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# Shoalwater Bay Fringing Reef Resource Assessment

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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## SUMMARY

We were asked to survey fringing reefs in the Shoalwater Bay region using techniques that would enable value ranking of the reefs for management purposes. It was suggested that the biodiversity and bioconstruction values proposed by Done (1995) could be used as an aid to such ranking. All 24 reefs for which information was required were visited between the 11 and 18 December 1995 and detailed surveys made on 18 of these. Measurements of coral cover were made using two sites of five 20-metre line intersect transects on each reef. Coral diversity was measured by counting the number of species recorded during the transect surveys, and during an additional 30 minute haphazard swim around each location. Estimation of bioconstruction value required measurement of size frequencies, and these were obtained from the transect intersects and also by making additional measurements of large corals during a 90 minute search of each location. This gave biased measures of size frequency, but as the same technique was used on all survey reefs we considered that value comparisons among reefs were valid.

Coral cover was very variable, ranging from 7.3 to 66.3%, but was, on average (grand mean 37.8%), lower than has been recorded from most other fringing reef areas in the Great Barrier Reef region, where grand means have ranged from 50 to 80%. However, the Shoalwater Bay reefs appear to have relatively high coral cover when compared to other fringing reefs within the strong tide region between Mackay and Port Clinton where the maximum tidal range is more than five metres. Coral communities were dominated by acroporids; explanate *Montipora* species on reefs in the southern sector of Shoalwater Bay, and both *Acropora* and *Montipora* species on northern sector reefs. A total of 87 coral species were recorded overall, with a range of 23–58 species counted from individual reefs. Coral diversity was lower than has been recorded from fringing reef areas to the north, where overall totals have ranged from 120 to 143, but was equivalent to the approximately 90 species recorded from the Keppel Islands to the south. Done's biodiversity value was relatively similar for all the survey reefs, suggesting that they are of similar value in a Great Barrier Reef wide context. Mean colony age as calculated from the biased measures of size frequency gave an underestimation of age. Mean age estimates ranged from 9 to 16 years for the Shoalwater Bay reefs (grand mean 12.3 years), but was over 27 years for the Pearl Bay location. Done's biodiversity value gave a good range of values for the survey reefs, and was useful for ranking the relative value of the reefs. As well as calculating this bioconstruction value, we also used a count of the number of coral colonies over 100 centimetres across that were encountered during the surveys on each reef as an additional bioconstruction measure. The number of large colonies encountered on each reef was also very variable ranging from 4 to 63. Our experience suggests that the number of large colonies on the Shoalwater Bay reefs was lower than on most other fringing reefs, with the possible exception of other reefs within the strong tide area mentioned above, and their size was generally smaller.

A number of reef attributes were used to rank the value of these reefs for managers. The most obvious feature of any reef is the percentage of live coral cover, and this was used as one attribute in the ranking process. Done's biodiversity value had limited ability to rank reefs when used in a local context such as within Shoalwater Bay, and as a result we also used a simple count of coral species to rank these reefs. We also used mean colony age, Done's bioconstruction value, and a count of all coral colonies over 100 centimetres across, as further attributes for ranking reef value. The final reef attribute used for ranking these reefs was the subjective aesthetic value, on a scale of 0–5, given to each reef after the survey to put their value in a social context. By combining these seven attributes, an overall ranking of reef value on a 0–5 scale was arrived at. Reef value in the Shoalwater Bay region was very variable, ranging from a low of only 1.83–4.36. Two reefs were considered to have above average value, while three had below average value.

A number of features of these reefs, including the high variability in reef attributes and the possible low mean colony age, suggest that they are subject to relatively high levels of

disturbance. While the highest value reefs are comparable to fringing reefs in other areas, many are of lesser value than most other fringing reefs, with the exception of those reefs in the strong tide area between Mackay and Port Clinton. Like other reefs in this strong tide area, it is possible that the Shoalwater Bay reefs are surviving in a region that is marginal for fringing reef development. Some suggestions of management options are made for the reefs in this region.

## INTRODUCTION

The Great Barrier Reef Marine Park Authority is involved in preparing management strategies for the whole Shoalwater Bay area, as well as zoning plans for the Byfield Coast area, immediately east of Shoalwater Bay. They have found a lack of information on the state of the fringing reefs that aerial photographs suggest are present around many of the shoals and islands in this area.

T.J. Done has recently suggested various parameters that may be useful for managers in evaluating coral reefs in a paper in *Coral Reefs* entitled, 'Ecological criteria for evaluating coral reefs and their implications for managers and researchers' (Done 1995). Done points out that to provide data for his suggested evaluations researchers and assessors need to look beyond a simple quantitative survey of percentage cover, to get a valuation of each site based on coral composition and ages, and an assessment of recoverability, as well as on total cover. His value assessments focused on estimates of biodiversity value and bioconstruction value to give some quantitative guide for managers. The Great Barrier Reef Marine Park Authority would like to test some of the ideas offered in this paper in making an assessment of the resources of the Shoalwater Bay fringing reefs.

The Great Barrier Reef Marine Park Authority provided a list of 24 possible fringing reefs within the Shoalwater Bay-Byfield Coast region for which they required biological information. Within the time/budget limitations available we attempted to get as much information as possible from each of these reefs, and collected this information in such a way as to make Dóne-type evaluations possible. In practice we found that some of Done's ideas were not appropriate for our purpose: to put a relative value on the different Shoalwater Bay reefs, and we also used a number of other attributes to rank these reefs. This report presents the results from these surveys and attempts to put relative values on the reefs visited so that managers have an indication of which reefs it would be most appropriate to protect.

## METHODS

### Study Reefs

There were 24 reefs/shoals for which the Great Barrier Reef Marine Park Authority required information (table 1, figure 1). All of these reefs were visited during this survey but quantitative surveys were only made at 18 locations. Three of the supposed reefs were mobile sand banks, one was shallow and algal dominated, another was a rock reef with only a few encrusting corals, and the last was unworkable at the time of our visit because of extremely poor visibility.

