Assessing the status of temperate reefs in Gulf St Vincent II: Survey results

A report to the Environment Protection Authority

**Anthony Cheshire, Stephen Hall, Jon Havenhand
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By

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1. Executive overview

This study reports on a program of ecological surveys to examine the composition of reef communities in subtidal habitats along the Adelaide metropolitan coast. The work represents the first quantitative account of the composition of these communities in the gulf waters of South Australia and provides a basis for comparison with previous work and an informed basis for the formulation of hypotheses about some of the processes which act to structure these communities. With the current paucity of knowledge about these ecosystems, this is an important initial step.

This study has demonstrated that differences occur in the structure of reef communities from the south to the north along the Adelaide metropolitan coast. These changes comprise a shift from communities dominated by robust brown algae in the south to foliaceous red algae in the north. This change in community structure correlates with gradients in both wave exposure and anthropogenic impacts. The data are not conclusive, but one explanation for this change in community structure is that the northern communities represent a degraded habitat from which significant losses have occurred including the dominant brown algae. One proposition that appears to be consistent with our data is that the absence of these algae from northern sites is mediated more by sedimentation effects on recruitment rather than by effluent. However, a series of studies focussing on the ecological factors controlling the structure of the brown algal dominated communities would need to be undertaken to clarify the extent to which those communities in Gulf waters are degraded and/or susceptible to degradation from anthropogenic impacts.

The lack of historical data make this proposal speculative but it will be important to continue to monitor the more southerly reef systems as the industrial and residential developments in the south progress.

2. Introduction

Temperate reefs in Gulf St Vincent are important and distinctive habitats that support highly diverse marine communities. Although limited in their spatial extent within the Gulf, compared to seagrass habitats (Shepherd and Sprigg 1976) reefs are, nevertheless, prominent with respect to the biodiversity of the resident biota and in their contribution to the productivity of nearshore environments. As such, they represent a habitat that it is especially desirable to protect from possible human-induced degradation.

It has already been demonstrated that seagrass habitats are under threat throughout South Australia and more particularly in waters close to metropolitan Adelaide where a variety of impacts (storm water runoff, effluent disposal, sedimentation resulting from coastal development) have resulted in significant losses (Table 1). These losses are significant in both biological terms and possibly economic terms (eg increasing costs of managing coastal systems, reduced profitability of associated fisheries).

Table 1 - Summary of seagrass losses (in hectares) in eastern Gulf St Vincent. P = *Posidonia*; A = *Amphibolis antarctica*; H = *Heterozostera tasmanica*. (Table taken from Shepherd et al. 1989)

Location	Period	Loss	Species	Possible Causes
Inshore area south of Outer Harbor breakwater	Before 1949	100	P	Sediment accretion due to up drift trapping by breakwater
Offshore area south of Outer Harbor breakwater	Before 1949	828	P,A	Sedimentation, turbidity, nutrients
Largs Bay	1949 - 81	80	P	Sedimentation from Outer Harbor breakwater and North Haven marina
Port Adelaide sludge pipeline	1977 - 82	15	P,A	Pipeline excavations and ensuing erosion
Port Adelaide sludge outfall	1978 - 82	365	P,A	Nutrients, turbidity
		1135	A	
Glenelg sludge outfall	1968 - 82	23	P,A	Nutrients, turbidity
Glenelg sewage effluent outfall	1935-61	50	P,A	Nutrients
Brighton to Grange	1935 - 81	800	P,A	Blowout expansion
Inshore seagrass regression Brighton to Semaphore	1935 - 85	1926	P,A	Fragmentation of beds (effect of nutrients, turbidity, land-based discharges and erosion)
Intertidal area off Fork Creek	1955 - 68	130	H	Nutrients from Bolivar sewage outfall
Subtidal areas between St Kilda and the Gawler River	1965 - 85	355	P	Nutrients as above, sediment accretion or movement
		315	H	

The extent to which these impacts have affected reef systems has not been previously investigated. A pre-requisite for examining change, however, is quantitative baseline data on the status of reefs in the region. Only with such data and a subsequent program of monitoring to determine how/whether reefs change from this baseline can the potential impact of man's activities be determined. The objective of this study was to provide that initial assessment.

This report provides an analysis of the data collected during baseline studies of reefs in Gulf St Vincent and includes an interpretation of findings in relation to the factors which are likely to have impacts on the biota. This document should be read in conjunction with two other reports in this series which provide a detailed summary of what is known about temperate reef systems in southern Australia (Cheshire *et al.* 1998) and a methodology for investigating the status of reefs (Miller *et al.* 1998). A summary of the first of these reports is also provided in Appendix 1 of this document.

3. Materials and Methods

3.1 Study sites

Six reefs representing the range of habitats (reef types and depths) found along the Adelaide metropolitan coast were examined (Figure 1). A brief description of each reef is given below, along with the depth at which observations were made. The geographic locations are given in Table 2.

Table 2 - Latitude and longitude of study sites

Location	Latitude (South)	Longitude (East)
Aldinga	35° 16.13'	138° 25.50'
Noarlunga	35° 09.03'	138° 27.50'
Hallett Cove	35° 04.34'	138° 29.40'
Broken Bottom	34° 57.86'	138° 28.78'
Dredge/Barge	34° 58.82'	138° 26.38'
Semaphore	35° 50.86'	138° 26.85'

3.1.1 Semaphore (10 m)

Semaphore reef is comprised of narrow strips of relatively flat rock at depths of 7.5 - 9 m. It is elevated from the surrounding sand substratum by approximately 0 - 2 m and is part of a series of similar narrow broken strips of reef along the northern metropolitan coast. The reef experiences relatively low wave energy due to its depth and distance from shore. Sampling was along the top surface of the reef, a generally consistently flat rock surface with occasional patches of accumulated sand in rock holes.

3.1.2 Broken Bottom (10 m)

Broken Bottom reef is a similar formation to Semaphore reef, being similarly comprised of narrow strips of rock platform elevated by 0 - 2 m from the substrate. The reef is located off Glenelg at depths of 9 - 11 m, and is subject to low wave energy. Due to it's proximity to Glenelg it may be influenced by water discharged from the Patawalunga. As with Semaphore reef sampling was carried out along the reef top. Sampled areas were generally flat rock surfaces broken up by occasional sand covered holes and small protruding outcrops of rock ("bommies") generally under half a metre high.

3.1.3 Dredge and Barge (15 m)

The dredge and barge are artificial reefs on sunken, steel hulled vessels. Both are approximately 40 m long by 10 m wide by 5-6 m high, and lie in 18 -20 m of water. They are located directly offshore from Glenelg and are subject to negligible wave energy. Both were sampled along the upper deck surface (15 m). The dredge has a flat metal deck with wheel house and entrance structures mid deck, a narrow central hole in the deck at the bow end, and a raised area (approx. 1 m) at the stern. The barge has a flat metal deck which is dominated by two large open holds, resulting in little actual deck surface.

3.1.4 Hallett Cove (5 m)

Hallett Cove reef is comprised of a long narrow strip of rock platform elevated by 1 - 2 m from the sand bottom. It has a consistently flat surface. Unlike Semaphore and Broken Bottom, Hallett Cove reef is quite close to shore, occurring in shallow water (approximately 5 m) and is therefore subject to greater wave energy. Sampling was carried out along the upper surface of the reef which had a similar topography to the other two reefs.

3.1.5 Noarlunga (5 and 10m)

5m: Noarlunga reef extends several hundred metres north and south of the end of the Noarlunga jetty. The width varies between 20 - 100 m along its length. On the seaward side the base is 7 - 10 m deep, and on the shore side, 5 - 7 m. The reef top is exposed at low tide. The seaward side in particular provides a high energy environment due to constant wave action, and the fact that the reef acts as a barrier to passing swell. Noarlunga reef is situated between the Onkaparinga river mouth to the south and Christies beach effluent outfall to the north (both several kilometres away). It is also subject to heavy recreational use by swimmers and divers. Sampling was carried out on the seaward side and northern end of the northern section of the reef. Transects were sampled at 5 - 7 m depth. All transects ran north - south along the reef slope, over terrain made up of large boulders and platforms.

10m: The ten metre transects were sampled over similar terrain as the five metre transects, and all the same conditions applied. These transects were on the seaward side and located at the southern end of the northern section of reef in approximately 9 m of water.

3.1.6 Aldinga (5 and 10m)

5m: Aldinga reef was surveyed south of an area known as the drop off. The reef is comprised of an extensive, gently sloping, rock surface with occasional protruding outcrops of varying size and experiences intermediate wave exposure. The survey area was approximately 1km offshore. The coastline is predominantly low cliffs with narrow sand or rocky beach. Transects were sampled at a depth of 4 to 6 metres.

10m: Sampling transects were located directly off-shore from the 5 m site at a depth of 8.5 to 10 m. Conditions and topography were similar to the 5 m site although wave energy may have been slightly lower due to depth.
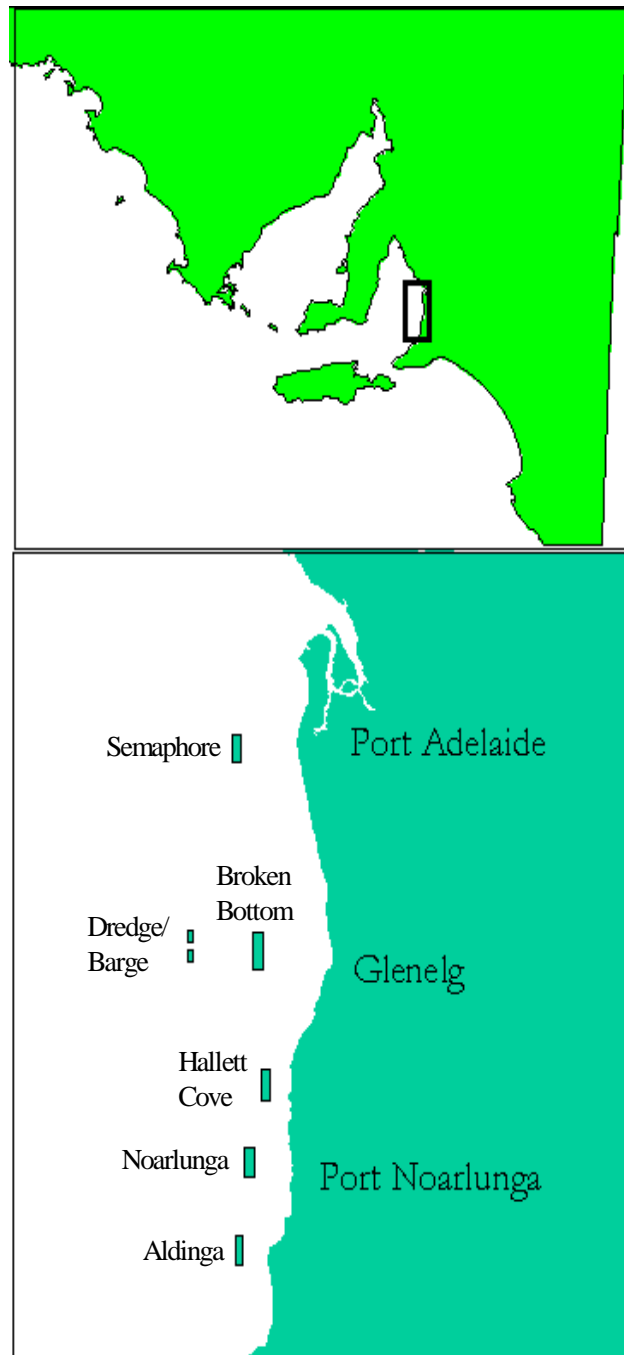
Figure 1 - Map of Adelaide metropolitan coast showing the location of all study sites.

3.2 Field sampling methods

Three sampling methodologies were adapted to assess reef status each of which was appropriate for a different component of the reef flora and fauna. Line intercept transects (LIT) were used to assess sessile biota, quadrat sampling for sedentary biota and visual census was used for fish. The justification for choosing these methods is given in Cheshire *et al.* (1998).

3.2.1 Line Intercept Transects (sessile biota)

The Line Intercept Transect method (LIT; Turner 1995) was used to obtain estimates of the percent cover of sessile benthic organisms. A twenty metre tape was placed over the substratum, from a random start point. The distances at which the underlying biota changed were recorded (Figure 2) for the entire length. To overcome the problem of macroalgae moving under the influence of waves and currents a 1 m weighted ruler (1.5 kg) was used to pin down the biota along the transect (Turner 1995).

For most sites six sample transects were measured. Exceptions to this were at Aldinga (5 m) and Noarlunga (5 m), where only 5 transects were sampled, and at Noarlunga (10 m) where only one transect was sampled. Another exception was at the barge and dredge sites where there was little horizontal surface available. In view of the close proximity of the two sites and their similar nature and water depth, they were sampled as one reef with four transects sampled on the dredge and two on the barge.

All transects were placed randomly by dropping a weight from the boat at the required depth. The weight served as the starting point to which the transect measuring tape was attached. Transects were sampled by two divers each surveying a ten metre section. The taxonomic classification scheme used with this method is given in section 3.3.

Figure 2 - Schematic view of benthos showing LIT.

RCORAL (8)
SUBSTRATE (12)
GFOLI (28)
RFOLI (49)
BRROBUST (60)
RFOLI (65)
GFOLI (75)
BRROBUST (100)
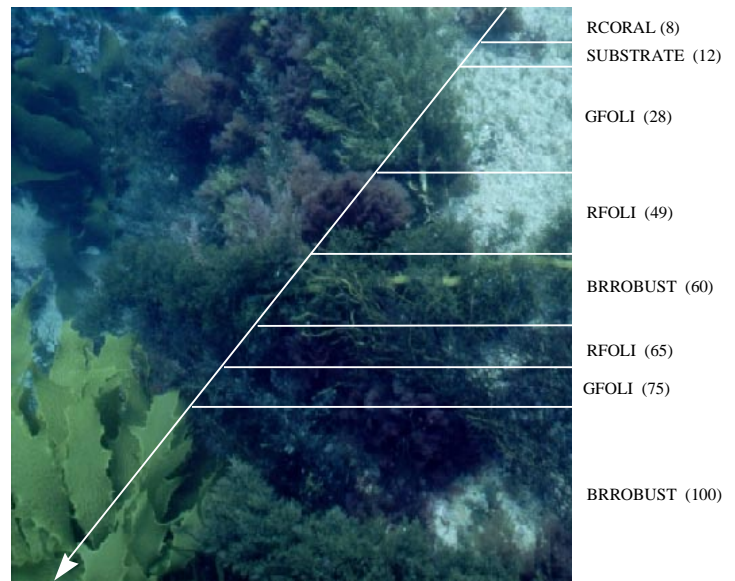
Table 3 - Example of data recorded from LIT shown in Figure 2.

Transition	Lifeform	Taxa
8	RCORAL	Unknown
12	SUBSTRATE	
28	GFOLI	Caulerpa
49	RFOLI	Asparagopsis
60	BRROBUST	Cystophera
65	RFOLI	Asparagopsis
75	GFOLI	Caulerpa
100	BRROBUST	Ecklonia

LIT data were prepared for analysis by calculating the percentage cover of each taxa/lifeform per transect using the following formula:

$$\text{Percent cover of any lifeform A} = \frac{\sum L_A}{Y - \sum D} \times 100$$

where $\sum L_A$ = the sum of the individual lengths of lifeform A on the transect,

Y = the total length of the transect and

$\sum D$ = the sum of the lengths where no data was recorded.

These were then used to calculate summary statistics for each site.

3.2.2 Quadrats (sedentary biota)

The abundance of sedentary biota was also assessed using 25cm x 25cm quadrats which were taken at random distances along LIT transect lines. The only exception to this was Noarlunga reef where quadrat data was collected independently of LIT and fish census data. Abundances were recorded for all macro-fauna within each quadrat and eight quadrats were assessed per 20 m transect. Transects were the same as those used for LIT measurements. The taxonomic classification scheme used with this method is given in section 3.3.

Quadrat data were prepared for analysis by calculating the abundance of each taxa/lifeform per square meter (no's. m^{-2}). These were then used to calculate summary statistics for each site.

3.2.3 Fish Visual Census

Fish visual censuses were carried out on the same transects as the other two survey methods, but were extended to fifty metres in length. They were carried out prior to LIT and quadrat sampling to minimise disturbance to the fish prior to assessment. Two divers swam the transect, the first recording fish abundance within a three metre radius (above and to either side), while the second noted distance swum. This provided an abundance count for all fish taxa within a 50 x 3 m radius tunnel. The taxonomic classification scheme used with this method is given in section 3.3.

Visual census data were prepared for analysis by recording the abundance of each taxa per transect. These were then used to calculate summary statistics for each site.

