

The health of subtidal reefs along the Adelaide metropolitan coastline 1996-99



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Cover Photo: Giant Cuttlefish swimming above a kelp bed.

Courtesy PIRSA Marine Habitat

Report prepared by Sam Gaylard
Environment Protection Authority

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For further information please contact:

Information Officer

Environment Protection Authority

GPO Box 2607

Adelaide SA 5001

Telephone: (08) 8204 2004

Facsimile: (08) 8204 9393

Free call (country): 1800 623 445

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SUMMARY

In recent years there has been growing concern about the health and welfare of our marine environment. While it has been known for some time that human activity has had a negative impact on seagrass communities, the status of local reefs has remained largely unknown. In response to growing concerns, the Environment Protection Agency* (EPA) commissioned scientists from the Adelaide and Flinders Universities to investigate the issue.

This report is a summarised version of the technical documents produced for the EPA by Cheshire et al (1998a,b and 2000), Miller et al (1998), along with conceptual annotations provided by Turner (pers.comm.).

The program initially assessed the effectiveness of using easily identified reef life as biological indicators of general reef health. Macroalgae (also known as seaweed and kelp) were found to be suitable for this purpose, and became the focus for the development of a rapid assessment technique. The first survey, undertaken in 1996, assessed eight sites between Aldinga and Semaphore. A second survey, undertaken in 1999, extended this work to include an additional ten sites and provided an opportunity to identify community changes during those three years.

The surveys indicated that the health of subtidal reefs along Adelaide's metropolitan coast ranged from poor in the north to good in the south. This was highlighted by changes in community structure on the reefs surveyed. The northern reefs (Semaphore to the 'Broken Bottom' at Glenelg) were generally in poor condition over the period of the surveys. The central reefs (Hallett Cove to Southport) were in a moderate to good condition and the southern reefs (Moana to Aldinga) were the healthiest along the metropolitan coastline and were thus classified as good. All reef systems were generally in a stable condition with no significant deterioration evident over the period of the surveys.

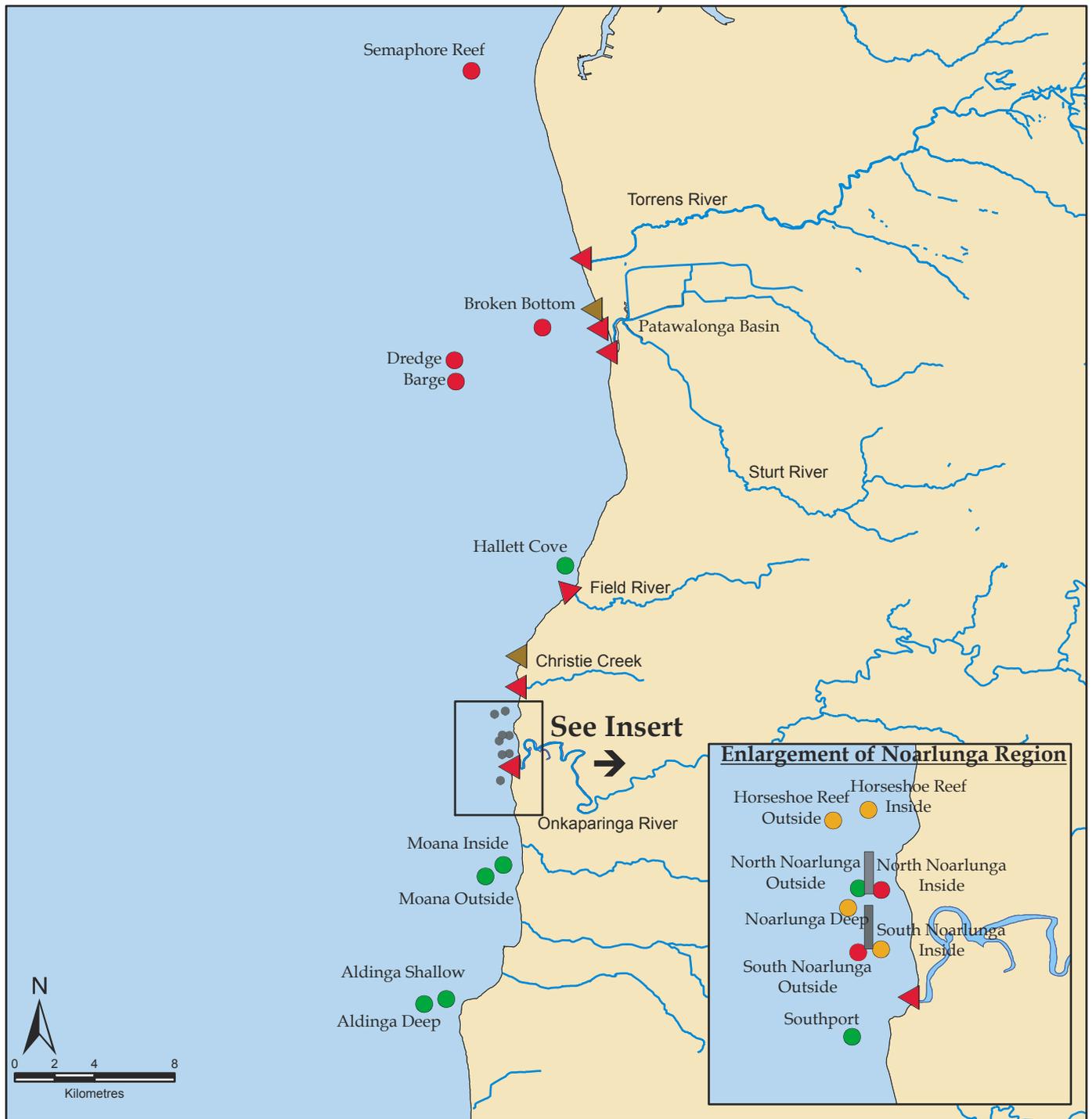
This trend in reef health is consistent with the increased industrialisation and urbanisation of the northern areas of Adelaide over the last 50 years. The northern region receives effluent from three wastewater treatment plants (WWTPs) as well as most of Adelaide's stormwater. The Port Adelaide, Torrens and Patawalonga rivers also discharge into this region. The central region is impacted by discharge from one WWTP and the Onkaparinga River, whereas the southern region currently receives limited discharge, predominantly from small coastal communities.

Improving the water quality in Gulf St Vincent should lead to improvements in reef health, particularly in the northern region. Current initiatives to improve water quality along the Adelaide metropolitan coastline include:

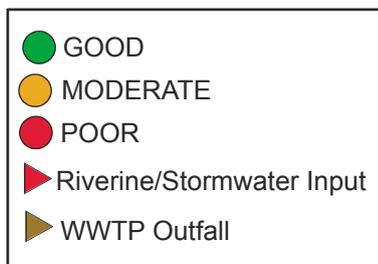
- environment improvement programs (EIPs) and effluent reuse schemes for WWTPs to greatly reduce nutrients discharged into the gulf
- continued enforcement of the *Environment Protection (Marine) Policy 1994* by the EPA
- enactment of the draft Environment Protection (Water Quality) Policy with the aim of preventing and improving wastewater discharges. This policy will supersede the Marine policy mentioned above.
- improvements in the quality of water discharged from rivers along the coast through the continuing work done by catchment water management boards
- development and implementation of EIPs for industries discharging water into the Port River and other coastal catchments
- continued EPA monitoring of the water quality of Gulf St Vincent and the Port River estuary to determine trends in water quality and provide feedback on improvement programs
- creation of a greater awareness of the significance of reef systems through community programs such as Reef Watch.

It is anticipated that reef health surveys will be undertaken periodically to provide data on the long-term changes in reef health.

*From 1 July 2002, the Environment Protection Agency was made independent of the Department for Environment and Heritage and re-named Environment Protection Authority.



1999 Reef Health Classification



**Gulf St Vincent
South Australia**

**Reef Health
Survey Area**



Figure 1 The health of reefs in 1999 survey

1 INTRODUCTION

The word 'reef' generally conjures up images of brightly coloured corals with equally colourful fish, in crystal clear, warm, tropical water. While this image may be appropriate for Australia's northern tropical waters, particularly the Great Barrier Reef, in temperate waters of South Australia the reality is somewhat different.

South Australian reef systems are typically rocky outcrops covered in macroalgae (seaweed) and invertebrates. Like coral reefs they are highly diverse environments, but are generally not well understood by the general community except perhaps by those who dive and fish.

Seagrass coverage along the coast of Adelaide has drastically declined over the past 50 years due to increased pollution in Gulf St Vincent. The loss of seagrass is now seen as a major cause for concern in the marine environment through increased sand erosion, loss of biodiversity and valuable habitat. It is likely that some of the same stressors impacting seagrass may also be impacting macroalgal reefs. While pollution has a direct effect on macroalgae, the reduction in seagrass coverage may also be amplifying degradation on macroalgal reefs through increased sedimentation (Scheil and Foster 1986; Cheshire et al 1998a,b).

The Reef Health Survey was commissioned by the then South Australian Environment Protection Agency (EPA) in 1996 in response to potential pressures on the reef systems and the significant environmental value of these systems.

