Assessing the status of temperate reefs in Gulf St Vincent IV: Results of the 1999 survey

A report to the Environment Protection Agency
of South Australia

By

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Anthropogenic impacts on sub-tidal macroalgal communities along the metropolitan coast of Adelaide are largely undocumented. In 1996, three southern reefs (Aldinga, Noarlunga and Hallet Cove) were compared to three northern reefs (Dredge and Barge, Broken Bottom and Semaphore). Differences in the community structure were revealed with robust brown macroalgae dominating reefs in the south and foliaceous red macroalgae dominating reefs in the north. This difference correlated with the impact of sediment and nutrient inputs from numerous sources along the northern metropolitan coast. Increased sedimentation was considered the most likely cause for differences in community structure through impacts on the recruitment of robust brown macroalgae. Foliaceous red algae were considered more capable of tolerating high sediment loads through their ability to reproduce by asexual means and cope with reduced light. Reefs dominated by robust brown macroalgae were classified as healthy whereas those where they were absent were classified as degraded. The 1996 survey supplied a solid baseline of information and a set of methodologies for further environmental monitoring.

In 1999, the survey was repeated with additional sites in the south (comprising Aldinga and Moana reefs), central (comprising Southport, Noarlunga, Horseshoe and Hallet Cove) and north (Dredge and Barge, Broken Bottom and Semaphore). The pattern of change in reef communities that occurred in 1996 was found again in 1999 with brown macroalgae proliferating in south and central reefs giving over to foliaceous reds at the northern sites. On healthy (south and central) reefs there were large increases in the cover of robust brown macroalgae between 1996 and 1999. There was also evidence suggesting that there has been a considerable increase in the cover of mussels (*Xenostrobus pulex*) at Noarlunga and Horseshoe reefs (central) which appear to be restricting the recruitment of the robust brown macroalgae. In general the southern and central reefs were found to be stable and healthy, however the change in mussel cover at some central sites should be considered as a potential threat. The lack of change across the northern section suggests that these reefs, although degraded, are also basically stable. Continued monitoring of the expansion of mussel beds on the central reefs is recommended. The mechanisms that promote the high cover of foliaceous red algae in the north are considered worthy of further study.

4. Introduction

The sub-tidal macroalgal communities of southern Australia are considered unique in terms of both their high diversity and degree of endemism (Womersley 1987). These communities 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 and Butler 1983, Foster and Scheil 1985, Keough 1984a,b, Butler and Connolly 1996).

Effective environmental impact assessment requires an understanding of the broad scale structure and processes operating within the system (Underwood and Kennelly 1990, Keough and Quinn 1991). There are a large number of potential sources of environmental impacts along the Adelaide metropolitan coast mostly in the form of nutrients and suspended sediments from stormwater run off, effluent disposal, sedimentation from coastal development and the silting of riverine inputs due to altered catchment management (Cheshire *et al.* 1998a,b). It has been argued that these impacts have been responsible for substantial seagrass losses recorded along the eastern shore of Gulf St. Vincent from 1960 up to the present (Shepherd *et al.* 1989, Cheshire *et al.* 1998a,b, Seddon *et al.* 2000). What influence these inputs (and indeed the effect of the loss of seagrass) have on macroalgal communities on rocky substrate along the metropolitan coast remains unclear.

In a report on water quality at seven jetties along the metropolitan coast the Environment Protection Agency (EPA 1997) reported that at most sites, there was elevated nitrogen, turbidity, heavy metals and microbial activity. The report considered the total effect of combined environmental impacts from numerous sources along the metropolitan coast rather than any single input. The possible health risk to swimmers seemed to be the focus of the survey. Although conceding that these inputs were responsible for seagrass losses, no mention was made of macroalgal communities.

4.1 The 1996 reef health survey

In November 1996, a survey was made of the macroalgal communities on six rocky, sub-tidal reefs along the Adelaide metropolitan coastline. The reefs included (from south to north) Aldinga, Noarlunga, Hallet Cove, Broken Bottom, the Dredge and Barge off Glenelg and Semaphore, covering a total distance of about 47 km and ranging in depth from 5 - 15 m (Figure 1). The aims of that study were to establish baseline measurements for the formulation of hypotheses as to processes that may be structuring biotic communities on metropolitan reefs and to develop protocols for monitoring future changes in these systems. A series of three reports were developed dealing with the background and sampling strategy (Cheshire *et al.* 1998a), the survey results (Cheshire *et al.* 1998b) and a critical review of the methods (Miller *et al.* 1998).

The 1996 survey established that there were substantial differences in the composition of sub-tidal reefs from south to north along the metropolitan coast. Southern (Aldinga), and Central reefs (Noarlunga and Hallet Cove) being dominated by robust brown macroalgae, generally from two orders, the Laminariales and Fucales, while the northern reefs (Dredge, Barge, Broken Bottom and Semaphore) were dominated by foliaceous red algae from various families. The lack of brown algae from the north was considered an indication of their degraded state with increased sedimentation rates suggested as the responsible mechanism. A detailed review of the effects of sediments on reefs was included in 1999 report (Cheshire *et al.* 1999) which reviewed the impact of sediments on the recruitment of algae on selected reefs.

4.2 The 1999 reef health survey

With a solid baseline of information obtained in 1996 a number of questions were developed:

1) Was the gradient observed in 1996 stable or are reefs further south along the coast, in the middle and southern sections, tending towards a degraded state?

2) If the southern reefs are not impacted how much has the community structure of these reefs changed since the 1996 survey?

3) Given that the sampling strategy used in 1996 detected changes from south to north over a scale of 10's of kilometres, can it be usefully employed to detect differences in community structure over smaller spatial scales (100 - 500 m)?

In November 1999, the survey was repeated with the aim of dealing with the above questions through an examination of the same sites from 1996 as well as several new sites.

