Initiation of Marine Biological Inventory Targeting Regional Hotspots

Literature Review for the Northern and Yorke Natural Resources Management Region Committee Inc.

Government of South Australia

Department for Environment and Heritage

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For further information please contact:
Coast and Marine Conservation Branch
Natural and Cultural Heritage
Department for Environment and Heritage
GPO Box 1047
Adelaide SA 5001

Telephone: (08) 8124 4900
Facsimile: (08) 8214 4920

Project Team:
Bryan McDonald (Scientific Officer, Marine Protected Areas) Coast and Marine Conservation, DEH
Ali Bloomfield (Research Officer, Marine Protected Areas) Coast and Marine Conservation, DEH

Initiation of Marine Biological Inventory Targeting Regional Hotspots – Reef Health Project

Table of Contents

Figures, Tables and Plates

1.0 Project Summary

Current knowledge of the ecology of South Australia's marine environment is restricted in most parts to spatial scales that are not suitable to underpin regionally based management. Management practices typically target the maintenance of environmental condition, the exclusion or control of exotic taxa and the regulation of activities within specific localities or regions. The key to successful management, therefore, lies in the ability of managers to understand the current state of systems within the area of interest (including biological health and the presence of natural and anthropogenic stress agents) and to be able to predict the effects of future activities on those systems.

With the development and expansion of new and existing resource uses comes threatening processes that enhance the capacity to change environmental conditions. Changing environmental conditions are a cause of stress in resident biological communities, and those stresses are often additive (Turner and Cheshire 2002). Where a healthy system can generally withstand an impact, an already stressed one may suffer further degradation. Therefore persistent agents of change are likely to increase the susceptibility of ecological systems to acute disturbance events and the invasion of exotic taxa: an undesirable natural resource management outcome (Turner and Cheshire 2002). Hence the need to initiate research programs that inform managers at a hierarchy of scales, beginning with the assessment of individual areas and culminating with an understanding of variability within a region. The assessment of each ecological system at the proposed level would empower managers to identify particular condition targets specific to areas and broader protocols throughout an area of responsibility.

The Northern and Yorke Natural Resource Management Region (NYNRMR) Committee has identified within their current *Regional Plan* and associated *Investment Strategy* a priority need to identify resource condition and initiate appropriate management actions for marine ecological systems. The initiative has clear linkage opportunities with the South Australian Government's commitment to the development of regionally based Marine Plans and a representative network of Marine Protected Areas (MPAs) throughout the State. The integration of management initiatives through the establishment of ecosystem specific biodiversity inventories, the establishment of representative protected areas, and the implementation of broader regional planning and ecosystem condition monitoring is a desirable management outcome.

A scheduled agreement between the NYNRMR Committee and the Department for Environment and Heritage (DEH) has been established that engages the Department to undertake a survey of the biodiversity of shallow subtidal reefs in the NYNRMR. The project will establish monitoring sites, survey protocols and reef health indicators to underpin resource condition assessments in the region, and is integrated with the broader *Reef Health Project* (which extends from the Murray Mouth and includes metropolitan Adelaide) run by SARDI Aquatic Sciences in partnership with DEH. The following literature review fulfils the Department's contractual obligations to the NYNRMR, providing a summary of temperate reef ecology in Southern Australia and the region specifically. Also included is a synopsis of monitoring protocols and expected outcomes from the project.

2.0 Temperate Reefs in Southern Australia

The temperate waters of Southern Australia (see Figure 1) are unique both in terms of the variety of species that they harbour, and the levels of endemism within the reef communities in particular. Physical, chemical and biological processes all influence reef ecology. Physical influences include substrate, exposure and water turbidity. Chemical influences include nutrients and salinity. Biological processes include competition and predation between individuals and species.

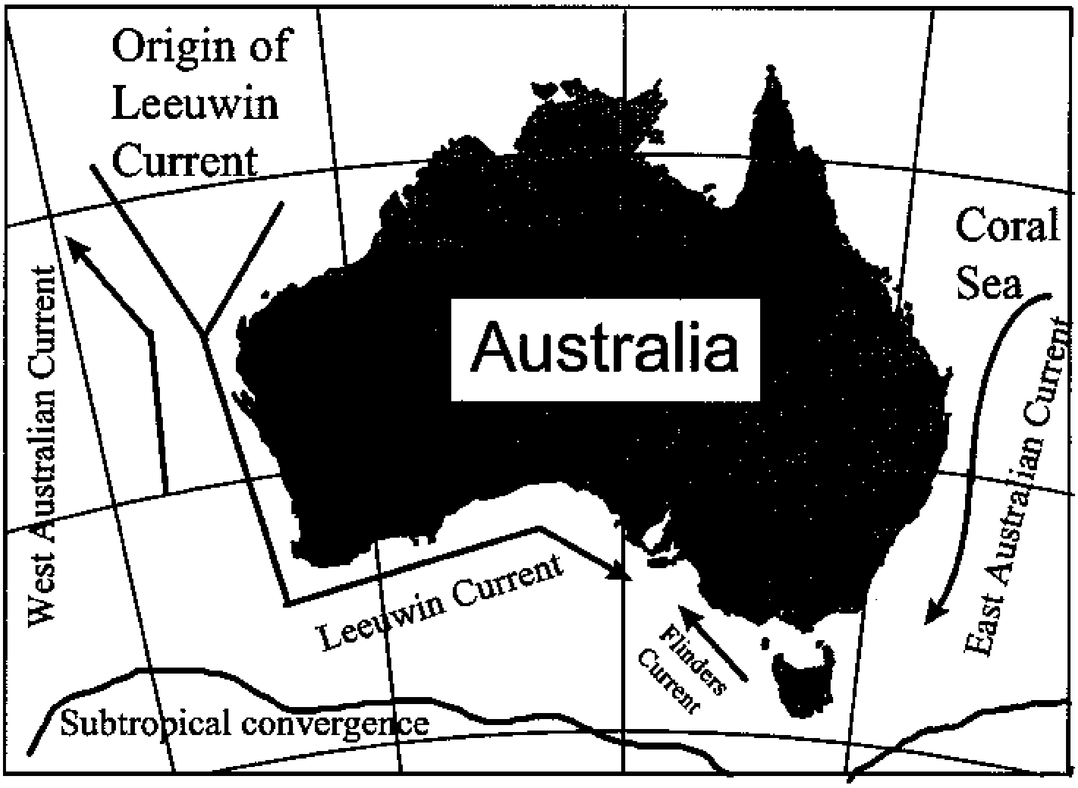

Figure 1: Southern Australian waters include waters off the south coast of Western Australia, east to New South Wales and Tasmania. The major influencing currents are shown (Cheshire *et al.* 1998 pg4)

Reefs consist of a hard surface to which organisms attach themselves, forming structured habitat for other flora and fauna. In the tropical regions reefs are dominated by corals, which can build on themselves allowing them to grow and expand in size. In temperate regions reefs are mostly dominated by macroaglae (seaweed) and invertebrates (eg sponges, ascidians), that attach to rocky outcrops or other hard surfaces, such as jetty pylons and shipwrecks. The Southern Australian coastline mostly consists of promontories on rough coasts of Precambrian granites or gneisses, usually steeply sloping, interspersed with horizontal calcareous rock platforms (Womersley 1984). This gives rise to either calcareous flat, platform reefs or to granitic reefs with high relief. The physical and chemical environments in temperate waters are also very different to those in tropical waters. Temperate waters are much cooler and usually have comparatively higher dissolved nutrients than tropical waters.

The macroalgal assemblages associated with reefs in South Australia are regarded as being highly productive. Annual primary production has been estimated as 20-40 kg of wet weight per metre squared per annum (from a typical standing biomass of 3-6 kg of wet weight per metre squared) (Cheshire *et al.* 1998). This is comparable to productivity of cereal crops and sugar cane fields and it also makes reef productivity three times higher than that of inter-reefal seagrass systems (Cheshire *et al.* 1998). Therefore temperate reefs contribute significantly to primary productivity and ecosystem services.

Kelp is a dominant macroaglae in Southern Australia (see Plate 1) and can form large mono-specific and mixed algal communities on shallow subtidal reefs. Kelps concentrate biomass and are a significant source of nutrition for coastal marine ecosystems (Duggins *et al.* 1989; in Steneck *et al.* 2002). This is mostly through detrital breakdown by detritivores and microbes, as herbivores rarely consume more than 10 per cent of the living biomass (Mann 2000; in Steneck *et al.* 2002). The complex organic carbon from kelp plants then becomes available for suspension feeders (filtering food from the water). Therefore macroalgal reef systems in temperate waters are a major contributor of complex organic carbon to coastal ecosystems.

Plate 1: An exposed granite reef with mixed brown algae, dominated by kelp.