This report is a summary of the four technical documents 'Assessing the status of temperate reefs in Gulf St Vincent I-IV' generated for the EPA by Cheshire et al (1998a&b and 2000) and Miller et al (1998). Results of these documents have been compared to the EPA's ambient water quality monitoring reports and various pollution sources along Adelaide's metropolitan coast.

The survey was intended to provide detailed information and develop a reliable methodology for the assessment of the reef health along South Australia's metropolitan coastline. At the time, very little work had been done to assess temperate reef systems anywhere in the world let alone southern Australia. A subsequent survey was completed in 1999 to attempt to assess the health of the reefs over a longer period and detect any changes since 1996.

1.1 TEMPERATE OR TROPICAL?

There are some quite fundamental differences between temperate and tropical reef systems:

- Temperate waters are typically cooler and nutrient levels are generally higher than tropical waters.
- Temperate reefs only exist in locations where consolidated sediment or rocky substrate provides a site for attachment and settlement of algae and sessile (immobile) invertebrates. Tropical reef systems are largely built up by corals which, once established, can grow and expand the size of the reef
- Tropical reef inhabitants are largely corals and sponges, many of which contain zooxanthellae. Zooxanthellae are photosynthetic algae living in partnership with the coral by providing nutrients in exchange for shelter and access to light. This symbiosis helps to combat the lower nutrient levels in the water. The dominant biota on temperate reefs are free living algae which are very rarely involved in these beneficial partnerships (Cheshire et al 1998a) reflecting the higher nutrient levels common in temperate waters.



Figure 2 Brown macroalgal dominated reef
(Photo A Eaton)

There is also significant variation within temperate reefs on a global scale. The southern Australian coastline represents the longest east-west running stretch of coast in a temperate region in the world. Also, while nutrients in South Australia's waters are generally higher than in tropical regions, they are lower when compared with other temperate regions. This, and various oceanographic anomalies such as reverse estuaries and a lack of significant upwellings, has created a unique environment of highly diverse and endemic (localised) species.

1.2 THE IMPORTANCE OF REEFS

Subtidal macroalgal communities in temperate regions are important ecosystems due to their high productivity (the amount of organic matter fixed by an ecosystem per unit of time) and complex three-dimensional organisation, which provides habitat and food for diverse invertebrate and fish communities. Southern Australia's temperate reefs have a particularly high degree of species diversity and a very high proportion of endemic species; for example, up to 95% of southern Australia's marine mussels are endemic.

Brown and red algae, bryozoans, sea squirts (ascidians) and crustaceans have a much higher species richness in these reefs than in equivalent temperate habitats elsewhere in the world (Womersley 1981; Zann 1996). South Australia's subtidal reefs are important for commercial and recreational fisheries and also for recreational diving. However, despite their great importance they are not well understood scientifically, and are not well protected.



Figure 3 Sea squirt (ascidian) common in temperate reefs (Photo A Eaton)

1.3 STRUCTURE OF TEMPERATE REEFS

In general, southern Australian temperate reefs rely on three strata of algal vegetation.

- An upper zone of perennial larger brown robust algae (e.g. *Cystophora*, *Sargassum* and *Ecklonia* spp.) provide the canopy species. They are taller and stand above the rest of the community providing shelter, food and structure for the other algae and invertebrates living in the understory. This is the most significant aspect of the reef structure.
- The middle zone of small green, brown or red algae is usually less than 25 cm in height.
- The lower zone of mostly brown or red algae can reach up to 5 cm in height (Shepherd and Sprigg 1976; Cheshire et al 1998a).

1.4 HOW TEMPERATE REEFS VARY

Reef systems are highly dynamic and the canopy structure can change within a short period. For example, storm and wave action can remove large canopy species. Often temperate reefs are dominated by large macroalgae but when a disturbance, such as a storm, creates space on a reef then animals such as sea urchins or mussels can establish themselves (Johnson and Mann 1988). Even small differences in the environment can alter the composition and structure of a reef. A healthy reef has a diverse range of species and there will be various forms of competition between the species present. These may be predator-prey interactions or even competition for space and light.

The following key biological and ecological processes can affect the composition of the reef environment and whether the reef can change back from an altered state (Zann 1996):

- wave action
- turbidity
- light
- mode of growth (solitary or colonial)
- dispersal and recruitment processes
- genetic structure
- competition
- predation
- linkages (ease of mobility from one location to another)
- oceanographic features (e.g. upwellings)
- rock and/or sand characteristics.

Outside of natural variability within the reef community there are longer-term trends that can be seen in the composition and structure of the reef (see Section 5.1).

These are largely seen over long time periods and can be used as indicators of the health of the reef. Currently there is little literature on the effects of human activities on temperate reefs. However, impacts on habitat or canopy forming species (such as the large brown algae) have been identified as potentially the most damaging to the reef as a whole (Zann 1996, Cheshire et al.1998a&b). Anthropogenic impacts upon reef environments can vary through a range of factors, many of which are interlinked. These are discussed below.

Turbidity and sediments

Turbidity is a measure of the amount of light scattered by particulate matter. Turbidity is increased when particulate matter such as sand, silt, clay and plankton is suspended in the water column. Dredging, sewage and industrial discharges, stormwater, land reclamation, increased erosion from already degraded areas and changes in land use can increase turbidity levels and generate increased suspended sediment loads. Increased turbidity reduces light penetration through the water, decreasing the photosynthetic activity of algae. Sediments can be deposited on reefs, resulting in smothering of organisms and decreased light penetration, which hinders recruitment and the growth of algae and sessile invertebrates (Gorostiaga and Diez 1996; Cheshire and Turner 2000).



Figure 4 Example of kelp and urchin competition
(photo: Kim Westerskov, Natural Images)

Toxicants

Heavy metal contamination along Adelaide's metropolitan coastline can be directly linked to urban runoff (stormwater) and industrial sources such as manufacturing plants, power stations, port facilities and wastewater treatment plants (WWTPs) (Environment Protection Authority 1997). Heavy metals can be acutely toxic to marine organisms or can inhibit the growth or recruitment of organisms, including macroalgae.

Nutrients

Elevated levels of nitrogen and phosphorus in the marine environment can cause an increase in algal growth. This can cause higher turbidity, reducing the amount of light reaching plants in the water. This in turn may result in increased competition for light and space and could also reduce the abundance of algae, resulting in more competition for food and habitat.

In addition, nutrient enrichment can cause harmful algal blooms under certain conditions (shallow, still and warm water). Algal blooms can be harmful by decreasing the oxygen concentration in the water. Some algal species also produce toxins when the cells die; these chemicals can be directly toxic to other organisms. Harmful algal blooms are especially problematic in the Port River, where 'red tides' restrict the harvesting of shellfish due to the toxins produced by blooming organisms (in this instance dinoflagellates). Nutrient enrichment has contributed largely to the loss of over 4000 hectares of seagrass in Gulf St Vincent over the last sixty years [EPA 1998].

Displacement by grazers, opportunistic species and marine pests

The relationship between grazers and the canopy species is dynamic and highly variable. Grazers (mobile organisms which eat by grazing on algae and plants) are a natural part of the reef community. They increase diversity, and in some cases productivity. However, where canopy degradation or removal of key predators results in grazing on a large scale, grazers can significantly affect the community structure of the reef. They can change the mixture of species present in the grazed area restricting algal larvae from settling and growing on the reef (Kennelly 1995).

Opportunistic species are organisms that are able to take advantage of temporary or local changes in a community (grazers can be opportunistic species). These changes can be subtle such as slight changes in water quality or obvious like the loss of canopy forming species. Opportunistic species such as *Ulva* (sea lettuce) and *Enteromorpha* species respond to increases in nutrient levels, and the mussel *Brachidontes erosus* can thrive in recently cleared areas, expanding to smother other sessile organisms. The introduction of opportunistic species can cause a decline in species richness and diversity and inhibit the recruitment of the vital large canopy forming species of macroalgae (Smith 2000).



Figure 5 Bloom of *Ulva* spp.
(Photo F Peat)

A growing number of introduced marine species are arriving in Australian waters. The key sources of these organisms are ballast water of ships originating from international ports and fouling organisms on ship hulls. To date there have been approximately four fish and 50 invertebrates accidentally released in Australian waters from ballast water or hull fouling. Two algal species have been introduced, the macroalgae *Caulerpa taxifolia* and *Undaria pinnatifida* (McEnnulty et al 2001). Most introduced species that become established have some negative effects on their surrounding environment. This is often through direct competition with native organisms and often displacing them to a point of total removal. Negative effects can also be indirect, through the introduction of pathogens into the native populations, decreased productivity of commercial fisheries and the economic costs of eradication or containment (McEnnulty et al 2001).



Figure 6 *Caulerpa taxifolia* (with *Sabellidae*) West Lakes, SA 2002
(Photo courtesy PIRSA Marine Habitat).

Caulerpa taxifolia (aquarium strain) was first identified in the Mediterranean in 1984 and in 1996 it was estimated that it covered over 3000 hectares of benthic habitat, smothering all competing species.