5. Sites

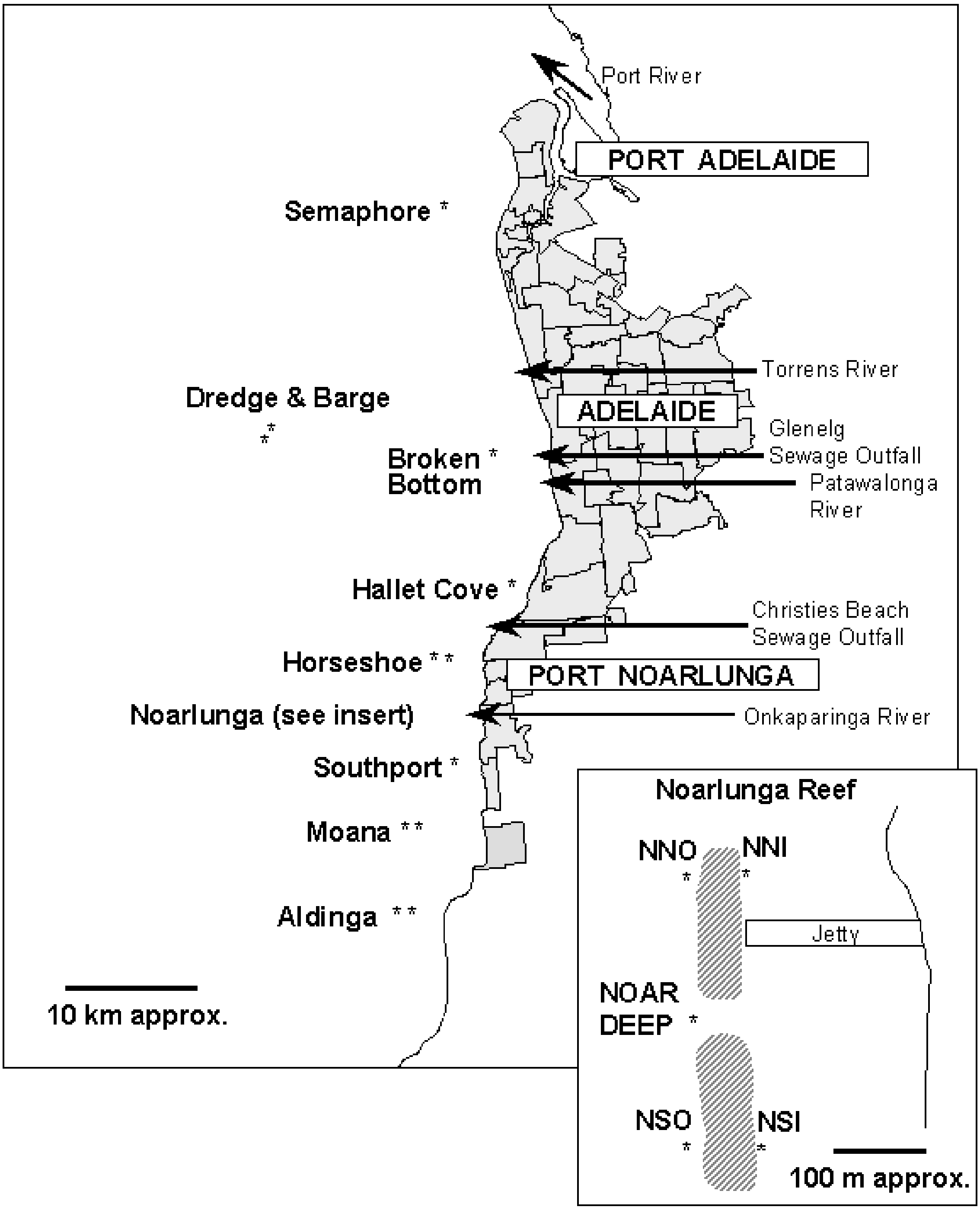
Surveys were conducted at seventeen sites spread over nine reefs and split into two depth classes (Shallow ranged from ~ 3 - 8 m, and Deep sites from 8 - 15 m) along the eastern shore of the Gulf St Vincent, generally within the Adelaide metropolitan (Figure 1). In addition to the sites used in the 1996 reef health survey, Moana, Southport and Horseshoe reefs were added. In addition, the number of sites surveyed at Noarlunga reef was increased (Figure 1, Table 1).

Table 1 - The location of all sites employed in both the 1996 and 1999 surveys. Maximum depth is the range of the deepest points surveyed at each site in 1999. Position fixes were obtained from a Garmen GPS and were accurate to within 300 m. Where the number of transects in each survey is "-" there was no data collected at that site in that year.

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

* These transects were combined in the analysis of the 1996 data.

Figure 1 - The location of all reefs surveyed in 1996 and 1999 (stars are generalised - see Table 1 for accurate positions). Major inputs of nutrients and sediments are also indicated, although it should be noted that there are a considerable number of stormwater drains not shown on this map. Shaded area represents metropolitan Adelaide. At Noarlunga the site labels are NNI and NNO = Noarlunga North Inside and Outside respectively, NOAR DEEP = Noarlunga Deep (10 m) and NSI and NSO = Noarlunga South Inside and Outside respectively.



5.1 Northern reefs

The northern section has probably the highest number and density of nutrient and sediment inputs into the gulf and corresponds to the bulk of the runoff and effluent disposal from the Adelaide Metropolitan area. Information on water quality is also concentrated within this zone with Environment Protection Agency (EPA) data obtained from five sites.

5.1.1 Semaphore (Deep)

This was the northern-most of the study sites comprising a flat series of rock platforms broken into strips by patches of sand. Wave exposure is low due to its depth and distance from shore. Water quality measurements taken at the nearby Largs and Semaphore Jetties by the EPA in 1996 indicated that there were moderate levels of ammonia, turbidity, heavy metals and chlorophyll a but little evidence of faecal contamination (EPA 1997).

5.1.2 Barge and Dredge (Deep)

The Dredge and Barge artificial reefs were established in 1985 by sinking two vessels off the coast of Glenelg (Table 1; Figure 1). They have been popular fishing and diving locations since that time. In both surveys, only two transects were undertaken along the deck of the barge, as it was quite small. Four transects were obtained on the deck of the dredge. The encrusting community on the horizontal decks of both wrecks is starkly different to those encrusting the vertical hull surfaces. The latter were not sampled as this was beyond the scope of the study (all sites were sampled on the horizontal plane - see methods). These wrecks are less than 100 m apart and comprise the deepest and therefore the least wave exposed sites in the survey.

No water quality data are available from this site and it is somewhat remote from the Glenelg, Henley Beach and Grange Jetties (EPA 1997). There are, however, a number of potential impacts in this area, including outflows from the Patawalonga River, the Glenelg Sewage Outfall and the Torrens River Outlet (Figure 1). At Glenelg, which is south of these sources, there were moderate levels of ammonia, suspended sediments, heavy metals and chlorophyll and no faecal contaminants (EPA 1997). Henley Beach Jetty to the north of the Torrens River Outlet was similar to Glenelg but chlorophyll a levels were higher (in the poor range) and there were moderate levels of faecal coliforms and streptococci, probably because of the sewage inputs. At Grange, the chlorophyll a level was reduced to moderate levels but faecal contamination remained moderate (EPA 1997).

5.1.3 Broken Bottom (Deep)

This site is very similar in terms of substrate to the Semaphore site with a series of flat rocky strips interspersed with sandy patches in a generally low wave exposure environment. Broken Bottom is considerably closer to the shore than the Dredge and Barge (Figure 1) and thus is more likely to be affected by the nutrient and sediment inputs in this area (see above).

5.2 Central reefs

The cental section has fewer impact sources than further north; the major inputs are likely to be the Christies Beach Sewage Outfall and the Onkaparinga River Outlet (Figure 1). In 1996, water quality data was obtained at the Noarlunga Jetty and sampling for faecal contaminants was undertaken in the vicinity of the Christies Beach Outfall. Water at Noarlunga was clearer, had low heavy metal levels and no faecal contamination. Chlorophyll a and nutrient levels were at moderate levels (EPA 1997). This information may prove useful for the surveys at Noarlunga reef, and possibly Southport, but it is difficult to relate this information to the more distant reefs at Horseshoe and Hallet Cove. Faecal contaminants at the Christies Beach Sewage Outfall were low at all points except at the outfall itself and this is likely to provide the best indication of conditions at Horseshoe reef which is about 500 m south of the outfall.

5.2.1 Hallet Cove (Shallow)

This reef is around 50 m offshore and as such the closest to the coast of all sites. The shore comprises a steep cliff above a narrow rocky beach at the northern end of the Hallet Cove beach. The reef is a narrow undulating spur of rock that rises 1 – 2 m above the surrounding sand. Wave exposure is likely to be moderate to heavy.