**Table 1**. List of the study reefs. The abbreviations used in subsequent tables are shown (Ab.), along with the ID number, date of visit, depth of survey area where appropriate, underwater visibility in metres at time of visit, and comments. Shoalwater locations are grouped into four sectors.

| Reef | Ab. | ID no. | Date | Depth | Vis. | Comments |
|---|---|---|---|---|---|---|
| Pearl Bay Group | PB | 22-081 | 11/12 | 1.5–2 | 4 | Rubble reef with some corals |
| Clara Group | | 22-075 | 12/12 | na | 5 | Steep rock reef with some corals: not surveyed |
| Donovan Shoal | | 22-040 | 16/12 | na | 7 | Clean sand bank: not surveyed |
| White Shoal | | 22-055 | 16/12 | na | 6 | Clean sand bank: not surveyed |
| Turn Shoal | | 22-050 | 16/12 | na | 6 | Clean sand bank: not surveyed |
| **NE Sector:** | | | | | | |
| North Ripple Is. | NR | 22-047 | 17/12 | 1–3.5 | 7 | |
| Holt Is. | Ho | 22-045 | 17/12 | 1–3 | 9 | |
| Unnamed Is. | Un | 22-046 | 17/12 | 1–2.5 | 9 | |
| Mumford Is. | Mu | 22-042 | 16/12 | 1–3.5 | 8 | |
| Ten Pin Rock | TP | 22-044 | 16/12 | 1–4 | 7.5 | |
| **NW Sector:** | | | | | | |
| Five Trees Cay | FT | 22-051 | 18/12 | 0–2 | 4 | |
| Collins Is. | Co | 22-052 | 15/12 | 1–4 | 4.5 | |
| Eliza/Annie Is. | | 22-052 | 14/12 | 0–2 | 4 | Shallow reef, algal dominated: not surveyed |
| Lingham Is. | Li | 22-049 | 15/12 | 1–3 | 6 | |
| White Rocks | WR | 22-043 | 15/12 | 1–2.5 | 8 | |
| **SW Sector:** | | | | | | |
| Osborne Is. | Os | 22-056 | 13/12 | 1–3 | 3.5 | |
| Clara Is. | Cl | 22-038 | 13/12 | 1 | 4 | Algal dominated reef |
| Swan Is. | Sw | 22-062 | 13/12 | 1–2 | 4 | |
| Sun Is. | Sn | 22-061 | 14/12 | 1–2.5 | 2 | |
| Akens Is. | | 22-067 | 14/12 | | 0.5 | Limited reef area, gorgonian dominated: too dirty to survey |
| Edward Is. | Ed | 22-060 | 14/12 | 1.5–3.5 | 4 | |
| **SE Sector:** | | | | | | |
| Bay Is. | Ba | 22-064 | 12/12 | 1.5 | 4 | |
| Connor Rock | Cn | 22-066 | 18/12 | 0–2 | 2 | Too small for two sites |
| Blind Rock | Bl | 22-057 | 18/12 | 1–3 | 5 | Too small for two sites |

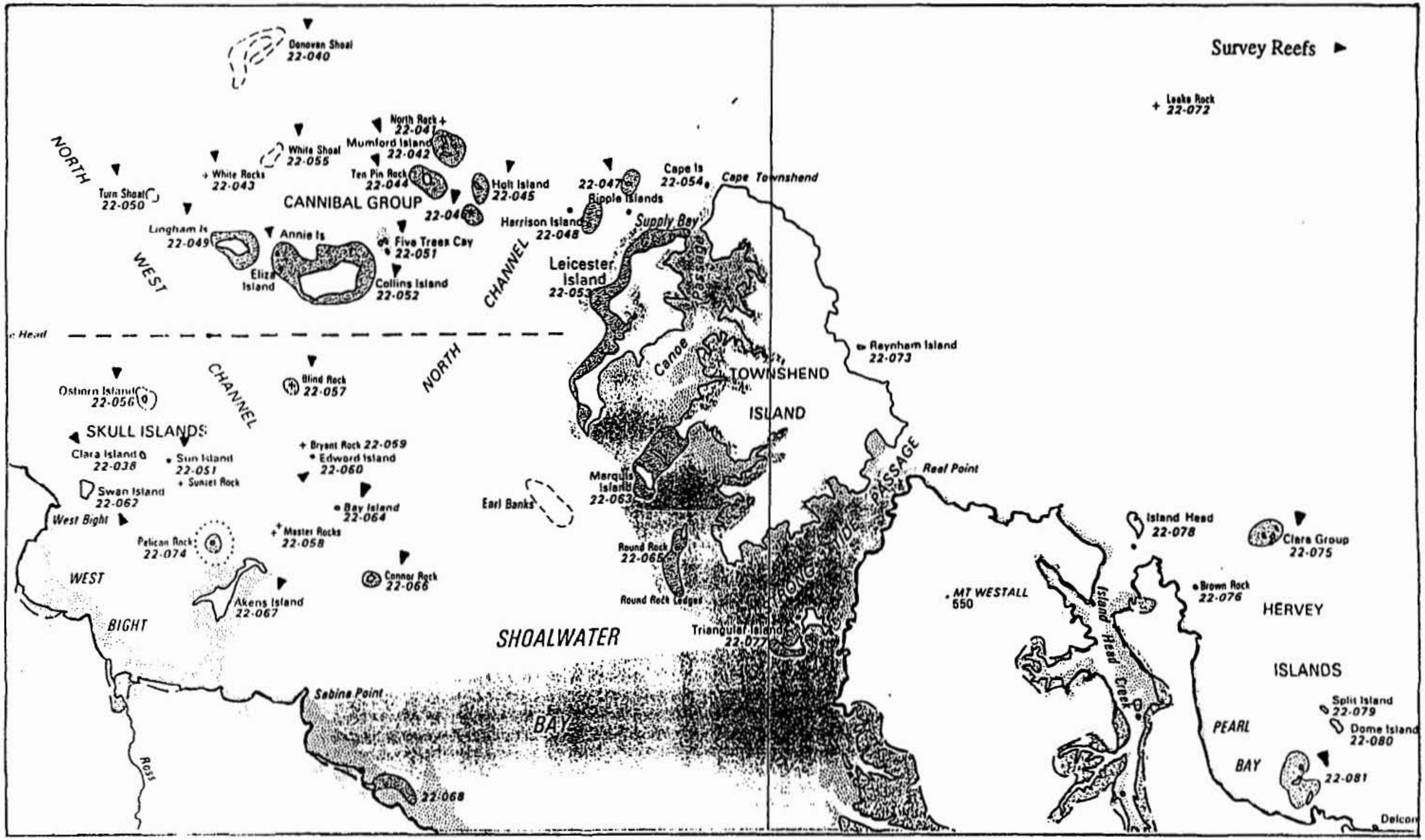



**Figure 1.** Map of the Shoalwater Bay area showing survey reef positions. Dashed line divides northern reefs from southern reefs.