Partial eradication of ~2 ha in the Spanish Mediterranean is estimated to have cost 383 E m⁻² (McEnnulty et al 2001). A program is currently under way to eradicate *Caulerpa taxifolia* (aquarium strain) from West Lakes where it was discovered in 2002.

Overfishing

Intensive fishing and harvesting of organisms living on the reef (such as fish, lobster and abalone) can cause a loss of diversity and have follow-on effects such as the removal of key predators allowing an opportunistic species to thrive. Heavy fishing on a reef can also have indirect impacts such as physical damage from anchors and pollution such as litter.

2 SITES SURVEYED

The initial survey conducted in 1996 covered eight reefs selected for their range of habitats (variation in reef type and depth) and close proximity to the suburbs of Adelaide. As a result of the success and effectiveness of the methodology used in the initial assessment an additional 10 reefs were added to the 1999 survey bringing the total to 18 reefs surveyed (Table 2; Figure 5). All reefs were classified by location (northern, central or southern sections) and depth (deep: 10–15 m; or shallow: approximately 5 m).

Table 1 Survey sites in the 1996 and 1999 surveys (Cheshire and Westphalen 2000)

Site	Maximum depth	Depth class (m)**	Position#	1996 transects##	1999 transects
North section					
Semaphore	8.4–10.1	Deep	34°50'51.8"S 138°26'51.4"E	6	4
Barge	15	Deep	34°58'44.7"S 138°26'23.9"E	2	2
Dredge	15	Deep	34°58'49"S 138°26'23"E	4	4
Broken Bottom	9.9–10.1	Deep	34°57'51.5"S 138°28'46.9"E	6	4
Central section					
Hallett Cove	4.2–6.1	Shallow	35°04'20.4"S 138°29'24"E	6	4
Horseshoe Reef inside	5–5.5	Shallow	35°08'16.6"S 138°27'46.5"E	-	4
Horseshoe Reef outside	4.9–5.5	Shallow	35°08'21.9"S 138°27'29"E	-	4
Noarlunga Deep	8.3–8.8	Deep	35.0902S 138.2745E	1	4
North Noarlunga outside	5–7.1	Shallow	35°08'55.8"S 138°27'41.7"E	3*	4
North Noarlunga inside	5–6.3	Shallow	35°08'54.3"S 138°27'50.6"E	2*	4
South Noarlunga outside	4.5–5.8	Shallow	35°09'27.4"S 138°27'52.8"E	-	4
South Noarlunga inside	3.3–5	Shallow	35°09'25.7"S 138°27'49.2"E	-	3
Southport	6.2–7.1	Shallow	35°10'10"S 138°27'38.4"E	-	4
South section					
Moana outside	5.2–8	Shallow	35°12'27.7"S 138°27'41.7"E	-	4
Moana inside	5–6.1	Shallow	35°12'29.5"S 138°27'43.5"E	-	4
Aldinga shallow	5–6	Shallow	35°16'16.9"S 138°25'35"E	6	4
Aldinga deep	12–12.5	Deep	35°16'15.6"S 138°25'46.9"E	4	6

* These transects were combined in the analysis of the 1996 data. ** Maximum depth is the range of the deepest points surveyed at each site in 1999. # Position coordinates were obtained from a Garmin GPS and were accurate to within 300 m. ## - indicates no data collected at that site in that year.

2.1 NORTHERN REEFS

The reefs surveyed in this section represent the region north of Brighton. This region receives the highest loading and frequency of nutrient and sediment inputs into the gulf. The outflows from the Port, Patawalonga and Torrens rivers and the effluent from the Bolivar, Port Adelaide and Glenelg WWTPs along with heavy industries such as Penrice discharging effluent are all located in this region, as are most Adelaide metropolitan stormwater discharges. The northern area has the most water quality information available through the EPA's Ambient Water Quality Program (6 sites).

Semaphore—Deep

This reef is the northern-most reef of all the sites surveyed. It consists of a series of flat rock platforms broken into strips by patches of sand. Wave exposure at this reef is low due to its depth and distance from shore. Ambient water quality monitoring by the EPA in 1996 observed that sites close to Semaphore reef (Largs and Semaphore jetties) had moderate nutrient and turbidity levels (see Appendix 1 for water quality criteria) (Environment Protection Authority 1997).

Broken Bottom—Deep

This reef has a very similar substrate structure to Semaphore with a series of flat, rocky strips interspersed with sandy patches in a low wave exposure area. Broken Bottom is more likely to be impacted by nutrient and sediment inputs than the other northern sites as it is closer to the shore. Water quality monitoring at sites close to this reef (Glenelg, Henley and Brighton jetties) showed nutrient concentrations and turbidity levels to be moderate to poor.

Barge and Dredge—Deep

The Dredge and the Barge are two artificial reefs established in 1985 by sinking two separate steel-hulled vessels 100 m apart off the coast of Glenelg. They are both popular diving and fishing locations. The sampling of these reefs took place along the horizontal decks of both wrecks. Due to the depth of both reefs, there was negligible wave action.

There is no current water quality information at this site as it is too far removed from the EPA's sampling points to make reliable comparisons.

2.2 CENTRAL REEFS

The central reefs section stretches from Hallett Cove to Southport. This region has fewer potential impact sources than the northern section; major inputs are likely to be Christies Beach WWTP, the Onkaparinga River outlet and Port Stanvac oil refinery. This area is also subject to occasional dredging for the Coast Protection Board's Beach Replenishment Program.

Hallett Cove—Shallow

This reef is located about 50 m offshore and is the closest to shore of all the reefs surveyed. It is a narrow undulating spur of rock that rises 1–2 m above the surrounding sand. There is a narrow rocky beach at this location and wave exposure is moderate to heavy.

Horseshoe Reef—Shallow

Horseshoe Reef forms an arc of rock with the 'open' end facing towards the shore. The seaward side of the reef drops away from a steep platform to a series of broken but flat regions of stone that persist for some distance offshore. Towards shore, the reef becomes narrower and steeper making up more of a field of boulders than a solid structure. Sampling was undertaken on the outer exposed platforms (outside) and on the southern edge (inside). Wave exposure was considered moderate, and there was very little wave difference between inside and outside reefs. This reef was not part of the initial 1996 survey.

Noarlunga—Shallow and deep

Noarlunga reef extends over several hundred metres to the north and south of the Noarlunga jetty. The seaward side of the reef is approximately 7–10 m deep, while the shore-side is in approximately 5 m of water and the top of the reef is exposed at low tide. Wave exposure at this location is highly variable with the seaward side of the reef experiencing high wave energy and the shore-side being relatively calm. The entire reef is a marine reserve and therefore is not exposed to fishing pressure; however, it is popular with divers and swimmers.

The 1996 survey covered only the northern section in 5 m of water, and a single transect was made near the break in the northern and southern sections of the reef at 10 m. In the 1999 survey, the reef was divided into five areas consisting of inside and outside of both the northern and southern sections (5 m) of the reef and a deep section (10 m) at the area known as the Gap (see Figure 1). Ambient water quality in this region was classed as moderate based on nutrient concentrations at the Port Noarlunga sampling site. Corresponding turbidity levels were low.

Southport—Shallow

Southport comprises a series of flat rock platforms with small patches of sand and occasional rocky outcrops. This reef is quite similar in topography to the Broken Bottom and Semaphore reefs. Wave exposure is likely to be moderate. Due to its relatively close proximity, water quality can be compared with data from the Noarlunga sampling site.

2.3 SOUTHERN REEFS

The southern reefs are exposed to the fewest impacts. There are currently no WWTP outfalls in the region; it is the least urbanised area of the survey and receives drainage from only small riverine/coastal catchments. Currently the EPA does not collect ambient water quality data from this region.

Moana—Shallow

Moana Reef is similar to Hallett Cove. It consists of a gently sloping rock platform that abruptly falls away on the shoreward side, creating a steep slope above a broad expanse of sand. Moana Reef was only surveyed in 1999. This reef was sampled both on the inner steep slope (Moana inside) and on the outer platform (Moana outside). Wave exposure is likely to be moderate at both sites.

Aldinga—Shallow and deep

The sampling at Aldinga Reef was undertaken on a series of gently sloping rock platforms (5 m and 10 m) with occasional rocky outcrops (again similar to Semaphore and Broken Bottom). Wave exposure is considered moderate at 5 m and slightly less than this at 10 m. This reef is a marine reserve and therefore receives no pressures from fishing.

3 SURVEY METHOD

3.1 LINE INTERCEPT TRANSECT

Line intercept transecting (LIT) is a non-destructive sampling procedure that allows for reliable and repeatable sampling of macroalgal systems (Turner 1995). LIT involves randomly placing a 20 m tape over the horizontal reef surface. The tape is used as a guide for a weighted 1 m ruler from which biota measurements are taken (Turner 1995). The distances along the ruler at which the biota changed were recorded for the full length of the ruler (see Figure 7). When possible, four transects were measured to ensure representative estimates of algal cover were assessed at each site. This method has been proven useful for differentiating reefs based on the dominant upper layer taxa and high quality quantitative estimates on percentage cover of sessile organisms (Miller et al 1998). Because it focuses on the dominant communities, LIT is ideal for picking up large scale or structural changes in reefs outside of natural variation (Miller et al 1998). Estimates of percentage cover of sessile organisms were assessed in the 1996 and 1999 surveys using the LIT method.