3.2.4 Topographic complexity

The complexity of the reef surface can have a marked influence on the ecological community it supports and obtaining a measure of this complexity can often aid interpretation of ecological data. Using methods outlined by Aronson *et al*. (1994) a complexity index (C) was calculated for each reef transect sampled. The complexity index (C) is defined as:

$$C = 1 - d/L,$$

where d is the horizontal distance covered by a conformed chain (measured against the transect tape used for LIT and quadrat transects) and L is the chain's length when fully extended. For this survey a 3 m chain with 15 mm long links was used.

3.3 Taxonomic resolution

For both the LIT and the quadrat surveys taxa were recorded at relatively low taxonomic resolution, using a system of functional life form groups. This approach is preferred because identification is relatively simple, and allows field workers to maintain a consistent taxonomy throughout the surveys. The life form groups used are listed in Table 4 and Table 5 for flora and fauna respectively.

Table 4 - Algal life forms classification used in this study. Note: this classification is based on Turner's (1995) scheme and is also comparable to that used by Littler and Littler (1985)

Lifeform	General description	Typical member taxa
Encrusting browns	Ralfsiod browns which includes the alternate phase in the life-history of some otherwise upright forms.	*Ralfsia, Scytosiphon* (gametophytes)
Encrusting reds	Comprises mainly corallinaceous red algae	*Porolithon, Lithothamnion*
Filamentous turfs	Smaller (<20 mm) filamentous forms	*Ectocarpus, Sphacelaria, Cladophora, Polysiphonia* and other ceramiaceous reds
Foliaceous browns	Bushy non-membranous browns	*Halopteris, Zonaria, Padina, Lobophora, Lobospira*
Foliaceous greens	Bushy non-membranous greens	*Caulerpa, Codium, Apjonia*
Foliaceous reds	Bushy non-membranous reds	*Plocamium, Phacelocarpus, Asparagopsis*
Membranous browns	Flattened membrane forms generally relatively transparent in general appearance	*Colpemenia, Hydroclathrus, Scytosiphon* (sporophytes)
Membranous greens	Flattened membrane forms generally relatively transparent in general appearance	*Ulva, Enteromorpha*
Membranous reds	Flattened membrane forms generally relatively transparent in general appearance	*Kallymeniaceae*
Robust browns	Generally the larger canopy dominants	*Sargassum, Cystophora, Ecklonia, Seiroccocus, Scytothalia, Acrocarpia.*
Thick fleshy reds	Generally robust persistent forms	*Osmundaria, Lenormandia*

Table 5 - Faunal life form classifications used in this study .

Taxonomic group	Life form	Taxonomic group	Life form
Bryozoans	Bryozoa	Echinoderms	Urchins
Hydroids	Hydroidia		Coscinasterias sp
Molluscs	Bivalvia		Other stars
	Gastropoda		Chrinoids
	Opishobranchia	Anemones	Anemone
	Chiton	Corals	Coral
	Squid	Crustaceans	Crabs
	Octopus		Goose barnacles
Ascidians	Stalked		Shrimps
	Colonial		Other
	Other	Worms	Tube Polychaetes
Sponges	Discreet sponges		Other Polychaetes
	Amorphous sponges		Sabellids
Benthic fish	Benthic fish		Holothurians

Fish identifications were to the level of common names, thereby leading to a mixed level of taxonomic resolution (Table 6), but one that is likely to be relatively robust for divers with little taxonomic training. The species identified are given in Table 6.

Table 6 - Fish taxa recorded during visual census surveys

Common Name	Latin Name	Considered to be resident on reef systems	Common Name	Latin Name	Considered to be resident on reef systems
Blenny	*Blennidae*	yes	Old Wife	*Enoplosus armatus*	yes
Blue Devil	*Paraplesiops meleagris*	yes	Salmon trout	*Arripis truttaceus*	no
Bullseye	*Pempheris spp*	yes	Silver Drummer	*Kyphosus sydneyanus*	yes
Cowfish	*Aracana spp*	yes	Squid	*Sepioteuthus australis*	no
Crab	*Portunidae*	no	Stingray	*Myliobatis australis*	no
Cuttlefish	*Sepia*	yes	Sweep	*Scorpis spp*	yes
Dragonet	*Bovichthys variegatus*	yes	Talma	*Chelmonops spp*	yes
Dusky Morwong	*Dactylophora nigricans*	yes	Three fin	*Norfolkia clarkei*	yes
Fry	*Fry*	no	Toadfish	*Tetradontidae*	no
Goatfish	*Upeniechthys vlamingii*	yes	unknown	*Unidentified*	no
Goby	*Gobidae*	yes	Victorian Scalyfin	*Parma victoriae*	yes
Herring Cale	*Odax cyanomelas*	yes	Weedfish	*Clinidae*	yes
Hula Fish	*Trachinops spp.*	Yes	Weedy Whiting	*Odacidae*	yes
Leather Jacket	*Meuschenia spp.*	Yes	Whiting	*Sillaginidae*	no
Long Finned Pike	*Dinolestes lewini*	no	Wrasse	*Thalossoma spp.*	Yes
Magpie Perch	*Cheilodactylus nigripes*	yes	Yellowtail Scad	*Trachurus novaezelandiae*	no
Moonlighter	*Tilodon sexfasciatum*	yes	Zebra Fish	*Girella zebra*	yes
Mullet	*Aldrichetta forsteri*	no	Silver Belly	*Parequula melbournensis*	yes

3.4 Statistical methods

3.4.1 Descriptive statistics

A series of summary statistics (means, standard deviations, etc) were calculated for each taxa at each site to provide an overall summary of the distributions and their relative abundance across sites.

3.4.2 Community patterns and trends

Multivariate analyses allow us to characterise communities using information about all components of the system (community) simultaneously. As such they provide us with a tool which enables us to deal with the complexity inherent in community data sets without losing the richness contained within the raw data.

A variety of multivariate analysis techniques available within the PRIMER package (Clarke and Warwick 1995) were used to assess community patterns and trends. This suite of approaches (each with a different analytical framework) was adopted so that the robustness of trends or patterns in the data could be determined.

3.4.2.1 Classification and ordination analyses

Matrices of similarities between each pair of samples were generated using the Bray-Curtis coefficient (Bray and Curtis 1957) and then were subject to cluster analysis and ordination for each sampling method. Clustering was by a hierarchal, agglomerative method employing group-average linking with results being displayed in dendograms. Ordination plots based on similarity measures were created using multidimensional scaling (MDS).

3.4.2.2 *Transformation and standardisation*

No standardisation was used for multivariate analysis so that the information contained in the abundance totals was retained (Clarke 1993). However, all data was square root transformed except for the data used in the canonical correlation analysis. The square root transform is fairly moderate in effect and, when used with Bray-Curtis similarity measures, tends to reduce the loss of structure in resultant analyses due to large fluctuations in dominant taxa (Clarke and Green 1988). This is achieved by increasing the contribution of middle abundance taxa (Clarke 1993) to the overall dissimilarity measure.

3.4.2.3 *Simper analysis*

Where ordination techniques indicated differences in community structure between reefs, Simper analysis was used to examine which species contribute most to that difference. Simper (similarity percentages) provides a quantitative index of the similarity between transects (or quadrats) within a location and of the dissimilarity between transects (or quadrats) between locations (see Clarke and Warwick 1995, for a full description of the method). Sites which have a high value for the average similarity are comprised of transects which in general are similar in terms of the biota they contain. A low average similarity would indicate that transects within a site are variable and that overall communities are more heterogeneous.

Conversely, any two sites which have a high value for the average dissimilarity are likely to be quite different in the nature of the constituent communities whereas a low average dissimilarity would indicate that transects are more similar across the two sites.

SIMPER analysis also gives estimates of the average contributions of individual taxa to these similarities and dissimilarities. By studying the consistency with which various taxa contribute to the overall measures of similarity/dissimilarity it is possible to determine which taxa can be used as indicators of community differences.

3.4.2.4 *Canonical correlation analysis*

Canonical correlation analysis provides an alternative method for representing the relationships between transects within and between sites. In general terms the method is similar to factor analysis in that relationships between samples are determined by the extraction of a series of eigenvectors which represent linear combinations of the constituent variables. The canonical vectors extracted using this technique can then be correlated with the original variables used to characterise the samples and this in turn provides an assessment of the relative importance of taxa in characterising sites. Canonical correlations were determined using JMP (JMP 1995).

4. Results

4.1 Descriptive summary

This section gives a basic description of the structure of each reef and what was found on it. These summary data are presented at the outset to provide the reader with a broad appreciation of the current status of each reef. It should be borne in mind, however, that any picture of what is on a reef is critically dependent on the method of sampling that is used. Thus, data are presented separately for each of the sampling methods to give a more complete summary of reef community structure. Discussion of the relative value of the various data collection techniques is dealt with in the companion report (Miller *et al.*, 1998).

4.1.1 Topographic complexity

A summary of the distribution of topographic complexity estimates for the sample sites on each reef is given in Figure 3. The highest estimates of complexity were observed at Noarlunga, where the structure of the reef meant that samples had to be taken on a wave exposed slope. In contrast, for the other reefs it was possible to sample reef tops/flats at the required depth.
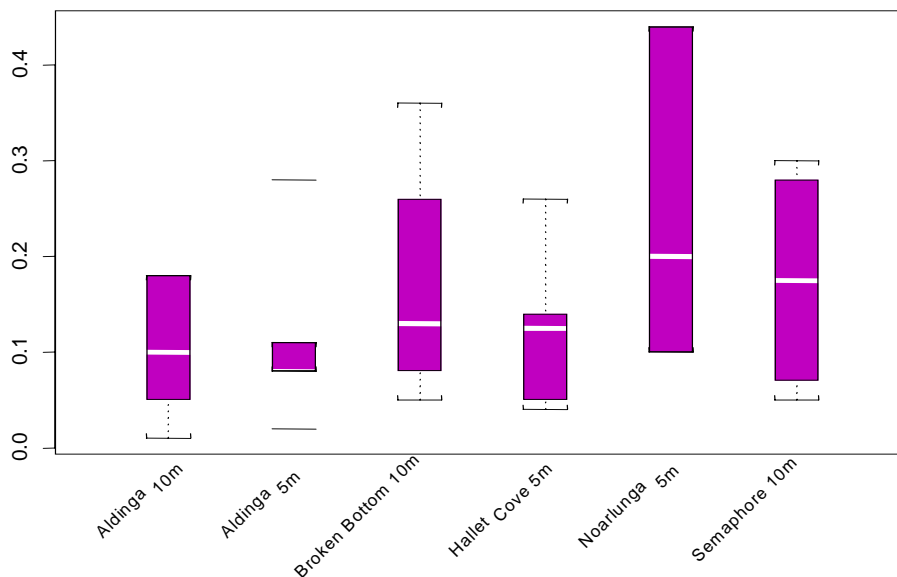
Figure 3 - Boxplots showing the distribution of complexity indices for all sites where more than two estimates were obtained.

Despite this difference, however, the overall distribution of estimates indicates that there is little difference in the complexity of the habitat at the different locations. This conclusion is supported by Analyis of Variance which indicated no statistically significant difference between sites (Table 7). It should be noted, however, that Aldinga reef in particular is known to be topographically quite variable and our estimates are likely to have been biased downwards by choosing survey areas similar to those found on other reefs. Our purpose, however, was to determine topographic complexity on the parts of the reef where faunal and floral censuses were undertaken and not to characterise the reefs themselves.

Table 7 - Results of single factor analysis of variance for topographic complexity between sites.

	Df	SS	MS	F
Site	5	0.0574	0.0115	0.9810 NS
Residual	23	0.2691	0.0117	

4.1.2 Faunal and floral composition

4.1.2.1 Line Intercept Transects

A total of 34 taxonomic classes were recorded on line intercept transects and, as one might expect, the majority of recordings were of red or brown algae of various types. Summaries of the LIT data for each taxa are given in Appendix 2, and a graphical representation of the distribution of observations among reefs is given in Figure 4. Figure 4 shows a broad separation between sites supporting foliaceous and robust brown algae, with some red foliaceous algae or turf forming species, and those supporting red foliaceous algae or turf forming species, but with brown algae absent. The majority of other taxa were represented at all sites in relatively low abundance.

Aldinga 5m   Aldinga 10m   Hallett Cove   Noarlunga 5m   Broken Bottom   Dredge/Barge   Semaphore

Red foliaceous algae
Turf
Bare sand
Green foliacious algae
Bare rock
Amorphous sponge
Discreete sponge
Red robust algae
Coral
Brown membranous alga
Bivalve
Urchin
Holothurian
Stalked ascidian
Starfish
Crab
Seagrass
G membranous algae
Hydroid
Crinoid
Brown lumpy algae
Gastropod
Green lumpy algae
Bryozoan
Green lobed algae
Colonial ascidian
Red membranous
Red coraline algae
Red lumpy algae
Tube polychaete
Other ascidians
Brown foliacious algae
Encrusting algae
Brown robust algae

Figure 4 - Graphic showing the relative abundance (log % Cover + 0.01) of the various lifeforms recorded on LIT transect.

4.1.2.2 Quadrats

A total of 27 taxonomic classes were recorded in quadrat samples. Of these hydroids, tubicolous polychaetes, and anemones were generally most abundant, with particularly high densities observed at Hallett Cove and Noarlunga. For the most part however, species distributions were patchy and low abundances were recorded. Summaries of the quadrat data for each taxa are given in Appendix 3, and a graphical representation of the distribution of observations among reefs is given below (Figure 5).

This figure shows the particularly high numbers of tubicolous polychaetes and hydroids found at Hallett Cove and Noarlunga, respectively, but also suggests that these same taxa, along with anemones were also relatively more abundant at the other sites. The only sites which seem distinct are Dredge/Barge which has a uniformly low abundance of all sedentary taxa and Broken Bottom, which has relatively high numbers of non-tubicolous polychaetes.
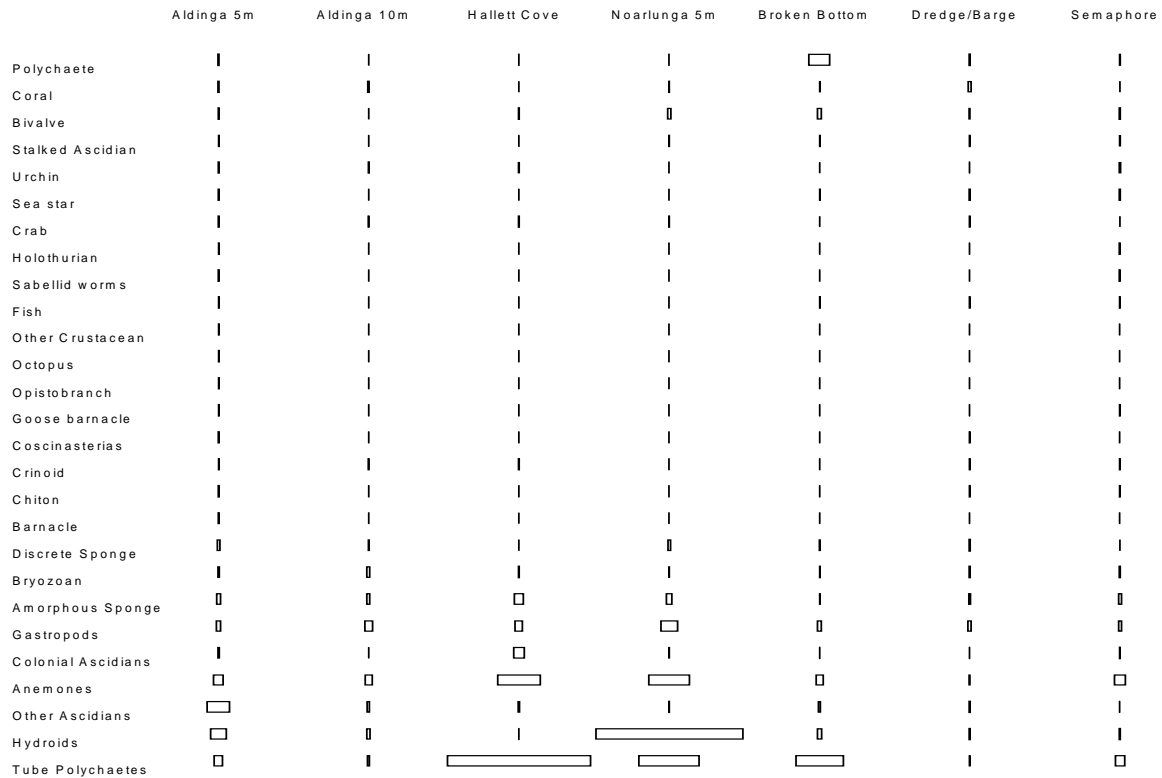
Figure 5 - Graphic showing the relative abundance (log density + 0.01) of the various taxa recorded in quadrats.

