of Australia however there is a lack of data on species distribution at this depth which is needed to confirm this idea (Last et al. 2005). According to Williams et al. (1996), the upper slope (200-600m) is dominated by Acropomatidae, Trachichthyidae, Macrourocyttidae and Chlorophthalmidae, while the Macrourids dominate in terms of both species diversity and abundance below 600 m (mid and upper mid slope). Sqaulids and Oreosomatidae occur across the depth range of the continental slope and both groups contribute significantly to species diversity and abundance. In terms of commercial species orange roughy and ribaldo typically occur in the deeper regions (below 500m) and are mostly taken by commercial trawlers from depths between 800 and 1100m (mid slope biome). Dogfish and oreo-dories are taken throughout the depth range though individual species within each group inhabit narrower depth strata. Ling and gemfish are predominantly taken from the upper and mid-upper slope (Newton & Klaer 1991).

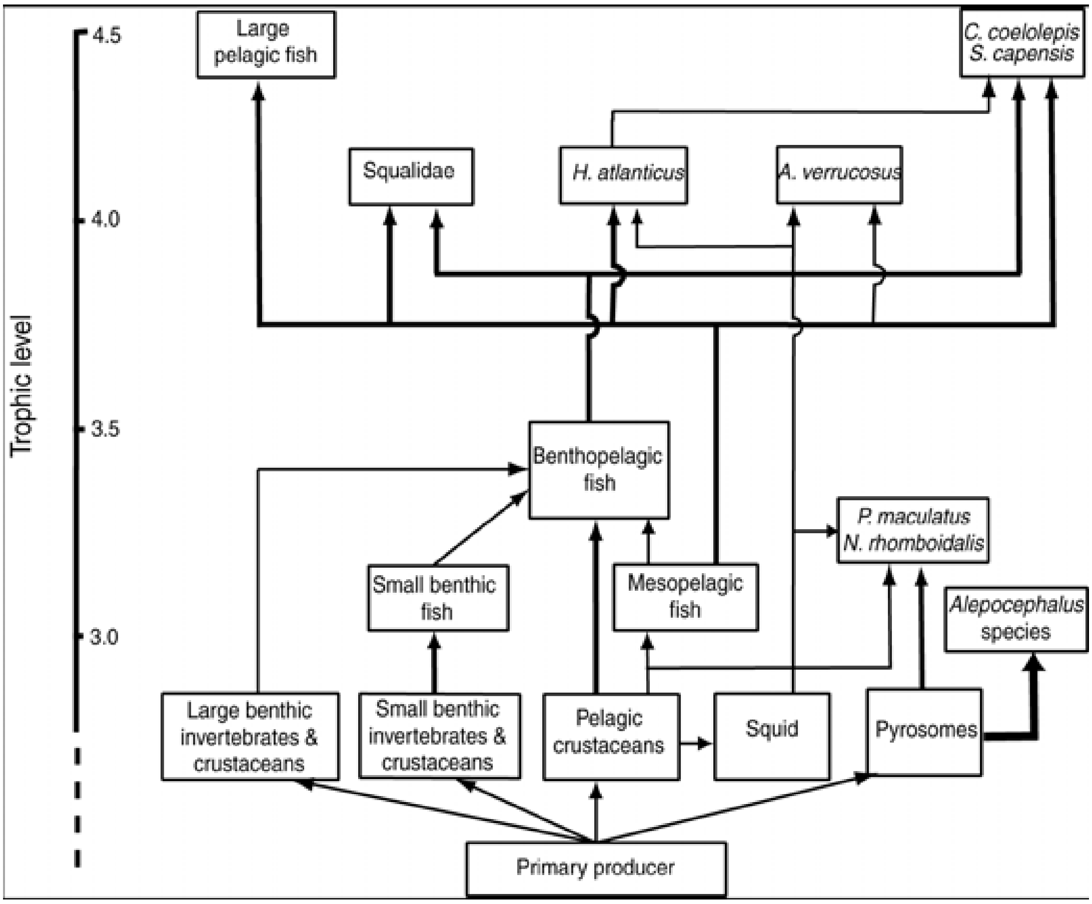
Significance of the species group in the sw planning area

Ecological significance of the species group to the region is difficult to assess. Deepwater benthopelagic species predominantly rely on meso- and bathypelagic prey and appear to employ one of at least two general ecological strategies: pursuit of prey into the water column, such as by *Coryphaenoides* spp and many squalids; and, aggregation on banks and seamounts, as shown by orange roughy, and al.so *Sebastes* spp. These strategies affect the distribution and abundance of the species with in the region and reflect the trophic linkages of this biome with shelf and surface waters.

The slope and relatively flat portions of the deep sea are generally dominated by species belonging to the Gadiformes, and in particular the Macrouridae. These species are generalized predators and scavengers, feeding both in the water column and over the bottom (Koslow et al. 2000). al.though their life-history characteristics are generally not as extreme as the seamount-aggregating species, several species have been aged to approximately 60 years and have been shown to have very low growth rates as well. Morids (Moridae), cusk-eels (Brotulidae), and hakes (Merlucciidae) are more robust-bodied Gadiformes than the macrourids and are more active predators (Koslow et al. 2000).

The diets of the major demersal slope fishes off southern Australia are dominated by pelagic or benthopelagic prey, especially fish. Bathylagids fishes are prominent in the diets of both juvenile and adult orange roughy, *Coryphaenoides* species are caught regularly in demersal and midwater trawls and are some of the most abundant species of the mid-slope (Koslow et al.. 1994, Williams and Koslow 1997), while al.*locyttus verrucosus* are abundant in the deeper midslope region, and prey primarily on fish, crustaceans and squid (Koslow et al.. 1994). Dietary overlap within species guilds on the upper slope appears to be quite high, while moderate levels between some species of different guilds al.so occurs. The level of dietary overlap is likely attributed to an excess of resources (Bulman et al. 2002, Blaber and Bulman 1987).

Species that aggregate on seamounts and banks generally do not migrate vertically but are often robust and deep-bodied in order to be able to manoeuvre in the strong currents characteristic of this environment. Deepwater aggregating species depend on the flux of meso- and bathypelagic organisms past the seamount and on intercepting mesopelagic migrators on their downward migration. This influx of energy from vertical migrating organisms enables them to maintain high population densities despite the low productivity of the deep sea (Koslow, 1996, 1997). However high population densities do not necessarily equate to high productivity as many of these species, such as orange roughy, are slow growing, late to mature (>20 years), are exceptionally long-lived (>100 years) and have very low natural mortality rates (Koslow et al. 2000).



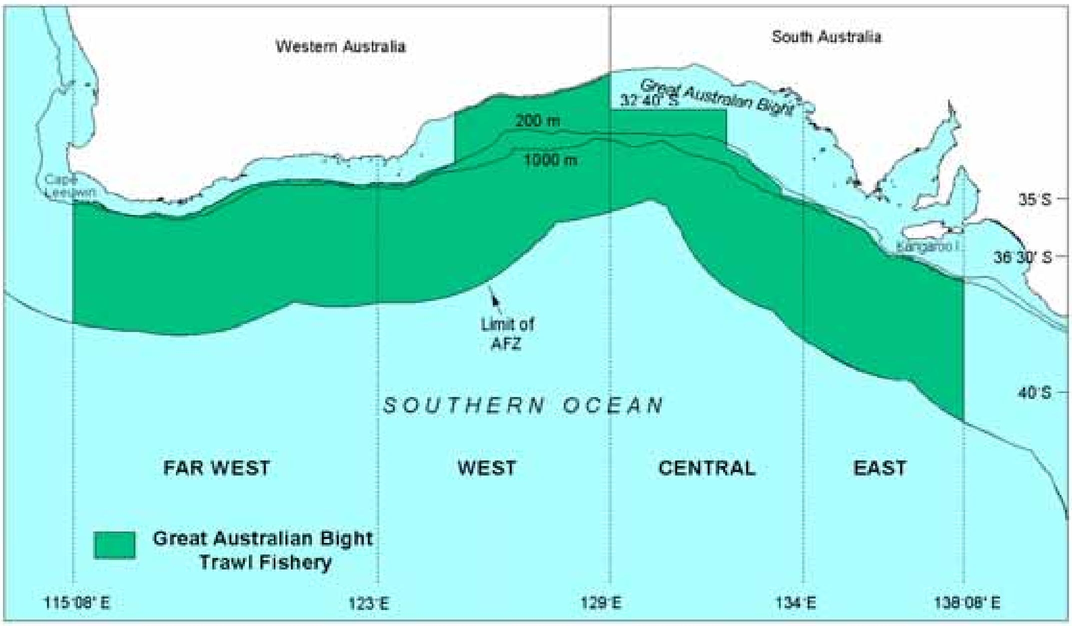
A number of species of demersal fish found along the continental slope are commercially significant to the SW marine region. There are two main commercial fisheries which target demersal slope fishes in the region; the Western Deepwater Trawl Fishery (WDWTF); located in water off Western Australia; and, the Great Australian Bight Trawl Fishery (GABTF) which extends from Cape Leeuwin, Western Australia, to Cape Jervis near Kangaroo Island, South Australia [See Maps below].

Exploratory fishing in the WDTF began in 1979, when the stern trawler, 'Taiyo maru 71' conducted a series of trawls at depths between 90 and 600 m (Jernakoff 1988). Initial catches were of Big-spined boarfish (*Pantaceros decacanthus*), nannygai (*Centroberyx affinis*), alfonsino (*Beryx splendens*), mirror dory (*Zenopis nebulosus*) and piked dogfish (*Squalus megalops*), (Jernakoff 1988). Current target species include orange roughy and oreo dories in mid slope regions (>600m) south of 33^{o}S and big spine boarfish between 300 and 500m depth, south of 26^{o}S. Estimated catch for the WDWTF in 2003-2004 was 109.5 tonnes, with an estimated value of $A 979, 600, which was down from the $2,579,500 GVP for the fishery in 2002-2003. It should be noted, however that these figures include part of the fishery which extends beyond the northern boundary of the SW marine region.

Species diversity is considerable in this principally finfish trawl fishery, with over 50 species taken on the upper (200-600m) and mid-continental slope (>600 m), though generally not in large quantities. al.though biological data for nearly al.l stocks are limited, effort levels are considered to be well below sustainable levels for the fishery. In the WDWTF, communities vary by depth and latitude with highest densities occurring in the shelf break region (200-400m) (Williams et al. 2001). The composition of the mid-slope fauna in the southern part of the WDWTF is potentially part of a wide-ranging Australasian mid-slope community shared with the Great Australian Bight, south-eastern Australia and New Zealand (Williams et al. 2001).

The GABTF is a demersal trawl fishery and is in fact a sector of the Commonwealth managed Southern and Eastern Scalefish and Shark Fishery (SESSF). Catches in this fishery come from two distinct depth regions: the shelf/upper slope fishery and the deepwater slope fishery. Estimated value of the entire catch in the GABTF during 2003-04 was 5,781,700 tonnes with a gross value of $A14, 094, 500. The shelf fishery extends approximately out to the 400 metre isobath and targets deepwater flathead and bight redfish. The deepwater slope fishery is seasonal and targets orange roughy and oreo dories in waters deeper than 600 metres. In the deeper lower slope waters there are only a few known orange roughy aggregations which are large enough to support commercial fishing (Lynch and Garvey 2003).

In 1988, 68% of the fishery's total effort was on the continental slope at a time when orange roughy landings peaked (3757t) but this has declined sharply with the orange roughy fishery. Since 1991 slope effort has been low, between 5-9% of the total effort in the fishery. Fifty eight percent of the catch between 1998 and 2002 was taken from aggregations to the south of Kangaroo Island and to the south east of Esperance. CPUE in the slope sector of the GABTF is highly variable; this is because orange roughy is the primary target species which is naturally prone to wide variations in CPUE given that fishing for orange roughy mostly occurs on spawning aggregations. Monitoring of the slope sector indicates that about 96% of the catch, by weight, is retained. The retained catch is dominated by orange roughy (99.9%), though some dogfish (Squalidae), Ling (*Genypterus blacodes*), blue grenadier (*Macruronus novaezelandiae*), ribaldo (*Mora moro*) and gemfish (*Rexea solandri*) are al.so taken. The small discarded catch included spikey oreo (66%), soft coral (7%), whiptails (3%) and squid (3%).



Map courtesy of the Australian Fisheries Management Authority

Impacts/threats

Detailed studies of fishing induced habitat impacts have not been conducted for the western trawl Fisheries, however an ecological risk assessment (ERA) for the affects of fishing is being conducted by AFMA in order to identify any potential impacts of this fishery and this should be finalised in 2005. al.terations to benthic habitats caused by trawling may impact on deep sea crab stock productivity but is yet to be quantified. As mentioned orange roughy stocks have declined sharply since the late 1980s and these stocks will require a long time to recover to virgin levels.

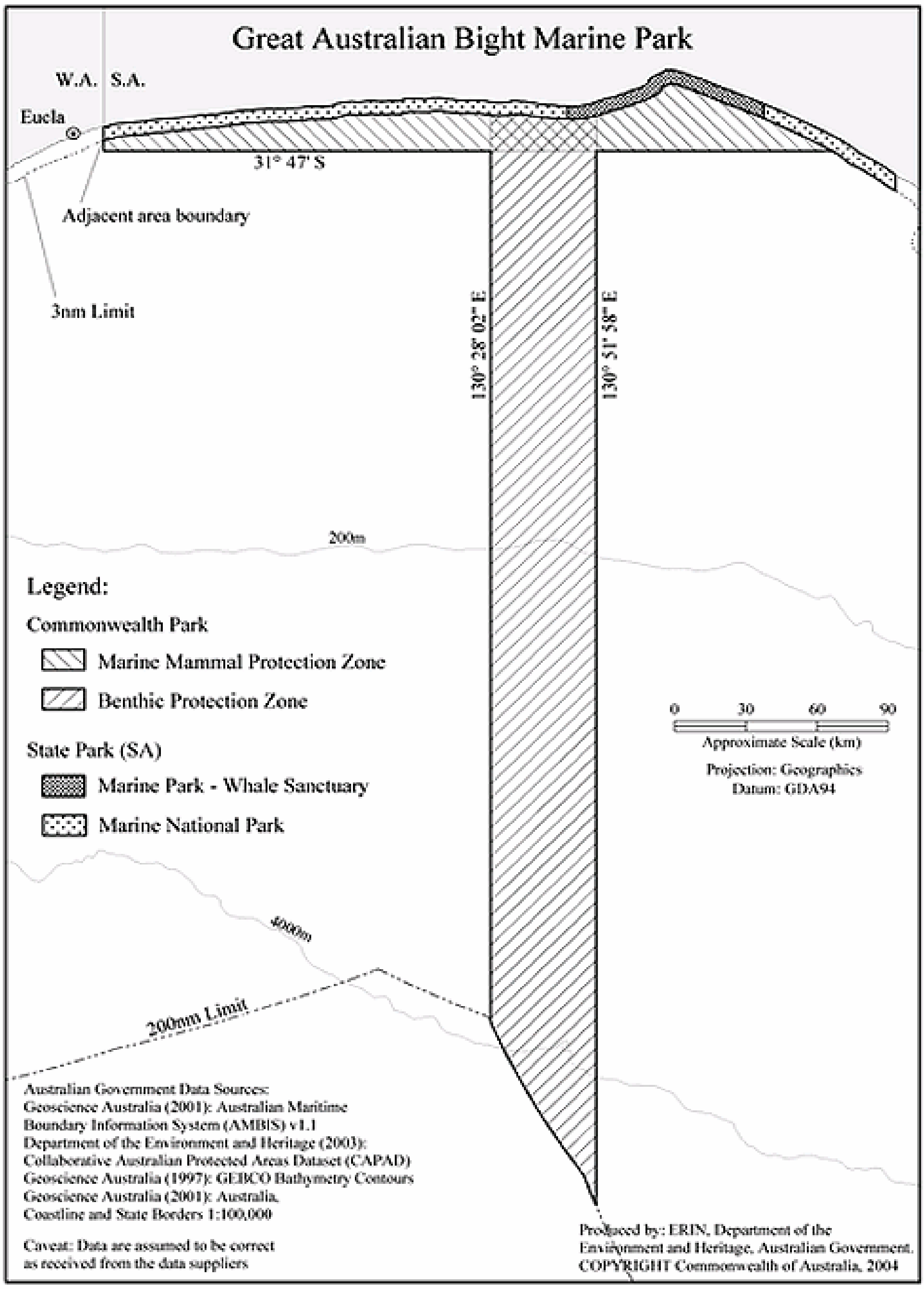
Deepwater commercial trawling on the east coast of Australia has severely impacted on local populations of a number of dogfish species, particularly Harrison's dogfish (*Centrophorus harrisoni*) and Endeavour dogfish (*C. moluccensis*). These species that occur in the SW marine region, are taken by commercial trawl fisheries, though in small numbers and therefore may al.so be at risk of long term impacts if not managed effectively.

Though not yet confirmed commercial fishing for seamount species such as orange roughy and oreos may adversely impact fish community structure in these regions. Commercial orange roughy fisheries on the Chatham Rise, New Zealand, were examined to determine if commercial exploitation of one or two species could possible affect any shift in the demersal fish community. Between 1984 and 1994, 9 out of the 17 species examined showed a downward trend, with a median decline of 50%, while only one species, *Centroscymnus crepidater* (a dogfish), was observed to increase significantly in the same time, suggesting that no significant shift had occurred in the community structure (Koslow et al. 2000). Similar studies in the Northeast Atlantic have shown no significant shift in species composition of deepwater slope communities as a result of commercial fishing efforts supporting the general conclusion that evidence for shifts among competing species due to the impact of fishing is weak. However, changes to community structure in the deep sea may operate on relatively long time scales, given the longevity, slow growth, and late maturation of many species, and as such, most deepwater fisheries are probably too recent to provide a clear picture regarding community stability on the continental slope and around seamounts (Koslow et al. 2000).

While uncertainty still exists over the direct impacts of commercial fishing on demersal fish community structure, one of the clearest impacts of deepwater fisheries has been on benthic habitats. The benthic fauna of seamounts is typically distinct from that found on the surrounding seafloor, because the intensification of currents leads to a fauna dominated by suspension feeders, including scleractinian, antipatharian, and gorgonian corals (Koslow et al. 2000). Deepwater trawling on seamounts may severely impact the benthic fauna, owing to incidental damage and removal as by-catch. A study on seamounts around Tasmania found that benthic biomass was reduced by 83% and the number of species per sample by 59% in a comparison of fished and unfished areas. Photographic transects indicated that 95% of the bottom was bare rock on a heavily fished seamount compared with about 10% on the most comparable unfished seamount (Koslow and Gowlett-Holmes, 1998). Concerns about the impacts of trawling on benthic seamount fauna led to one of the world's first deepwater marine reserves being established on the continental slope south of Tasmania. Given the high degree of endemism, adequate conservation will require a network of similar reserves within areas of national jurisdiction while changes in fishing practice, such as switching from trawling to long-lining, should be considered in some fisheries (Koslow et al. 2000).

Despite the potential risk to some demersal stocks in the region, there are a number of refugia available from commercial fishing. The GAB marine park is the only marine reserve in the region but under the GAB Marine Park Management Plan, a benthic protection zone has been established to protect benthic and demersal fauna, and includes a section of the continental slope. Apart from this single formal refuge a large portion of the continental slope in the GAB appears to be potentially unsuitable for demersal trawl fishing due to the hazards posed to fishing gear by the sea-bottom. Newton & Klaer (1991) found that 59% of the areas surveyed in their multivessel survey were untrawlable. If a similar percentage can be applied to the entire GAB then the amount of untrawlable ground, at least in the southern zone of the region, provides a certain level of protection to the demersal slope fish fauna. Large areas of the eastern and central sectors of the GAB were particularly found to be untrawlable which may reflect the concentration of commercial trawling south of kangaroo island, SA, and south-west of Esperence, WA, in conjunction with the presence of orange roughy aggregations sites in these areas. It should be noted however that gear and vessel advances since 1991 and the use of midwater trawling for fish species which aggregate on and above seamounts, such as orange roughy, may mean that previously untrawlable ground is now accessible. However, fishing effort in the region is still relatively small and if managed correctly should be able to continue without causing significant impacts on the continental slope fish communities with in the SW marine region.

Between July 11 and August 7 of 2005 a temporary closure within the western zone of the SESSF was implemented under the fisheries management plan for this fishery. The temporal closure was made to protect spawning and resident stocks of orange roughy in the GAB while minimising the impact of the closure on trawl fishers targeting upper slope species such as spiky dory, king dory, ribaldo and ling. The area closed to fishing during this time was between the lines of longitude at 138º 48” E and 128º 8” E.



Map courtesy of the Commonwealth Government Department of Environment and Heritage

Information gaps

There are considerable gaps in the taxonomic understanding of demersal slope fishes in Australia. These gaps reflect a general lack of scientific faunal sampling around the country and especially so for lower continental slope regions. Detailed data relating to taxonomic elucidation, reproductive biology, stock status, and geographic distribution are lacking.

Given the potential for commercial exploitation of some deepwater fish stocks more work on the impacts of commercial fishing on fish communities and slope and seamount habitats is needed. While there have been few studies on the direct impacts of fishing on target species, there have been no studies of the impact of deepwater fisheries on predator or prey populations of the target species. Neither has there been any examination of the potential coupling between the benthic and benthopelagic components of seamount ecosystems. Given thatresident fish aggregated over seamounts presumably rain down a significant quantity of detrital material the removal of this biomass by commercail fishing could potentially cut off a significant energetic input to the benthic community (Koslow et al.. 2000).

Key references and current research

Research

In the 1960s and 1970s, the Soviet Union carried out extensive fishery surveys on the shelf and upper slope of northern, western and southern Australia. Trawling was relatively concentrated on the continental shelf in the Great Australian Bight, Northwest Shelf and Gulf of Carpentaria, but was not comprehensive on the continental slope, nor on the shelf off eastern and southeastern Australia, except Bass Strait, and off central western Australia.

The CSIRO conducted a review and analysis of this data and re-identified much of the retained samples from these cruises in the 1990s (Koslow et al. 1999). The reliability of original identifications appeared to be most dependent on region and was higher in temperate than tropical Australia, with the GAB/SW Australian region most reliable. While this data set provides a unique baseline record of the relative abundance of demersal fishes in the SW marine bioregion over an approximately ten-year period, a lack of trawls over the continental slope, inconsistency in survey intensity between subregions and uncertainty surrounding species identification mean that the data from these trawls is of limited use.

More recent surveys of the continental slope off western and south eastern Australia (May and Blaber 1989, Koslow et al. 1994, Williams et al. 2001) by CSIRO have been sufficiently comprehensive and extensive to fill in many of the gaps from the Russian data sets. Most notably the recent surveys have enabled researchers to delineate the depth structure of Australian fish communities with in the SW marine region. However, most trawls conducted during these surveys occurred above 1200 m and subsequently very little data exists on the fish communities of the continental slope beyond these depths.

A recent review of demersal slope fish datasets conducted by the Commonwealth Scientific & Industrial Research Organisation (CSIRO) found that of the 1489 Australian species examined, 312 did not have a full scientific name and many were new to science (Last et al.. 2005). While some of these species have since been described and named, many species are still to be properly described.

With the exception of the two following examples, there has been no scientific research in the WDWTF since 1993. AFMA has begun the ERA process mentioned above. The ERA is designed to evaluate fishing induced impacts on ecological systems by identifying high-risk activities and recommending risk management responses. The CSIRO has al.so just completed a scientific marine survey of the SW marine region to map the benthic ecosystems on the deep continental shelf and slope. The aims of this survey were to 1) apply targeted field-based observation to develop, test, refine and validate multiple use management frameworks developed for the SW Region as part of the Regional marine Planning under Australia's Oceans Policy, and 2) explore and characterise marine ecosystems of the SW region. Two survey voyages were completed between July and August, 2005 as to complete the survey.

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4.19 Mackerels, tunas and billfishes

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Species group name and description

Mackerels, tunas and billfishes form a diverse group of marine fishes with a broad distribution from tropical to temperate waters. Many are highly prized for the quality of their flesh and sustain large commercial, artisanal and recreational fisheries of significant social and/or economic importance. They are currently classified into three families, i.e. Scombridae (mackerels and tunas), Xiphiidae (swordfish) and Istiophoridae (marlins and sailfishes), within the suborder Scombroidei.

The family Scombridae comprises 15 genera and 51 species of which all but one monotypic genus, i.e. *Gasterochisma*, are divided into four main tribes (Collette *et al.* 2001):
Tribe Scombrini (the mackerels)
Tribe Scomberomorini (the Spanish mackerels)
Tribe Sardini (the bonitos)
Tribe Thunnini (the tunas)
The diversity of scombrids in Australian waters clearly decreases with increasing distance from the tropics. Compared to the Western Central Pacific, where at least 28 species are known to occur, 22 species (12 genera) are likely to inhabit the north coast (Stapley *et al.* 2004); 21 species (13 genera) the west coast south of Shark Bay; and 14 species (10 genera) the south coast between Cape Leeuwin and Kangaroo Island (Table 4.19.1).

The group generally referred to as 'billfishes' includes swordfish (the only species in family Xiphiidae) and the 11 species (three genera) of the family Istiophoridae, containing marlins, sailfishes and spearfishes (Nakamura 1985). Of these, only swordfish is abundant throughout the South West Marine Region (SWMR), whereas the five (three genera) istiophorids with an Indo-Pacific distribution are more often encountered off the west coast (Table 4.19.1).

Status

There are no scombrids or billfishes listed under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999), the *Wildlife Conservation Act 1950* (WA) or the *National Parks & Wildlife Act 1972* (SA). However, it should be noted that each of these Acts forms a framework for the classification of the broadest range of species and that, therefore, the assessment criteria do not necessarily lead to an appropriate evaluation for certain groups of species – especially fish with high reproductive potential, fast growth and broad geographic ranges. Many scombrids and billfishes fall into this category. Nevertheless, the *1996 IUCN Red List of Threatened Species* listed five scombrids, three of which occur in the SWMR (Table 4.19.1). Additionally, eight species of tuna and all billfishes occurring in the SWMR are listed as 'highly migratory species' under the 1982 UN Convention on the Law of the Sea, indicating that stocks of these species are likely to be subjected to fishing pressure within the EEZs of multiple nations as well as in international waters. Explicit protective legislation does exist for blue and black marlin, both protected under the *Fisheries Management Act 1991* from being taken or landed by commercial fishers in Australian waters; and blue mackerel, protected from commercial fishing pressure in WA waters under the *Fish Resources Management Act 1994*. The latter also prohibits the targeting of bonito (both leaping and oriental bonito, Table 4.19.1) by recreational fishers. Other species are partially protected through commercial input or output controls and/or recreational fishing bag/boat and size limits.

The current status for each of the more commercially important species, as determined by regional or international stock assessments, are briefly summarised as follows:
Narrow-barred Spanish mackerel – In WA the Spanish mackerel stock is considered 'fully exploited' and the Department of Fisheries (WA) is in the process of introducing output controls for the commercial fishery (Mackie and Kennedy 2005). Further noted is the fact that the breeding stock levels are thought to be adequate and that the minimum size of 90cm TL is appropriate as approximately 50% of females and 90% of males are mature at this size (Mackie *et al.* 2003).
Skipjack tuna –Indian Ocean skipjack tuna is possibly 'underfished' (Anon.[B] 2004), despite a strong increase in the total catch over the last decade peaking at over 500,000t in 2003 (Caton and McLoughlin 2004). The resilience of skipjack to fishing pressure is mainly due to its biological characteristics (i.e. fast growth, early maturity, high fecundity and year round spawning) and further aided by the fact that relatively few juveniles are caught. However, given the strong variability in abundance of skipjack tuna in the southwest and the uncertainty of the stock structure, the Bureau of Rural Sciences (BRS) determined the status of skipjack in the western AFZ 'uncertain' (Caton & McLoughlin 2004).

- Southern bluefin tuna – The spawning stock biomass of southern bluefin tuna remains at historically low levels: 3-14% of the unfished biomass and less than half of the 1980 level (Anon.[A] 2004), which has been adopted as the recruitment-overfishing reference limit: the point where recruitment declines noticeably. The stock is therefore considered to be 'severely recruitment-overfished' and at considerable risk of further and abrupt decline due to environmental variability (Caton & McLoughlin 2004). Of particular concern for the immediate future of the stock is the confirmed further reduction in recruitment first observed in 1999, but more pronounced in 2000 and 2001 (Anon.[C] 2005). Recent results from model runs show a rapid and continuing decline in the spawning biomass if there is no reduction in the annual global catch. At the current catch levels, the model suggested a 50% probability that the spawning stock will decline to 0t by 2030 and only a 20% chance that it will be at or above its current level by 2030 (Anon.[C] 2005).
- Bigeye and yellowfin tuna – The status of both Indian Ocean stocks is 'uncertain' and in threat of becoming overfished by recent unsustainable catch levels (Anon. 2004; IOTC[A] 2004). As the status of the Australian resource is also unclear, due to the uncertainty about the degree of mixing between the Southern and Western Tuna and Billfish Fishery (SWTBF) and the broader Indian Ocean, AFMA has decided to introduce output controls during 2006 (Caton & McLoughlin 2004).
- Swordfish – The current Indian Ocean swordfish stock status is 'fully fished' but possibly 'overfished' in the western and south-western Indian Ocean where localised depletion may already be taking place (IOTC[B] 2004). There is also concern for the viability of the resource in the SWTBF and a Total Allowable

Catch (TAC) and Individual Transferable Quotas (ITQs) are planned for implementation during 2006 – along with those for bigeye and yellowfin tuna (Caton & McLoughlin 2004).

Habitat and distribution

Mackerels, tunas and billfishes exhibit a distinct diversity in biological and life history traits but have in common that they inhabit the pelagic marine environment. Running through the group is a series of biological adaptations shaped by the pronounced selection pressures of this environment. A streamlined body, high percentage of red muscle, caudal keels, finlets (or small second dorsal/ventral fins), high metabolic rates and powerful locomotion are all characteristics that allow these fishes to maintain high cruising speeds and thus scan large volumes of a vast environment where food is patchily distributed (Bushnell & Jones 1994; Dickson 1995).

The variation in biological and life history characteristics is particularly evident in the scombrids and has resulted in distinct habitat preferences and distributions for each group. Butterfly mackerel (the only species of subfamily Gasterochismatinae) is of a more primitive evolutionary lineage than other scombrids, but possesses independently evolved adaptations that allow it to inhabit the oceanic waters of the Southern Ocean (Collette *et al.* 2001). Individuals grow to a large size (up to 180 cm); have a thick layer of fat under the scales; and possess an eye and brain heater (Collette & Nauen 1983; Collette *et al.* 2001). The mackerels of Tribe Scombrini, in contrast, lack sophisticated heat retention mechanisms and are predominantly neritic – rarely occurring in open waters beyond the continental slope. They are relatively small and are characterised by long gillrakers used for feeding on plankton. The mackerels of genus *Rastrelliger* are confined to tropical and sub-tropical waters of the Indo-West Pacific region, whereas the species of genus *Scomber* additionally inhabit temperate waters and have a wider pattern of distribution (Collette & Nauen 1983; Ward *et al.* 2001). Within their distributional range, mackerels are thought to form a series of disjunct regional populations – supported by the results of several studies on the population structures of *Scomber* species (e.g. Rhode 1987; Scoles *et al.* 1998). The larger Spanish mackerels (with the exception of wahoo) of Tribe Scomberomorini and the bonito's of Tribe Sardini also have a neritic or coastal distribution. All species are predators and most are restricted to tropical and sub-tropical waters. These groups differ, however, in distributional range. Whereas Spanish mackerels (again with the exception of wahoo) have relatively restricted distributions, bonito's tend to be more widespread, typically occurring along the coasts of several continents (Collette & Nauen 1983). More advanced, in terms of morphological and physiological traits, are the tunas of Tribe Thunnini (Collette *et al.* 2001). Tunas possess countercurrent heat exchangers of retia mirabilia in the circulatory system that conserve metabolic heat in the swimming muscles, viscera and brain and permit these fishes to maintain body temperatures warmer than the surrounding water (Block *et al.* 1993; Collette *et al.* 2001). The heat retention mechanisms and other adaptations (such as the recruitment of white muscle for sustained swimming activity) enable tunas to adopt highly migratory lifestyles in oceanic waters that, for several species (i.e. slender tuna, albacore, bigeye tuna and the bluefin tunas), include those of cooler, more productive regions at higher latitudes. All tunas, however, exclusively spawn in tropical and/or sub-tropical waters with surface temperatures in excess of about 24°C (Schaefer 2001).

Many of the adaptations that characterise billfishes resemble those of tunas (or scombrids in general) as a result of convergent evolution or reversals (Carpenter *et al.*

1995, Finnerty & Block 1995). One example worth mentioning is the eye and brain heater organ that permits billfishes to hunt in cold waters without experiencing a decrease in brain and visual function (Block *et al.* 1993; Block & Finnerty 1994). Like the larger tunas of genus *Thunnus*, billfishes are migratory predators of oceanic waters that may include those at temperate latitudes and/or at depth. They (with the exception of swordfish – described below) do not have a circumglobal distribution, though. All istiophorids are restricted either to the Indo-Pacific region or the Atlantic region (including the Mediterranean Sea). Of the five species of Indo-Pacific istiophorids, only blue marlin has a predominantly tropical distribution and only sailfish tends to live in continental shelf waters, while the other three species inhabit the oceanic environment from the tropics to temperate latitudes (Nakamura 1985; Campbell *et al.* 1998). Differences in vertical distribution between taxa are also evident. Shortbill spearfish spend extended periods of time in deep waters well below the thermocline; whereas blue and black marlin have a more variable depth range; and striped marlin and sailfish almost exclusively inhabit the surface layer (Nakamura 1985; Campbell *et al.* 1998). Other elements of billfish behaviour are less known. In relation to movement dynamics, for instance, it is becoming clear that several species may not as highly migratory as once thought. Swordfish, sailfish and striped marlin all appear to display regional fidelity to some extent, which – if confirmed – will have important implications for fisheries management (Nakamura 1985; Bromhead *et al.* 2004).

All scombrids and billfishes are dioecious (separate sexes) and display little sexual dimorphism in morphology or colour pattern, although females of several species, the billfishes in particular, are larger, mature later and may have a longer life span (Collette & Nauen 1983; Nakamura 1985). Batch spawning predominantly occurs in specific areas and at particular times, although several tropical-distributed species spawn all year round (Schaefer 2001). For mackerels and Spanish mackerels spawning is thought to occur in regional hotspots (Scoles *et al.* 1998; Mackie *et al.* 2003), whereas for larger tunas and billfishes tropical spawning grounds may lie thousands of kilometers from high latitude feeding grounds (Schaefer 2001; Bromhead *et al.* 2004; Young *et al.* 2004). The eggs are pelagic and hatch into planktonic larvae. Initial growth is assumed to be rapid for all species.

Distributional differences between juveniles and adults are common. In neritic species (mackerels, Spanish mackerels and bonito's) juveniles often inhabit coastal waters whereas adults are often found to have a broader distribution (Shuntov 1969; Stevens *et al.* 1984). In the oceanic tunas and billfishes such differences are particularly distinct and appear to be related to physiological requirements, with juveniles being dependent on higher water temperatures (Sharp 2001). This may be expressed in a difference in horizontal distribution, where juveniles are restricted to tropical (or coastal) waters whereas adults have temperate (or oceanic) distributions (e.g. swordfish and albacore tuna); or a difference in vertical distribution, where juveniles inhabit the waters of the mixed surface layer, while adults prefer the deeper waters close to (yellowfin tuna), or below (bigeye tuna) the thermocline (Hisada 1988; Block *et al.* 1997). These differences in temperature requirements may be a result of a more advanced stage of development of, and thus more efficient, heat retention mechanisms of mature individuals, and/or by larger thermal inertia afforded by larger size.

Biological and life history traits for the species that occur in the SWMR are summarised in Table 4.19.2.

Blue mackerel

Blue mackerel is a neritic species mainly abundant in sub-tropical and temperate waters of the Indo-West Pacific region. Like many small pelagic fish, blue mackerel are rapid colonizers that grow fast, mature early (i.e. at ~28cm FL and 3 years of age, Stevens *et al.* 1984) and are highly fecund (Ward et al 2001). Interannual variability in abundance is distinct and a result of the impact of environmental conditions on recruitment. Blue mackerel may live for over 10 years. Juveniles typically inhabit shallow coastal waters (Shuntov 1969) while adults may occupy waters further from the shore and as deep as 200m, possibly exhibiting a diurnal migration pattern of spending most of the day in deeper waters and coming to the surface during the afternoon (Ward et al 2001). In the GAB spawning is thought to peak during late summer (Stevens *et al.* 1984).

Whereas the results of a mitochondrial DNA study indicate the Australian-New Zealand stock to be separated from those in the northern hemisphere, a further separation of the south-east Australian population from the New Zealand resource, as suggested by the results of a parasite study (Rhode 1987), could not be confirmed (Scoles *et al.* 1998). Ward *et al.* (2001) further noted that although the stock structure within Australian waters is unclear, mixing between southeastern and southern populations is possibly limited due to the cool waters of the Bass Strait.

Narrow-barred Spanish mackerel

The narrow-barred Spanish mackerel is a large-sized epipelagic neritic species common in tropical and sub-tropical waters of the Indo-West Pacific region (Collette & Nauen 1983). In WA it is most abundant in the Kimberley region but also occurs in the Pilbara region, Gascoyne region and further south along the west coast within the SWMR. Narrow-barred Spanish mackerel are generally more abundant than the other three occurring species of *Scomberomorus*, although occasionally outnumbered by grey mackerel in commercial catches off the Gascoyne and lower west coast (Mackie *et al.* 2003).

In WA waters individuals are very fast growing, mature within 18 months and may live for more than 20 years (Mackie *et al.* 2003). The length at which 50% of individuals reaches maturity is ~80 cm FL for females and ~63 cm FL for males. Females also grow more rapidly and attain larger sizes. Spawning activity is influenced by water temperature, resulting in northern areas having earlier and longer spawning periods than those lower down the coast. Mackie *et al.* (2003) reported that the majority of spawning adults were captured in water temperatures of 25.5 - 28.5°C north of Exmouth, but further suggested that a strong Leeuwin Current may allow spawning at higher latitudes during some years. As the Leeuwin Current additionally may transport a proportion of larvae southward along the coast, it is probably of considerable importance to recruitment within the SWMR. This idea is supported by the relatively large catches in the region over the last few years, which are thought to be a result of strong recruitment in 1999-2000, i.e. a season characterised by a strong Leeuwin Current (Caton & McLoughlin 2004).

Spanish mackerel are the main target species of the WA Mackerel Fishery (operating from Geraldton to the WA/NT border) and usually constitute 80-90% of the annual catch (Mackie & Kennedy 2005). They are taken by trolling close to the surface in coastal areas around reefs shoals and headlands. Highest catches occur from May to October when they form large aggregations close to shore – probably associated with feeding and gonad development prior to spawning (Mackie *et al.* 2003). The monthly catch peaks in May in the SWMR, several months before reaching its maximum in northwestern waters (Mackie & Kennedy 2005). During spring and summer, adults are thought to migrate to several spawning hotspots at deeper reefs further from the coast where they are less easily captured.

Currently managed as a single stock in WA waters, Spanish mackerel do not appear to make lengthy migrations and possibly form a series of discrete and/or semi-discrete populations along the northern coastline (Lester *et al.* 2001; Moore *et al.* 2003), although these results have not been confirmed by genetic studies (Stapley *et al.* 2004). Research on the stock structure of Spanish mackerel is ongoing and several reports are in progress (Buckworth *et al.* in prep.; Newman *et al.* in prep.; Ovenden *et al.* in prep.).

Skipjack tuna

Skipjack tuna are abundant throughout tropical and sub-tropical waters around the world but commonly make long-distance movements including seasonal incursions into warm temperate regions – limited only by temperatures under ~15-17°C (Blackburn & Serventy 1981). They inhabit the uppermost layer of oceanic as well as coastal waters and are often associated with fronts or isotherms where they tend to feed on krill and fish. Juveniles have high growth rates and may mature around the end of their first year at 41-43 cm FL (IOTC[A] 2004). Adults spawn throughout the year in equatorial waters and during spring-summer at higher latitudes, with the spawning season becoming shorter with increasing distance from the equator. Spawning does not appear to occur in waters cooler than 25°C (IOTC[A] 2004). Individuals may live up to 12 years and grow to 120 cm FL in some regions but rarely exceed 80 cm FL in the waters of Australia's southern half (Blackburn & Serventy 1981).

Skipjack tuna abundance in the SWMR displays strong seasonal and interannual variability. Off southern WA a distinct seasonal influx occurs in association with the front of the tropical Leeuwin Current around March-April when schools of 1+ - 2+ fish may quite suddenly be encountered, especially during La Nina episodes (Kemps *et al.* [A] 2003). As a result of this variation in abundance, skipjack tuna is only opportunistically targeted in some years by purse seining vessels in the GAB at the end of the southern bluefin tuna fishing season (Caton and McLoughlin 2004).

Southern bluefin tuna

Southern bluefin tuna is an epipelagic oceanic species distributed throughout the temperate waters of the southern hemisphere between 30°S and 50°S (Shingu 1978). Forming a single global stock, adults migrate into tropical waters southeast of Java to spawn between September and April. Young juveniles generally migrate southward along the Australian west coast during their first year, with a proportion of the stock turning eastward past Cape Leeuwin and others heading westward towards South Africa. They first appear off southern WA at around 12 months of age (45-55 cm FL) during spring-summer and predominantly inhabit inshore waters up to the shelfbreak (Nishida & Lyne 1996; Kemps *et al.* [A] 2003).

By April, most 1+ fish have moved on towards the feeding grounds of the Great Australian Bight where they tend to form aggregations over the deeper half of the shelf and particularly near the shelfbreak. By the time they are three years old juveniles are highly migratory, often making annual cyclical migrations between the inshore waters of the GAB for summer and the waters of the Indian Ocean during winter (Gunn & Block 2001). Individuals over 5 years old have a circumglobal oceanic distribution and are rarely encountered in inshore waters.