### Site Selection

At each location, sites were selected either using aerial photographs, where available, or by running around the area in the dive boat and selecting appropriate reef areas; usually those areas where the reef was widest. In some cases the 'reefs' around these islands dropped quickly to a sand or rubble floor and were merely algal covered rubble banks with a few corals amongst the algae. These areas were avoided in favour of reefs where coral development was greater. Where coral reefs were not present formal quantitative surveys were not carried out.

### Benthic Cover Surveys

Surveys were made on the reef slope at depths determined appropriate from a quick initial reconnaissance. Many of the reefs were shallow and surveys were made along the lower edge of the reef where coral cover was usually highest, but in other cases the surveys were made in whichever stratum supported the highest coral cover. If the entire reef was algal dominated with very low coral cover (< 5%), no quantitative benthic surveys were made at that location. Where possible, two sites were surveyed at each location with at least 100 m between sites, in order to avoid confounding location with site. At two locations, Blind Rock and Connor Rock, the reef area was so small that two sites could not be surveyed. At each site five 20 m line intersect transects, run parallel to the depth contours, were recorded for the intersects of all benthic organisms. The following groups were recorded: macroalgae, algal turf, sponges, all hard corals, all soft corals. Hard corals were identified at species level except for the following familiar and structural groups: explanate *Montipora*, corymbose plate acroporids, staghorn acroporids, tabulate acroporids, massive poritids, finger poritids, all *Goniopora* and *Alveopora* species, all *Fungia* species. Most faviids were only separated to generic level in the quantitative surveys.

### Species Diversity and Size Frequencies

Species lists were made during the transect surveys and were added to during a 30 minute random swim around each location covering the depth range of the reef. Intersect lengths from the line transects were used to construct size frequencies for each location. Such size frequencies are necessarily biased as the intersect length is almost always less than the true diameter of the coral colony, but we suggest that they provide a useful relative estimate for these reefs as the same technique was used in all locations. For larger species, records of the diameter of all large colonies (greater than 100 centimetres for acroporids, greater than 50 centimetres for all other groups) encountered during an approximately 90 minute haphazard swim around the location by a second observer (R. Berkelmans) were made while the first observer (A.M. Ayling) was completing the intersect transects and the species list. These were added to the frequencies from the line transects, adding a further source of bias, but again the same techniques were used in all locations and these data were considered useful for comparative purposes.

### Other Criteria

In addition to the above measurements, a measure of underwater visibility was made at each site (table 1), and an assessment of the aesthetic value of each location made on a five point scale from poor (1) to excellent (5). The Great Barrier Reef Marine Park Authority requested that aesthetics be ranked from the point of view of a casual scuba diver to give an indication of their value in a social context. Representative underwater photographs were taken of each location when underwater visibility permitted.

**Done Biodiversity Value**

Done's suggested biodiversity value ($V_b$) indicating the uniqueness of the area of interest in the regional context is :

$$V_b = \Sigma\,(c_j \bullet \alpha^j)$$

where $c_j$ = the proportion of colonies, plants or bottom cover (as appropriate) in category $j$ with $j$ = commonness index for regional species pool, and with $j$ = 1 for common; $j$ = 2 for rare, and $j$ = 3 for previously unreported and $\alpha$ = a constant, here arbitrarily set at 10 so as to produce a maximum $V_b$ of 1000 (i.e. when 100% of colonies, plants or bottom cover in the area are previously unreported).

Thus a site with a species list typical of the region would score 10, a site with equal abundance of common, rare and unreported would score 366, and a site with a unique composition (all species previously unreported in the region) would score 1000.

This index depends entirely on the definition of the region within which the area of interest (in this case Shoalwater Bay) is compared. Presumably in this case the region would have to be considered as the entire Great Barrier Reef, the region the Great Barrier Reef Marine Park Authority is responsible for managing. We used the abundance references from Veron (1986) to assign each species to one of the three commonness categories suggested by Done. Because of the species groupings we made in surveying the line intersect transects it was not possible to separate the area covered by rare species from that covered by common species as some of the groupings included both rare and common species. Instead we calculated a biodiversity value based on the *number*, rather than area covered, of species in each abundance category.

**Done Bioconstruction Value**

Done suggests that 'time for replacement' is a 'natural' currency for bioconstruction value, since longevity and large size equate with mass and structural importance. He further suggests that each site may be assigned two values:

Unweighted value $V_u$ = age of the oldest sessile benthos (be it coral, algae, sponge or soft coral).

Alternatively, taking into account the abundance of benthos of different ages,

$$\text{Area-weighted value } V_w = \Sigma\,(a_i \bullet m_i) \text{ years}$$

where $a_i$ = age class i (in years) $m_i$ = proportion of individuals, or of defined area covered by individuals, of age class $a_i$.

Both indices assign a zero value to bare sand, and low value to young benthos (< 5 years old, e.g. the algal turfs or pioneer corals on rubble or other newly disturbed areas). Both assign a value of 1000 to a site completely covered by 1000 year old coral heads.

We found that the area weighted index gave a different value when calculated based on the proportion of individuals compared to that calculated based on the percentage cover of individuals, and as a result we calculated two different bioconstruction values. As mentioned above we used biased size frequency data to define age class, and converted size to age for the different coral groups using the data of Done (1990) and personal observations on fringing reef communities. Average annual *diameter* increases for the different groups were assumed to be:

| | |
|---|---|
| Acroporids | 8 centimetres |
| Pocilloporids | 5 centimetres |

| | |
|---|---|
| *Turbinaria* spp. | 5 centimetres |
| Poritids | 2 centimetres |
| Faviids | 1 centimetres |
| Other corals | 5 centimetres |

No data on growth rates of corals on these southern fringing reefs are available, and it may be that growth rates are lower in this area than on other fringing reefs due to lower average temperatures and turbid water conditions. However, as the indices obtained from these data were used for comparative purposes within the Shoalwater Bay locations only, the accuracy of these growth estimates is not particularly important.