4.1.2.3 Fish

A total of 24 fish taxa were recorded by visual census. Of these the numerical dominant at all but one of the sites was the hulafish (*Trachinops* sp) (Appendix 4, Figure 6). This species was not recorded in large numbers at Aldinga at 5m, but since it was dominant at 10m on this reef and is commonly found on rocky reefs in large schools, it would be difficult to argue that it absence at 5m was significant. Leather jackets (*Meuschenia* spp) and bullseyes (*Pempheris* sp) were also common, particularly on Broken Bottom, Dredge and Barge and Semaphore. Most other species occurred occasionally with no obvious separation of taxa between sites
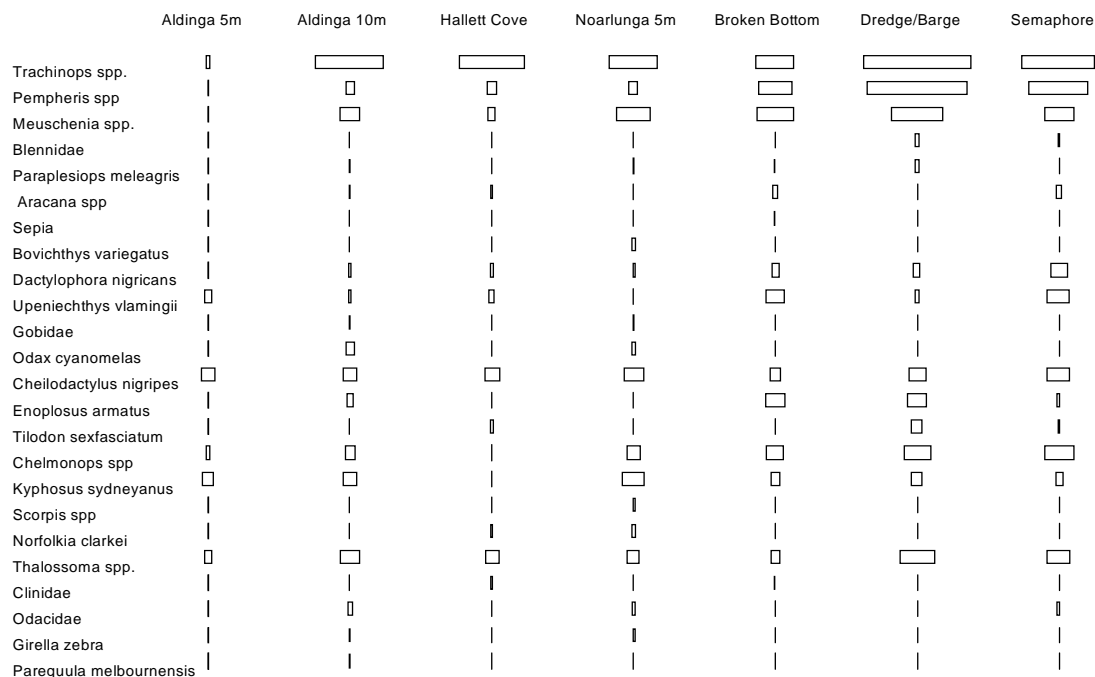
Figure 6 - Graphic showing the relative abundance (log density + 0.01) of the various fish taxa recorded by visual census

4.2 Comparative analysis

This section looks in more detail at the similarities and differences in the community structure of the six reefs. The objective is to identify features of community structure that are either common to groups of reefs or which set particular reefs apart from the rest. This allows a determination of the extent to which the various sampling methods reveal consistent patterns. The analyses are presented separately for each method.

4.2.1 LIT (sessile biota)

4.2.1.1   Cluster analysis

There is a distinct north-south difference in reefs (Figure 7) but there is no evidence for any effect of depth on the structure of the reef communities. Reefs can be defined using three groups. The first group comprises all of the northern reefs (Broken Bottom, Dredge/Barge and Semaphore); the other two groups are comprised of the southern reefs with Aldinga and Hallett Cove forming one group, and Noarlunga reef the other (Figure 7).
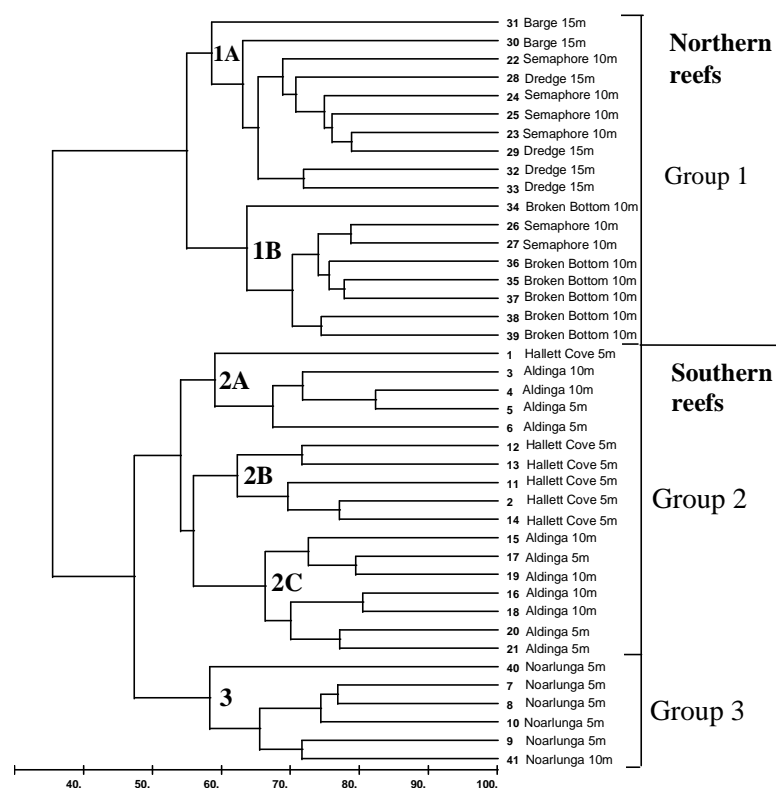
Figure 7 - Cluster analysis of LIT data. Three major groupings occur with a distinct north/south differentiation.

These groups may be further sub-divided into six minor groupings, two northern and four southern. The southern groups (2A, 2B, 2C and 3) show almost complete discrimination of reefs with the exception of one Hallett Cove transect (1) in group 2A. Of the northern groups, Broken Bottom is largely distinct (1B), while the other group comprised a mixed selection of transects from the other northern reefs (1A). From this analysis it would appear therefore, that each reef supports a distinct biota.

4.2.1.2   MDS

The results of the MDS analysis were entirely consistent with those from the cluster analysis. Figure 8 shows the ordination plot from this analysis. Here, sites closer together on the plot are more similar to one another in community composition. The north-south difference can be clearly seen in the plot and transects from each reef are grouped together.   However, the

arrangement of reefs within the northern or southern zone does not reflect geographical proximity.
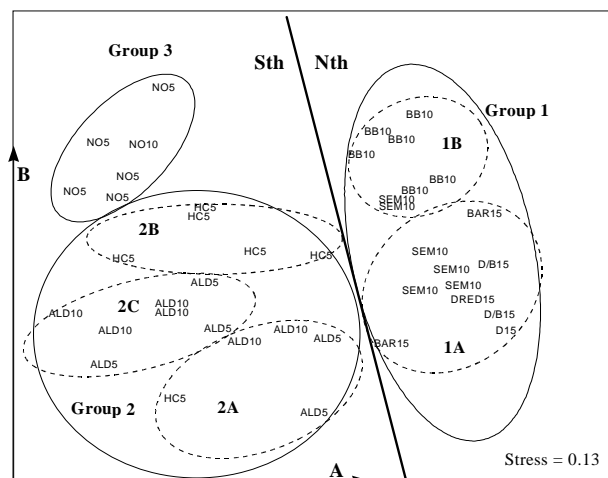
Figure 8 - MDS ordination plot of LIT data. Overall a north-south gradient was evident. Sub-groupings found in the cluster analysis are also apparent in the ordination.

4.2.1.3   Simper analysis

Simper analysis was used to assess the consistency in community structure of transects within the groups defined by both cluster and MDS analyses. The average similarity of transects within each of the three major regions was moderate ranging from 59-66%.

Various lifeforms contribute to the similarity or dissimilarity within and between sites, but the majority of the contribution can be attributed to differences in only 6 major lifeforms: red and brown foliaceous algae, red turfing algae, red encrusting algae, brown leathery algae and amorphous sponges (Table 8, Table 9).

Table 8 - Within site similarity percentages for the three major groupings. Similarities within groups indicate a moderate degree of homogeneity.

Group - average similarity across all taxa and samples	Taxa	Average percent cover	Average similarity[1]	Ratio[2]	Percent contribution to similarity
Northern Reefs - average similarity = **61.09**	Red Foliaceous algae	52.87	25.2	2.84	41.19
	Bare sand	16.39	9.9	1.48	16.26
	Bare Rock	5.40	6.9	2.44	11.26
	Red turfing algae	11.84	4.9	.79	7.96
	Amorphous sponges	2.14	3.0	1.25	4.87
Southern reefs (Aldinga and Hallett Cove) - average similarity = **58.75**	Brown robust algae	30.61	15.8	2.59	26.82
	Red encrusting algae	9.66	8.5	2.36	14.42
	Brown foliaceous algae	15.11	8.0	1.50	13.55
	Bare sand	10.31	7.1	1.68	12.12
	Red Foliaceous algae	12.44	4.9	.84	8.28
Southern reefs (Noarlunga) - average similarity = **65.50**	Brown robust algae	22.11	14.6	10.82	22.30
	Red encrusting algae	25.47	12.3	3.56	18.81
	Mixed turfing algae	7.94	8.3	3.68	12.66
	Red turfing algae	16.51	8.2	2.36	12.50
	Amorphous sponges	5.51	7.0	7.99	10.69

[1]Average similarity is based on an average measure of all pairs of samples where the taxa co-occurs.
[2]The ratio is a measure of the extent to which a taxa can be used to discriminate sites. If delta is large and sd is small then the ratio is large which indicates that the ith species not only contributes much to the dissimilarity between groups but it also does so consistently in intercomparisons of all samples in the two groups. It is thus a good discriminating species.

4.2.1.3.1 Discrimination of sites

The average dissimilarity between transects reinforces the north-south discrimination of sites. The lowest level for average dissimilarity (53%) was between groups 2 and 3 (the southern sites). The average dissimilarity between either of the southern groups and the northern group was higher (62% and 73% respectively; Table 9).

Table 9 - Dissimilarity results from SIMPER analysis. The highest dissimilarity exists between the southern and northern reefs.

Taxa	Average percent cover group 1	Average percent cover group 2	Average dissimilarity	Ratio	Percent contribution to dissimilarity
Dissimilarity between groups 1 & 3. Average dis-similarity=72.49	**Northern Reefs**	**Noarlunga**			
Red foliaceous algae	52.87	0.28	13.06	3.14	18.02
Red encrusting algae	0.17	25.47	8.43	2.63	11.63
Brown robust algae	0.19	22.11	8.36	6.25	11.53
Bare sand	16.39	1.78	5.85	1.70	8.07
Red turfing algae	11.84	16.51	5.04	1.32	6.95
Dissimilarity between groups 1 & 2 average dis-similarlity=61.67	**Northern Reefs**	**Aldinga and Hallett Cove**			
Brown robust algae	0.19	30.61	10.00	2.41	16.22
Red foliaceous algae	52.87	12.44	9.14	1.61	14.83
Brown foliaceous algae	1.17	15.11	5.61	1.43	9.09
Red encrusting algae	0.17	9.66	5.32	2.09	8.63
Red turfing algae	11.84	0.94	4.55	1.18	7.38
Dissimilarity between groups 2 & 3 average dis-similarity = 52.61	**Noarlunga**	**Aldinga and Hallett Cove**			
Red turfing algae	16.51	0.94	5.66	1.37	10.76
Brown foliaceous algae	0.52	15.11	5.04	1.39	9.58
Red foliaceous algae	0.28	12.44	4.58	1.19	8.71
Bare sand	1.78	10.31	4.37	1.50	8.30
Red encrusting algae	25.47	9.66	3.90	1.39	7.42

4.2.1.4 Canonical correlation analysis

Results from the canonical correlation analysis of LIT data were consistent with those above in that there was a clear discrimination of almost all sites (reefs). The clear north-south trend is seen in the ordination of the southern sites in the negative domain of axis I (left hand side of the plot; Figure 9). There is an overlap between Semaphore and Broken Bottom which illustrates the similarities in the these northern reefs (10 m depth).
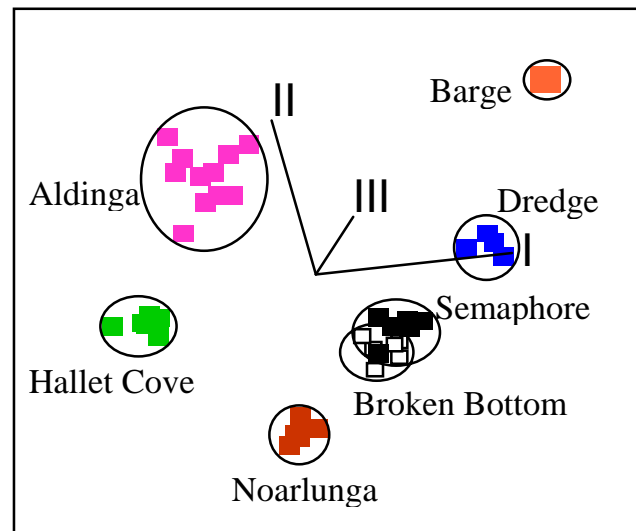
Figure 9 - Canonical correlation ordination of community LIT data showing canonical vectors I to III. All sites can be discriminated from one another on the basis of the LIT data showing clear differences in the community structure at the various sites.

4.2.2 Quadrat data

4.2.2.1 Cluster analysis

In general there were no clear associations between reefs in terms of the abundance of taxa assessed using the quadrat surveys. This indicates that the patterns in the distribution of the sessile and sedentary taxa identified using the quadrat surveys do not vary in the same way as the taxa quantified using the LIT surveys. The cluster analysis of the quadrat data showed no real discrimination of reefs (Figure 10). Samples from the various reefs were frequently distributed broadly across the dendogram and intermixed with one another which indicates a relatively high level of heterogeneity within reef systems.

On a finer scale there was some aggregation of samples. Groups one, two and five (Figure 10) largely comprise samples from the three southern reefs; group three can be split into two groups comprising southern reefs in one section and Semaphore in the other. Group 4 is predominantly a mix of northern reefs, while the remainder of transects, which are scattered throughout the dendogram, are also northern reefs with the exception of two southern reef transects.

These results suggest that transects within reefs may display common characteristics which can characterise that reef, however there is a high level of overlap between reefs making it very difficult to distinguish reefs from one another on the basis of these data.
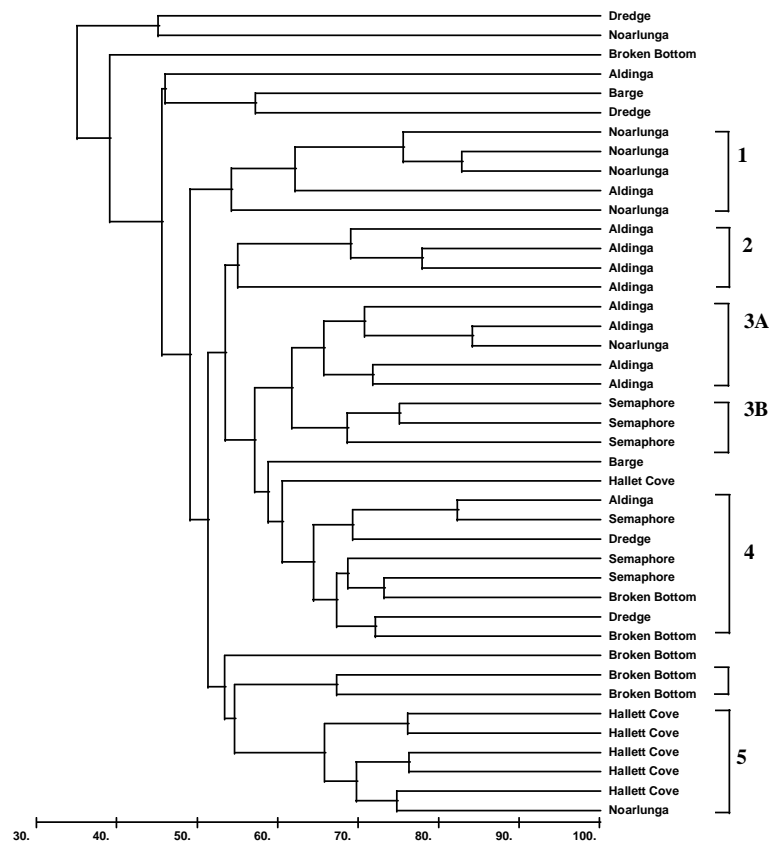
Figure 10 - Cluster analysis results for quadrat data. There are no broad scale groupings present. Some grouping is apparent on the finer scale but there association of these groups is not consistent with the overall association of these reefs in geographical or depth terms.