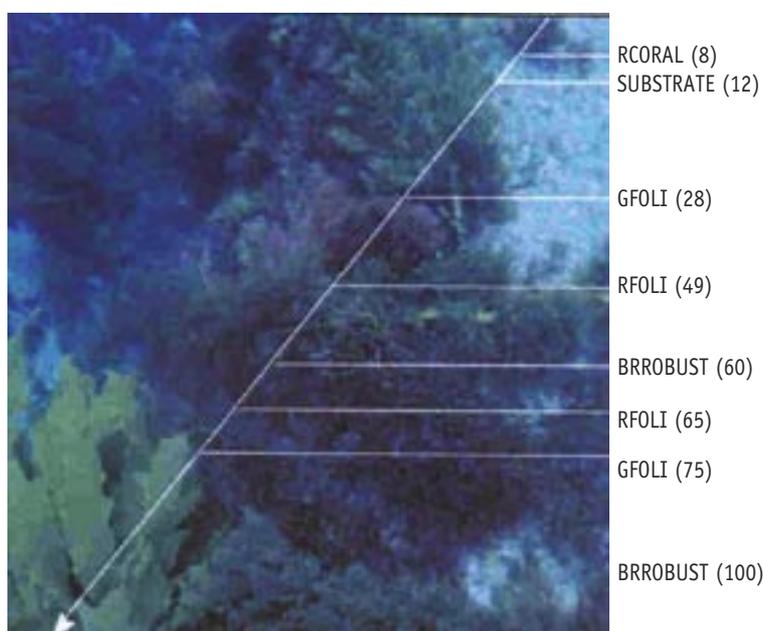


Figure 7 Schematic view of reef organisms showing LIT method (Miller et al 1998)

Transect	Metre	Transition	Lifeform	Species
1	4	8	RCORAL	Unknown
		12	SUBSTRATE	
	28	28	GFOLI	<i>Caulerpa</i>
		49	RFOLI	<i>Asparagopsis</i>
	60	60	BRBRANCH	<i>Cystophora</i>
		65	RFOLI	<i>Asparagopsis</i>
	75	75	GFOLI	<i>Caulerpa</i>
		100	BRFLAT	<i>Ecklonia</i>

For the purpose of this study, broad biological classifications at a relatively low taxonomic resolution were used. At this low resolution identification is relatively simple and means field workers will be consistent across all surveys. Codes were developed to describe these broad biological classifications (see Appendix 2 for full list of codes and example lifeforms). Brown, flat algae (BRFLAT) are species with blades that are much broader than they are thick, not membranous but feel leathery and are usually 10–200 cm in size (e.g. *Ecklonia*, *Durvillaea*). Brown branched algae (BRBRANCH) are highly branched and usually about 10–100 cm in size (e.g. *Cystophora*, *Sargassum*). These two categories are commonly the most dominant canopy forming species on a healthy southern Australian reef. In this report they are classified as the robust brown algae (BROBUST). This classification system is based on that used by Turner 1995 and is incorporated in the Reef Watch community reef monitoring program.



Figure 8 Brown robust algae *Cystophora* spp. (Photo A Eaton) and *Ecklonia radiata* (photo: Kevin Deacon Dive 2000)

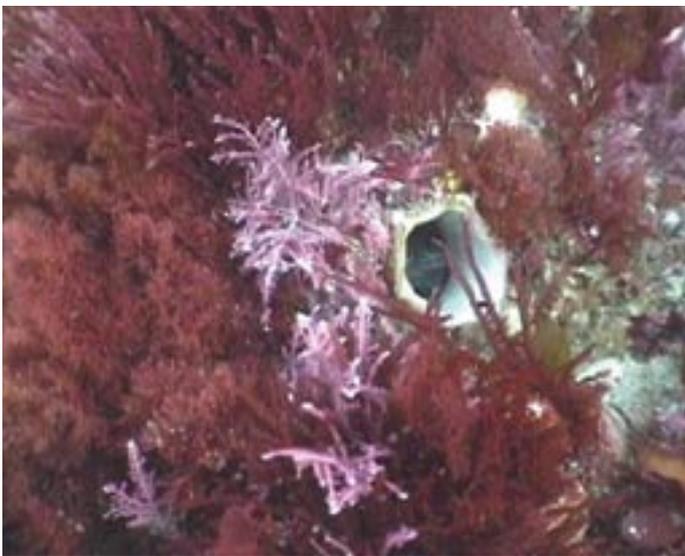


Figure 9 Foliaceous red and coralline algae (with ascidian) (Photo A Eaton)

Foliaceous brown algae (BRFOLI) are fluffy or bush like in appearance (e.g. *Halopectis*, *Cladostephus*). Red and green foliaceous algae have a similar appearance to BRFOLI but are obviously red (RFOLI) or green (GFOLI).

Encrusting algae cover the surface of the substrate like a crust and can be red (RENC) or brown (BRENC). Turfing algae are similar to encrusting algae in the way the organisms cover and expand on a substrate, but turfing algae (TURF) are generally fine and filamentous and can be soft and slimy. Green membranous algae (GMEM) are often slimy or translucent (e.g. *Ulva* spp.). A more complete description of the methodology as well as a critical assessment of its value can be found in Miller et al (1998).

3.2 BIOLOGICAL INDICATORS OF REEF HEALTH

The defining feature of a southern Australian subtidal reef system is the brown algal canopy. Robust brown algae are generally the major primary producers on reefs and provide significant habitat for the remainder of the reef community. They are typically perennial with an annual cycle of growth and reproduction. However, recruitment of brown macroalgae is commonly highly variable. Over the seasons there can be large changes in recruitment between locations and also large differences in total numbers of recruits in the same location. This situation creates a highly dynamic environment dependent on the success of recruits each season.

Over the last 50 years over 4000 ha of seagrass has been lost from Adelaide's coastline. This loss has been attributed to increases in nutrients, sediment and turbidity loadings. Robust brown macroalgae respond similarly as a community structure to seagrass when impacted by nutrients, sediment and turbidity loadings (Cheshire et al 1998b). Additionally laboratory tests have shown that brown macroalgae such as *Ecklonia radiata* are sensitive to low concentrations (parts per billion) of several heavy metals (Bidwell et al 1998). Recently the use of seagrass growth or productivity has been shown to be a good visual marker of pollution in Gulf St Vincent (Environment Protection Authority 1998). Due to similarities in responses, macroalgae would provide a similar indicator of stresses in regions where seagrasses don't grow (Cheshire et al 1998b).

Turfing algae are believed to both tolerate and promote sedimentation along the reefs and they may also be responsible for the restriction of the recruitment of the larger macroalgae (Cheshire and Westphalen 2000). Once a reef is in a degraded state, it may be very difficult for it to return to a healthy state. A dominant canopy of turfing and foliose red algae has therefore been used in this report as an indicator of a degraded or impacted reef.

Smith (2000) has shown that the presence of the bivalve mussel *Brachidontes erosus* on a subtidal reef will inhibit the recruitment of several species of brown robust macroalgae. There is considerable evidence that mussel invasions are often a result of a disturbance such as a storm or pollution event. Once a mussel colony is established it uses many different strategies to not only remain but also to expand, smothering underlying organisms, and reducing the canopy and diversity within the reef (Smith 2000). The presence of large areas of bivalve mussels is also used as an indicator of a degraded reef.

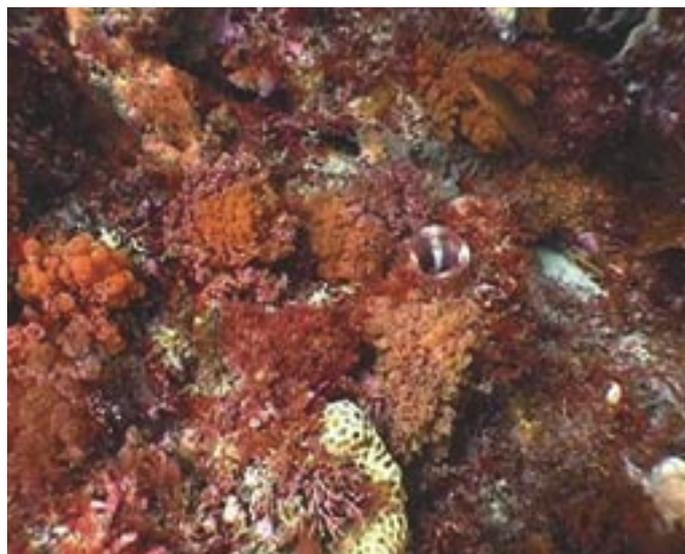


Figure 10 Turfing and coralline algae (with bryozoans) (Photo A Eaton)

3.3 STATISTICAL ANALYSIS

Descriptive statistics

LIT data from the marine environment is often highly variable, so descriptive statistics are used to summarise the data. Comprehensive statistical analyses were performed to identify patterns in the data. Results can be seen in Miller et al (1998) and Cheshire and Westphalen (2000). Key findings and conclusions have been drawn from these reports rather than duplicating the analyses in this report.