## RESULTS

### Physical Characteristics of the Reefs

True reef development on most of the reefs appeared to be minimal; the reefs were developed on broken rocky shores, or on rubble banks. Apart from the relief provided by rock boulders in shallow water, and by the occasional large coral colony, there was little topographic complexity to these reefs. Most of the reefs were shallow, extending only a few metres below AHD (Australian Height Datum - approximately the level of the lowest spring tide), although, given the extreme tide range in the Shoalwater Bay area of from four to seven metres, depths would exceed 10 metres at high tide. The NE sector reefs were the deepest, reaching depths of between five and 10 metres below AHD in places.

The large tidal range, combined with the size of the enclosed bay, gives rise to high currents throughout this area. Although we surveyed the area through the neap tide period, tidal currents of from 1–4 knots were experienced.

### Cover of Benthic Organisms

With few exceptions the reefs supported a high cover of turfing and macroalgae, with cover in the surveyed strata ranging from about 10 to 60% (figure 2, appendix 1). This cover was not restricted to a narrow fringe in shallow water, as is normal for most fringing reefs, but covered the range of depths encountered at most locations, down to at least six metres below AHD. Seagrasses occurred on many of the reefs, and were recorded in the transects at up to 18% cover from sites where regular sand patches were encountered. The grand mean cover of algae and seagrasses from all locations was about 38%, the same as the grand mean cover of hard corals.

Sponges were not an important benthic group on any of the reefs, with the highest cover recorded being only 1.6% on Blind Rock, and with a grand mean from all reefs of only 0.5% cover.

As mentioned above grand mean coral cover was very similar to total algal cover at 37.8%. There were significant differences in total coral cover between sites within each reef (table 2). Sites were between 100 and 500 metres apart and patchiness at this scale is a feature of most reefs. Hard coral cover at the locations surveyed was very variable (figure 2), with mean cover per reef ranging from a low of only 7.3% at Clara Island to a high of 66.2% at Sun Island. There were seven groupings of reefs with non-significantly different coral cover, each group covering from six to nine reefs and spanning a coral cover range of about 20% (table 3). There was no general correlation of coral cover with the position of each reef within Shoalwater Bay, although cover was on average lower around the north-west sector reefs of Collins, Five Trees, Lingham and White Rocks (figure 2).

Pocilloporid corals were not generally abundant, with a grand mean of only 1.4% cover. This group was, however, about twice as abundant on the northern reefs than on the southern reefs (figure 2). The needle coral *Seriatopora hystrix* was only recorded as occasional colonies from two of the southern reefs but was commonly found on almost all northern reefs. Acroporids were the dominant coral group on all reefs except coral-poor Clara, accounting for a mean of over 56% of total coral cover (figure 2). On the northern reefs explanate *Montipora* species covered an area about equal to the area covered by all *Acropora* species (mainly corymbose plate forms), but on all southern reefs explanate *Montipora* species were about four times as abundant as *Acropora* species (figure 3). Poritid corals were not abundant on these reefs, covering a mean of only 1.6% of the substratum, and showed no differences between northern and southern reefs. Of the other coral groups, *Turbinaria* spp. was most abundant with a grand mean cover of 6.8%, followed by faviids with 4.3% cover. Both these groups were moderately more abundant on the southern reefs, and formed a higher proportion of the total coral cover on these reefs (figure 2, appendix 1).