4.2.2.2 MDS

Ordination of quadrat data further supported the conclusion that transects within reefs were similar, but low variability existed between reefs. The majority of transects for individual reefs ordinated together (Figure 11). However, these groupings overlap one another suggesting that the between reef variability is similar in magnitude to the variability between transects within a reef.
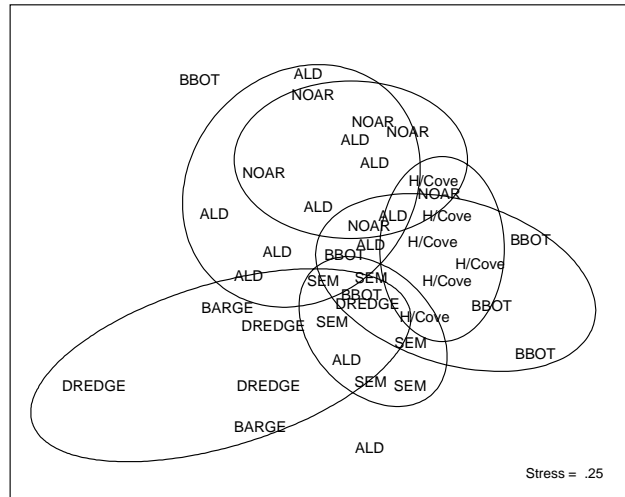
Figure 11 - MDS ordination of quadrat data. Most transects from the various reefs appear close to one another in the ordination space. The groupings of the individual reefs overlap suggesting variability within reefs is similar to that between reefs.

4.2.2.3   Canonical correlation

Whereas there is little natural structure in the quadrat data a canonical correlation analysis does provide a tool for discriminating the reefs. A more or less complete discrimination of individual reefs can be achieved using this technique (Figure 12). Further, a north-south discrimination exists on vector I of this ordination, while discrimination between Broken Bottom, the Barge and Semaphore is present on vector III.

This result provides some support for the conclusions drawn from the cluster analysis (Figure 10) and the MDS ordination (Figure 11) in that there is some degree of similarity between transects from within each site. Furthermore, it is suggests the general north-south trend in community structure is reflected in the structure of these communities.
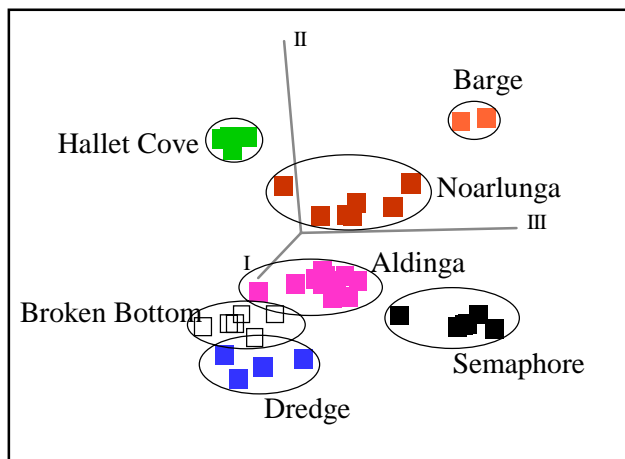
Figure 12 - Canonical correlation ordination of community quadrat data showing canonical vectors I to III. North-south discrimination is evident on vector I. Almost complete discrimination individual reefs is evident.

4.2.2.4   Analysis using presence-absence data

Presence-absence data provides an alternative way of analysing the data which removes the effect of differences in abundance of taxa and focuses simply on whether a taxa is found at a site or not. The analysis of the data at this level did not provide any new insights on the structure of these communities.

4.2.3 Fish Visual Census

4.2.3.1 Cluster analysis

Cluster analysis using fish data showed some discrimination of reefs, although not complete (Figure 13). This discrimination seems to be on a fine scale. Each reef is represented by a small group of transects, with the exception of Dredge/Barge which show complete discrimination, and Broken Bottom and Semaphore which tend to be more scattered. This suggests higher variability on these two reefs. Some depth discrimination appears with groups one and two being predominantly 5 m and group three comprising 10 and 15 m transects.
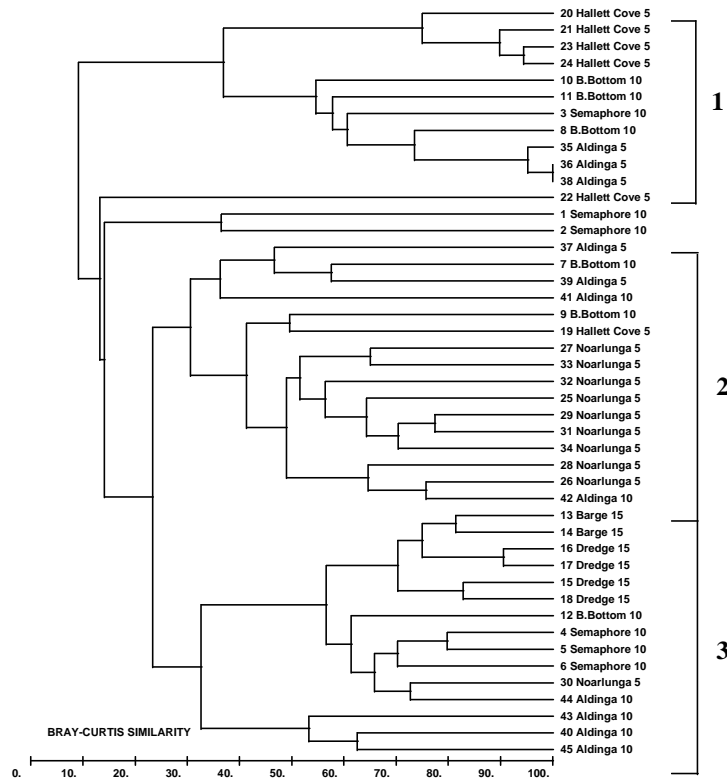
Figure 13 - Cluster analysis of fish visual census data. Some discrimination of reefs is present although not complete. Some depth discrimination appears with groups one and two being predominantly 5 m and group three comprising 10 and 15 m transects

4.2.3.2 MDS

MDS ordination of fish visual census data suggest high variability overall (Figure 14). This was evident in the high stress value and mixing of groups of transects. Dredge/Barge and Noarlunga group tightly suggesting transects at these sights were more consistently similar.
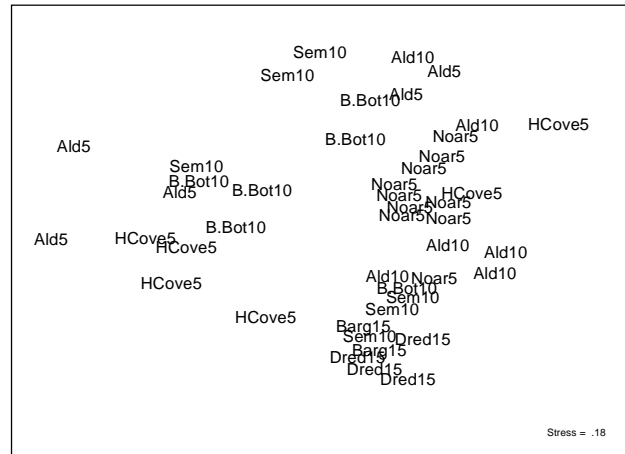
Figure 14 - MDS ordination of fish visual census data. The high stress value and mixing of groups of transects suggest high variability overall. Dredge/Barge and Norlunga group tightly suggesting transects at these sights were consistently similar.

4.2.3.3   *Canonical correlation*

Canonical correlation ordination of fish visual census data showed clear discrimination of all reefs (Figure 15). Dredge, Barge and Semaphore are discriminated on axis I, while the remainder are dispersed along axis III.
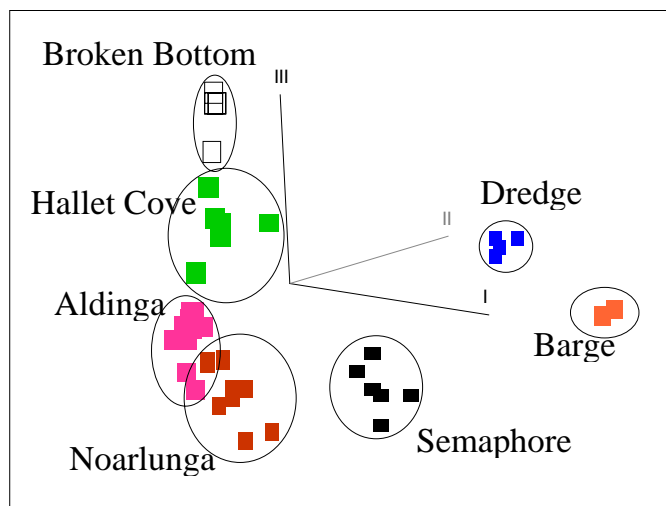
Figure 15 - Canonical correlation ordination of fish visual census data. Showing canonical vectors I to III. Dredge, Barge and Semaphore are discriminated on axis I, while the remainder are dispersed along axis III.

4.2.3.4   *Fish Visual Census for non-migratory species*

Further analysis of the visual census data was undertaken using a data set which comprised only the non-migratory species. This was based upon the proposal that these resident species would reflect more closely changes/differences in the reef environment.

Few new insights were gained from this analysis other than an indication that transects on Noarlunga reef illustrated remarkably consistent fish communities (Figure 16).
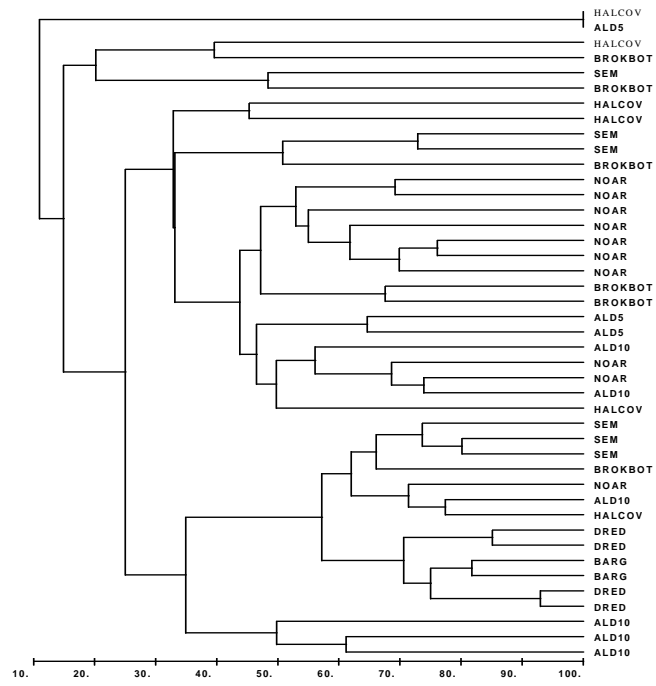
Figure 16 - Cluster analysis of non-migratory fish species. Note the clustering of the Noarlunga sites.

5. Discussion

5.1 The status of reefs in Gulf St Vincent

Macroalgal dominated communities are a distinctive feature of subtidal rocky reefs and rocky coastal margins of southern Australia. They are generally highly productive (Cheshire *et al.* 1996, Westphalen and Cheshire 1997) and this productivity underpins the provision of both food and habitat for a diverse assemblage of associated fish and invertebrate taxa in these regions (Collings and Cheshire 1998, Butler 1986, 1991; Kay & Butler 1983; Keough 1984a,b, Butler and Connolly 1996). In Gulf St Vincent reefs comprise an important habitat

Few studies of subtidal reefs in South Australia have attempted to integrate information on both plant and animal components of the benthic communities. The series of studies by Shepherd and Womersley (1970, 1971, 1976, 1981) while extensive in their geographic extent and range of depths examined, were restricted to an investigation of macroalgal communities at locations influenced by oceanic waters. Whereas the studies by Butler and others (Butler 1986, 1991; Kay & Butler 1983; Keough 1984a,b, Butler and Connolly 1996) have tended to focus on invertebrate communities with special reference to communities on jetty pilings rather than in reef habitats. In most cases these habitats provide vertical (often shaded) surfaces where the invertebrate taxa do not grow in association with macroalgae.

Across southern Australia the composition of reef communities varies both quantitatively and qualitatively over a range of spatial scales. In terms of the macroalgal communities the region comprises the Flindersian Biogeographical province (Womersley 1987). Within this province physical factors such as nutrient status, degree of water movement, light regime and substratum type are likely to play an important role in determining community composition (Shepherd and Womersley 1981, Lobban and Harrison 1994). Further, biotic factors such as herbivory (eg Jones and Andrew 1990) and competition are likely to exert a major influence on the community at any given location. Between them, these factors play a major role in determining which species, from the suite of available species, exist in a particular area. It is a combination of the demography and life history of the species interacting with the physical environment which determines the outcome of the interactions and succession sequences that ultimately shape community composition (Schiel 1988).

In this study we have examined the composition of the reef communities dominating subtidal reefs along the Adelaide metropolitan coast. This work represents the first quantitative account of the composition of these communities in the gulf waters of South Australia and it provides a basis for comparison with previous work and an informed basis for the formulation of hypotheses about some of the processes which act to structure these communities. With the current paucity of knowledge about these ecosystems, this is an important initial step.

Overall our results demonstrate a pattern of changing community structure (at least in terms of the dominant macroalgal elements) along a north south gradient down the metropolitan coast. This pattern is also reflected, although with much less clarity and definition, in the associated sessile and sedentary fauna. The community composition changed from the southern sites (Aldinga, Noarlunga and Hallett Cove), which were generally dominated by robust brown algae (including *Ecklonia* and a variety of fucoid species including *Cystophora* and *Sargassum),* to the northern sites (Broken Bottom, Dredge/Barge and Semaphore), which were dominated by red foliaceous algae with very few larger brown algae. In all cases the sessile invertebrate taxa contributed very little to the characterisation of either the sites or the differences between sites and there were no clear differences in the structure of the resident fish communities.

The differences in the structure of the algal communities may be explained in a number of ways. In general terms the change in the nature of the habitat from the southern metropolitan coast to

the north is representative of a wave exposure gradient with greater levels of wave exposure at the southern sites. There is also, however, a gradient in the level of anthropogenic impacts on the nearshore communities with increasing levels of impact along the northern extent of the coastline (induced via higher levels of land based effluent discharges and stormwater flows). Either of these gradients would be likely to cause changes in the structure of reef communities and it is these changes that we need to consider in order to come to some understanding of these processes.

If the change in structure of the algal communities were caused by wave exposure along the coastline then one would expect to see specific suites of species along this gradient. Shepherd and Womersley (1970, 1971, 1976, 1981), demonstrated that the structure of algal communities at selected sites on the oceanic coasts of South Australia varied largely in response to levels of wave exposure and this has subsequently been demonstrated for South Australian Gulf Waters by Collings and Cheshire (1998). Dominant brown algal genera commonly associated with low energy sites include *Sargassum* and *Scaberia*. At moderate levels of exposure *Cystophora* and *Seirococcus* are typically dominants, while in more extreme energy environments *Acrocarpia* and *Scytothalia* are most common. *Ecklonia radiata*, the dominant laminarialean species in this region is known to form monospecific forests under a wide range of wave exposure conditions (Larkum 1986; Kirkman 1989) and therefore may be found across the range of sites investigated in this study.

The differences in community structure we observed are not, however, consistent with the pattern expected in response to a simple gradient of wave exposure. By and large the northern sites reflect a flora which is depauperate in terms of the robust brown algae with almost no stands of mixed fucoid algae on reefs where experience suggests they should be quite common. For example, one observes such species at sites in Spencer Gulf (Collings and Cheshire 1998) or in protected locations on the other side of the St Vincent's Gulf (Cheshire *pers obs*).

Conversely, the difference in community structure along the north-south extent of the coastline is potentially of great significance in the context of the "health" of these systems. It is relevant that the loss of robust brown algae from the reef systems correlates with the areas of major seagrasses loss along the mid-northern extent of the metropolitan coastline (Table 1). Moreover, the lack of robust or foliaceous brown algae on the northern reefs is consistent with observations from elsewhere on the effects of sewage effluent on macroalgal communities (see extensive list of citations in Bellgrove *et al*. 1997). It has been repeatedly reported that domestic sewage outfalls affect larger brown algae. Polluted sites commonly show an absence of brown algae and an increase in opportunistic and turf-forming taxa (such as those found in this study). These changes relate to a complex interplay of processes relating to the effects of effluent and nutrient pollution on growth and recruitment of the dominant brown algal species. Such conclusions must however remain tentative in the absence of more detailed experimental studies to clarify their role in this system.