Reef communities of Southern Australia are unique on a global scale, due to their extreme diversity and high proportion of endemic species (see Tables 1 and 2). In fact, it is estimated that 80-90 per cent of Southern Australian marine species are endemic to the region (Poore 1996), compared to less than 15 per cent of tropical Australian marine species being endemic. This unique species diversity and endemicity of Southern Australia can be attributed to three main factors:

1. the oceanographic isolation of Southern Australian coasts from other temperate coasts;
2. the comparatively long stretch of coastline at relatively constant latitudes; and
3. (with respect to endemism) that our waters are comparatively naturally nutrient poor compared to other similar coasts (Cheshire *et al.* 1998).

Table 1: Diversity and endemism of major temperate reef taxa in Southern Australia (Cheshire *et al.* 1998 pg5).

Taxonomic group	Diversity (number of species)	% Endemic	Source
Fishes	600	85	(Poore 1996)
Molluscs		95	(Poore 1996)
Echinoderms		90	(Poore 1996)
Chlorophyta (green algae)	124	30	(Womersley 1990)
Rhodophyta (red algae)	800+ (currently > 1000)	75	(Womersley 1990)
Phaeophyta (brown algae)	231	57	(Womersley 1990)

Table 2: Comparative diversity of macroalgal taxa (Womersley 1990).

Region	Coast length (km)	Temperature range	Number of species
Southern Australia	5,500	Cool-warm temperate	1,155
NE North America	8,000	Arctic-warm temperate	399
Pacific North America	12,000	Arctic – tropical	1,254
Japan	6,500	Subarctic – subtropical	1,452
New Zealand	6,970	Subantarctic warm temperate	835

2.1 Oceanographic Isolation

The two major oceanographic currents on both sides of Australia (the Eastern Australian Current and the Leeuwin Current) have acted to isolate the temperate waters of Australia from other temperate coastlines and regions. As the waters in the tropics are warmed they flow south along the east and west coasts to the cooler, denser waters of the temperate region (see Figure 1). These currents bring with them tropical larvae and plankton that can survive during summer further south (this is particularly well documented in New South Wales), however, they die out in winter and never successfully perpetuate the population in lower latitudes. The two major currents act to largely isolate the Southern Australian coast from the westerly flowing currents in the Southern Ocean. This limits the dispersal of larvae and plankton between Southern Australia and other temperate regions, except for some exchange with New Zealand, resulting in a high proportion of species being endemic (Cheshire *et al.* 1998).

2.2 Coast Length

The Southern Australian coastline is approximately 5,500 km long within a small latitudinal range. It is the longest east-west stretch of coast in temperate regions in the world. Most other continents that have long coastlines traverse latitudes (eg the Americas) and water temperatures. The Southern Australian coast provides a very large area of habitat with similar physio-chemical attributes (such at temperature) to species, giving them the opportunity to diverge and evolve.

2.3 Nutrient Paucity

Compared to other temperate regions, Southern Australian waters are comparatively nutrient poor. This is the result of three main factors:

1. the flow of low nutrient waters from the tropics along the east and west coasts;
2. the lack of significant upwelling zones and the slow weathering of the mainland; and
3. geological history[1] and low rainfall.

This means that even if Australia did receive inputs of larvae and plankton from other temperate regions, the likelihood of them being able to establish is reduced by the fact that Australian waters have lower nutrient content than that to which foreign species have evolved. This has contributed to the high proportion of endemic species, by way of inhibiting species from elsewhere being able to establish in Australian waters and inhibiting Australian species from being able to establish elsewhere.

3.0 Reef Structure – An Introduction to Habitat Forming Flora and Fauna

3.1 Algae

There are three major groups of algae: the green, brown and red algae. Green algae generally dominate the intertidal and upper sublittoral zones[2]. The brown algae dominate the mid sublittoral zone and in areas of low wave action, they also dominate the upper sublittoral. The red algae dominate the lower sublittoral zone and areas of lower light penetration, such as in turbid waters and under the canopy of the large brown algae.

Considering that this project focuses on shallow subtidal reefs, the focus shall mainly be on the mid-sublittoral zone dominated by brown algae, particularly kelp. An analogy between terrestrial forests and kelp forests/algal reefs in this zone can be drawn; considering both ecosystems have canopy forming species and understorey species. In terrestrial forests, trees form the canopy and upper layers. On algal reefs there are large canopy forming algae, such as giant kelp (*Macrocystis* spp. found in Tasmania, Victoria and southeast South Australia), and there are smaller canopy kelps that hold their fronds above the reef with rigid stipes (see Figure 2). These are called ‘stipitate’ kelps and are less than 5 m high (Steneck *et al.* 2002). The stipitate kelps include *Ecklonia radiata,* which is found in Southern Australia and is often the dominant algae in the mid sublittoral zone.

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[1] Australian soils are weathered and low in nutrients compared to other continents, where glacial scouring of the rock surface over geological time has revealed new, unweathered rock. There has been little glacial scouring in Australia, leaving us with the originally weathered rock surface.

[2] The coast is divided horizontally into zones, with the intertidal ranging from the highest high tide mark to the mean low tide mark. The sublittoral zone is the photic zone below the intertidal region; from about mean low tide level downwards.

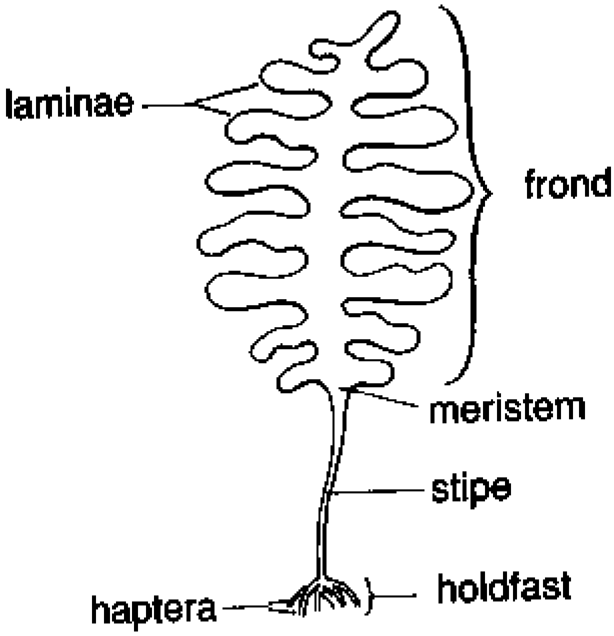

Figure 2: The basic morphology of a kelp plant is made up of a number of laminae, held up by the stipe or stem, attached to the rock by the holdfast. The holdfast consists of many separate branches, called haptera. Unlike most trees that grow from the top of the plant, kelps grow from the base of the frond at the meristem (Kennelly 1995 pg106), allowing them to continue to grow after losing the canopy.

There are other large brown algae that also form part of the canopy in mid sublittoral temperate reefs. These are called fucoids and include mostly large (reaching less than 2 m in Southern Australia) brown robust and highly branched algae (including corkweed and crayweed). The understorey in terrestrial forests includes bushes, shrubs and grasses. In a kelp forest/algal reef the understorey can include smaller algae (encrusting, turfing, and foliose[3]; see Plate 2 and Figure 3) and attached invertebrates (ascidians, sponges, corals).

Plate 2: A pale blue sponge surrounded by red understorey algae; encrusting to the right of the sponge and coralline below it. Photo by David Muirhead.

[3] Algae have a diverse range of life forms (see Figure 3). Encrusting algae are flat and very strongly attached to the reef. They are usually hard because of a calcareous or shell-like upper layer, or they can be leathery. It can also be difficult to distinguish between the encrusting algae and the rock beneath. Turfing algae are short and form dense clumps or turfs and they are much softer than encrusting algae. Foliose algae are upright branching algae that can be a few millimetres to several centimetres. They can be either tough and wiry or soft and flexible.

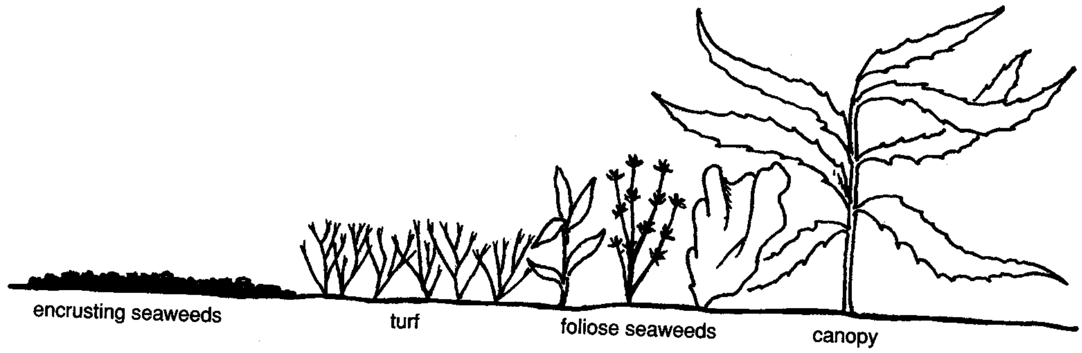

Figure 3: Types of algae found on rocky reefs: encrusting, turfing, foliose and canopy forming (Underwood and Chapman 1995 pg59).