5.2.2 Horseshoe Reef (Shallow)

Horseshoe reef was not part of the 1996 survey. As the name suggests this reef is formed from an arc of rock with the “open” end towards the shore. On the seaward side the reef drops from a steep platform to a series of broken but generally very flat expanses of stone which persist for some distance off shore. Toward shore, the reef becomes narrower and steeper comprising more of a boulder field than a solid rock structure. This reef is close to the Christies Beach sewage outfall, to the sand dredging area off O-Sullivan’s Beach and is a popular recreational fishing location. Sampling was undertaken on the outer exposed platforms (Horseshoe outside) and on the southern edge (Horseshoe inside). Wave action was considered moderate with only minor differences between inner and outer sites.

5.2.3 Noarlunga (Shallow and Deep)

Wave exposure is highly variable from the inside to the outside of this prominent reef depending on the tide. At low tide, the upper reef can be exposed and the inside is comparatively protected. At high tide, the exposure can be considerably higher (though still less than the outside of the reef which has moderate to high wave exposure). The entirety of Noarlunga reef is a marine reserve and as such it is not exposed to fishing pressure. The inner northern part of the reef is a popular recreational SCUBA and snorkel diving site and intertidal areas are subject to heavy trampling when exposed at low tide. Noarlunga reef offers a uniquely varied environment the dynamics of which should form the basis of a more intensive research program.

Noarlunga reef may be impacted from the north by the Christies Beach sewage outfall and sediment fallout from periodic sand dredging off shore from the O’Sullivan Beach boat ramp. To the south, the mouth of the Onkaparinga River discharges significant quantities of stormwater into the near shore area.

In 1996 Noarlunga Reef was surveyed on the northern section on the outside at 5 m (3 transects) and on the inside at 5 m (2 transects) however data from both sides was combined in analysis. On the outside at 10 m a single transect was surveyed near the break between northern and southern sections of the reef. In the 1999 survey, the reef was divided into five areas comprising the inside and outside of both north and south reefs (Figure 1) and a 10 m site (Noarlunga Deep) comprised two transects on the outside of the reef on either side of the “Gap”.

5.2.4 Southport (Shallow)

Southport reef is comprised of a series of flat rock platforms with small patches of sand and occasional rocky outcrops. The topography is quite similar to the Broken Bottom and Semaphore reefs. Wave exposure is likely to be moderate. The nearest impact source is the Onkaparinga River to the north.

5.3 Southern reefs

There are no large riverine or sewage inputs in the southern section as it is the least urbanised of the three survey zones (Figure 1). The EPA did not collect any water quality data within the southern section for their 1996 report.

5.3.1 Moana (Shallow)

As with Horseshoe reef the Moana site was not surveyed in 1996. The reef is similar to the Hallet Cove site, consisting of a band of gently sloping rock platform that abruptly falls away on the shoreward side to form a steep (2 – 3 m high) slope above a broad expanse of sand. Wave exposure is intermediate. The reef was sampled both on the inner steep slope (Moana Inside) and on the outer flatter platform (Moana Outside). Differences in wave energy between these points are probably only slight.

5.3.2 Aldinga (Shallow and Deep)

Sampling was undertaken at 5 and 10 m depths (about 300 m apart) on a series of gently sloping rock platforms with occasional prominent outcrops (again similar to Semaphore and Broken Bottom) south of a popular dive site locally referred to as “The Dropoff”. Wave exposure is considered intermediate at 5 m and slightly lower at 10 m.

6. Methods

6.1 Line Intercept Transects

The Line Intercept Transect method (LIT; Turner 1995) was used to obtain estimates of the percent cover of sessile benthic organisms at each location. A 20 m tape was randomly stretched over horizontal substratum (Figure 2) and used as a guide for a weighted 1 m ruler (1.5 kg) that prevented underlying macroalgae from waving about in the water (Turner 1995). Measurement of the transition from each taxon to the next was then obtained in every metre section for the entire length of the tape (Figure 2). At almost all sites four transects were measured. Exceptions to this were at Hallet Cove (5 m) where five transects was measured and Noarlunga South Inside (5 m), where only three transects was sampled. Each pair of divers sampled two 20 m transects.

The life form criteria developed in the 1996 survey (Appendix 1) were used again in 1999. All macroalgae and sessile or sedentary organisms (sponges, ascidians, gastropods, etc) could be placed within one of 39 different life forms (Appendix 1: Tables 2 - 5). All analyses were based on the percentage cover of life forms at each site.

Figure 2 - Schematic view of benthos showing Line Intercept Transect.

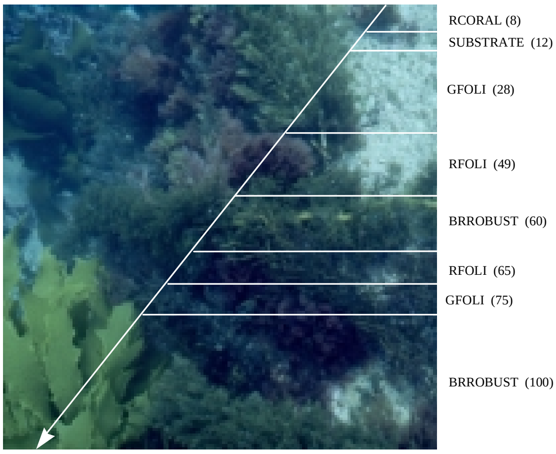


Table 2 - Example of data recorded from LIT shown in Figure 2.

Transition	Life form	Example taxa
8	RCORAL	Unknown
12	SUBSTRATE	Bare Rock
28	GFOLI	*Caulerpa*
49	RFOLI	*Asparagopsis*
60	BRBRANCH	*Cystophora*
65	RFOLI	*Asparagopsis*
75	GFOLI	*Caulerpa*
100	BRBRANCH	*Ecklonia*

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

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

Where $\sum L_A$ = the sum of the individual lengths of life form A on the transect,

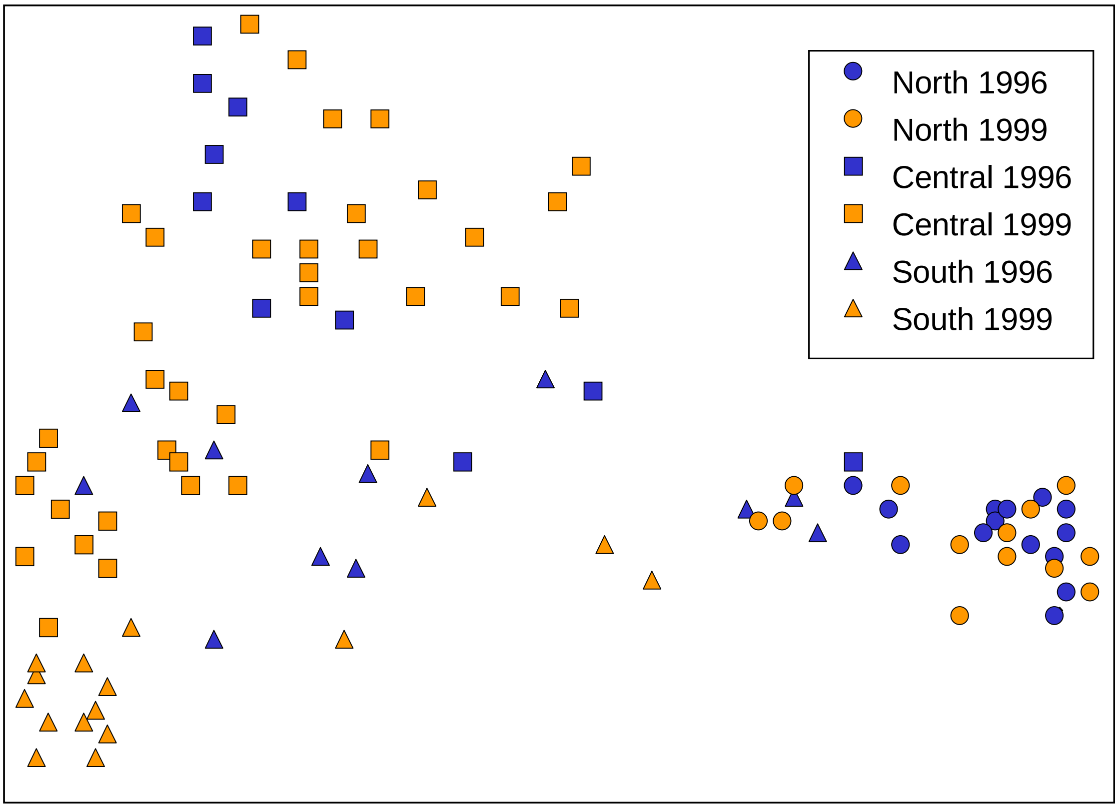
Y = the total length of the transect and
$\sum D$ = the sum of the lengths where no data was recorded.