Alternative explanations for the absence of the larger brown algae include the impact of sedimentation on recruitment processes. In this respect, it is relevant to note that at least one artificial reef system in the northern region, the Glenelg Blocks (which was not included in this survey) does support large populations of *Ecklonia radiata* (Cheshire pers obs.) The existence of this alga at that location (which is within a few hundred meters of the outfall of the Patawalunga and around 1 km from Broken Bottom) would seem to negate the proposal that these algae are affected by effluent pollution. Importantly, the *Ecklonia* at Glenelg is mostly growing only on vertical surfaces, which would be less affected by sedimentation than horizontal surfaces (where sediments would accumulate). This observation may indicate that the absence of these algae from the other northern sites is mediated more by sedimentation effects on recruitment rather than by effluent.

Not withstanding these observations it is also possible that the absence of the larger browns from the northern reefs is a natural phenomena mediated by factors such as grazing (both invertebrate and vertebrate) or competition with the foliaceous red algae. These are all questions worthy of more detailed investigation.

5.2 Indices for the assessment of reef status

The development of a set of indices for characterizing reefs would provide a valuable tool for summarizing data on the status of reefs and provide a basis for comparing reefs (regionally or through time). In general two sorts of indices could be used a) indices which relate to indicator taxa or lifeforms (eg % cover of dominant taxa) and b) multivariate indices of community status. Both sorts of indices have utility depending on the nature of the comparisons that are being attempted.

The use of indicator taxa may be worthwhile if one or more species can be identified which are known to be indicative of environmental status and which are ubiquitous in their distribution. In the case of temperate reef systems however, there are no species which stand as obvious candidates for this role; in most cases we do not have the knowledge about the responses of specific organisms to impacts. Furthermore, there are few species that are sufficiently general in their distribution to fulfil the role as an indicator. The exceptions in this respect are when considering the presence of invasive exotic species (such as *Sabella* or *Undaria*). The presence of these species must be considered a contraindication of reef health.

Multivariate indices provide a more abstract system for classifying the status of reefs. Such indices are generally derived from the underlying data set using some sort of factor analysis and provide a numerical value (index) which is calculated based on the abundance of more than one taxa simultaneously. Multivariate indices enable comparisons between communities even when there are species which are not common to all communities being compared. Furthermore, because these indices include information on many species within a community they are sensitive to interactions between species which are characteristics of most dynamic systems.

Most multivariate techniques aim to simplify the interpretation of community data by a) reducing the dimensionality of the data set so that individual entities (eg sites or transects) can be described using a smaller number of indices (variables/dimensions) or b) reducing the number of entities by developing classifications which group similar entities (Gauch 1982). These two approaches are complementary and provide a basis for quantitatively visualizing the comparisons whilst retaining a large proportion of the information content of the original data set. Whereas this approach will provide a system for formulating quantitative indices these formulations are abstract; although useful for quantifying similarities or differences between samples within any given analytical framework (as in preceding parts of this report) they may be difficult to comprehend in a general sense (see discussion by Gauch 1982 p 30-35).

5.2.1.1 *Circumscribed indices of reef health.*

Notwithstanding the preceding comments it is possible to identify biotic indices of reef status with a more circumscribed application. An alternative approach to defining a index of reef status is to start by asking the question:

> **"What is the defining feature of a southern Australian shallow subtidal reef system?"**

With few exceptions the answer would be **a phaeophycean (brown algal) dominated macro-algal canopy**. Reefs in southern Australia, which are not suffering excessively from human impacts, are generally dominated in biomass and cover terms by phaeophycean algae between the depths of (3-)5 and 10(-15) m. This generality is supported by an extensive series of published papers (see Underwood and Kennelly, 1990 for a detailed summary). This is not to say that robust brown algae may not be equally dominant at both shallower and deeper depths but rather that this pattern is subject to change depending on natural levels of water movement and

turbidity (Shepherd and Womersley 1970, 1971, 1976, 1981, Collings 1996, Collings and Cheshire 1998). Furthermore, whereas the species present may vary between locations the canopy is generally comprised of kelps (order Laminariales), fucoids (order Fucales) or *Durvillaea* (order Durvillaeales). On this basis we would argue that, the dominance of "robust brown" algae over the 5-10 m depth range, is an indicator of a "healthy" reef system.

This conclusion may appear to be nothing more than a restatement of conventional wisdom but therein lies its value. Importantly, this index has the following properties:

1. Robust brown algae would provide the community with an object for their concern which is analogous to "seagrasses". We have almost reached the situation where the general public automatically accepts seagrass loss as a bad thing even though they may not understand the detail in respect of changes in epiphyte loadings, depressed rates of photosynthesis or toxic effects on growth and reproduction. To establish "robust browns" as an icon for healthy reefs would provide the community with a comparable measure for reef systems.

2. Robust brown algae respond similarly to seagrasses to excessive nutrients, sediment or turbidity loadings (see section 5.1 above) and therefore provide an indicator of these stresses in systems with a consolidated substratum (where seagrasses don't grow).

3. Robust brown algae (regardless of species) are generally perennial with an annual cycle of growth and reproduction. As such they integrate impacts over longer temporal scales.

4. Robust brown algae are generally the major contributors to primary production on reefs and are significant in the provision of a complex (structured) habitat for reef biota. As such, they are potentially of great significance in determining the quality of the habitat (provision of food and living space) for at least 2 important commercial fisheries (southern rock lobster and abalone).

In summary, the use of the percent cover of robust brown algae in the shallow subtidal, as a general index of reef health, provides an easily quantified measure of system status. Whereas there are some systems which may be quite "healthy" even though they have a low cover of robust browns these will be the exceptions. In most systems a decrease in the percent cover of brown algae will be a valuable indicator of stress which may lead to a degraded habitat. In other cases a finding of a low percentage cover will be the stimulus for a more detailed investigation to assess whether this represents a natural situation or is an indicator of problems (such as the findings from this study which shows a much lower cover by robust browns on northern reefs of Adelaide's metropolitan coast).

6. Conclusions

This study has demonstrated that differences occur in the structure of reef communities from the south to the north along the Adelaide metropolitan coast. These changes comprise a shift from communities dominated by robust brown algae in the south to foliaceous red algae in the north. This change in community structure correlates with gradients in both wave exposure and anthropogenic impacts. The data are not conclusive, but one explanation for this change in community structure is that the northern communities represent a degraded habitat from which significant losses have occurred including the dominant brown algae. The lack of historical data make this proposal speculative but it will be important to continue to monitor the more southerly reef systems as the industrial and residential developments in the south progress. Early remedial action (such as the reduction of effluent inputs to southern reef systems) may well prevent similar degradation occurring on the southern reefs.

Uncertainty about the basis for this change in community structure could be addressed through a coordinated series of experimental studies which aim to identify the ecological processes which are operating in these systems and which control the structure of the dominant macro-algal communities.

7. Recommendations for future work

Consideration should be given to undertaking a series of studies focussing on the ecological factors controlling the structure of the brown algal dominated communities. The objective of this work would be to clarify the extent to which these communities in Gulf waters are degraded/susceptible to degradation from anthropogenic impacts.

Future work on developing the survey methodologies has been detailed in the companion report.

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9. Appendix 1 - Temperate reefs in southern Australia

9.1 Temperate reefs - what are they?

The term "Temperate Reef" will indicate different things to different people depending upon their background and interests. For many people the word reef conjures up images of idyllic tropical locations, a splash of colour and a multitude of corals and fishes. Extensive media exposure has reinforced this view and a large tourist industry has been built around the attractions of coral reefs. For people living in southern Australia however a reef is quite a different thing. It is generally a rocky outcrop covered in seaweeds; like coral reefs they are highly diverse environments and are good places to catch fish but overall they are not as well understood by the general community. We do not for example have glass bottomed boats or "Green Island" type resorts where people go simply to view "the reef". Rather, although our reefs are visited regularly by fishers they are largely unseen except by diving enthusiasts.

The distinction between temperate and tropical (coral) reefs is not simply one of perception. There are in fact quite fundamental differences in the structure and dynamics of these ecosystems. Temperate reefs only exist in areas where consolidated sediments or rocky seabeds provide a site for settlement and attachment of algae and sessile invertebrates. In contrast, coral reefs are largely built up by the constituent corals and algae and once established they can develop and expand upon this substrate. Furthermore, the physical and chemical environments are distinctly different. Temperate waters are cooler and nutrient levels tend to be higher than in reefs in tropical waters. Together, these factors have had a profound effect on the evolution of the biota in these regions.

Instead of being dominated by corals and sponges (many of which have zooxanthellae or other photosynthetic symbionts) the dominant biota on temperate reefs are the free living algae. Whereas many sponges, a few corals and a diverse array of other animals do exist on temperate reefs, they are rarely involved in mutualistic symbioses and are therefore largely heterotrophic in their nutrition. In essence, there is a more distinct separation between the producers and consumers on temperate reefs and consequently there are fundamental differences in many of the dynamic processes (especially in relation to trophic connections).

In accepting these general differences between tropical and temperate systems it is important to recognise that temperate reef systems vary considerably on a global scale. Importantly, the temperate reefs of southern Australia are unique in terms of both the species richness (there are for example more species of seaweed in southern Australia than there are corals on the Great Barrier Reef!) and the degree of endemism at both specific and generic levels. This uniqueness can be broadly attributed broadly to 3 principle factors including:

- the oceanographic isolation of southern Australian coasts from other temperate coasts,

- the length of our coastline at a relatively constant latitude and,

- (with respect to endemism) the fact that southern Australian coastal waters are naturally nutrient poor relative to similar temperate locations elsewhere in the world.

Oceanographic isolation has resulted from the dominance of the north-south flowing currents on both the eastern and western seaboards (East Australian Current and Leeuwin Current; Jeffrey *et al.* 1990; Figure 17). These currents bring warm nutrient poor waters south and largely isolate the southern Australian coast from the westerly flowing currents of the Southern Ocean. This in turn limits the dispersal of temperate species both to and from the southern Australian coast (although reasonably strong connections do occur across the Tasman with New Zealand; Poore 1991).

Figure 17- Dominant features of Australia's oceanic circulation (based on Jeffrey *et al.* 1990).
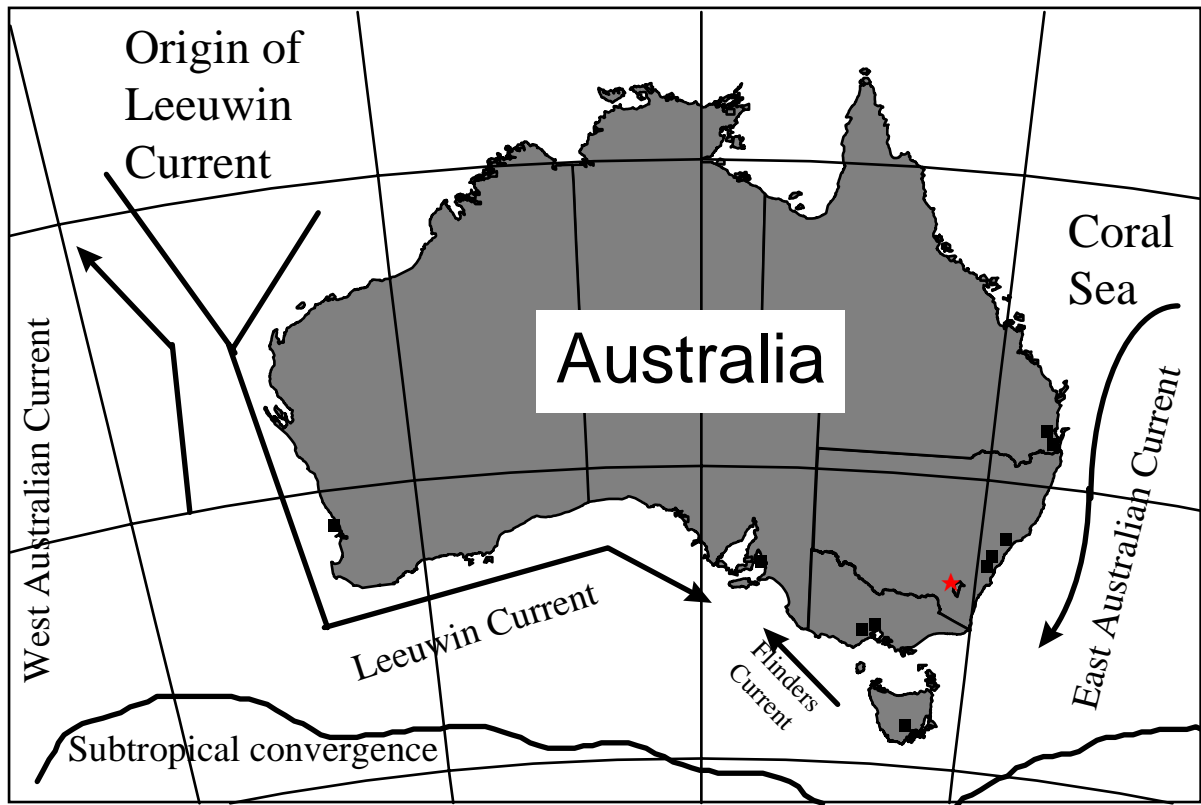
Low nutrient levels result as a consequence of 3 factors: the flow of nutrient poor waters from the northern tropical regions (via the north-south flows), the lack of significant upwelling zones and the slow weathering and low rainfall of the southern regions of the Australian continent. These processes act together to isolate southern Australian coastal waters from any significant additional nutrient inputs.

The southern Australian coastline represents the longest east-west running stretch of coast in a temperate region anywhere in the world and it has a wide diversity of habitats including bays, gulfs, promontories, islands and estuaries.

Together, these factors have led, over geological times (particularly since the Cretaceous - 125 mya), to an isolation of our temperate biota. Subsequent speciation has led to a very high degree of endemism (Poore 1991, Womersley 1990; Table 10). Coupled with this we have a coastal environment with a wide diversity of habitats inducing a similarly high diversity of species (Womersley 1990; Table 11).

Table 10 - Endemism and diversity of major temperate reef taxa in Southern Australia.

Taxonomic group	Diversity (# species)	% Endemic	Source
Fishes	600	85	Poore 1991
Molluscs		95	Poore 1991
Echinoderms		90	Poore 1991
Chlorophyta	124	30	Womersley 1990
Rhodophyta	800+ (currently >1000)	75	Womersley 1990
Phaeophyta	231	57	Womersley 1990

Table 11 - Comparative diversity of southern Australian macroalgal taxa (after Womersley 1990).

Region	Coast length	Temperature range	# of species
Southern Australia	5,500	Cold-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

This unique character, with respect to both the physical/oceanographic environment and the biota in this region, has significant consequences for the understanding and management of our reefs The fundamental differences in character of southern Australian temperate reefs, and the implications this has for the underlying processes operating in these systems, make it imperative that management decisions are based upon relevant data that have been obtained from local systems.   Consequently, it would be inappropriate to assume that findings from systems elsewhere in the world will be generally applicable to southern Australian reefs.

9.2 What does a reef look like

Naturally occurring subtidal hard substrata range in size from small isolated patches, such as *Pinna* shells, to large contiguous areas of rocky reef. Substantial artificial surfaces, such as jetties and piers, are also abundant particularly in metropolitan areas. This heterogeneous array of hard surfaces provide anchorage points for many species of macroalgae and sessile animals which in turn form physical habitat used by a variety of other species.

9.2.1 Reefs of Gulf St Vincent

Gulf St Vincent is primarily a carbonate sedimentary province in which a number of limestone reefs occur along with shell bed platforms and aeolianite dunes (Shepherd and Sprigg 1976).

In addition, a number of artificial reefs are also present comprising scuttled ships (4), tyre constructs (10) and the concrete blocks at Glenelg. There are also a number of shipwrecks that could be classified as artificial reefs. These systems have been colonised to form lush and productive ecosystems which have increased the total amount of reefal habitat in the Gulf.

9.2.2 Flora

Gulf reefs have a diverse flora of macroalgae conservatively numbered in excess of 500 species. Representatives of all 3 major macroalgal divisions (Rhodophyta, Phaeophyta and Chlorophyta) are common with most reefs being visually dominated by the larger brown algae. Only one species of kelp, *Ecklonia radiata*, is found on these reefs but there are many species of rockweeds (fucalean alga) commonly including species of *Cystophora* and *Sargassum*.   There have been relatively few published accounts of the benthic flora of the Gulf reefs except for a comparison of algae (Collings and Cheshire 1998) between selected lower Gulf reefs and the oceanic sites surveyed by Shepherd and Womersley (1970, 1971, 1976, 1981). The major conclusion from this work was that many of the dominant (canopy) species found on reefs in the lower Gulf are the same as those found in the more exposed oceanic environments. In general the distribution of algae on gulf reefs follows a similar pattern to that proposed by Shepherd and Womersley (1970, 1971, 1976, 1981; Figure 18) for oceanic environments.

A number of unpublished theses (Collings 1989, Harvey 1990, Emmerson 1992, Turner 1995) provide details on the variability in composition and dynamics of macroalgal communities from selected sites. These have shown that community structure varies both annually (seasonal growth, shedding and recruitment) and interannually with major shifts in the dominance being reported on interannual scales (Collings 1996). Spatial variability is high with small stretches of coastline often showing more variation over small (<400 m) spatial scales than is seen seasonally over annual cycles.