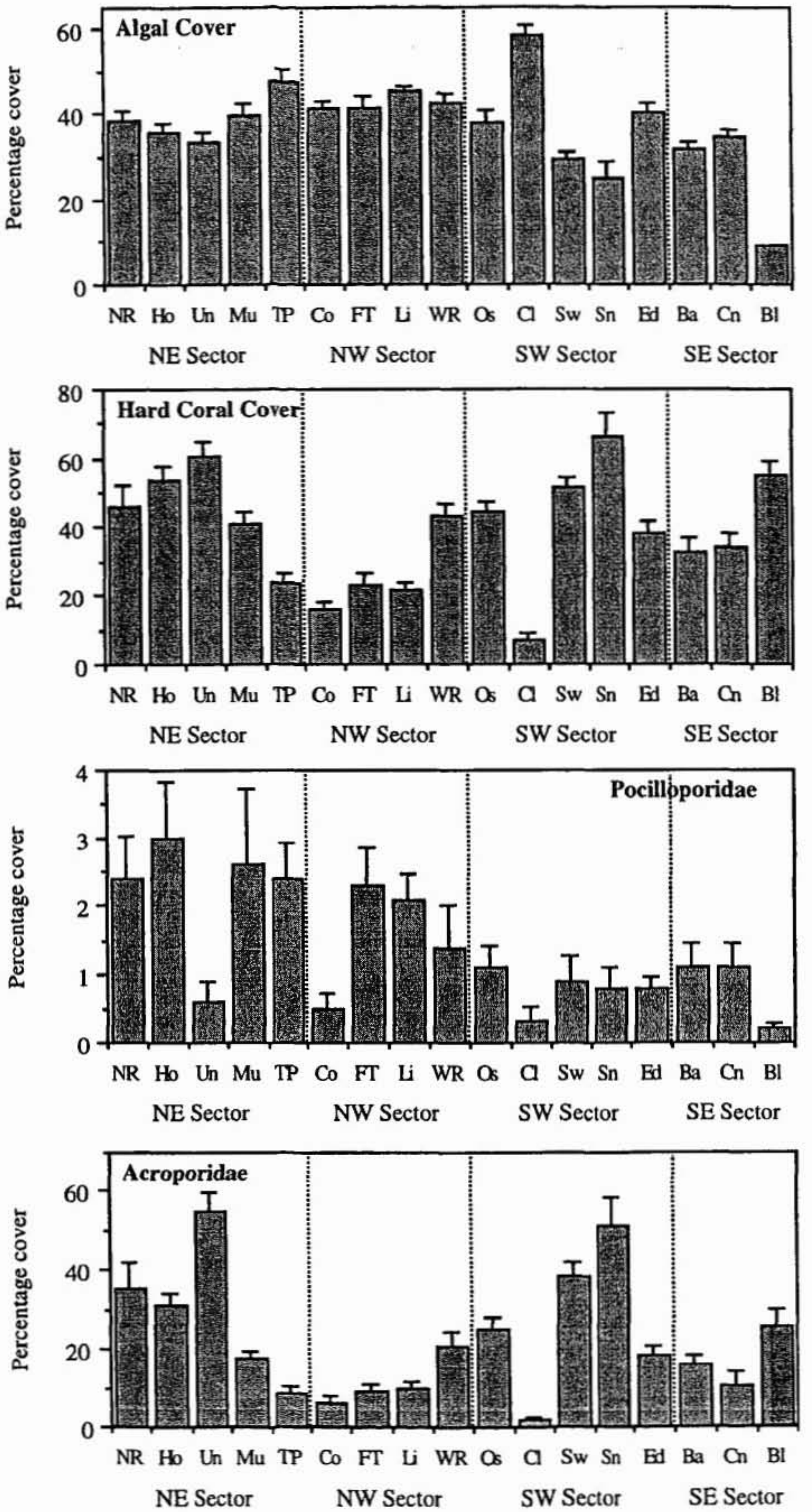



**Figure 2.** Abundance of benthic groups on the survey reefs. Reefs are grouped into north-east (NE), north-west (NW), south-west (SW) and south-east (SE) sectors of Shoalwater Bay. Graphs show mean percentage cover. Error bars are standard errors. Reef abbreviations as in table 1.

**Figure 2.** (continued)

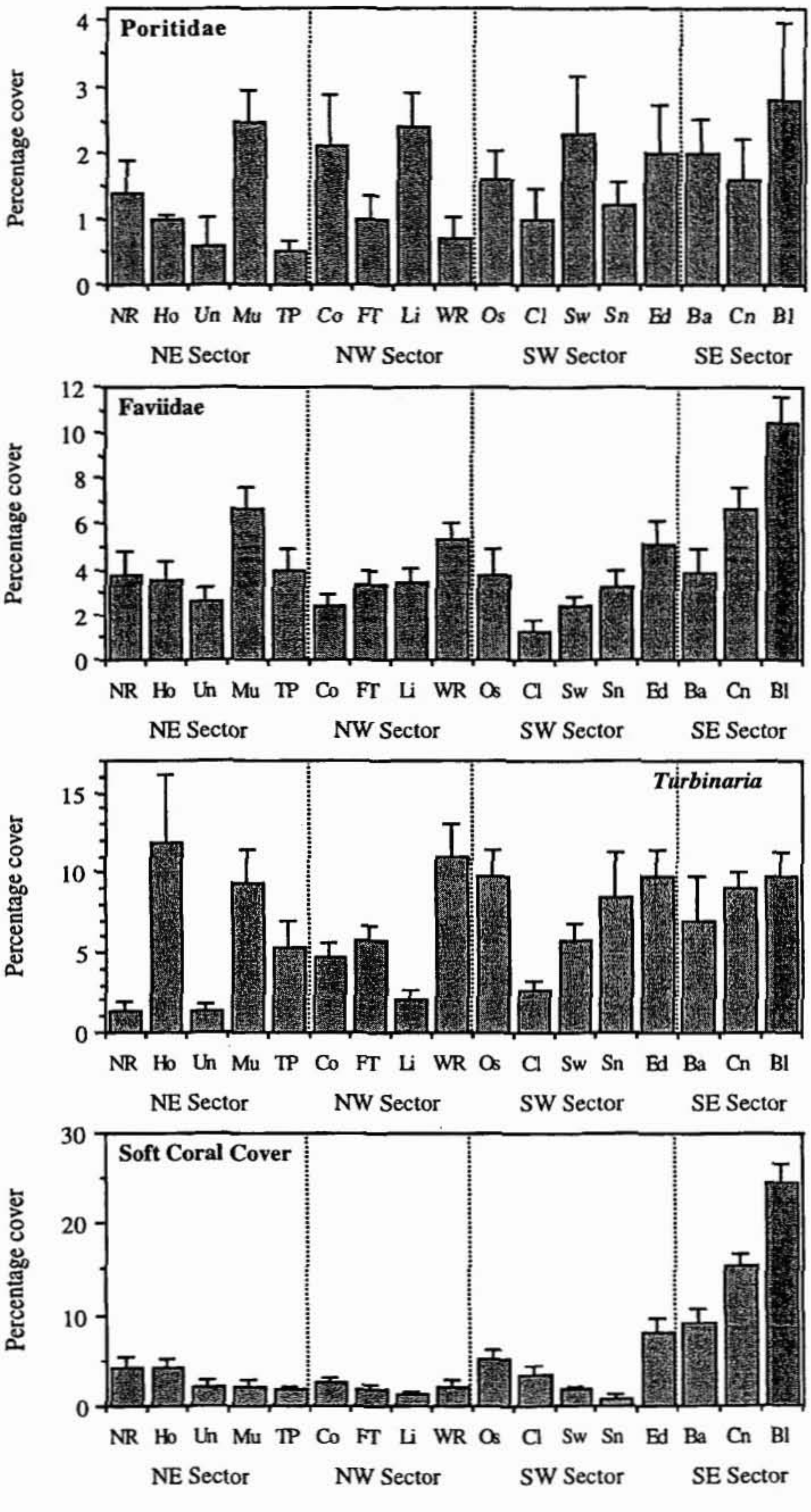
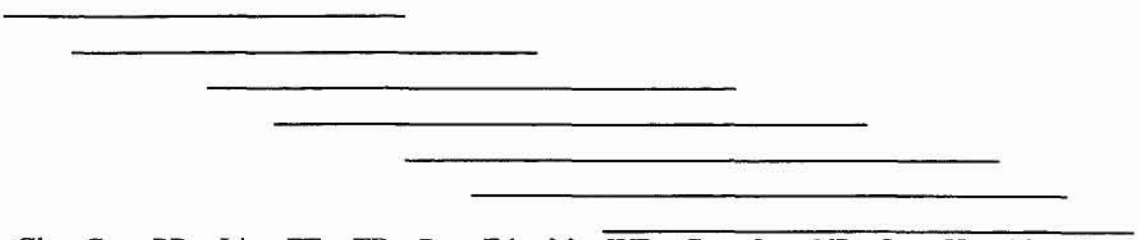


**Table 2.** Anova table for patterns of total coral cover among the survey reefs

| Source of Variation | df | MS | Error Term | F value | p value |
|---|---|---|---|---|---|
| Reef | 16 | 2823.5 | Site (reef) | 4.446 | 0.002 |
| Site (reef) | 17 | 604.816 | Residual | 6.956 | <0.001 |
| Residual | 136 | 86.949 | | | |

**Table 3.** Groupings of reefs with similar coral cover. The significance of differences was determined using Fishers LSD tests. Abbreviations as shown in table 1. Solid lines cover reefs with non-significant coral cover differences.