Despite being able to draw an analogy between terrestrial forests and kelp forests/algal reefs they are incredibly different. Kelp forests are more productive and diverse (at the phyla level) than terrestrial forests, but the average lifespan of plants and height of the canopy is less (Steneck *et al.* 2002).

3.2 Attached Invertebrates

Included in the understorey and structure of algal reefs are attached invertebrates. These are filter-feeding animals that gain nutrition from filtering particles from the water column. They include sponges, ascidians, bryozoans, anemones, bivalves and corals to name but a few. In shallower depths, algae dominate space on a reef because of the available light and other favourable conditions that enable them to out-compete animals. At depth more and more light is scattered and less penetrates the water column. In Southern Australia, light penetrates between 10 and 50 m deep (the photic zone), but may be less in some inshore waters (Womersley 1984). Beyond the photic zone algae and other photosynthetic plants cannot photosynthesize. It is here that sessile or attached invertebrates dominate reefs, forming *sponge gardens*. Invertebrates also dominate the underside of overhanging rocks, vertical surfaces, and other shaded places.

There are a few incidences of animals dominating reefs at shallower depths, where significant light still penetrates. This mostly occurs in areas of high water flow, such as Backstairs Passage. In areas of strong currents or high water flow filter-feeders are favoured because there is a good food supply for them to thrive on. This enables them to out-compete algae, which would potentially suffer from the high water flows that could remove them from the reef.

4.0 Reef Ecology

Ecology attempts to describe the distribution and abundance of organisms. The limiting factors could be abiotic or biotic, including interactions with other organisms through competition and predation (Underwood and Chapman 1995). Shepherd and Womersley have undertaken a series of studies in South Australia (1970; 1971; 1976; 1981) on the macroalgal communities of reefs. They proposed a mosaic chart of the distribution of algal communities (see Figure 4).

Where communities are *"a distinctive assemblage of interacting organisms, usually with one or a few dominants which govern the appearance of the community and usually account for* *a high proportion of the biomass"* (Womersley 1984 pg 43). There is also graduation between communities, especially subtidally, where one community fades into another, with distinct communities usually being associated with particular environmental regimes.

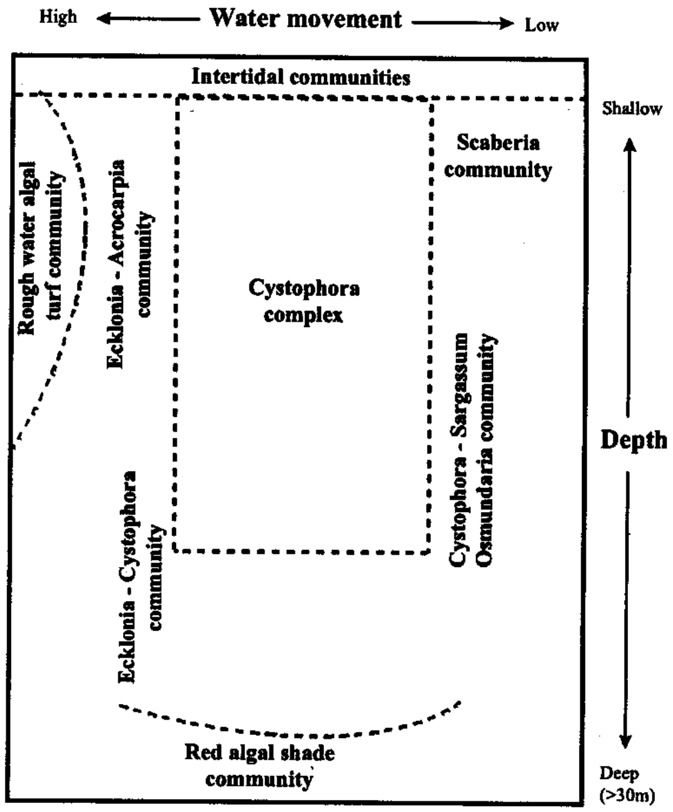

Figure 4: Schematic showing the relationship of macroalgal communities to water movement and depth on South Australian reefs (based on Shepherd and Womersley 1981) (Cheshire *et al.* 1998 pg 8).

Shepherd and Womersley's work provided three important conclusions:

- that there are consistent patterns of vertical zonation on South Australian coasts;
- that this zonation can be divided into three levels; but
- that zones may be characterised by a variable array of species at different sites.

There have been similar studies to Shepherd and Womersley's in Southern Australia, some that have supported the above conclusions and some that have not (see Cheshire *et al.* 1998). As these other studies are from eastern Australia (Sydney and Tasmania), which have been shown to be different to South and Western Australia (Fowler-Walker and Connell 2002), we will consider the studies by Shepherd and Womersley from South Australia as relevant and discuss them further here.

In areas of high water movement in shallow waters, communities are dominated by turfing algae that can persist in agitated water. This community can extend as deep as 8-10 m on horizontal and sloping surfaces on high energy coasts (Shepherd and Womersley 1981). As water movement decreases with depth and/or exposure, communities become dominated by *Ecklonia radiata* and other large, brown canopy forming algae.

At shallower depths *Acrocarpia paniculata* is often co-dominant with *Ecklonia. Cystophora spp.* are the common co-dominants deeper than approximately 10 m (see Figure 4). These communities can be found from 2-25 m deep, mostly on horizontal surfaces.

A *Cystophora* complex is found in the intermediate range of water movement and from the intertidal to deeper waters. Here the canopy consists of many species of *Cystophora*, each with their own distribution relating to water depth and movement. They occur on rock of moderate to low relief and in places subject to abrasion by sand. In areas of low water movement in the upper sublittoral *Scaberia* dominates the community, along with several other brown alga. This community can be found as deep as 8 m in areas of very low water movement. Deeper than this (7-11 m), in areas of low water movement, a *Cystophora-Sargassum-Osmundaria* community is found, with a rich understorey of red algae.

Red 'shade' algae that thrive in lower light conditions dominate deeper water reefs. They can be found between 6 and 25 m on vertical surfaces and under canopy-forming algae, and 25-28 m (or deeper) on horizontal surfaces. Beyond the limits of the red algae attached invertebrates dominate space on reefs.

4.1 Food Webs

Food webs of reef habitats can vary considerably, depending on the species present and a great variety of mobile animals inhabit temperate reefs. In any basic food web there are the primary producers (usually photosynthetic plants), detritivores, herbivores and carnivores. On algal reefs the primary producers are the seaweeds, phytoplankton (microscopic algae) and epiphytic algae (algae that live on other algae). Detritivores are mostly small invertebrates, such as polychaetes (worms), isopods, shrimps and crabs. The herbivores and carnivores include zooplankton (microscopic animals), invertebrates, and fishes (see Figure 5). Carnivores on temperate reefs also include marine mammals and birds.

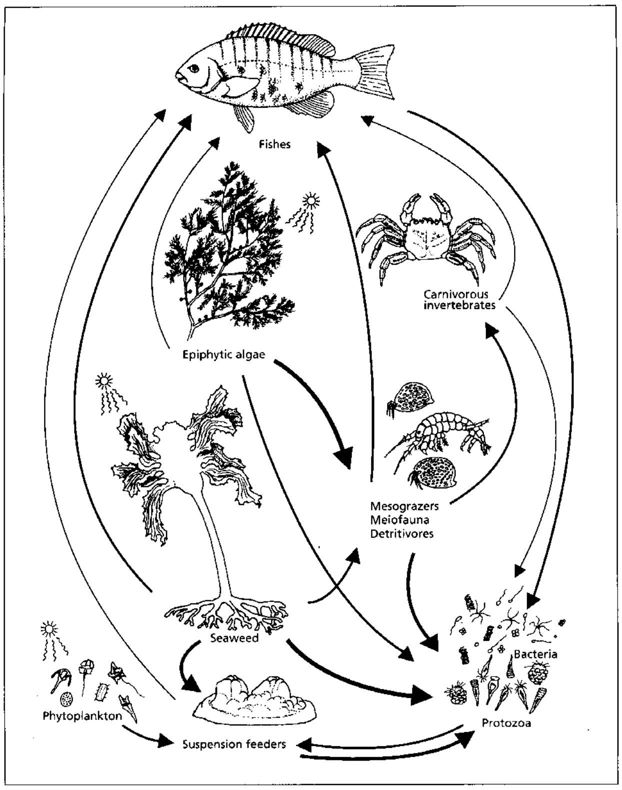

Figure 5: Food web showing major dietary linkages in a kelp forest. The width of arrows reflects the relative importance of each linkage (Edgar 2001 pg184).

Detritivores, bacteria and suspension feeders rapidly consume macroalgae that is released as detritus. Algae are also consumed by herbivores, however as mentioned earlier, detritivores consume much more of the biomass. The detritivores are in turn eaten by carnivorous invertebrates and fishes, which are eaten by larger animals. These interactions between algae, herbivores and carnivores on temperate reefs are very important to maintaining the 'balance' or resisting change on the reef.