These macroalgal communities are highly productive with primary production rates around 1.1% per day in winter to 2.3% per day in summer (Cheshire *et al.* 1996, Westphalen and Cheshire 1997). This gives rise to annual production figures of 20-40 kg wet weight. m^{-2}. y^{-1} (from a typical standing biomass of 3-6 kg wet weight. m^{-2}).   This rate of primary production is comparable to that of a cereal crop or sugar cane stand growing under agricultural mono-culture conditions. These rates are around three times higher than those for inter-reefal seagrass systems and it may therefore be concluded that these reefs are a major source of complex organic carbon to coastal ecosystems.

Figure 18a - Schematic showing the relationship of macroalgal communities to water movement and depth on South Australian reefs (based on Shepherd and Womersley 1981).
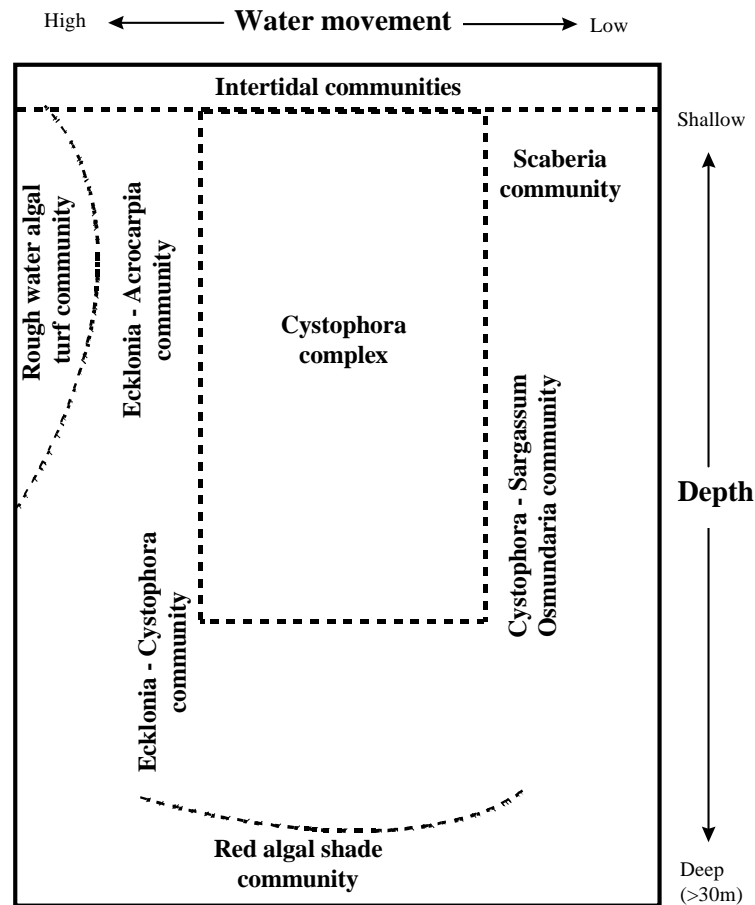
Figure 19b - Schematic showing the distribution of algae over depth and wave exposure gradients on a reef (based on Shepherd and Sprigg 1976)
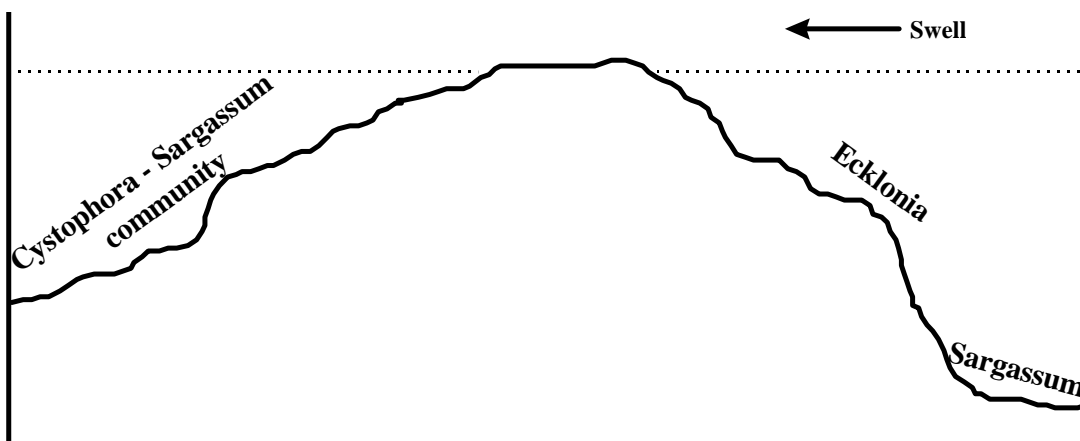
9.2.3 Sessile/ sedentary fauna

Like the algae, the sessile (or non-motile) and sedentary (low-motility) animals of temperate reefs are characteristic of this habitat. The availability of a solid substratum presents colonisation opportunities for a variety of species that are absent from the surrounding seagrass beds and sand flats. However not all reefs provide the same sorts of habitat, and several factors are known to influence the community composition of temperate reefs.

The sessile fauna of temperate reefs are characterised chiefly by suspension feeders. On a typical temperate reef the most common groups encountered are anemones, corals and hydroids

(Cnidaria), bryozoans (Bryozoa, Ectoprocta), sponges (Porifera), polychaete tube worms (Annelida), bivalve molluscs (Mollusca), and ascidians (Urochordata). These groups are well represented on the rocky reefs of South Australia, but densities and diversities of sponges, bryozoans, and ascidians are particularly high (Butler 1995, Keough and Butler 1995). In particular, the diversity of ascidians in South Australia is considerable (Kott 1985, 1990, 1992).

In contrast to the sessile fauna, the sedentary fauna inhabiting temperate reef systems are often less obvious. Characterised by unitary, rather than modular, organisms the sedentary fauna comprises a variety of taxa including herbivores, predators and scavengers. Typical sedentary herbivores on temperate reefs include sea urchins, gastropods (particularly abalone), and several species of isopod. Sedentary carnivores include species of seastars, decapod crustaceans (notably crabs), some polychaetes and gastropods. Although these species are far less numerically dominant than their sessile counterparts, their impact on the structure and dynamics of temperate reef systems may be significant.

9.2.4 Fish

We define mobile fauna as those taxa that cannot adequately be sampled by static point sampling methods such as quadrat counts. For the most part, this category is comprised of fish species which, although often closely associated with particular reef features, are capable of ranging over wide areas of a reef in short periods of time.

A total of 680 species have been recorded for southern Australia, many of which exploit temperate reef habitats for part of their lives. In contrast to tropical reefs, a high proportion of these temperate species are unique to Australia. Some species, such as the herring cale (*Odax cyanomelas*) are endemic to temperate Australia. Other species have more restricted geographic ranges. Within the genus *Achoerodus* (blue groper), for example, there are two species, one found in the east (*A. viridus*) and the other in the west (*A. gouldii*). The latter is the species found in eastern South Australia. Whilst very narrow geographic ranges appear to be rare, some species, including the seadragon *Phycodurus eques* have extremely limited distributions.

Although it is convenient to speak of an Australian temperate reef fish fauna, species exhibit a range of biogeographic patterns and the structure of reef fish assemblages can differ markedly between regions. Nevertheless, there appear to be functionally equivalent species exploiting the same habitats and resources in different regions. For example, territorial damselfish, large roving herbivorous species, predatory wrasse, and larger predators such as wobbegong sharks are common members of temperate reef fauna, even though the species may differ between locations (Lincoln-Smith & Jones 1995).

The temperate reef fish fauna is dominated by carnivorous taxa which either feed on reef dwelling invertebrates, or on zooplanktonic organisms above the substratum. Most of these fish species eat mobile crustaceans and molluscs, but some, such as the leatherjackets (Monocanthidae) feed on vertical drop offs and under piers and prey on a wide range of encrusting taxa. Notwithstanding the dominance by carnivores, herbivorous reef fish are by no means rare on temperate rocky reefs. Jones & Andrew (1990) estimate, for example, that 20-30% of species eat at least some algae. Moreover, in some areas herbivores dominate in biomass terms, owing to their often large body size (Lincoln-Smith & Jones 1995). Most herbivores feed on foliose red and green algae with few exploiting the often large biomass of kelp found on reefs; the only exception to this is the herring cale (*Odax cyanomelas*) which has a specialised diet consisting almost entirely of *Ecklonia radiata*.

On a local scale, those species that do occur in the region often exhibit consistent patterns of abundance which reflect changes in either the physical or biological structure of the reef. Changes associated with depth or discontinuities in habitat type (eg at the rock sand boundary, or between the kelp and the algal turf zone) are particularly marked. Lincoln-Smith & Jones (1995) reported that the distribution of many species is determined by the topography of the rocky

substratum. Greater physical complexity is associated with higher densities perhaps because refuges from predators are more abundant. The presence or absence of kelp and other large macroalgae is also a key determinant of assemblage structure for reef fishes. For example, experiments on reefs show clearly that a number of herbivorous species which feed preferentially on foliose red and green algae occur in higher densities in cleared patches within kelp beds (Jones 1992).

The life-cycle of most reef fishes includes a pelagic larval phase of between one and three months, during which time there is considerable potential for dispersal.

9.3 Reef dynamics

One feature of all ecological systems is that they are naturally variable on a range of spatial and temporal scales. For the casual observer the scales of spatial variability are easy to appreciate – a dive on a reef or video footage can easily demonstrate that reefs are not uniform and that fauna and flora are aggregated into patches of varying sizes. What is more difficult to appreciate is the temporal aspect of this variability because it is rare for repeated observations to be made at the same location over long time scales. Nevertheless there are many well documented cases of large scale natural variability, such as the removal of large kelp patches due to storms and subsequent suppression of recruitment through changes in urchin behaviour. Alternatively, urchin die back due to disease and predation may result in a shift back to a kelp dominated system. Clearly the possibility of such variation cannot be ignored when attempting to assess the extent to which human activities are responsible for observed changes.

9.3.1 Algal communities

Although a significant amount of information exists on the composition of the phaeophycean (brown algae) dominated macro-algal communities typical of reefs in southern Australia, there have been few attempts to synthesise or summarise this knowledge in order to extract unifying principles relating to the dynamics of these systems. Underwood and Kennelly (1990) undertook a critical review of the literature but their focus was very much directed to what could be definitively concluded rather than what had we learnt from work to date. Similarly, Scheil (1990), reviewed the status of knowledge on macro-algal assemblages in New Zealand. The conclusion common to both of these studies was that much work remains to be done to develop a knowledge of the processes responsible for structuring these communities in Australasia. Scheil (1990) also argued, (as do Andrew and Mapstone 1987) that the nature of interactions between algae and their environment (including both the biotic and abiotic components) can only be understood with reference to the life history and phenological traits of particular species. This emphasises the need for more extensive studies on the basic biology particularly of the dominant species.

Southern Australia is notable for the diversity of the macro-algal flora (Table 11; Womersley 1990). This diversity has long been recognized and reported with respect to the comparative biogeography of the region but the potential significance of diversity to the ecology of the these systems has not been discussed. It is this aspect of the southern Australian systems, perhaps more than any other, that underscores our need for caution in abstracting general ecological principles from other systems. The complex nature of interspecific processes that may emerge from more diverse systems should stand as a caution against the abstraction of generalities about ecosystem processes from systems elsewhere.[1]

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[1] See for example the work on the chemical ecology of kelp, herbivore interactions in southern Australia compared with North America (Steinberg 1989, Van Altena and Steinberg 1992).

An important local series of studies which correlated the structure of macro-algal communities with differences in substrata, depth, light and water movement, was conducted at selected sites along the exposed rocky coasts of South Australia (and offshore islands) by Shepherd and Womersley (1970, 1971, 1976, 1981). This work concluded

- that there are consistent patterns of vertical zonation on South Australian coasts,

- that this zonation can be divided into 3 levels but

- the zones may be characterised by a variable array of species at different sites.

These studies by Shepherd and Womersley have subsequently provided the basis for a number of comparable investigations throughout southern Australia. Such studies have variously supported the observations on the existence and composition of zones for a variety of habitats (eg Farrant and King 1982, Edgar 1983, Sanderson and Thomas 1987). Other studies have noted differences in either the number or composition of the zones (see eg May and Larkum 1981, Van der Velde and King 1984) and, in response, have questioned the general applicability of Shepherd and Womersley's proposals.

The review by Underwood and Kennelly (1990) also concluded that attempts to compare and contrast the structure of subtidal macro-algal communities from different regions in southern Australia have been seriously confounded by a lack of suitable replication or a consideration of any seasonal or inter-annual changes. Thus, conclusions about variability at either local or regional scales can only be speculative until appropriate studies have been developed which address these problems.

This should not however, detract from the fact that a large proportion of the work to date has provided valuable insights on the nature of macro-algal assemblages in southern Australia. This work allows us to define a series of assemblages (Table 12) which, when considered in terms of the life history processes of the dominant taxa, are likely to be a) persistent and b) qualitatively dissimilar in terms of the structuring processes.

Table 12- Phaeophycean dominated community assemblages from southern Australia.

Assemblage	Dominant taxa	Functional classification of canopy	Reference
Ecklonia	*Ecklonia radiata, Acrocarpia paniculata, Scytothalia dorycarpa, Seirococcus axillaris*	Stipitate	Shepherd and Womersley (1970, 1971, 1976, 1981)
Macrocystis	*Macrocystis angustifolia* or *Macrocystis pyrifera*	Floating	Sanderson & Thomas (1987)
Lessonia	*Lessonia corrugata (+/- Xiphophora gladiata)*	Stipitate-foliaceous	
Durvillaea	*Durvillaea potatorum*	Stipitate	Cheshire and Hallam (1989a, 1989b)
Cystophora		Foliaceous	(Shepherd and Womersley (1970, 1971, 1976, 1981), Cheshire *et al.* (1996)
Caulocystis	*Caulocystis uvifera* often forming mixed assemblages with *Cystophora spp.* or *Sargassum spp.*	Foliaceous	
Sargassum		Foliaceous	Shepherd and Womersley (1970, 1971, 1976, 1981), Cheshire *et al.* (1996)
Phyllospora	*Phyllospora comosa*	Floating	
Xiphophora	*Xiphophora gladiata*	Foliaceous	

9.3.2 Sessile / sedentary fauna

A considerable body of literature has described the characteristics and dynamics of South Australian hard substratum systems (eg Butler, 1986, 1991; Kay & Butler, 1983; Keough, 1984a,b). It is clear from this work that although community composition varies substantially across both space and time, the scale of variation is local and large-scale community characteristics at a site remain more or less constant over relatively long periods and large distances. For example, Kay & Butler (1983) showed that although 20 - 40% of the occupants of a jetty piling may be eaten, outcompeted, or overgrown within 3 months, the overall species

composition and relative abundances in these assemblages on a given jetty were roughly constant for more than two years. Similar small-scale dynamics have also been noted by Keough (1984a,b), for communities encrusting *Pinna* shells. Butler and Connolly (1996) in examining communities developing on a new jetty found that it may take a long time for this kind of large-scale "stability" to develop. Thus, these small-scale differences in community composition form a spatially and temporally dynamic mosaic. The dynamics of hard-substratum communities on jetty pilings and *Pinna* shells can be extended, with caution, to apply to communities on more expansive natural substrata such as rocky reefs (Butler 1995). To date, however, there have been no comprehensive studies to address variation in faunal community structure on South Australian rocky reefs (this contrasts with the work by Collings 1996 which comprised an extensive study of the spatial and temporal scales of variation in macroalgal communities in this region).

The rocky reefs in Gulf St Vincent are relatively isolated from each other and the majority of sessile fauna which typify these reefs reproduce by dispersive larvae. Consequently some of the species on each reef have "open" populations in which recruitment rates are independent of local adult fecundity (*sensu* Roughgarden *et al.* 1985). Other species in these populations have their own local recruitment, growth and mortality rates and then collectively behave as a metapopulation (Hanski 1992; eg Davis & Butler 1989). For example, recruitment rates onto the pilings of jetties in Gulf St Vincent have been found to vary significantly both seasonally and interannually, but some jetties show consistently higher levels of recruitment over periods of several years (Butler, 1986, 1991). These rates will be influenced by local dynamics, such as migration between patches, so that although a species may thrive on some reefs it may be displaced on others. Rates of growth and mortality will also vary temporally, however the dynamics of the system are such that on average the populations of a given species may be maintained within a region even though local extinctions may occur (Butler & Chesson, 1990).

This variation presents problems when attempting to assess the "health" of a reef system. Clearly, some variability is natural, and might indeed be a fundamental component of the mechanisms maintaining biodiversity in the system. Our problem is to detect changes, against this background or natural variability, which represent deterioration of the system.