A more complete description of the methodology as well as a critical assessment of its utility can be found in Miller *et al.* (1998).

7. Results

The south to north, gradient observed in 1996 was evident in the 1999 survey results (Figure 3). Northern sites are still distinct from central and southern sites with little apparent difference between the two surveys (Figure 3). Southern reefs are mostly distinct from the central section with most overlap between southern 1996 and central 1999 transects. Central reef transects form a very diffuse group implying that these reefs encompass a wide range of community structures.

Figure 3 - Bray-Curtis ordination (axes 1 and 3 in a 3D plot) of the 1996 and 1999 transects.



The six dominant life forms across all sites (with the exclusion of bare sand) were robust browns (BRLEATH), foliaceous reds, (RFOLI) turfing algae (TURF), red encrusting algae (RENC), brown foliaceous macroalgae (BRFOLI) and mussels (BIV) (See Appendix 1 for details).

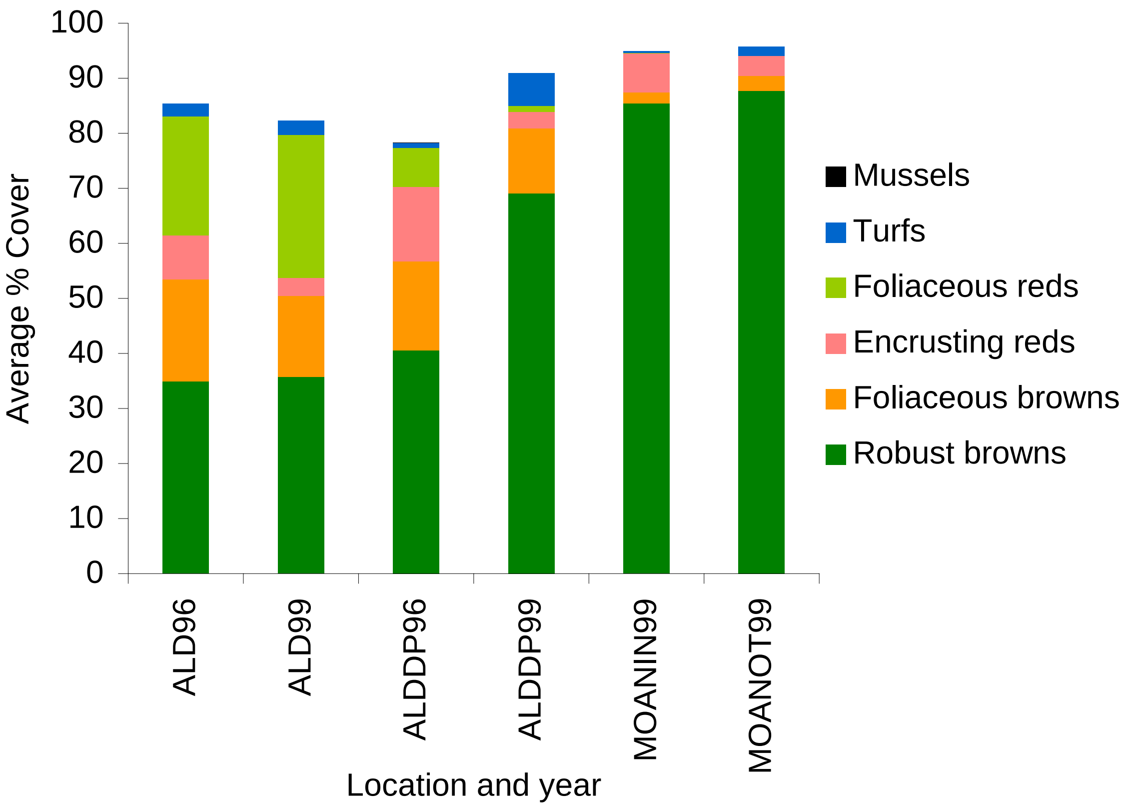
7.1 Southern reefs

At the shallow Aldinga site (ALD96 and ALD99), the average percentage cover of its major constituents, robust brown macroalgae, red encrusting algae and brown foliaceous algae did not differ substantially from 1996 to 1999. Robust and foliaceous browns were unchanged at 34.9 % and 18.5 % respectively in 1996 and 35.7 % and 14.1 % in 1999 (Figure 4). Encrusting reds were halved (7.9 – 3.2 %) while other components, the foliose reds and turfs, were unchanged. At the deeper Aldinga site (ALDDP96 and ALDDP99) the average cover of robust browns increased from 40.5 to 69.1 % from 1996 to 1999. The average cover of red encrusting algae declined from 13.5 to 3 %, probably because of over topping by the increase in brown macroalgae rather than an actual change in encrusting cover (Figure 4). The Aldinga deep site was the only location in the southern section at which a small amount (0.1 %) of mussels was detected (present in 1996 but not evident in 1999)

There were few differences in the community structure between the inner and outer reefs at Moana (MOANIN99 and MOANOT99) with the average cover of major community constituents more or less equivalent. The sites were dominated by robust browns with an average cover of 85.5 and 87.7 % on the inside and outside sites respectively (Figure 4). Other components, foliose brown algae, red encrusting, foliose reds and turfs were collectively less than 10 % of the total cover.

The dominance by robust brown algae at all locations in the southern section is an indication of their fundamentally good condition. Further, the only substantial change from 1996 to 1999 has been an increase in the robust brown cover at the Aldinga deep site.

Figure 4 - Average % cover of major life form components in the southern section comprising Aldinga shallow and deep for both 1996 and 1999 and Moana inside and outside for 1999.



7.2 Central reefs

The central section was comprised of the Southport (1 location), Noarlunga (5 locations), Horseshoe (2 locations) and Hallet Cove (1 location) reefs (Figure 1).

Southport (SOUTPT99) was surveyed for the first time in 1999. This reef appears similar to the Moana sites a few kilometres further south with a high cover of robust brown macroalgae (62 %) followed by red encrusting (16 %) and some foliaceous browns (4.5 %). Unlike the southern reefs, this site had some turf cover (13.1 %; Figure 5).