4.2 Herbivores

There are several groups of grazers that are strict herbivores on algal reefs, making them directly dependent on primary production from algae. The most conspicuous of these are some fishes, sea urchins, abalone, and other molluscs. Of the herbivorous fishes, herring cale (*Odax cyanomelas*) is the only one that grazes on kelp directly and female herring cale have been known to denude patches of kelp beds at particular times of the year (Jones and Andrew 1990). Most other fishes graze on a variety of algae and include luderick (*Girella tricuspidata*), marblefish (*Aplodactylus arctidens*), scalyfin (*Parma victoriae*), numerous leatherjacket species, silver drummer (*Kyphosus sydneyanus*) and western buffalo bream (*Kyphosus cornelii*) (Edgar 2001).

Of the herbivorous fishes, apart from herring cale, scalyfin are interesting in their behaviour and their ability to affect algal structure. Scalyfins are damselfish and are territorial like their tropical cousins. It has been noted that they maintain turfing algae in particular areas for nesting by removing other algae. It has also been suggested that they may affect other non-territorial fishes and their foraging behaviour (Jones and Andrew 1990). For example, Jones and Andrew (1990) suggest that leatherjackets may be forced to forage more intensively between scalyfin territories, as they are forced out of these areas. Although there is a relatively small portion of herbivorous reef fish species, they are often abundant and grow to a large size (for example silver drummer), contributing more than half of the total weight of reef fishes (Edgar 2001).

Sea urchins are another important herbivore and can be very abundant on reefs with high relief or topography, where they rely on crevices for protection from predation. Some sea urchins wrap themselves in large brown algae and graze on the tips, while most prefer the softer foliose algae near the seabed or drifting algal fragments (Edgar 2001). Abalone and other large molluscs also capture drifting algae, however unlike sea urchins, they do not have spikes to capture the algae. Instead they use their 'foot' (the sticky side of the animal that creates suction onto the rock/substrate) by lifting their shell and grabbing the algae with this muscular part of their body. Limpets, turbinids and other large grazing gastropods generally eat the soft turfing algae or microscopic algae attached to the reef (Edgar 2001).

Large mobile herbivores on algal reefs can play an important role in structuring the reef, by the amount of grazing pressure they exert. The best-documented example of herbivore pressure on algal reefs is that exerted by sea urchins. It has been documented that sea urchins have the ability to exert such grazing pressure on algae so as to wipe them out, creating what is know as 'urchin barrens' and is thought to be an alternative state to the algae-covered reef. Although fish can exert large grazing pressure on algae also, they are much more mobile than urchins and can select their preferred food. Sea urchins, however, may be restricted to graze within a distance of their crevice where they shelter from predation and cannot cover as much distance as a fish in the same period of time. They are therefore generalist grazers, as they cannot afford to expend the energy to find their preferred food.

Less conspicuous grazers (mesograzers, mostly invertebrates such as amphipods, gastropods and isopods) are actually the most important grazers in macroalgal reefs. They may reach very large densities of 50,000 per square metre and over 50 different species of mesograzers can be found on one plant alone (Edgar 2001). Mesograzers could be a very important link in the food web as they can be the major dietary component of common reef fishes such as wrasse and morwong, however, little research has been done on their feeding habits.

4.3 Carnivores

Carnivores can play a very important role on reefs by controlling herbivore numbers. They can also control reef structure by preying upon attached invertebrates preferentially. For example, in north America the predatory sea star *Pisaster ochraceus* eats mussels which would otherwise monopolise space, creating alternative stable states depending on its presence/absence and two very different food webs (Edgar 2001).

In South Africa, another dichotomous food web has been identified between predatory whelks and lobsters around inshore islands. At a particular island mussels, sea urchins, whelks and barnacles dominate the habitat. At another nearby, seaweed and rock lobsters dominate the reef. Rock lobsters eat mussels, removing them from the reef and allowing seaweed to grow. Confounding this, when whelks are present in high numbers they attack rock lobsters, allowing mussels to dominate space by removing their major predator (Edgar 2001). These two major interactions create two very different stable states on what could otherwise be similar reefs.

In Port Phillip Bay, Victoria, it has also been documented that in the absence of predatory fish, reefs become colonised and dominated by ascidians. When fish are present they eat the ascidians as they settle, allowing bryozoans and other sessile animals to colonise the reef (Edgar 2001). Leatherjackets are one of the key fish species believed to be important predators of sessile animals on reefs.

Predators of large animals consume more prey by weight, however, they may not have as significant influence on population numbers as planktivores. Planktivores consume the larvae of animals and may have a disproportionate impact on certain species by consuming most of their young.

5.0 Ecosystem Health and Threats

The metaphor of the ‘health’ status of an ecosystem has been used for over half a century (Boesch and Paul 2001). However, how the definition of ecosystem health is ambiguous and it has been argued that ecosystem health is not really a scientific measure, as ‘ecosystem health’ does not exist outside of human value judgements. There is great spatial and temporal variability within any ecosystem type and who is to argue that one state is more ‘healthy’ than another other than to place a value judgement on the characteristics that those states possess.

Recognising that ecosystem health is a human value judgement we can progress to considering what we value in an ecosystem to make it 'healthy.' Some consider that it is the integrity or ability to resist change that defines 'health' and this is related to the original state of the ecosystem. Therefore an ecosystem is healthy if it can resist change and maintain the biological processes and species naturally found there. However, there is great natural temporal variability within ecosystems and this makes us more concerned about the variation that is not due to natural processes, but rather due to human activities.

Impacts from human activities that cause most concern as a threat to shallow subtidal reef health are those that most threaten the habitat forming species such as *Ecklonia radiata* and sponges (Cheshire *et al.* 1998). The most prominent human impacts threatening reefs include sedimentation, turbidity, nutrient enrichment, opportunistic and exotic taxa, toxicants and extractive resource use (i.e. fishing).

5.1 Sedimentation and Turbidity

An increase in sediment loads on subtidal reefs has the potential to smother algae, reducing the amount of light reaching the fronds affecting photosynthetic rates. High sedimentation loads can also affect recruitment and the growth of algae and sessile invertebrates. Similar to sedimentation, increased turbidity reduces the amount of light reaching algae at any one depth, reducing photosynthesis. Increases in turbidity and sedimentation commonly result from dredging, sewage and industrial discharges, stormwater, land reclamation and increased run off and erosion, often caused by changes in surrounding land uses.

5.2 Nutrient Enrichment

Increases in nutrients can have dramatic affects on reef communities, particularly in Southern Australian waters. These waters are naturally nutrient poor and a dramatic increase in nutrients has the potential to have grave consequences on reef communities. Increased nutrient loads of coastal waters often lead to phytoplankton blooms, which inevitably increase turbidity and reduce photosynthetic rates of attached macroalgae. These impacts can be particularly pronounced in shallow waters with little mixing, and can often result in toxic water conditions.

We are only recently beginning to understand the effects of increased nutrient loads on subtidal reef assemblages in temperate waters. A recent study at West Island, South Australia, showed that an increase in nutrients had interactive effects with grazers and canopy cover. Russell and Connell (in review) found that the loss of canopy forming algae is likely to be a precursor to nutrient driven changes of benthic assemblages. In the presence of kelp no effect was detected on macroalgal assemblages by increasing the ambient nutrients. However, when nutrients were increased in the absence of kelp and when grazers (mostly molluscs) were present foliose algae dominated the community. In the absence of kelp and grazers however, and with increased nutrients, filamentous turf-forming algae dominated space. Steneck *et al.* (2002) believe herbivory is the greatest threat to kelp forests and although they were mostly referring to urchins, these results from South Australia show that combined herbivory and nutrients have the potential to change macroalgal assemblages and reef structure.

5.3 Opportunistic and Exotic Taxa

Opportunistic and exotic taxa reduce biodiversity, smother other attached organisms and can reduce recruitment success of other species. Exotic taxa also have the potential to introduce pathogens, which can be more devastating than the organism itself. A reduction in recruitment success is particularly true for large canopy forming algae and combined with a variety of other factors, such as increased nutrients and grazers could lead to dramatic changes in reef structure. Some of the introduced species recognised as potential threats to reefs due to their invasive nature include: *Caulerpa taxifolia* (aquarium Caulerpa), *Undaria pinnatifida* (Japanese kelp), *Carcinus maenas* (European shore crab), *Ciona intestinalis* (European sea squirts), *Asterias amurensis* (Northern Pacific sea star), *Sabella spallanzanii* (Mediterranean fan worm), and *Musculista senhousia* (Asian date mussel) (Reef Watch 2002).

5.3.1 *Caulerpa taxifolia* (aquarium Caulerpa)

Caulerpa taxifolia has been a major problem in West Lakes and recently in the Port River. It was successfully eradicated from West Lakes, however, another outbreak has been recorded in the Port River. Large amounts of salt are presently being dumped on the affected area in an effort to control the outbreak. *Caulerpa taxifolia* has the ability to out compete other algae and smother invertebrates and is considered a threat to seagrass beds. It produces toxins that deter herbivores, including fish. In the Mediterranean, where it has colonised 6,000 hectares since its release in 1984, fish density and production from coastal fisheries has decreased dramatically. As it can survive up to two weeks out of water it has the potential to travel long distances in recreational boats, attached to anchors or on hulls.