The mean, often called the average, is the most common measure of central tendency. In this report the mean was used over other measures of central tendency (such as median or mode) as it was deemed the most appropriate for this data. The standard deviation is a measurement of the variability of all the measurements in the data set. Generally speaking, it is the average distance of the sample points from the sample mean.

Community patterns and trends

Community patterns and trends across the reefs were investigated using multivariate analyses. Multivariate analysis is a sophisticated statistical technique that takes complex data containing many variables and summarises it as a measure of the relative similarity between samples. In this case the relative proportions of different kinds of algae present were used to determine how similar different reefs were to each other. Details of these assessments can be found in Cheshire et al (1998b), Miller et al (1998), and Cheshire and Westphalen (2000).

3.4 CLASSIFICATION SYSTEM FOR REEFS

A dominant canopy of large brown macroalgae is generally considered to be an indicator of a healthy reef system along Adelaide's metropolitan coastline. The classification system used in this report uses the following criteria:

GOOD	Mean percentage cover of total brown algae (robust brown + foliaceous brown) cover is greater than 50%
MODERATE	Mean percentage cover of total brown algae is 50–25%
POOR	Mean percentage cover of total brown algae is less than 25%.

This classification system recognises the importance of the brown algal species in the canopy for their role in providing habitat and structure for the understory species (see Section 1.3). While there are significant differences in the roles that robust brown and foliaceous brown algae play in reef systems, it was considered appropriate to group them together as they both play an integral and generally advantageous role in the reef structure.

A reef in this survey dominated by more than 50% cover of brown macroalgae has been classified as a reef in GOOD condition. Conversely a brown macroalgal cover of less than 25% in the reefs surveyed has been used to show a reef in POOR condition. Further investigation is required to better understand the impacts and dynamics of any particular reef. Between these markers the reef is deemed to be in MODERATE condition. This means that these reefs could be vulnerable to further degradation through continued pollution, infestation from invasive species and natural disturbances such as storms. Alternatively the reef may be in the process of shifting from kelp domination to domination by a secondary species such as urchin or mussel (see Section 1.4 or Johnson and Mann (1988) for further detail).

This classification system is a simplification of complex environmental interactions. However, it is not a universal system. There are instances where a temperate reef in southern Australia can be dominated by species other than robust brown macroalgae but still be considered healthy. Usually these circumstances are when the system is unsuitable for larger browns, such as in the deeper water communities seen in Investigator Strait (Shepherd and Womersley 1970; Shepherd and Sprigg 1976). However, in both the 1996 and 1999 surveys depth did not have a significant effect on the community structure on these reefs.

4 RESULTS

There is a definite improvement in reef health from north to south, evident in the difference in community structure on the reefs in both the 1996 and 1999 surveys (Figure 11) (Cheshire et al 1998b). Analysis showed that this trend was not due to differences in the topographical complexity of the reef nor to the differences in depth between the reefs. The six dominant life forms across all sites (excluding bare substrate/sand) were robust browns, brown foliaceous algae, foliaceous reds, red encrusting algae, turfing algae and mussels.

4.1 REEF HEALTH

There was a north-south trend in community structure of the reefs surveyed, improving from POOR to GOOD (see Appendices 3 and 4).

Northern reefs

The northern reefs were dominated by the foliaceous red algae and turfing algae. There was little coverage of robust or foliaceous browns. The Broken Bottom showed an increase in the cover of turfing algae (30–44%), at the expense of foliaceous reds (24–5%), which indicates potential further habitat and diversity loss. The northern reefs are the most impacted of the three regions in terms of coastal discharges. This region has been urbanised for the longest period of time and has been receiving stormwater and WWTP discharges for over 50 years. The northern reefs have been deemed as degraded, but stable over the time scale investigated. The northern reefs were all classified as being in POOR condition.

Central reefs

Overall there was little difference in the cover of robust brown algae on the central reefs between the 1996 and 1999 surveys. However, there was a significant increase observed at North Noarlunga outside and Hallett Cove (23–65% and 19–51% respectively). There was still very little foliaceous red algae and the coverage of turfing species had been stable over the time period. The main focus of concern in the central reefs was presence of the bivalve mussel *Brachidontes erosus*, particularly throughout Noarlunga reef and the newly surveyed Horseshoe Reef. This organism seemed to have expanded at the expense of the encrusting red algae, with little corresponding reduction in the robust brown algae. However, due to the dynamics of the mussel and the variable recruitment of the robust brown algae (see Section 3.2) there is a concern that there may be a decline of robust browns over the next few years. Overall, the central reefs were classified as being MODERATE, with Hallett Cove and north Noarlunga outside increasing from POOR to GOOD (due to a significant increase in cover of robust brown algae) and Southport, which was surveyed for the first time, was also in GOOD condition.

Southern reefs

The southern reefs were dominated by the brown algae *Ecklonia*, *Sargassum* and *Cystophora*. The cover of robust brown algae was stable from 1996 through to 1999 at almost all reefs; Aldinga deep increased in robust brown cover (40–69%) in 1999. Moana was not surveyed in 1996 but showed very high cover of robust brown algae (85% and 87%) in 1999. There was little evidence of mussels on these reefs with only 0.08% cover at Aldinga in 1996 and none in the 1999 survey, but this very small change may be accounted for through sampling error and the inherent variation in the LIT sampling method.

These reefs have the highest wave action and the highest degree of water movement of all three regions. Overall the southern reefs are considered healthy and each reef's condition classification was GOOD.

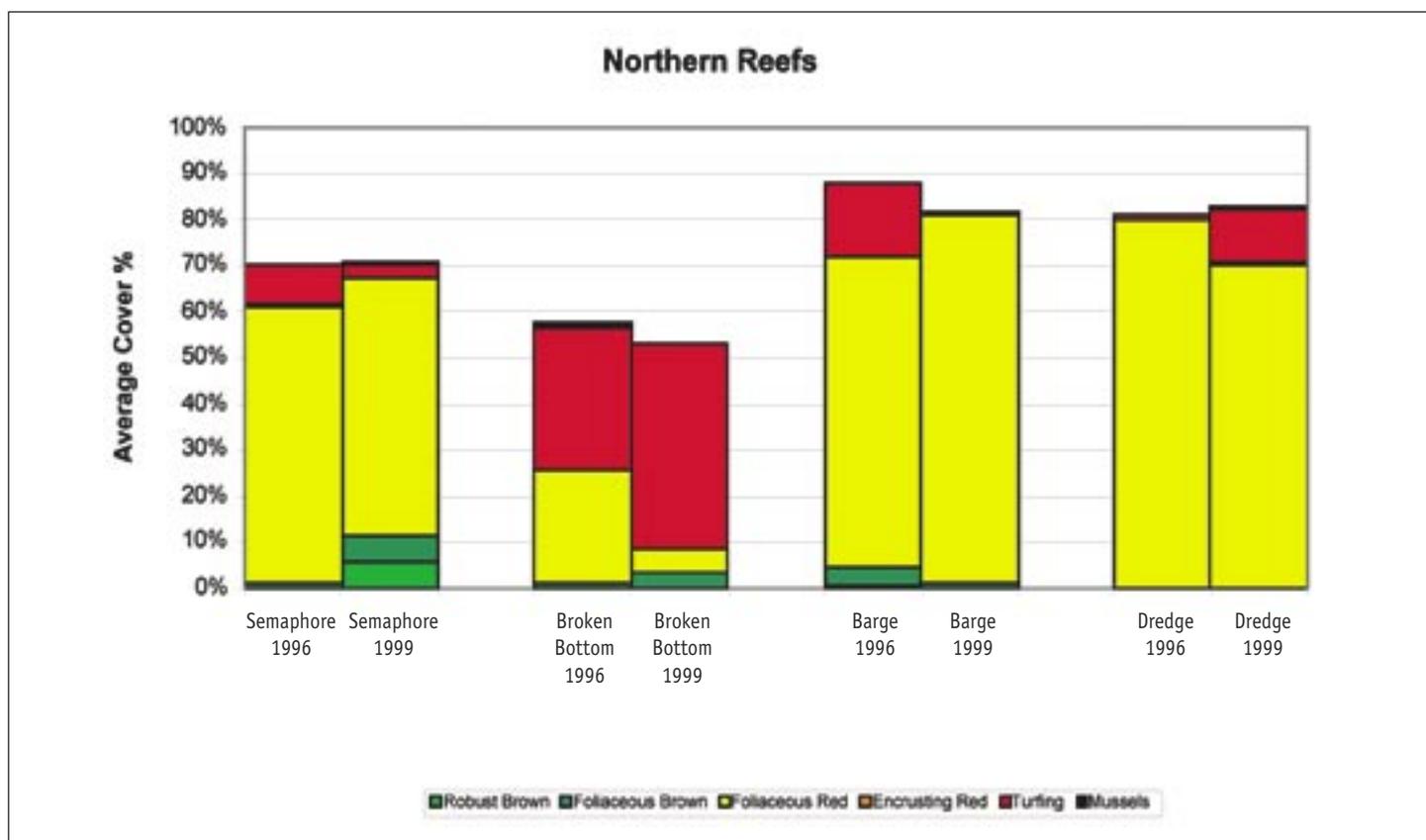


Figure 11 Average percentage cover of major life-form components in the Northern region for 1996–99