At Noarlunga south (NSI99 and NSO99) there is broad similarity between inner and outer sides of the reef (Figure 5). Robust brown cover is lower on the outer side (20.6 verses 30.2 %) as is the turf cover (5.9 and 13.1 %). In contrast, the mussel cover on the outside was slightly higher at 19.6 % compared to 14.8 % on the inner reef. These differences may reflect a wave energy gradient although higher robust brown cover would have been anticipated on the outer reef in such a circumstance. The southern end of Noarlunga reef is the first site to exhibit a considerable cover of mussels and is in sharp contrast to the Southport site just south of Noarlunga (Figure 1) where none were observed.

The Noarlunga north inside (NNI96) site was very close to the extreme end of the reef where the wave crest was submerged even at low tide. This section is now known to be less variable (inside to outside) by virtue of the decreased level of protection from wave exposure. As a result the transect data from each side of the northern section in 1996 (NNI96 and NNO96) were combined for analysis. Separation of the data indicates that the community structure was indeed very similar in 1996 (Figure 5). The cover of robust browns was 25.9 % and 23 % from the inside and outside of the reef respectively. There was very low cover of foliaceous algae (0.8 % to 0.7 % for foliose and 0.9 % to 0.0 % cover of foliose reds) but encrusting reds and turfing algae had high cover (27.2 % to 24 % for encrusting reds and 20 to 23.8 % for turf). Of particular interest was the low cover of mussels on the inner reef (0.5 %) that were absent on the outside.

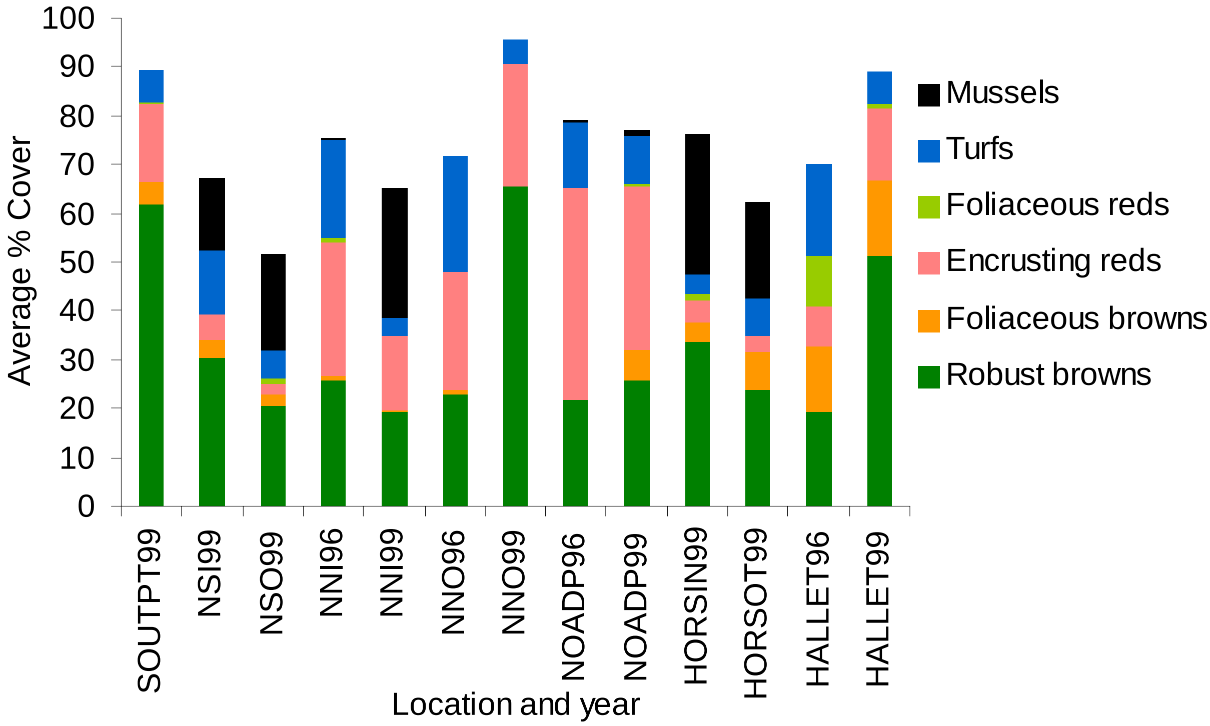
In 1999 both the inner and outer reefs had changed substantially but in quite a divergent manner. On the inner reef (NNI96 and NNI99) the robust brown cover declined slightly (25.9 % down to 19.3 %) but there was a three-fold increase in this life form on the outer reef (NNO96 and NNO99; 23 % to 65.6 % respectively; Figure 5). Foliose macroalgae declined or disappeared on the inner reef (0.8 % down to 0.3 % for foliose browns and 0.9 % to 0.0 % for foliose reds). Foliose red algae did not occur on the outside of the reef in either survey but foliaceous browns declined from 0.7 % in 1996 to 0.0 % in 1999. Encrusting red algae on the inner reef declined from 27.2 % down to 15.4 % from 1996 to 1999 respectively but were unchanged on the outside (24 % and 24.9 %). Turfing algae declined on both sides of the reef with 20 % down to 3.5 % cover on the inside and 23.8 % down to 5.1 % on the outside (Figure 5). The large increase in robust brown algae on the outside may have occurred at the expense of turfs (or masked turf cover). On the inside the change in turf cover (and the encrusting reds) is due to a very large increase in the cover of mussels (0.5 % up to 26.6 %). The Noarlunga north inside (NNI99) site appears more similar to the two southern Noarlunga sites (NSI99 and NSO99) ~ 500 m away than to the site just over the reef crest ~ 10 m away and Horseshoe reef to the north (HORSIN99 and HORSOT99). Changes between the 1996 and 1999 surveys could in part be due to the differences in the location of the transects. The 1999 surveys more to the south of where the 1996 survey was conducted. The outer reef appears similar to the Southport (SOUTPT99) and Hallet Cove sites (HALLET99) that are some kilometres away in either direction (Figure 1; Figure 5).

At the deep Noarlunga site, (NOADP96 and NOADP99) there were small differences in the cover of robust and foliose browns from 1996 to 1999 (robust browns = 21.6 % and 23.8 %; foliose browns = 0.0 % and 6.3 % respectively) (Figure 5). Encrusting red algae were ~10 % lower in 1999 and there were minor changes in turfs (reduced 3.4 %) and mussels (increased 0.9 %). Little importance can be attributed to these differences as the 1996 average percent covers are based on only a single transect.

The inner and outer Horseshoe reef sites (HORSIN99 and HORSOT99) were both sampled for the first time in 1999. While these sites had amongst the highest average mussel cover of the central section for both the inner and outer reef (28.8 and 19.7 % respectively) they also supported a substantial robust brown macroalgal cover (33.6 % on the inside and 23.8 % at the outside) (Figure 5). These sites are quite similar to the Noarlunga north inner site (NNI99) and the Noarlunga south sites (NSI99 and NSO99). There was no reflection of a wave energy gradient from the outer to inner sites.

Hallet Cove Reef was surveyed in both 1996 (HALLET96) and 1999 (HALLET99). The cover of robust brown algae more than doubled on Hallet Cove Reef (19.2 % up to 51.1%) associated with reductions in cover of both turfs (19.1 % down to 6.4 %) and foliaceous red macroalgae (10.2 % down to 0.8 %). There were virtually no mussels at this site in either survey (Figure 5).