Southern bluefin tuna is a large (i.e. up to 220 cm FL), late maturing (i.e. 10-12 years, Farley & Davis 1998) species with a life span of over 40 years. Highly developed heat retention mechanisms and a large thermal inertia permit adults to permanently inhabit temperate oceanic waters and dive well below the thermocline while maintaining a viable muscle temperature. Like most scombrids, southern bluefin tuna are opportunistic feeders, mainly targeting pelagic schooling fish off southern WA as young juveniles and extending their diet to a variety of fish, squid and even krill depending on the area and/or season (Young *et al.* 1997; Kemps *et al.*[B] 2003).

Although larger juveniles and adults are frequently encountered by longline fishers in deep offshore waters of Australia, 95-98% of the national TAC is caught as 15-30 kg juveniles (i.e. 2-4 years old) by purse seine vessels in the GAB and towed back to the 'grow out' cages off Port Lincoln, where they are fattened for several months prior to export (Caton & McLoughlin 2004).

Bigeye and yellowfin tuna

Both bigeye and yellowfin tuna have a circumglobal oceanic distribution between approximately 40°N and 40°S and spawn predominantly in waters north of 20°S (yellowfin) or 10°S (bigeye) during November-March (Larcombe *et al.* 1997). Juveniles of both species are epipelagic and commonly form mixed schools with skipjack in tropical waters. Biological differences between bigeye and yellowfin tuna are distinct, however, with yellowfin tuna growing faster, maturing earlier (at 2 years vs. 3 years), reaching a smaller size and having a shorter lifespan (~8 vs. ~15 years) (Campbell *et al.* 2002). Additionally, bigeye tuna can tolerate lower water temperatures and dissolved oxygen levels. Habitat preference therefore differs with bigeye tuna preferring waters below the thermocline and yellowfin tuna predominantly inhabiting the waters above it.

Bigeye are abundant north of 15°S throughout the year and south of 25°S during winter, suggesting individuals to commonly migrate over large distances between southern winter feeding grounds and northern spawning grounds (Larcombe *et al.* 1997). Yellowfin, in contrast, do not migrate extensively to higher latitudes within the Indian Ocean and are more abundant north of 25°S at all times (Larcombe *et al.* 1997).

In the SWMR both species mainly occur in deeper waters off the continental shelf where they are captured by the SWTBF longline fleet. Catches of yellowfin are seasonal with the greatest catches north of 33°S off the west coast during summer and smaller catches off the south coast during autumn (Kalish 2005, Dowling *et al.* 2005). Yellowfin within the SWMR are thought to be part of an eastern Indian Ocean stock, although the existence of a western and eastern stock remains unconfirmed (Nishida 1992). Bigeye tuna, caught equally off both the west and south coasts, are assumed to belong to a single Indian Ocean stock.

Swordfish

Swordfish is an oceanic species with a broad circumglobal distribution inhabiting tropical to cold temperate waters. They spend most of the day at depths well below the thermocline but come to the surface at night (Campbell *et al.* 1998). Females grow larger than males, live longer, can tolerate colder waters and occupy higher latitudes (Young *et al.* 2004; Campbell *et al.* 1998). In most areas fish over 180 cm eye-fork length are female (Young *et al.* 2003). Recently, Young *et al.* (2004) estimated the age-at-maturity for female swordfish in Australian waters to be around 10 years, much higher than previous estimates (i.e. 4-6 years) and significantly later than that for males (i.e. ~2 years). Spawning is restricted to tropical and subtropical waters and peaks occur in most areas during spring-summer, although the duration of the spawning season tends to be extended closer to the equator and in the equatorial Atlantic Ocean occurs all year round (Young *et al.* 2003). Juveniles slowly move from these warmer regions into more temperate habitats as they grow (Campbell *et al.* 2002).

Genetic data suggest a population subdivision within the Pacific Ocean, but do not, at present, separate Indian Ocean swordfish from those of the southern Pacific stock (Reeb *et al.* 2000; Ward *et al.* 2001). However, there is some evidence to suggest that local depletion is occurring in the southwest Indian Ocean, which would point to the existence of regional semi-discrete populations (IOTC[B] 2004). Weakly supporting this hypothesis is the finding of Ward *et al.* (2001) that there may be a slight microsatellite differentiation of western Australian swordfish compared to those found at Reunion Island (in the eastern Indian Ocean) and the east coast of Australia. The authors further noted that two individuals caught off the west coast were genetically similar to the Atlantic Ocean stock and suggested the presence of these fish to be evidence of some current or historical gene flow from the Atlantic into the Indian Ocean. These results are preliminary and additional future research is required before the stock structure of swordfish within the Indian Ocean is resolved.

Swordfish are abundant in the deep oceanic waters of the SWMR and are closely associated here with temperature/salinity fronts. They are generally responsible for over half the total catch of the SWTBF.

Significance of the species group in the SW Marine Region

Mackerels, tunas and billfishes occupy various ecological positions within the SWMR. In oceanic waters, the tunas of the genera *Allothunnus*, *Auxis* and *Katsuwonus* occupy a key position between lower trophic levels and the apex predators, whereas the larger tunas and billfishes are at the top of the food webs in which they occur, affecting local populations of fish and squid by opportunistically targeting locally abundant species. Closer to the coast, Spanish mackerels, bonito's and neritic tunas occupy the positions near the top of the food chain, whilst the lesser mackerels form an important trophic link between plankton and higher predators such as tuna, billfish, seal, dolphin and albatross (Ward *et al.* 2001). Epipelagic tunas and mackerels are also known to form a relationship with seabirds by driving schools of baitfish to the surface, which assists the birds in finding food. Surface feeding events can be seen from a large distance and may be of particular importance to seabirds that forage over offshore waters where bait is distributed in sparse, isolated patches.

The economic and social significance of the species group in the SWMR is considerable (4.19. 3). The southern bluefin tuna fishery alone is worth $250m – 450m annually in exports after ‘grow out’. Swordfish, bigeye tuna, yellowfin tuna and (to a lesser extent) albacore have a potential combined annual value of over $30m (2002), although this potential has not been realised in recent years due to a strong decline in activity in the SWTBF longline fishery – attributed to poor financial returns as a result of high costs and relatively low prices (G. Diver pers. Com.). Spanish mackerel (and grey mackerel) form the basis of the WA Mackerel Fishery. The economic significance of the species group is expected to further increase in the future with two planned developments, i.e. a yellowfin tuna ‘grow out’ farm venture at the Houtman Abrolhos Islands and a southern bluefin tuna ‘hatchery’ in Port Lincoln.

The recreational importance of the group is also considerable as a growing number of anglers specifically target several popular species. Spanish mackerel, in particular, are caught (and retained) in large numbers by recreational fishers on the west coast with the total recreational catch rivaling the commercial catch for the same region (Mackie *et al*. 2003). On the south coast, blue mackerel is a very popular baitfish and an estimated total of 45,000 fish were caught and retained during 2000-01 (Jones & Doonan 2005). Skipjack tuna, oriental bonito and the lesser mackerels are other species that are accessible to anglers in coastal waters, whereas larger tunas, marlins and sailfish are very popular target species for sport fishers further out to sea. It is estimated that over 65% of the recreational billfish catch are captured during game-fishing competitions and that the majority is tagged and released (Anon. 2004).

The significance of the species group to the indigenous community in the SWMR is unclear but probably quite low as mackerels, tunas and bonito’s were estimated to constitute less than 0.5% (in numbers) of the annual harvest by indigenous fishers in Western Australia during 2000-01 (Henry & Lyle 2003).

Most of the fishes within the species group are migratory pelagics and respond to seasonal changes in environmental conditions and production within the SWMR. Many form local seasonal aggregations, related to feeding or spawning, only to disperse again during the onset of a different set of conditions. Tunas and billfishes may even disappear from the region all together during certain seasons. The impact of these fishes on the ecosystem is therefore variable and likely to be influenced by regional environmental features such as the Leeuwin Current. Clarifying these relationships will improve our understanding of the ecosystem.

Impacts/threats

The main threat to the sustainability of stocks of widely distributed pelagic fishes in general, is the impact of fishing. This is especially true for scombrids and billfishes as many are valuable target species for various types of fisheries. The severity of the threat, however, varies significantly between species and largely depends on biological and life history traits as well as stock structure and management.

The lesser mackerel stocks are not targeted by commercial fisheries within the SWMR. For this group, fishing pressure is usually limited to a relatively small recreational catch. The only exception is blue mackerel, which is targeted by commercial and recreational fishers in the GAB for bait and human consumption. Blue mackerel, like many other small pelagics, has a highly variable abundance and is susceptible to localised depletion, which would affect the ecosystem at several trophic levels. Currently, the fishery is allowed to develop slowly and in Zone B (west of Kangaroo Island) the resource is protected by what is considered to be a low-risk trigger catch level (TCL) of 5,000t (Caton & McLoughlin 2004).

Narrow-barred Spanish mackerel and, to a lesser extent, grey mackerel are caught commercially on the west coast of the SWMR. The troll-caught product is of a high-quality and sought after by domestic and export markets. Narrow-barred Spanish mackerel are additionally caught in significant numbers by recreational anglers. Of concern for the sustainability of the current catches is the uncertainty of the stock structure and the fact that this species forms predictable seasonal aggregations in shallow coastal waters very accessible to commercial fishers and recreational anglers alike, making it vulnerable to over-exploitation. Bag limits and a minimum size of 90cm TL limit the recreational catch while output controls (TAC and ITQs) and seasonal closures are currently being implemented for the commercial fishery.

For the wide-ranging tunas and billfishes the impact of fishing is a particularly serious threat as their biological (e.g. late maturity, slow growth and long lifespan) and life history traits (e.g. predictable seasonal aggregations and migratory paths) make them susceptible to overfishing and slow to recover from excess fishing pressure. As high-quality fishes, swordfish, southern bluefin, bigeye and yellowfin tuna are target species for a range of artisanal, and both local and high seas commercial fisheries of significant social and economic importance. Stocks typically straddle the EEZs of several nations as well as international waters and are exploited at several different life stages by numerous fleets. Both bigeye and yellowfin juveniles, for instance, are caught in large numbers by surface fisheries in various regions of the Indian Ocean, while adults are captured by longline fleets in different areas. Likewise, the Australian purse seine fleet exclusively targets young southern bluefin juveniles while older juveniles and adults are caught by longliners under various flags in oceanic waters and along specific migration paths. For these species, sustainable harvesting requires appropriate domestic as well as international management. The dual nature of management of tunas and billfishes is often complicated by the fact that a population may appear to be fished at sustainable levels when viewed for the Indian Ocean as a whole, while being locally over-exploited – a problem that is pronounced for species that tend to be locally resident for relatively long periods of time (as appears to be the case with swordfish). A further problem is that international management relies on the voluntary cooperation of fishing nations to form management bodies that have little control over fishing by non-member fleets and illegal, unregulated or unreported exploitation. Even within the management structures of such commissions disputes over stock assessments between cooperating members are common and can result in ‘stalemate’ situations that may last for years. The result is that the introduction of quotas to limit catch is delayed and subsequent reductions are difficult to achieve.

The stocks of swordfish, bigeye and yellowfin tuna in the Indian Ocean are managed by the Indian Ocean Tuna Commission (IOTC). For all three species the current catch levels are unlikely to be sustainable in the long term, but management action has been limited and the fisheries remain largely unregulated (Kalish 2005). In 2005, the IOTC passed a resolution to limit the catch of bigeye tuna to recent catch levels (IOTC[c] 2005). In Australia, TACs and ITQs for these species are planned to be introduced in the SWTBF during 2006. The situation for southern bluefin tuna differs in that the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) has been successful in maintaining TACs for members since 1989 and, recently, in obtaining the cooperation of previously non-complying nations. However, disagreements between members over appropriate TACs have also impeded management action in this fishery. Currently, the spawning stock biomass (SSB) is severely depleted and in considerable danger of further decline (because of recent markedly low recruitment) if the global catch is not reduced in the immediate future (Anon.[C] 2005). In acknowledgement of this plausible sequence of events, the Scientific Committee of the CCSBT has recommended to reduce the global quota by 48% (7,160t) for the 2007-08 fishing season and to implement the recently developed Management Procedure, aimed at determining appropriate annual quota's from fishery data and recruitment indices, for the 2008-09 season. The successful implementation of both will provide an estimated 50% probability that the SSB in 2014 will be no lower than the 2004 biomass; and an estimated 90% probability that the 2022 SSB will be at or above the 2004 SSB (Anon.[C] 2005). This recommendation was supported by most members late in 2005, but remains to be adopted by the CCSBT as a whole (Anon.[D] 2005). Testament to the management situation in this fishery is the recent, and somewhat counter-intuitive, decision of the then Australian Minister for the Environment and Heritage Ian Campbell not to list southern bluefin tuna as a threatened species under the Environment Protection and Biodiversity Act 1999 with the following conclusion: "The Minister has concluded that the listing of the southern bluefin tuna as a threatened species under the EPBC Act would be detrimental to the survival of the species, as it may weaken Australia's ability to influence both the management of the global fishing effort and the global conservation of the species. As a result, conservation of the Southern Bluefin Tuna in Australian waters could not be achieved" (Department of the Environment and Water Resources website).

Information gaps

The amount and quality of available information on scombrids and billfishes greatly varies between species with a wealth of publications on the economically important species and sparse accounts on the less exploited taxa. For most mackerels (including butterfly mackerel), Spanish mackerels and bonito's, in particular, little or no information is available for populations in the SWMR. The lack of data on the lesser mackerels was also noted by Staply and Gribble (2004) for the Northern Planning Area. They made three suggestions for future research that appear to be appropriate for mackerels, Spanish mackerels (except for the narrow-barred Spanish mackerel) and bonito's in the SWMR:

- Collating, mapping and preliminary modelling of existing fisheries information, however sparse on this group of species in the SWMR
- Develop targeted (research) surveys of potential grounds, based on local knowledge gained from involvement of commercial/recreational/indigenous fishers
- Conduct similar studies to that carried out for the northern narrow-barred Spanish mackerel stock involving genetic, parasite and allozyme assessment of stock structure of the mackerels, Spanish mackerels and bonito's

More information is available on narrow-barred Spanish mackerel, although the stock structure and the spawning/recruitment processes in the SWMR remain two important areas that require additional research. Both are, to some extent, addressed by two reports that are currently in preparation (Buckworth *et al.* in prep., Newman *et al.* in prep.).

For the slender tuna and the neritic tunas of the genera *Auxis* and *Euthynnus* the situation is the same as for the mackerels in the SWMR and can be improved upon with the research outlined above. Skipjack tuna is a little better understood, but details on stock structure in Australian waters and spawning/recruitment processes in the GAB are crucial gaps now that the species is commercially targeted. The available information on tunas of the genus *Thunnus* strongly varies between species. Longtail tuna is not well understood and information on albacore is also lacking, whereas much research effort has focused on the commercially significant high-quality species bigeye, yellowfin and southern bluefin tuna. But even for these species biological and ecological profiles are incomplete and fishery-independent data for bigeye and yellowfin tuna are not collected. Knowledge of the biology and status of swordfish has also improved over the last few years, although the stock structure within the Indian Ocean remains to be resolved. As the three target species of the SWTBF, the current research priorities are (Caton & McLoughlin 2004):

- Investigate the stock structure of bigeye and swordfish in the eastern Indian Ocean, with particular emphasis on determining the relationship between fish caught within the SWTBF and those caught in nearby waters and the broader Indian Ocean
- Establish a tagging program in the eastern Indian Ocean to improve knowledge of mortality rates, movements and stock structure
- Monitor catch and effort by the recreational and charter fishing sectors targeting highly migratory species
- Assess the impact and reliance of the SWTBF on the pelagic ecosystem, including trophic linkages and the impact of fishing on ecologically related species
- Develop ecological indicators, reference points and mitigation measures to reduce impacts

For the status of these species there is also the need: to improve ocean-wide catch estimates; to expand size-sampling programs; and for a closer consideration of recent changes in efficiency and catchability.

Research priorities for southern bluefin tuna differ as the severely depleted state of the stock emphasizes the importance of recruitment. Currently, CSIRO and NRIFSF (Japan) are jointly making progress on the development of real-time annual recruit-abundance indices. As the accuracy of these fishery-independent recruitment indices improves, there will be less need to wait for indicators from the fishery before management action can be taken, increasing the potential for stock recovery. To achieve this level of accuracy, it is essential to determine the extent of interannual variation in the proportion of the total juvenile biomass that inhabits Australian waters – where all fishery-independent recruitment research is currently conducted. Another important area of research involves the productivity of the stock as future projections have proven to be strongly dependent on assumptions regarding the relationship between the spawning stock biomass and recruitment (M. Basson, pers.com.).

Marlins, sailfish and spearfish are not as consistently targeted, caught or retained as some of the *Thunnus* species. As a result, fishery catch and effort data is unreliable and knowledge is lacking in many areas. The IOTC Working Party on Billfish recommended the following research on the biology of istiophorids to be undertaken (IOTC[B] 2004):

Collect tissue samples of the main istiophorid species from widely separated locations in the Indian Ocean for genetic studies on stock structure

Collect and preserve hard parts of individuals for future age estimation studies

Establish popup satellite tagging experiments on blue, black and striped marlins in order to provide information on many aspects of their biology, including long-term vertical behaviour, horizontal movement and mixing rates
Increase the tagging of billfish in the Indian Ocean on an opportunistic basis
Collect improved catch and effort statistics for artisanal fisheries of coastal countries
Collect selected catch and effort statistics from key billfish sport fishing areas to provide CPUE indices

Particularly relevant to an improved understanding of the SWMR ecosystem as a whole, is research into the movement dynamics of the migratory scombrids and billfishes. Crucial areas of research include: the stock structures within the (eastern) Indian Ocean; the mixing rates between individuals in the SWMR and the broader region; and the residence times of individuals within the SWMR.

Key references and current research

The authors are not aware of any current research on the lesser mackerels in the SWMR, apart from a single FRDC project (FRDC02/061) mainly aimed at developing and evaluating stock assessment methods for blue mackerel in Southern Australia – to be completed during 2005. Future research, however, may be offered through the Small Pelagic Fishery Research Program that is currently being developed by the Small Pelagic Research Assessment Team (SPRAT). Another project with the potential to help identify areas that require urgent research in relation to mackerels is FRDC Project 02/096, a review and assessment of previous and future research regarding several species of northern mackerel (i.e. Spanish, grey, spotted and small mackerel). The stock structure of grey mackerel in northern Australia is the subject of study for FRDC Project 2005/010, while FRDC Project 02/096 is currently investigating the potential of genetic marking for real-time harvest rate monitoring of narrow-barred Spanish mackerel. New information regarding the stock structure of narrow-barred Spanish mackerel is presented in two pending publications (i.e. Buckworth *et al.* in prep., Newman *et al.* in prep.).

A project to develop status indicators for tropical tunas and billfishes in the Eastern Indian Ocean was initiated and jointly funded by FRDC and CSIRO. This Australian project adds to IOTC research on stock status indicators and an operational model for stocks and fisheries in the Indian Ocean (Kalish 2005). Improving catch estimates is crucial to this project and the catch monitoring program, aimed at reducing uncertainties regarding the catch of bigeye, yellowfin and southern bluefin tuna by Indonesian and Taiwanese vessels, is one significant current development in this regard. SWTBF activities of relevance include: the port-sampling program (collecting length/weight data on bigeye, yellowfin and swordfish); the AFMA observer program (monitoring compliance); the pilot scientific monitoring program (providing information on swordfish sex ratios that can be applied to size composition data); and the size monitoring program (Kalish 2005).

Research programs on southern bluefin tuna include: investigations of Japanese SBT market and Australian farming anomalies (to assess the level of over-catching); conventional tagging; direct ageing; the development of a spawning biomass index; and the analysis of fisheries oceanography for improved habitat definition. Of particular importance are the projects of the Southern Bluefin Tuna – Recruitment Monitoring Program, aimed at providing fisheries-independent indices of recruitment biomass, which include: acoustic tagging, i.e. a project on horizontal movement and residence times of young juveniles off southern WA; the transect line acoustic survey, monitoring the migrating one-year cohort; and the aerial survey, monitoring juveniles in the GAB. Archival and pop-up tagging programs also continue to provide valuable information on vertical and horizontal movements, residence times, biology and ecology of juvenile southern bluefin tuna. Another major area of research over the last few years involves the development of a management procedure that, once agreed upon by the CCSBT members, has the potential to reduce disagreements regarding assessments; future projections and TAC's.

Contact details of scientists holding sources of mackerel and tuna information applicable to the SWMR are listed in Table 4.19.4.

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Family Subfamily	Tribe	Genus	Species	Common name	SWMR freq of occ west coast	 south coast	EPBC Act	WC Act (WA)	NPW Act (SA)	1996 IUCN Red List (ver 2.3 1994)	1982 CLS	Stock status (Caton & McLoughlin 2004; Anon. 2004; Mackie & Kennedy 2005)
Scombridae												
Gasterochismatinae		*Gasterochisma*	*G. melampus*	butterfly mackerel	+	+	-	-	-	NE	-	-
Scombrinae	Scombrini	*Rastrelliger*	*R. kanagurta*	Indian mackerel	+	-	-	-	-	NE	-	-
		Scomber	*S. australasicus*	blue mackerel	++	++	-	-	-	NE	-	Uncertain
	Scomberomorini	*Acanthocybium*	*A. solandri*	wahoo	+	-	-	-	-	NE	-	-
		Grammatorcynus	*G. bicarinatus*	shark mackerel	+	-	-	-	-	NE	-	-
		Scomberomorus	*S. commerson*	Spanish mackerel*	++	+	-	-	-	NE	-	Fully exploited
			S. munroi	spotted mackerel	+	-	-	-	-	NE	-	-
			S. queenslandicus	school mackerel	+	-	-	-	-	NE	-	-
			S. semifasciatus	grey mackerel	+	-	-	-	-	NE	-	Underexploited
	Sardini	*Cybiosarda*	*C. elegans*	leaping bonito	+	+	-	-	-	NE	-	-
		Sarda	*S. orientalis*	oriental bonito	++	++	-	-	-	NE	-	-
	Thunnini	*Allothunnus*	*A. fallai*	slender tuna	+	+	-	-	-	NE	-	-
		Auxis	*A. rochei rochei*	bullet tuna	+	-	-	-	-	NE	HM	-
			A. thazard thazard	frigate mackerel	+	+	-	-	-	NE	HM	-
		Euthynnus	*E. affinis*	mackerel tuna	+	+	-	-	-	NE	HM	-
		Katsuwonus	*K. pelamis*	skipjack tuna	++	++	-	-	-	NE	HM	Uncertain
		Thunnus	*T. alalunga*	albacore	++	+	-	-	-	DD	HM	Underfished
			T. maccoyii	southern bluefin tuna	++	++	-	-	-	CR A1bd	HM	Severely recruitment-overfished
			T. obesus	bigeye tuna	++	++	-	-	-	VU A1bd	HM	Uncertain but overfishing is occurring in IO
			T. albacares	yellowfin tuna	++	+	-	-	-	LR/lc	HM	Uncertain
			T. tonggol	longtail tuna	+	?	-	-	-	NE	-	-
Xiphiidae												
		Xiphias	*X. gladius*	swordfish	++	++	-	-	-	DD	HM	Uncertain
Istiophoridae												
		Istiophorus	*I. platypterus*	sailfish	+	-	-	-	-	NE	HM	Uncertain
		Makaira	*M. indica*	black marlin	+	+	-	-	-	NE	HM	Uncertain
			M. nigricans	blue marlin	+	-	-	-	-	NE	HM	Uncertain
		Tetrapterus	*T. audax*	striped marlin	+	+	-	-	-	NE	HM	Uncertain
			T. angustirostris	shortbill spearfish	+	-	-	-	-	NE	HM	Uncertain

Table 4.19.1: Scientific, common names and status of species that occur in the SWMR.

SWMR	South West Marine Region
freq. of occ.	frequency of occurrence, as far as could be determined from sources
++	frequently encountered
+	less frequently encountered
-	not encountered
EPBC Act	Environmental Protection and Biodiversity Act 1999 (Commonwealth)
WC Act (WA)	Wildlife Conservation Act 1950 (Western Australia)
NPW Act (SA)	National Parks & Wildlife Act 1972 (South Australia)
1996 IUCN	Red List International Union for Conservation of Nature and Natural Resources Red List of 1996
CR	critically endangered: facing an extremely high risk of extinction in the wild in the immediate future, as defined by:
	A1 a population reduction of at least 80% in the last 10 years or three generations, based on:
	b an index of abundance appropriate for the taxon
	d actual or potential levels of exploitation
VU	vulnerable: not endangered but facing a high risk of extinction in the wild in the medium-term future, as defined by:
	A1 a population reduction of at least 20% in the last 10 years or three generations, based on:
	b an index of abundance appropriate for the taxon
	d actual or potential levels of exploitation
DD	data deficient
LR	low risk: evaluated, but does not satisfy the criteria for any of the categories CR, EN or VU
	lc least concern: does not satisfy criteria for Conservation Dependent or Near Threatened
NE	not evaluated
HM	highly migratory
1982 CLS	1982 United Nations Convention on the Law of the Sea

*Note: Spanish mackerel may in the text be referred to as: narrow-banded Spanish mackerel to prevent confusion with the species of the tribe Scomberomorini in general, which are known as the Spanish mackerels.

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Caton & McLoughlin (2004)
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IOTCb (2004)
Kalish (2005)
Larcombe et al (1997)
Mackie & Kennedy (2005)
Whitley (1962)
FishBase (www.fishbase.org)
IUCN Red list (www.iucnredlist.org)

Family Subfamily	Species	Common name	Habitat	Habitat	Schooling behaviour juv. / adult	Distribution	Spawning peak	Diet	Mean size of maturity (cm FL)	Mean age of maturity (y)	Maximum size (cm FL)	Maximum age (y)	Temperature range (degrees C)	Depth range (m)
Scombridae														
Gasterochismatinae	*G. melampus*	butterfly mackerel	Ep	Oc	?	Cg 35S - 50S	?	F, Ce	?	?	180	?	8 - 15	0 - 200
Scombrinae	*R. kanagurta*	Indian mackerel	Ep, Ne	Cs, C, Re	St	IWP 35N - 35S	aut - spr	Pl (Sf)	23	?	35	4+	> 17	0 - 90
	S. australasicus	blue mackerel	Ep, Ne	Cs, C	St, Co	IP 45N - 50S	sum	F, Ce, Pl	~28	3	65	8 - 24	18-22	0 - 200
	A. solandri	wahoo	Ep	Oc, Cs	Wk / Sol	Cww 40N - 35S	?	F, Ce	?	?	210	?	?	0 - 15
	G. bicarinatus	shark mackerel	Ep, Ne	Cs, C, Re	St	Aus 10S - 38S	?	F (Cr)	?	?	130	?	?	0 - 15
	S. commerson	Spanish mackerel*	Ep, Ne	Cs, C, Re	St	IWP 40N - 45S	spr - sum	F, Ce (Cr)	f 81 / m 63	1-1.5	240+	22	?	0 - 70
	S. munroi	spotted mackerel	Ep, Ne	Cs, C	St, Co	Aus/PNG 7S - 37S	spr	F, Ce, Cr	50 - 55	?	105	?	?	0 - 100
	S. queenslandicus	school mackerel	Ep, Ne	Cs, C, E	St, Co	Aus/PNG 7S - 35S	spr - sum	F, Ce, Cr	45 - 50	?	100	?	?	0 - 100
	S. semifasciatus	grey mackerel	Ep, Ne	Cs, C	St ?	Aus/PNG 7S - 28S	spr - sum	F (Ce)	55 - 60	?	120	?	?	0 - 100
	C. elegans	leaping bonito	Ep, Ne	Cs, C	St	Aus/PNG 5S - 40S	?	?	?	?	54	?	?	0 - 50
	S. orientalis	oriental bonito	Ep, Ne	Cs, C	St, Co	IP 40N - 40S	?	F, Ce, Cr	?	?	105	?	13 - 23	0 - 30
	A. fallai	slender tuna	Ep	Oc	St	Cg 20S - 55S	?	Pl, Ce, Sf	?	?	105	?	?	?
	A. rochei rochei	bullet tuna	Ep, Ne	Oc, Cs, C	St	Cww 45N - 47S	spr - sum	Sf, Cr, Ce	35 - 37	2	66	?	?	0 - 10
	A. thazard thazard	frigate mackerel	Ep, Ne	Oc, Cs, C	St	Cww 61N - 47S	timing varies	Sf, Cr, Ce, Pl	29 - 35	?	65	5	?	0 - 50
	E. affinis	mackerel tuna	Ep, Ne	Cs, C	St, Co	IWP 35N - 38S	timing varies	F, Cr, Ce, Pl	50 - 65	3	100	?	18 - 29	0 - 200
	K. pelamis	skipjack tuna	Ep	Oc, Cs	St, Co	Cg 60N - 50S	year round	F, Cr, Ce, Pl	41 - 43	1-2	110	12	14 - 30	0 - 260
	T. alalunga	albacore	Ep, Mp	Oc	St, Co / Wk	Cg 60N - 45S	spr - sum	F, Ce, Cr	90 - 100	5-6	170	10+	9 - 25	0 - 600
	T. maccoyii	southern bluefin tuna	Ep	Oc, Cs	St, Co	Cg 30S - 50S	spr - sum	F, Ce, Cr	155	8-12	245	40+	> 5	0 - 500+
	T. obesus	bigeye tuna	Ep, Mp	Oc	St, Co / Wk	Cg 45N - 43S	sum	F, Ce, Cr	85 - 120	3	240	15+	> 10	0 - 500+
	T. albacares	yellowfin tuna	Ep	Oc, Cs	St, Co / Wk	Cg 40N - 40S	sum - aut	Cr, F	80-120	2	210	8+	> 15	0 - 250
	T. tonggol	longtail tuna	Ep, Ne	Cs, C	St	IWP 45N - 35S	?	F, Ce, Cr	?	?	150	?	?	0 - 10
Xiphiidae														
	X. gladius	swordfish	Mp	Oc	Sol	Cg 60N - 50S	spr - sum	F, Ce	f 200 eye-FL	f 10 / m 2	f 540 kg / m 445 kg	f 32 / m 14	5 - 27	0 - 1000
Istiophoridae														
	I. platypterus	sailfish	Ep	Oc, Cs	St / Wk	IP 50N - 50S	sum - aut	F, Ce (Cr)	?	?	360 TL	15	?	0 - 200
	M. indica	black marlin	Ep, Mp	Oc, Csl	St / Wk, Sol	IP 40N - 45S	spr - sum	F, Ce (Cr)	f 70kg / m 60kg	f 4-5 / m 3-4	f 700 kg / m 200 kg	f ~20	15 - 30	0 - 900
	M. nigricans	blue marlin	Ep, Mp	Oc	Wk / Sol	IP 25N - 35S	year round	F, Ce	80 kg	3	f 900 kg / m 170 kg	f 28 / m 21	> 21	0 - 2000
	T. audax	striped marlin	Ep	Oc	St / Sol	IP 45N - 45S	spr - sum	F, Ce (Cr)	140-160 (eyeFL)	2-3	420 TL	10+	?	0 - 300?
	T. angustirostris	shortbill spearfish	Mp	Oc	Sol?	IP 40N - 45S	win	F, Ce (Cr)	?	?	230 TL	?	?	0 - 1800

Table 4.19.2 General summary of biological and life history traits of mackerels, tunas and billfishes.

Ep	epipelagic
Mp	mesopelagic
Ne	neritic
Oc	oceanic
Csl	associated with the continental slope
Cs	over the continental shelf
C	coastal
E	in estuaries
Re	associated with reefs
St	strong
Wk	weak
Co	forming schools with other species
Sol	solitary
Cg	circumglobal
Cww	cosmopolitan in warm, mostly inshore waters
IP	Indo-Pacific
IWP	Indo-West Pacific
AUS	Australia
PNG	Papua New Guinea
spr	spring
sum	summer
aut	autumn
win	winter
F	fish
Sf	small fish
Ce	cephalopods
Cr	crustaceans
Pl	plankton
FL	forklength
TL	total length
eye-FL	length from eye to fork in tail
f	female
m	male

Main sources: Campbell *et al.* (1998)
Campbell *et al.* (2002)
Collette & Nauen (1983)
Gomon *et al.* (1994)
Kailola *et al.* (1993)
Larcombe et al (1997)
Nakamura (1985)
Stapley *et al.* 2004
Whitley (1962)
Young *et al.* (2004)
FishBase (www.fishbase.org)

Family Subfamily	Tribe	Genus	Species	Common name	Stock structure	Commercial Fishery (SWMR)						Recreational fishery target species
						Target	Byproduct	Bycatch	Main Fishery	Annual catch (in t)	Annual value (in AU$)	
Scombridae												
Gasterochismatinae		*Gasterochisma*	*G. melampus*	butterfly mackerel	?	-	?	Y	SWTBF	very small	-	-
Scombrinae	Scombrini	*Rastrelliger*	*R. kanagurta*	Indian mackerel	?	-	-	-	-	-	-	?
		Scomber	*S. australasicus*	blue mackerel	R ?	Y	-	-	SPF	very small	?	Y
	Scomberomorini	*Acanthocybium*	*A. solandri*	wahoo	?	-	Y	-	MF	very small	?	Y
		Grammatorcynus	*G. bicarinatus*	shark mackerel	?	-	Y	-	MF	very small	?	?
		Scomberomorus	*S. commerson*	Spanish mackerel*	R	Y	-	-	MF	15 - 37	?	Y
			S. munroi	spotted mackerel	?	-	Y	-	MF	very small	?	?
			S. queenslandicus	school mackerel	?	-	Y	-	MF	very small	?	?
			S. semifasciatus	grey mackerel	?	Y	-	-	MF	~4 - 15	?	Y
	Sardini	*Cybiosarda*	*C. elegans*	leaping bonito	?	-	-	-	-	-	-	?
		Sarda	*S. orientalis*	oriental bonito	R	-	-	?	-	-	-	?
	Thunnini	*Allothunnus*	*A. fallai*	slender tuna	?	-	-	-	-	-	-	?
		Auxis	*A. rochei rochei*	bullet tuna	?	-	-	-	-	-	-	?
			A. thazard thazard	frigate mackerel	?	-	?	-	SBTF/WSTF	very small	?	?
		Euthynnus	*E. affinis*	mackerel tuna	?	-	-	-	-	-	-	?
		Katsuwonus	*K. pelamis*	skipjack tuna	IO / R ?	Y	-	-	WSTF	0 - 1,400	0 - 1.8m	Y
		Thunnus	*T. alalunga*	albacore	IO	-	Y	-	SWTBF	34 - 121	?	?
			T. maccoyii	southern bluefin tuna	G	Y	-	-	SBTF	~5,500 (Q)	250 - 450m	Y
			T. obesus	bigeye tuna	IO	Y	-	-	SWTBF	89 - 448	2 - 6m	Y
			T. albacares	yellowfin tuna	EIO ?	Y	-	-	SWTBF	158 - 598	1 - 4m	Y
			T. tonggol	longtail tuna	?	-	Y	-	SWTBF	very small	?	?
Xiphiidae												
		Xiphias	*X. gladius*	swordfish	IO ?	Y	-	-	SWTBF	360 - 2,164	5 - 25m	-
Istiophoridae												
		Istiophorus	*I. platypterus*	sailfish	?	-	Y	-	SWTBF	very small	?	Y
		Makaira	*M. indica*	black marlin	IO ?	-	-	Y	SWTBF	-	-	Y
			M. nigricans	blue marlin	IO ?	-	-	Y	SWTBF	-	-	Y
		Tetrapterus	*T. audax*	striped marlin	EIO ?	-	Y	Y	SWTBF	very small	?	Y
			T. angustirostris	shortbill spearfish	?	-	-	?	-	-	-	?

Table 4.19.3 Commercial significance of the species group in the SWMR**.**

G	global
IO	Indian Ocean
EIO	eastern Indian Ocean
R	regional
Y	yes
SWTBF	Southern and Western Tuna and Billfish Fishery (Commonwealth)
SPF	Small Pelagics Fishery (Commonwealth)
MF	Mackerel Fishery (Western Australia)
SBTF	Southern Bluefin Tuna Fishery (Commonwealth)
WSTF	Western Skipjack Tuna Fishery (Commonwealth)
Q	national quota
m	million

Main sources: Caton & McLoughlin (2004)
Henry & Lyle (2003)
Jones & Doonan (2005)
Mackie & Kennedy (2005)

State	Contact	Organisation
WA	Michael Mackie mmackie@fish.wa.gov.au	Department of Fisheries Western Australia
SA	Tim Ward ward.tim@saugov.sa.gov.au	South Australian Research and Development Institute
ACT	Donald Bromhead donald.bromhead@daff.gov.au	Department of Agriculture Fisheries and Forestry
ACT	Kevin McLoughlin Kevin.McLoughlin@brs.gov.au	SWTBF Research and Assessment Group
TAS	Marinelle Basson marinelle.basson@csiro.au	Commonwealth Scientific and Industrial Research Organisation

Table 4.19.4 Contact list of scientists holding sources of mackerel and tuna information applicable to the SWMR, Australia.

4.20 Mesopelagic fish

Principal contributor
Sam McClatchie
Jock Young

Species group name and description

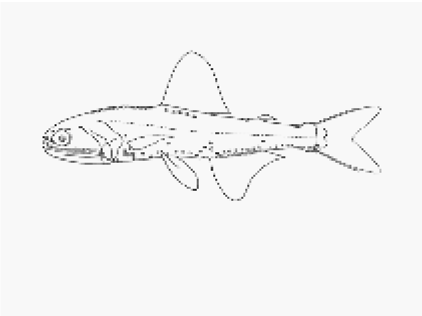

Figure 4.20.1: *Lampanyctodes hectoris* (Günther, 1876) Myctophidae (Lanternfishes).

Mesopelagic fish commonly refers to the small mid-water fishes that form one of the dominant faunal groups of the mesopelagic regions of the ocean between 150 to 1000 m, as defined by Parsons, Takahashi and Hargrave (1977). Mesopelagic fish are one component of the deep scattering layers that form the largest acoustic signal in the oceans (Farquhar 1970, Anderson and Zahuranec 1977). The group often bear light organs and hence the common name "lantern fish" for myctophids. The arrangement of the photophores has taxonomic significance.

The largest group of mesopelagic fishes are the myctophids (family Myctophidae). Among these, *Lampanyctodes hectoris* (Figure 4.20.1) is known to occur in southern Australia (Paxton et al. 1989) and is common in SE Australian continental slope waters (Anonymous 1977), where it is seasonally abundant along the upper continental slope (May and Blaber 1989). Another myctophid, *Diaphus danae* Tåning, 1932 is also reported from south of Australia (Paxton et al. 1989). Although it is not a myctophid, a species that is also common in the area (Anonymous 1977) is *Maurolicus australis* Hector 1875 (Sternoptichidae), previously *M. muelleri*, also known as light fish (Parin and Kobyliansky 1996). These three species form aggregations along the continental slope where they are preyed on by a suite of mesopelagic and benthopelagic predators (Blaber and Bulman 1987).

Status

Mesopelagic fishes have been described as one of the last great fishery resources in regions where they are known to be abundant (e.g. the Arabian Sea and the North Pacific) (Gjoesaeter and Kawaguchi 1980), and also off South Africa (Crawford 1980). Their abundance in Australian waters has not been surveyed, apart from some exploratory fishing in Tasmanian waters (May and Blaber 1989), and is totally unknown over most of the SW region. There is no commercial exploitation of mesopelagic fish in the SW region and their status can be regarded as virgin biomass.

Habitat and distribution

This suite of mesopelagic fishes occupy a discreet niche in waters just over the edge of continental shelf (neritic) out to a depth of ~500m where they concentrate in densities of 80-530 g m^{-2} (May and Blaber 1989). Further offshore there is a more diverse mix of mesopelagic fishes, although they are far less concentrated (Young, Lamb and Bradford 1996). Few fishery-independent research surveys have been published from the region (but see May and Blabber 1989), at least two CSIRO surveys (May and Blaber 1989, Kloser et al. 1998) reported considerable backscatter from mesopelagic fish along the edge of the continental shelf. There is also unsubstantiated evidence for deep-scattering layers, likely to include mesopelagic fish, in the Murray canyon complex off Kangaroo Island. A commercial survey from fishing trawlers (Anonymous 1977) found layers of light fish (identified as *M. muelleri* in the papers referenced here) and lantern fish (*L. hectoris*) off SE Australia, mainly between the 200 and 500 m depth contours.

Different species of mesopelagic fish vertically migrate over different depth ranges, but some species migrate over as much as 600 m, often reaching the surface at night. Their vertical migration forms an important pathway for vertical flux of materials in the oceanic system. Anonymous (1977) reported a strong diel migration signal by mesopelagic fish layers off SE Australia in 200-500 m depths. *L. hectoris* was reported to be a stronger vertical migrator, rising from near bottom at dusk to form sub-surface layers. *M. muelleri* rose from near bottom to midwater rather than sub-surface depths, and in some areas did not show much evidence of vertical migration, instead forming a monospecific near-bottom layer (Anonymous 1977). Both *M. muelleri* and *L. hectoris* were associated with *Apogonus anomalus* (three spined cardinal fish) in near-bottom layers during daylight hours (Anonymous 1977). Acoustic records of different vertical migration patterns of mesopelagic fish, probably associated with different species that are relevant to the southern Australian waters were given in McClatchie & Dunford (2003).

Mesopelagic fish are primarily crustacean feeders, eating copepods, euphausiids, amphipods, ostracods and small decapods (Hulley, www.museums.org.za/sam/resource/marine/lantern.htm). *M. muelleri* and *L. hectoris* feed primarily on euphausiids and secondarily on copepods in eastern Tasmanian waters (Young and Blaber 1986) (there is no information from SA or WA). *D. danae* has a higher proportion of fish in its diet, feeding on smaller myctophids like *L. hectoris* (Young and Blabber 1986). The proportion of taxa and species composition of prey of all three species varies with season and with the size of the fish (Young and Blaber 1986).