Table 3 Data table for lifeform components (average percentage cover) in the Northern region 1996–99

Location	Robust Brown	Foliaceous Brown	Foliaceous Red	Encrusting Red	Turfing	Mussels	Classification
Semaphore 1996	0.22	0.90	60.05	0.43	8.83	0.10	POOR
Semaphore 1999	5.54	6.23	55.40	0.10	3.18	0.41	POOR
Broken Bottom 1996	0.08	1.06	24.75	0.03	30.59	0.95	POOR
Broken Bottom 1999	0.00	3.26	5.36	0.09	44.50	0.29	POOR
Barge 1996	0.70	4.30	66.70	0.20	15.85	0.00	POOR
Barge 1999	0.00	1.40	79.48	0.09	0.80	0.13	POOR
Dredge 1996	0.05	0.22	79.50	0.00	1.18	0.14	POOR
Dredge 1999	0.00	0.18	69.94	0.52	11.86	0.11	POOR

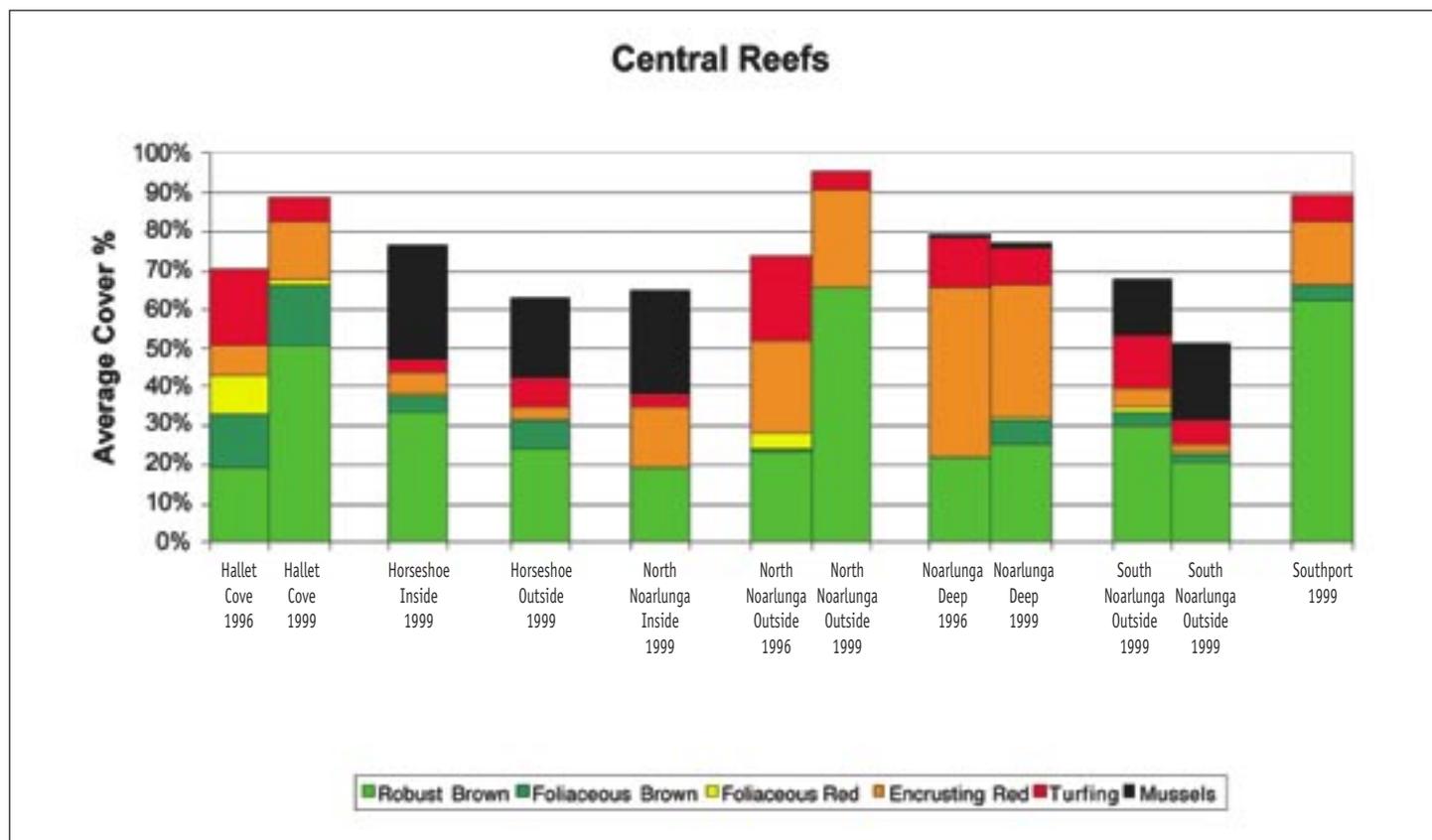


Figure 12 Average percentage cover of major life-form components in the Central region for 1996–99

Table 4 Data table for lifeform components (average percentage cover) in the Central region 1996–99

Location	Robust Brown	Foliaceous Brown	Foliaceous Red	Encrusting Red	Turfing	Mussels	Classification
Hallett Cove 1996	19.18	13.72	10.21	8.00	19.11	0.04	MODERATE
Hallett Cove 1999	51.08	15.60	0.81	15.03	6.42	0.00	GOOD
Horseshoe inside 1999	33.58	4.00	1.23	4.59	4.08	28.84	MODERATE
Horseshoe outside 1999	23.81	7.74	0.00	3.41	7.66	19.71	MODERATE
North Noarlunga inside 1999	19.31	0.29	0.00	15.37	3.48	26.56	POOR
North Noarlunga outside 1996	24.21	0.74	3.67	25.30	22.28	0.19	POOR
North Noarlunga outside 1999	65.57	0.00	0.00	24.94	5.09	0.00	GOOD
Noarlunga Deep 1996	21.59	0.00	0.00	43.67	13.44	0.44	POOR
Noarlunga Deep 1999	25.81	6.31	0.20	33.56	10.01	1.30	MODERATE
South Noarlunga inside 1999	30.23	3.79	0.20	5.18	13.11	14.84	MODERATE
South Noarlunga outside 1999	20.65	2.37	0.98	2.15	5.90	19.60	POOR
Southport 1999	61.99	4.55	0.31	16.04	6.41	0.00	GOOD