Figure 5 - Average % cover of major life form components in the central section comprising Southport for 1999 only, Noarlunga North Inside and Outside (1996 and 1999), Noarlunga South Inside and Outside (1999), Horseshoe Inside and Outside (1999) and Hallet Cove (1996 and 1999).



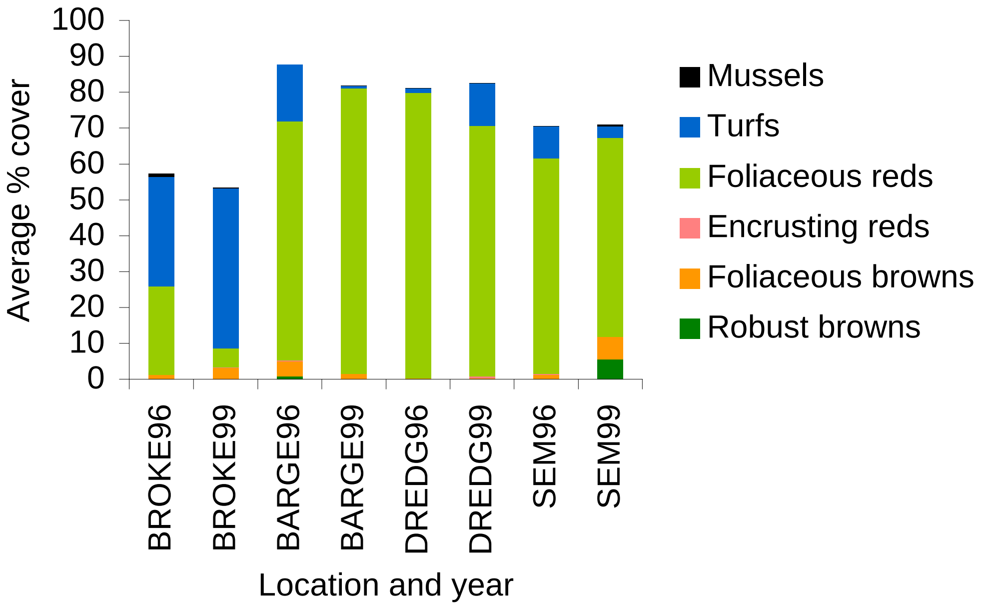
7.3 Northern reefs

All reefs from the northern section, Broken Bottom (10 m), Barge (artificial reef at 15 m depth), Dredge (artificial reef at 15 m) and Semaphore (10 m) were surveyed in both 1996 and 1999.

In 1996, Broken Bottom (BROKE96) was dominated by foliose red and turfing algae (24.7 and 30.6 % respectively). There was a marked increase in the turf cover in 1999 (BROKE99; 44.5 %), which was most likely due to the loss of foliaceous reds (reduced to 5.4 %; Figure 6). Other life forms have only minor cover and do not change much between 1996 and 1999. Mussel cover is very low at this site (0.9 % and 0.3 % in 1996 and 1999 respectively).

The Dredge, Barge and Semaphore reefs in 1996 were dominated by foliaceous red algae ranging from 60 % at SEM96, to 66.7 % at BARGE96 and 79.5 % at DREDG96. In 1999, the foliose red cover declined at the Dredge and Semaphore sites (DREDG99 down to 69.9 % and SEM99 reduced to 55.4 %). Mussel cover was negligible at all of the northern sites. Turfing algae declined at the Barge (15.8 down to 0.8 %) in line with the increase in foliaceous reds. There was an increase in turf cover at the Dredge (1.2 up to 11.9 %), again, probably because of changes in the foliose red cover (Figure 6). At Semaphore, turfing algae declined from 8.8 % down to 3.2 % but instead of changes in foliaceous red cover (which declined as well - see above) there was in increase in both the robust browns (0.2 up to 5.5 %) and foliose browns (0.9 up to 6.2 %). At all other sites brown macroalgae were negligible in terms of cover and did not change much between surveys (Figure 6).

Figure 6 - Average % cover of major life form components in the central section comprising Broken Bottom for 1996 and 1999, the Barge and Dredge off Glenelg in 1996 and 1999 and finally Semaphore reef in both 1996 and 1999.



8. Discussion

Effective environmental impact assessment requires prior understanding of the broad scale structure and processes operating within the system (Underwood and Kennelly 1990, Keough and Quinn 1991). In southern Australian temperate reef systems such assessments are complicated by the high levels of both diversity, which adds to complexity, and endemism (Womersley 1987) that make generalisations from other systems difficult to apply (Scheil 1990). In a review of research in Australian temperate macroalgal communities in Australia, Kennelly and Underwood (1992) argued that the spatial and temporal variability of marine macroalgal systems were poorly understood. Consequently, the quality of environmental impact assessment within Australian marine systems has been low (Fairweather 1989). The current research base developed from both the 1996 and 1999 reef health surveys have demonstrated the effectiveness of broad scale benthic surveys, firstly in establishing the status of reef systems on Adelaide’s metropolitan coast and secondly by identifying areas of concern where further information should be obtained.

Keough and Quinn (1991) described three different forms of disturbance. Pulse disturbances that are sudden “one off” impacts that are not sustained (eg cyclones). Press disturbances that are maintained in an unchanged form for a prolonged or indefinite period and finally combined pulse/press disturbances that are prolonged but uneven over time. The metropolitan coast of Adelaide is subjected to all three types of disturbances over much of its length (Figure 1). Pulse disturbances take the form of periodic sand dredging at Pt Stanvac (since 1991) and extreme storm events. Press disturbances are present in the form of sewage outfalls (Christies Beach and Glenelg) and combined pulse/press disturbances are represented by seasonal stormwater run off in winter (Port, Torrens, Patawalonga and Onkaparinga Rivers and flows from numerous drains) or variations in diver activity on coastal reefs across the year (in particular the Dredge, Barge, Noarlunga and Aldinga reefs). It should be noted that many of these influences are manifested through increased sedimentation and/or nutrients.

8.1 Health of metropolitan coast reefs

There is little doubt that the pollution of Gulf St Vincent has resulted in dramatic losses of seagrass along the Adelaide coast (Shepherd *et al.* 1989). Loss of seagrass is now seen as a major cause for environmental concern (Rogers 1990, Cheshire *et al*. 1998a,b, Seddon *et al.* 2000) and reduction in seagrass cover may have consequences for macroalgal systems, as seagrass beds are a site for sediment settlement and stabilisation (Scheil and Foster 1986). The actual sedimentary load on macroalgal communities may thus be considerably larger with the frequent remobilisation of sediments that were previously held in seagrass beds.

At the southern sites there has been little change in the reef communities from 1996 to 1999 and as such these reefs are considered healthy. The changes that have occurred include an increase in the robust brown algal cover at Aldinga Deep while the other site (Aldinga Shallow) has remained stable. New sites for the 1999 survey (Moana Inside and Outside) have very high cover of robust brown algae. While the situation at these sites appears to be stable, the continued spread of urbanisation to the south of Adelaide may lay the foundation for future threats. The changes evident at reefs in the central section suggest that this may already be happening.