Significance of the species group in the southwest planning area

Mesopelagic fish are key forage fishes in the oceanic ecosystem. A wide range of predators eats mesopelagic fishes as part of their diet, including commercial (Blaber and Bulman 1987) and non-commercial finfish, squid, seabirds (especially penguins), seals and toothed whales. *L. hectoris* and *M. australis* are important prey for blue grenadier, or hoki, *Macruronus* *novaezelandiae* (Clarke 1982)*.* In New Zealand, in preferred depths for hoki, the weight of hoki at size is higher where the abundance of their mesopelagic prey is greater (McClatchie et al. 2004). Mesopelagic fish are present in great abundance in relatively small areas in New Zealand waters (on banks, and along some areas of the shelf edge, McClatchie & Dunford 2003). In these areas they are extremely important forage species (McClatchie et al. 2004). The same situation may pertain in southern Australian waters, but we lack the data to determine if that is the case.

Impacts/threats

There is no fishery for mesopelagic fish in the SW region, and so they are not threatened by removal of biomass. Some mesopelagic fish species are closely associated with particular water masses, and have been used as "indicator species" in biogeographic studies. If climate change significantly modifies the properties of water masses it is likely that a shift in the vertical and horizontal distributions of mesopelagic fishes will change in synchrony with changes in the distribution of their preferred temperature regimes. This could have significant, but currently unpredictable, effects on oceanic food webs.

Information gaps

- There are no fishery independent surveys of mesopelagic fish, and so their distribution and biomass is virtually unknown in the SW marine region, apart from the observations that they are found at the shelf edge and are likely to be part of the deep scattering layer in canyons.
- The fishery potential of mesopelagic fish in the SW marine region has not been adequately assessed, largely because there is currently no market for them in the region.
- The significance of mesopelagic fish in shelf and slope food webs, although suspected to be high, has not been quantified in the SW marine region. We do know however that they are central to the continental slope food web at least off eastern Tasmania and are likely to have a similar role in other temperate shelf/slope ecosystems around Australia
- The role of these important vertical migrators in carbon flux between surface and deep waters has not been assessed, despite their potential role in contributing to removal of carbon from surface waters by predation, vertical migration and faecal production.

Key references and current research

Research

No current research is being conducted on mesopelagic fishes in southern Australian waters.

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4.21 Small pelagic fishes

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Species group name and description

Small pelagic fish populations support some of the largest, high volume-low value fisheries in the world. The total worldwide capture production of sardine and anchovy fisheries in 2003 was 19 million tonnes (Whitehead 1985; FAO Website 2005). By comparison, Australian capture production is relatively small with <100,000 tonnes of small pelagic fish (species combined) taken annually. In southern Australia, most of the market demand for small pelagic fish stems from the need to provide fodder for the southern bluefin tuna (SBT) mariculture industry located in Port Lincoln, South Australia (SA). This industry has a total value of production in excess of AUD $200 M per annum.

Small pelagic fishes inhabit a diverse range of marine environments, including inshore embayments, river-mouths and estuaries, the waters over the continental shelf and shelf-break. Population sizes fluctuate markedly in response to environmental variability, inter-species competition, food availability, predation, recruitment variability and commercial fishing pressure. Small pelagic fishes form schools that vary in size from several hundred individuals to immense aggregations of hundreds of tonnes. This schooling behaviour makes them particularly vulnerable to larger pelagic predators and to exploitation by fisheries for bait, mariculture fodder and human consumption. Although single species schools comprising similar size and age classes are common, mixed species schools also occur, especially among (a) redbait, jack mackerel and blue mackerel, (b) sardine (pilchard) and round herring in offshore waters and Australian anchovy and blue sprat in the inshore gulfs and bays.

The South West Region encompasses the area between Kangaroo Island in SA and Shark Bay in Western Australia (WA). The ‘small pelagic fishes’ species group found in this region comprise eleven key species belonging to six families. These families include Clupeidae, Engraulidae, Scombridae, Carangidae, Emmelichthyidae and Scomberesocidae. Members of family Clupeidae (herring-like fishes) are dominant and five species occur in the SW Region. Small pelagic fish species found in South Australia and Western Australia include sardine (pilchard) (*Sardinops sagax*), scaly mackerel (*Sardinella lemuru*), Australian anchovy (*Engraulis australis*), round herring (*Etrumeus teres*), sandy sprat (*Hyperlophus vittatus*), blue sprat (*Spratelloides spp.*), jack mackerel (yellowtail scad) (*Trachurus declivis and T. novaezelandiae*), blue or slimy mackerel (*Scomber australasicus*), redbait (*Emmelichthys nitidus*) and saury (*Scomberesox saurus*).

Sardine *S. sagax* (Clupeidae) is highly abundant in the SW Region. Individuals are elongated, olive green to blue in colour and have characteristic black to blue spots along the lateral line and down the dorsal flanks. Sardines grow to approximately 25 cm FL (commonly 13 –17 cm) and live for up to 7 years (commonly 1 – 4 years). Sexual maturity (50%) is reached at approximately 15 cm and 1.5 to 2 years of age. Sardine spawn in shelf waters out to the shelf break and in the southern gulfs in SA.

Australian anchovy *E.australis* (Engraulidae) is found inshore and is also highly abundant in offshore shelf waters during years when sardine abundance is low (Ward *et al.* 2001a; Dimmlich *et al.* 2004). This species is elongated, green-brown dorsally to silver-white and has the characteristic under-slung jaw and large mouth of all members of the family Engraulidae. Australian anchovy typically grow to approximately 15 cm and may live for up to 4-5 years (Dimmlich and Ward in review). This species appears to have the capacity to exploit pelagic niches that are outside the preferred temperature and salinity ranges of sardine.

Scaly mackerel *S. lemuru* (Clupeidae) is a tropical species found in WA waters (Gomon *et al.* 1994; Gaughan *et al.* 2000). Individuals are elongated like sardine, blue to silver in colour and have a distinct black spot at the hind border of the gill cover (Fishbase Website 2005). Scaly mackerel grow to approximately 24 cm, live for 6-7 years and is seasonally abundant. In the WA West Coast Purse Seine Fishery, approximately 773 t of scaly mackerel was taken in 2003 (Gaughan *et al.* 2000; WA State of Fisheries Report 2003/04).

Jack mackerel *T. declivus* and yellowtail scad *T. novaezelandiae* (Carangidae) are found throughout the SW Region (Gomon *et al.* 1994; Kloser *et al.* 1998). At first glance, these two species are morphologically similar, however they can be separated by the length of the accessory lateral line below the base of the dorsal fin (*T. declivis* – accessory lateral line extends beyond soft rays of second dorsal fin) (Gomon *et al.* 1994). *T. declivis* attain maximum sizes of approximately 64 cm and ages of up to 16 years, whereas *T. novaezelandiae* reach sizes of 50 cm and attain ages of up to 14 years (Gomon *et al.* 1994; Lyle *et al.* 2000; Stewart and Ferrell 2001). *T. novaezelandiae* is taken as bycatch in the SA and WA purse seine fisheries and is a target species in the Commonwealth Small Pelagic Fishery (SPF).

Blue mackerel *S. australasicus* (Scombridae) is abundant in the SW Region. This species is characterised by green to blue dorsal sides interspersed with irregular dark markings, fading to silver on the ventral side and has dorsal and anal finlets that are a feature of all members of the family Scombridae. Blue mackerel grow to approximately 50 cm and live for approximately 8 years (Gomon *et al.* 1994; Ward *et al.* unpublished data). Spawning aggregations have been observed during summer and autumn in the eastern Great Australian Bight (GAB), Spencer Gulf, Gulf St Vincent and Investigator Strait. A recent FRDC project (2002/061) provided extensive biological data on blue mackerel ().

Round herring or maray *E. teres* (Clupeidae) grows to approximately 30 cm and is typically blue to green in colour on the dorsal side fading to silver. There are few biological data available for this species. Round herring is taken as bycatch by the state managed purse seine fisheries and occasionally form large schools that dominate individual catches in South Australia (Rogers *et al.* 2004).

Blue sprat *S. robustus* (Clupeidae) is a small (12 cm) short-lived (8 months) and predominantly temperate species (Rogers *et al.* 2003). Blue sprat form large schools and are predominantly an inshore species. This species is occasionally taken as bycatch in the SA Sardine Fishery in southern Spencer Gulf and as a component of 'other species' in the West Coast Beach Bait Managed Fishery in Western Australia (WA State of the Fisheries Report 2003/2004).

Sandy sprat *H. vittatus* (Clupeidae) is small (10 cm), relatively slow growing and lives for up to 4 years (Gaughan *et al.* 1996; Rogers and Ward in press). Like blue sprat, sandy sprat is mostly found in inshore waters and aggregates to spawn near the entrances to rivers, estuaries and inlets (Gaughan *et al.* 1996; Rogers and Ward in press) Both sprat species are important food sources for little penguins (*Eudyptula minor*) (Klomp and Wooler 1988; Kailola *et al.* 1993). Sandy sprat is common in the Coorong (SA) where they are prey items of terns. and juvenile Australian salmon.

Saury *S. saurus* (Scomberesox) is a migratory species found in offshore waters of the Indian and Southern Oceans between 30° and 40°S (Fishbase 2005). Saury grow to approximately 45 cm (Gomon *et al.* 1994). This species is characterised by it double beak, silvery blue colouration and its skipping jumps when pursued by larger predatory fish. Observations during SARDI research surveys for sardine in the GAB suggest saury inhabit the neuston (surface) layer.
Redbait *E. nitidus* (Emmelichthyidae) grow to approximately 36 cm, live for up to 8 years and is generally restricted to temperate waters of the continental shelf and shelf break (Gomon et al. 1994; Welsford and Lyle 2003). Individuals are usually rosy red to blue in colour on the dorsal side, fading to white or pink ventrally. This species forms large schools in deep water adjacent to offshore islands off Eyre Peninsula and South of Kangaroo Island in South Australia. Redbait has also been observed in mixed schools with jack mackerel, sardine and round herring during SARDI research surveys in the eastern GAB.

Status

Small pelagic fishes are the target of three fisheries that include the Commonwealth Small Pelagic Fishery (SPF), the SA Sardine Fishery and the South Coast and West Coast Purse Seine Fisheries in WA.

The SPF operates in the area outside 3 nautical miles across southern Australia to 31°S, near Lancelin in Western Australia (AFMA Website 2005). This fishery has four zones, A-D and the SW Region is part of Zone B of this fishery. Mid-water trawl and purse seine vessels in the SPF are licensed to take blue mackerel, jack mackerel spp., yellowtail scad, and redbait. The current stock status of these small pelagic species is uncertain. Trigger Catch Levels (TCL), are set in accordance with advice provided by the Small Pelagic Research and Assessment Team (SPRAT). In 2004/2005, TCLs were set at 5,000 t for blue mackerel, 4,000 t for jack mackerel spp., 100 t for yellowtail scad and 1,000 t for redbait (SPF Management Plan 2002). The TAC for mackerel in Zone B was 7,000 t.

In 1995 and 1998, mass mortalities of that originated in SA waters spread throughout the Australasian sardine population (Griffin *et al.* 1997; Hyatt *et al.* 1997; Jones 2000; Jones *et al.* 1997; Whittington *et al.* 1997; Gaughan *et al.* 2000; Ward *et al*. 2001b). Each event eventually killed more fish over a larger area than any other mono-specific fish-kill ever recorded. Herpesvirus was identified as the likely disease agent on both occasions (Hyatt et al. 1997; Whittington et al. 1997). These events both had detrimental effects on both the sardine populations and the fisheries that they support. For example, in SA over 70% of the estimated sardine spawning biomass was killed during each mortality event (Ward *et al.* 2001b).

The SA Sardine Fishery is located in Port Lincoln and is the largest finfish fishery by weight in Australia. This purse seine fishery mostly operates in southern Spencer Gulf and Investigator Strait and is licensed to take sardine (*S. sagax*), Australian anchovy (*E. australis*), round herring (*E. teres*), sandy sprat (*H. vittatus*) and blue sprat (*S. robustus*). The size of the spawning population of sardine in SA has been monitored using the Daily Egg Production Method (DEPM) since 1998. These estimates form the scientific basis for management decision rules that are used to set the annual TAC for the fishery in the following year. This target TAC for the fishery has been set at 30,000 t.

In Western Australia, the purse seine fishery is divided into two main regions that include the South Coast and West Coast. The South Coast fishery includes the Albany, Bremer Bay and Esperance regions and the West Coast Fishery mostly operates between 31 and 33° S (WA State of the Fisheries Report 2003/2004). The West Coast Purse Seine Fishery targets *S. lemuru* and *S. sagax*, with ‘other’ species comprising a minor percentage of the total catch. WA Fisheries use the DEPM and predictive age structured models to assess the status of the sardine stock. The most recently published biomass estimate for the South Coast Purse Seine Fishery was approximately 84,000 t (WA State of the Fisheries Report 2003/2004). In 2003, the total catches for the West Coast and South Coast Fisheries were approximately 1,164 and 1,592 t, respectively (WA State of the Fisheries Report 2003/2004). Following the second mass morality event, the purse seine fishery in WA has been specifically managed to avoid industry over-capitalization. This strategy has resulted in catches significantly lower than during the early 1990’s, but was the favoured option for stakeholders due to concerns about the potential for another mass mortality event.

In Western Australia, the West Coast Beach Bait Managed Fishery targets sandy sprat to supply bait markets. Studies of sandy sprat in South-west

Western Australia suggested the distribution of the spawning population was limited to inshore environments and preliminary spawning biomass estimates ranged between 142 and 625 tonnes (Gaughan et al. 1996). In 2003, the total catch of sandy sprat in the West Coast Beach Bait Managed Fishery was 103 tonnes (WA State of the Fisheries Report 2003/2004). There have been concerns raised by the public regarding the potential negative effects of this fishery on little penguin populations.

Habitat and distribution

Members of this species group typically inhabit regions characterized by significant physical and oceanographic features including coastal upwellings, gyres, jet streams, frontal systems, bathymetric mounts and ridges, which interact to drive primary production and in turn provide important food sources for these species, which are predominantly planktivorous. The smaller species, including the sprat spp. and, to a lesser extent, the Australian anchovy tend to prefer inshore waters that are not dominated by adult sardine.

Sardine (*S. sagax*) is found throughout southern temperate waters of Australia, from Rockhampton in Queensland to Shark Bay in Western Australia and throughout the shelf and southern gulf waters of South Australia (Gomon *et al.* 1994). Egg and larval data collected in between 1995 and 2005 suggest adult sardine are distributed throughout the southern gulf and shelf waters, out to the shelf break (Ward *et al.* 2001a, b). However, movement patterns of sardines are poorly understood in southern Australia. Sea-surface temperature (SST) and salinity interfaces form near the mouth of Spencer Gulf during summer and autumn (Bruce and Short 1990). Larval sardine aggregate near these fronts to feed on planktonic organisms and juveniles aggregate in inshore areas near small islands in southern Spencer Gulf and in upper Gulf St Vincent (2000/125) (Ward *et al.* 2004).

In WA, significant quantities of sardine don't mix along the coast over timescales that would allow the entire stock to be fished without spatial management (Gaughan *et al.* 2002). There is some uncertainty over the level of connectivity between sardine stocks in South Australian and Western Australian waters. Given the poor understanding of the spatial dynamics of sardine stocks in South-western Australia, and to what degree stock structure might be present, there is a need for cross-jurisdictional communication in managing this broadly distributed species.

Australian anchovy (*E. australis*) is found throughout South Australian gulf and offshore shelf waters. Populations fluctuate in size in response to changes in the size and distribution of the sardine population (Ward *et al.* 2001a). Anchovy larvae are less abundant in the regions/periods where sardine are abundant (Ward *et al.* 2001a; Alheit and Niquen 2004; Dimmlich *et al.* 2004). High abundances of Australian anchovy eggs have been found in northern Spencer Gulf, which is characterised by high SST (26ºC) in summer and high salinities (Dimmlich *et al.* 2004).

Scaly mackerel *(S. lemuru)* is predominantly found in subtropical and tropical waters of Western Australia and is distributed from Fremantle in the south to the Pilbara region in the north (Gomon *et al.* 1994; Gaughan and Mitchell 2000). Distribution and recruitment of this species is influenced by inter-annual variation in the strength of the tropical Leuwinn Current (Gaughan and Mitchell 2000).

Jack mackerel and yellowtail scad (Trachurus spp.) both aggregate in shelf and southern gulf waters between Kangaroo Island and Shark Bay. Juveniles tend to be found closer to shore and are sometimes taken as bycatch in the purse seine fishery in South Australia. There are few data on the distribution of these species over finer spatial scales in the South West Region

Blue or slimy mackerel (*S. australasicus*) is a migratory species with a broad distribution that ranges from south-eastern Australia to Shark Bay in Western Australia (Gomon *et al.* 1994). In South Australia, blue mackerel is found in the southern regions of both gulfs and in offshore waters out to the shelf break (Ward *et al.* unpublished data).

Round herring (*E. teres*) is found in gulf and shelf waters in South Australia. Schools of juveniles are typically found inshore and adults are found offshore. This species sometimes forms mixed schools with other small pelagic species, including sardine, redbait and jack mackerel. Round herring is a bycatch of the South Australian sardine fishery and occasionally dominates a single catch. Data on the abundance of eggs and larvae of this species suggest the local populations are relatively small compared to sardine (Ward *et al.* unpublished data).

Blue (*S. robustus*) and sandy sprats (*H. vittatus*) are found in a wide range of inshore environments, including the gulfs, sheltered embayments, inshore reefs, seagrass meadows and near river mouths. Within the South West Region their geographic range spans from Kalbarri to Kangaroo Island. These species support small-scale fisheries in Western Australia, Victoria and New South Wales. Sprats also form important food sources for little penguins (*Eudyptula minor*) and inshore pelagic fishes (Klomp and Wooler 1988; Kailola *et al.* 1993; Gaughan *et al.* 1996; Rogers *et al.* 2003; Rogers and Ward in press).

Saury (*S. saurus*) has an oceanic distribution. There is little data available on the distribution and abundance of this species in the South West Region, however it is found in offshore waters south of Eyre Peninsula in South Australia (SARDI unpublished data). This species is a food source for a range of predatory fish and seabird species.

Redbait (*E. nitidus*) is typically found offshore on the continental shelf and shelf break (Gomon et al. 1994; Welsford and Lyle 2003). This species is an important component of the diet of adult male Australian fur seals (*Arctocephalus pusillus doriferus*) that feed on the shelf and shelf break south of Kangaroo Island (Page et al. 2005). Redbait usually aggregate near seamounts, mid-oceanic ridges and in deepwater adjacent to offshore islands

(Lyle 2004). Redbait schools are commonly observed in association with Nyctiphanes krill swarms in the surface layer.

Significance of the species group in the SW Marine Region

Fluctuations in the abundance of small pelagic fishes have significant implications for the function of pelagic ecosystems (Barker and Vestjens 1990; Bax 1991; Blaber *et al*. 1995; Ward *et al*. 1998; Goldsworthy *et al*. 2003). This species group represents a critical energy pathway between primary (phytoplankton) and secondary (zooplankton) producers and larger predatory fishes, sharks, seabirds, seals and cetaceans. Despite this, few data are available on the potential effects of the reduced the availability of small pelagic fishess on larger predators (Ward *et al.* 1998). A current assessment of the importance of small pelagic species in regionally productive pelagic ecosystems of the eastern Great Australian Bight involves the development of a trophodynamic model. This model includes information on levels of primary and secondary productivity, the abundance of planktivorous fishes (with special emphasis on sardine), and the diets of key pelagic predators, including juvenile southern bluefin tuna (SBT) (*Thunnus maccoyii*), Australian salmon (*Arripis truttacea*), little penguins (*Eudyptula minor*), shearwaters (*Puffinis* spp.), Australasian gannets (*Morus serrator*), terns (*Sterna* spp.), Australian sea lions (*Neophoca cinerea*), New Zealand fur seals (*Arctocephalus forsteri*), Australian fur seals (*Arctocephalus pusillus doriferus*)and numerous shark species, including bronze whalers (*Carcharhinus brachyurus*) and hammerheads (*Sphyrna zygaena*) .

Recognition of the importance of small pelagic fishes in the less productive pelagic waters of Western Australia has been underpinned through examination of relevant local and international literature (e.g. Cole and McGlade, 1998; Crawford 2003), many studies on the diets of seabirds (e.g. Klomp and Wooller 1988; Burbidge and Fuller 1989; Dunlop 1997; Gaughan *et al.* 2003; Lenanton *et al*. 2003; Surman and Wooller 2003) and observations of predators (e.g. Australian salmon, tunas, cetaceans and squid) consuming small pelagic fish. Seabirds provide accessible (through terrestrial breeding colonies) components of marine ecosystems so have been the most intensively studied predators of small pelagic fish worldwide. Studies in Australia (e.g. Bunce and Norman 2000; Dann et al. 2000; Surman and Wooller 2003) and elsewhere (e.g. Crawford 2003) have shown that success of seabird breeding or population health is closely coupled to abundance of small pelagic fish.

The South Australian Sardine Fishery was valued at AUD 22.5 million in 2003/04 (ABARE Australian Fisheries Statistics 2005). This fishery supports the southern bluefin tuna mariculture industry, which has an estimated annual value of approximately $AUD 230 million. Th direct value of the fishery does not include the economic value of this fishery to the community in Port Lincoln on Eyre Peninsula, where the fishery supports 14 licence holders, their families, the skippers and crews of each vessel, workers at the processing facilities and all of the local businesses, industries and tradespeople that provide infrastructure and services to support day to day operations. Due to the complexities of these relationships at a community level, it is extremely difficult to accurately assign a broader socio-economic value and assess the significance of this and other small pelagic fisheries.

The recreational sector mostly uses small pelagic species for bait to target larger predatory species. Sardines are a favoured as bait by recreational anglers and are used to target Australian salmon (*Arripis truttacea*), snapper (*Pagrus auratus*), mulloway (*Agyrosomus japonicus*), tailor (*Pomatomus saltatrix*) tuna spp., dhufish (*Glaucosoma hebraicum*) and Spanish mackerel (*Scomberomorus commerson*). Blue mackerel, jack mackerel and yellowtail scad are often used as live-bait to target kingfish (*Seriola lalandi*), Samson fish (*S. hippos*), tuna spp., and Spanish mackerel.

Information on the significance of small pelagic species to recreational fisheries was sourced from the results of *The National Recreational and Indigenous Fishing Survey*, conducted in 2000 and 2001 (Henry and Lyle 2003) (Table 4.21.1). Given the predominantly temperate distributions (with the exception of *S. lemuru*) of most of these species, for the purpose of this report it was assumed that most of the recreational catch of mackerels and baitfish in both South Australia and Western Australia occurred within the SW Region.

The socio-economic, cultural, economic and recreational value of fishing in indigenous communities of the SW Region is poorly understood. There have been no recent attempts to address this knowledge gap, which is surprising considering the long history of interactions between Australian indigenous communities that inhabit the coastal fringe, and inshore marine ecosystems. During the recent national indigenous fishing survey, communities were only surveyed in northern Western Australia (outside the SW Region). However, given the paucity of information available on indigenous fishing Australia-wide, these data were included to provide an indication of the importance of small baitfish species to indigenous communities who mostly fish for subsistence and cultural reasons (Table 4.21.1).

Table 4.21.1 Recreational catch of small pelagic fishes in South Australia and Western Australia between 2000 and 2001. Indigenous catches for North-west Western Australia during the same period. Source Henry and Lyle (2003).

State	Species group	Total catch (n fish ±s.e.)
SA Recreational	Scads/mackerel	2,679 (*1,270*)
	Blue mackerel	45,044 (*17,394*)
	Small baitfish	1,227
Total		**48,950**
WA Recreational	Scads/mackerel	125,746 (*27,478*)
	Blue mackerel	78,631 (*17,377*)
	Small baitfish	29,626 (*10,358*)
Total		**234,003**
WA Indigenous	Scads/mackerel	72
	Blue mackerel	132
	Small baitfish	7,951
Total		**8,155**

Impacts/threats

- Ecological and/or anthropogenic vectors for viral diseases. Separate mass mortalities in 1995 and 1998 that were attributed to herpesvirus killed more sardine than any previously recorded single species mortality event (Ward *et al.* 2001b).

- Recruitment overfishing and localised depletion are key threats to small pelagic fisheries and the health of the stocks that underpin them. In Western Australia, the threat of localised depletion is managed by (a) zonation of the fishery and (b) setting of conservative annual TACs in each zone.

- Successive years of unfavourable environmental conditions for survival, spawning and recruitment, in combination with significant commercial fishing pressure can lead to unsustainable declines in populations of small pelagic fish. These issues are managed via the implementation of conservative decision rules for setting the annual TACs.

- Until recently, the focus has been on single species fishery assessments and hence, the potential impacts of commercial exploitation of small pelagic fish stocks on the broader ecosystem remain poorly understood.

Information gaps

Gaps in the published literature for small pelagic fish species found in the SW Region are summarized in Table 4.21.2. Baseline scientific information is available for sardine due to the commercial importance of this species. In the past decade, most of the other small pelagic species have only been the subject of preliminary studies.

Current research projects in the SW Region

- In response to the need to establish an ecosystem-based management framework for the SA Sardine Fishery, fishers and the FRDC, funded a pilot study (2003/072) titled, '*Trophodynamics of the GAB: assessing the need for an ecological allocation in the SA pilchard fishery*'.

  This pilot study led to the development of the current FRDC funded study titled, '*Towards ecosystem-based management of the SA pilchard fishery: developing ecological performance indicators to assess the need for ecological and/or spatial allocations*'.

- An FRDC funded study (2002/061) titled, 'Development and evaluation of egg-based stock assessment methods for blue mackerel Scomber australasicus in southern Australia', is being undertaken to provide stakeholders with fishery and biological information on blue mackerel, and other small pelagic species that are commercially exploited in the SW Region.

- An FRDC-funded study (2000/135) titled, "Regrowth of pilchard (*Sardinops sagax*) stocks off southern Western Australia following the mass mortality event of 1998/99." is being undertaken to assess the medium-term (6 years) increases in the Western Australian sardine population from the very low levels recorded in 1999 (Gaughan *et al.* 2004).

- Comprehensive studies of the nutrient/phytoplankton/zooplankton (NPZ) cycle for pelagic waters in WA are currently underway, using funds from the WA Strategic Research Fund for the Marine Environment (SRFME) initiatives.

Table 4.21.2 ELH = Early life history, D = Diet, RT = Recruitment, DH = Distribution and habitat, FD = Fishery catch and effort data, FB = Fishery bycatch information, LF = Length frequency, AS = Age structure, GR = Growth rates, R = Reproductive information, M = Movement, SSt = Stock structure, SB = Spawning biomass, EE = Ecosystem effects of fishing. Key to colours in available data and information gaps columns – Most necessary baseline data is available although still minor gaps = white. Some biological and ecological data available in other regions of southern Australia yet still significant gaps = green. Scanty biological data available for the species throughout its distribution = grey shading. No biological or ecological data available for species in Australia or elsewhere = black.

Common/ species name	Family	Available data	Information gaps in SW Region
Sardine (pilchard) *S. sagax*	Clupeidae	ELH, DH, GR, FD, AS, LF, R, FB, SB.	RT, M, SSt, EE, D
Australian anchovy *E. australis*	Engraulidae	ELH, DH, LF, GR AS.	SSt, SS, FD, SB, RT, R, FB, EE, M, D
Round herring *E. teres*	Clupeidae	ELH, DH, R , GR, AS, LF	
Scaly mackerel *S. lemuru*	Clupeidae	LF, AS, FD, SSt, DH, FB, GR, R	RT, ELH, M, FD, SB, EE
Blue sprat *S. robustus*	Clupeidae	ELH, DH, GR, FD, AS, LF, R, SB.	**RT, FD, M SST, SB, EE.**
Sandy sprat *H. vittatus*	Clupeidae	ELH, DH, GR, FD, FB, AS, LF, R, SB.	RT, M, SSt, EE
Blue mackerel *S. australasicus*	Scombridae	FD, LF, AS, GR	**ELH, RT, FB, R, M, SST, SB, EE.**
Jack mackerel *Trachurus spp.*	Carangidae	ELH, DH, LF, AS, GR, FD, D.	**RT, FB, R, M, SST, SB, EE.**
Redbait *E. nitidus*	Emmelichthyidae	LF, AS, FD, DH, GR, R, D.	
Saury *S. saurus*	Scomberesocidae		

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4.22 Syngnathid fish (seahorses, seadragons, pipehorses and pipefishes)

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Species group name and description

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The Syngnathidae is a large family of fish distributed throughout the Atlantic, Indian, and Pacific Oceans, mostly in the shallow, warm temperate to tropical waters of the continental shelf, and is one of the largest families of coastal fish in southern Australian waters (Museum of Victoria, 2005). The main groups in Syngnathidae are the seahorses and pygmy pipehorses (Hippocampinae); the pipehorses and seadragons (Solegnathinae), and the pipefishes (Syngnathinae). Some authorities, such as Kuiter (2000, 2003) separate the flag-tail group of pipefishes into a separate sub-family (Doryrhamphinae).

Syngnathidae comprises about 53 or 54 genera, however authorities do not agree on the exact number of species. The international database of fish nomenclature and biology, *FishBase* (Froese and Pauly, 2006) listed 277 named species. However, Kuiter (2003a) reported an even higher number, in the order of 330 species. Some authorities do not recognise a number of the species identified by Kuiter (2000, 2001), and have reported them to be regional forms of previously identified species (e.g. see Pogonoski et al., 2002; Lourie et al., 2004). Compared with other countries, Australian waters support the largest number of syngnathid genera (Dawson, 1985, cited by Wilson et al., 2001), and a large number of species (about 129) (CSIRO, 2005). A number of new species, particularly small forms, have been discovered in recent years (e.g. Kuiter, 2003b, 2004; Brown and Smith, in press).

Most species are marine, but some occur in brackish or fresh waters. Many of the pipefishes, seahorses and the two seadragon species live in shallow bays and coastal waters, especially in seagrass beds, and on reefs covered with macroalgae, where they are well camouflaged. Pipehorses usually occur in deeper continental shelf waters. Generally, coastal syngnathids such as seahorses and seadragons are site-associated in nearshore habitats (Baker, 2002a,b and 2005a,b; Connolly et al., 2002; Moreau and Vincent, 2004; Browne, 2004; Sanchez-Camara et al., 2005). Seadragons are not good swimmers, due to their fragile flotation bladders, which cannot cope with sudden changes in water pressure or depth, such as might occur during bad weather (Department of Fisheries, Western Australia, 2004b). Therefore, seadragons are often found washed up on beaches after storms (Museum of Victoria, 2005), sometimes in large numbers (e.g. Baker, 2002b, 2005b).

Members of the family have external armour of bony plates and rings enclosing an elongate body. Syngnathids have no ventral fins, and some species also lack caudal, dorsal, anal, and/or pectoral fins. The pipefishes are generally long and stick-like in shape, with a straight, tapering tail. Seahorses have a prehensile tail and a thickened body. Pipehorses and seadragons have a slightly prehensile tail, and a somewhat thickened body. Syngnathids range in size from several cm (species of pygmy seahorse) to at least 65cm (*Leptoichthys fistularius*, the Brush-tail Pipefish).

Syngnathids feed in the water column, on or near the substrate, depending on the species. Most eat small invertebrates, such as mysids in the zooplankton and small amphipods on surfaces (Kuiter, 2000, 2003; Smith et al., in prep.). A few species also eat other invertebrates (e.g. shrimps), and larval fishes. The syngnathid snout is tipped with a hatch-like mouth (Museum of Victoria, 2005), and prey are sucked up whole, into the tubular snout. Some adult syngnathids are preyed upon by flathead, snapper (Kuiter, 2003) and other demersal fish species, and there are isolated records of syngnathids being taken by diving sea birds.

Syngnathids exhibit specialised forms of courtship, reproduction and paternal care. Several studies have reported that seahorses form monogamous pairs (e.g. Jones et al., 1998; Kvarnemo et al., 2000). All appear to be monogamous within a breeding cycle, but some are polygamous across cycles (Foster and Vincent, 2004). During mating, female syngnathids transfer eggs to structures that are located on either the abdomen or tail of the male. The male provides all post-fertilisation parental care, and has morphological and physiological adaptations to osmo-regulate, aerate, and nourish the developing embryos (Wilson et al., 2001). The brooding structure with which this is accomplished varies between species in the family, from simple ventral “gluing” areas, to more complex structures, such as completely enclosed brood pouches, in seahorses (Wilson et al., 2001).

Most syngnathids have a relatively low reproductive potential, with the numbers of eggs in a single batch typically in the 100's – 200s for seahorses, however some seahorse species can release as few as 5 or as many as 1500+ young per batch, depending on the species and the adult size (Foster and Vincent, 2004; Foster, in Bruckner et al., 2005). For pipefish, the average number of eggs is often less than 100, for most species (Browne, 2004; Browne and Smith, unpublished data) The number of young in each brood will generally be lower in the smaller-sized species of syngnathid (Kuiter, 2000, cited by Pogonoski et al., 2002).

Status

In southern Australia, it is difficult to adequately assess the conservation status of syngnathids as a group, which contains species that range from the apparently rare and localised, to the widely distributed and very common. Conservation status assessments are further hindered by lack of agreement about species identities (e.g. for seahorses, see Kuiter, 2001 and 2003, compared with Lourie et al., 2004; and for taxonomic problems with pipefish identity, see Browne, 2004). Also, for some species, particularly the more cryptic pipefishes, the apparent limited distribution and uncommonness of the species is likely an artefact of sampling difficulty (Browne, 2004; Smith et al., in prep.), and the opportunistic,

rather than systematic, nature of existing collections. For many species, there is poor knowledge of the distribution, relative abundance and critical habitats (e.g. Pogonoski et al., 2002; Browne, 2004), hence status cannot be adequately determined.
The lack of adequate studies on the systematics, ecology, and distribution of species, and the consequent reliance upon recent studies and assessments of tropical species, makes a balanced assessment of the conservation status of Australian syngnathids difficult (R. Kuiter, pers. comm., 2003; Browne, 2004). Due to a vigorous international trade in seahorses and pipehorses for traditional medicine, and for aquaria and curios, syngnathids have attracted much global-scale conservation attention during the past decade (e.g. Vincent, 1995, 1996; CITES, 2002; Foster and Vincent, 2004, 2005; Bruckner et al., 2005). Very few southern Australian species are taken from the wild for this purpose, as explained later in this chapter.

In 2002, the entire genus of *Hippocampus* was listed in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), and the listing took effect from May 2004. International trade is monitored through a licensing system (under CITES II), and a minimum size of 10cm applies. The Australia Government DEH (the CITES management authority) relies heavily on the Australian Customs Service to implement CITES at ports of exit and entry for syngnathid trade (Bruckner et al., 2005).

At a national level, syngnathids are afforded a high level of legislative protection, compared with almost all other marine fish. All syngnathids (seahorses, seadragons, pipefishes and pipehorses) and solenostomids (ghost pipefishes) are listed as marine species under Section 248 of the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999.* That listing makes it an offence under the Act to recklessly kill, injure, take, trade, keep or move a member of either family, unless duly authorised by a permit. Since January 1998, all syngnathids have also been subject to the export controls of the *Commonwealth Wildlife Protection (Regulation of Exports and Imports) Act 1982*. DEH is responsible for ensuring that Commonwealth managed and State export fisheries are assessed under the *EPBC Act* to ensure that they are managed in an ecologically sustainable manner.

Most southern States have some formal level of protection for members of the Syngnathidae, and the Acts under which syngnathids are listed are indicated in the table below. In N.S.W., Victoria, Tasmania and S.A., it is now an offence to have in one's possession, or to collect or harvest any species of seahorse, seadragon, pipefish, pipehorse, without a permit.

A number of syngnathids that are found in southern and western Australia are listed internationally on the *IUCN Red List* of threatened species. The table below summarises current conservation status, at international, national and State levels, preceded by the key to acronyms

IUCN 2006: *2006 IUCN Red List of Threatened Species* www.redlist.org

- VU = Vulnerable; A2d = population reduction of at least 20%, projected or suspected to be met within the next ten years or three generations (whichever is longer), based on actual or potential levels of exploitation
- LR-CD = Lower Risk, but Conservation Dependent
- LR-NT = Lower Risk, but Near Threatened
- LR-LC = Lower Risk, and Least Concern
- DD = Data Deficient

DEW = Suggested status in Australia, according to the Australian Government Department of the Environment and Water Resources (formerly Environment Australia) report by J. Pogonoski, D. Pollard, and J. Paxton (2002): *Conservation Overview and Action Plan for Australian Threatened and Potentially Threatened Marine and Estuarine Fishes*.

ASFB = Australian Society for Fish Biology (2001). *Conservation Status of Australian Fishes – 2001*. www.asfb.org.au/research/tscr/tf_constat2001.htm (accessed October, 2005)

SA1 = Protected from capture, under the *South Australian Fisheries Act 1982*
WA1 = Protected from capture, under the *Fish Resources Management Act 1995*
TAS1 = Listed under the *Tasmanian Threatened Species Protection Act 1995*
TAS2 = Protected under *Tasmanian Living Marine Resources Management Act 1995*
TAS3 = Protected in Tasmania under the *Fisheries Regulation 1996*
VIC1 = Listed under Schedule 2 of *Victorian Flora and Fauna Guarantee Act 1988*
VIC2 = Listed as Protected Aquatic Biota under the *Victorian Fisheries Act 1995*
NSW = Protected Species in N.S.W., under the *Fisheries Management Act 1994*

Species	**IUCN Red List**	**Australia**	**States**
Acentronura australe / Idiotropiscis australe	DD		
Festucalex scalaris		DEW: LR-LC ASFB: LR-LC	
Filicampus tigris			NSW, SA1
Heraldia sp. 1 / *H. nocturna*			VIC2, TAS2, SA1, NSW (eastern form *H. nocturna*)
Hippocampus abdominalis / H. bleekeri N.B. Lourie et al. (2004) considered *H. bleekeri* to be a form of *H. abdominalis*, whereas Kuiter (2000, 2001) assigned the two forms to separate species.	DD (as *H. abdominalis*)	DEW: LR-CD (as *H. bleekeri*) ASFB: LR-CD	TAS2, VIC2, SA1, NSW
Hippocampus angustus	DD	DEW: DD ASFB: DD	
Hippocampus biocellatus		ASFB: LR-NT (as *Hippocampus* sp. 5) DEW: LR-NT	
Hippocampus breviceps	DD	ASFB: DD DEW: DD	TAS2, VIC2, SA1
Hippocampus planifrons		ASFB: DD DEW: DD	

Hippocampus subelongatus / H. elongatus	DD	ASFB: DD DEW: DD	
Hippocampus tuberculatus		ASFB: DD DEW: DD	
Histiogamphelus cristatus			VIC2, SA1, TAS2
Histiogamphelus meraculus / Mitotichthys meraculus		ASFB: DD (as *Mitotichthys meraculus*) DEW: DD (as *Mitotichthys meraculus*)	
Hypselognathus horridus		ASFB: DD DEW: DD	SA1
Hypselognathus rostratus			VIC2, SA1, TAS2
Kaupus costatus			VIC2, SA1, TAS2
Kimblaeus bassensis			VIC2, SA1, TAS2, NSW
Leptoichthys fistularius			VIC2, SA1, TAS2
Lissocampus caudalis			VIC2, SA1, TAS2, NSW
Lissocampus fatiloquus		ASFB: LR-LC DEW: LR-LC	
Lissocampus runa			VIC2, SA1, TAS2, NSW
Maroubra perserrata			VIC2, SA1, TAS2, NSW
Notiocampus ruber			TAS2, SA1, NSW
Phycodurus eques	NT	ASFB: LR-CD DEW: LR-CD	NSW, VIC2, SA1, WA1
Phyllopteryx taeniolatus	NT	ASFB: LR-CD DEW: LR-CD	NSW, TAS2, SA1, VIC2
Pugnaso curtirostris			VIC2, SA1, TAS2
Solegnathus lettiensis	VU A2d	ASFB: DD DEW: DD	
Solegnathus robustus	VU A2d	ASFB: DD DEW: DD	VIC2, SA1, TAS2
Stigmatopora argus			NSW, VIC2, SA1, TAS2
Stigmatopora sp. nov.			SA1
Stigmatopora nigra			NSW, VIC2, SA1, TAS2
Stipecampus cristatus			VIC2, SA1, TAS2
Syngnathoides biaculeatus	DD	ASFB: DD DEW: DD	NSW
Trachyrhamphus bicoarctatus			NSW
Urocampus carinirostris			VIC2, SA1, TAS2, NSW
Vanacampus margaritifer			VIC2, SA1, NSW
Vanacampus phillipi			VIC2, SA1, TAS2, NSW
Vanacampus poecilolaemus			VIC2, SA1, TAS2
Vanacampus vercoi		ASFB: LR-NT DEW: LR-NT	SA1

Table 4.22.1 Summary of conservation status of syngnathids in the South-west Marine Region

Habitat and distribution

The sections below summarise the currently known distribution and habitat of syngnathids found in the South West Marine Region. Species with uncertain southern or western geographical limits are not included. Regarding a western limit for example, the Trawl Pipefish (Bass Strait Pipefish) *Kimblaeus bassensis* Dawson 1980, has been found in deeper waters of the continental shelf, and is known from less than one dozen museum records, mostly from Bass Strait in Victoria, and locations in eastern Tasmania / Tasman Sea, but also including one museum record from southern New South Wales (Dawson, 1980; Gomon et al., 1994; Butler et al., 2002a; Museum of Victoria record A4338, cited in OZCAM database, 2006). However, there is a photograph (by N. Coleman) of a specimen from Port Lincoln in S.A., purported to be this species (Kuiter, 2000). Apparently, no other South Australian records are known, hence the species is not included here. Regarding a southern limit, there is no agreement about how far south along the Western Australian coast the species (or species complex) known as *Hippocampus trimaculatus* extends. Kuiter (2003a) did not recognise this species, however Lourie et al. (2004) grouped together *H. mannulus* Cantor 1850; *H. kampylotrachelos* Bleeker 1854d; *H. manadensis* Bleeker 1856; *H. planifrons* Peters 1877; *H. dahli* Ogilby 1908; and *H. takakurae* Tanaka 1916 as synonyms of *H. trimaculatus*, and reported that the range of this mainly tropical species extends as far south as approximately Geraldton in W.A.