Cl Co PB Li FT TP Ba Ed Mu WR Cn Os NR Sw Ho Un Sn
Lowest Highest

Soft corals were generally not common on these reefs, with the notable exception of the south-east sector reefs (figure 2). On Connor Rock soft corals covered over 15% of the substratum and on Blind Rock a variety of gorgonian and tufty low species, along with *Sinularia* and *Sarcophyton* species, accounted for almost 25% cover.

**Biodiversity**

The number of species recorded on each reef ranged from 23 on coral-poor Clara Island to 58 on Osborne Island, with a grand mean of 48 species (appendix 2). The number of species recorded on northern reefs (49) was similar to that on southern reefs (47). The most notable feature of the coral species from these reefs was the presence of several common species that are normally very rare on the Great Barrier Reef but are usually found on more southern fringing reefs and around Lord Howe Island and Elizabeth and Middleton Reefs. This group included *Acropora glauca*, *A. solitaryensis*, *Acanthastrea hillae* and *A. bowerbanki*, but may have included other species that were not recognised: these are all species none of the field personnel were familiar with. Two siderastreid species, *Psammocora superficialis* and *Coscinarea columna*, that are usually uncommon on fringing reefs were common on all reefs surveyed. There were also a number of notable absences of species and whole groups that are normally common on fringing reefs elsewhere on the Great Barrier Reef, including the Northumberland Islands and Percy Isles. The absences included: all *Pavona* species, all free living fungiids (*Podabacia crustacea* was recorded from three reefs), all *Pectinia* species, *Merulina ampliata*, all *Echinopora* species, *Porites cylindrica* and all *Caulastrea* species. The branching fire coral *Millepora tenella* was also not recorded from these reefs.

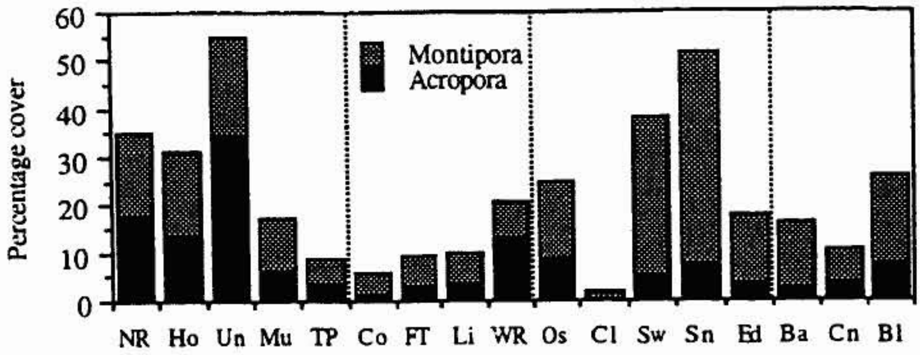



**Figure 3.** Distribution of *Montipora* spp. and *Acropora* spp. on the survey reefs. Mean percentage cover is shown. Reef abbreviations as per table 1.

Done's biodiversity value was calculated for each location using the species lists from appendix 1 and species abundance information from Veron (1986). Of the 87 species recorded during this survey, 13 were classed as rare in the Great Barrier Reef region by Veron (although there may be some coral species in this area that have not been previously reported from the Great Barrier Reef region, they were not recognised by the field personnel). The biodiversity values were all similar, ranging from 18.5 at Collins Island to a high of 25.7 at Clara Island (table 4). This value was converted to a rating between 0 and 5 by setting a biodiversity value of 0 as a rating of 0, and the maximum value of 25.7 as a rating of 5, and converting all intermediate values proportionally (table 4).

**Table 4.** Biodiversity values for the Shoalwater Bay locations. Hard coral only. Absolute values for Done's biodiversity value are shown along with a rating between 0 and 5

| Location | No. coral species | No. rare species | Biodiversity value | Rating |
|---|---|---|---|---|
| Pearl Bay Group | 41 | 5 | 21.0 | 4.09 |
| North Ripple Is. | 55 | 7 | 21.4 | 4.16 |
| Holt Is. | 55 | 8 | 23.0 | 4.47 |
| Unnamed Is. | 44 | 5 | 20.3 | 3.95 |
| Mumford Is. | 53 | 7 | 21.9 | 4.26 |
| Ten Pin Rock | 53 | 8 | 23.6 | 4.59 |
| Five Trees Cay | 37 | 5 | 22.1 | 4.30 |
| Collins Is. | 42 | 4 | 18.5 | 3.56 |
| Lingham Is. | 56 | 8 | 22.9 | 4.46 |
| White Rocks | 49 | 6 | 21.0 | 4.09 |
| Osborne Is. | 58 | 10 | 25.5 | 4.96 |
| Clara Is. | 23 | 4 | 25.7 | 5.00 |
| Swan Is. | 52 | 6 | 20.3 | 3.95 |
| Sun Is. | 51 | 5 | 18.8 | 3.66 |
| Edward Is. | 48 | 7 | 23.1 | 4.49 |
| Bay Is. | 56 | 7 | 21.3 | 4.14 |
| Connor Rock | 36 | 5 | 22.5 | 4.38 |
| Blind Rock | 50 | 8 | 24.4 | 4.75 |

### Bioconstruction

Done's bioconstruction value calls for the use of either the 'proportion of individuals, *or* of defined area covered by individuals' (authors' italics) and the value is expressed in years. In practice using proportion of individuals gives a completely different result to using percentage area covered. Using proportion of individuals gives a value that approximates mean colony age but using percentage cover does not. We calculated Done's bioconstruction value ($V_w$) for each of the reefs surveyed using both proportion of individuals and percentage cover, and converted both these to a rating between 0 and 5 in the same way as the biodiversity value (table 5). The value based on proportion of individuals may have a few problems as an indicator of reef bioconstruction, e.g. age is not necessarily related to size and a 50 year old *Acropora* colony may contribute far more to reef structure than a 200 year old faviid. We also used a direct count of the number of colonies encountered during the line transect surveys, and the search for larger colonies by the second observer on each reef, that were over 100 centimetres in diameter as a measure of relative bioconstruction value, again converted to a rating of between 0 and 5 (table 5). This sample of large colonies was obtained in a similar manner on each reef and was suitable for comparative purposes among the locations. Done's bioconstruction value based on percentage cover was positively correlated to the number of large corals counted at each location ($r = 0.552$; $p<0.05$), suggesting that these two estimates probably provide a better measure of bioconstruction than does mean colony age.