The central reefs can be considered to be in generally good condition with no significant reduction in the cover of robust brown algae (at Noarlunga North Outside and Hallet Cove there were considerable increases). The cover of mussels at most sites is a potential source for concern as to the directions taken by the communities comprising the Noarlunga marine reserve and Horseshoe reef. These mussels (*Xenostrobus pulex;* Mytilidae) form dense monospecific mats that can exclude all other life forms. Visual assessments over the last 3 years indicated a rapid increase in the cover of mussels on the reefs since the dredge event of 1997. At that time, large amounts of sediments were observed on Noarlunga reef (and were probably on Horseshoe Reef that is closer to the dredge site; (Cheshire *et al.* 1999). Mussels appear to have increased at the expense of the encrusting red algae and hence there has not been any measurable reduction in cover of robust brown macroalgae. This is readily apparent from Noarlunga sites and Horseshoe reef where mussels and robust brown macroalgae coexist. It is also apparent from the large changes that have occurred at the northern outer Noarlunga site from 1996 to 1999 that the macroalgal communities within the reserve are not stable over time even in the absence of mussels. It also needs to be recognised that juvenile brown algae tend to recruit onto encrusting algae (which provide a secondary substratum). It is likely that the effect of mussels will be seen over the next few years as reductions in recruitment of brown algae manifest through a thinning out of the canopy. There is a very real need to increase our understanding of the dynamics of both mussels and macroalgal communities at these sites and this would warrant further monitoring.

There was little change in the nature of the northern reefs between 1996 and 1999 and this suggests that their current situation, although degraded, is stable. At the Dredge and Barge sites the community is typical of that found in deeper water systems which is consistent with this location representing the deepest and calmest of all the reefs in the survey. This site is also the furthest from shore which may afford some protection from pollutants. Conversely, Semaphore and Broken Bottom are closer to shore and sources of land based pollution. The high cover of foliaceous red and turfing algae indicates that they are heavily degraded.

8.2 Factors affecting macroalgal community structure

The structure of macroalgal communities is determined by a variety of processes which respond to both natural factors and to anthropogenic influences. Wave energy, substratum type, topography and depth are all likely to have a profound influence (see review in Cheshire *et al.* 1998a). Anthropogenic influences include dredging, construction of marinas and port facilities, spoil dumping, sewage disposal, stormwater discharge and land reclamation. These induce disturbances which are likely to impact on coastal systems and thereby impact on algal communities.

To understand or interpret the responses of communities to impacts we need to consider both the nature of the disturbances and the types of algae which are present in the system. Differences in life history strategies of different algae (in terms of reproduction, growth and morphology) and the timing of disturbance in relation to recruitment events will influence the way in which any given species will respond to environmental changes (whether natural or anthropogenically induced; Noble and Slatyer 1980, Seapy and Littler

1982, Posey *et al.* 1996). In Gulf St Vincent, elevated rates of sedimentation and nutrient inputs are considered to be amongst the most important anthropogenic influences on algal communities.

Numerous studies have considered the effect of sedimentation on macroalgal communities and have concluded that it mainly impacts on algal recruitment, particularly of the larger brown macroalgae (Neushal *et al.* 1976, Devinny and Volse 1978, Norton 1978, Gorostiaga and Diez 1996, Cheshire *et al.* 1999). In a study of recruitment of the robust brown macroalgae on reefs on the southern/central section of the coast Cheshire *et al.* (1999) concluded that the low rates of recruitment at Noarlunga and Horseshoe reefs, which were in close proximity to recent dredging operations, were due to heavy sediment loads (Cheshire *et al.* 1999).

Sedimentation is also thought to reduce macroalgal productivity either by smothering of algal fronds or through increased turbidity in the water column (Lyngby and Mortenson 1996, Cheshire *et al.* 1999). Lower productivity may reduce levels of stored carbohydrate and result in a decline in reproductive output and limit an alga's ability to compete with its neighbours or pass through lean periods. High levels of sedimentation also adversely affects sessile marine invertebrates (Moore 1977, Gorostiaga and Diez 1996) and may lead to dramatic changes in community structure (Gorostiaga and Diez 1996, Renaud *et al.* 1996).

Turfing algae are thought to both tolerate and promote sedimentation (Phelps 1970, Neumann *et al.* 1970, Kendrick 1991, Greig 2000) and high turf cover may be indicative of heavy sediment loads. The large turf cover at Broken Bottom supports this view however the cover of turf at Semaphore is low, but this could be due to overtopping by the high cover of foliose red algae. Apart from trapping sediment, turf algae may also restrict the recruitment of large macroalgae (Dayton *et al.* 1984, Reed and Foster 1984, Scheil 1985b) although Harris *et al.* (1984) suggest that they may also provide some protection for recruits from herbivores. Turfs are known to be highly productive (Westphalen and Cheshire 1997) which prevents them from being smothered by sediment and possibly affords some advantage in high nutrient situations.

Most studies on the effects of sewage effluent on marine systems have concentrated on the propensity for nutrients to cause blooms of harmful microalgae. In turn, such blooms are likely to impact on the system through increased turbidity (reducing light penetration to the benthos), changes in oxygen status of the water body or more directly through the production of toxins.

More recently there have been a series of studies aimed directly at establishing the effects of sewage effluent on algal dominated benthic systems. A number of consistent responses have been reported including changes in the richness and diversity of algal communities (Brown 1990, Smith 1996) and associated fauna (Smith 1996) and increases in the abundance of nuisance algae such as *Ulva* and *Enteromorpha* (Brown 1990, Smith 1996). Changes in the composition of the associated faunal communities are also likely to result in a fundamental change in the trophic structure of these systems with shifts in relative abundances of taxa such as amphipods and polychaetes (Smith 1992). Such changes are thus likely to have much more far reaching effects in relation to rehabilitation and recovery of these systems.

Many of these changes, particularly on temperate reefs appear to be mediated by direct effects of effluent on the survival of spores of the dominant, canopy forming brown algae (Brown 1990, Bellgrove 1997, Burridge 1996) with a concomitant increase in the abundance of turfing species (Brown 1990, Cheshire *et al.* 1998a) which collectively results in scale-dependant changes in the complexity of the habitat (Cheshire *et al.* 1998a).

8.3 Qualification of the findings

A concern with the 1999 survey method was that sampling did not occur on exactly the same transects as in 1996. As a result there is the possibility of spatial differences in community composition being misinterpreted as temporal changes, however, repeated measures of the same point are difficult to achieve in marine systems, particularly over prolonged intervals. This is of particular concern at the Noarlunga and Horseshoe reefs where there is an apparent increase in the cover of mussels (*Xenostrobus pulex*).

To address this concern, a detailed study was undertaken at Horseshoe reef from October 1999 to February 2000. This companion study was prepared as an honours thesis through The Department of Environmental Biology at The University of Adelaide and is available. Observations of mussel cover and macroalgal recruitment were made in a series of experimental clearances with removal of either or both the mussels and/or macroalgae (Smith 2000). Over the sampling period mussel cover increased, not only in cleared patches, but also through the invasion of undisturbed macroalgal stands (Smith 2000). Conversely there was relatively low recruitment of macroalgae in all treatments except where the adult canopy was still in place (Smith 2000).

Mussels can recruit onto other mussels, bare rock (including encrusting reds; Lasiak and Barnard 1995) or filamentous communities (Davis and Moreno 1995, Lasiak and Barnard 1995), which may include turfs. Smith (2000) concluded that this substrate variety and the diversity of recruitment strategies employed by mussels, including the ability of adults to reattach after either accidental dislodgment or as an active dispersal mechanism, gave them an advantage at Horseshoe reef. Heavy sedimentation loads may promote the growth of turfing algae which, in turn, are colonised by mussels which, once established, can form an extensive matrix (Paine and Suchanek 1983) that blankets the substrate and excludes competitors (Lubchenco and Menge 1978), including macroalgae (McCook and Chapman 1993, Minchinton *et al.* 1997).