Species in Solenostomidae are not included in the table below, but it is noted that one of these, the Indo-Pacific Blue-finned Ghostpipefish / Robust Ghostpipefish *Solenostomus cyanopterus* occurs at the northern end (Shark Bay) of the SWMR.

Latin and Common Names	***Notes on Distribution and Habitat***
Acentronura australe Waite & Hale, 1921 (= *Idiotropiscis australe*) Southern Little Pipehorse / Southern Pygmy Pipehorse	Known from southern Gulf St Vincent (GSV) in S.A., but is not commonly recorded, and may have a limited distribution in South Australia. The range extends to southern W.A. (based on specimens from the Carnac I. and Fremantle area), but there are very few published records anywhere across southern Australia (Dawson, 1985; Kendrick and Hyndes, 2003; Kendrick and Morgan, 2006; OZCAM database records, 2006). The Southern Little Pipehorse is assumed to live in red macroalgae habitat (on semi-exposed coastal reefs) and also in and near seagrass beds, and is found in very low densities . The full depth distribution is not known, however the Cape Jervis (S.A.) specimen was found at 20m depth, and specimens in W.A. have been found at shallower depths (Kendrick and Hyndes, 2003). The 2 specimens from 10km east-south-east of Troubridge Island in S.A. came from rocky bottom with strong currents, which supports a rich community of red macroalgae (S. Shepherd, SARDI, pers. comm., cited by Baker, in press).
Campichthys galei (Duncker, 1909) Gales Pipefish	The species is not well known, with few specimens (Dawson, in Gomon et al., 1994; S.A. Museum data, cited by Baker, in press). Gale's Pipefish ranges from central S.A. through to the central coast of W.A. (Dawson, in Gomon et al., 1994). In recent years, specimens have been collected from beam trawls in Spencer Gulf (SG) (B. McDonald, unpubl. data, 2001), the eastern edge of the known range. Gales Pipefish is found on shallow rubble substrates (Kuiter, 2000), and in seagrass beds (B. McDonald, unpubl. data, 2001), in the shallow subtidal to around 18m (Dawson, 1985, and in Gomon et al., 1994; Kuiter, 1996a and 1996b; Froese and Pauly, 2006).
Choeroichthys latispinosus Dawson, 1978 Muiron Island Pipefish	A rarely recorded species, reportedly endemic within W.A., and previously known only from South Muiron I., near Exmouth (Kuiter, 2003); however there is a museum record from further south, at Port Denison (G. Moore, WA Museum, pers. comm., 2005). The species is reported to occur on rubble reef slopes, to about 8m deep (Kuiter, 2003).
Choeroichthys suillus Whitley, 1951 Pig-snouted Pipefish	A tropical species known from PNG and northern Australia (W.A., Qld and McCluer Island, NT) (Dawson, 1985; Kuiter, 2003). In W.A., the species has been recorded as far south as Jurien, with other localities including Port Denison and Port Gregory (G. Moore, W.A. Museum, pers. comm., November, 2005). The species is found on reefs (e.g. specimens have been recorded under rubble pieces on reef flats) (Kuiter, 2003), with a reported depth range of about 0m – 14m (Dawson, 1985).
Festucalex scalaris (Günther, 1870) Ladder Pipefish	An endemic W.A. species, known mainly from Kalbarri to Ningaloo Reef, including Shark Bay (WA Museum, 2003). There are few published records (OZCAM database, 2006). The Ladder pipefish is found mainly amongst vegetation in shallow rock pools (Dawson, 1985), but is also known from shallow trawling grounds (Western Australian Museum, 2003). Kuiter (2000) reported the depth to range from the intertidal to about 20m. The currently known depth limit is possibly based on a specimen collected in 1911 from Cape Jaubert, at 16.5m deep (Swedish Museum of Natural History record, cited in Froese and Pauly, 2006).

Latin and Common Names	**Notes on Distribution and Habitat**
Filicampus tigris (Castelnau, 1879) Tiger Pipefish	Mainly a tropical and sub-tropical species, known from central and southern Qld coast; parts of N.S.W.; northern and central SG in S.A., and locations along the central and northern coast of W.A. (Dawson, 1985; Kuiter, 1996a, 1996b; P. Jennings, SARDI, unpubl. data, 2003; Australian Museum records, W.A. Museum records, CSIRO Marine Research records, cited in OZCAM database, 2006). There are also unverified records, purported to be *F. tigris*, from Victoria, and eastern Bass Strait (Museum of Victoria records, CSIRO Marine Research records, cited in OZCAM database, 2006). Despite the mainly tropical distribution of this species, IMCRA Technical Group (1996) considered *F. tigris* to be one of the indicator species for the Gulfs Province in S.A.. The species is usually found near the entrance of deeper estuarine areas and in sheltered bays, adjacent to tidal channels. It lives near muddy, sandy, rubbly or rocky bottom, with sparse plant life (Dawson, 1985; Kuiter, 1996b; Edgar, 2000), and is also recorded along the edges of seagrass beds. Most specimens have been found between 2m and 25m deep, however records to at least 30m are known (S.A. Museum record, 1982; Dawson, in Gomon et al., 1994; Kuiter, 2000).
Halicampus brocki (Herald, 1953) Brock's Pipefish	A widespread tropical species, known from the West Pacific, Japan, and northern Australia (Kuiter, 2003). In W.A., the species has been recorded as far south as Jurien, with other known sites in W.A. including Port Denison, Abrolhos Is., and Kalbarri (G. Moore, W.A. Museum, pers. comm., 2005). Brock's Pipefish is a well camouflaged species found on coral reefs, and on macroalgae-covered rocky reefs (Kuiter, 2003), from the shallow subtidal to at least 35m deep. Currently known deeper records are tropical, and from outside of Australian waters.
Haliichthys taeniophorus Gray, 1859 Ribboned Seadragon / Ribboned Pipefish / Pipehorse	A tropical pipehorse species known from northern W.A., N.T., Torres Strait and New Guinea (Kuiter, 2003). Freycinet Harbour in Shark Bay is the type locality (Eschmeyer, 2004). Kuiter (2003) described the habitat as being vegetation in shallow water, bordering open substrates such as tidal channels, often to depths of about 16m, but also in deeper waters, to about 50m (e.g. prawn trawl bycatch records in tropical waters – OZCAM database, 2006), on soft-bottom substrates.
Heraldia nocturna Paxton, 1975 (southern form) (= *Heraldia* sp. 1 in Kuiter, 2000) Western Upside-down Pipefish	Kuiter (1993, 2000) recognised two distinct forms (eastern and southern) that may be separate species. The southern form of Upside-down Pipefish *Heraldia nocturna* ("*Heraldia* sp. 1") is a mottled yellow-brown, with light markings, and has a smaller caudal fin than the east coast form. The southern form is recorded from Port Phillip Bay in Victoria, and westward to S.A. and southern W.A.. Generally, the Upside-down Pipefish lives in low energy coastal bays (protected from ocean swell), shallow reef areas, and the ocean side of large estuaries, down to about 20m depth. The species, which is rarely recorded due to its cave and ledge association, associates with the Serrated Pipefish *Maroubra perserrata*, sometimes occurring in the same caves and ledge areas. *Heraldia* is usually recorded in pairs, swimming upside down on the ceiling of caves or rock crevices, and in low and deep ledges on shallow rocky reefs. The species has also been recorded off jetties (Kuiter, 1996a, 2000; Edgar, 2000; Browne, 2004; Australian Museum, 2004a).
Hippocampus angustus Günther, 1870 Western Spiny Seahorse Narrow-bellied Seahorse	A tropical species, known from northern W.A., N.T. and north Queensland (Lourie et al., 2004). Shark Bay is the southern limit of distribution (Kuiter, 2003; Lourie et al., 2004). The species occurs in reef habitats, including areas of macroalgae cover (Kuiter, 2003). The reported depth range is 3m to about 63m (Lourie et al., 1999, cited in Froese and Pauly, 2005), but specimens are more commonly known within the range 12m - 25m (Kuiter, 2003).

Latin and Common Names	**Notes on Distribution and Habitat**
Hippocampus subelongatus (= *H. elongatus)* Castelnau, 1873 Western Australian Seahorse West Australian Seahorse	Endemic to W.A. and mainly known from sub-tropical areas; however the range may extend further south, into the Great Australian Bight (GAB) (Kuiter, 2003). The species appears to be common only in localised areas, such as Fremantle, Perth / Swan River area (where large numbers occur periodically), Cockburn Sound, and further north at the Houtman Abrolhos Is. (Pogonoski et al., 2002; Bruckner et al., 2005). Large numbers of *H. subelongatus* congregate in the lower reaches of the Swan River in early summer, reportedly to feed their offspring on small crustaceans (Kuiter, 2003). The species occurs in sheltered coastal bays, often in “mixed reef and vegetated habitats”, with seagrass, mixed short macroalgae and/or rich invertebrate growth (Kuiter, pers. comm., 1999, cited by Pogonoski et al., 2002; Kuiter, 2003). Other descriptions of the habitat include rocky reef and edges of rocky areas; seagrass meadows; muddy bottoms and areas of high sediment load; jetty piles and moorings; habitats with sponges or sea squirts; and man-made objects, to which individuals attach (Coleman, 1980; Lourie et al., 2004). Western Australian Seahorse is often found at 1m – 10m depth, but may move into deeper water during winter (Lourie et al., 1999; Kuiter, 2003). Lourie et al. (1999, 2004) reported the full depth range to be about 1m – 25m.
Hippocampus biocellatus Kuiter, 2001 False-eyed Seahorse	Described by Kuiter as a distinct species, known only from the Shark Bay region of W.A. (Kuiter, 2001). Although Lourie et al. (2004) considered it to be a form of the widely distributed Indo-Pacific species H. trimaculatus, genetic work has confirmed that *H. biocellatus* is a true species (S. Lourie, pers. comm., cited by Bruckner et al., 2005). The species occurs in macroalgal reef habitats and seagrass beds, in shallow, wave-protected bays, with are reported depth range from the intertidal down to about 20m or 25m (Kuiter, 2000, 2001; Bruckner et al., 2005).
“Hippocampus bleekeri” Fowler, 1908 Southern Potbelly Seahorse / Potbelly Seahorse / Pot-bellied Seahorse Some authorities consider *H. bleekeri* to be the same species as *H. abdominalis* Lesson 1827 (e.g. see Lourie et al., 2004). Armstrong (2001, cited by Bruckner et al., 2005) showed that there were no significant differences in the cytochrome b sequence *of H. abdominalis* and *H. bleekeri*, suggesting that *H. bleekeri* is a form of *H. abdominalis*, rather than a distinct species. The name *H. bleekeri* is used in this review, as it is a commonly accepted name for the Southern Potbelly Seahorse in South Australia.	*H. bleekeri* (or the southern form of *H. abdominalis*) is known from the GAB in S.A., eastwards to Victoria and Bass Strait, and southwards to Tasmania (Kuiter, 2001, cited by Pogonoski et al., 2002). In S.A., this seahorse has been recorded in the western and central part of the State, including the GAB, Eyre Peninsula (EP), SG, Yorke Peninsula (YP), and GSV (e.g. Baker, 2005a,b; Australian Museum records, and S.A. Museum records, cited in OZCAM database, 2006). In Victoria, overall abundance has been observed to fluctuate every year, and abundance is likely to be dependent on food (i.e. abundance of mysids) (Bruckner et al., 2005). Southern Potbelly Seahorse is often found near reef edges, also under jetties / wharves, and is often seen attached to *Ecklonia* kelp holdfasts (Bruckner et al., 2005) or even to structures such as mooring chains. The young are pelagic and have been found floating attached to bits of seagrass or macroalgae. In deeper water this species is often associated with sponges (and sometimes bryozoans), to which the seahorses attach themselves (Kuiter, 1993 and 1996; R. Kuiter, pers. comm., cited by Pogonoski et al., 2002; Bruckner et al., 2005). In S.A. the species has also been recorded in seagrass beds (B. McDonald, unpubl. data, cited by Brook, 2002), and also occurs near the entrances to estuaries, where it lives on the bottom or near reef edges. According to Bruckner et al. (2005), the species is found from the shallow subtidal to at least 35m deep.

Latin and Common Names	Notes on Distribution and Habitat
Hippocampus breviceps Peters, 1869 Short-headed Seahorse (N.B. In W.A. = *H. tuberculatus* Knobby Seahorse, Castelnau, 1875)	*H. breviceps* is mainly a south-eastern Australian species, found in Bass Strait, parts of eastern Tasmania, Victoria (where it is common in Port Phillip Bay), and S.A. (Last et al. 1983; Kuiter, 1993; Lourie et al., 1999 and museum records, cited by Pogonoski et al., 2002; Kuiter, 2000, 2003). In S.A., the species has been recorded mainly in central and western areas i.e. GSV, YP, SG and EP and parts of GAB (e.g. B. McDonald, unpubl. data, 2001; Cheshire et al., 2002; Muirhead, 2002; Fairhead et al., 2002a; K. Smith, unpubl. data, 2002-2005; D. Muirhead, pers. comm., 2005; Baker, 2005a,b; South Australian Museum records, cited in OZCAM database, 2006). The species occurs mainly in protected coastal bays and estuaries (Bruckner et al., 2005). The species is found in the shallow subtidal on sheltered coastal reefs and reef patches near sand, often in yellowish- to brown-coloured macroalgae (e.g. species of *Cystophora* and *Sargassum*), and also at the edge of seagrass stands (e.g. *Amphibolis* spp.). They are generally found attached to (or among) the fronds of macroalgae, and although rarely seen because of good camouflage, they can be common in localised areas, and form aggregations (Kuiter, 1993; Edgar, 2000). Depth range is shallow subtidal to ~ 15m, but are sometimes seen on sponge reef in deeper water (Kuiter, 2000, 2003). *H. breviceps* is occasionally found amongst seaweed floating at the surface (Dawson, in Gomon et al., 1994) and is also associated with jetty habitats (e.g. Muirhead, 2002; Coleman, 1980, cited by Pogonoski et al., 2002).
Hippocampus planifrons Peters, 1877 Flat-face Seahorse N.B. Not recognised by Lourie et al. (2004) as a valid species, but considered to be a form of *H. trimaculatus* Leach, 1814.	According to Kuiter (2001, 2003), an endemic species, known from central and northern W.A. (Kuiter, 2001; Pogonoski et al., 2002). Shark Bay appears to be the southern limit of distribution (Kuiter, 2001; Pogonoski et al., 2002). Recorded in macroalgae and rubble areas in shallow bays, to about 20m (Kuiter, 2001, 2003). It is noted that *H. trimaculatus*, of which Lourie et al. (1999, 2004) consider *H. planifrons* to be a form, occurs to 100m deep in tropical waters.
Hippocampus tuberculatus Castelnau 1875 Knobby Seahorse N.B. Lourie et al. (2004) did not consider *H. tuberculatus* to be a valid species, but rather a synonym for the southern Australian *H. breviceps*. It is noted that in W.A., the name *H. breviceps* is used in the commercial trade of *H. tuberculatus* (e.g. Newman and Brand-Gardner, 2005).	Kuiter (2000, 2001) considered *Hippocampus tuberculatus* to be separate from the eastern and southern H. breviceps. Knobby Seahorse is endemic to W.A. waters, from the Mandurah region northwards to Onslow. The Knobby Seahorse is often found in floating *Sargassum* as juveniles and sub-adults, while adults often settle on sponge reefs in depths of about 20m (Kuiter, 2000, cited by Pogonoski et al., 2002).

Latin and Common Names	Notes on Distribution and Habitat
Histiogamphelus cristatus (Macleay, 1881) Macleay's Crested Pipefish / Rhino Pipefish	Ranges from northern Tasmania and western Victoria, through to south-western W.A.. Most reports to date are from S.A., where specimens have been recorded from the S.A. / Victorian border, Encounter Bay, Kangaroo Island (KI), GSV and SG, and westwards to the GAB (Glover, 1979; Dawson, in Gomon et al., 1994; B. McDonald, unpubl. Data, 2001; P. Jennings, SARDI, unpubl. Data, 2003; CSIRO Marine Research record H 4211-03, Museum of Victoria records, S.A. Museum records, Australian Museum records, cited in OZCAM database, 2006; D. Muirhead and K. Smith, unpubl. Data, 2004, 2005; Smith, 2005). *H. cristatus* is a shallow subtidal species that has been recorded from seagrass beds, including sparse seagrasses that border onto open sand and rubble substrates (Kuiter, 2000), and open seagrass with sand and rubble, in estuaries (Browne, 2004). Juveniles have been recorded amongst loose vegetation that accumulates on sand due to current action, providing a form of transport (Kuiter, 2000). Specimens have also been recorded around jetties (e.g. in Tasmania and W.A.) (OZCAM database records, 2006).
Histiogamphelus meraculus Whitley, 1948 = *Mitotichthys meraculus* (Whitley, 1948) Western Crested Pipefish N.B. Originally placed in the genus *Histiogamphelus.* Dawson (1985) changed it provisionally to *Mitotichthys* on the basis of a missing snout ridge. Since this feature develops mainly in males, R. Kuiter (pers. omm.., 1999, cited by Pogonoski et al., 2002) considered that it possibly should revert back to the original genus.	Paxton et al. (1989, cited by Pogonoski et al., 2002) considered the species to be endemic within W.A., from Perth to Augusta. Kuiter (2000) considered that the species may represent a range extension (form) of *H. briggsii* McCulloch, 1914, which is generally distributed from N.S.W. through to south-eastern South Australia. The Western Crested Pipefish is known from few specimens, mainly taken from Flinders Bay and Perth in W.A. (Kuiter, 2003). Western Crested Pipefish inhabits "weedy areas in protected waters" (B. Hutchins, W.A. Museum, pers. omm.., 1999, cited by Pogonoski et al., 2002), and has also been recorded from detached macrophytes in sandy surf zones (Crawley et al., 2006).
Hypselognathus horridus Dawson & Glover, 1982 Shaggy Pipefish / Prickly Pipefish	Currently known only from the eastern part of the GAB (134o37'E to 133o30'E), and appears to be endemic to South Australia. The known distribution is largely based on 8 specimens (taken mainly by trawlers) during 1981 and 1982 (Dawson, 1985, cited by Pogonoski et al., 2002; OZCAM database, 2005). The paratype comes from Anxious Bay, S.A. (Dawson and Glover, 1982). Records range from the Anxious Bay area, westwards to the Ceduna area (e.g. locations south and south-east of Evans Island) (S.A. Museum records, 1981, 1982; Museum of Victoria record, 1973, cited in OZCAM database, 2006). The habitat has not been documented in detail; however, based on collected specimens, the Prickly Pipefish is known to occur in benthic habitat within parts of the GAB, at least at depths of 40m-55m (with possibly a wider depth range).

Latin and Common Names	***Notes on Distribution and Habitat***
Hypselognathus rostratus (Waite and Hale, 1921) Knife-snout Pipefish	Found in Victoria, Bass Strait, northern Tasmania and S.A. (Dawson, in Gomon et al., 1994; Kuiter, 2000; Moran et al., 2003; OZCAM database records, 2006). Spencer Gulf (SG) in S.A. is the type locality (Waite and Hale, 1921). In S.A. the species has been found in various locations with differing oceanographic conditions, ranging from sheltered waters in bays of the eastern GAB, and the mid-north of both gulfs, to more exposed islands offshore from EP. Records range from Encounter Bay through to the eastern GAB, with most reports coming from various locations in GSV and SG (e.g. Glover, 1979; Dawson, 1985; Kuiter, 1996a, 1996b, 2000; P. Jennings, SARDI, unpubl. data, 2003; T. Brindle, unpubl. record, 2004; Australian Museum record, S.A. Museum record, cited in OZCAM database, 2006; K. Smith, unpubl. data, 2003 – 2005, and K. Smith, pers. comm., 2005). During previous decades, the species was known mainly from dredge and trawl samples, at “moderate offshore depths” (Dawson, 1985, cited in Froese and Pauly, 2006). Juveniles (to around 15cm long) are reported to be “not uncommon” in surface water with large jellies, when oceanic waters run into Port Phillip Bay in Victoria (Kuiter, 2000). Surveys and diving records in recent years have recorded sub-adult and adult *H. rostratus* mainly in shallow waters, to about 10m deep. In S.A., Victoria and Tasmania, the species has been recorded in waters as shallow as 1m or less (Museum of Victoria record; CSIRO records; K. Smith, pers. comm., 2005). Adult *H. rostratus* have been recorded as regular visitors to sand flats off the shore at Victor Harbor in S.A. (about 10m deep) (Kuiter, 2000). The species has also been recorded in seagrass beds in shallow water in Port Phillip Bay, Victoria (Moran et al., 2003). In general, adults are rarely seen, but according to R. Brown (2004), the species probably inhabits unsilted seagrass meadows, at “moderate depths”. The Knife-snout Pipefish has been collected from *Posidonia* seagrass beds in Spencer Gulf in S.A. (B. McDonald, pers. comm., cited by Brook, 2002), and very shallow *Zostera* seagrass in GSV (K. Smith, pers. comm., 2005). The species has also been collected from sandy substrate in the shallowest subtidal (e.g. 40cm deep) (K. Smith, pers. comm., 2005).

Latin and Common Names	Notes on Distribution and Habitat
Kaupus costatus (Waite and Hale, 1921) Deep-bodied Pipefish / Deepbody Pipefish	This pipefish is known mainly from S.A., and isolated populations in Victoria and Flinders I. (Bass Strait). *K. costatus* has been recorded from a number of regions in S.A., such as the Ceduna area in eastern GAB; SG (including warmer northern waters, such as the Chinaman Creek area); lower central and lower western SG; and Hardwicke Bay area in south-eastern SG); western GSV (e.g. Port Vincent; Edithburgh / "heel" of YP, and further east into the centre of lower GSV); various parts of eastern GSV (e.g. Outer Harbour, Barker Inlet system; Port Gawler to Middle Beach; and lower Fleurieu locations), and KI (Investigator Strait area; the north-eastern bays, and American River) (Glover, 1979; Jones et al., 1996; Kuiter, 1996b, 2000; Fairhead et al., 2002b; R. Browne and K. Smith, unpubl. data 2003-2004, cited in Browne, 2004; Australian Museum records; S.A. Museum records, Museum of Victoria records, cited in OZCAM database, 2006). A survey of pipefish in far northern GSV showed that the relative abundance of *K. costatus* along the north-eastern coast (from Pt Gawler to Middle Beach, and possibly further north), makes that area the site of the greatest known population of *K. costatus* in Australia (R. Browne, pers. comm., 2003). The species is not common on the other (north-western) side of GSV (R. Browne, pers. comm., 2003). It is usually found in quiet (i.e. low energy), shallow (usually 3m or less, but see below) seagrass beds in silty-bottomed, clear-water environments. It also occurs in very warm, shallow-water habitats with sediment disturbance and periodic inflows of polluted fresh water (R. Browne, pers. comm., 2003). *K. costatus* often occurs in small aggregations, in the intertidal zone (Kuiter, 1996b; Smith et al., in prep.). In S.A., the species has been recorded from *Zostera* seagrass beds on north-eastern KI (Kuiter, 2000), and in parts of north-eastern GSV, such as Barker Inlet estuary (Jackson, 1996; Jones et al., 1996), and at Middle Beach - Port Gawler (R. Browne, pers. comm., 2003; Browne, 2004). In GSV, *K. costatus* has been recorded as abundant in some areas, such as the Middle Beach channel, where 75 specimens were found in inshore *Zostera* habitat, after 2 hours searching (R. Browne, pers. comm., 2003). The species has also been found in beam trawl samples from *Posidonia* and *Amphibolis* seagrass beds in SG (B. McDonald, pers. comm., cited by Brook, 2002).
Leptoichthys fistularius Kaup, 1853 Brush-tail Pipefish	Brush-tail Pipefish has a discontinuous distribution across southern Australia, from Bass Strait and north-east Tasmania, Victoria, S.A., and southern W.A. (Scott, 1971; Dawson, in Gomon et al., 1994; Kuiter, 1996b; Butler et al., 2002a). In S.A., records range from the mid south-east through to EP, with most records from the gulfs region (e.g. Glover, 1979; Savarton et al., 1987; Fairhead et al. 2002b; P. Jennings, SARDI, unpubl. data, 2003; K. Smith, unpubl. data, 2002-2005; D. Muirhead, unpubl. data, 2004; Australian Anglers Association, 2004; S.A. Museum records, cited in OZCAM database, 2006). The species is found in shallow seagrass beds (Dawson, in Gomon et al., 1994), including *Zostera* species, in which it is well camouflaged (Kuiter, 2000). Adults are usually found in seaward estuaries and bays with vast areas of dense seagrass, between 3m – 20m deep (Kuiter, 1996a). Small juveniles are sometimes observed swimming well above the substrate, along reef slopes, sometimes in small aggregations, perhaps seeking suitable habitat for settling (Kuiter, 1996b). In 2001, the species was found in abundance (i.e. 373 specimens) in beam trawl samples from seagrass beds in SG (S.A.), and in that area, the Brush-tail Pipefish was found to prefer deeper coastal water (>5m) seagrass meadows, especially monospecific stands of *Posidonia* (B. McDonald, pers. comm., cited by Brook, 2002).

Latin and Common Names	Notes on Distribution and Habitat
Lissocampus caudalis Waite & Hail, 1921 Smooth Pipefish	Smooth Pipefish is widespread along Australia's south coast (Kuiter, 2000), and considered locally common in some areas (Browne, 2004). Kangaroo Island in S.A. is the type locality (Waite and Hale, 1921). The species is known from Victoria, Bass Strait and northern Tasmania; S.A. (e.g. from Encounter Bay and Kangaroo I. through to the Great Australian Bight) and southern W.A. (Scott, 1971; Glover, 1979; Dawson, in Gomon et al., 1994; Butler et al., 2002a, 2002b; Fairhead et al., 2002a; K. Smith, unpubl. data, 2004; S.A. Museum records, Museum of Victoria records, Australian Museum records, cited in OZCAM database, 2005). Smooth Pipefish has been reported from a variety of habitats, mostly less than 15m deep, including (i) mixed rubble areas and low macroalgae-covered reefs in semi-exposed shallow coastal bays; (ii) rock pools / tide pools; (iii) *Zostera* seagrass beds in shallow inshore waters; (iv) *Amphibolis antarctica* seagrass beds, in shallow water (i.e. 3m – 4m); and (v) amongst floating *Sargassum* plants (Dawson, 1985; Dawson, in Gomon et al., 1994; Kuiter, 2000; Browne, 2004; S.A. Museum record, cited in OZCAM database, 2006).
Lissocampus fatiloquus (Whitley, 1943) Prophet's Pipefish	A temperate, Western Australian endemic pipefish known from continental shelf waters. Specimens range from Shark Bay (25o 55' S) to Fremantle (32o 18' S) (Paxton et al., 1989, cited by Pogonoski et al., 2002), with most records to date from the Shark Bay area. It has also been recorded from offshore islands, such as Rottnest Island and the Houtman Abrolhos. Biogeographically, Prophet's Pipefish is listed as an indicator species for the Central Western Province, an area from approximately Geraldton in the south to Carnarvon at in the north (IMCRA Technical Group, 1996). Most specimens of Prophet's Pipefish are known from seagrass and adjacent sand, but there is a single record of a specimen floating in a *Sargassum* plant offshore (data by B. Hutchins, cited by Kuiter, 2000; B. Hutchins, pers. comm. to J. Baker, 2007). There are also specimens from shallow trawl and dredge (Dawson, 1985; Australian Fish Collection Records). This is a shallow water species, rarely known from deeper than 5m (B. Hutchins, pers. comm. to J. Baker, 2007). Depth range of museum specimens is 0m – 21m (Pogonoski et al., 2002).
Lissocampus runa (Whitley, 1931) Javelin Pipefish	Javelin Pipefish is widespread along Australia's south coast, and known from N.S.W.; northern Tasmania and Flinders Island / Bass Strait region; Victoria; S.A. (South-East through to the Great Australian Bight) and southern W.A. (Glover, 1979; Dawson, in Gomon et al., 1994; Kuiter, 2000, Anonymous, 2001, cited in Froese and Pauly, 2006; Butler et al., 2002a, 2002b; S.A. Museum records, Museum of Victoria records, Australian Museum records, cited in OZCAM database, 2006). There is one unverified record from Queensland (Australian Museum record, 1993, cited in OZCAM database, 2006). Javelin Pipefish is recorded from shallow coastal fringing reefs; rubble habitat with short macroalgae, as well as in *Zostera* seagrass beds, and in tide pools / rock pools (Dawson, in Gomon et al., 1994; Kuiter, 2000). Most records are from less than 5m, however the maximum depth recorded to date is 18m (Kuiter, 2000; Australian Museum records, cited by NSW Department of Primary Industries, 2004).

Latin and Common Names	**Notes on Distribution and Habitat**
Maroubra perserrata Whitley, 1948 Sawtooth Pipefish	Broadly distributed across southern Australia, ranging from the Queensland / N.S.W. border area, through Victoria, Tasmania and S.A., to southern W.A.. Given the known distribution, in addition to anecdotal evidence from divers, and verifying photographs in S.A.,poor representation in museum collection is likely to be due to the cryptic nature of the species in its preferred habitat, and hence lack of recording opportunity. To date, the few records from S.A. have come mostly from GSV (including Fleurieu Peninsula) and Kangaroo I. (e.g. Glover, 1979; K. Smith, unpubl. data, 2001, 2004, 2005; Smith, 2005; D. Muirhead, unpubl. data, 2005; Australian Museum and SA Museum records, cited in OZCAM database, 2006). Sawtooth Pipefish occur in nearshore rocky reef habitat, usually in caves or at the back of crevices. They often shelter in pairs or small groups, behind sea urchins (Kuiter, 2000).
Nannocampus subosseus Günther, 1870 Bony-headed Pipefish	A Western Australian endemic pipefish known from a small number of coastal locations, ranging from the western Great Australian Bight (Point Dempster) through to Shark Bay (Kuiter, 2003), and including islands such as Rottnest and the Houtman Abrolhos (G. Moore, W.A. Museum, pers. comm., 2005). The species is found in rock pools and shallow subtidal reef and mixed reef / seagrass habitats, usually to about 8m (Kuiter, 2003), with a few records to date known from deeper waters (e.g. 14m).
Notiocampus ruber (Ramsay & Ogilby, 1886) Red Pipefish	Red Pipefish is an uncommonly recorded species, known to date from about 9 records, between N.S.W. and southern W.A.. Specimens have come from Port Jackson in N.S.W.; Flinders Island and Bicheno in Tasmania; Cape Jaffa, northern Kangaroo Island and south-eastern GSV in South Australia; and Lucky Bay and Israelite Bay in W.A. (Dawson, 1985; Kuiter, 1996a, 1996b, 2000; R. Charles, unpubl. data, 2004; Froese and Pauly, 2006; S.A. Museum record, Australian Museum records, cited by Baker, in press). Red Pipefish occurs in coastal waters, in association with filamentous and other red macroalgae, in which it is well camouflaged (Kuiter, 2000). The species has been recorded in reef areas (e.g. W.A. – Hutchins, 2005), and on other hard substrates (e.g. a shipwreck in S.A.), and also in intertidal seagrass beds (e.g. in N.S.W. – Kuiter, 2003). Specimens in museum collections were collected in association with rocky ledges, seagrasses, algae and rocks in a depth range of 0-20 m (Australian Fish Collection Records; Dawson, 1985).
Phycodurus eques (Günther, 1865) Leafy Seadragon	Leafy Seadragons are found mainly in S.A. and W.A., where they are commonly recorded, but the distribution extends to Victoria (Edgar, 2000; Kuiter, 2000, 2003) and there are also isolated but probable records from north-western Tasmania, reported to the Dragon Search program (Baker, in prep.). Leafy seadragons occur mainly near the edges of stands of *Ecklonia* macroalgae (Kuiter, 2003), but have also been recorded in the vicinity of other canopy macroalgae, seagrasses, various mixed habitats (e.g. the junction between Cystophora and Sargassum communities with seagrasses such as Amphibolis and/or Posidonia), and artificial structures such as jetties and tyre reefs (e.g. Baker, 2002b, 2005a,b). The recorded depth range for leafy seadragons ranges from as shallow as 1m (Baker, 2005a,b) to about 50m deep (Australian Museum, 2004b).

Latin and Common Names	**Notes on Distribution and Habitat**
Phyllopteryx taeniolatus (Lacépède, 1804) Weedy Seadragon / Common Seadragon	*Phyllopteryx taeniolatus* occurs in N.S.W., Victoria, Tasmania, S.A. and W.A. (Hutchins and Swainston, 1986). In W.A., Weedy Seadragons have been recorded by the Dragon Search program as far north as Geraldton and the Abrolhos Islands (Baker, 2002a). In S.A., the species is found in all coastal waters of the State, from the lower south-east through to the GAB (Baker, 2002b, 2005a, 2005b). In the southern part of its range, Weedy Seadragon is found from shallow estuaries to offshore reefs in depths from about 1m - 50m (Pogonoski et al., 2002). In general, the species is usually found on reefs with macroalgae, and along the edges of sand patches, near vegetation (Kuiter, 1993). More specifically, the Dragon Search community-based monitoring program has shown that in S.A. and W.A., seadragons occur mainly in the vicinity of macroalgal-covered reefs (e.g. *Ecklonia*, *Cystophora*, *Sargassum* and/or various other canopy species), also in seagrass beds (e.g. *Amphibolis*, *Posidonia*, *Heterozostera*) on sand, and at the junction of such reefs and seagrass beds. Many sightings have come from mixed habitats (e.g. patch reefs in or near seagrass beds; patch reefs surrounded by sand; and sandy and rubble bottoms with sparse macroalgal or seagrass cover). The species also occurs in the vicinity of invertebrate-dominated reefs; sponge-dominated habitats; artificial reefs; shipwrecks; and near jetties and other structures (Baker, 2000a,b; 2005a,b).
Pugnaso curtirostris (Castelnau, 1872) Pug-nose Pipefish / Pug-nosed Pipefish	Member of a monotypic genus that occurs along the southern Australian coast, including Victoria, Bass Strait, S.A. (Encounter Bay through to GAB), Tasmania and southern W.A. (Kuiter, 1996b, 2000; Fairhead et al., 2002a, 2002b; Higham et al., 2002; Australian Museum records, S.A. Museum records, Museum of Victoria records, cited in OZCAM database, 2006; Froese and Pauly, 2006; K. Smith, unpubl. data 2003-2005 and pers. comm., 2005). In S.A., there are numerous museum specimens, and the Pug-nose Pipefish is more commonly recorded than many other pipefish species, but usually in low numbers per site (Browne, 2004). The species has been recorded from a variety of habitats, from low tide level to about 11m deep. Examples include mangrove-lined creeks; *Zostera* seagrass; *Posidonia* and *Amphibolis* seagrass (including seagrass patches near reef); macroalgae on low reef patches in sand; "broken areas of seabed along channels"; large rubble on sand; and in shallow, low-energy estuaries and protected bays, where juveniles have been recorded in decaying vegetation (Dawson, 1985, cited in Froese and Pauly, 2006; Kuiter, 1996b, 2000; Browne, 2004; K. Smith, pers. comm., 2005).
Solegnathus lettiensis Bleeker, 1860 (= *S. guentheri* Duncker 1915, according to Kuiter, 2000) Günther's Pipehorse / Indonesian Pipehorse	*Solegnathus lettiensis* is a temperate to tropical western Pacific pipehorse that is known from Western Australia, Northern Territory, Arafura Sea and Indonesia (Dawson, 1985; Paxton et al., 1989, cited by Pogonoski et al., 2002). In Western Australia it is known from off Albany, northwards to North West Cape (Paxton et al., 1989, cited by Pogonoski et al., 2002). Günther's Pipehorse is a benthic inhabitant of mid to outer continental shelf waters, which has been captured to date in depths of 42 to 180m (Paxton et al., 1989).). Most records to date are from waters deeper than 50m (OZCAM, 2006; CSIRO Marine Research records, cited in CSIRO, 2006).

Latin and Common Names	**Notes on Distribution and Habitat**
Solegnathus robustus McCulloch, 1911 Robust Pipehorse	Known to date only from S.A., based on approximately 26 trawled specimens (most collected 1909 – 1982) from Point Weyland to Flinders Island in the eastern GAB, including coastal waters adjacent to Venus Bay and Anxious Bay) (Dawson, 1985; Pogonoski et al., 2002; Froese and Pauly, 2006; and S.A. Museum records 1920, 1981, 1982). The species has also been recorded at Corny Point, at the bottom of SG (S.A. Museum record, 1912). The species is apparently fairly common within its known depth range, at least in S.A. (Dawson, in Gomon et al., 1994, cited by Pogonoski et al., 2002). *Solegnathus robustus* occurs in benthic habitats of the continental shelf, and has been recorded in depths of 42 to 68m (Dawson, 1985; Paxton et al., 1989, cited by Pogonoski et al., 2002). The full depth distribution is not known, because records are principally from trawl bycatch.
Stigmatopora argus (Richardson, 1840) Spotted Pipefish The taxon previously recognised by Dawson (1985) as *Stigmatopora argus* may represent several species over the range, from southern Qld through to W.A. (Browne, 2004).	The species (or species complex) that is commonly referred to as *Stigmatopora argus*, is found across southern Australia, from central N.S.W. through to W.A., and including Tasmania (Kuiter, 1996a, 2003); however, there may be separate populations over that geographic range, some of which may warrant species status (Browne, 2004). According to Browne (2004), the "true" form of Spotted Pipefish *S. argus* is found throughout N.S.W. and Victoria, and in the gulfs region of S.A.. Spotted Pipefish is the most abundant and widely dispersed pipefish in S.A., and lives in high densities in seagrass beds in the shallow subtidal, to about 20m (Browne, 2004). Studies have shown that *S. argus* occurs in higher densities in *Posidonia* seagrass, compared with *Zostera* / *Heterozostera* and *Amphibolis* (B. McDonald, Ph.D. in prep.; Kendrick and Hyndes, 2003).
Stigmatopora sp. nov. (Browne and Smith, in review) Southern Gulf Pipefish Gulf Pipefish / Gulfs Pipefish	Apparently restricted to the S.A. gulfs (GSV and SG), and may be endemic within the central coast of S.A. (Browne, 2004). *Stigmatopora* sp. was previously confused with other species in the *Stigmatopora* complex (Kuiter, 2000, 2003; Browne, 2004; Browne and Smith, in review). Records and possible sightings have come from southern metropolitan area / upper Fleurieu; western GSV; the "foot" of YP; north-eastern KI, and mid-eastern and south-eastern SG (K. Smith, unpubl. data, 2003 – 2004; Browne, 2004; Dragon Search records, cited in Baker 2005a,b; Browne and Smith, in review). In 2005, large numbers of Gulf Pipefish were seen and photographed in eastern SG (data by D. Teubner, cited by Smith, 2005). Despite its restricted distribution, the species may be locally common in some inshore areas, about 1m - 4m deep (Browne, 2004). Recorded habitat includes seagrass beds (Kuiter, 2003) and mixed habitats of brown macroalgae and rubble/rock substrate within seagrass; also small patches of seagrass (*Zostera* and *Posidonia*) with sandy substrate, amongst stands of brown macroalgae (Browne, 2004; Browne and Smith, in review).

Latin and Common Names	***Notes on Distribution and Habitat***
Stigmatopora nigra Kaup, 1856 Wide-Body Pipefish It is possible that more than one species exists over the range, and molecular biological comparison of specimens from New Zealand, South Australia and W.A. has been recommended (Browne, 2004).	An abundant species (or possibly a species complex) across southern Australia, from southern Queensland through to W.A., and also found in New Zealand. South Australian records are from the gulfs region, with examples including Barker Inlet, and the Section Bank / Outer Harbour area in north-eastern GSV; western GSV (e.g. Port Giles); eastern GSV (e.g. Port Willunga); and estuarine creeks off Port Pirie in northern SG, and other parts of SG (Anonymous, 1993; Connolly, 1994; Cheshire et al., 2002; Fairhead et al., 2002a, 2002b; South Australian Museum records, cited in OZCAM database, 2006). According to Browne (2004), the species may not inhabit the west coast of South Australia, based on pipefish surveys in 2003 and 2004 off the lower and upper western EP, in which no Wide-body Pipefish were found. *S. nigra* is often recorded in beds of intertidal *Zostera* (e.g. Browne, 2004) and shallow subtidal *Heterozostera* (e.g. Jenkins et al., 1997; Plummer, 2003), as well as near bare sand, and appears to prefer more silty areas than *S. argus* (but in intermediate habitats the two species are sympatric) (Browne, 2004). *S. nigra* is also found in *Posidonia* seagrass (Kendrick & Hyndes, 2003), and has been reported from mangroves (Smith and Hindell, 2005).
Stipecampus cristatus (McCulloch and Waite, 1918) Ring-back Pipefish / Ring-backed Pipefish	Member of a monospecific genus, known from Victoria, Bass Strait and islands, northern Tasmania, and S.A. (Gomon et al., 1994; Kuiter, 1996b, 2000, 2003). During spring in Victoria, the species enters Port Philip Bay (presumably from Bass Strait) in large numbers, probably for breeding (Kuiter, 1996b). The holotype was collected by dredge in Spencer Gulf in 1919 (South Australian Museum record, cited in OZCAM database, 2004). There are very few museum records from South Australia, and most of these are old (e.g. 1896, 1919, 1920). In S.A., the Ring-Back Pipefish has been recorded in south-central SG (collected by dredge in 1919, in an area that is now part of the trawl grounds), GSV (including the metropolitan area), and lower western EP (S.A. Museum records, cited in OZCAM database, 2004). The species has recently (2004) been recorded during an inshore fish survey at Edithburgh, in south-western GSV (K. Smith, unpublished data, 2004, 2005; Smith, 2005). There is some discrepancy in the published information about habitat. Dawson (1985, cited in Froese and Pauly, 2006) reported that the Ring-back Pipefish is found among brown and red macroalgae in sheltered reef habitats. Similarly, Dawson (in Gomon et al., 1994) reported that the species appears to prefer macroalgal habitats and areas of sand, rather than seagrass beds. However, Kuiter (1996b, 2000, 2003) reported that the Ring-back Pipefish is associated with clean sandy areas containing sparse seagrass, near tidal channels in large estuaries. Similarly, Browne (2004) reported the species to be in “estuaries among open seagrass”, and Smith (2005) recently found a specimen at the edge of a *Posidonia* seagrass bed. The species is usually recorded between 3m and 15m, although it occurs in deeper water in Bass Strait (Kuiter, 1996b).
Syngnathoides biaculeatus (Bloch, 1785) Double-ended Pipehorse or Alligator Pipefish	A tropical Indo-West Pacific species of widespread distribution, including East Africa, Red Sea, Japan, Indonesia, Micronesian islands, PNG and Australia (W.A., N.T., Queensland and N.S.W.) (Randall et al., 1997; Kuiter, 2003; Froese and Pauly, 2005). In W.A., the species has been recorded recently in trawl bycatch, in the Shark Bay area (G. Moore, W.A. Museum, pers. comm., 2005), and there are museum records from the Shark Bay / Kalbarri area, and from Geraldton (Pogonoski et al., 2002; OZCAM database, 2006). Occurs in shallow, sheltered lagoons, amongst seagrasses and macroalgae (e.g. *Sargassum* spp.), including floating rafts of vegetation (Myers, 1991; Kuiter, 2003). Juveniles are occasionally found offshore, in floating debris near the water surface (Dawson, 1985, cited in Froese and Pauly, 2006).