**Table 5.** Bioconstruction values of the survey reefs. Three measures of bioconstruction are given: Done's bioconstruction value ($V_w$) based on both proportion of individuals ($V_w1$), and percentage cover ($V_w2$), and a count of the number of colonies over 100 cm recorded during the survey. Both absolute values, and ratings on a scale of 0–5, are given for these measures.

| Reef | $V_w1$ (age) | $V_w1$ rating | $V_w2$ (% cover) | $V_w2$ rating | No. > 100 | > 100 rating |
|---|---|---|---|---|---|---|
| Pearl Bay Group | 27.53 | 5.00 | 28.67 | 3.70 | 31 | 2.46 |
| North Ripple Is. | 11.26 | 2.05 | 11.52 | 1.49 | 44 | 3.49 |
| Holt Is. | 11.35 | 2.06 | 28.67 | 3.70 | 52 | 4.13 |
| Unnamed Is. | 8.83 | 1.60 | 20.22 | 2.61 | 58 | 4.60 |
| Mumford Is. | 13.37 | 2.43 | 20.54 | 2.65 | 45 | 3.57 |
| Ten Pin Rock | 14.17 | 2.57 | 18.11 | 2.34 | 29 | 2.30 |
| Five Trees Cay | 11.34 | 2.06 | 16.34 | 2.11 | 16 | 1.27 |
| Collins Is. | 13.49 | 2.45 | 12.20 | 1.57 | 16 | 1.27 |
| Lingham Is. | 10.50 | 1.91 | 10.48 | 1.35 | 18 | 1.43 |
| White Rocks | 11.77 | 2.14 | 18.17 | 2.34 | 39 | 3.10 |
| Osborne Is. | 10.23 | 1.86 | 16.17 | 2.09 | 32 | 2.54 |
| Clara Is. | 11.62 | 2.11 | 14.36 | 1.85 | 4 | 0.32 |
| Swan Is. | 12.18 | 2.21 | 17.87 | 2.31 | 56 | 4.44 |
| Sun Is. | 16.34 | 2.97 | 38.77 | 5.00 | 63 | 5.00 |
| Edward Is. | 15.76 | 2.86 | 23.88 | 3.08 | 38 | 3.02 |
| Bay Is. | 12.49 | 2.27 | 14.69 | 1.90 | 32 | 2.54 |
| Connor Rock | 14.55 | 2.64 | 20.97 | 2.70 | 10 | 0,79 |
| Blind Rock | 11.18 | 2.03 | 14.26 | 1.84 | 23 | 1.83 |

With the exception of the Pearl Bay Group reefs our estimate of mean colony age on these reefs was low, ranging from 8.8 years on Unnamed Island to 16.3 years on Sun Island (table 5). Note that these age estimates are on the low side as the biased length frequency distributions would have underestimated colony diameter in most cases. In the Pearl Bay Group a combination of very few small corals and a few large colonies gave a mean age of 27.5 years. The bioconstruction values obtained from the count of large colonies and from the percentage cover of the different age classes were usually at variance with that derived from mean colony age (table 5). For example Pearl Bay Group and Connor Rock both rated below average in number of large colonies but were first and fourth rated respectively in mean age. At the other extreme, Unnamed Island was ranked second in number of large colonies but had the lowest mean age. Done (pers. comm.) suggests that the bioconstruction value obtained from the percentage cover data provides the most useful measure.

## Rating of Overall Reef Value

Done suggests combining the criteria of biodiversity and bioconstruction values to get a five point scale for reef value (figure 4). Using this system for the Shoalwater Bay reefs confirms that they all have similar biodiversity value, in the lower half of the moderate value (3) square, and shows that they span a bigger range of bioconstruction value, from young to moderately old. All the reefs have moderate value based on this ranking.

To better rate the relative value of the reefs within Shoalwater Bay to managers we combined a number of attributes of each reef to make an overall estimate of relative reef value (table 6). The seven attributes used were: total coral cover, number of coral species recorded during the survey, biodiversity value ($V_b$), mean colony age ($V_w 1$), bioconstruction value based on percentage cover ($V_w 2$), number of large coral colonies recorded during the survey, and the subjective aesthetic rating given to each reef.

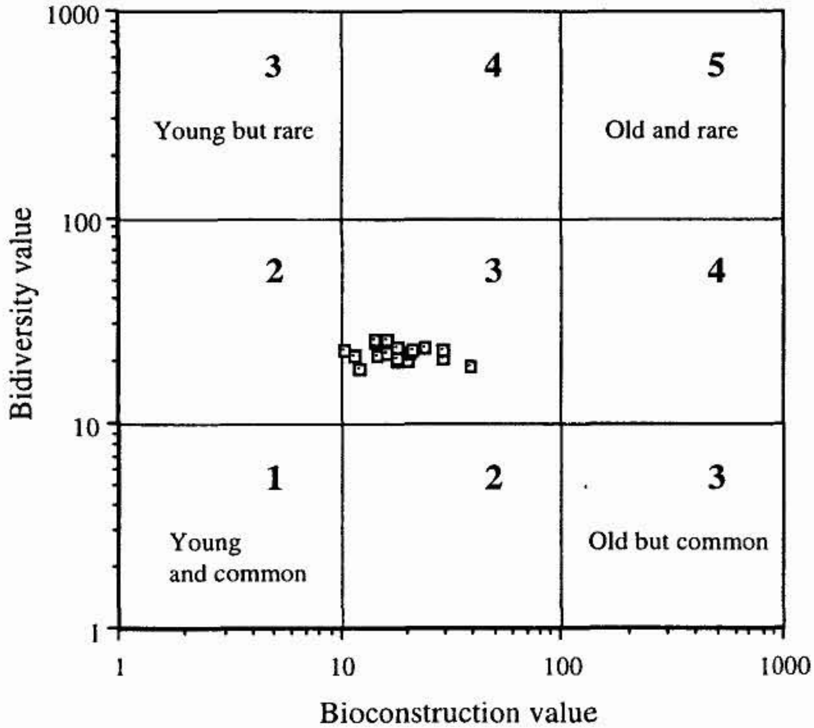



**Figure 4.** Suggested five point scale for reef value showing ranking of the Shoalwater Bay reefs. Done's joint criteria value is shown (1–5), combining biodiversity value with bioconstruction value based on age structure and the percent cover of the coral groups.