On northern reefs, mussels have only been observed at Broken Bottom and Semaphore with very low cover (< 1 %). If mussels are an indication of a decline in reef health there must be some reason for their poor representation on the degraded reefs in this section.

It is possible that mussels are being excluded from the northern sites due to elevated levels of pollutants. Heavy metal loads and water clarity have been reported as being moderate at all jetties north of (and including) Brighton whereas at Noarlunga the water quality with respect to these parameters was good (EPA 1997). It needs to be recognised however, that there is no evidence from other research to indicate that mussels are particularly sensitive to high levels of heavy metals. As such this explanation is considered unlikely. Alternatively the lack of mussels may be a result of the successional changes that occur across the period of decline in the health of a reef at these sites; the early phase may be dominated by high mussel cover with this being gradually replaced by the foliose red algae which dominate the community we now find. If this is the case then we may expect to find communities comprised of a mixture of mussels and foliose red algae on less degraded reefs further south; to date these have not been observed and this remains speculative.

The predominance of foliose red algae at the northern sites has been suggested as a sign of the degraded state of these reefs (Cheshire *et al.* 1998a,b). This is supported by evidence from the Dredge and Barge sites where there is a stark contrast between the community on the decks where sediment can accumulate and which are comprised almost exclusively of foliose red algae, and the vertical surfaces which are dominated by a prolific invertebrate community (Cheshire Personal Observation). There remains, however, the difficulty in determining why the vertical surfaces of the barge should maintain a rich invertebrate community when at “the Blocks” off Glenelg there is *Ecklonia radiata* growing on the vertical faces of the reef (Cheshire Personal Observation).

The Barge and Dredge are both from 15 – 20 m deep, which is well within the depth range observed elsewhere for *Ecklonia radiata* (Cheshire Personal Observation). The existence of seagrass beds adjacent to the wrecks suggest that the light climate is sufficient for *Ecklonia* growth, which leaves open the question as to why this species is absent. Competition for space is certainly an issue, as is the frequency of the arrival of *Ecklonia* propagules.

While sedimentation has been considered the dominant structuring influence in Adelaide’s metropolitan reefs, the role of toxins and nutrients in macroalgal communities needs to be considered. Changes in the species richness and diversity of systems have been observed along with the proliferation of opportunistic species such as *Ulva* and *Enteromorpha* (Brown 1990, Smith 1996). Toxins, including heavy metals, tend to accumulate in food chains in particular the top predators and filter feeders. Where macroalgae are concerned the effect of toxins is likely to be complex with the synergistic effect of a variable cocktail of chemicals in effluent and stormwater.

8.4 Future research

More detailed information should be obtained on the recruitment strategies employed in the mussel, *Xenostrobus pulex.* At this time the information we have has been extrapolated from other species. Specific life history information on the timing and triggers for recruitment, the substrate preferences (or tolerances) of recruits and the ability of adults to redisperse should be collected. A closer examination on the role of this mussel as an invader of macroalgal communities within the central reefs should be considered with the role of turf forming algae explored in more detail. Other factors such as the effect of heavy metals and nutrients on mussel growth, reproduction and settlement should also be examined.

In a similar vein the role of sediments on the settlement of macroalgal spores should be considered in more detail as well as recruitment of the macroalgal community dominants within turf forming algae. Nutrient and heavy metal effects on macroalgal spores could also be investigated.

The nature of the degraded systems is also worthy of further consideration with an investigation of recruitment strategies of the major foliose macroalgal species, in particular their ability to recruit by asexual (ie. fragmentary) methods.

At the Dredge and Barge further research should be undertaken on sedimentation rates and the biota of both the decks and hulls of these wrecks. This would help to establish the importance of sedimentation as a potential control over reef community structure. As the decks and sides have identical substrate (steel), are very close spatially and have been in place for the same period, the number of variables to consider other than sedimentation is greatly reduced.

8.5 Conclusions

There has been little change in composition at the northern reefs which were defined, based on the 1996 survey, as in a degraded state. This situation is thus considered stable and not likely to alter in the foreseeable future. Southern reefs from the 1996 survey (some of which were grouped into the central section in 1999) are also outwardly stable. Increased cover of robust brown macroalgae occurred at most sites between 1996 and 1999. Additional sites surveyed from the southern section in 1999 were all healthy.

Central reefs represent a cause for concern. There is evidence of a dramatic increase in the cover of the mussel *Xenostrobus pulex* at both Noarlunga and Horseshoe reefs. A link to increased sedimentation as the fundamental cause has been proposed but still has to be tested.

8.6 Recommendations

1. More research is needed into the dynamics of the communities on Noarlunga and Horseshoe reefs. These have been shown to be potential areas of concern with the possible expansion of mussel beds to the exclusion of everything else.

2. The survey should be repeated in 2002 with more deep sites (10 m) in the southern and central sections with the inclusion of a new sites off Marino and Brighton where there is a large gap between the central and northern sections. Shallow water sites (5 m) in the north should be identified (eg Glenelg Blocks) to balance those in the central and southern sections.

3. Further basic research into the effects of sediments on macroalgal recruitment and longevity is needed to establish this as a cause of reef degradation.

4. Quantitative studies are needed of sedimentation rates along the Adelaide metropolitan coast, particularly at Noarlunga and Horseshoe reefs.

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10. Appendix 1 – Life forms employed in the 1999 survey

Table 3 - List of the life form codes employed for all red (Rhodophyta), green (Chlorophyta) and brown (Phaeophyta) macroalgae encountered in the reef health survey.

	Morphology			Colour	
Size (cm)	Shape	Texture	Red	Green	Brown
<2 cm	Fine feathery Surface crust	Soft / slimy Hard	TURF RENC	TURF -	TURF BRENC
2 – 7	Branched and spiky or fern like	Hard, brittle	RCORAL	-	-
2 – 20	Membranous / sheet like / sack like	Soft may be slimy	RMEM	GMEM	BRMEM
2 – 20	Bushy, frequently branched	Soft	RFOLI	GFOLI	BRFOLI
2 – 20	Flattened and rounded or fan shaped	Firm	RLOBE	GLOBE	BRLOBE
2 - >100	Robust, branched with robust or leaf like blades	Leathery, tough	RROB	-	-
10-200+	Robust, flattened blades may be corrugated or smooth with well defined stalk at base	Leathery, tough	-	-	BRFLAT
10-100+	Robust, branched often bushy in appearance. One or more tough central stalks	Leathery, tough	-	-	BRBRANCH
2 – 20	Lumpy or spherical	Firm	-	GLUMP	-

Table 4 - Examples of the species represented by each of the macroalgal life forms from the reef health survey.

Life form code	Description	Representative taxa
BRENC	Brown encrusting algae	*Ralfsia*
BRFOLI	Brown foliaceous algae	*Halopteris, Cladostephus, Lobospira*
BRFLAT	Brown robust algae, large flattened blades (much broader than thick), not membranous but leathery	*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, Bryopsis Chaetomorpha, Apjohnia, Codium,*
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 5 - List of the life form codes employed for all animals encountered in the reef health survey and the quadrating that was undertaken as part of the algal recruitment survey.

Broad category	Life form 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
Hydroids	HYD	Hydriods
Anemones	ANEM	Anemones
Coral	CORAL	Corals
Crustaceans	CRAB	Crabs
	GOOS	Goose barnacles
	CRUS	Other crustaceans