Latin and Common Names	**Notes on Distribution and Habitat**
Trachyrhamphus bicoarctatus (Bleeker, 1857) Bentstick Pipefish / Bendstick Pipefish / Stick Pipefish / Double-ended Pipefish	A tropical Indo-West Pacific species, possibly several closely related species over the widespread distribution (Kuiter, 2003). In Australia, the Stick Pipefish is known from the central coast of W.A. (including shark Bay), around the tropical north, and south to central N.S.W. (Australian Museum, 2004c). The preferred habitat varies with locality, but generally includes seagrasses, rubble, sand and mud bottoms. The species has been recorded in sheltered bays and estuaries, but also in areas prone to currents (Kuiter, 2003). The Bentstick Pipefish is found from the shallows to at least 40m deep (Australian Museum, 2004c), with records in eastern Australia to at least 49m (Graham et al., 1993), and several tropical and sub-tropical records from deeper waters (e.g. 57m, 72m)..
Vanacampus margaritifer (Peters, 1868) Mother-of-Pearl Pipefish	A widely distributed species, recorded in southern Queensland, N.S.W. (from where records are abundant), Victoria, S.A. and southern W.A. (Dawson, 1985; Kuiter, 2003). Records from W.A. include Israelite Bay, Lucky Bay, Jurien Bay, and off Rottnest I. (Dawson, 1985). Records from S.A. range from Encounter Bay through to the eastern Great Australian Bight, with recent reports from the gulfs region (e.g. Fairhead et al., 2002a; South Australian Museum and Museum of Victoria records, cited in OZCAM database, 2006; D. Muirhead, unpublished data, cited by K. Smith, pers. □omm.., 2005). The Mother-of-Pearl Pipefish is found mostly among vegetation over sand and rubble, but also on muddy substrates, in harbours and estuaries. Depth range is from the intertidal to about 10m (Gomon et al., 1994; Kuiter, 2003). Two specimens have been taken from floating *Sargassum* plants (Dawson, 1985).
Vanacampus phillipi (Lucas, 1891) Port Phillip Pipefish (There may be regional forms of *V. phillipi*).	Port Phillip Pipefish is an abundant species across southern Australia, ranging from N.S.W. through to W.A.. It is common in the gulfs and bays of the south coast (Dawson, in Gomon et al., 1994) particularly in Victorian bays such as Western Port Bay and Swan Bay (EPA Victoria, 1996, cited by Plummer et al., 2003). In South Australia, there are regional forms that differ in characteristics such as trunk width, striping, and colour (Browne, 2004, citing data by R. Browne and K. Smith). Port Phillip Pipefish has been regularly recorded in GSV (eastern and western sides); northern, central and southern SG coasts, north-eastern Kangaroo Island, and the bays of the west coast of S.A., in the eastern Great Australian Bight (e.g. B. McDonald, unpublished data, 2001; Fairhead et al., 2002b; P. Jennings, SARDI, unpublished data, 2003; R. Browne and K. Smith, unpublished data, 2004, cited in Browne, 2004; Australian Museum records and S.A. Museum records, cited in OZCAM database, 2006). Port Phillip Pipefish is found in estuaries and seagrass beds in shallow coastal waters. Specific examples of habitat in S.A. in which the species has been recorded, include (i) very shallow sand and mud flats with *Zostera* and *Posidonia* seagrass, in shallow channels edged by mangroves, and (ii) shallow *Zostera* seagrass beds at the edge of mud flats that are exposed at low tide (Browne, 2004).

Latin and Common Names	Notes on Distribution and Habitat
Vanacampus poecilolaemus (Peters, 1868) Long-Snout Pipefish (Populations in W.A. may represent a separate species, according to Kuiter, 2003)	The species (or species group) currently named *V. poecilolaemus* is widespread along the southern coast, as separate populations (Kuiter, 2000, 2003). Long-Snout Pipefish is known mainly from S.A. (particularly GSV and SG, but also from Kangaroo I., and the eastern GAB) (e.g. Glover, 1979; Dawson, 1985; Kuiter, 1996b, 2000; B. McDonald, unpublished data, 2001; Fairhead et al., 2002b; K. Smith, unpubl. data, 2003, 2005; Browne, 2004; West Australian Museum records; South Australian Museum records, Museum of Victoria record, cited in OZCAM database, 2006). The species has also been recorded from Bass Strait (both Victoria and Tasmania) (Glover, 1979; Dawson, 1985; Kuiter, 1996b, 2000, 2003); however it is rarely recorded in Victoria. Populations in W.A. may represent a separate species (Kuiter, 2000, 2003). The Long-snout Pipefish is known from estuaries and shallow bays (Dawson, 1985, cited in Froese and Pauly, 2006), including intertidal / shallow subtidal seagrass beds (Zostera) in quiet, silty-bottomed, clear-water areas (Kuiter, 1996b and 2000), and also in subtidal *Posidonia* seagrass beds (B. McDonald, Ph.D. in prep.; Kendrick and Hyndes, 2003). Recently, Long-snout Pipefish has been recorded in shallow subtidal *Zostera* seagrass adjacent to cliffs at Wool Bay, western GSV in S.A. (K. Smith, pers. comm., 2005). The species has also been recorded on shallow reefs with macroalgae. Long-snout Pipefish has been recorded in waters from as shallow as 1m (K. Smith, pers. comm., 2005), to around 10m deep (Kuiter, 1996b).
Vanacampus vercoi (Waite & Hale, 1921) Verco's Pipefish *V. vercoi* is related to the previously recognised species Flinders Pipefish *V. flindersi* Scott 1957, and revision of this species complex through meristics and molecular analysis is current (R. Browne, pers. comm. 2005).	Currently known only from the central part of the South Australian coast. Verco's Pipefish has been recorded from central and southern SG (including the paratype specimen), south-western GSV / southern YP, and north-eastern Kangaroo Island, where the holotype was collected (Pelican Lagoon) (Waite and Hail, 1921; Glover, 1979; Gomon et al., 1994; Kuiter, 1996a, 2000; Paxton et al., 1989, cited by Pogonoski et al., 2002; B. McDonald, unpublished data, 2001; K. Smith, unpublished data, 2003; Australian Museum record; South Australian Museum records, cited in OZCAM database, 2006). Previously, based on the specimens from Pelican Lagoon on Kangaroo I., *V. vercoi* was reported to occur only amongst shallow macroalgae and seagrass, often in tidal channels, over a narrow depth range (mainly to 3m deep) (Dawson, 1985, and in Gomon et al., 1994; Kuiter, 2000). In southern SG, the species has been found in tide pools (e.g. at Point Turton – South Australian Museum record F 03296), but also *Zostera* seagrass further north into the gulf (B. McDonald, unpublished data, 2001). According to Browne (2004), the habitat at Pelican Lagoon on Kangaroo I. (i.e. warm, shallow, seagrass-lined tidal channels) is not typical, and the species may also exist over "broken bottom" (rubble) habitat adjacent to seagrass beds in cooler, subtidal waters, as occurs in the northern part of the known range. Specimens have been located over a moderate range, and no males with brood pouches have been found. According to R. Browne (pers. comm., 2005), it is possible that these specimens are shallow water vagrants, or that the species is more common, but lives in inaccessible micro-habitats, where collecting opportunities are limited.

Latin and Common Names	Notes on Distribution and Habitat
Urocampus carinirostris Castelnau, 1872 Hairy Pipefish	The species (or species group) currently known as *U. carinirostris*, has an extremely wide distribution, ranging from tropical Australia and Papua New Guinea, to as far south as Tasmania (Kuiter, 1996b; Froese and Pauly, 2006), and it is likely that this comprises more than one *Urocampus* species (Kuiter, 2000). The species is considered to be common and abundant in N.S.W. and parts of Victoria (such as Western Port Bay and Corner Inlet – e.g. see EPA Victoria, 1996; Cappo et al., 1998; Jenkins et al, 1997, cited by Plummer et al., 2003). There are scattered populations across eastern, south-eastern, southern and south-western Australia (Kuiter, 2000; Australian Museum records, CSIRO Marine Research records, Museum Victoria records, South Australian Museum record, West Australian Museum records, cited in OZCAM database, 2006). The species is very uncommonly recorded in South Australia. The first record from S.A. was a specimen collected in 1965, from Davenport Creek, near Ceduna, eastern GAB (S.A. Museum record F 03441). More recently, the species has been recorded at Laura Bay, also near Ceduna (R. Browne and K. Smith, unpubl. data, 2004; Smith, 2005). Hairy Pipefish inhabits the lower reaches of rivers, estuaries (including brackish areas) or other protected inshore habitats, and often occurs in intertidal and shallow subtidal *Zostera* and *Heterozostera* beds (Dawson, 1985; Kuiter, 1996b; EPA Victoria, 1996; Jenkins et al., 1997; West & Jones, 2001). Recently in S.A., Hairy Pipefish was recorded from a shallow, sandy bay and a sandy creek / bay tributary, both lined by *Zostera* seagrass and surrounded by samphire saltmarsh and mangroves (R. Browne and K. Smith, unpubl. data, 2004; Smith, 2005). The species is also reported to be associated with "long stringy macroalgae", occurring on low rocks in sand, to around 5m (e.g. in Sydney) (Kuiter, 1996b), and it has also been recorded in rock pools (e.g. Griffiths et al., 2004).

Significance of the species group in the south-west planning area

Conservation interest

In southern Australia, syngnathids have received much conservation attention from the Australian and state governments and agencies. Despite the fact that some members of the Syngnathidae are very common and widespread, the entire family is protected nationally, and in most southern States. Strong conservation interest in syngnathids in southern Australia has arisen due to factors such as:

- concern about the vulnerability of the group, based on the biology, behaviour, habitat preferences, and population dynamics of syngnathids;
- undue emphasis on the impacts of harvesting in the wild. Harvesting occurs at low levels in southern Australia; however some conservation authorities in southern Australia appear to have been influenced by concern about impacts that relate to Indo-Pacific / South-East Asian syngnathids, many of which are listed on the IUCN Red List of threatened species. It is noted that A. Vincent, of Project Seahorse, reported at an international workshop in 2004 that the organisation intends to "*collaborate with experts on these species to ensure that syngnathids are one of the most represented taxa in the IUCN Red List*" (Vincent, 2005);
- public fascination with the attractive and unusual appearance and behaviour of some syngnathids, resulting in strong lobbying for species protection;
- the endemic status of most species in southern Australia; and
- perceived (and actual, in a few cases) rarity of some species.

Many syngnathids, particularly the seahorses, have (i) relatively low population densities; (ii) low mobility and small home range sizes (hence recolonisation of over-exploited areas would be slow); (iii) possible low rates of natural mortality in adults (hence fishing may place excessive pressures on the population); (iv) dependency of birth and survival of offspring on the survival of the males; (v) monogamous breeding (hence a "widowed partner" may temporarily stop reproducing until another mate is found); (vi) small brood sizes, which limits the potential reproductive rate (although this may be offset by higher juvenile survival); and (vii) strong association with the preferred habitat, which can make populations vulnerable to site-specific impacts (Foster and Vincent, 2004; Foster, in Bruckner et al., 2005). However, many inshore pipefish have very high population densities and live in unstable habitats, subject to stochastic damage from storms or dramatic changes in temperature or salinity, and such species can quickly colonise even small patches of suitable habitat (Smith et al., in prep.).

Most of the syngnathids in the South-west Planning Area are endemic to southern Australia. Due to their limited global distribution and "unique" status within temperate Australian waters, endemic species are of conservation interest at national and State scales. Four species are recorded as being endemic within South Australian waters, these being *Hypselognathus* *horridus*; *Solegnathus robustus*; *Stigmatopora* sp. nov. and *Vanacampus vercoi* (Kuiter, 2000, 2003; Browne, 2004; Browne and Smith, in review). Within the South-West Planning Area, Western Australian endemic species (or forms) include *Hippocampus subelongatus* (= *H. elongatus*), *H. biocellatus*, *H. planifrons*, *H. tuberculatus*, *Choeroichthys latispinosus*, *Histiogamphelus meraculus* (= *Mitotichthys meraculus*), *Festucalex scalaris*, *Lissocampus fatiloquus*, *Nannocampus subosseus* and possibly one or more *Stigmatopora* species (see section on **Current Research**).

Southern Australian species that are widely considered to be peculiar and beautiful, such as the seadragons, have served as popular rallying points for conservation initiatives, despite the relative abundance and wide distribution (e.g. see Baker, 2002a,b; 2005a,b) and apparently secure status of these species. The apparent "rarity" of a number of species, particularly those for which few specimens are known, or for which known distribution is geographically limited, has also helped to bolster the conservation value of syngnathids. An example species is *Vanacampus vercoi*, for which few specimens are recorded.

Eco-tourism and education

The bizarre and charismatic appearance of some syngnathids, particularly seadragons, has endeared them to the public. Both Weedy and Leafy Seadragons are popular, "iconic" species, and are the respective marine emblems of Victoria and South Australia.

Several dive sites, where people can view seadragons with reliable frequency, have become extremely popular during the past decade, for recreational divers and local, national and international tourists. Examples in S.A. include sites on the lower Fleurieu Peninsula and northern Kangaroo Island, which have also been used in various films, documentaries, books and magazine articles on seadragons. In W.A., popular dive spots for viewing seadragons include parts of the Perth metro area (e.g. Cottesloe), North Mole (Fremantle area), Rottnest I., Marmion Marine Park and surrounds (e.g. Hillarys Boat Harbour), Mandurah, and south coast dive spots such as Bremer Bay, and around the Albany and Esperance area. Locations with site-associated seahorses are also popular for diving, and examples in S.A. include some of the jetties in the western Gulf St Vincent / lower Yorke Peninsula area.

Aquaria and breeding facilities also have a significant role in eco-tourism and education about syngnathids. South Australia's only seahorse breeding facility is a popular tourist attraction, and also has educational significance (e.g. see South Australian Seahorse Marine Services, 2004). Some of the seahorse species held at the aquarium facility include the southern Australian species *Hippocampus bleekeri*, *H. breviceps*, *H. tuberculatus*, *H. subelongatus, Stigmatopora argus*, *S. nigra*, *Phyllopteryx taeniolatus* and *Phycodurus eques* (South Australian Seahorse Marine Services, 2004). In W.A., the Aquarium of Western Australia (AQWA, formerly Hillarys Underwater World), is a popular facility in which seahorses, seadragons and pipefish can be viewed.

The strong public interest in seadragons has resulted in a number of community-based projects, including Dragon Search (www.dragonsearch.asn.au), a successful monitoring program in southern Australian States. During the past decade, Dragon Search has encouraged divers, snorkellers, beach walkers and fishers to provide information about seadragon sightings. The program has also served as a means of public awareness and education about seadragons (and syngnathids in general), and Dragon Search has also contributed to the development of a diving code of conduct related to viewing of seadragons. Another community-based project in S.A. is the 'Leafy Seadragon Friendly Catchment Project', part of the 'Our Patch' program supported by Patawalonga and Torrens Catchment Water Management Boards, and Greening Australia. The project aimed to highlight the impact that catchment water has on the nearshore environment, including habitat for species such as the Leafy Seadragon, and to encourage community participation in programs to reduce run-off, and to help restore the habitat quality of catchment areas.

A number of schools have been involved with marine education projects featuring seadragons and other syngnathids. Examples include Hallett Cove School, and the Marine Discovery Centre at Henley Beach Star of the Sea School, both in South Australia.

In W.A., the Cottesloe Marine Protection Group has campaigned to highlight the importance of that area for Weedy and Leafy Seadragons. The local environment group has been working since 1998 to: protect the biodiversity of the reef system at Cottesloe; increase scientific research into human impacts in the area; increase public recognition of the significance of Cottesloe's seagrass beds and limestone reef system for seadragons (including the role of the area as a breeding site for Weedy Seadragons), and campaign for the Weedy Seadragon to be protected under WA legislation (Beros, 2000; McCauley and Macintyre, 2002).

Trade

International trade of Australian seahorses is regulated using a licencing system (CITES II, since May 2004). Also, due to the listing of syngnathids under the *Environment Protection and Biodiversity Conservation Act (EPBC) 1999*, permits are required for exports derived from approved captive breeding programs, or from the wild (under an approved management regime). Various requirements must be met in order for an operation to be approved under the *EPBC Act*, including (i) ensuring that any commercial utilisation of Australian native wildlife for the purposes of export is managed in an "ecologically sustainable" way, and (ii) that Australia's obligations under CITES are complied with. Permits may also be issued for non-commercial purposes, including education and research (Bruckner et al., 2005).

The trade in dried syngnathids (for traditional medicine) mainly utilises tropical and sub-tropical species of *Hippocampus* seahorses, and *Solegnathus* pipehorses. In Australia, major sources include bycatch from Queensland and South East trawl fisheries (Martin-Smith et al., 2003). It is noted that the tropical *Syngnathoides biaculeatus* (Double-ended Pipehorse or Alligator Pipefish) is also used in traditional medicine (Martin-Smith et al., 2003), however, there appears to be no evidence of *S. biaculeatus* being captured in Australia to supply Asian markets (Pogonoski et al., 2002).

Seahorses are currently exported for the aquarium trade, from Victoria, Queensland, South Australia, Western Australia, and Northern Territory. Several of the species (*H. abdominalis* / *H. bleekeri*, *H. breviceps / H. tuberculatus*, *H. angustus* and *H. subelongatus*) that are exported from Australia (Vincent and Perry, 2002, cited in CITES, 2002; Bruckner et al., 2005), occur in the South-west Planning Area.

In Western Australia, there are 13 licences in the commercial fishery, permitting the take of syngnathids by hand or hand-held net (Bruckner et al., 2005). There is an annual quota of 750 syngnathids, but has been slightly exceeded in recent years (e.g. 833 in 2002, according to Department of Fisheries W.A., 2004a). For some species, the actual catch may be higher than the reported catch (G. Moore, W.A. Museum, pers. comm., November, 2005). Seven species of syngnathids have been retained by the fishery, although only four are generally targeted: *Hippocampus angustus / H. subelongatus*, *Phyllopteryx taeniolatus*, *Hippocampus breviceps* (= *H. tuberculatus*) and *Stigmatopora argus* (Table 4.22.2).

The majority of seahorses destined for the aquarium trade are collected from the south-western part of the State, thus most listed as the more northerly species *H. angustus* are likely to be *H. subelongatus* (Commonwealth of Australia 2005). However, these specimens are still referred to as *H. angustus* by commercial collectors (Payne, in Bull and Shedd, 2001; Lourie et al., 2004; Bruckner et al., 2005). According to catch return data from these commercial collectors, annual catches of “*H. angustus*” (most likely *H. subelongatus*) is usually around 200 – 300 individuals. Most of these are sold as aquarium fish, either locally or to overseas markets such as Asia (Payne, in Bull and Shedd, 2001).

In Western Australia, license holders in the Marine Aquarium Fish Managed Fishery are required to submit monthly catch and effort returns, detailing the species and number of syngnathids taken, and the locations of take. The returns are recorded in the W.A. Fisheries Catch and Effort Statistical System. In accordance with the provisions outlined in the Marine Fish Aquarium Management Plan, yearly reports must be provided by Fisheries WA to the Commonwealth, including information about total catch and catch per unit effort on a monthly basis by species and location; quantities, size, reproductive state and sex of individuals; total mortalities by species; and results and analysis of resource assessment forms (Australian Government Department for Environment and Heritage, 2003).

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Weedy seadragon *Phyllopteryx taeniolatus*	50	24	22	99	123	136	223	325	332	215
WA spiny seahorse *Hippocampus angustus*	290	364	192	378	358	178	329	330	456	110
Short-snout seahorse *Hippocampus breviceps*		2		21	39	64	62	56	18	
Spiny seahorse *"Hippocampus histrix"* (probable misidentification)				1						
Spotted seahorse "*Hippocampus kuda"* (possible misidentification)				1						
Tiger pipefish *Filicampus tigris*						3				
Ribboned pipefish / pipehorse *Haliichthys taeniophorus*						1				
Spotted pipefish *Stigmatopora argus*						78	24	1	21	50
Other								29	6	
Total	340	390	226	513	552	460	638	741	833	383

Table 4.22.2 Reported catches of syngnathids by licensees in W.A., 1994 to 2002
(Department of Fisheries, W.A., 2004a, 2005a)

In South Australia, a permit system is in place for the annual take of a small number of *Hippocampus abdominalis* (= *H. bleekeri*) and *H. breviceps.* Collection from the wild for commercial purposes requires an exemption under section 34(1) of the *Fisheries Act 1982*. Current policy is to only issue exemption for the collection of brood stock for recognised and competent breeders for the aquarium trade. Since 1st January 2000, 4 and 3 permits have been issued for collection of *H. abdominalis* and *H. breviceps* respectively, approximately on an annual basis, for a single known breeder. Reported landings data since that time are: 23, 20, 20, and 10 for *H. abdominalis*, and 10, 6, 10 for *H. breviceps* (Bruckner et al., 2005). In South Australia, current policy limits the number of individuals taken from the same locality within a specified time period (particularly where there is the intent to collect male and female specimens), to avoid the removal of entire populations or breeding potential from one area (Bruckner et al., 2005). No more than 5 of each species of seahorse or pipefish can be collected within 5 kilometres of any one collection site. Local species are taken from waters within a 20km radius of Port Lincoln, and harvest sites are not returned to for a period of at least 5 years in line with current permit stipulations (South Australian Seahorse Marine Services, 2004). Species from interstate/overseas are purchased from licensed collectors/importers. In the captive breeding operation, a small number of specimens are taken from the wild, and those specimens are bred in an aquaculture facility, and the progeny are exported to overseas buyers. None of the wild-caught brood stock is sold (South Australian Seahorse Marine Services, 2004). During 2004, the facility made application to harvest from the wild *H. abdominalis*, *H. breviceps*, *H. elongatus*, *H. tuberculatus* and *H. whitei*, *Stigmatopora argus*, *S. nigra*, *Phyllopteryx taeniolatus* and *Phycodurus eques*, for brood stock enhancement, in order to culture the species (to 4th generation only) and export the progeny (South Australian Seahorse Marine Services, 2004; Australian Government Department of DEH, 2005).

Impacts/ threats

Many of the life history characteristics of syngnathids make them susceptible to impacts, and vulnerable to population decline. Such characteristics include low population densities in many species; strong habitat association (mainly in nearshore areas); small home range sizes and low mobility; possible low rates of natural adult mortality (due to low levels of predation, hence human-induced mortality may disrupt population dynamics); monogamy and localised reproduction; aggregation (in some species) for feeding and/or breeding; small brood sizes, and strong association between adults (particularly males) and young.
Natural vulnerability, as outlined above, is exacerbated by a number of human-induced threats.

Nearshore habitat damage

Many of the syngnathids in southern Australia, including the South-west Marine Region, occur in nearshore habitats, such as shallow subtidal seagrass beds and macroalgal- dominated reefs. Even without the compounding effect of habitat damage, populations of some syngnathids may exhibit a high degree of fragmentation due to the patchy nature of suitable habitat, and the limited ability of syngnathids to disperse away from habitat “patches”. Additionally, it has been shown that seahorses, for example, have specific microhabitat preferences, occupying only the edges of particular habitat types (e.g. seagrass / sand or reef / sand interfaces); thus, large areas of seemingly suitable habitat are unoccupied (Vincent, 1996, cited in CITES, 2002).

Habitat decline is considered to be one of the main threats to nearshore populations of syngnathids (e.g. Vincent 1996, cited in CITES, 2002; Kuiter, 2000, 2003; Department of Fisheries W.A., 2004b). Degradation of nearshore habitats is especially prevalent in highly urbanised areas such the metropolitan coast of Gulf St Vincent (GSV) in South Australia, and off Perth and Fremantle (e.g. Cockburn Sound) in Western Australia. In GSV, habitat degradation has resulted from a combination of nutrients (principally from sewage effluent discharge), multiple contaminants from stormwater and other run-off, and sedimentation effects (from sand dredging; sewage and stormwater run-off; land reclamation and coastal erosion, and other sources). The impacts of land-based pollutants on seagrasses are well documented (e.g. Shepherd, 1970; Shepherd et al., 1989; EPA S.A., 1998), and such impacts have caused a loss of several thousand hectares of seagrass in GSV (Hart, 1996 and 1997; EPA S.A.1998 and 2003). Furthermore, studies undertaken on metropolitan and southern GSV reefs since the mid-1990s (see Cheshire et al., 1998; Cheshire and Westphalen, 2000; Turner and Cheshire, 2002) have shown that decline in cover of large macroalgae at some reefs is, like seagrass decline, an indicator of pollution. The authors of these reef studies consider that in some areas, the presence of large, brown, canopy-forming macroalgae may be an indicator of reef health, and the studies have shown that, in the northern metropolitan area (e.g. Glenelg), reefs are generally in poor condition, with little cover of large brown macroalgae, and a dominance of turfing brown and red algal species. On central reefs such as Noarlunga, increased coverage of mussels in sites that were previously dominated by macroalgae is also considered to indicate a decline in reef health (Smith, 2000, cited by EPA S.A., 2003). Declines in seagrass and macroalgal reef cover, may have a negative impact upon populations of syngnathids, by reducing available habitat in which life processes can be carried out.

A number of syngnathids rely upon specific nearshore habitats, and degradation of such environments is a threatening process. For example, recent studies by R. Browne (pers. comm., 2003) indicate that although the Deep-bodied Pipefish *Kaupus costatus* can survive in harsh, physically disturbed environments, its abundance depends on the presence of fine, shallow-water *Zostera* seagrass, in which it is normally found. Such seagrass provides critically important habitat for this pipefish species (Browne, 2004). In areas where *K. costatus* is present, any processes that destroy shallow subtidal seagrass beds, may adversely affect the populations in those areas. The habitat of the Southern Gulfs Pipefish (*Stigmatopora* sp. nov.) also appears to be particularly susceptible to inshore disturbance. This species appears restricted to moderately sheltered, shallow open water habitats between 2-5m deep, over a mosaic of patches of brown algae and *Posidonia* species (R. Browne, pers. comm., 2005). This habitat is restricted, and only occurs along limited sections of the Southern Gulf Pipefish's known range of Spencer Gulf and Gulf St Vincent (Browne and Smith, in review).

Endemic species of limited geographic range may be particularly susceptible to the impacts of habitat degradation, particularly those species which occur in the vicinity of urbanised and industrial areas, or in rural areas where nearshore waters are subject to fertiliser run-off and other pollutants. For example, Browne (2004) considered that the endemic Gulf Pipefish and Verco's Pipefish are conservation dependent in South Australia, due to their inshore habitat (largely in developed areas, in the case of the Gulf Pipefish), and very limited spatial scale of occurrence.

Poaching

The poaching (illegal collecting) of syngnathids in southern Australia is poorly documented; however some conservation authorities and government agencies are concerned about the potential impact of this activity on populations. According to the Department of Fisheries Western Australia (2004b), the declaration in 1991 of Leafy Seadragon as a Totally Protected Species in W.A., was prompted by concern about "rapidly decreasing numbers" of this species due to poaching.

Inshore syngnathids such as seadragons and seahorses, which are of interest to collectors, are strongly site-associated; easily captured by hand nets (and in some cases by hand); relatively slow moving, and are poorly equipped to escape capture, because the solid outer "armour" of seadragons (and seahorses) limits their mobility, and the only way such animals can propel themselves along is through rapidly oscillating their small fins (Department of Fisheries Western Australia, 2004b).

It is noted that during the past 10 years of the Dragon Search community-based program, only one record in the S.A. database has provided details of likely poaching activity of seadragons in this State, from southern Yorke Peninsula, in 1995. Possible poaching (from northern Kangaroo Island) was also reported to the S.A. government in 1997. However, in locations where seadragons and seahorses have become increasingly popular with recreational divers and tourists, informal community monitoring of activities can help to limit poaching, and provide protection for syngnathids in those areas. Examples in S.A. include popular dive spots such as Rapid Bay and Second Valley on the Fleurieu Peninsula, and northern Kangaroo Island. Strong community interest in seadragon habitat can result in protected area status, as occurred in W.A. with the designation of the Cottesloe Reef Fish Habitat Protection Area, near Perth.

Collecting

Regarding legal collecting of syngnathids under permit, the trade from southern Australia appears to be well regulated, with limitations to the number permitted to be taken per annum, size limits, some area restrictions, and monitoring of trade routes, amongst other requirements (see section above, on **Trade**). South Australia's trade in seahorses comprises farmed specimens, however in W.A., approximately 750-800 animals per annum are permitted to be taken from the wild. Approximately 3272 specimens of Western Australian Seahorse *H. subelongatus* and 1427 specimens of Weedy Seadragon *Phyllopteryx taeniolatus* are reported to have been taken in W.A. since 1976 (Department of Fisheries WA, 2005). Lourie et al. (1999 and 2004, citing G. Moore, pers. comm.) mentioned localised over-collecting of *H. subelongatus* during the late 1990s, in the Swan River area near Perth. This species is known to have been targetted by collectors in that area (G. Moore, pers. comm., 2005). According to Newman and Brand-Gardner (2005), the syngnathid species taken in the W.A. fishery are widely distributed; an estimated 80% of populations occur in areas that "receive little to no impact from fishing"; and "there is no evidence of decline for any syngnathid species retained in the W.A. fishery". The need for monitoring in this fishery is discussed below, in the section on **Information Gaps.**

Bycatch

In parts of the South-west Marine Region, scientific observer programs in trawl, gillnet and longline fisheries indicate that syngnathids are not a significant component of the bycatch (e.g. Brown and Knuckey, 2002, for the GAB Trawl Fishery; McAuley and Simpfendorfer, 2003, for the Western Australian Temperate Demersal Gillnet and Demersal Longline Fisheries). In the South Coast Trawl fishery in W.A., syngnathids are reported to be "occasionally incidentally caught", and are "generally discarded, presumed to be dead" (Department of Fisheries Western Australia, 2005). Catch rates of all small fish such as syngnathids are reported to be low due to the 100mm mesh size used in the fishery. Similarly in the South Coast Scallop fishery in W.A., results from an observer program further north in the Shark Bay Scallop Fishery suggested that low numbers of syngnathids are caught (Department of Fisheries Western Australia, 2005). According to that Department, the number caught by the South Coast Scallop fleet is likely to be even lower, given the larger mesh sizes, slower speeds used by the fleet, smaller fleet size, short fishing season, and avoidance by fishers of habitats favoured by many syngnathid species (e.g. seagrass and macroalgal communities) (Department of Fisheries Western Australia, 2005). However, results from a comprehensive study of the bycatch of prawn trawl and scallop fisheries of Shark Bay, have indicated that the following species have been captured, and at least some of these in moderate numbers (Department of Fisheries W.A., 2004a, Appendix 7; G. Moore, W.A. Museum , pers. comm., 2005): *Filicampus tigris, Haliichthys taeniophorus, Hippocampus angustus, Hippocampus biocellatus, Hippocampus planifrons, Stigmatopora argus, Syngnathoides biaculeatus, Trachyrhamphus bicoarctatus*.

In the recent environmental risk assessment for the Commonwealth-managed Gillnet, Hook and Trap Fishery (Webb et al., 2004), based on the methods of Hobday et al. (2004), a quantitative assessment of factors (including "productivity" and "susceptibility" scores) resulted in a number of syngnathid species listed as being at "Medium Risk" or "Low Risk" to impact by the various sectors of this fishery. Purported "Medium Risk" species are shown in the table below. It is noted that, despite these riok assessment rankings, very few (if any) of these mostly shallow water species would be expected to occur in the bycatch of these Commonwealth-managed fisheries. To date, there is no available evidence to suggest any interaction with almost all of these syngnathid species:

Fishery Sector	***"Medium Risk"***
Southern Shark Gillnet	Southern Little Pipehorse; Mother-of-Pearl Pipefish; Port Phillip Pipefish; Long-snout Pipefish; Verco's Pipefish Gale's Pipefish; Shaggy Pipefish; Brushtail Pipefish; Smooth Pipefish; Javelin Pipefish; Sawtooth Pipefish
Southern Shark Demersal Longline	Shaggy Pipefish; Knife-snouted Pipefish; Hairy Pipefish; Mother-of-Pearl Pipefish; Port Phillip Pipefish; Long-snouted Pipefish; Verco's Pipefish; Gale's Pipefish; Brushtail Pipefish; Smooth Pipefish; Javelin Pipefish; Sawtooth Pipefish; Robust Pipehorse
Scalefish Automatic Longline	Mother-of-Pearl Pipefish; Trawl Pipefish; Sawtooth Pipefish; Port Phillip Pipefish; Long-snouted Pipefish; Verco's Pipefish; Gale's Pipefish; Upside-down Pipefish; Smooth Pipefish; Javelin Pipefish; Tiger Pipefish; Short-headed Seahorse; Shaggy Pipefish; Knife-snouted Pipefish; Brushtail Pipefish; Half-banded Pipefish; Red Pipefish; Robust Pipehorse; Ring-backed Pipefish
Scalefish Demersal Longline	Trawl Pipefish; Sawtooth Pipefish; Mother-of-Pearl Pipefish; Long-snouted Pipefish; Verco's Pipefish; Port Phillip Pipefish; Gale's Pipefish; Tiger Pipefish; Upside-down Pipefish; Shaggy Pipefish; Knife-snouted Pipefish; Brushtail Pipefish; Smooth Pipefish; Javelin Pipefish; Red Pipefish; Robust Pipehorse; Ring-backed Pipefish; Short-headed Seahorse; Southern Pygmy Pipehorse; Rhino Pipefish; Deep-bodied Pipefish; Wide-bodied Pipefish; Hairy Pipefish; Potbelly Seahorse
Scalefish Dropline	Trawl Pipefish; Sawtooth Pipefish; Red Pipefish; Mother-of-pearl Pipefish; Long-snouted Pipefish; Verco's Pipefish; Port Phillip Pipefish; Gale's Pipefish; Tiger Pipefish; Upside-down Pipefish; Short-headed Seahorse; Shaggy Pipefish; Knife-snouted Pipefish; Brushtail Pipefish; Smooth Pipefish;Javelin Pipefish; Leafy Seadragon; Robust Pipehorse; Ring-backed Pipefish; Southern Little Pipehorse; Potbelly Seahorse; Rhino Pipefish; Deep-bodied Pipefish; Wide-bodied Pipefish; Hairy Pipefish
Great Australian Bight Trawl	West Australian Seahorse

Table 4.22.3 Syngnathids listed as being at Medium Risk or Low Risk to impact from fishing in GHAT sectors (from Webb et al., 2004)), and Great Australian Bight Trawl Fishery (Daley et al., 2006). It is also noted that the solenostomid Blue-finned Ghostpipefish / Robust Ghostpipefish *Solenostomus cyanopterus* is recorded as being at "medium risk" of impacts from operation of the GHAT fishery (Webb et al., 2004), despite almost all of the geographic range of that species not overlapping with the distribution of the GHAT fishery.

Syngnathids taken by shallow water trawling or dredging activities may survive if returned to the water, especially if the trawl duration is relatively short (A. Mednis, pers. comm., cited by Pogonoski et al., 2002). However, syngnathids taken in deeper water trawling operations (e.g. the *Solegnathus* spp. pipehorses) may suffer prolapse, and are unlikely to survive (K. Graham, pers. comm., cited by Pogonoski et al., 2002). Notably, Kuiter (2003a) reported most *Solegnathus* species prefer reef areas, and trawlers do not generally operate in such habitats. Furthermore, the majority of Australia's pipehorse catch comes from northern, eastern and south-eastern Australia (Dunning et al., 2001; AFMA, 1999, 2003) and involves species such as *Solegnathus dunckeri*, *S. hardwickii*, and *S. spinosissimus*, which do not occur in the South-west Marine Region.

A number of syngnathid species are known or suspected to be caught in trawling bycatch in the South-west Marine Region. Some examples include:

- The seahorses *Hippocampus angustus*, *Hippocampus biocellatus*, and *Hippocampus planifrons:* Recorded in trawl bycatch in Shark Bay (G. Moore, W.A. Museum, pers. comm., November, 2005);
- Robust Pipehorse *Solegnathus robustus,* known principally from a small number of prawn trawling records over a narrow depth range in the eastern Great Australian Bight (GAB). Given that trawled pipehorses may not survive when hauled to the surface, commercial trawl fishing in the GAB is considered to be a potential threat this species (Pogonoski et al., 2002). Despite the likely occasional presence of this species in prawn trawl bycatch on the west coast of S.A., there are no published investigations of bycatch or discards in the West Coast Prawn fishery in S.A. (Ward et al., 2003).
- Günthers Pipehorse *Solegnathus lettiensis*: Gloerfelt-Tarp and Kailola (1984, cited by Pogonoski et al., 2002) listed this species as being trawled in north-western Australia and southern Indonesia, however there is reported to be limited commercial trawl fishing undertaken within the range of this species in Western Australian waters (B. Hutchins, pers. comm., cited by Pogonoski et al., 2002).
- Shaggy Pipefish / Prickly Pipefish *Hypselognathus horridus* is currently known only from the eastern part of the Great Australian Bight (134o37'E to 133o30'E), and appears to be endemic within the region. The species is known from very few specimens, over a very limited depth range (40m-55m), where it was recorded in trawl bycatch during the early 1980s. The species may have specific habitat requirements over a small spatial scale, and Pogonoski et al. (2002) considered that benthic habitats within parts of the GAB might be important to the survival of this species. It is possible that this species is present in the Great Australian Bight Marine Park (Pogonoski et al., 2002). Outside of that protected area, any commercial fishing methods (e.g. trawling) that catch this species are considered potentially threatening to the survival of Shaggy Pipefish populations, within the limited documented distribution (Pogonoski et al., 2002). As is the case with Robust Pipehorse, likely occasional presence of this species in prawn trawl bycatch on the west coast of S.A. is not formally recorded, because there are no published investigations of bycatch and discards in the West Coast Prawn fishery in South Australia (Ward et al., 2003).
- Potbelly Seahorse *Hippocampus bleekeri* (*H. abdominalis*): During a fishery independent monitoring program in Spencer Gulf in S.A. (see PIRSA 2003, for overview) few syngnathids have been recorded, however the most commonly occurring syngnathid in the bycatch is *H. bleekeri* (= *H. abdominalis*). In some sites up to 3 per tow were captured, and all were alive on capture. According to PIRSA (2003), it is expected that "the spatial closures implemented, and the adaptation of hoppers, will minimise the risk of trawling" on syngnathids such as seahorses.
- Prophet's Pipefish *Lissocampus fatiloquus*: Known from a limited area between the Shark Bay and Fremantle in W.A., and according to Dawson (1985, cited by Pogonoski et al., 2002), this species has been taken from

trawl and dredge samples. The species might occur in a number of protected areas in W.A., such as Shark Bay Marine Park, Hamelin Pool Marine Nature Reserve, and the Abrolhos Islands Fish Habitat Protection Area (Pogonoski et al., 2002) According to Pogonoski et al. (2002), the small size of this species may "protect it somewhat from trawling operations within its range, as it may be able to escape through the mesh".

- The pipefish *Filicampus tigris, Stigmatopora argus, Syngnathoides biaculeatus, and Trachyrhamphus bicoarctatus*: Caught in trawl bycatch in Shark Bay (G. Moore, W.A. Museum, pers. comm., November, 2005).
- Pipefish (unspecified): Pipefish are recorded in the prawn trawl fisheries in South Australia (PIRSA, 2003). One example location in which pipefish bycatch has been recorded is the Corny Point / Hardwicke Bay area, on the eastern side of Spencer Gulf (fishing report, cited in Baker, 2005a). A fishery independent monitoring program (see PIRSA, 2003) is currently being undertaken, in order to document the species composition and abundance of pipefish caught in the Spencer Gulf Prawn Trawl fishery.
- Seadragons: Leafy Seadragon *Phycodurus eques* is occasionally recorded in the prawn trawl fishery in South Australia. Although Leafy Seadragon did not appear in previous bycatch statistics (e.g. Carrick, 1997) or more recent fisheries assessment reports (e.g. Carrick and Williams, 2001; Carrick, 2003), it has been reported by fishers, and also observed during a recent monitoring program. For example, during 1985 – 87, *Phycodurus eques* specimens were observed in the bycatch of trawlers operating in seagrass adjacent to reef ledge habitat with sponges, off the Cowell area, on the mid western side of Spencer Gulf. Leafy Seadragons have also been reported in the prawn trawl bycatch off Corny Point (Hardwicke Bay), on the eastern side of Spencer Gulf (Baker, 2005a). The extent to which this species, and also the Weedy Seadragon *Phyllopteryx taeniolatus*, are captured in the Spencer Gulf Prawn trawl fishery is now being investigated, through a fishery independent monitoring program to document bycatch, based on research trawl surveys (PIRSA, 2003).
- Ribboned Seadragon *Haliichthys taeniophorus*: Recorded in trawl fishery bycatch in Shark Bay (G. Moore, W.A. Museum, pers. comm., November, 2005).