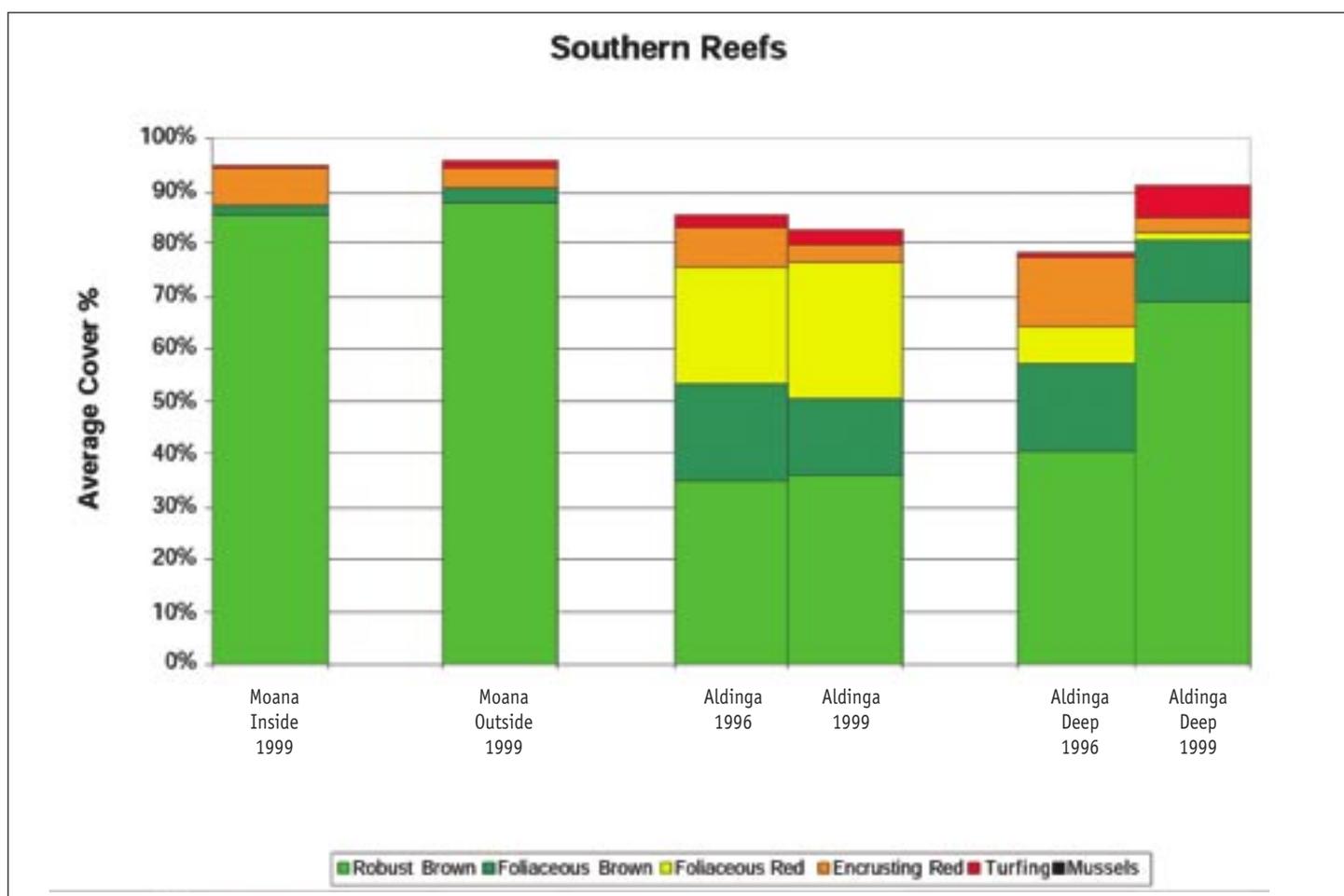


Figure 13 Average percentage cover of major life-form components in the Southern region for 1996-99

Table 5 Data table for lifeform components in the Southern region 1996-99

Location	Robust Brown	Foliaceous Brown	Foliaceous Red	Encrusting Red	Turfing	Mussels	Classification
Moana inside 1999	85.48	1.90	0.07	7.16	0.28	0.00	GOOD
Moana outside 1999	87.69	2.73	0.00	3.63	1.69	0.00	GOOD
Aldinga 1996	34.93	18.55	21.67	7.95	2.34	0.00	GOOD
Aldinga 1999	35.72	14.75	26.00	3.25	2.65	0.00	GOOD
Aldinga Deep 1996	40.51	16.22	7.05	13.55	0.92	0.08	GOOD
Aldinga Deep 1999	69.11	11.77	1.07	3.03	5.96	0.00	GOOD

4.2 SUMMARY OF REEF HEALTH

The results of the 1996 survey showed a definite increase in brown algae in a southerly direction along the metropolitan coast. The health of the reefs surveyed ranged from POOR in the northern reefs to GOOD in the southern reefs. The central reefs are in MODERATE to GOOD condition, although potentially vulnerable to increasing impacts due to urban expansion and the invasion from the bivalve mussel *Brachidontes erosus* resulting in the POOR classification of two reefs in the Noarlunga section. The high regular use by divers and swimmers of the Noarlunga reefs may have an adverse effect on the health of the reefs.

The observed north-south gradient correlates with the degree of wave exposure to the reefs along the metropolitan coast. However, studies suggest that the current state of the northern sites reflects a macroalgal flora that is disproportionate to what would be expected, wave exposure taken into account. It could be argued that an additional pressure on these systems is having an adverse effect (Shepherd and Womersley 1970; Collings and Cheshire 1998; Cheshire et al 1998b).

The level of anthropogenic inputs along the coast also corresponds to this gradient, with increased urbanisation and human activity prevalent in the northern region (see Section 5.0). This view is supported by observations elsewhere on the adverse effects of WWTP discharges on macroalgal and seagrass communities (Neverauskas 1987; Bellgrove et al 1997; Cheshire et al 1998b). It has also been noted that polluted sites often are lacking in larger brown algae and show an increase in opportunistic and turfing species, as was seen in the northern reefs. This result also corresponds with the regions of seagrass decline along Adelaide's metropolitan coast, which has been largely attributed to the effects of discharges such as effluent and stormwater.

4.3 STABILITY OF REEF HEALTH OVER TIME

The 1999 survey, while incorporating additional reefs, has shown that at the majority of locations the condition of the reefs is stable over the five-year period. Some reefs have shown an increasing cover of robust brown algae (North Noarlunga and Hallett Cove), while very few have decreasing cover of these algae. Still, caution needs to be exercised in drawing conclusions from study observations, as the nature of the impacts may not show effects on community structure in the short survey period. Currently little is known on the effects of water quality on recruitment and the follow-on impacts it has on community structure. Continued research into reef health should detect changes in reef structure, function and recruitment as a result of impacts in locations throughout the metropolitan coastline over a longer timeframe.



Figure 14 Common reef species in Southern Australia (Photos A Eaton)

5 HUMAN INPUTS IN GULF ST VINCENT

The majority of Adelaide's liquid wastes and stormwater runoff ultimately end up in the coastal waters of Gulf St Vincent. The pollutant loads discharged to the coastal waters have increased significantly with the development of the metropolitan region.

Ambient water quality monitoring by the EPA has shown that there is a general trend in increasing water quality moving south along the coast. Turbidity, total nitrogen and phosphorus all increase in the northern regions close to the WWTP outfalls and the Torrens and Patawalonga river outlets (Environment Protection Authority 1997).

Scientists in other regions of southern Australia have shown that at some locations the discharge of wastes into near-shore habitats has led to the decline of large macroalgae and has generally been associated with an increase of opportunistic, stress tolerant algal species. It has especially been the case in near shore sewage discharge and stormwater runoff sites. Whilst larger mature macroalgae are generally considered to be relatively tolerant to pollutants, less obvious, microscopic reproductive phases may be quite sensitive and therefore susceptible to pollutants. This may adversely affect recruitment of the macroalgae (Burrige & Bidwell, 2002).

Industrial and treated WWTP discharges are major sources of nutrients (particularly nitrogen and phosphorus), sediments and heavy metals (particularly lead, cadmium, zinc and copper). They contribute major organic pollution loads which, combined with nutrients, can cause algal blooms and reduce dissolved oxygen levels in the water column. Turbidity levels in industrial and WWTP discharges can reduce water clarity and light penetration through the water column.

Stormwater contains a complex mix of heavy metals from tyres and general car usage, hydrocarbons from fuels, nutrients and pesticides from domestic gardens and agricultural regions, and sediments.

A study by the University of Adelaide has shown that during the latter part of 1997 a combination of an El Nino climate effect, local stresses of anthropogenic origin (as outlined above), and a large turbidity plume caused by beach replenishment dredging (see Figure 17) caused recruitment of large brown macroalgae to fail on the Noarlunga and Horseshoe reefs. This has had a destabilising effect on the algal communities present, allowing the systems to further deteriorate, and will make these reefs more vulnerable to other impacts by reducing their ability to recover from stresses (Turner & Cheshire, 2002).

Climatic changes must also be considered when investigating environmental impacts on reef health. The years 1997 and 1998 were very unusual, with lower sea levels coinciding with a severe El Nino effect. This caused higher water temperatures (average of 3-5 degrees higher over the 1997-8 summer months) in the macroalgal recruitment season. It is unclear exactly what effects climatic events have on biological systems such as macroalgal reefs; however, many species are adapted to only a certain temperature range. Beyond this range the algae can be stressed and reproductive cycles disrupted, resulting in a general decline in algal abundance (Turner & Cheshire 2002).



Figure 15 Glenelg WWTP sludge outfall, which increased turbidity and nutrient levels, resulting in losses of seagrass around Glenelg; it may have had a similar impact on nearby reef systems. The outfall ceased discharging in 1993. (Photo courtesy PIRSA Marine Habitat)

Key pollution sources into the coastal waters are listed below.

Northern region

- Glenelg WWTP (nutrients, heavy metals, sediments and turbidity)
- Bolivar WWTP (nutrients, heavy metals, sediments and turbidity)
- Port Adelaide WWTP (nutrients, heavy metals, sediments and turbidity)
- most of Adelaide urban stormwater (nutrients, heavy metals and sediments)
- various industries in river catchments (nutrients, heavy metals and turbidity) discharging through the Barcoo and Patawalonga outlets, the Torrens and Port Adelaide rivers.

Central region

- Christies Beach WWTP (nutrients, heavy metals, sediments and turbidity)
- minor stormwater from southern suburbs (nutrients, heavy metals and sediments)
- industries in river catchments (nutrients and heavy metals) discharging at the Onkaparinga River, Christies Creek and Field River.



Figure 16 Turbidity from routine dredging at Glenelg (Photo P Pfennig)

Southern region

- minor stormwater from the far southern suburbs catchments (nutrients, heavy metals and sediments).

All these activities have potentially adverse effects on macroalgae and other reef species.