5.3.2 *Undaria pinnatifida* (Japanese kelp)

Undaria pinnatifida is native to the Japan Sea and is cultivated extensively in a number of countries for fresh and dried food. It was first found in Tasmania in 1988, however, it may have been present as early as 1982. It has also established itself in Victoria, but nowhere else in Australia as yet. It was probably introduced by shipping vessels, however, not all vessels are suitable as it will only grow on the waterline of hulls. If vessels are constantly taking on and discharging cargo/water the Japanese kelp can often not establish (Western Australian Department of Fisheries 2001). It has the ability to form dense stands of macroalgae which limit the amount of light penetrating to the benthos and is likely to displace native plants and animals. The impacts of its introduction are not yet known, however, it is likely to have wide reaching effects on the reef inhabitants as it changes the structure and species present on the reef.

5.3.3 *Carcinus maenas* (European shore crab)

The European shore crab is found in intertidal habitats, as its name suggests. It can tolerate a wide range of temperature and salinity values, giving it the ability to colonise many areas of coast. It has been found in the Barker Inlet and has apparently been there for some years. It is unlikely that this species will have devastating impacts on reefs, as it does not appear to predate voraciously.

5.3.4 *Ciona intestinalis* (European sea squirts)

European sea squirts are from the northeast Atlantic, including the Mediterranean and Baltic Seas. They can tolerate very low salinities and are abundant in docks, harbours and estuaries overseas. They have been found in South Australian waters in Outer Harbour, West Lakes and more recently Seacliff reef (Reef Watch 2004). European sea squirts may not pose a major threat to subtidal reefs, however, they have the potential to become widely distributed in Gulf St Vincent.

5.3.5 *Asterias amurensis* (Northern Pacific sea star)

The Northern Pacific Sea Star is a highly invasive marine predator from the northern Pacific, around countries including Korea, China and Japan. It has already been recorded in Victoria and Tasmania and there is no known predator of the sea star in Australian waters. It is a voracious predator and is considered a threat to aquaculture and native shellfish species. It is found from the intertidal down to 25 m deep on mud, sand or rocky benthos and is limited to sheltered areas (Reef Watch 2002). As yet there are no known sightings in South Australia, however, it could easily be transported here and become established. Similar to Japanese kelp it has the potential to have major affects on subtidal reefs.

5.3.6 *Sabella spallanzanii* (Mediterranean fan worm)

The Mediterranean fan worm is fairly well established in Adelaide metropolitan waters, including Outer Harbour and most jetties and marinas. It can be found as deep as 30 m on hard surfaces, such as rocky reefs, but can also be found in sandy areas. It is fast growing and can form dense meadows. Although there is little evidence that it excludes native species, it probably competes with native suspension feeders and may interfere with their recruitment.

5.3.7 *Musculista senhousia* (Asian date mussel)

The Asian date mussel is small (3 cm long) and fast growing, reaching sexual maturity in nine months. It comes from the northwest Pacific, from waters off Siberia to Korea and Japan and China. It is found in enclosed intertidal and shallow subtidal flats (to 8 m deep) with either soft or hard substrate. It was first recorded in Western Australia in 1983, later in Victoria and in Tasmania in 1995. They are small enough to grow in water intake pipes of tankers and are transported around the oceans by large shipping vessels. It has the potential to out-compete native species and have been recorded to reach densities of 15,000 individuals per square metre in California (Reef Watch 2002). They are already in South Australian waters, however, because of their small size they often go unnoticed.

5.4 Toxicants

The most concerning toxic substances in the marine environment are those that are persistent and toxic even at low concentrations. Many inhibit growth or recruitment and are often associated with urban and stormwater runoff and industrial discharges. Toxic chemicals preferentially bind to fats instead of staying in solution in seawater and this leads to bioaccumulation in organisms. The degree to which any chemical accumulates in an organism depends on the chemical and the organism itself, however, it may be as high as 500,000 times greater within the organism than the surrounding seawater (Edgar 2001).

Suspension feeders are at the greatest risk of having high concentrations of toxicants as they filter large quantities of water and accumulate the toxicant. Algae are also likely to have high concentrations of toxic substances due to their large surface-area compared to their mass. Bio-magnification in carnivorous animals is also of concern, as they eat many times their body weight in prey, all potentially containing the toxic substance. The toxicants that are of most concern are heavy metals, tributyltin, organochlorine pesticides, dioxins and polychlorinated biphenyls.

5.4.1 Heavy Metals

There are several heavy metals that naturally occur in seawater due to rock weathering and most of these are required trace elements for metabolism. However, there are several heavy metals that in high concentrations can block metabolic processes. The toxicity of heavy metals can also be dependent on the local chemical environment including the pH and salinity. The heavy metals that are of most concern in Australian waters include mercury, copper, cadmium, lead and zinc (Edgar 2001). Apart from mercury most of these metals are usually local pollutants associated with smelters and industrial discharge. With widespread recognition of these problems there has also been more controls implemented resulting in reduced heavy metals in coastal waters.

5.4.2 Tributyltin

Tributyltin (TBT) is a stable chemical toxic to most marine invertebrates. It is an additive in anti-fouling paints for boats to prevent the hulls from becoming encrusted in organisms. However, since its development in the 1970s, it has been found to cause abnormal growth in resident shellfish such as oysters and sterilisation in others. TBT has since been banned in anti-fouling paints for boats smaller than 25 m long, however, because of its effectiveness it has not been banned in paints for larger shipping vessels. Fouled hulls on larger vessels, which travel greater distances, pose a risk to transporting and introducing invertebrates trans continentally and TBTs are recognised for their role in preventing significant spread of exotic species.

5.4.3 Organochlorine Pesticides, Dioxins and Polychlorinated Biphenyls

Organochlorine pesticides, including DDT, are persistent and toxic in the environment as was their purpose and are washed into waterways and the ocean from agricultural runoff. Some have been banned and others now have more stringent controls on them. Dioxins are by-products of industries, such as paper bleaching, and their distribution and impacts in the marine environment are poorly understood. Polychlorinated biphenyls were manufactured as insulating fluids in transformers and other electrical devices. However, since the discovery of their toxicity their use has been greatly restricted.

5.5 Extractive Resource Use

Extractive resource use is capable of instigating change in subtidal reefs. As discussed earlier there are instances where two completely different stable states of reef ecology can exist either in the same place through time (eg urchin barrens or macroalgae reef) or in close proximity to each other (eg mussel beds or macroalgae). If it is human impacts that result in the change through time from one alternative state to another then it is concerning for reef 'health.' The case of urchins dominating space through time instead of macroalgae is of concern because the change has mostly been due to human influences from removing predators.

Urchin barrens have occurred from the removal of predators of urchins, such as sea otters in California (Fanshawe *et al.* 2003) and lobsters in New Zealand (Shears and Babcock 2003), by way of 'trophic cascades.' Trophic cascades occur in ecosystems that are more strongly influenced by top-down interactions, such as predation and grazing, than by inputs, such as nutrients, being limiting. Although urchin barrens have been documented in New South Wales, none have been documented in South Australia as an alternative state to kelp/macroalgal beds as in other cases. This could be due to Southern Australian waters having typically low nutrients and therefore ecosystems are more strongly influenced by bottom-up inputs instead of top-down interactions. This ties in with the threat of increased nutrients in our oceans. Increases in inputs (nutrients) so that they are no longer limiting may invoke top-down interactions to play a more important role in structuring the reef, allowing trophic cascades to begin.

6.0 The Northern and Yorke Natural Resources Management Region

NYNRMR includes coast from Gawler east to Pt Germain, along the Yorke Peninsula. This peninsula straddles the two gulfs of South Australia, Gulf St Vincent and Spencer Gulf, which give us some of the most unique waters of Southern Australia. Gulf St Vincent is a carbonate sedimentary province with mostly limestone reefs. It has a diverse flora of macroalgae of green, red and brown alga, however, it is visually dominated by large brown algae. Algal-covered platform reefs dominate Spencer Gulf, except for in the north where there are few large brown algal dominated reefs (Edyvane 1999). Here there are more attached invertebrates and the area also has a strong relict[4] element of tropical species.

The 'foot' of Yorke Peninsula is subject to strong seasonal currents as water flows out of the gulfs due to oceanographic changes. Here there are heavy calcareous reefs with diverse and abundant reef flora. The area is also more wave exposed than the rest of the coast, with large brown algae dominating the reefs.