Current research

Seahorses

Given the peculiarity of syngnathid reproduction, considerable research effort has focussed on this topic, and various recent studies have included southern and western Australian species (e.g. Jones et al., 1998, 2003; Kvarnemo, et al., 2000; Wilson *et al*., 2003; Kvarnemo and Simmons, 2004; Sanchez-Camara *et al*., 2005). Developing methods for growing and reproducing syngnathids in captivity is also a growing area of research (e.g. Lawrence, 1998, and Payne and Rippingale, 2000, for *Hippocampus angustus* / *H. subelongatus*; Wilson and Vincent, 2000, for several tropical species). In W.A., seahorses have been successfully reared since 1989 (Lawrence, 1998).

Staff and affiliates of the University of British Columbia, where the international program Project Seahorse is based, have undertaken a number of studies on southern Australian seahorses. Examples include a recent study of social structure and space use in the short-headed seahorse *Hippocampus breviceps* in Port Phillip Bay in Victoria (Moreau and Vincent, 2004). That study showed that populations in the area's macroalgal reef habitat generally remained within a 12m home range, and opposite-sex partners engaged in frequent displays and social interactions. The site fidelity of *H. breviceps* contrasts with previous work by A. Vincent (1990) on the home range of *H. abdominalis*, which often ranged over an area of several hundred meters.

Other Australian research projects associated with the University of British Columbia include (i) mark-recapture studies of the potbelly seahorse (*Hippocampus abdominalis*) and White's seahorse (*H. whitei*) to determine population sizes, age, growth and movement; (ii) the role of artificial structures in the population dynamics of seahorses, including evaluation of attraction versus production hypotheses; (iii) analysis of syngnathid bycatch in major Australian fisheries - catch composition, abundance, habitat associations and trade; and (iv) genetic identification of individuals and breeding patterns of *H. abdominalis* (University of British Columbia, Project Seahorse web site, October, 2005).

Recent development in tagging methods, using visible implant fluorescent elastomer (e.g. Woods and Martin-Smith, 2004), have assisted various syngnathid studies in which the animals are tracked over space and/or time.

Seadragons

Recent research on seadragons has included (i) a study of the abundance and movement of Leafy Seadragon *Phycodurus eques* at West I. in South Australia (Connolly et al., 2002); and (ii) a study on the movement, home range / site fidelity, reproductive cycle and growth of the weedy Seadragon *Phyllopteryx taeniolatus* (Sanchez-Camara, 2002; Sanchez-Camara and Booth, 2004; Sanchez-Camara et al., 2005).

During the past decade, the Dragon Search program has contributed to a more detailed and accurate understanding of the geographical distribution (including northern, southern, eastern and western limits) and relative abundance of Leafy and Weedy Seadragons in each of the southern States. The program has also collated information on the variety of habitats in which these species reside, as well data on breeding periods, breeding aggregations, individual and group behaviour, "mass death" events, and other relevant topics (e.g. see Baker, 2002a,b, and 2005a,b).

Staff from the South Australian Museum are currently collecting samples of *Phycodurus eques* and *Phyllopteryx taeniolatus* across the geographic ranges, as part of a molecular study to determine whether there are more than two species of seadragon across southern Australia (G. Rouse, pers. comm. to Australian Marine Science Association S.A. branch meeting, October, 2005).

Pipefishes

Since 2002, the voluntary work of Kevin Smith (ex-Reef Watch, South Australia) and Robert Browne (Seadragon Foundation Inc.) has helped to fill significant gaps in the knowledge of the taxonomy, distribution, relative abundance, reproduction, and other aspects of several southern Australian pipefishes, particularly one of the endemic species found in South Australia. Meristics and DNA studies are currently being undertaken to elucidate the relationships in the *Stigmatopora* complex (R. Browne, pers. comm., 2005). In South Australia the work of Browne and Smith (in review) has resulted in the description of a new *Stigmatopora* species, the Southern Gulf Pipefish, and an extensive study has also been undertaken on the reproductive seasonality, population dynamics, and reproductive investment of the Deep-bodied Pipefish (*Kaupus costatus*) (Smith et al., in prep.).

Other recent pipefish projects in southern Australia include (i) the feeding ecology of the spotted pipefish *Stigmatopora argus* in seagrass meadows (University of British Columbia Project Seahorse web site, October, 2005); and (ii) a study of the abundance, size-distribution and feeding habits of *S. argus*, *S. nigra*, *Vanacampus poecilolaemus* and other pipefishes among various seagrass-dominated habitats in W.A. (Kendrick and Hyndes, 2003, 2005).

All syngnathid groups

In South Australia, fishery independent research surveys have recently been undertaken in the Spencer Gulf Prawn Trawl Fishery, to document the number and species composition of syngnathids captured in areas closed and open to fishing (PIRSA, 2003). Part of the trawl sampling is designed to assess (if possible) spatial and temporal changes in the numbers of seahorses, seadragons, pipefish and pipehorses; and also to clarify the taxonomic status (PIRSA, 2003). A field manual for identification has been developed, and digital images of specimens collected from field studies have been taken. Independent trawl surveys to map syngnathid species distribution patterns have been initiated in Spencer Gulf, and it is reported that fishers will be engaged in voluntary monitoring of specified syngnathid bycatch using logbooks. PIRSA (2003) reported that, because syngnathid species populations are small on the trawl grounds, fecundity is low, and population dispersal is restricted, they are a suitable indicator for fishery risk assessment. Further work is being undertaken on syngnathid distribution, in order to evaluate the risk that trawling poses to the population viability of the various species. It is noted however, that bycatch counts to date are reported to be very low, hence it may not be possible to detect significant inter-annual differences, unless a substantial decline in numbers is recorded (PIRSA, 2003).

In W.A., there has been a recent, multi-species study of the diets and foraging ability of various seahorses, pipefishes and the Weedy Seadragon, from a seagrass-dominated habitat (Kendrick and Hyndes, 2005). Another recently completed project has documented the species composition and relative abundance of seahorse and pipefish species in the bycatch of trawl fisheries in Shark Bay (G. Moore, pers. comm., November, 2005).

Information gaps

Seahorses

More work is required on the taxonomy, systematics, distribution and range limits of seahorse species that occur in Australia, particularly those used in trade. There is currently little agreement between authorities (such as A. Vincent and R. Kuiter) as to the taxonomic identity and distribution limits of several species, particularly those with strong morphological similarity. Further genetic and morphometric work is needed to ascertain the true number of species (Bruckner et al., 2005). Lack of agreement leads to difficulties in conservation and management decision-making, and consequently, little consensus between national and international bodies in these matters. For example, CITES (2002) and Lourie et al. (2004) considered the W.A. species *Hippocampus biocellatus* Kuiter, 2001 (False-eyed Seahorse) to be a form of *H. trimaculatus* Leach 1814 (Low-crowned Seahorse), a tropical species used for traditional medicine and curios. *H. trimaculatus* is listed as Vulnerable (A4cd) by IUCN, and also in Vietnam, and is formally protected in India. However, *H. biocellatus* is recognised as a distinct species in Australian marine fish conservation listings (e.g. ASFB, 2001; Pogonoski et al., 2002). Furthermore, CITES (2002) and Lourie et al. (2004) also grouped together *H. dahli* (Low-crown Seahorse) and *H. planifrons* (Flat-faced seahorse) as synonyms of *H. trimaculatus,* yet the former two were recognised by Kuiter (2000, 2001, 2003) as separate species, and are treated as such in conservation listings in Australia (e.g. ASFB recommended a classification of LR–NT for *H. dahli*, and DD for *H. planifrons*). Another example is *H. tuberculatus* (Knobby Seahorse) considered by Kuiter (2000, 2003) to be an endemic species in Western Australia. Lourie et al. (2004) did not recognise *H. tuberculatus* as a valid species, but rather a synonym for the more widely distributed species *H. breviceps*.

According to Foster and Vincent (2004), considerable research is needed to advance seahorse conservation and management, including data on (a) fisheries dependent and fisheries independent abundance estimates; (b) age- or stage-based natural and fishing mortality estimates; (c) growth rates and age at first maturity, and (d) intrinsic rates of increase and age or size-specific reproductive output.

There is also a dearth of objective and accurate information on species specific trade statistics (for traditional medicine, aquaria, and curios), fisheries bycatch, poaching, and other impacts and threats. Collection of accurate trade data is further hindered by taxonomic problems, and there are issues with accurate identification of seahorses in trade. For example the sub-tropical W.A. species *Hippocampus angustus* (Western Spiny Seahorse) is used live for aquarium or hobbyist use; however the specimens of *H. angustus* in trade are most likely mis-identified *H. subelongatus*, which occurs further south (Lourie et al., 2004). It is noted that CITES (2002) did not recognise *H.*

subelongatus (*H. elongatus*) as a separate species, and considered it to be a synonym for the tropical species *H. angustus*.

Seahorses (and seadragons) may be vulnerable to over-fishing because they are patchily distributed, highly habitat-dependent; reproduce relatively slowly, have a small number of young, and have low rates of dispersal. Therefore, for syngnathids of commercial interest in the aquarium trade, it is important that monitoring and reporting programs be undertaken at an appropriate spatial scale, in wild-harvest fisheries (such as the Western Australian fishery). In W.A., information on size, sex and reproductive status has been collected sporadically by some operators, using Resource Assessment Forms. However, according to the Department of Fisheries WA, (2005, citing a departmental report from October 2002), these data have very limited value without a specific project, and support funding to co-ordinate data collection and analysis. The Department intends to negotiate an "industry-contribution-to-research" fee to accommodate such data collection and analysis. There is reported to be "a severe lack of consolidated funds" within the Department to undertake research on this small fishery, and recommendations have been made for funding / resources to be secured for universities to undertake further research into the species collected in the Marine Aquarium Fish Managed Fishery (Department of Fisheries WA, 2005).

Pipehorses

Pipehorses in southern Australia are poorly studied, with one species, Robust Pipehorse (*Solegnathus robustus*) known principally from a small number of prawn trawling records over a narrow depth range in the eastern Great Australian Bight. Similarly, *Acentronura australe* Southern Little Pipehorse is known from very few records, some of which are old (mid last century) and were taken by dredge, and others recorded opportunistically during seagrass and reef studies. In W.A., Günther's Pipehorse *Solegnathus lettiensis* Bleeker, 1860 (= *Solegnathus guentheri* Duncker 1915, according to Kuiter, 2003) from W.A., N.T. and Indonesia, is known mainly from museum specimens, and data from trawl catches are not formally or regularly collated.

As with the seahorses, there is little agreement about the taxonomy of pipehorses. For example, Kuiter (2000, 2003) regarded the Indonesian and Western Australian forms of *Solegnathus lettiensis* to be separate species, purportedly due to colour pattern (Pogonoski et al., 2002). Kuiter reported the W.A. form to be *Solegnathus guentheri* Duncker, 1915; however that name is not recognised in conservation assessments of the species (e.g. Pogonoski et al., 2002; IUCN, 2004).

Virtually nothing is known about the biology, ecology, behaviour, population dynamics, critical habitats, full distribution (geographically, and the depth range), and relative abundance of southern Australian pipehorses (see Pogonoski et al., 2002; Kuiter, 2003). This distinct lack of information makes it difficult for the conservation status of pipehorses in southern Australia to be assessed (Pogonoski et al., 2002). Despite the protected status of pipehorses under Commonwealth legislation, there is also surprisingly little data on retained and discarded bycatch in southern Australia, and quantities in trade.

Monitoring of bycatch of pipehorses taken in trawl fisheries (both State- and Commonwealth-managed) in the South-west Marine Region is required, to obtain baseline data on species' distribution and abundance. Also, some of the specimens which die in trawling operations should be made available for taxonomic / systematics study, so that the number of species and regional forms can be more accurately determined. In particular, given that one of the most uncommonly recorded syngnathids known in southern Australia (Robust Pipehorse), has been reported in the West Coast Prawn fishery in South Australia (as shown by museum specimens), provision should be made for spatially-explicit bycatch data to be collected, collated and made publicly available.

Further research is necessary to accumulate information on the basic biological and population dynamics characteristics of pipehorses, and accurate distributional and depth data are required to identify key habitats (Pogonoski et al., 2002). To date, there has been no research undertake on the critical habitats of pipehorses in southern and south-western Australia. It is likely that such species have specific habitat preferences that determine their abundance within their geographic ranges (Pogonoski et al., 2002).

Protected (non-trawled) areas have been advocated as a primary means of protecting pipehorse populations in southern Australia from decline (Pogonoski et al., 2002). Research could be undertaken to determine the appropriate size and placement of such protected zones, and monitoring programs would be required to determine their effectiveness.

Pipefishes

Other than the recent work of Browne and colleagues (see above), for southern Australian syngnathids, very little research effort has been undertaken on taxonomy / systematics to determine species richness and distribution, nor work on relative abundance over space and time, habitat requirements, biology and population dynamics (e.g. see Pogonoski et al., 2002; Browne, 2004). There is a paucity of funding for such research, and currently, information gaps in pipefish research are being filled mainly by the dedicated efforts of unfunded individuals (e.g. Browne, 2004). A small number of community divers (in the S.A. Reef Watch program www.reefwatch.asn.au) have provided valuable assistance to syngnathid research, by recording information about pipefish sightings, including the date, location, specimen details (size, reproductive status etc), and verifying the sightings with a photograph or preserved specimen.

A number of pipefish in southern Australia are known from very few specimens, in most cases likely to be due to sampling deficiencies rather than true rarity. Specific sampling methods in each habitat type are required to determine the presence of some of the smaller and more cryptic syngnathids, particularly the pipefishes, and for many southern Australian species, this is only now starting to occur (e.g. see Browne, 2004). Examples of species in S.A. for which very few records exist include the rubble-bottom species Verco's Pipefish *Vanacampus vercoi* and Gales Pipefish *Campichthys galei*, and also the Red Pipefish *Notiocampus ruber*, the latter of which is small and cryptic in red macroalgae, and unlikely to be seen unless targetted searches are made. In W.A., Prophet's Pipefish *Lissocampus fatiloquus* is an endemic species of apparent limited distribution, and virtually nothing is known of the relative abundance, biology, population dynamics or habitat requirements of this species.

In addition to targetted surveys in nearshore areas (see Browne, 2004) further work is required to determine the presence of uncommon pipefish species in fisheries bycatch, particularly in some of the trawl fisheries. As shown by museum data, one of the most uncommonly recorded syngnathids known in southern Australia (Shaggy or Prickly Pipefish), has been reported in the West Coast Prawn fishery in South Australia. Provision should be made for bycatch data on pipefish (and other syngnathids) to be collected, collated and made publicly available in this west coast sector of the fishery, as is currently occurring for the Spencer Gulf Prawn Trawl Fishery (e.g. PIRSA, 2003).

For nearshore pipefish species in areas that are threatened by ongoing habitat degradation, monitoring of some core populations has been suggested, to determine future changes in abundance (Browne, 2004).

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Lesser Noddies *Anous tenuirostris* are the only EPBC Threatened species breeding in the SW marine region. They have a very limited geographic range and specific nesting habitat. They are listed as vulnerable. (C.Surman).

4.23 Seabirds

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Species group name and description

Seabirds may be defined as those species of birds whose normal habitat and food source is derived from the sea, whether that be coastal, offshore or pelagic (Harrison 1983). For consistency with other publications in this series (Chatto *et al*. 2004), we will consider as seabirds the following families that occur throughout the region covered by this book; Penguins (Spheniscidae), Albatrosses (Diomedeidae), Petrels and Shearwaters (Procellariidae), Storm-petrels (Hydrobatidae) Diving Petrels (Pelecanoididae), Pelicans (Pelecanidae) Gannets (Sulidae), Cormorants and Shags (Phalacrocoracidae), Tropicbirds (Phaethontidae) Skuas, Noddies, Terns and Gulls (Laridae), as well as the marine raptors the Osprey and White-bellied Sea Eagle (Accipitridae). Not included in this section are waterbirds (i.e. ducks) or shorebirds (i.e. migratory waders).

Significant numbers of seabirds not only feed across waters in the south-western region, but the area also contains the most significant and arguably diverse seabird breeding islands within Australia's territorial waters. Of the 110 species of seabirds that comprise the Australian seabird fauna 81 (72%) are found in this region. Twenty two (22) species of seabirds as well as the two marine raptors breed regularly on islands throughout the area, half of the total number of breeding seabird species found in Australia.

Several species have been included as they feed in coastal regions but breed predominately adjacent to fresh or estuarine waters, these are the Great Cormorant (*Phalacrocorax carbo*), and the Little Black Cormorant (*P. sulcirostris*)(Serventy *et al*. 1971).

Nomenclature throughout this chapter follows that of Christidis and Boles (1994), although for albatrosses the more recent Croxall and Gales (1998) is used.

Crested Terns feed on medium-sized schooling fish such as Australian Anchovy throughout the SWMR (C.Surman).

Status

All seabird species and their eggs are protected under State and Federal Government legislation to the 200 nm EEZ. Each species reported from the South West marine Region (SWMR) and their conservation status under various listings are presented in Table 4.23.1.

Several species are listed under the Bonn Convention and migratory bird agreements between Australia and Japan (JAMBA) and China (CAMBA). Several migratory species are also listed as Vulnerable or Endangered under the EPBC Act, or W.A. and S.A. state legislation. The Lesser Noddy is the only nesting species listed as Vulnerable under the EPBC Act 1999.

Garnett and Crowley (2000) list two penguins, the King (near threatened) and Rockhopper (Vulnerable), nine petrels, two prions, nine albatrosses, two storm-petrels, the Red-tailed tropicbird, Antarctic Tern and Lesser Noddy under the Action Plan for Australian Birds.

Species groups: Seabirds

Table 4.23.1: Seabird species visiting or nesting within the South West marine region and their conservation status.

Species	Common Name	JAMBA	CAMBA	Bonn	CITES	SA	WA	EPBC
King Penguin	*Aptenodytes patagonicus*	-	-	-	-	-	-	-
Rockhopper Penguin	*Eudyptes chrysocome*	-	-	-	-	-	-	-
Fiordland Penguin	*Eudyptes pachyrhynchus*	-	-	-	-	-	-	-
Little Penguin	*Eudyptula minor*	-	-	-	-	-	-	-
Erect-crested Penguin	*Eudyptes sclateri*	-	-	-	-	-	-	-
Southern Giant Petrel	*Macronectes giganteus*	-	-	II	-	-	-	End.
Northern Giant Petrel	*Macronectes halli*	-	-	II	-	-	-	Vul.
Cape Petrel	*Daption capense*	-	-	-	-	-	-	-
Southern Fulmar	*Fulmarus glacialoides*	-	-	-	-	-	-	-
Great-winged Petrel	*Pterodroma macroptera*	-	-	-	-	-	-	-
Kerguelen Petrel	*Lugensa brevirostris*	-	-	-	-	-	-	-
White-headed Petrel	*Pterodroma lessonii*	-	-	-	-	-	-	-
Soft-plumaged Petrel	*Pterodroma mollis*	-	-	-	-	Vul.	-	Vul.
Gould's Petrel	*Pterodroma leucoptera*	-	-	-	-	-	-	End.
Blue Petrel	*Halobaena caerulea*	-	-	-	-	Vul.	-	Vul.
Antarctic Prion	*Pachyptila desolata*	-	-	-	-	-	-	-
Salvin's Prion	*Pachyptila salvini*	-	-	-	-	-	-	-
Slender-billed Prion	*Pachyptila belcheri*	-	-	-	-	-	-	-
Broad-billed Prion	*Pachyptila vittata*	-	-	-	-	-	-	-
Fairy Prion	*Pachyptila turtur*	-	-	-	-	-	-	-
White-chinned Petrel	*Procellaria aequinoctialis*	-	-	II	-	-	-	-
Grey Petrel	*Procellaria cinerea*	-	-	II	-	-	-	-
Sooty Shearwater	*Puffinus griseus*	-	-	-	-	-	-	-
Hutton's Shearwater	*Puffinus huttoni*	-	-	-	-	-	-	-
Fluttering Shearwater	*Puffinus gavia*	-	-	-	-	-	-	-
Streaked Shearwater	*Calonectris leucomelas*	+	+	-	-	-	-	-
Little Shearwater	*Puffinus assimilis*	-	-	-	-	-	-	-
Wedge-tailed Shearwater	*Puffinus pacificus*	+	-	-	-	-	-	-
Flesh-footed Shearwater	*Puffinus carneipes*	+	-	-	-	Rare	-	-
Short-tailed Shearwater	*Puffinus tenuirostris*	+	-	-	-	-	-	-
Common Diving-petrel	*Pelecanoides urinatrix*	-	-	-	-	-	-	-
Wandering Albatross	*Diomedea exulans*	-	-	II	-	Vul.	Vul.	Vul.
Royal Albatross	*Diomedea epomophora*	-	-	II	-	End.	Vul.	Vul.
Black-browed Albatross	*Thalassarche melanophris*	-	-	II	-	Vul.	Vul.	Vul.
Atlantic Yellow-nosed Albatross	*Thalassarche chlororhynchos*	-	-	II	-	-	Vul.	Vul.
Indian Yellow-nosed Albatross	*Thalassarche carteri*							
Grey-headed Albatross	*Thalassarche chrysostoma*	-	-	II	-	Vul.	Vul.	Vul.
Sooty Albatross	*Phoebetria fusca*	-	-	II	-	Vul.	Vul.	Vul.
Shy Albatross	*Thalassarche cauta*	-	-	II	-	Vul.	Vul.	Vul.
Salvin's Albatross	*Thalassarche salvani*	-	-	II	-	Vul.	Vul.	Vul.
Leach's Storm-petrel	*Oceanodroma leucorhoa*	-	-	-	-	-	-	-
Wilson's Storm Petrel	*Oceanites oceanicus*	+	-	-	-	-	-	-
White-faced Storm Petrel	*Pelagodroma marina*	-	-	-	-	-	-	-
Grey-backed Storm-petrel	*Garrodia nereis*	-	-	-	-	-	-	-
Black-bellied Storm-petrel	*Fregetta tropica*	-	-	-	-	-	-	-
Cape Gannet	*Morus capensis*	-	-	-	-	-	-	-
Australasian Gannet	*Morus serrator*	-	-	-	-	-	-	-
Red-tailed Tropicbird	*Phaethon rubricauda*	-	-	-	-	-	-	-
Lesser Frigatebird	*Fregeta ariel*	+	+	-	-	-	-	-
Pied Cormorant	*Phalacrocorax varius*	-	-	-	-	-	-	-
Little Pied Cormorant	*Phalacrocorax melanoleucos*	-	-	-	-	-	-	-
Black-faced Cormorant	*Phalacrocorax fuscescens*	-	-	-	-	-	-	-
Great Cormorant	*Phalacrocorax carbo*	-	-	-	-	-	-	-
Little Black Cormorant	*Phalacrocorax sulcirostris*	-	-	-	-	-	-	-
Darter	*Anhinga melanogaster*	-	-	-	-	-	-	-
Pelican	*Pelecanus conspicillatus*	-	-	-	-	-	-	-
Great Skua	*Catharacta skua*	-	-	-	-	-	-	-

Species	Common Name	JAMBA	CAMBA	Bonn	CITES	SA	WA	EPBC
South Polar Skua	*Catharacta maccormicki*	-	-	-	-	-	-	-
Arctic Jaeger	*Stercocarius parasiticus*	+	+	-	-	-	-	-
Pacific Gull	*Larus pacificus*	-	-	-	-	-	-	-
Kelp Gull	*Larus dominicanus*	-	-	-	-	-	-	-
Silver Gull	*Larus novaehollandiae*	-	-		-	-	-	-
White-winged Black Tern	*Chlidonias leucoptera*	+	+	-	-	-	-	-
Gull-billed Tern	*Sterna nilotica*	-	-	-	-	-	-	-
Caspian Tern	*Sterna caspia*	-	+	-	-	-	-	-
Crested Tern	*Sterna bergii*	+	-	-	-	-	-	-
Lesser Crested Tern	*Sterna bengalensis*							
Roseate Tern	*Sterna dougalli*	-	-	-	-	-	-	-
Bridled Tern	*Sterna anaethetus*	+	+	-	-	-	-	-
Sooty Tern	*Sterna fuscata*	-	-	-	-	-	-	-
Fairy Tern	*Sterna nereis*	-	-	-	-	Vul.	-	-
Little Tern	*Sterna albifrons*	+	+	-	-	Vul.	-	-
Antarctic Tern	*Sterna vittata*	-	-	-	-	End.	-	Vul.
Arctic Tern	*Sterna paradisea*	-	-	-	-	-	-	-
Whiskered Tern	*Chlidonias hybrida*	-	-	-	-	-	-	-
Common Tern	*Sterna hirundo*	-	-	-	-	-	-	-
White Tern	*Gygis alba*	-	-	-	-	-	-	-
Lesser Noddy	*Anous tenuirostris*	-	-	-	-	-	Vul.	Vul.
Common Noddy	*Anous stolidus*	+	+	-	-	-	-	-
Osprey	*Pandion halietus*	-	-	II	II	Rare	-	-
White-breasted Sea Eagle	*Haliaeetus leucogaster*	-	+	II	II	Vul.	-	-

JAMBA= Listed under the agreement between the Government of Australia and the Government of Japan for the protection of migratory birds in danger of extinction and their environment.

CAMBA= Listed under the agreement between the Government of Australia and the Government of China for the protection of migratory birds in danger of extinction and their environment.

Bonn = Listed under Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals.

SA = Listed under the South Australia Threatened Species List. (Rare, Vul. = Vulnerable, End. = Endangered).

WA = Ranking of Western Australian threatened fauna and flora taxa into IUCN Threat Categories. (Rare, Vul. = Vulnerable, End. = Endangered).

EPBC = Listed under the Environmental Protection and Biodiversity Conservation Act 1999.

Species names follow Christidis and Boles (1994), except for Albatrosses which follow Croxall and Gales (1998).

Habitat and distribution

The marine habitat between Kangaroo Island, South Australia, and Steep Point, Western Australia, covers a wide range of water bodies and coastal islands used by seabirds to forage and breed. It is dominated along the west coast by the poleward moving tropical Leeuwin Current, which flows most strongly during the winter months and extends eastwards into the Great Australian Bight (Pearce 1991). In addition to the Leeuwin Current another seasonal current, the northward flowing Capes Current, is driven by northward wind stresses over the austral summer (Pearce and Pattiaratchi 1999). Cooler Southern Ocean waters predominate between Cape Leeuwin and Kangaroo Island, and offshore, occasional intrusions of nutrient-rich sub-antarctic water masses extend to within the 200nm territorial waters (see Surman and Wooller 2000). Off the gulfs in South Australia, positvitve wind stress drives the westward Flinders Current, resulting in areas of upwelling in this region (Middleton and Platov 2005). Different suites of seabirds are associated with each water type (Surman and Wooller 2000). The different water types likely account for the unusual range of breeding seasons found in Western Australia. Most species breed during the spring/summer, however there are also several winter-breeding species, as well as three species (Roseate Terns, Crested Terns and Silver Gulls) that may breed during spring/summer or autumn (Dunlop and Wooller 1990).

The diversity of water types provides a wide range of foraging opportunities for the diverse seabird fauna. Typically, this fauna is composed of three main groups of seabirds, characterized on the basis of their breeding and migratory behaviour.

These are

- Breeding seabirds,
- Visiting non-breeding seabirds, and
- Vagrant seabirds.

The area bounded by the South West marine region (SWMR) includes hundreds of continental islands that provide important nesting habitat for the regions breeding population of seabirds. Of these, several archipelagos are considered significant in terms of their seabird communities. These are;

- the Houtman Abrolhos (28^{o} 30'S, 114 ^{o}E), 146 islands extending 80 km,
- Inshore islands between Dongara and Mandurah, W.A. including the Shoalwater Bay Islands (32^{o} S, 115^{o} 41'E), 50 islands over 400km.
- Recherche Archipelago (34^{o} S, 122^{o} E),105 islands over 200 km,
- Nuyts Archipelago (33^{o} S, 135^{o} E), 20 islands,
- Flinders Island and the Investigator Group (32^{o} S, 135^{o} E**),** seven islands,
- and the Sir Joseph Banks Group (34^{o} 30', 136^{o} 17'E), 20 islands.

Photo: Part of the massive breeding colony of Sooty Terns on Pelsaert Island, Houtman Abrolhos (C.Surman)

Continental islands covered by the region are of two main types; Aeolianite limestone islands and granite-gneiss islands (Seddon 1972). Aeolianite-based islands are limestone covered with dunes of varying size and represent remnant former Holocene dune systems. They are typically low-lying, rarely exceeding 20m in height and found between Cape Leeuwin and Dongara. Granitic islands are typically higher (to 108m) and domed, composed chiefly of a granite base with occasional dunes and aeolianite limestone capping. They are principally found in southern regions extending across from the east coast of South Australia to Cape Leeuwin. A third island type predominates at the Houtman Abrolhos, where islands here have formed on Pleistocene coral reef bases and are covered with beach cast coral rubble and low dune systems. They rarely exceed 3m in height.

During winter months, offshore areas near the continental shelf break (200m) are visited by sub-antarctic albatrosses and petrels. Sub-antarctic species such as the Cape Petrel and Soft-plumage Petrel have been recorded regularly as far north as the Montebello Islands, W.A. (Surman *pers. obs.*) and albatrosses are common in pelagic waters. Similarly, some summer-breeding species migrate to or through this area as part of a regular migratory pattern and forage as they do so. Notably, Hutton's Shearwater, which breeds in the Kaikpura Mountains on New Zealand's South Island, undergo an annual migration that was once thought to be circum-Australia, but may now prove to terminate in the NW Shelf area (Surman *pers. obs*.). Presumably, this species transits through coastal waters from Bass Straight to Cape Leeuwin, west of Rottnest Island and through the Houtman Abrolhos before forming large feeding aggregations north of North West Cape (Surman *pers.obs*, Harrison 1983). Interestingly Serventy *et al*. (1971) suggest that this migration may involve a pre-breeding component of the population.

Occassionally large cold fronts drive ashore large numbers of seabirds not often associated with these waters, and may include species from sub-antarctic areas, such as prions, or more tropical species usually only found in northern regions of the SWMR, such as the Lesser Noddy or Brown Noddy.

Of the 24 breeding seabirds found in the South West marine region, 14 (58%) are residential, remaining in local waters during the non-breeding period, whilst 10 (42%) are migratory, spending the inter-breeding period elsewhere. Of these, the dominant migratory seabird species is the Wedge-tailed Shearwater. Over one million pairs return from northern waters to nest on islands in the SWMR, most at the Houtman Abrolhos.

Below are comments on the major groups of seabirds covered by the South West marine region.

Penguins

Five species of penguin have been recorded from the SWMR, however only the Little Penguin *Eudyptula minor* breeds. Little Penguins nest on numerous islands extending from Kangaroo Island in the east to Carnac Island in the west. They nest in burrows dug in sand, usually under vegetation but also amongst rocky outcrops and limestone tombolo. Approximately 3 500 pairs nest in the SWMR, representing 5 % of the total Australian breeding population (Ross *et al.* 1995). Of the four remaining species of penguins two are vagrants (King and Erect-crested Penguins) and two are regular, albeit uncommon, winter visitors to the southern coastal regions of Australia (Rockhopper and Fiordland Penguins).

Albatrosses

Nine species of albatross regularly visit waters bounded by the SWMR, however the single breeding species found in Australia (Shy Albatross) nests on islands in Tasmania (Serventy *et al*. 1971). Albatrosses typically forage in the SWMR during the winter months, and are most often observed along the edge of the continental shelf (200m) and in oceanic waters. Their migratory habit and long-range dispersal from natal colonies exposes them to encounters with fishing vessels. Large numbers are observed in association with Australian tuna long-line fishing vessels, where they take advantage of discarded baits (eg. in Western Australia off the Naturalist Plateau, Surman *pers.obs*.).

Shearwaters and petrels

This is the largest group of seabirds utilizing the SWMR . Twenty six species including 12 petrels, 8 shearwaters, 5 prions and a diving petrel regularly visit or breed in the SWMR (Ross *et al*. 1995, Serventy *et al.* 1971, Harrison 1983). However, only five species (Wedge-tailed Shearwater, Little Shearwater, Flesh-footed Shearwater, Short-tailed Shearwater and the Great-winged Petrel) nest on coastal islands, all constructing long burrows in sand or more rarely on the surface amongst bushes or between rocks. More of the widely distributed Wedge-tailed Shearwaters breed here than anywhere else in Australia, representing approximately 82% of the total breeding population. Most of these inhabit West Wallabi Island, Houtman Abrolhos, where an estimated 1 million pairs nest (Fuller *et al*. 1994). Other significant breeding areas include Pelsaert Island (75 000 pairs) and Rottnest Island (5 800 pairs). The SWMR also encompasses the only breeding area for the Flesh-footed Shearwater, where the entire population of 104 000 pairs nests on continental islands between the SA border and Cape Leeuwin (Ross *et al.* 1995). Similarly, the Little Shearwater (27 000 pairs) and the Great Winged Petrel (33 000 pairs) breed only here within Australia, although they do breed outside Australia. It also is an important transition zone between the three dominant Australian conspecific shearwater species (Surman and Wooller 2000). The distribution of the Short-tailed Shearwater overlaps that of the Flesh-footed Shearwater at the Recherche Archipelago which is in turn itself replaced by the Wedge-tailed Shearwater north of Cape Leeuwin (furthest south at Carnac Island).

Hutton’s Shearwaters breed above 1300m on mountains in the South Island of New Zealand (Serventy *et al.* 1971). They regularly pass through continental shelf waters during their post-breeding migration. Aggregations have been observed at the Houtman Abrolhos, and large numbers foraging west of Thevenard Island and the Montebello Islands on the NW Shelf during May, June and July (Surman pers*. obs*.). Streaked Shearwaters are another unusual regular migrant, which breed on coastal islands in Japan during the boreal summer. However, some individuals over-summer in Australian waters as far south as the Houtman Abrolhos with larger numbers off the Montebello Islands during May, at a time when breeding would be in full swing (Storr *et al*. 1986, Surman *pers. obs*.). This species is protected by both JAMBA and CAMBA, and the west coast may provide important pre-breeding and inter-breeding foraging areas.

The greater majority of other petrel species observed throughout the SWMR are winter migrants that breed on sub-antarctic islands.

Storm petrels

Five species of Storm-petrels occur in the region, although Leach's, Grey-backed and Black-bellied Storm-petrels are recorded as vagrants (Pizzey and Knight 1997). The only regular breeder is the White-faced Storm-petrel, and the only regular visitor is the Wilson's Storm-petrel. White-faced Storm-petrels breed in sandy areas throughout the SWMR , extending as far north as Beacon Island, Houtman Abrolhos (Surman 1994). At least 160 000 pairs breed in the SWMR, representing 65 % of the Australian total (Ross *et al*. 1995). Significant breeding islands are Lancelin Island, Blyth Island S.A., Lorraine Island (2000 pairs), Frederick Island (5000 pairs), and Canning Island (2000 pairs).

Tropicbirds and frigatebirds

The Red-tailed Tropicbird is found breeding in very small numbers on two islands in the SWMR, Sugarloaf Rock (34 pairs in 1969 declining to around 15 at present) and intermittently on Pelsaert Island (2 pairs, Surman *pers. obs*.). Previously it had bred on Rat Island and Pelsaert Island regularly (Serventy *et al.* 1971), however Rat Island populations were likely displaced by the presence of guano diggers at the turn of the 20th century, and the Pelsaert Island colony was abandoned in the 1950's until the return in the 1990's. Eruptive breeding attempts occurred on Rottnest Island (1957-1959) until a colony established on Sugarloaf Rock in 1963 (Serventy *et al*. 1971, Storr *et al*. 1984). The range extension of this tropical species is linked to the long-term fluctuations in the influence of the Leeuwin Current (Dunlop and Wooller 1990). Occasional cyclone-cast Lesser Frigatebirds have also been observed as far south as Geraldton, W.A. (Surman *pers. obs*.).

Cormorants and Australian pelican

The Australian Pelican and five species of cormorant breed and forage in the SWMR. Approximately 4 500 pairs of Black-faced Cormorants nest in the SWMR representing 69 % of the Australian total (Ross *et al*. 1995) all off the south coast. The SWMR is also an important breeding area for the Pied Cormorant, where an estimated 4 800 pairs nest (or 38% of the Austalian total; Ross *et al*. 1995). The distribution of each species is determined largely by water types, with the Black-faced Cormorant dominant in areas east of the Recherche Archipelago, and the Pied Cormorant north of Cape Leeuwin, although the latter is found breeding on many islands in the eastern portion of the SWMR . Two species, the Great Cormorant and the Little Black Cormorant are not known to breed on coastal islands, but rather in freshwater lakes or estuaries (Serventy *et al*. 1971). However, both species are known to forage in coastal regions of the SWMR. Little Pied Cormorants nest in small numbers on the limestone islands off the west cost including Lancelin and Penguin Island.

Marine raptors

The two species of marine raptors included here are the Osprey and the White-bellied Sea Eagle. Both inhabit coastal areas and breed predominately on coastal islands throughout the SWMR. Osprey feed almost exclusively on fish prey, whereas White-bellied Sea Eagles are known to feed on fish, seabirds, and at West Wallabi, Houtman Abrolhos, on Tammar Wallabies (Storr *et al*. 1986). Apart from humans, White-bellied Sea Eagles represent one of the few native predators of breeding seabirds on islands except Pacific Gulls and Land-rails (eggs). There is a significant and unusually large breeding population on West Wallabi Island where approximately 10 pairs nest (Johnstone and Storr 1994). The Houtman Abrolhos is also a stronghold for Osprey, where Fuller *et al*. (1994) report 47 pairs breeding on 41 islands. Osprey also nest occasionally along the mainland coast on isolated rocky stacks or man-made structures. This species is absent from much of the south-eastern parts of Australia, although in the SWMR it breeds in all areas from Kangaroo Island eastwards, including Yorke Peninsula and Eyre Peninsula (Pizzey and Knight 1997).

Skuas and gulls

Three species of skuas visit the SWMR, and three species of gulls breed in the area (Pizzey and Knight 1997). The skuas are typically winter visitors from Antarctic or sub-antarctic breeding areas, whereas the Arctic Jaeger is a summer migrant from Arctic regions. Silver Gulls breed on many islands throughout the SWMR, however larger colonies nest adjacent to urban areas, where numbers have increased dramatically. A recent example of this has been the doubling of Silver Gull numbers to 20 000 at Port Lincoln over five years in association with caged tuna culture (The Advertiser 2004). The increased numbers of Silver Gulls are expected to impact upon vulnerable seabird species at the Sir Joseph Banks Group. Kelp Gulls breed in the eastern regions of the SWMR, but are rare west of Port Phillip Bay. In Tasmania this species maybe displacing the Pacific Gull (Coulson and Coulson 1996). Pacific Gulls remain the dominant large gull throughout the SWMR. They breed in small numbers (usually 1-2 pairs/island) across the SWMR, with strongholds at the Recherche Archipelago (at least 21 pairs) and the Houtman Abrolhos (51 pairs on 39 islands – Fuller *et al*. 1994) and The Brothers Islands, Coffin Bay, S.A. (10 pairs – Gill 1985). The population is likely larger than that listed here due to the lack of recent surveys in some regions (i.e. Recherche Archipelago).

Terns and noddies.

Fifteen species of terns and two species of noddies have been recorded in the area (Table 4.23.1). Of theses the Arctic and Antarctic Terns are irregular visitors to the southern coast of Australia, while the White Tern and Common Tern are vagrants and the Gull-billed Tern, Whiskered Tern and White-winged Black Terns are associated with inland water bodies, although they may frequent the coast. The most significant breeding and foraging area for terns and noddies in terms of biomass and diversity are the Houtman Abrolhos, where all six species of terns and two species of noddies that breed in the SWMR do so in significant numbers. The Houtman Abrolhos are also the only breeding area for the Lesser Noddy in Australia, and the major nesting areas for Brown Noddies and Sooty Terns in the SWMR. A small population (~1000 pairs) of Brown Noddies breed on Lancelin Island alongside a very small population (~10 pairs) of Sooty Terns.

The populations of tropical terns at the Houtman Abrolhos account for a significant proportion of the total breeding population in Australia (see below). Several species have undergone range extensions in recent ornithological history. Bridled Terns were not observed south of the Shoalwater Bay Islands until it was observed breeding on Seal Island, Cape Leeuwin in 1957 (Serventy *et al*.1971). The population on Penguin Island has also increased over this time, from no pairs in 1942 to approximately 3 500 pairs in 2004 (J.N.Dunlop *pers. com*.). Similarly, Brown Noddies have extended their range from the core colony at the Houtman Abrolhos to a frontier colony at Lancelin Island 300km to the south (Dunlop and Mitchell 2001). The first Brown Noddies were observed breeding in 1992, and by 1999 had increased to 900 pairs. By the 2003/04 season this colony had stabilized at just under 1000 pairs (Dunlop 2005).

Positive changes in the populations of a number of tropical seabirds have been observed south of the Houtman Abrolhos since 1900, with the rate of change apparently increasing over the last three decades. The seabirds appear to be indicating a significant long-term shift in ocean climate within the region (Dunlop edit 2004).

Significance of the species group in the south-western planning area

The area encompassed by the South West marine region includes the largest proportion of breeding seabirds in Australia (based on the only recent census compiled by Ross *et al.* 1995), excluding the Short-tailed Shearwater rookeries that dominate the seabird fauna in the south-eastern part of Australia. Of the estimated 14.8 million pairs of seabirds breeding in Australian coastal waters, the Short-tailed Shearwater comprises 11.9 million pairs. Of the 2.9 million pairs of other species nesting, approximately 2.4 million pairs (83.9%) do so in the SWMR. Significantly, the SWMR contains the following species and percentages of the Australian breeding population (Table 4.23.2).