Figure 17 Turbidity from beach replenishment dredging at O'Sullivan Beach in 1997 (Photos P Pfennig)

6 VALIDATION OF FINDINGS

The nature of biological monitoring of marine systems makes it difficult to repeat measurements in identical locations, particularly over long periods of time. A concern with the 1999 survey data is that the sampling did not occur on exactly the same transects as were sampled in 1996 and there is a possibility that spatial changes in reef community structure were observed as temporal changes.

Caution needs to be exercised in assessing changes in marine ecosystems, as these systems exhibit significant natural variation. Some sources of variation are predictable due to natural fluctuations. Other unpredictable events may lead to dramatic changes in ecosystems. Predictable variations include tide, wave exposure and seasonal changes. These are always present and can account for some variability in reef systems, such as seasonal growth. Unpredictable events like storms and biological interactions (such as outbreaks of predators, disease or opportunistic species) can cause quite dramatic changes in community structure. If major elements of the system are damaged or removed it can take several years for the system to re-establish itself, if at all (English et al 1994). The season and weather conditions before sampling can have an effect on the structure of reefs observed.

In order to identify human-induced changes it is necessary to be able to distinguish them from natural variation. Many human-induced changes are gradual and effects are slow to be observed. Monitoring programs designed to identify changes in reef health need to consider long timeframes to reliably identify trends in anthropogenic impacts. Resurveying the reefs periodically should enable trends in reef health to be identified. In addition to providing an indication of reef health, this monitoring can provide feedback on the effectiveness of water quality improvement programs and management strategies being implemented under the guidance of the EPA and catchment water management boards.

It seems logical to assume that an increase in water quality will result in an increase in robust brown algae, and therefore ultimately increase reef health. However, a lack of historical data on these reefs means we cannot be certain of this as there are other physical, chemical and biological interactions at work. Nevertheless we can be optimistic that improvements in water quality will result in an increase in reef health throughout Adelaide's metropolitan coastline.

7 CONCLUDING REMARKS

Based on the findings of the two reef health surveys, the health of Adelaide's metropolitan reefs can be described as good in the south ranging to poor in the northern regions. It is believed that stormwater, wastewater and industry discharges have largely contributed to the decline in water quality and thus reef health in the northern region, although this has not been proven. Changes to reef community structure may take longer to assess than the three years between these surveys, but the studies indicate that the health of the reefs has remained stable over the last five years.

The poor state of the northern reefs is disturbing, but a number of initiatives instigated by industry, government and the catchment water management boards should improve water quality in this region over time. These include:

- extensive nutrient reduction and effluent reuse schemes for the treatment of wastewater
- environment improvement programs established by industry
- catchment management plans to curb pollution at its source and reduce impacts from river outflows
- raised community awareness of the sensitivity of temperate reef communities and the effect of poor water quality
- the enactment of the Environment Protection (Water Quality) Policy with the aim of reducing all wastewater discharges
- the development and implementation of a Marine and Estuarine Strategy for South Australia
- continued work by the EPA on ambient water quality monitoring
- initiation of the Coastal Waters Study to investigate a broad range of water quality issues in South Australia's coastal waters.

These initiatives should reduce the total flow of water and its concentration of pollutants entering the marine environment. In time this should also improve the water clarity and reduce heavy metal concentrations.

It is anticipated that water quality improvements should also have positive impacts on the health of reefs along the coast of Adelaide.

Further reef health surveys will be conducted in the future to assess changes in reef community structure over time.

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APPENDIX 1 - WATER QUALITY CRITERIA

Guidelines for comparison of the 90th percentile to classify water quality for nutrients, turbidity and chlorophyll

	zTKN-N (mg/L)	Oxidised Nitrogen (mg/L)	Total Phosphorus (mg/L)	Ammonia (as N) (mg/L)	Turbidity (NTU)	Chlorophyll a (mg/L)
Good	<1.0	<0.1	<0.1	<0.05	<5	<1
Moderate	1.0–10.0	0.1–1.0	0.1–1.0	0.05–0.5	5–25	1–10
Poor	>10.0	>1.0	>1.0	>0.5	>25	>10

From EPA Ambient Water Quality Monitoring (Environment Protection Authority 1997)

APPENDIX 2—ALGAL LIFEFORM IDENTIFICATION CHART

Lifeform code	Description	Examples of lifeform
Algal lifeforms		
BRBRANCH	Brown highly branched robust algae	<i>Cystophora sp. Sargassum, Acrocarpia</i>
BRFLAT	Robust brown algae with large flat blades	<i>Ecklonia, Durvillaea</i>
BRENC	Brown encrusting algae	<i>Ralfsia</i>
BRFOLI	Brown foliaceous algae	<i>Halopteris, Cladostephus</i>
BRMEM	Membranous brown algae	<i>Scytosiphon</i>
GLOBE	Lobed green algae	<i>Dictyosphaeria</i>
GFOLI	Green foliaceous algae	<i>Caulerpa spp. Cladophora</i>
GMEM	Membranous green algae	<i>Ulva spp.</i>
RENC	Red encrusting algae	<i>Sporolithon</i>
RFOLI	Red foliaceous algae	<i>Plocamium, Phacelocarpus</i>
RROB	Red lobed algae	<i>Osmundaria</i>
RMEM	Membranous red algae	<i>Gloiosacchion</i>
TURF	Turfing algae of all colours	<i>Ectocarpus, Sphacelaria</i>

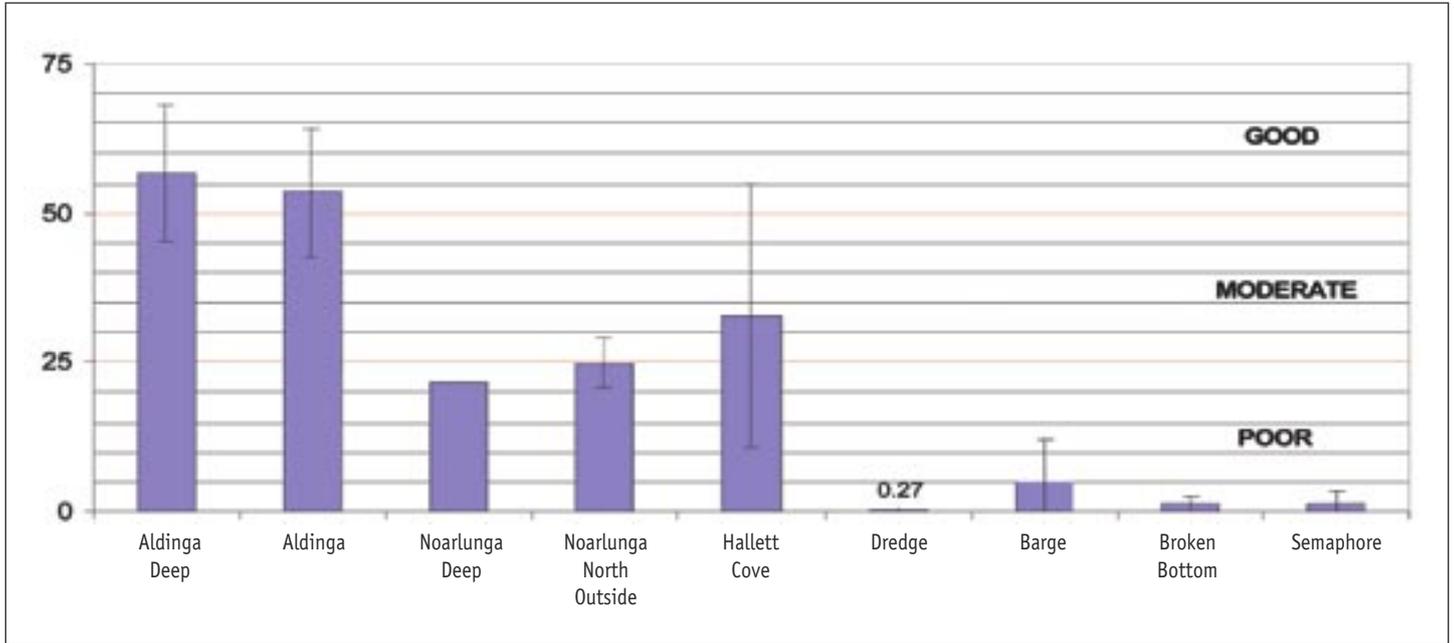
(Miller et al 1998)

Invertebrate lifeforms commonly seen in LIT transects

Lifeform code	Broad category	Taxa included
AMOSP	Sponges	Amorphous sponges
DISP		Discreet sponges
GAST	Molluscs	Gastropods
BIV		Bivalves
COLASC	Ascidians	Colonial ascidians
OASC		Other ascidians
URCHIN	Echinoderms	Sea urchins
STAR		Starfish
CORAL	Coral	Corals

APPENDIX 3—REEF HEALTH CLASSIFICATION—1996

– Mean percent cover of total brown algae greater than 50% = GOOD; 25–50% = MODERATE; less than 25% = POOR – Error bars represent 1 standard deviation of the mean.



APPENDIX 4—REEF HEALTH CLASSIFICATION—1999

– Mean percent cover of total brown algae greater than 50% = GOOD; 25–50% = MODERATE; less than 25% = POOR.
 – Error bars represent 1 standard deviation of the mean.