The waters of South Australia have been divided into bioregions with Northern Spencer Gulf, Spencer Gulf, Eyre and St Vincent Gulf bioregions within the NYNRMR (see Map 1). There are also biounit divisions in State waters, which are almost subdivisions of bioregions, however, the boundaries do not match up exactly. The NYNRMR covers the biounits of Winninowie, Yonga, Franklin, Tiparra, Wardang, Pondalowie, Gambier, Sturt, Investigator, Orontes, Sprigg and Clinton (see Map 2). Some of these either have only deep waters within the NYNRMR (Franklin, Gambier, Investigator, Sprigg) or do not have significant subtidal reefs to be considered in this project (eg Winninowie, Clinton, see Map 3).

The following information is taken from Edyvane (1999) and more details on other marine habitats and social and economic uses are available in this report.

[4] When Australia was situated further north in geological time the coast would have been dominated by tropical species. As Australia moved south tropical species would have gradually retreated to the northern parts of the country. Only those that retreated into the gulfs would have had nowhere to go and would have been isolated, preserving their tropical heritage.

6.1 Yonga

The Yonga biounit is characterised by low wave energy, which increases south of Shoalwater Point. It has subtidal macroalgal communities off of rocky shores, such as Shoalwater Point, which are dominated by a mixture of red algae with some brown algae (*Sargassum spinuligerum*). Weerona Island near Port Pirie is recorded as the only coastal or offshore island in the area, with reefs composing a small portion of the benthic habitat in this biounit.

Large colonies of stony corals have also been documented in this area. The stony coral *Plesiastrea versipara* used to be more common if the gulf, some being between 1.5 and 3 m high. The main threat to these colonies is trawling which has bought up some corals as large as 3 m. Although trawling does not occur over subtidal reefs that will be the focus of this study, the stony corals are found on subtidal reefs and therefore reefs can act as a refuge for the coral colonies.

6.2 Tiparra

The Tiparra biounit has double the amount of reef habitat that Yonga has, however, it is still less than 5 per cent. The major islands and reefs in the Tiparra biounit include Riley Shoal, Moonta Shoal, Tiparra Reef and Bird Islands (Green Island), all with predominantly low to moderate wave energy. The macroalgae on these reefs are dominated by *Sargassum* species with *Scaberia agardhii* as the subdominant species. The understorey is dominated by the prostate brown alga *Lobophora variegata* with mixed red algae species making up the remainder of the community.

Tiparra Reef is very important in the region as it contributes more than 80 per cent of the total catch of greenlip abalone in the Central Zone. It is a seagrass-reef shoal system in Moonta Bay that extends from Cape Elizabeth to Warbuto Point and Bird Islands. It is composed of flat rocky surfaces with low erosional escarpments, making excellent habitat for a diverse faunal community and is a popular fishing ground. There are also artificial reefs in the biounit, one near Port Broughton made of car bodies and another near Wallaroo of tyre modules. The *San Miguel* was a barque that ran aground in 1865 on Tiparra reef, providing extra structure for fauna to congregate around.

Bird Islands Conservation Park is composed of two small islands north of Warbuto Point. They provide important breeding and feeding grounds for birds including Pied Cormorants, Crested Terns, Caspian Terns, Pacific Gulls and Silver Gulls.

6.3 Wardang

Limestone reefs are the second most dominant benthic habitat in the Wardang biounit (38 per cent of the biounit), creating mostly low profile reefs. The area mostly experiences low to moderate wave energy, however, Wardang Island itself experiences higher wave energy. Wardang Island, Goose Island and Green Island are listed as the coastal and offshore islands in the area. On exposed rocky shores, such as Wardang, the macroalgae are dominated by *Cystophora* and *Sargassum* species, with prostate brown algae commonly growing beneath them. In moderately exposed areas, such as the east coast of Wardang, *Scaberia* and *Cystophora spp* dominate, mixed in with *Sargassum spp* and a red algal understorey.

The reefs around Wardang Island, including the one that extends to Goose Island, are considered to be highly diverse and have a large community of algae, seagrasses and benthic fauna. There are several shipwrecks in the biounit, the most recent sinking in 1975 and an underwater heritage trail has been created between them all (see the Heritage Branch of the Department for Environment and Heritage for more details).

6.4 Pondalowie

The Pondalowie biounit has much higher waver energy than the previous biounits. Islands include Daly Head Island and the Pondalowie Islands – Royston and Middle Island, part of Innes National Park. There are exposed rocky shores at Berry Bay and Formby Bay, to name a couple, which have communities dominated by *Ecklonia radiata* and *Scytothalia dorycarpa* with a red algae and crustose coralline understorey. Less exposed shores such as Daly Head, have *Carpoglossum confluens* and *Cystophora spp* with mixed red algae understorey in deeper waters. *Ecklonia radiata*, *Acrocarpia paniculata* and *Cystophora moniliformis* are found shallower in these areas, with mixed coralline algae underneath. Sheltered areas such as Royston Head have reefs dominated by *Cystophora spp* and *Ecklonia radiata* in the shallows, with *Caulerpa cactoides, Scytothalia dorycarpa* and *Sargassum verruculosum.* In deeper sheltered areas *Sargassum spp, Ecklonia radiata* and other fucoids make up the algal reef habitat.

6.5 Sturt

This region has predominately high wave energy, particularly around the offshore islands including Althorpe, Little Althorpe (North and South), Haystack and Seal Islands, which make up the Althorpe Islands Conservation Park. Royston, Middle and Chainman's Hat Islands are part of Innes National Park and also have macroalgal reef surrounding them.

High-energy wave-exposed coasts in this region include West Cape, Cable Hut Bay, Cape Spencer, Althorpe Island, Haystack Island and Troubrigde Hill. These rocky shores are dominated by *Ecklonia radiata, Acrocarpia paniculata, Carpoglossum* and *Cystophora spp* in shallow waters (<5 m), with an understorey of red, green and articulated coralline algae. *Ecklonia* still dominates deeper waters with a mixed red algae understorey, but *Sargassum fallax* and *Seirococcus axillaris* are present in the canopy. Moderately exposed coasts include Rhino Head and Hillock Point. In the shallows these areas are dominated by *Cystophora spp, Scaberia agardhii, Scytothalia dorycarpa* and *Caulerpa flexilis* with prostate brown algae dominating the understorey. Sheltered areas in the Sturt biounit include areas around Haystack Island and Cootes Hill. The reefs in sheltered areas are dominated by *Sargassum spp*, and *Cystophora spp*, with *Caulerpa spp*, reds and browns in the understorey.

The Althorpe Islands have a distinctive reef fauna typical of high-energy coasts. They are well known for the large Blue Groper that are usually seen around them. Several of the islands also have Australian Sea Lion and New Zealand Fur Seal colonies on them, although most of them are only haul-out sites and are not used for breeding. Several of the islands also provide important bird roosting habitat for mutton birds, fairy terns, little penguins, and white-bellied sea eagles. Troubridge Island provides important bird breeding habitat and the shoal that extends from the island has large expanses colonised by attached invertebrates. Within the Troubridge region there are also reefs dominated by large red algae, which is unusual within South Australian waters. This rough section of coast is also renown for shipwrecks with some 26 known wrecks between Cape Spencer and Troubridge Point.

6.6 Orontes

The Orontes biounit is characterised by generally low wave energy, with wave energy decreasing northwards into the gulf. Reefs are second only to seagrass in aerial coverage of the benthos in this biounit (37 per cent), making it an important habitat. Troubridge Island, Marion reef and Orontes Bank are listed as offshore or coastal islands or reefs. The higher energy wave-exposed areas include Troubridge Hill and Marion Reef. In the shallower parts these areas are dominated by *Cystophora spp*, *Ecklonia radiata* and a diverse mixed red and coralline algae understorey. *Sargassum spp* and green algae (*Caulerpa brownie, Codium pomoides*) are also prevalent in the community. Moderately exposed shores include Troubridge Point, which has reef dominated by *Cystophora moniliformis* in the shallows. These reefs also have *Sargassum spp* in the canopy and mixed red algal and prostate brown algae in the understorey. Sheltered shores and reefs, including Pine Point and Ardrossan, are dominated in the shallows by *Sargassum spp* and the red algae *Botryocladia obovata* and *Caulocystis uvifera*, *Cystophora moniliformis*, and diverse mixed reds. The understorey is mostly the prostate *Lobophora variegata* and mixed reds.

There are artificial reefs near Ardrossan made of a sunken barge and near Giles Point, made of tyre modules. There are several shipwrecks in the area, most of which are associated with the Troubridge Shoals. The best-known wreck is the *Zanoni*, which has a protected area under the *Historic Shipwrecks Act 1981* surrounding it.

7.0 Developing Monitoring for Reefs of the NYNRMR

An effective monitoring program that is designed to assess the success of management arrangements and to detect change in reef ecosystems will depend on a number of steps. Ultimately, the monitoring program must recognise the need to develop and deliver capacity to communities in the region to undertake or contribute to the monitoring program in the long term. The reef biodiversity assessment program will serve to achieve the first five stages of effective monitoring in Figure 6. This literature review is compiled in part completion of background tasks that include the collation and review of existing information, including planning documents. Priorities for monitoring will be identified from existing information, including the selection of focal species and populations to use as indicators for the program.