The factors which bring about variability in community structure of temperate reefs are well documented, and include flow rate, turbidity, shade, availability of food, recruitment, competition, and predation (see Butler 1995). These factors, and how they influence the community structure on South Australian rocky reefs are considered below.

Many of the sessile individuals on subtidal reefs require access to the water column in order to feed, hence space and access to flowing water are probably the primary factors governing the distribution of these species. Levels of suspended food are low in South Australian waters (Butler, 1995), therefore suspension and filter feeders have adapted to processing large volumes of water. Passive suspension feeders tend to be colonial species and occur commonly only in areas of relatively high flow (eg gorgonians). Erect or branching species which feed actively, but with relatively weak currents (eg bryozoans), are also found primarily in areas of high to moderate flow. In addition to their dependence on flow rates these species are especially sensitive to suspended sediment loads. If these rise too high feeding may be compromised. Moreover, if sedimentation rates are high, the feeding apparatus may become clogged. Consequently the interaction between turbidity and flow rate plays an important role in determining local distributions of such species.

Active filter feeders, such as sponges, may supplement their feeding currents with the aid of ambient currents. Different species have different optimum conditions of water movement, for example ascidians are less dependent on ambient flow conditions than other taxa which are sensitive to changes in the suspended sediment load, and undue sedimentation can lead to clogging of the filtering apparatus and death (Rogers, 1990). Consequently in areas of low flow

these species tend to inhabit near-vertical or overhanging substrata where sedimentation rates are low. Tolerances of different species vary widely, for example, the ascidian *Botrylloides leachii* is common in areas of high flow and wave surge, whereas *Ciona intestinalis* is only found in the most sheltered locations.

Keough and Butler (1995) noted that areas of high flow tend to be characterised by colonial species while in low flow areas unitary organisms dominate. Unitary species such as the bivalve molluscs *Pinna*, *Ostrea*, and *Mytilus*, are probably the least influenced by flow and sedimentation rates. These species generate sufficient internal flow to be able to grow in almost any conditions and have elaborate mechanisms to clear sediment from the filtering apparatus. *Mytilus*, for example, will often grow in dense beds on near-horizontal substrata even in areas of relatively high sedimentation rates.

Perhaps the greatest impact of water flow and sedimentation are through their effects on reproduction, larval dispersal, settlement, and recruitment. On average, areas of high flow will be exposed to greater numbers of potential settlers. However, larval settlement preferences for regions of particular flow characteristics have recently received much attention (eg Mullineaux & Butman, 1990; Pawlik & Butman, 1993), and it has become clear that many species actively select certain flow regimes (eg Wethey 1986; Havenhand & Svane, 1991). Thus, flow rate may often determine not only the numbers of larvae in a given location but also the numbers of larvae choosing to settle there. Again, turbidity and flow rate interact as the larvae of many species common to rocky reefs actively avoid settlement on upward-facing surfaces which may lead to early mortality caused by sedimentation and/or algal overgrowth (Svane & Young 1989).

Competition from algae plays a major role in determining depth distributions of sessile species on temperate reefs however secondary effects such as shading may also be important. (Butler, 1995). The upper few meters of any reef system are almost invariably dominated by macroalgae, and while that canopy may substantially modify the understorey environment (and hence the associated faunal composition; Duggins and Eckman (1994) it is only below this algal zone that the sessile fauna begin to dominate.

Competition among the sessile fauna is primarily restricted to competition for space (Butler 1995). Here sub-dominant species such as barnacles and tubicolous polychaetes survive by virtue of their high recruitment rates and ability to rapidly colonise even small patches of available free space (Keough, 1984a; Butler 1991), while slower growing dominant species (eg sponges *Mycale* and *Clathria*, and colonial ascidians) may overgrow their competitors, but have low recruitment rates and are more susceptible to periodic disturbances such as storm-induced wave action. Within this dominant group, state-dependent interactions occur such that no single species is consistently dominant (Keough, 1984a). Consequently the competitive dominance of sponges and ascidians on southern Australian hard substrata is countered by disturbance and rapid recruitment and colonisation by sub-dominant species. Again, the importance of spatial and temporal variability is apparent, this time in maintaining diversity in these systems.

9.3.3 Fish

Many experimental studies indicate that fish taxa are an integral component of coastal reef systems in temperate waters and changes in reef habitat are almost certain to result in changes in the fish fauna. One might imagine, therefore, that this can be used as an index of reef status. However, the proximate cause of changes (ie a change in habitat characteristics) will often provide a more direct and interpretable index of change. One notable feature of the fish fauna which is particularly problematic is the considerable spatial variation that occurs between sites, within regions and the inter-annual variation that can occur even on a single reef (Kingsford, 1989). Indeed Lincoln-Smith and Jones (1995) note that 'one of the greatest challenges in the study of reef fishes is to understand the causes of the huge natural variation we see in abundance from place to place and time to time'. With respect to the assessment of the status of reefs, this poses particular problems because detecting any signals that are indicative of undesirable trends

from the noise of natural variability is likely to be difficult in short-term studies. Although changes in abundance can sometimes be associated with changes in the habitat (eg the loss of kelp due to storms), it is variable recruitment of juveniles from the pelagic larval phase that is the major source of variability (Lincoln Smith *et al.*, 1991). With respect to longer term monitoring, there are few data available from which we can document long-term trends.

The fish fauna itself can have controlling effects on other components of the system through predatory interactions. For example, Jones & Andrew (1990) have shown that the herring cale (*Odax cyanomelas*) can have a seasonal impact on kelp (*Ecklonia radiata)* stands whereby changes in the behaviour of females led to the clearing of kelp in approximately the same locations between August and October in each of three years. Although the generality of such effects remains undetermined it is clear that such behaviours have implications for the interpretation of change in temperate reef systems.

9.4 Reef Health

The analogy between the health of human beings and health of ecosystems is one that is finding growing acceptance. It is worth considering, however, how far the analogy can be pushed. Calow (1992) identifies two forms: a weak form in which the term health simply signals normality (implying of course that ill-health signals abnormality) and a strong form in which health defines a condition that is favourable (ie optimal) for the functioning of the system. In this latter case the optimal state is actively defended by homeostatic processes. Ideally, a healthy state should be the same for all reef systems since only then can objective health criteria be defined.

Calow (1992) considers the degree to which the strong form of the analogy can be applied to an ecosystem, arguing that for such a form to be valid the existence of a controlled 'optimum' state for a system is necessary. Control is occurring if systems remain unchanged with perturbation (ie they resist it), or if they have the ability to return to their previous state after perturbation (ie they are resilient to it). Such system behaviour can be achieved by active feedback (usually negative) control in which the system moves towards a future 'goal state' that is programmed into it. Alternatively, the dynamics of the interacting parts might simply lead to an equilibrium state which is not achieved by a goal directed mechanism (program) but is achieved passively - it is difficult to argue that this latter passive control is of the kind that is required if we are to accept the strong form of the analogy. Moreover, Calow argues (correctly in our view) that it is unlikely that component parts of ecosystems are programmed for active control that will lead to a 'balanced economy' in the ecosystem as a whole. This is because natural selection on individuals and populations will favour those that maximise command of resources even if it is at the expense of the rest of the ecosystem. Thus, the strong sense of the analogy with health in humans is flawed.

Although the strong form of the health analogy is invalid can we use the weak form usefully? In other words is there a definable 'normal' or baseline state which would constitute a healthy system? One approach to defining such baselines might be to list the properties of putatively pristine systems (ie those which have been unaffected by human activity). This is analogous to what happened in early medicine where physicians sought to correlate body states with conditions of health and ill-health. However, a key point to make in this respect is that the structure of the biotic components of a system (ie biodiversity in all senses of the word) varies with 'natural' environmental conditions (see below). Thus, to use some ecosystem state as a baseline from which to judge the effects of our activities, requires a clear specification of the relationship between structure and environmental factors. Unfortunately, we are far from possessing such understanding.

More fundamentally, we feel there is some difficulty with equating 'normality' or 'health' with the absence of human influence. This is because it implies that affected systems are inherently abnormal or 'un-healthy'. This is not to say that the changes made to systems are desirable or

morally defensible, clearly many of them are not, it is simply that there is no a priori reason why a system we have affected should be viewed as being any more or less healthy than one in which our influence is minimal. This stated however, it stands to reason that the only impacts we are likely to be able to control are those that are the result of human activities. We should therefore attempt to separate these from other impacts and control them according to our perceived common goals, whether they be commercial, recreational, aesthetic or spiritual.

There are of course inherent difficulties in making these kinds of judgements. Consider a reef that has been surveyed and shown to have rich kelp beds and a diverse fish and invertebrate fauna. In others words, the reef is in a state that most people would be happy to describe as healthy. Now imagine that before a second survey a year later (and unbeknown to the surveyor) a storm removes most of the kelp from the reef. At the same time there was a very successful recruitment of sea urchins and that these circumstances conspired such that most of the algal cover was removed and the reef became a depauperate urchin barren. Would the surveyor be correct to call the second state less healthy than the first? It is easy to see that it is less desirable from a human perspective but if the criterion for poor health is a state not engendered by human activities it clearly does not qualify. Although it is powerfully emotive to call undesirable system states unhealthy, it seems to us to be more reasonable and intellectually honest to consider reefs as being in desirable or undesirable states. This does not of course remove the difficulty of determining the controls on those states and the degree to which our actions can effect changes, but it does remove some of the hyperbole surrounding the issues.

9.5 Determining the causes of change

The link between defining states which are more or less desirable and identifying the processes which have created these states is generally beyond the scope of any short-term study. It either requires a series of long-term mensurative experiments or a series of targeted experiments designed to investigate specific processes and controls.

There are a number of examples where supposed early warnings of pathological conditions have proved deceptive. Rapport (1992) for example, cites the sudden die-back of macro-algal beds along the Finnish coast in the late 1970's. This change was first thought to be indicative of coastal wide environmental degradation resulting from eutrophication. In the mid 1980's, however, algal beds started to recover despite continued high nutrient loadings suggesting a more complex chain of events and a coastal system that was under less threat than was originally envisaged (Rosenberg *et al.*, 1984).

10. Appendix 2 - LIT summary data

Table 13 - Summary data for LIT survey. Lifeform codes and the taxa they represent are listed in appendix 5.

Location	Lifeform	Minimum percent cover	Maximum percent cover	Average percent cover	Standard error
Aldinga	AMOSP	0	1.05337079	0.447495954	0.085364
(5 m)	BR	0	4.53869048	1.531676881	0.447468
	BRFOLI	3.0898876	41.4893617	16.4436164	3.728598
	BRLEAT	8.3469722	65.2354571	35.47564116	5.053963
	BRMEM	0	0.24549918	0.049099836	0.02455
	BRY	0	0.3511236	0.135691168	0.041589
	BS	2.956636	15.7202216	8.698035189	1.29741
	DISP	0	0.90016367	0.394545279	0.093106
	ENC	0.8184524	19.5926966	10.80922778	1.756798
	GFOLI	0	0.73649755	0.441765014	0.060321
	GLOBE	0	0.5913272	0.282046495	0.061309
	GLUMP	0	0.49157303	0.098314607	0.049157
	OASC	0	5.75842697	1.519945455	0.534644
	RCORAL	0	0.21067416	0.042134831	0.021067
	RFOLI	0.2077562	30.0327332	18.40404384	2.709426
	RLEAT	0	0.37202381	0.074404762	0.037202
	RLUMP	0	1.86011905	0.552056543	0.185287
	RMEM	0	0.90016367	0.180032733	0.090016
	TUBPOL	0	4.4241573	0.963675087	0.434241
	TURF	0	8.21629213	3.341984697	0.755938
	URCH	0	0.57283142	0.114566285	0.057283
Aldinga	AMOSP	0	2.05438066	1.105878304	0.161739
(10 m)	BIV	0	0.32743942	0.101356863	0.028795
	BR	0	8.02204532	4.0685048	0.556383
	BRFOLI	2.815979	29.5162278	15.01820699	1.907071
	BRLEAT	20.070175	59.9565532	40.88517452	2.812811
	BRY	0	0.21723389	0.036205648	0.016192
	BS	2.1517554	32.940406	12.48307242	2.158699
	COLASC	0	0.50687907	0.131667463	0.039418
	DISP	0	1.01925255	0.40854111	0.081555
	ENC	5.1929825	28.6748733	17.25841861	1.545446
	GFOLI	0	1.04102878	0.173504797	0.077594
	OASC	0.3274394	1.30237826	0.726058566	0.064715
	RCORAL	0	0.42105263	0.130518185	0.037073
	RFOLI	0	24.9122807	5.71989786	1.739364
	RLEAT	0	2.10526316	0.381495687	0.154761
	RLUMP	0	0.77192982	0.128654971	0.057536
	RMEM	0	0.67360686	0.148473458	0.049576
	STAR	0	0.3021148	0.050352467	0.022518
	TURF	0.2896452	1.65339865	1.044017282	0.10575
Hallett	AMOSP	0.2906977	3.99610136	1.276727018	0.251795
Cove	BIV	0	0.3431709	0.05719515	0.025578
	BR	7.9922027	20.7343413	13.7189894	1.044769
	BRFOLI	0.2995806	45.4191033	12.16058693	3.2075
	BRLEAT	9.6087852	35.7598978	21.95611371	1.663078
	BRLUMP	0	1.07212476	0.178687459	0.079911
	BRY	0	1.16959064	0.194931774	0.087176
	BS	0.3898635	27.5909403	10.23870618	1.82241

	COLASC	0	1.97956577	0.426826854	0.145227
	CORAL	0	0.06863418	0.01143903	0.005116
	CRIN	0	0.21802326	0.036337209	0.01625
	DISP	0	0.68226121	0.181975891	0.048375
	ENC	4.8043926	12.8654971	8.799466357	0.703994
	GAST	0	1.25823847	0.45242923	0.089797
	GLUMP	0	0.70242656	0.165804038	0.052533
	OASC	1.3181546	4.85312899	2.422228151	0.264981
	RCORAL	0	1.0295127	0.30357489	0.086953
	RFOLI	0	34.1798216	9.85149576	2.69056
	STAR	0	0.64794816	0.335053723	0.049394
	TUBPOL	0	0.21598272	0.0679256	0.019264
	TURF	1.8518519	40.625	17.16350564	2.5477
Noarlunga	AMOSP	3.0529172	8.42332613	5.006737576	0.489566
	BIV	0	0.47489824	0.166973888	0.051926
	BR	0	3.11252993	1.066352657	0.334053
	BRFOLI	0	2.01706749	0.92193667	0.18332
	BRLEAT	14.205906	31.338265	24.61205081	1.573772
	BRMEM	0	0.88195387	0.176390773	0.088195
	BRY	0	0.54274084	0.24372308	0.053731
	BS	0	0.46547711	0.160344918	0.050147
	COLASC	0	6.128782	1.791957005	0.574559
	DISP	0	0.33624748	0.11044604	0.035128
	ENC	10.3751	39.4103957	30.49398817	2.619962
	GAST	0	0.73974445	0.375572645	0.060761
	GFOLI	0	0.20352782	0.040705563	0.020353
	GMEM	0	0.33921303	0.067842605	0.033921
	HYD	0	0.47489824	0.094979647	0.04749
	OASC	0	4.11171451	2.419375622	0.442008
	RCORAL	0	5.49525102	2.03658389	0.577682
	RFOLI	0	2.37580994	0.475161987	0.237581
	STAR	0	0.50395968	0.100791937	0.050396
	TUBPOL	0	0.31031808	0.062063615	0.031032
	TURF	15.903801	68.4756584	29.06430501	4.981348
	URCH	0	2.08783297	0.511715889	0.202218
Broken Bottom	AMOSP	0	8.02919708	3.901637108	0.496414
	BIV	0	1.72532781	0.880839972	0.122828
	BR	1.2408759	14.8414986	6.055542435	0.871716
	BRFOLI	0	4.20979986	1.344232283	0.342638
	BRLEAT	0	0.62111801	0.103519669	0.046295
	BRY	0	0.2919708	0.0486618	0.021762
	BS	16.49635	37.6046362	30.45052759	1.494186
	COLASC	0	2.16138329	0.521261143	0.162784
	CORAL	0	0.80291971	0.283348362	0.064547
	DISP	0	5.54744526	1.354442112	0.383475
	ENC	0	0.21613833	0.036023055	0.01611
	GFOLI	0	11.3832853	2.063584849	0.834776
	OASC	0	1.31124914	0.742907087	0.0792
	RFOLI	13.400576	39.3099199	23.92397857	2.040206
	RLEAT	0	0.30807147	0.051345245	0.022962
	SEAGRASS	0	0.257566	0.042927667	0.019198
	STASC	0	0.2919708	0.0486618	0.021762
	TUBPOL	0	0.34506556	0.057510927	0.02572
	TURF	14.409222	41.8978102	27.89970724	2.121368
	URCH	0	0.58394161	0.189341084	0.053585