Table 4.23.2 The percentage of the total Australian breeding population of selected species of seabirds breeding in the South West marine region.

Species	Percentage Breeding
Australian lesser noddy	100
Great-winged petrel	100
Flesh-footed shearwater	72
Little shearwater	58*
Wedge-tailed shearwater	71
Sooty tern	72
Common noddy	66.7
Roseate tern	59.7
Bridled tern	50.0

* 100 per cent of the south-west Australian subspecies of the little shearwater (*Puffinus assimilis tunneyi*) breeds adjacent to the Region.

Significant species

The Lesser Noddy is listed as Vulnerable, due to its requirement for mature mangroves as nesting areas and its restricted geographical range. This species nests on only three islands, separated by 20km, at the Houtman Abrolhos. The only other populations of this species breed in the western Indian Ocean (Surman 1995). It also appears largely dependent upon a single species of larval fish with its abundance seasonally and annually variable (Gaughin *et al*. 2002). Roseate Terns are threatened by coastal development in the northern hemisphere (Ramos *et al.* 1995) and have only recently been discovered to migrate between Australia and Japan/Taiwan (Flightlines, July 2003).

Although in recent years more information regarding the at sea distribution of seabirds has increased dramatically, it is still under represented compared with research at islands. The relationship between seabirds and their prey is poorly understood, although research at the Houtman Abrolhos has shown that reproductive output is influenced by both prey and the delivery of that prey by the Leeuwin Current (Surman and Wooller 2003).

Photo: Lesser Noddies nest only amongst the mangroves at the Houtman Abrolhos (C.Surman).

Impacts/threats

Human disturbance

One of the most dramatic impacts on a seabird breeding island occurred as a direct result of guano mining at the Houtman Abrolhos between 1890's and the 1940's. Initial estimates of Rat Island Brown Noddy and Sooty Tern populations were 1, 452, 000 birds in December 1889. The practice of egging, attributed to fishermen, the activity of guano diggers, combined with the introduction of cats and rats led to the complete desertion of the island by both species by the 1940's (Serventy *et al*. 1971). Adults of the Lesser Noddy were used as food by guano diggers at Pelsaert Island, and elsewhere, muttonbirds (shearwaters) were used as food and fishing bait (Serventy *et al*. 1971).

Visits to islands may impact upon reproductive performance of seabirds (GBMPA 1997). Surface-nesting species such as Crested ,Fairy and Roseate Terns are vulnerable to disturbance at early stages of nesting, and may desert colonies. Disturbance from people approaching colonies on foot and low flying aircraft cause “dreads” in which adults fly off the nest, often leaving eggs and/or young chicks vulnerable to predation by gulls and reptiles. Birds exposed to regular, close passes by aircraft are unlikely to habituate to intense short-term exposure to piercing sound and wind, and helicopter activity has been attributed to breeding failure in some species on the Great Barrier Reef (Stokes 1996). Regular helicopter traffic around seabird breeding islands, where the same flight paths are used and colonies are not approached below 200m, does not appear to have the same detrimental impacts (Nicholson 2002).

Burrow-nesting shearwaters are vulnerable to disturbance through collapsed burrows as unwary visitors walk through often attractive sandy areas containing rookeries. Some species, however, acclimatise to regular human traffic. Bridled Terns on Penguin Island, for example, nest under boardwalks and roost on handrails habituated to passing visitors (Dunlop 1996).

Introduced species

The introduction of exotic plants to breeding islands usually occurs as a result of visitors unknowingly carrying seeds on their shoes and belongings. These weeds can affect areas where seabirds breed, sometimes increasing erosion or altering habitat so that it is no longer suitable for nesting. Birds can also become entangled in vegetation which covers burrows (GBRMPA 1997).

The impacts upon breeding seabirds from rats and cats are well known, although few currently are under threat in the SWMR. In New Zealand over 100 islands have been cleared of exotic mammals, with dramatic recovery of nesting seabird populations (Bell 1995). Rats and cats have now been eradicated from Rat Island, Houtman Abrolhos, however the seabird population has not yet returned (Fuller *et al.* 1994).

Silver gulls

Silver Gull populations have been estimated as increasing at 10-13% annually (Meathrel *et al*. 1991) in response to increased food sources (domestic rubbish, aquaculture feeding methods and fishing bait discards), pastorisation and reservoirs. The large Kelp Gull is considered a recent arrival to Australia from New Zealand. It has been colonizing and out-competing the native Pacific Gull and Silver Gull in Tasmania (Serventy *et al* .1971, Coulson and Coulson 1996). Huge increases in the population of Silver Gulls at Port Lincoln (a doubling to 20 000 birds over five years) have been attributed to poor tuna feed management, associated with the cage culture of Bluefin Tuna. Silver Gulls are known predators on many seabird eggs and nestlings and may displace other nesting species through competitive exclusion for nesting sites or from predation on young or eggs.

Longlining and other fisheries

Longline fishing is known as a major contributor to the death of seabirds. Some estimates put the annual mortality of immature albatrosses as high as 16% as a result of the southern bluefin tuna fishery between 1980-1986 (Croxall *et al*. 1990). Recent changes to the deployment of fishing gear in Australian waters reduces the chances of albatross and other seabird species bycatch in this fishery (Alexander *et al.* 1997). Fishing gear debris, such as fishing line, hooks and netting may also entangle or impair foraging in seabirds. The rock lobster fishery in the SWMR discards the remains of fishing bait from pots which contributes to increased gull populations on some fishing islands. Purse seine fisheries for pilchards and scaly mackerel may reduce food supply for some species of seabirds, and the overexploitation of tuna species throughout the world may impact upon those species of seabirds, particularly tropical terns, that rely upon them to drive their prey to the surface, as they feed.

Marine pollutants

Marine pollution has been identified as a major contributor to mortality in offshore seabird species. Studies in Albatrosses indicate that the cumulative effect of feeding chicks ingested plastic particles may prove fatal in some cases. Similarly, seabirds accumulate heavy metals in much the same way as other top order predators (i.e. Tunas). Hindell *et al*. (1995) found that mercury levels in albatrosses increase with age. Accidental oil spills from the shipping industry also pose a potential threat to seabirds in the SWMR. An example of this was the wrecking of the *Sanko Harvest* off the coast of Esperence in February 1991, and the *Kirki* off the mid-west coast of W.A.in July of the same year. Impacts upon seabirds include direct oiling of foraging birds resulting in large-scale fatalities, pollution of the shores (and potentially breeding habitat) of breeding islands, as well as the reduced abundance of some prey species due to the exposure of fish eggs and larvae to slicks and sheens (Symens and Al Suhaibani 1995).

Aquaculture

The recent increase in aquaculture activities within the SWMR pose some potential threats to seabird prey sources. This occurs as the result of an increase in nutrient levels from feeding and wastes in waters and sediments surrounding aquaculture operations (Van Delft and Mills 1993). Areas in which activities such as pearl oyster farming are increasing include the Houtman Abrolhos and Shark Bay. Another potential impact of aquaculture is the transference of disease and genetic influences to wild stock.

Information gaps

The remoteness of seabird breeding islands, and the difficulty of studying resource use at sea invariably increases the difficulty of obtaining baseline knowledge of this group in the SWMR. Most of the current information is the result of independent researchers funding their own projects, a few University based research projects, Conservation and Land Management endorsed surveys, and a few short and long-term monitoring programs carried out by consulting companies for industry.

Currently Conservation and Land Management manage a seabird breeding island database (SBID), that collates both professional and amateur observations alike. Research institutions and government agencies are tending to move away from undertaking field research in remote, offshore regions due to logistical and safety issues, and funding for the maintenance of baseline seabird data is in short supply.

There is no ongoing or coordinated census of seabird breeding numbers within the region. Similarly, little is understood of the dynamics between various nesting species and their food supply, aside from detailed studies at the Houtman Abrolhos and Penguin Island (Surman and Wooller 2003).

Current research

There are few seabird-based research projects currently undertaken within the region. Several PhD candidates are currently submitting their results from research conducted at Esperence and the Houtman Abrolhos, but no other research is planned. At least two independent researchers (J.N.Dunlop and C.A. Surman) continue to self fund long-term research into seabirds centred along the mid-west coast of Australia.

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4.24 Pinnipeds

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Australian sea lion (*Neophoca cinerea*) adult female with pup, Nuyts Archipelago, South Australia. Source: Simon Goldsworthy – SARDI Aquatic Sciences

Species group and description

Pinnipeds are recognised as members of the order Carnivora that includes three monophyletic lineages, the Otariidae (fur seals and sea lions), Phocidae (true or earless seals) and the Odobenidae (the walruses). There are ten species of pinniped that occur in Australian waters. Three species of otariid seals, the Australian sea lion (*Neophoca cinerea*), the New Zealand fur seal (*Arctocephalus forster*i) and the Australian fur seal (*A. pusillus pusillus*) breed off the coast of southern Australia. Two other otariids, the Antarctic and subantarctic fur seal (*A. gazella* and *A. tropicalis*) and one phocid, the southern elephant seal (*Mirounga leonina*) breed on Australia's subantarctic islands (Macquarie, Heard and McDonald Islands) and four additional phocid seals, the leopard seal (*Hydrurga leptonyx*), crabeater seal (*Lobodon carcinophagus*), Ross seal (*Ommatophoca rossii*) and Weddell seal (*Leptonochotes weddellii*) breed on the pack or fast ice of Antarctica.

Two otariids seals breed within the South-West Planning Area (SWPA), the Australian sea lion and the New Zealand fur seal. Although Australian fur seals do not breed in the SWPA, they are common in the eastern part of the region. Subantarctic fur seals and southern elephant seals are common vagrants in the SWPA region. Other species are rarely recorded there.

Status

The Australian sea lion has recently been listed as *Threatened* under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. Southern Elephant seal, subantarctic fur seal are also listed as Threatened.

CITES – Convention for International Trade in endangered Species (CITES): *Appendix 1* species (all *Arctocophalus* and *Mirounga* species).

In South Australia, pinniped species are scheduled as follows under the National Parks and Wildlife Act 1972:

Australian sea lion - *Schedule 9, Rare*
New Zealand fur seal - *Protected*
Australian fur seal - *Schedule 9, Rare*

Other species listed under the Act include the Southern Elephant seal and Leopard seal, both listed under *Schedule 9, Rare*.

In Western Australia, Australian sea lions and New Zealand fur seals are listed under Schedule 4 of the Wildlife Conservation Act 1950, as *Other Specially Protected Fauna*.

Habitat and distribution

Distribution and abundance

The breeding distribution of the Australian sea lion extends from Abrolhos Islands on the west coast of Western Australia to The Pages Islands in South Australia (Figure 4.24.1). The current distribution of the Australian sea lion is, in part, a product of past exploitation by humans. Historical records indicate that the species' pre-sealing range incorporated Bass Strait in Victoria, particularly the southern Furneaux Group (Clarke, Passage and Battery Islands) and Kent Group, in Bass Strait (Warneke 1982). The historical extent of the Australian sea lions' western range is not known, but some loss of breeding colonies within the current range is thought to have occurred, particularly at East Waldergrave Island (South Australia), Rottnest and Garden Island, and populations in the Albany and Houtman Abrolhos regions (WA) appear considerably reduced (Campbell 2005, Gales *et al.* 1994, Shaughnessy et al. 2005).

It is impossible from historic accounts to reconstruct the size of Australian sea lion populations prior to European colonisation. With the recent ongoing recovery of fur seal populations in southern Australia, it has been assumed that the small Australian sea lion population has not recovered. However, it is possible that with the exception of certain colonies, full recovery has taken place throughout most of the species range during the last 170 years, and a recent recovery in the species may not be apparent because for the most part, the recovery may have already taken place. However, there is little quantitative data on which to base such hypotheses. At best we can only state that there is great uncertainty about the size and range of pre-sealing populations, and about the extent of any recovery. It is possible that the status of sub-populations throughout the range of the Australian sea lion may vary considerably (i.e. recovered, not-recovered, increasing, stable and decreasing).

Australian sea lion pups have been recorded at 76 sites over the past 20 years; 28 in Western Australia and 48 in South Australia. The current national estimate of pup production is around 3,000 (3,022), with 83% (2,521) in South Australia and 17% (501) in western Australia. More than 66% of all births (1,978) occur in the top 10 (13%) breeding sites, all of which occur in South Australia. There is a marked variation in the size of colonies, with the average pup number per colony being 41. Based on the Goldsworthy *et al.* (2003) population model, and an estimated minimum pup production of 3,022, the estimated size of the Australian sea lion population is about 11-12,000.

There is little time-series data on pup production at various sites for the species that enable trends in populations to be determined. The only exception are data on pup counts from Seal Bay, South Australia, where a decline of 12.7% between 1985 and 2002-03 (13 breeding seasons, 17.6 years) has been reported (Shaughnessy et al. in review).

Recent population genetic studies on Australian sea lions (Campbell 2003) have indicated that the species population is subdivided at both large and small geographic scales, with some fixed differences in maternal lineages occurring among breeding colonies separated by very short (20km) distances. In contrast, genetic evidence for male-biased dispersal suggests males are limited to approximately 200 km. The critical discovery by Campbell (2003) was the identification of extreme female natal-site fidelity, an outcome of which is the high risk of extinction of smaller colonies from stochastic processes. This has significant conservation and management implications, which at its extreme, may indicate the need for a colony specific management approach.

The New Zealand fur seal breeds on rocky islands off South Australia, the southern coast of Western Australia and south-west coast of Tasmania. Recently, new colonies of have established on some offshore islands in Victoria (eg. Lady Julia Percy Island, Kanowna Island and The Skerries) (Figure 4.24.2). In New Zealand, the species breeds on rocky headlands of the South Island, on Stewart and Chatham Islands and on their subantarctic islands (Snares, Campbell, Chatham, Auckland, Bounty and the Antipodes Islands). Irregular rock platforms or large boulder-filled beaches are usually favoured sites for breeding colonies and haul-out areas.

In the nineteenth century, the New Zealand fur seal was indiscriminately harvested throughout its range by sealers. There is little information on the numbers of animals killed or the location of colonies prior to exploitation, but the range in Australia once extended into the Furneaux Group in eastern Bass Strait, where it was quite abundant. Historical records of skins exported from Australia indicate that at least 350,000 fur seals skins were taken from southern Australia, most between 1800-1830. What proportion of these were Australian and New Zealand fur seals is unknown. Most of the recovery of populations of New Zealand Fur seals in Australia has taken place since the 1980s. Populations on Kangaroo Island have increased 6-fold since 1987. The total annual pup production in Australia is approximately 19,100. There are about 51 known breeding sites for the species in Australia, with most in

South Australia (30) and Western Australia (17). More than 80% of the Australian population occurs in South Australia with key breeding populations being at North and South Neptune Islands that produce about 7,300 pups per annum, Kangaroo Island (Cape Gantheaume and Cape du Couedic) produces about 6,300 pups per annum, and Liguanea Island (off southern Eyre Penninsula) producing about 2,000 pups per annum. These sites (collective pup production approximately 15,600) account for 99% of South Australia's population and more than 80% of the national population. The New Zealand fur seal population in Western Australia is centred in the Recherche Archipelago, with the western most population being near Cape Leeuwin. The most recent estimate of pup production, in 1999, suggested that approximately 3000 fur seal pups are born every year in Western Australia. This rate of production had been increasing at a rate of 9% per annum from 1989 and the level of pup production had doubled in the ten years from 1989-1999. This produced a population estimate of approximately 15,000 animals and at the measured rate of population increase, the current population size would be approximately 25,000. This species appears to be undergoing a range expansion in Western Australia with greater numbers of animals hauling out and breeding on the south-west coast. The total population in Australia is estimated to be about 80,000.

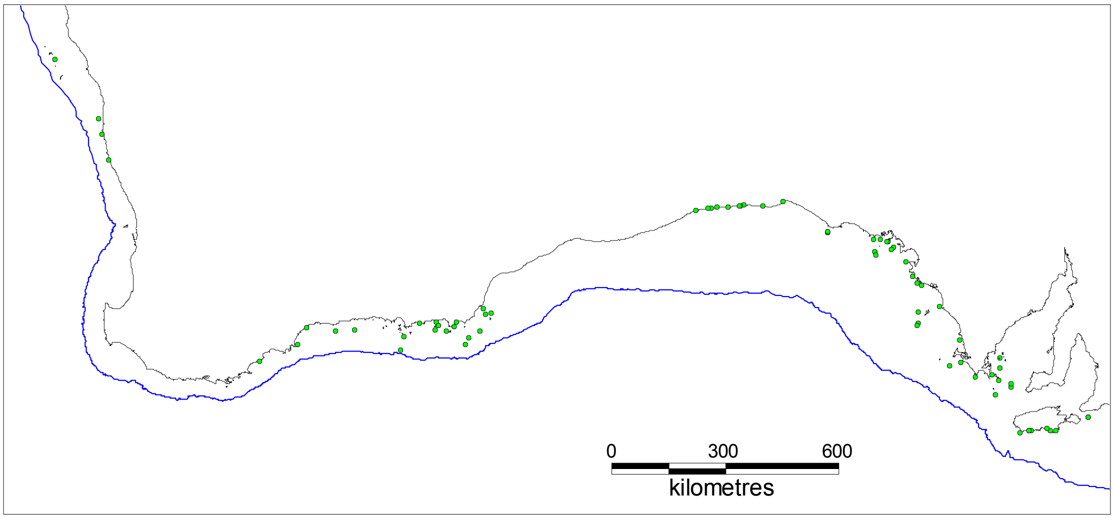


Figure 4.24.1. Distribution of breeding sites of the Australian sea lion, Australia's only endemic seal.

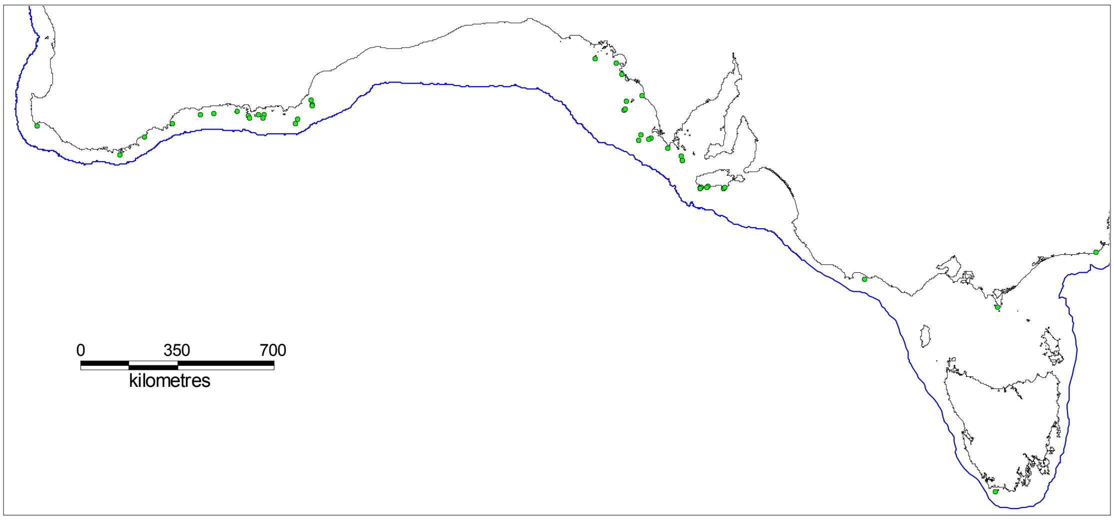


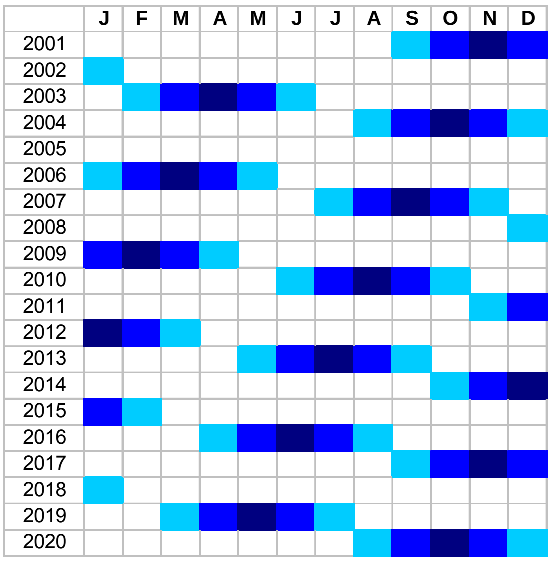
Figure 4.24.2 Distribution of breeding sites of the New Zealand fur seals in Australian waters.

Life history and reproductive ecology

Most otariid seals share similar life history characteristics, with females giving birth to a single pup annually, during highly synchronous breeding seasons. In New Zealand fur seals, females pup for the first time when 4 or 5 years old, with most pups being born over a five-week period between late November and early January, with peak pupping occurring around 25-26 December. In contrast, the duration of the pupping season in Australian sea lions extends over a period of about five months. Analysis from 19 breeding seasons at Seal Bay, Kangaroo Island indicates that 90% of births occur over 4.7 months. In comparison, 90% of births in the New Zealand fur seal occur over about 40 days. The duration of the pupping season in the Australian sea lion is the longest recorded among otariid seals (Gales and Costa 1997).

Whereas most seals (including the New Zealand fur seal) are annual synchronous breeders, the Australian sea lion is unique in being the only seal that has a non-annual breeding cycle that is also temporally asynchronous across its range. For example, the interval between successive breeding seasons at Seal Bay (Kangaroo Island) is about 17.5 months, but has varied between 16 to 20 months over 17 seasons (Shaughnessy *et al.* in review). A breeding cycle of slightly less than 18 months causes a seasonal drift in the timing of pupping (Figure 4.24.3), so that for any site, pupping will take place at all times of the year over about a 24 year period (Higgins 1990, Gales *et al.* 1992).

Figure 4.24.3 Predicted timing of the pupping season of Australian sea lions at Seal Bay, Kangaroo Island for the next 20 years – note seasonal drift in timing of breeding. (Light shading denotes the beginning and end of the breeding, darkest shading represents the mid-point of the breeding season; from McKenzie et al. 2005).



Australian sea lions also display asynchrony in the timing of breeding among colonies throughout their range. Gales *et al.* (1994) and Gales and Costa (1997) documented asynchrony in the timing of breeding among Western and South Australian colonies, and could not detect any pattern that could explain the degree of asynchrony among nearby and distant colonies (Figure 4.24.4). Some colonies that may only be tens of kilometres apart, may differ in the timing of breeding by more than 6 months.

They have the longest gestation of any pinniped, a protracted breeding and lactation period and greatly reduced dispersal capacity relative to other pinnipeds (extreme philopatry). The evolutionary determinates of this atypical life-history remain enigmatic.

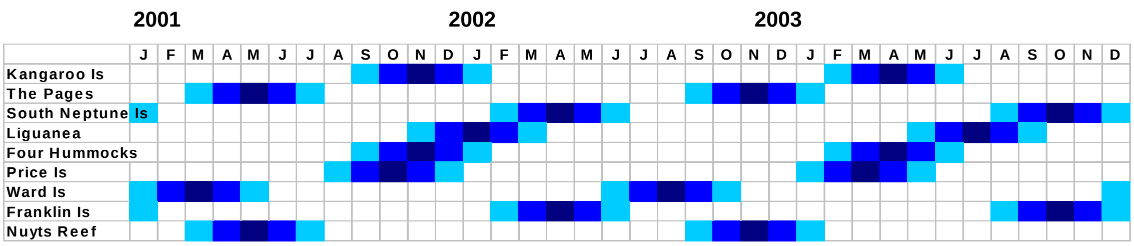


Figure 4.24.4 Example of temporal asynchrony in the timing of the breeding (shaded bars) across nine Australian sea lion colonies in South Australia (from Dennis unpublished data, Figure 2 in Shaughnessy *et al.* 2005). (Light shading denotes the beginning and end of the breeding, darkest shading represents the mid-point of the breeding season).

Mating, gestation and lactation

The New Zealand fur seal is polygynous, with adult males defending territories usually containing five to eight females (but up to 16 have been reported in a single territory). Throughout the non-breeding period, the spatial arrangement of adult males in breeding colonies is similar to that observed during the breeding season, but territorial behaviour is reduced. Pregnant females come ashore a day or two before giving birth to a single, dark-furred pup. As in most other otariid seals, lactating females are mated about one week following birth, usually by the nearest male. Embryonic diapause is thought to last approximately four months (until about April), followed by an active gestation of about eight months. Females remain with their pups for about ten days, then depart the breeding colony to forage at sea, returning regularly to nurse their pup. Periods ashore usually last about two days, but foraging trips increase in duration throughout lactation in response to the increasing energy demands of the pup, costs of gestation and perhaps the increased costs of foraging over winter months when prey availability may be limiting. Foraging trips usually last 3-5 days early in lactation and 8-11 days late in lactation.

The early growth rates of pups are rapid (doubling birth weight in 60-100 days), but decline markedly as weaning is approached. Pups weigh about 3-4 kg at birth and average 13-16 kg at weaning. Pups wean when approximately 10 months old. Most pups wean themselves and females continue to alternate between foraging trips and periods of shore attendance. Almost all pups have weaned prior to the next breeding season (late November), at which time the number of females ashore declines rapidly. During this period, females may be foraging intensively to build up their own energy reserves in preparation for the next breeding season.

Because of the protracted pupping season in Australian sea lions, it is not possible for adult males to simultaneously monopolise the oestrus periods of multiple females. As such the mating system in Australian sea lions differs from the polygynous systems typical of other otariid seals, and is described as serial monogamy, where males serially mate-guard pre-oestrus and oestrus females. As with fur seals, Australian sea lion females produce a single pup within 1-2 days of coming ashore, and are mated about a week later. They also have a 3-4 month period of diapause, however, the active period of gestation lasts up to 14 months, the longest gestation of any seal species (Gales *et al.* 1997). The slow rate of foetal development may represent an energetic advantage by spreading the costs of gestation over a longer period, enabling greater resources to be directed towards nursing unweaned young (Gales *et al.* 1997).

Females nurse their pup ashore in between foraging trips to sea. The duration of foraging trips varies among sites. At Dangerous Reef in Southern Spencer Gulf, foraging trips are short, averaging about 21 hrs (longest 2.4 days), in between shore attendance bouts of similar duration (23 hrs, longest 4.5 days), spending about equal proportions of time on land and at sea. In contrast, at Seal Bay on Kangaroo Island, shore attendance bouts (1.4 days) and foraging trips (2 days) are typically longer, with females spending a greater proportion of time at sea (60%) than on land (40%).

Female Australian sea lions nurse their pups for between 15-18 months, with pups typically weaning around one month prior to the birth of the next pup (Higgins and Gass 1993). If a female fails to pup in consecutive seasons, it may nurse its pup for a further 15-18 months and occasionally over three breeding seasons (i.e. > 4 years, Higgins and Gass 1993). When pups reach 4-6 months of age, they may disperse to nearby haul-out sites with their mothers. Pups weigh about 7-8 kg at birth, and put on about 100g/d during the first 100 days. Growth slows following this and appears to asymptote prior to weaning (most at 15-18 months) when pups may weigh between 25-45 kg.

Foraging ecology

New Zealand fur seals prey on a large variety of cephalopods, fish, and birds. In South Australia, key cephalopods prey include Southern Ocean arrow squid and Gould's squid; key fish species include redbait, ocean jackets, swallowtail and myctophids; and the most frequently taken bird species are little penguins and short-tailed shearwaters (Page et al. 2005). Recent satellite tracking studies in South Australia (Page et al. unpublished data) indicate marked spatial separation in foraging regions used by juvenile and adult female and males seals. Lactating females forage predominantly in mid- to outer-continental shelf waters, while adult males feed in deeper waters of the continental slope. In contrast, juvenile seals forage in oceanic waters where they target nocturnal surface-migrating myctophid fish. Adult female and male seals both forage in the water column in relative shallow depths (0-20m) and near or on the benthos in deeper water. In females, benthic or bottom dives on the continental shelf in South Australia are typically at 60-80m, while those of males on the continental slope are between 100-200m. The maximum dive durations and depths recorded for adult females are 9.3 min and 312m, and 14.8 min and 380m for males.

There is little quantitative information on the diets of Australian sea lions, prey items recorded include fish, cephalopods (squid, cuttlefish and octopus), sharks, rays, rock lobster, and penguins (Gales and Cheal 1992, Ling 1992, K. Peters pers. comm.). Many of the species identified in the diet of Australian sea lions are benthic species, supporting results from diving behaviour studies that indicate benthic foraging.

Recent tracking and diving studies of lactating females at Seal Bay indicate that seals foraged about 57 km offshore on the continental shelf and dived to a maximum depth of 105m (Costa and Gales 2003, Fowler and Costa 2004). The mean dive depth of female Australian sea lions recorded was 61m and the average maximum depth was 86m (Costa and Gales 2003). In contrast, in the shallow waters of the southern Spencer Gulf, lactating females typically dive to 30-45 m (Goldsworthy 2004). Because Australian sea lions are benthic foragers, the proportion of their at sea time that can be spent foraging is dictated by the depth of the water column. As such, Australian sea lion populations in the shallower southern Spencer Gulf can spend a greater proportion of their time at sea foraging compared to Australian sea lions in the Seal Bay population (Goldsworthy unpublished data).

Significance of the species group in the south-west palnning area

All of the current extant breeding range of the Australian sea lion occurs within the South West Planning Region. Given the Threatened conservation status of the species, appropriate management of the region is critical to the species' conservation. Around 99% of the Australian population of the New Zealand fur seal occurs in the SWPA, with only small populations on several Bass Strait Islands and in SW Tasmania.

Although Australian fur seals do not breed in SWPA, juvenile, sub-adult and adult male seals regularly disperse from the Bass Strait Islands to forage in waters in the eastern region of the SWPA. Large numbers of Australian fur seals haul-out within and adjacent to New Zealand fur seals colonies on Kangaroo Island (especially at Cape Gantheaume and Cape du Couedic), and are occasionally seen at the Neptune Islands.

Impacts/threats

Entanglement and entrapment in fishing gear and marine debris

Interactions with fisheries are a key management issues for many seal species in Australia. These take two main forms, operational interactions involving the seal interaction with fishing operations, gear and discarded nets and debris, and trophic or ecological interactions that involve food-web associated interactions between fisheries and seals. Entanglement and entrapment in fishing gear and other marine debris is an operational interaction. Seals with the SWPA can potentially interact with a large number of fisheries that are managed by the South Australian and Western Australian state governments (0-3 nm offshore) and Australian Governments (3-200 nm offshore).

The most comprehensive analysis of the entanglement rates of seals within the SWPA comes form the work of Page et al (2004), who detail the types of entanglement material, and changes in the rates of entanglement in New Zealand and Australian fur seals and Australian sea lions at Kangaroo Island over a 15 year period. In New Zealand fur seals, discarded lobster bait-box straps formed the largest component (30%) of entanglement material recorded/recovered from New Zealand fur seals on the south coast of Kangaroo Island (Page et al. 2004). Other material included trawl-netting (28%), rope (23%), plastic bags (7%), hooks and fishing line (3%), monofilament netting (1%) and other material including rubber 'o-rings', string and lobster-pot (8%). The estimated entanglement rates prior to 2000 were 0.4 % of the total population, and 0.9% since 2000. Based on these rates, Page et al. (2004) estimated that between 300-500 New Zealand fur seals die from injuries sustained by entanglements each year. Based on these finding, the main New Zealand fur seal operational interactions in South Australia occur with the southern rocklobster fishery and Commonwealth South East Trawl Fishery.

A recent report that that examined factors that may limit growth in Australian sea lion populations identified factor(s) that may contribute to a decline in their populations, and considered the most likely factors as those being of an anthropogenic and top-down (mortality driven) origin. Three factors fell into these categories: direct killing, pollutants and toxins, and fishery bycatch and entanglement. The report found no evidence that either direct killing or pollution and toxins were significant factors currently regulating the growth of Australian sea lion populations. There was, however, evidence that fishery bycatch and entanglement was a significant contributing mortality factor, at least in parts of Australian sea lion range. As a consequence, the report ranked fishery bycatch and entanglement as the most significant of all factors discussed, and the most likely factor contributing to limited growth in some populations of the Australian sea lion. The fisheries of major concern were the southern rock lobster and shark gill-net fisheries (McKenzie et al. 2005). Entanglement/entrapment of Australian sea lions in fishing gear and marine debris has been well documented (Robinson and Dennis 1988, Shaughnessy 1999, Gibbs 2000, Shaughnessy *et al.* 2003, Page *et al.* 2004, Campbell 2004). The foraging area of Australian sea lions is likely to overlap with a number of fisheries managed by state governments (southern and western rock lobster, abalone and other marine fishes, demersal gillnetting) as well as by the Australian Government (Great Australian Bight trawl, Southern Shark Fishery, south east trawl, and southern tuna and billfish fisheries) (Page *et al.* 2004, Campbell 2004). Operational interactions between Australian sea lions and fisheries in Australia were reviewed by Shaughnessy *et al.* (2003) and interactions between Australian sea lions and marine aquaculture were reviewed by Kemper *et al.* (2003). The major fisheries in Australia that have been identified as interacting with Australian sea lions are the gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF), the South and Western Australian Rock Lobster Fisheries and the Southern Bluefin Tuna Aquaculture industry in South Australia. Many regions around Australian sea lion colonies are also popular amongst sport and recreational fishers, and in South Australia support a growing finfish aquaculture industry. Although there is little quantitative data on the level of operational interactions between fisheries and Australian sea lions, recent entanglement surveys suggest that interaction rates are relatively high and/or their is a high rate of gear loss (Page *et al.* 2004).

Based on a 15-year study based on Kangaroo Island, South Australia, Page et al. (2004) identified that monofilament gillnet (from the gillnet sector of the SESSF) is the most prevalent (55%) entanglement material found on Australian sea lions at Kangaroo Island. Rope (14%), bait-box straps (11%) and trawl-netting were also significant, with fishing line and hooks (6%), tire-tubing (3%) making up the reminder. Entanglement rates in the Seal Bay population have increased in recent times from 0.2% prior to 2000, to 1.3% of population in 2002 (Page *et al.* 2004). Based on these entanglement rates and conservative estimates of subsequent mortality rates, Page *et al.* (2004) estimated that approximately 64 Australian sea lions may die each year in southern Australia from entanglement. Shaughnessy *et al.* (2003) and Page *et al.* (2004) stress however that observed incidences of entanglement are likely to greatly underestimate true mortality rates because an unknown proportion of individuals would die at sea prior to detection and entangled seals may spend less time onshore due to increased energetic demands, reducing the probability of observation. Despite attempts by governments and industry to reduce interactions between marine mammals and fishing gear (including lost fishing gear), entanglement rates have shown an increasing trend in recent years (Page *et al.* 2004). Entanglement rates of Australian sea lions in marine debris on the west coast of Western Australia are conservatively estimated at approximately 0.5% (McKenzie et al. 2005). Materials responsible for entanglement were fishing net (unknown origin), a pool toy and black elastic loops.

A low number of Australian sea lions were recorded to become entangled and drowned in anti-predator nets used in the southern bluefin tuna feed lots in the Port Lincoln area in South Australia in the 1990s (Pemberton 1996, Kemper and Gibbs 1997). The use of anti-predator nets has since been greatly reduced and farm management improved, including repairing holes in nets and reducing feed wastage, in order to reduce seal interactions.

Australian sea lion are also known to become entrapped in lobster pots, although quantitative data on this is limiting. Published fisheries reports suggest that the drowning of Australian sea lion pups in lobster pots is at a relatively low rate and only occurs within 30 kilometres of Australian sea lion breeding colonies on the west coast of Western Australia. Estimates of the numbers caught per year vary between 2-12 (Department of Fisheries, WA, 2002, Campbell 2004). Gales *et al.* (1994) reported that 'a significant proportion of pups from one colony had drowned in crayfish pots'. It is thought that pup and juvenile age classes are the vulnerable cohorts. A management programme is currently underway in Western Australia to develop sea lion exclusion devices (SLEDs) which can be fitted to conventional rock lobster pots for the commercial and recreational fishing sectors.

Trophic interactions with fisheries

There is limited information on the trophic interactions between New Zealand fur seals and Australian sea lions with commercial fisheries in the SWPA. Goldsworthy et al. (2003) estimated the spatial distribution of foraging and consumption efforts of seals in southern Australia, and identified the regions in the eastern Great Australian Bight around Kangaroo Island and off the southern Eyre Peninsula as being a region where consumption was high, and where trophic interactions with fisheries may be significant. Fine scale data on the spatial distribution of commercial fishery catch is not available for much of the SWPA, such information would enable the extend of overlap in fishery catch and seal consumption to be estimated, and in conjunction with dietary and food-web studies, determine the degree of trophic interactions, as detailed by Goldsworthy et al. (2003) for eastern Bass Strait. South Australia's pilchard fishery is currently Australia's largest volume fishery (51,000 t quota for 2005), and occurs in close proximity to some of the largest seal populations in Australia, and the extent of trophic between seals and this fishery are currently unknown. Australian sea lions are known to feed on both southern and western rock lobster, and several species of sharks. Videograhpic evidence of Australian sea lions around rock lobster pots in Western Australia has shown that individual animals can consume up to five lobsters from a commercial pot within 2 hours, and that a group of 8-10 animals consumed 23 lobsters from a single pot in approximately 3 hours (Campbell unpublished data). This rate of consumption and interaction suggests there may be a considerable trophic interaction with rock lobster fisheries. This plus the high incidence in some locations of young sea lions becoming entrapped in lobster pots, and of varying age classes becoming entangled in shark monofilament gill-net, suggest a significant trophic interaction occurs between seals and these fisheries.

Other threats/impacts

Direct killing

There have been numerous anecdotal reports of the shooting of Australian sea lions by commercial fishers and past reports of occasional shooting and harassing of seals around tuna aquaculture farms (Kemper *et al*. 2003). Of carcases retrieved in the Port Lincoln area between 1995 and 2000, five Australian sea lions were identified as being shot (Kemper *et al.* 2003). In Western Australia between 1980 and 1996, the most common unnatural causes of death recorded in stranded Australian sea lions were shootings (14 animals), with a further three deaths contributed to spearing or shooting with arrows and one death due to clubbing (Mawson and Coughran 1999).

Disturbance/harassment/displacement

Seal watching is a significant commercial operation in some parts of the SWPA. The most significant are Kangaroo Island where tourists can gain close access the Australian sea lions at Seal Bay and New Zealand fur seals at Cape du Couedic. Tourism based activities are known to occur at ten main Australian sea lion breeding colonies and haul-out sites; three in South Australia and seven in Western Australia (Orsini 2004). Although the level of disturbance caused by people is currently managed by State governments at popular tourist sites such as Seal Bay, Point Labatt and Jones Island through guided tours, viewing platforms, and the accreditation and licensing of tour operators, other breeding sites and haul-out sites both within and outside nature reserves are still accessible by the general public and hence are difficult to monitor and control. In most situations the onus is on the tour operator or general public to ensure their presence does not adversely impact on the seals present. Visitors' awareness of their ability to disrupt Australian sea lions or the safety risk posed by seals at close range is limited (Orsini 2004).

Oil spills and contaminants

Oil spills have affected at least two populations of seals in Australia in recent years. In 1991 the bulk carrier 'Sanko Harvest' was wrecked on the south coast of Western Australia spilling 700 tonnes of heavy fuel oil, washing ashore at two New Zealand fur seal colonies in the Recherche Archipelago. At least 64 two-month old pups were contaminated with oil, but swift action enable them to be captured and cleaned (Gales 1991). In 1995, following the wreck of the 'Iron Baron', some Australian fur seals breeding at Ninth Island were impacted by heavy fuel oil. At least 20 seals of various age groups were observed oiled (Pemberton 1999). Again an accurate estimate of mortality was not possible. However, the number of pups born in the following breeding season on Tenth Island was reduced, suggesting a possible impact on the population following the oil spill (Pemberton 1999). Many of the seal colonies in the SWPA occur close to major shipping lanes, and as such are vulnerable to oil spills in the event of major shipwrecks.

Disease

The habit of seals aggregating in colonies on land provide the opportunity for transmission of infectious diseases. Disease has featured in a number of seal populations around the world, and in some instances has had significant impacts on populations. Endemic diseases and parasites are now recognised as significant factors limiting population growth in the New Zealand sea lion and California sea lion (Castinel *et al.* 2004, DeLong *et al.* 2004). Mass disease epidemics in New Zealand, North America and Europe have demonstrated that disease can reduce seal populations directly through mass mortality of adult animals or through reduced recruitment of pups. In 2000, over a two month period approximately 10,000 Caspian seals, *Phoca caspica,* died in the Northern Hemisphere due to a canine distemper virus (Kennedy *et al.* 2000). In New Zealand over a 30 day period in 1998, approximately 60% (1606) of New Zealand sea lion pups and an unknown number of adult animals (> 74) died at the Auckland Islands, an area which accounts for over 95% of the species total pup production (Baker 1999). The cause of the mass mortality is unknown. During the 2002 and 2003 breeding seasons, epidemics again claimed over 30% of the New Zealand sea lion pup production (Duignan *et al.* 2004). In the recent epidemics the bacterium, *Klebsiella pneumoniae* was isolated from both pups and adult animals. Increased pup mortality due to disease may temporarily affect population growth. But in populations such as the Australian sea lion that are characterised by low recruitment, disease may contribute to the lack of recovery of small populations or, could lead to the extinction of small isolated populations.

Information on the type of disease agents and their prevalence in seal populations throughout Australia is limited. Hookworm, *Uncinaria* sp. (Beveridge 1980), and tuberculosis, *Mycobacterium pinnipedii* (Mawson and Coughran 1999, Cousins *et al.* 2003) have been recorded in Australian sea lions and New Zealand fur seals, however their prevalence in wild populations and their effect on survival and reproduction are unknown.