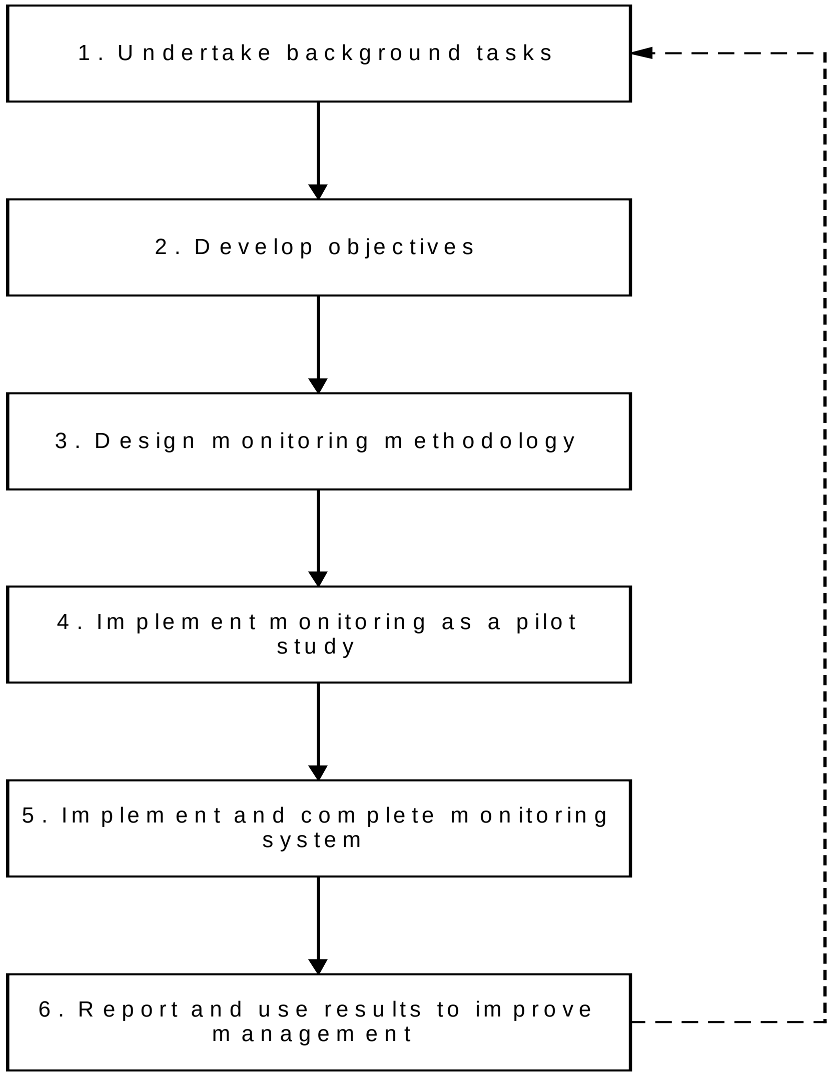

Figure 6: Stages involved in developing an effective monitoring program for the reef systems of the NYNRMR

7.1 Focal Species Abundance

A focal species is an organism that bears ecological and/or human value and as a result of that value is of particular interest to management. A range of different types of focal species may exist and are a common element in monitoring designs. Flora or fauna that are particularly susceptible to a particular toxicant or form of pollution may be used to monitor the effects of discharge into the environment for example. Alternatively, rare species exposed to extinction risk are usually of particular interest to managers and are often used as focal species in monitoring studies (Elzinga *et al.* 2001; Pomeroy *et al.* 2004). Species abundance is a measure of the number of individuals of a particular species found to occur within an area of interest. It is usually used as a surrogate for population size and is used to reflect the status of a species' population within a specific location. Thus measuring the abundance of focal species can be a useful gauge for a range of management goals.

7.2 Focal Species Population Structure

As well as measuring abundance, it is often useful to gain an understanding of how the population that is being assessed is structured. Structure refers to the life-history makeup of the population and is described by characteristics such as the size distribution and gender ratio of a group of organisms. By assessing structure, greater sensitivity to change is gained in a monitoring program. The ecology of a system can change not only if the abundance of organisms change but also if the average size of individuals is affected. Similarly, an activity or influence may preferentially remove a particular gender from a population, or size range of a gender that is critical to reproduction, thus affecting the reproductive capacity of a population (Pomeroy *et al.* 2004).

7.3 Composition and Structure of the Community

A community is a collection of different and interacting populations of plants and animals found living together in a defined geographical area. The diversity and occurrence of species in a community and their relative abundance describe the composition of a community. The structure of a community is defined by how the numbers and relative abundance of species occur and are located within the physical environment (Elzinga *et al.* 2001; Pomeroy *et al.* 2004). Shepherd and Womersley's (1981) conceptual model of how algae are distributed according to depth and exposure is a good example of how communities are structured. Changing elements of populations (abundance and structure) can affect community composition and structure. Activities and influences can also affect the overall community structure of a reef more subtly. A community may be changing without any of the focal species selected for monitoring responding, or with those species responding less rapidly than others or the community, making it important to monitor at a multi-species level as well.

7.4 Habitat Distribution and Complexity

Habitats provide living space for an organism, for populations of organisms and for communities in general. Changes in the extent or distribution of a habitat can have rapid and significant effects on the ecology of systems and targets to maintain or enhance habitats are often an integral part of natural resource management goals. The complexity of habitats is also important and is measured as the extent and diversity (number) of different habitats or distinct zones in a habitat within a specific area. Disturbance events in the community, whether natural or human induced, can lead to changes in habitat structure and declines in complexity. Such changes may lead to reductions in focal species abundance and changes in population structure and community composition.

8.0 Project Direction

The Department for Environment & Heritage has developed a project with the Northern and Yorke Natural Resource Management Region to initiate biodiversity surveys and a reef health monitoring program to underpin and measure future management success. As a part of that project, this document provides an introduction to the key elements of temperate water reef ecology in Southern Australia. The common threatening processes likely to influence the maintenance of healthy reefs are also introduced. Specifically, the project aims to:

1. Provide baseline data on the biodiversity content of reef systems in the Northern and Yorke Natural Resources Management Region.
2. Identify potential condition targets for reef systems in the Northern and Yorke Natural Resources Management Region, upon which to develop management actions;
3. Facilitate the establishment of ongoing monitoring to evaluate the success of management actions that focus on reef ecosystem responses to threatening processes.

A collaborative partnership with the South Australian Research and Development Institute has been created that allows broader inclusion of the current project with a significant reef health monitoring program. The partnership will expand the detail of the project to provide comparison of the status of reefs from the Murray River Mouth to Port Augusta. Scientifically robust surveys of the condition of reefs throughout the area will underpin initiatives to implement community based monitoring programs in the future.