Dredge/ Barge	AMOSP	0.2479851	4.66431095	1.870435439	0.38118
	BIV	0	0.80350621	0.133917701	0.05989
	BR	2.4028269	15.8730159	7.631079061	0.962002
	BRFOLI	0	10.459364	1.949898224	0.763416
	BRLEAT	0	1.27208481	0.251206766	0.092911
	BRMEM	0	3.37278107	0.748119018	0.2485
	BRY	0	0.18598884	0.03099814	0.013863
	BS	0	11.183432	3.543900057	0.784936
	CORAL	0	1.02040816	0.219058817	0.07482
	DISP	0	1.17577895	0.592625473	0.082088
	ENC	0	2.54416961	0.424028269	0.189631
	GAST	0	0.53254438	0.137748186	0.041325
	GFOLI	0.4703116	4.31952663	1.872523731	0.318258
	GLOBE	0	0.41420118	0.069033531	0.030873
	HOL	0	0.91872792	0.153121319	0.068478
	OASC	0	1.02040816	0.258513133	0.072188
	RFOLI	63.112213	81.3732652	71.76626452	1.597345
	RLEAT	0	4.73498233	1.738503652	0.297895
	STASC	0	0.29218408	0.085140495	0.024453
	TURF	0.1183432	25.0464972	6.523884468	1.732981
Semaphore	AMOSP	0	5.23138833	1.947010844	0.403891
	BIV	0	0.45781557	0.145747039	0.041292
	BR	0.591716	11.2706389	5.306375655	0.678526
	BRFOLI	0	6.75	1.235670564	0.494177
	BRLEAT	0	1.41666667	0.314358372	0.104385
	BRLUMP	0	0.27045301	0.045075501	0.020158
	BS	9.1387245	30.0469484	17.48258644	1.480475
	CORAL	0	1.05193951	0.583362137	0.0648
	CRAB	0	0.40241449	0.067069081	0.029994
	DISP	0	4.09121395	1.555099163	0.250953
	ENC	0	1.21703854	0.591636174	0.082339
	GAST	0	0.27045301	0.045075501	0.020158
	GFOLI	0.6036217	6.16666667	2.316833427	0.379875
	GLUMP	0	0.27045301	0.078610042	0.022591
	HOL	0	0.93323762	0.155539603	0.069559
	OASC	0.8547009	1.35226504	1.065877878	0.03169
	RFOLI	32.260228	81.0650888	56.88510286	3.047018
	STAR	0	0.91666667	0.287188026	0.070754
	STASC	0	0.74374577	0.156658741	0.054431
	TUBPOL	0	0.33806626	0.056344377	0.025198
	TURF	0.75	27.3381295	9.172131631	1.951488
	URCH	0	1.56965337	0.506646951	0.127809

11. Appendix 3 - Quadrat survey summary data

Table 14 - Summary data for the quadrat survey. Lifeform codes and the taxa they represent are listed in appendix 5.

Location	Lifeform	Minimum abundance (n.m⁻¹)	Maximum abundance (n.m⁻¹)	Average abundance (n.m⁻¹)	standard error
Aldinga	AMOSP	0	80	13.6	3.602848
(5 m)	ANEM	0	960	58.4	29.28789
	BARNACLE	0	32	1.2	0.885206
	BIV	0	16	0.4	0.4
	BRY	0	32	6.4	1.793435
	COLASC	0	80	6.8	3.183934
	CORAL	0	32	2.8	1.129556
	CRAB	0	16	1.2	0.674822
	CRUS	0	16	0.8	0.558386
	DISP	0	272	10	6.867239
	GAST	0	64	13.2	3.131969
	HYD	0	800	41.6	25.42633
	OASC	0	112	27.6	4.860727
	OPIS	0	16	0.4	0.4
	POL	0	32	2.4	1.22202
	SABEL	0	16	0.4	0.4
	STAR	0	32	1.2	0.885206
	STASC	0	48	1.2	1.2
	TUBPOL	0	320	24.4	10.60991
Aldinga	AMOSP	0	112	22.66667	3.835876
(10 m)	ANEM	0	256	9	5.793736
	BIV	0	32	3.333333	1.060799
	BRY	0	96	10.66667	2.91081
	CHITON	0	32	0.666667	0.666667
	COLASC	0	32	3.333333	1.162861
	CORAL	0	32	2.666667	1.198896
	CRAB	0	16	1	0.564933
	CRINOID	0	16	0.333333	0.333333
	CRUS	0	16	0.333333	0.333333
	DISP	0	48	5.333333	1.603778
	GAST	0	176	10.66667	3.879997
	HYD	0	240	11.33333	6.984617
	OASC	0	80	21.66667	3.451453
	POL	0	64	3.333333	1.779845
	STAR	0	16	1.333333	0.645039
	TUBPOL	0	160	8.333333	3.956919
	URCH	0	16	0.333333	0.333333
Hallett	AMOSP	0	128	22.33333	3.978369
Cover	ANEM	0	224	6.333333	4.709781
	BARNACLE	0	128	2.666667	2.666667
	BIV	0	48	1.333333	1.047343
	BRY	0	16	2.333333	0.823703
	CHITON	0	32	1.333333	0.932725
	COLASC	0	1280	29	26.6425
	CORAL	0	48	3.333333	1.34393
	COSCINO	0	16	0.333333	0.333333
	CRAB	0	32	2	0.907025

	CRINOID	0	32	0.666667	0.666667
	CRUS	0	16	0.333333	0.333333
	DISP	0	32	2.666667	1.100183
	FISH	0	16	0.666667	0.466363
	GAST	0	224	25.66667	5.488652
	GOOS	0	16	0.333333	0.333333
	OASC	0	1536	111.6667	34.02624
	OPIS	0	16	0.333333	0.333333
	STAR	0	32	4.333333	1.325331
	TUBPOL	0	2688	364.6667	80.68776
	URCH	0	16	0.666667	0.466363
Noarlunga	AMOSP	0	160	48	5.870395
	ANEM	0	16	1.6	0.768615
	BIV	0	672	21.2	16.82379
	BRY	0	64	5.6	2.029526
	COLASC	0	48	5.2	1.84641
	CORAL	0	128	3.6	3.21471
	CRAB	0	16	1.6	0.768615
	DISP	0	128	10.4	4.566994
	FISH	0	32	0.8	0.8
	GAST	0	256	18	6.855281
	HYD	0	3840	374.8	126.9946
	OASC	0	496	112.8	17.57341
	STAR	0	16	0.4	0.4
	TUBPOL	0	896	172.4	41.4169
	URCH	0	16	0.8	0.558386
Broken Bottom	AMOSP	0	96	13	3.03759
	ANEM	0	320	8	6.720351
	BARNACLE	0	16	0.333333	0.333333
	BIV	0	96	13.33333	3.062779
	BRY	0	16	0.666667	0.466363
	CORAL	0	48	4.333333	1.632269
	CRAB	0	32	3	1.22908
	DISP	0	48	5.333333	1.803595
	GAST	0	32	4	1.304656
	HOL	0	16	0.666667	0.466363
	HYD	0	432	14	9.793615
	OASC	0	192	21	5
	OCTOPUS	0	16	0.333333	0.333333
	OPIS	0	16	0.333333	0.333333
	POL	0	1408	54.66667	31.35098
	STAR	0	32	3	1.22908
	STASC	0	32	1	0.738985
	TUBPOL	0	1664	123	47.01388
	URCH	0	16	1	0.564933
Dredge/ Barge	AMOSP	0	96	12.66667	2.6075
	ANEM	0	112	3	2.365533
	BIV	0	48	5	1.441532
	BRY	0	48	3	1.22908
	CHITON	0	16	0.333333	0.333333
	CORAL	0	400	10.33333	8.353734
	CRAB	0	16	1	0.564933
	CRUS	0	16	0.333333	0.333333
	DISP	0	16	2	0.771845

	GAST	0	64	7.333333	2.128274
	HOL	0	16	0.333333	0.333333
	HYD	0	96	2	2
	OASC	0	48	5	1.660983
	OPIS	0	16	0.333333	0.333333
	POL	0	48	2	1.129865
	STASC	0	32	2.333333	1.064137
	TUBPOL	0	176	4.333333	3.682108
	URCH	0	16	0.333333	0.333333
Semaphore	AMOSP	0	64	11	2.482563
	BIV	0	16	2	0.771845
	BRY	0	16	2	0.771845
	CHITON	0	16	0.333333	0.333333
	COLASC	0	64	1.333333	1.333333
	CORAL	0	32	3.333333	1.162861
	CRAB	0	32	3.666667	1.09047
	CRINOID	0	16	0.333333	0.333333
	CRUS	0	16	0.333333	0.333333
	DISP	0	64	3.333333	1.577022
	FISH	0	16	1.666667	0.712934
	GAST	0	96	10.33333	3.105322
	HOL	0	16	0.666667	0.466363
	HYD	0	80	3	2.112106
	OASC	0	176	31.33333	4.972739
	POL	0	64	6	2.163527
	SABEL	0	32	1.666667	0.857452
	STAR	0	32	7	1.339525
	STASC	0	32	3	1.027977
	TUBPOL	0	192	27	6.922571
	URCH	0	112	5	2.743141

12. Appendix 4 - Fish survey summary data.

Table 15 - Summary data for the fish survey.

Location	Fish	Min abundance (n.trans⁻¹)	Max Abundance (n.trans⁻¹)	Average Abundance (n.trans⁻¹)	Standard error
Aldinga (5 m)	Goatfish	0	1	0.667	0.149
	Hula Fish	0	1	0.333	0.149
	Magpie Perch	0	3	1.667	0.394
	Silver Drummer	0	2	1	0.258
	Talma	0	1	0.333	0.149
	Wrasse	0	1	0.666	0.149
Aldinga (10 m)	Blue Devil	0	1	0.167	0.068
	Bullseye	0	3	0.833	0.222
	Cowfish	0	1	0.167	0.068
	Dusky Morwong	0	2	0.333	0.136
	Goatfish	0	1	0.333	0.086
	Goby	0	1	0.167	0.068
	Herring Cale	0	2	0.833	0.164
	Hula Fish	0	320	69.5	20.729
	Leather Jacket	0	17	3.167	1.137
	Magpie Perch	0	3	1.5	0.175
	Old Wife	0	2	0.667	0.172
	Silver Belly	0	1	0.167	0.068
	Silver Drummer	0	6	1.5	0.376
	Talma	0	4	1	0.258
	Weedy Whiting	0	3	0.5	0.204
	Wrasse	1	6	2.667	0.328
	Zebra Fish	0	1	0.167	0.068
Hallett Cove	Bullseye	0	4	1	0.258
	Cowfish	0	1	0.167	0.068
	Dusky Morwong	0	1	0.333	0.086
	Goatfish	0	3	0.5	0.204
	Hula Fish	0	300	51.5	20.297
	Leather Jacket	0	4	0.667	0.272
	Magpie Perch	0	4	1.667	0.272
	Moonlighter	0	1	0.333	0.086
	Three fin	0	1	0.167	0.068
	Vic Scalyfin	0	2	0.333	0.136
	Weedfish	0	1	0.167	0.068
	Wrasse	0	4	1.5	0.230
Noarlunga	Blue Devil	0	1	0.1	0.032
	Bullseye	0	3	0.9	0.110
	Dragonet	0	2	0.4	0.070
	Dusky Morwong	0	1	0.2	0.042
	Goby	0	1	0.1	0.032
	Herring Cale	0	1	0.4	0.052
	Hula fish	0	180	19.8	5.630
	Leather Jacket	1	16	6.9	0.515
	Magpie Perch	0	5	2.6	0.190
	Silver Drummer	1	15	3.4	0.425
	Sweep	0	1	0.2	0.042
	Talma	0	4	1.5	0.118
	Three fin	0	3	0.4	0.097
	Vic Scalyfin	0	4	0.6	0.126
	Weedy Whiting	0	2	0.3	0.067
	Wrasse	0	3	1.2	0.103
	Zebra Fish	0	2	0.2	0.063
Broken Bottom	Blue Devil	0	1	0.167	0.068
	Bullseye	0	32	7.333	2.167
	Cowfish	0	1	0.333	0.086
	Cuttlefish	0	1	0.167	0.068
	Dusky Morwong	0	3	0.667	0.202
	Goatfish	0	9	2.5	0.545
	Hula fish	0	64	10.833	4.342
	Leather Jacket	0	27	9.333	1.601
	Magpie Perch	0	3	1.167	0.245
	Old Wife	0	17	2.833	1.157
	Silver Drummer	0	3	0.833	0.222
	Talma	0	9	2	0.577
	Vic Scalyfin	0	3	1.333	0.202
	Weedfish	0	1	0.167	0.068
	Wrasse	0	3	1	0.183
Dredge/	Blenny	0	2.5	0.417	0.170

Barge	Blue Devil	0	1.25	0.417	0.108
	Bullseye	208.75	1147.5	500.833	63.959
	Dusky Morwong	0	3.75	0.625	0.255
	Goatfish	0	1.25	0.417	0.108
	Hula Fish	200	1490	728.958	90.084
	Leather Jacket	7.5	37.5	25.625	1.997
	Magpie Perch	0	5	2.083	0.285
	Moonlighter	0	3.75	1.042	0.244
	Old Wife	0	5	2.5	0.373
	Silver Drummer	0	2.5	1.042	0.157
	Talma	1.25	11.25	4.792	0.596
	Vic Scalyfin	0	1.25	0.417	0.108
	Wrasse	3.75	11.25	7.5	0.437
Semaphore	Blenny	0	1	0.167	0.068
	Bullseye	0	148	41	10.022
	Cowfish	0	1	0.5	0.092
	Dusky Morwong	0	4	2	0.279
	Goatfish	0	16	2.833	1.077
	Hula Fish	0	200	91	16.870
	Leather Jacket	0	17	5.167	1.103
	Magpie Perch	0	8	3	0.471
	Moonlighter	0	1	0.167	0.068
	Old Wife	0	2	0.333	0.136
	Silver Drummer	0	2	0.667	0.172
	Talma	0	11	5.167	0.763
	Vic Scalyfin	0	7	1.833	0.427
	Weedy Whiting	0	2	0.333	0.136
	Wrasse	0	11	3.333	0.814

13. Appendix 5. Lifeform codes and taxa represented.

Table 16 - Algal lifeforms with representative species

Lifeform code	Description	Representative taxa
BRENC	Brown encrusting algae	*Ralfsia*
BRFOLI	Brown foliaceous algae	*Halopteris, Cladostephus, Lobospira*
BRFLAT	Brown robust algae with large flattened blades (much broader than thick) - not membranous because very robust	*Ecklonia, Durvillaea, Macrocystis*
BRBRANCH	Brown robust algae with highly branched habit (blades not much broader than they are thick)	*Cystophora spp, Sargassum, Caulocystis, Acrocarpia, Scytothalia, Seirococcus, Xiphophora*
BRLOBE	Brown lobed algae	*Zonaria, Padina, Turbinaria, Lobophora*
BRMEM	Brown membranous algae	*Scytosiphon,*
TURF	Turfing algae (all colours)	*Sphacelaria, Ectocarpus, Ceriamium, Cladophora*
GFOLI	Green foliaceous algae	*Caulerpa spp, Cladophora, Chaetomorpha, Apjohnia, Codium, Bryopsis*
GLOBE	Green lobed algae	*Dictyosphaeria, Avrainvillea*
GLUMP	Green lumpy algae	*Codium spp*
GMEM	Green membranous algae	*Ulva spp*
RCORAL	Red coralline algae	*Corallina, Metagonialithon,*
RENC	Red encrusting algae	*Sporolithon*
RFOLI	Red foliaceous algae	*Plocamium, Phacelocarpus, Nizymenia, Gelidium, Pterocladia*
RROB	Red robust algae	*Osmundaria, Lenormandia*
RLOBE	Red lobed algae	*Peyssonnelia*
RMEM	Red membranous algae	*Gloiosacchion, Pachydictyon*

Table 17 - List of animal lifeform codes and associated taxa. Lifeform codes in bold type represent those which are commonly found using the LIT method. Those underlined occur frequently.

Broad category	Lifeform code	Taxa included
Sponges	**AMOSP**	Amorphous sponges
	DISP	Discreet sponges
Molluscs	**GAST**	Gastropods
	OPIS	Opisthobranchs
	BIV	Bivalves
Ascidians	**COLASC**	Colonial ascidians
	STASC	Stalked ascidians
	OASC	Other ascidians
Echinoderms	**URCHIN**	Urchins
	COSC	Coscinastarias starfish
	CRIN	Crinoids
	STAR	Starfish (all other types)
Worms	TUBPOL	Tube polychaetes
	POL	Other polychaetes
	SABEL	Sabellid worms
	HOLO	Holothurians
Hydriods	HYD	Hydriods
Anemones	ANEM	Anemones
Coral	**CORAL**	Corals
Crustaceans	CRAB	Crabs
	GOOS	Goose barnacles
	CRUS	Other crustaceans