Information gaps

Key knowledge gaps for Australian sea lion are based on those detailed in McKenzie et al. (2005), and fall into five categories:

Populations

- Pup production and trend data for most colonies
- Detailed knowledge on population subdivision and structure (to identify management units), including use of haul-out sites by sub-populations.

Life-history

- Representative life table of basic population parameters (longevity, age structure, age-specific survival and fecundity)
- A realistic and representative population model based on the above parameters
- An understanding of the evolutionary determinants (selective factors) that have shaped the unique life-history of Australian sea lions, especially reproductive strategies, population structure (e.g., philopatry) and foraging ecology.

Mortality

- Main factors involved in mortality and their contribution at various stages/ages; especially the role of disease and fishery interactions (see below)
- Identification of the range of diseases present in Australian sea lion populations, particularly key diseases that may regulate populations
- Identification of the role of fisheries and aquaculture interactions in Australian sea lion mortality rates (i.e. identify fisheries, regions/populations, Australian sea lion age-classes most at risk etc.).

Foraging ecology

- Diet – key prey species and sizes, seasonal, annual and geographic variation
- Foraging habits – foraging range, distribution of foraging effort, identification of key benthic habitats and seasonal, annual, and geographic variation

For New Zealand fur seals, key knowledge gaps include:

- Up-to-date information on the status and trends in populations in Western Australia
- Representative population demographic models for this species
- Information on the diets and distribution of foraging effort of different age-sex classes across the range of the species ie. key habitats
- Extent of operational interactions with commercial fisheries
- Extent of spatial and trophic interaction with commercial fisheries

Key references and current research

Key references are listed below. Most current research being undertaken on pinnipeds within the SWPA are being undertaken by researches within South and Western Australia. In South Australia, there has been ongoing population surveys of Australian sea lions and New Zealand fur seals on Kangaroo Island (SA DEH, CSIRO, SARDI Aquatic Sciences). Other populations within the state have been surveyed recently as part of other projects (SARDI Aquatic Sciences, CSIRO/SA Museum). Studies on the populations and foraging ecology of Australian sea lions and New Zealand fur seals are being undertaken (La Trobe University, SARDI Aquatic Sciences), including studies into trophic interactions with fisheries, interactions with finfish aquaculture and southern rock lobster and gillnet shark fisheries (SARDI Aquatic Sciences). In Western Australia, studies are underway to investigate and manage interactions between Australian sea lions and the western rock lobster fishery, and ongoing assessment of the status of some sea lions populations (WA Fisheries, CALM). Investigation into the foraging ecology of Australian sea lions on the west coast of Western Australia has just commenced and will look at the overlap with commercial fisheries and marine protected areas. Investigation into dietary preferences of Australian sea lions across their range is underway (SARDI, DoFWA, SAM). Surveys of all New Zealand fur seal breeding colonies are planned to occur every ten years and due to be performed again in 2009/10.

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4.25 Cetaceans

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Species group name and description

Globally the Order Cetacea comprises more than 80 species of marine mammals known as whales, dolphins and porpoises. They are hairless, with streamlined body form, horizontally flattened tail flukes for propulsion, paddle-like forelimbs, nostrils (blowholes) located on top of the head, a blubber layer for insulation and fat storage, and ears adapted to underwater hearing. All species produce sounds which may be used for communication, navigation or food-finding.

There are two extant Sub-Orders. The Mysticeti, or baleen whales, are characterised by generally large size (8-30m), twin blowholes, and keratinous baleen plates which hang from the upper jaw, and are used to filter schooling prey such as crustaceans and small fish from engulfed water. ‘Australian’ species fall into three Families: the Balaenidae (southern right whale), the Neobalaenidae (pygmy right whale), and the Balaenopteridae, or rorquals (blue, fin, sei, Bryde’s, minke and humpback whales).

The Odontoceti, or toothed whales, are more diverse and extremely variable in size (1.5-18m), have a single blowhole, and true teeth for holding prey which are usually caught singly. Most species have well-developed echolocation. Several families are represented in the Southwest Region: Physeteridae (sperm whales); Kogiidae (pygmy and dwarf sperm whales); Ziphiidae (beaked whales); Delphinidae (killer whales, ‘blackfish’ e.g. pilot whales, and dolphins), and Phocoenidae, or porpoises (spectacled porpoise).

Status

Status varies considerably according to species. Several large baleen whales are listed as Threatened and/or Migratory Species under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) including blue, southern right, humpback, fin and sei whales, and are subject to Recovery Plans. Some small cetaceans (e.g. common dolphins) are undoubtedly abundant, however, due to the lack of basic biological or ecological data for most species, the majority of species are classified as Data Deficient or Not Listed (IUCN).

All cetaceans in Australian territorial waters including the SW region are protected to some degree through international agreements to which Australia is a signatory (e.g. CITES, IWC Indian Ocean and Southern Ocean Whale Sanctuaries, CMS); Commonwealth legislation and sanctuaries, namely the EPBC Act (1999) and the Australian Whale Sanctuary; and state and territory legislation. They are also protected under all Commonwealth and state marine protected areas and World Heritage sites.

Habitat and distribution

Cetaceans inhabit virtually all marine habitats, from shallow bays and estuaries to the deep ocean, and from polar to equatorial waters. At least 38 species are known to occur in the SW region (Table 4.25.1). While common bottlenose dolphins may be restricted to specific embayments, most other species are thought to carry out seasonal movements. The SW region provides a range of environments from temperate to sub-tropical, with the conjunction of cooler southern waters associated with the Sub-tropical Front, and the warm, south-flowing Leeuwin Current. This brings together species which inhabit the Southern Ocean (e.g. blue whales, southern right whales, and southern right whale dolphins), and others associated with warmer tropical waters (e.g. short-finned pilot whales, and striped and spinner dolphins).

Southern right whales breed while fasting during winter-spring in shallow sandy bays across the south of the continent, with the majority of the Australian population breeding west of Adelaide (Kemper *et al.,*1997; Burnell, 2001). During summer, blue (and probably fin and sei) whales feed on swarming krill in upwelling zones such as the shelf break south and west of Kangaroo Island, and around the rim of the Perth Canyon (Gill and Morrice, 2004, Morrice *et al.,* 2004, McCauley *et al.,* 2004). Recent surveys have frequently detected blue, humpback and southern right whales in Geographe Bay, south of Perth (Burton, 2003, 2004). Migration routes of blue whales to and from these areas are unknown. Sperm, pilot and beaked whales are likely to forage for squid and fish along the upper slope, while pelagic dolphins appear to aggregate in response to seasonal fish production (Gill and Morrice 2004, Morrice *et al.* 2004). Humpback whales use the coastal waters of the SW region as a migratory corridor between Antarctic feeding grounds and tropical breeding grounds, but rarely feed in temperate waters (Kemper, 2005). Photo-ID studies during the southern migration have shown that some humpback whales remain in the area north of Rottnest Island for up to a week (Burton, 1991). Sightings of killer whales in the SW region appear to be timed to the seasonal distribution of their preferred prey such as fish, squid, seals and humpback whales (Ling, 1991; Morrice, 2005).

Table 4.25.1: List of cetacean species which inhabit the SW region (Stranding data courtesy of WA Dept of Conservation and Land Management: D. Mell, D. Coughran, pers. comm.; and C. Kemper, SA Museum). IUCN categories: Lr/cd or nt= Lower risk & conservation dependent or Near threatened; EN= endangered; DD= data deficient; Vu= Vulnerable; ?= not listed.

Taxonomic group	**Species**	**Habitat**	**Known occurrence**	**Strand in SW**	**Selected references**	**IUCN Status**
Baleen whales	Southern right whale *Eubaleana australis*	Breed in shallow protected bays	Occur right along coast through SW region	Yes	Bannister et al, 1996, Burnell, 2001; Pirzl unpubl data	Lr/cd
	Pygmy right whale *Caperea marginata*	Pelagic	Rare sightings & strandings across southern Aust.	Yes	Bannister et al, 1996, Kemper, 2002	DD
	Blue whale (pygmy and 'true' ssp.) *Balaenoptera musculus brevicauda* and *B.m. intermedia*	Shelf to shelf-break; pelagic frontal zones	Polar to tropical waters; feed in temperate upwelling zones	Yes	Bannister *et al,* 1996; Gill and Morrice, 2004; McCauley *et al.,* 2004; DEH, 2005a, Burton 1997	EN
	Fin whale *Balaenoptera physalus*	Shelf to pelagic	Occasional sightings in Bonney Upwelling	Yes	Bannister *et al*, 1996, DEH, 2005b	EN
	Sei whale *Balaenoptera borealis*	Shelf to pelagic	Occasional sightings in Bonney Upwelling	No	Bannister *et al*, 1996, DEH, 2005b	EN
	Bryde's whale *Balaenoptera edeni*	Shelf to pelagic	Tropical to temperate	Yes	Bannister *et al*, 1996	DD
	Dwarf Bryde's whale *Balaenoptera omurai*	Shelf to pelagic	Tropical to temperate	Yes		?
	Antarctic minke whale *Balaenoptera bonaerensis*	Pelagic	Polar to tropical waters	No	Bannister *et al*, 1996	Lr/cd
	Dwarf minke whale *Balaenoptera acutorostrata*	Pelagic	Polar to tropical waters	Yes	Bannister *et al*, 1996	Lr/nt
	Humpback whale *Megaptera novaeangliae*	Migrate through southern shelf waters; breed on NW Shelf	Migrate between tropical Australia and Antarctic waters	Yes	Bannister *et al*, 1996; Kemper 1997; Burton 1991; Jenner et al, 2001; Kemper 2005	Vu
Toothed whales (includes dolphins)	Sperm whale *Physeter macrocephalus*	Shelf break to deep water; seamounts	Deep water, over shelf on sth coast. Widespread on west coast	Yes	Bannister *et al*, 1996	Vu
	Dwarf sperm whale *Kogia sima*	Oceanic but more coastal than pygmy	Pelagic; rarely sighted	Yes	Bannister *et al*, 1996	DD
	Pygmy sperm whale *Kogia breviceps*	Oceanic	Pelagic; rarely sighted	Yes	Bannister *et al*, 1996	DD
	Killer whale *Orcinus orca*	Coastal to pelagic	Often seen on continental slope	Yes	Bannister *et al*, 1996; Morrice, 2005	DD
	Pygmy Killer whale *Feresa attenuata*	Possibly pelagic	Rarely sighted prefers warmer waters	Yes	Bannister *et al*, 1996	DD
	Long-finned pilot whale *Globicephala melas*	Shelf break to deep water; seamounts	Cool temperate waters	Yes	Bannister *et al*, 1996	?

	Short-finned pilot whale *Globicephala macrorhynchus*	Shelf break to deep water; seamounts	Warm temperate waters but may follow Leeuwin C south	Yes	Bannister *et al*, 1996	Lr/cd
	False killer whale *Pseudorca crassidens*	Coastal to pelagic	Tropical to temperate oceanic waters	Yes	Bannister *et al*, 1996	?
	Strap-toothed beaked whale *Mesoplodon layardii*	Shelf break to deep water; seamounts	Poss seasonal move north to shelf	Yes	Bannister *et al*, 1996	DD
	Andrew's beaked whale *Mesoplodon bowdoini*	Shelf break to deep water; seamounts	Deep oceanic temperate seasonal moves	Yes	Bannister *et al*, 1996	DD
	True's beaked whale *Mesoplodon mirus*	Shelf break to deep water; seamounts	Deep oceanic temperate seasonal moves	Yes	Bannister *et al*, 1996	DD
	Blainville's beaked whale *Mesoplodon densirostris*	Moderate slope depth adj to canyon	Tropical to temperate ocean	Yes	Bannister *et al*, 1996	DD
	Hector's beaked whale *Mesoplodon hectori*	Oceanic deep water	Temperate to subantarctic	Yes	Bannister *et al*, 1996	DD
	Gray's beaked whale *Mesoplodon grayi*	Shelf break to deep water; seamounts	Poss seasonal move north to shelf	Yes	Bannister *et al*, 1996	DD
	Southern bottlenosed whale *Hyperoodon planifrons*	Shelf break to deep water; seamounts	Temperate to Antarctic deep waters widely	No	Bannister *et al*, 1996	Lr/cd
	Cuvier's beaked whale *Ziphius cavirostris*	Shelf break to deep water; seamounts	Tropical to subantarctic seasonal movements	Yes	Bannister *et al*, 1996	DD
	Arnoux's beaked whale *Berardius Arnuxii*	Shelf break to deep water; seamounts	Temperate to Antarctic deep waters widely	Yes	Bannister *et al*, 1996	Lr/cd
	Shepherd's beaked whale *Tasmacetus shepherdi*	Oceanic deep water	Temperate to subantarctic seasonal movements	Yes	Bannister *et al*, 1996	DD
	Common bottlenose dolphin *Tursiops truncatus*	Largely pelagic	Tropical to temperate oceanic waters	Yes	Bannister *et al*, 1996, Kemper 2004	DD
	Indo-Pacific bottlenose dolphin *Tursiops aduncus*	Coastal or estuarine	Tropical to temperate inshore Waters	Yes	Bannister *et al*, 1996, Kemper 2004	DD
	Spinner dolphin *Stenella longirostris*	Shelf to pelagic	Mainly tropical but occur in Leeuwin Current	Yes	Bannister *et al*, 1996	Lr/cd
	Striped dolphin *Stenella coeruleoalba*	Predominant pelagic shelf	Mainly tropical but occur in Leeuwin Current	Yes	Bannister *et al*, 1996	Lr/cd
	Pantropical spotted dolphin *Stenella attenuata*	Pelagic pref cont slope	Tropical to warm temperate	Yes	Bannister *et al*, 1996	Lr/cd
	Short-beaked common dolphin *Delphinus delphis*	Predominant shelf	Occur widely across GAB and on W coast	Yes	Bannister *et al*, 1996; Bell *et al.*, 2002	?
	Risso's dolphin *Grampus griseus*	Pelagic on cont slope	Tropical to subantarctic	Yes	Bannister *et al*, 1996	DD
	Dusky dolphin *Lagenorhynchus obscurus*	Pelagic	Temperate to subantarctic	No	Bannister *et al*, 1996, Gill *et al*., 2000	DD

	Southern right whale dolphin *Lissodelphis peronii*	Pelagic	Sub-tropical Front to Polar Front	Yes	Bannister *et al*, 1996	DD
Porpoises	Spectacled porpoise *Phocaena dioptrica*	Prefer sub-antarctic	Cold temperate to polar	Yes	Evans *et al.*, 2001	DD

Significance of the species group in the Southwest Planning Area

While the conservation significance of cetaceans in this planning area is represented by statutory mechanisms to protect them, the ecological, cultural and economic significance of most species is still poorly understood.

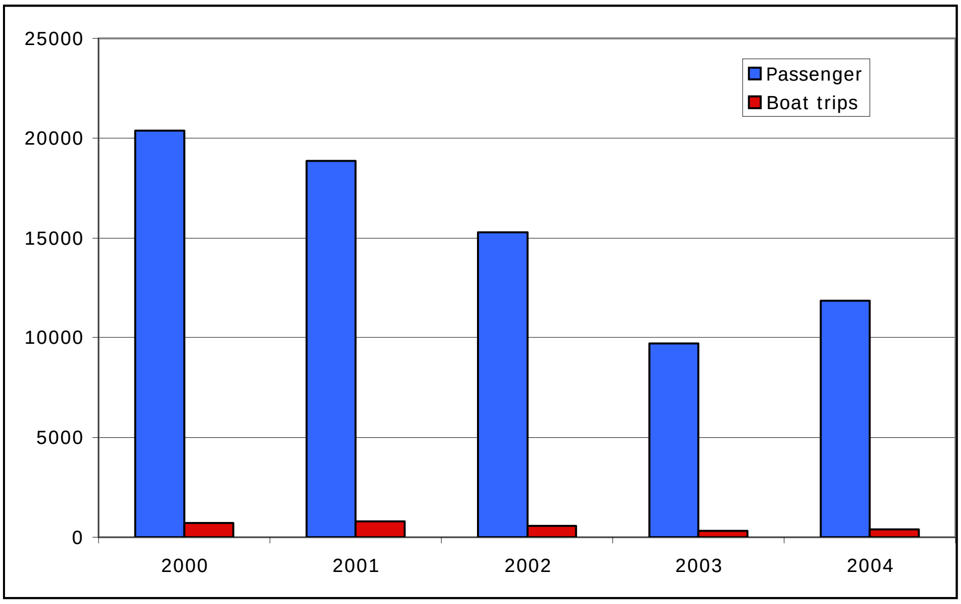
Whales and dolphins have probably always played a part in the economy of the indigenous inhabitants of southern Australia, with strandings providing opportunities for feasting since ancient times. Small cetaceans may also have been hunted. However, aboriginal people adapted quickly to European whaling, and gathered in numbers near whaling stations at Portland, Victoria, to feed on southern right whale meat discarded by whalers, and are likely to have done so in other parts of southern Australia where bay whaling stations were numerous and widespread. Flinders Bay on the SW tip of Western Australia was an important area for foreign whaling fleets to visit from the early 1800's. A British colony was founded there in 1830 and 'Bay whaling' commenced so after. Some early accounts record aborigines obtaining food from a beached whale and also provide evidence of the numbers of whales in the Bay (Lines, 1994). Aboriginals at Twofold Bay on Australia's east coast found employment as whalers, and are also likely have done so in South and Western Australia. Whales had spiritual significance for aboriginal people (T. Saunders, pers. comm.), being very common along coastlines prior to European occupation. Currently, indigenous Australians manage what is perhaps Australia's premier whale watching site, at the Head of Bight, South Australia, and are increasingly involved in a range of ecotourism ventures across south-west Australia.

Open-boat whaling was the first European industry across much of southern Australia, from about 1800. Fortunes were made and many towns grew from small 'bay whaling' settlements. A number of these settlements were formed in Geographe Bay in SW Western Australia during the 1830's and 40's (Heppingstone, 1966). Abundant southern right whales bred in most sheltered bays, until their virtual extinction from whaling by 1850, when the focus shifted to less valuable migrating humpbacks. During the 20th century mechanised whaling focused on sperm whales and humpbacks. Albany, where sperm whales were hunted, was the last Australian station to close, in 1978.

Some highly visible species, such as southern right and humpback whales, do not usually feed in the SW region, so they may have minimal ecological interaction within their breeding and migratory habitat. However, southern right whales in particular show strong site fidelity to these breeding sites. Others that regularly feed in these waters, such as blue, sperm and pilot whales, or common dolphins, presumably fill significant trophic roles. Between them, cetaceans are likely to be significant predators of a number of prey groups, including squid, a range of fish such as myctophids and clupeids, and euphausiid, amphipod and copepod crustaceans. However, until estimates of population size and trophic requirements are possible, their ecological significance remains theoretical. The biomass of all the large whale species (with the possible exception of sperm whales) is still greatly reduced from the whaling period, so presumably much greater numbers were supported within the region pre-whaling. As depleted species recover, they will consume a greater share of available prey, with unknown trophic cascade effects.

Whale watching has been a growth industry in Australia, due to the recovery from whaling by some conspicuous species such as humpbacks and southern rights. Humpbacks in particular support a significant boat-based industry, as they migrate past the continent's east and west coasts. Southern right whale watching tends to be more land-based, due to the potential impact of vessels on young calves, and the whales' inshore habit. Dolphins also support ecotourism, as at Bunbury, WA. A recent report (IFAW, 2004) has shown that in the five years to 2003, whale watching from both vessel and land based operations contributed approximately $276 million to the Australian economy. Recent preliminary data from WA (Figure 4.25.1) give an indication of the magnitude of the whale watching industry for the SW region between 2000 and 2004. These data are considered incomplete due to late returns, so no trend analysis should be attempted.

Figure 4.25.1: Passengers and boat trips for whale watching in south-western WA (Kalbarri to Esperance). (Data courtesy of D. Mell, D.Coughran, CALM).



Impacts/threats

Cetaceans are subject to a range of anthropogenic threats in the SW region (Bannister *et al.* 1996; DEH, 2005a,b). In most cases the scope and intensity of threats has not been quantified.

Whaling is not a current threat to most species, although Antarctic minke whales which may migrate past Australian shores are still targeted, and humpback and fin whales are likely to be targeted soon by Japanese ‘scientific’ whaling.

Shipping traffic and recreational boating is a known threat causing direct strikes resulting in injury or death, physical disturbance, or noise which can disturb cetaceans and mask the acoustic cues on which they depend for communication, orientation or food-finding. Other sources of noise pollution include military sonar, which has been linked to severe acoustic trauma in deep-diving beaked whales, and seismic hydrocarbon surveys, which may displace whales from migration routes or feeding areas. Offshore installations such as windfarms or wave generators are currently under assessment overseas.

Many species strand (e.g. Kemper and Ling, 1991), sometimes from natural causes, at others from human intervention. Entanglement in fishing gear is a known problem, with migrating humpback whales regularly caught and southern right whales sometimes entangled in craypot lines; dolphins, killer whales, and sperm whales are sometimes caught on tuna longlines; at least one humpback whale has been trapped inside a tuna pen; dolphins are regularly caught and sometimes die in aquaculture nets (Kemper and Gibbs, 2001), and recently, common dolphins have been killed in the pilchard trawl fishery in the eastern GAB (S. McLatchie, pers. comm.). Marine debris may also contribute to the death of cetaceans, with plastic bags a known culprit (K. Evans and M. Morrice, unpublished data).

Closer inshore, such animals as inshore bottlenose dolphins may be locally threatened by human disturbance, habitat modification or toxic pollution. Organochlorines are soluble in blubber and heavy doses may be passed to offspring through mother’s milk, and have been found in sperm whales off Tasmania, and in bottlenose dolphins off South Australia (Evans *et al.*, 2004; Long *et al.,* 1997). On a larger scale, the longterm effects of global warming are still speculative, but may significantly impact on circulation patterns which drive primary and secondary production. Finally, there may be cumulative effects of combinations of the above.

Information gaps

Of the diversity of cetaceans which are found in the SW region, only a handful have been the focus of dedicated studies. The better known are humpback whales, southern right whales, sperm whales (during whaling until 1978), inshore bottlenose dolphins, and more lately, blue whales. There is also some knowledge of the biology of pilot whales through mass strandings. Even with these studies, much of the knowledge required to assess the status and recovery of these species is unavailable. For the remainder, it is safe to say that there is minimal knowledge of their biology, life history, behaviour, ecology, genetics and movements. Due to their mobility, relatively long periods of submergence, and tendency to occur offshore, most of these species are very difficult even to encounter, let alone to study in any detail.

Prioritisation of potential research effort will not be attempted here. New technologies and techniques are constantly evolving, allowing unprecedented insights into many aspects of cetacean study. However, funding constraints mean that most research remains unfunded, regardless of its priority.

A fundamental problem with cetacean research around Australia is that most animals remain undetected or unreported. Comprehensive aerial surveys of shelf and upper slope waters, backed by more focused vessel surveys, would help to fill in many gaps. Passive acoustic monitoring can be combined with visual surveys, and is an increasingly useful technique for determining certain species' seasonal presence and even movements. Multidisciplinary ecological studies could utilise combinations of aerial and vessel surveys, remote sensing, oceanographic studies, and a range of standard cetacean research techniques, including biopsy, photo-ID, telemetry, diet and prey studies, acoustic monitoring and behavioural observation, including interactions with prey and other species. There is also a need for abundance estimates in order to determine the effect of mortality on long-term survival of species.

State agencies could be encouraged and resourced to further develop cetacean sightings and strandings databases, including the adoption of a standard reporting framework which would incorporate incidental sightings by shipping, commercial and recreational fishers, and yachtmen, and which would be accessible to a range of users, on a layered access basis. State and Commonwealth legislation could be reviewed to ensure that it is consistent with the current state of knowledge about cetaceans and central management issues. Fisheries agencies could incorporate additional reporting of cetacean sightings into existing operational reporting procedures e.g. AFMA and CCAMLR observer programs. They could more consistently incorporate cetaceans as a keystone predator when developing predator/prey models for fisheries, and ensure that a risk analysis is done for fisheries considered to be a high risk to cetaceans prior to changing fishing techniques or when developing new fisheries e.g. when changing to longline operations. There is also a need to collect and study carcasses from strandings and fisheries interactions because so much information could be gained.

It is likely that our knowledge of cetaceans in this region will continue to grow slowly, with greater advances in a few more easily studied species of current interest, and only minor, sporadic advances in the remainder.

Key references and current research

Current research relevant to the SW region

- South Australian cetacean sightings and stranding research: Dr Cath Kemper (South Australian Museum). Occurrence of cetaceans in SA waters, including all sightings and strandings; movements of southern right whales; biology of pygmy right whales, and of common and inshore bottlenose dolphins; toxicology, pathology, fisheries interactions, life history and abundance.

- Western Australian humpback whale research: John Bannister (WA Museum), Curt and Micheline-Nicole Jenner (Centre for Whale Research), Chris Burton (Western Whale Research), Robert McCauley (Curtin University) and others. Migration, recovery and population ecology, acoustic monitoring of Group IV humpbacks.

- Southern right whale habitat study: Rebecca Pirzl (Deakin University). Defining southern right whales' coastal habitat preferences in relation to their calving and mating grounds across southern Australia; potential impacts of human activities on a recovering right whale population; ARPs around the Antarctic: coastal component for year-round acoustic monitoring of right whales.

- Southern Australian southern right whale photo-ID matching study: Mandy Watson (Dept. Sustainability & Environment, Warrnambool, VIC), John Bannister (WA Museum). Main objectives: to expand photo-ID database to investigate movement patterns of SRWs across southern Australia, to enable estimation of population size, and to study life history of individual whales.

- Southern right whales off Western Australia: John Bannister (WA Museum). Use of aerial surveys to examine movements and population dynamics of SRWs.

- Southern right whale population genetics: Dr Rob Harcourt, Dr Nathalie Patenaude (Macquarie University). Biopsy sampling of SRWs at diverse locations to examine genetic diversity and relatedness of whales between areas.

- Humpback and southern right whale entanglement: Doug Coughran (CALM). Development of disentanglement procedures.

- Blue whale research, Perth Canyon/west coast: Dr Rob McCauley (Curtin Uni), Curt and Micheline-Nicole Jenner (Centre for Whale Research), Chris Burton (Western Whale Research), Susan Rennie (Curtin Uni). Ecology of blue whales in the Perth Canyon feeding area; oceanography of Perth Canyon; acoustics of blue whales on west coast; migration of blue whales along west coast.

- Blue whale research, south-east Australia: Dr Peter Gill, Margie Morrice, (Deakin University, Australocetus Research). Ecology of south-eastern Australian blue whale feeding areas: habitat and prey studies, blue whale distribution, feeding and acoustic behaviour; year-round acoustic monitoring of blue whales (with Scripps Institution and Curtin University (Dr Rob McCauley); seismic survey mitigation studies (with Santos Ltd); blue whale diet studies with AAD (Dr Simon Jarman).

- Blue and humpback whale satellite tagging: Dr Nick Gales (Australian Antarctic Division)), Curt Jenner (Centre for Whale Research), and Dr Peter Gill (Deakin University). Main objectives: to investigate migratory movement of blue and humpback whales between southern Australia, tropical wintering areas, and feeding areas; also to investigate foraging movement of blue whales within temperate feeding areas.

- Blue whale study in Geographe Bay: Chris Burton (Western Whale Research). Annual land, vessel and aerial surveys to obtain distribution, movement, behavioural and photo-ID data for blue whales. Proposed satellite tagging and genetic sampling.

- Whalewatching study, IFAW

- Killer whale study, Whale Ecology Group – Southern Ocean, Deakin University, Warrnambool, VIC (Margie Morrice). Main objectives to compile and research sighting and stranding data for killer whales from Australia's territorial waters.

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4.26 Marine pests in South Australia from Kangaroo Island to the Great Australian Bight

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Introduced marine species in Australia are derived from most of the major marine groups including (amongst others), ascidians, bivalves, crustaceans, echinoderms, bryozoans, annelids, dinoflagellates, cnidarians, macro- and micro-algae and fish. There are 200-250 introduced and cryptogenic marine species in Australia (Thresher 1999, McEnnulty *et al.* 2001), with 37 reported across South Australia and 43 in West Australia (NIMPIS 2005), although the actual number of introduced species at the state and national levels may be much higher (Hayes and Sliwa 2003). The precise number can never be known in part due to the lack of skilled observers that can identify exotic species, lack of information on Australian marine systems prior to settlement and a lack of certainty about the invasion status of some species. Finally, as of 2001, only 21 of the 72 trading ports in Australia have been surveyed for introduced marine species (McEnnulty *et al.* 2001).

Marine pests have gained recent notoriety both in Australia and overseas (SCC/SCFA 1999), but many introduced organisms, while undesirable, appear to do no lasting damage in their adopted system (McEnnulty *et al.* 2001, Hayes *et al.* 2005). A number of species in Australian waters are described as “cryptogenic” with broad, discontinuous, distributions across a number of continents such their origin cannot be readily determined. In terms of actual pests, there are currently 12 introduced species on the Australian Ballast Water Management Advisory Committee target list, however this list is currently being reviewed. Hayes *et al.* (2005) identified 23 medium and high priority species. These taxa will be assessed and “agreed pests of concern” will be the target of the National System for the Prevention and Management of Marine Pest Incursions (the National System) that is currently being developed to ensure consistent management arrangements across State/NT and Federal governments. The composition of both groups is subject to change as new species are introduced or become apparent.

The priority approach to pest management suffers from our lack of knowledge of the actual damage a pest may inflict (McEnnulty *et al.* 2001, Hayes *et al.* 2005) as well as from the problem of “lag phases” or periods after arrival wherein an exotic species has no apparent major influence, but then suddenly rapidly increases in population/density and potential for impact (Crooks and Soulé 1999). Examples include the Asian mitten crab (*Eriochier sinensis*) that failed to expand into its preferred habitat (slow-flowing rivers) in the United Kingdom until an unprecedented drought from 1989-1992. Similarly, the sediment-dwelling bivalve *Musculista senhousia* population in Mission Bay San Diego exploded with densities of up to 170,000 individuals per m^2 after unusually high rainfalls (Crooks and Soulé 1999). Once established the chances of eradication of an introduced marine pest is limited (McEnnulty *et* *al.* 2001) and thus the primary approach to marine pest management relates to identification and control of potential vectors (Thresher *et al.* 1999).

Status

West Australia has a total of 43 marine pests recorded (NIMPIS 2005) of which 10 are medium to high priority (based on Hayes *et al.* 2005). In spite of having a relatively shorter coastline South Australia has 37 marine pests (NIMPIS 2005) of which 12 are potential cause for concern (Hayes *et al.* 2005).

In terms of marine pests reports within the zone from KI to the GAB, reports are somewhat limited, although the highest number of pests is almost certainly in the area encompassing Adelaide (in zone SVG) with 22 species recorded in the Outer Harbour of Port Adelaide (Cohen *et al.* 2001). Otherwise the only other dedicated survey to marine pests in the region was at Port Lincoln (CRIMP 1996) with six species reported. Port Lincoln is probably SA's second busiest destination after Adelaide but there are a relatively large number of other ports and harbours within the zone that are subject to international shipping (SCC/SCFA 1999). South Australia has the least number of ports surveyed for marine pests in Australia (2 out of 12 ports) so there may be other marine introductions that have not been detected (see Hewitt and Martin 2001).

Apart from the surveys of Outer Harbour at Port Adelaide and Port Lincoln, reports of marine pests for the region are sporadic and/or constrained to specific taxonomic groups and/or have been inferential. Shepherd and Thomas (1982, 1989) and Shepherd and Davies (1997) suggested the presence of 12 introduced marine species in Eyre Peninsula and Spencer Gulf region (Table 4.26.1). Kott (1985) in a summary of Australian ascidians reported four introduced species in Gulf St Vincent; *Botrylloides leachii*, *Botryllus schlosseri*, *Ascidiella aspersa* and *Styella clava*, of which one (*Botrylloides leachii*) also occurred at Topgallant Island, somewhat distant from likely sources (EYR Bioregion) (IMCRA Technical Group 1997). *Botrylloides leachii* occurs on all Australian coasts as well as New Zealand, southeast Asia and much of Europe and has been described as cryptogenic (NIMPIS 2005). All the above species were later observed in more comprehensive harbour surveys (CRIMP 1996, Cohen et al. 2001).

Table 4.26.1 - List of introduced marine species reported from the South Australian coast between KI and the GAB. * denoted high priority pests based on the Australian Ballast Water Management Committee list.

Source(s)	**Type**	**Species**
Shepherd and Thomas 1982, 1989, Shepherd and Davies 1997	Hydroids	SARSIA RADIATA
		Obelia dichotoma
	Polychaets	*Myxicola infundibulum*
	Bryozoans	*Bugula neritina*
		Bugula flabellate
		Schizoporella unicornis
		Zoobotryon verticillatum
		Cryptosula pallasiana
	Ascidians	*Ascidiella aspersa*
		Botryllus schlosseri
		Botrylloides leachii
		Styela plicata
Kott 1985	Ascidians	*Ascidiella aspersa*
		Botryllus schlosseri
		Botrylloides leachii
		Styela plicata
CRIMP 1996	Dinoflagellates	*Gymnodinium catenatum* *
	Ascidians	*Ascidiella aspersa*
	Hydroids	*Sarsia eximia (= rediata)*
		Helecium deliculatum
	Bryozoans	*Schizoporella unicornis*
		Cryptosula pallasiana
		Watersipora arcuata
Cohen *et al.* 2001	Dinoflagellates	*Alexandrium catenella*
		Alexandrium minutum *
		Alexandrium tamarense
	Ascidians	*Ascidiella aspersa*
		Botryllus schlosseri
		Botrylloides leachii
		Ciona intestinalis
		Styela plicata
	Polychaets	*Sabella spallanzanii* *
		Myxicola infunibulum
	Crustaceans	*Carcinus maenas* *
		Caprella penatis
		Corophium acherusium
		Elminus modestus
		Monocorophium insidiosum
		Paracerceis sculpta
		Pseudoplydora paucibranchiata
		Sphaeroma quoianum
	Bryozoans	*Bugula nertina*
		Schizoporella errata
		Watersipora arcuata
	Bivalves	*Musculista senhousia*
	Chlorophytes	*Ulva luctuca*
Boxall and Westphalen 2002	Chlorophytes	*Caulerpa taxifolia*
Womersley 2003	Chlorophytes	*Caulerpa racemosa* v. *cylindracea*

There are at least 24 introduced marine species in the zone from KI to the GAB (Table 4.26.1), although some of the species recorded in the region (*Sarsia eximia, Zoobotryon verticillatum, Sphaeroma quoianum, Elminus modestus, Corophium acherusicum* and *Caprella penatis*) do not appear in the SA summary (NIMPIS 2005). This may be due to revision of the species identifications, taxonomic debate and/or confusion. Of these 24 species, five are considered to be high priority marine pests and therefore targeted for management strategies:.

- *Alexandrium minutum*
- *Carcinus maenas*
- *Gymnodinium catenatum*
- *Musculista senhousia*
- *Sabella spallanzanii*

Detailed description of each species, their impact to native system, vectors and control/management strategies can be found elsewhere (e.g. McEnnulty *et al.* 1999, Hayes *et al.* 2005, NIMPIS 2005).

Habitat and distribution

There are numerous vectors that may introduce or translocate (spread) marine species, with ballast water and hull fouling major transfer mechanism, particularly over larger distances (e.g. Carlton 1985, Geller and Carlton 1993, Ruiz *et al.* 1997 Thresher et al 1999). Alternative or additional vectors (Ribera and Boudouresque 1995, Ruiz *et al.* 1997) include (amongst others):

- Commercial and recreational fishing
- Aquarium trade
- Aquaculture

Ballast water discharge is one long-range vector for marine introductions and there is substantial shipping traffic in SA's gulfs although the available data is limited to the early 1990s (~ 140 ship visits across 8 ports in 1991; Kerr 1994). However, apart from Outer Harbour at Port Adelaide (26 ship visits in 1991) and Port Lincoln (16 visits) there have been no systematic surveys for marine pests at other ports and harbours in the SA coast. Even accounting for the lack of up-to-date information, shipping traffic in SA is much lower than in WA with 101 ship visits to Geraldton, 176 to Bunbury and 322 to Fremantle in the same period (1991; Kerr 1994). In the decade since the Kerr (1994) report, shipping is unlikely to have declined, particularly with the completion of the Adelaide-Darwin rail link that is likely to have promoted shipping traffic in both harbours.

Hull fouling on commercial and recreational vessels is another vector. Hull fouling is possibly underrated as a vector for translocating introduced species in the southwest zone, particularly given the large number of coastal fishing vessels and increasing recreational boating throughout the region. For example, the Outer Harbour area, in the Port River at Adelaide has at least 22 known exotic species (Cohen *et al.* 2001) with 17 in the nearby North Haven marina and a further 5 at the Royal South Australian Yacht Squadron. Although the area defined by Outer Harbour, and the marinas at North Haven and the RSAYS is relatively small, the absence of commercial shipping within the latter would suggest that recreational and small boat users is a significant vector for marine pests. Before the use of antifouling paints hull fouling was certainly a vector for marine pests, which may explain the cryptogenic distribution of many fouling organisms. The historical role of shipwrecks in marine pest distribution is also potentially underrated.

Relatively pristine habitats may be more resilient to invasion, and in the absence of major developments, (port and harbour facilities and marinas), the potential for invasion may be slowed, but there is increasing demand for waterfront housing. Coastal developments such as marinas, jetties or breakwaters may be considered from three interrelated perspectives.

1. There is the possibility of introducing or enhancing the distribution of a marine pest by the act of construction.
2. A development presents a large expanse of pristine habitat within an area that may not necessarily support species with the capacity of taking advantage (i.e. a seagrass dominated). Invaders, that may be local species from outside the general area, as well as pest species, may be afforded a substantial opportunity.
3. There is the ongoing probability of introducing pest species from other infected areas by virtue of the increased boating traffic.

The disturbance created during construction of a marina is likely to favour opportunistic marine organisms that tend to have high fecundity and rapid growth. Many of the most successful introduced species have these “weedy” properties and are thus likely to be successful in a disturbed habitat (ref?). Similarly the pristine substrates created by construction would also favour taxa with these habits.

Impacts and threats

Possibly the greatest threat to marine systems and industries in the KI to GAB region may derive from *Caulerpa taxifolia*, a more recent introduction the Port Adelaide area with as yet uncertain implications for the State in terms of potential threats to marine systems and industries. *Caulerpa taxifolia* was discovered in the upper Port River and West Lakes development in northwest metropolitan Adelaide in March 2002 (Cheshire *et al.* 2002). Since that time has sparked an intensive program of monitoring and eradication research (Cheshire *et al.* 2002, Collings *et al.* 2004a, Westphalen *et al.* 2004).

The aquarium strain of *Caulerpa taxifolia* is considered to be amongst the top 100 “world worst” invasive species (ISSG Global Invasive Species Database 2005) and has resulted in substantial damage to marine systems and industries throughout the Mediterranean (Woodfield 2001. The strain of the alga in SA is still uncertain in terms of its affinities, but it is suspected of having been transferred to the state via the aquarium trade (Cheshire *et al.* 2002).

Different strains of *C. taxifolia* have also been subject to substantial control measures and research (e.g. Creese et al 2004, Glasby *et al.* 2005a, 2005b), although the alga appears to be restricted to shallow coastal estuaries in NSW. However, the Adelaide strain is different from both the Mediterranean “aquarium” strain and that occurring in NSW (ref?). Furthermore, the areas in which it currently grows, the Port River / Barker Inlet estuary is substantially different the adjacent Gulf St Vincent, being shallower, less turbulent and maintaining a substantial nutrient load (EPA 2002). The behaviour of the alga in the Port River, where it forms dense, blanketing beds, is thus no indication of the growth habit in the open gulf. Of great concern is the evidence that *C. taxifolia* will out compete seagrasses, in particular *Posidonia* spp., which may have major consequences for southern coasts, but the level of potential threat has yet to be determined.

Removal of *C. taxifolia* from West Lakes in 2003 was achieved by diluting the entire water body (~ 4.3 GL) with stormwater (Collings *et al.* 2004a). This attempt has proved highly successful and is probably the largest successful eradication of the alga anywhere in the world. However, the stand of *C. taxifolia* in the Port River has proven to be more difficult to control (Westphalen *et al.* 2004), and the alga still poses a potential threat to coastal systems in industries across southern Australia. More recent expansion of the population has made the possibility of complete eradication unlikely.

There is a high level of morphological variation within *Caulerpa* species (Taylor 1960, Ohba *et al.* 1992, Carruthers *et al.* 1993), which may explain its broad geographical range (Womersley 1984, Huisman and Walker 1990, Ohba *et al.* 1992) as well as the recent notoriety that some members of the genus have recently gained as marine pests. *Caulerpa racemosa* (Forsskål) J. Agardh *sensu lato* is thought to represent an extreme manifestation of this variation (Taylor 1960, Peterson 1972, Ohba *et al.* 1992, Carruthers *et al.* 1993) as the taxon has been variously divided into a number of different varieties and forms, the delineation of which is often difficult, if not impossible in a hand specimen (Carruthers *et al.* 1993). *C. racemosa* var. *cylindracea* is, along with *C. taxifolia*, considered to be a substantial threat to systems in the Mediterranean (Ceccherrelli *et al.* 2002, Piazzi and Ceccherelli 2002) and may have derived from WA (Verlaque *et al.* 2003). A very similar, or possibly the same strain also occurs in the Port River estuary (Womersley 2003), where it appears to have rapidly expanded. The status of this alga in SA is thus problematic, but a natural range extension is unlikely (Collings *et al.* 2004b).

Key references and current research

Research on marine pests currently relates to risk assessment, vector management (ballast water treatment), detection systems (gene probes) and distribution monitoring (notably *Caulerpa taxifolia*). Research into eradication measures is limited as application of control strategies to the marine environment is problematic at best. CSIRO research into daughterless carp suggests a potential avenue for biological control of other aquatic pests, although this approach cannot be employed universally and the techniques need to be developed.

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