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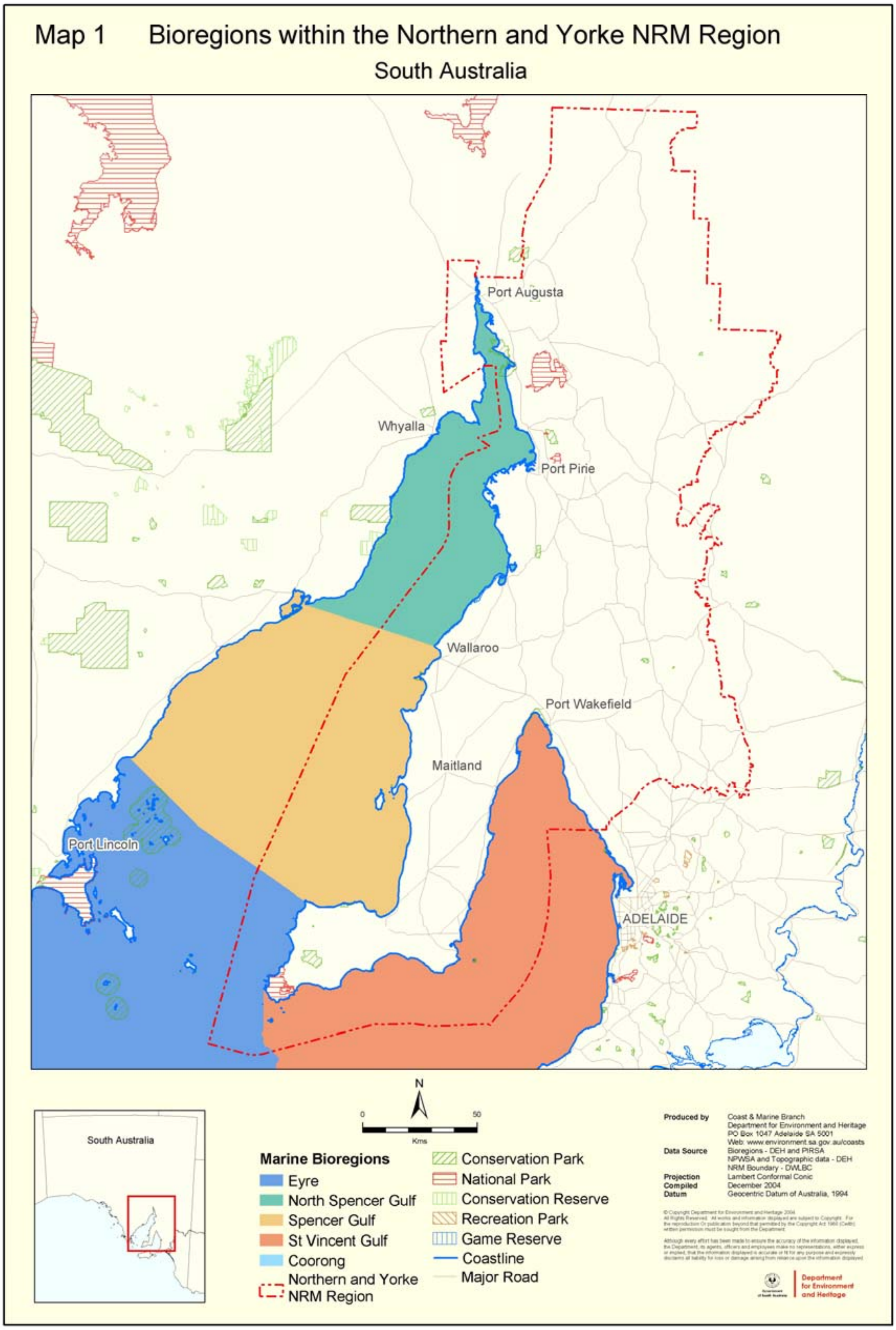
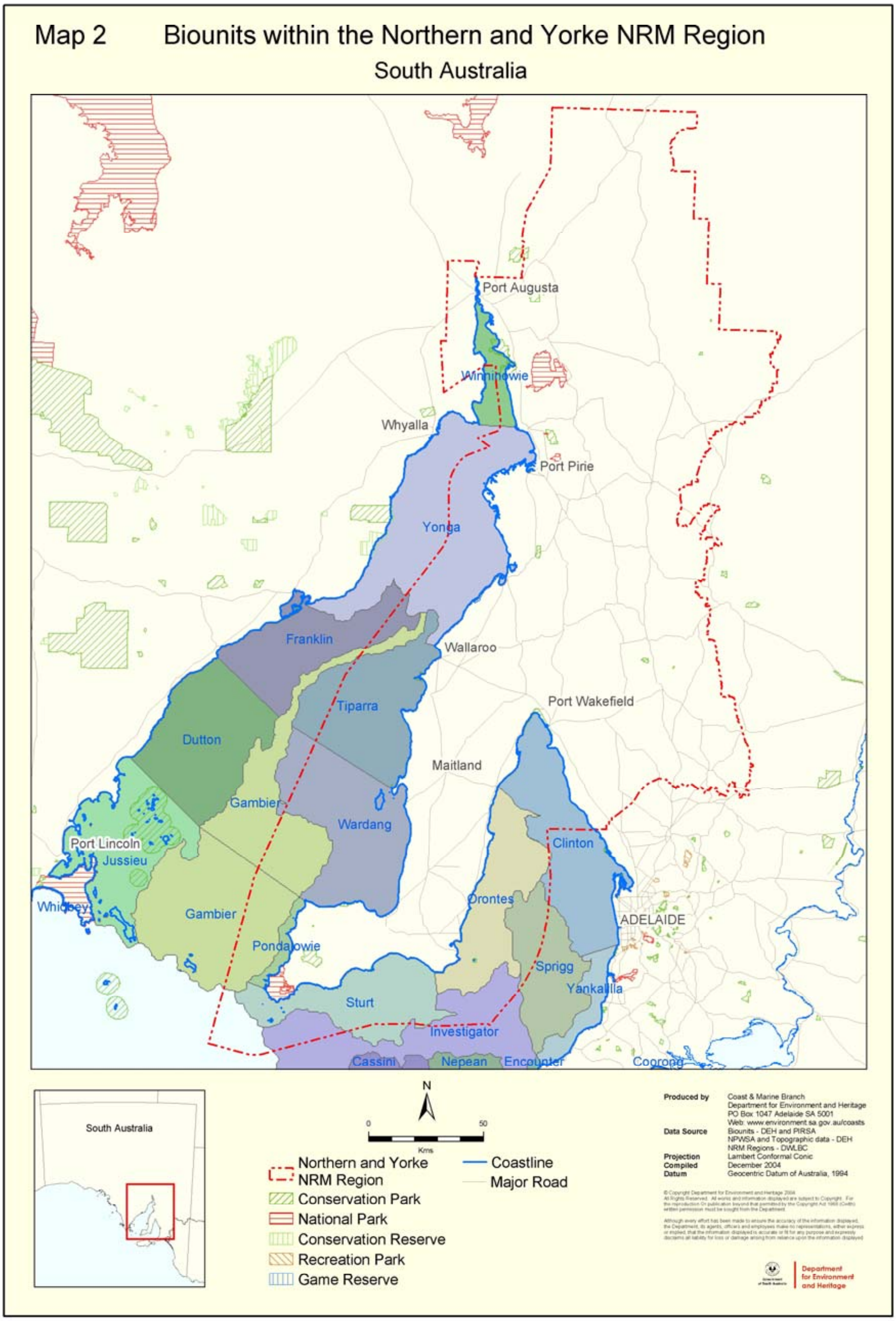
Glossary

Baseline	The territorial sea baseline is the line from which the seaward limits of Australia's maritime zones are measured.
Biodiversity	The variability among living organisms from all sources, including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes the diversity within species, between species and of ecosystems. (UNEP 1994)
Bioregion	An area defined by a combination of biological, social and geographic criteria, rather than by geopolitical considerations. Generally, a system of related, interconnected ecosystems. (Commonwealth of Australia 1996)
Conservation	The protection, maintenance, management, sustainable use, restoration and enhancement of the natural environment.
Ecologically Sustainable Development	Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life, now and for the future, can be increased.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. (UNEP 1994)
Endemic	Restricted to a specified region or site.
Habitat	The physical place or type of site where an organism, species or population naturally occurs together with the characteristics and conditions which render it suitable to meet the lifecycle needs of that organism, species or population.

Protected Area / Marine Protected Area	An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means. (IUCN 1994)
State Waters	Australia's Offshore Constitutional Settlement established Commonwealth, State and Territory jurisdictions over marine areas. States generally have primary jurisdiction over marine areas to three (3) nautical miles from the baseline.
Threatened Species and /or ecological communities	A species or ecological community that is vulnerable or endangered.
Threatening processes	The dominant limiting factors and constraints to the ongoing conservation of biodiversity.
Viability	The likelihood of long-term survival of the example/population of the particular ecosystem or species under consideration.
Vulnerability	The predisposition of an area to a threatening process.


Map 1 Bioregions within the Northern and Yorke NRM Region
South Australia
Port Augusta
Whyalla
Port Pirie
Wallaroo
Port Wakefield
Maitland
Port Lincoln
ADELAIDE
N
0
50
Kms
South Australia
Marine Bioregions
Eyre
North Spencer Gulf
Spencer Gulf
St Vincent Gulf
Coorong
Northern and Yorke NRM Region
Conservation Park
National Park
Conservation Reserve
Recreation Park
Game Reserve
Coastline
Major Road
Produced by
Coast & Marine Branch
Department for Environment and Heritage
PO Box 1047 Adelaide SA 5001
Web: www.environment.sa.gov.au/coasts
Data Source
Bioregions - DEH and PIRSA
NPWSA and Topographic data - DEH
NRM Boundary - DWLBC
Projection
Lambert Conformal Conic
Compiled
December 2004
Datum
Geocentric Datum of Australia, 1994
Department for Environment and Heritage


Map 2 Biounits within the Northern and Yorke NRM Region
South Australia
Port Augusta
Winninowie
Whyalla
Port Pirie
Yonga
Franklin
Wallaroo
Tiparra
Port Wakefield
Dutton
Maitland
Gambier
Wardang
Port Lincoln
Jussieu
Clinton
Whidbey
Orontes
Gambier
ADELAIDE
Pondalowie
Sprigg
Yankalilla
Sturt
Investigator
Cassini
Nepean
Encounter
Coorong
South Australia
N
0
50
Kms
Northern and Yorke NRM Region
Conservation Park
National Park
Conservation Reserve
Recreation Park
Game Reserve
Coastline
Major Road
Produced by
Coast & Marine Branch
Department for Environment and Heritage
PO Box 1047 Adelaide SA 5001
Web: www.environment.sa.gov.au/coasts
Data Source
Biounits - DEH and PIRSA
NPWSA and Topographic data - DEH
NRM Regions - DWLBC
Projection
Lambert Conformal Conic
Compiled
December 2004
Datum
Geocentric Datum of Australia, 1994
Department for Environment and Heritage

Map 3 Marine Habitats of the Northern and Yorke NRM Region
South Australia