On the basis of these value rankings (table 6) the survey reefs can usefully be divided into three groups. Two reefs (Sun and Holt) are of above average value, three others (Five Trees, Collins, Clara) are of below average value, while the other 13 are of average value (the average range is taken as the mean ± one standard deviation: 2.41–3.65).

It is interesting to look at the relationships among the various reef attributes. There was a strong positive correlation between coral cover and the number of large corals ($r^2 = 0.65$), but no relationship between coral cover and mean colony age ($r^2 = 0.09$), or between coral cover and the number of species ($r^2 = 0.11$). Subjective aesthetics depended strongly on both coral cover ($r^2 = 0.84$), and the number of large corals ($r^2 = 0.53$), but not on the number of species ($r^2 = 0.08$), or the mean colony age ($r^2 = 0.01$), or on underwater visibility ($r^2 = 0.01$). The lack of relationship between aesthetics and underwater visibility is interesting given that we have always suspected there would be a positive relation between these two factors.

**Table 6.** Relative value of the Shoalwater Bay reefs. Reef attributes on a scale of 0–5 are shown to give each attribute equal value, along with a grand mean value for each reef. $V_b$ = biodiversity value; $V_w1$ = mean colony age; $V_w2$ = bioconstruction value based on percentage cover

| Reef | Coral cover | No. of species | $V_b$ | $V_w1$ | $V_w2$ | Corals > 100 cm | Aesthetics | Mean value |
|---|---|---|---|---|---|---|---|---|
| Sun Is. | 5.0 | 4.4 | 3.7 | 3.0 | 5.0 | 5.0 | 4.5 | **4.36** |
| Holt Is. | 4.1 | 4.7 | 4.5 | 2.1 | 3.7 | 4.1 | 3.0 | **3.74** |
| Unnamed Is. | 4.6 | 3.8 | 4.0 | 1.6 | 2.6 | 4.6 | 4.0 | **3.59** |
| Swan Is. | 3.9 | 4.5 | 4.0 | 2.2 | 2.3 | 4.4 | 3.5 | **3.54** |
| Edward Is. | 2.9 | 4.1 | 4.5 | 2.9 | 3.1 | 3.0 | 3.0 | **3.35** |
| Mumford Is. | 3.1 | 4.6 | 4.3 | 2.4 | 2.7 | 3.6 | 2.5 | **3.30** |
| Blind Rock | 4.1 | 4.3 | 4.8 | 2.0 | 1.8 | 1.8 | 3.5 | **3.20** |
| White Rocks | 3.3 | 4.2 | 4.1 | 2.1 | 2.3 | 3.1 | 3.0 | **3.16** |
| North Ripple Is. | 3.5 | 4.7 | 4.2 | 2.1 | 1.5 | 3.5 | 2.5 | **3.13** |
| Osborne Is. | 3.4 | 5.0 | 5.0 | 1.9 | 2.1 | 2.5 | 2.0 | **3.12** |
| Pearl Bay Gp. | 1.2 | 3.5 | 4.1 | 5.0 | 3.7 | 2.5 | 1.5 | **3.08** |
| Ten Pin Rock | 1.8 | 4.6 | 4.6 | 2.6 | 2.3 | 2.3 | 1.5 | **2.81** |
| Bay Is. | 2.5 | 4.8 | 4.1 | 2.3 | 1.9 | 2.5 | 1.5 | **2.81** |
| Connor Rock | 2.6 | 3.1 | 4.4 | 2.6 | 2.7 | 0.8 | 3.0 | **2.74** |
| Lingham Is. | 1.6 | 4.8 | 4.5 | 1.9 | 1.4 | 1.4 | 1.5 | **2.44** |
| Five Trees Cay | 1.8 | 3.2 | 4.3 | 2.1 | 2.1 | 1.3 | 1.0 | **2.24** |
| Collins Is. | 1.2 | 3.6 | 3.6 | 2.5 | 1.6 | 1.3 | 1.0 | **2.10** |
| Clara Is. | 0.6 | 2.0 | 5.0 | 2.1 | 1.9 | 0.3 | 1.0 | **1.83** |

## DISCUSSION

The Shoalwater Bay area is a harsh environment for coral to live in. The tidal range during spring tides is around seven metres, currents are strong, and the water is normally turbid from stirred up silt. Mean visibility during this survey, during which we experienced mainly good weather, was just over five metres. Visibility was highest around the north-east sector reefs (seven to nine metres), which were visited during calm weather. When winds were 20 knots or more resuspended silt reduced visibility to two metres or less. The reefs were not true reefs, the corals growing on rocks or rubble banks in most cases, and only rarely extended deeper than about five metres below AHD. Dense macro algal forests were found over the entire depth range of hard substratum, even on North Ripple Island where hard substratum extended down to about 10 metres below AHD.

A comparison of coral cover on the Shoalwater Bay reefs with other areas in the Great Barrier Reef region is interesting (table 7). Hard coral cover on these reefs was generally lower than that recorded during previous fringing reef surveys from the Great Barrier Reef region, with the exception of those other reefs that, like the Shoalwater Bay reefs, lie within the area between Mackay and Port Clinton where the maximum tide range is greater than five metres. Van Woesik (1992) surveyed a large number of sites within this area and recorded coral cover values ranging from 5.3% around Percy Isles to 41% around Prudhoe Island. Most reefs in this area were algal dominated. Although the Shoalwater Bay reefs lie at the heart of this strong tide area, the coral cover we recorded was at the upper end of that recorded by van Woesik (1992) from 12 other locations within this area. The Shoalwater Bay grand mean coral cover of 38% was about twice the grand mean from van Woesik's locations of 19% cover. Coral cover from the Keppel Islands to the south of this strong tide area is comparable to that from the other fringing reefs to the north of this area (table 7). Hence, it is likely that the strong tidal currents and resulting silt movement are the major factor responsible for the low coral cover in this area, rather than lower sea temperatures.

**Table 7.** Summary of hard coral cover on Great Barrier Reef fringing reefs. Figures show grand mean percentage cover from groups of 20-metre line transects. [1] Ayling et al. 1997; [2] Ayling and Ayling 1991a; [3] Ayling and Ayling 1995a; [4] Kaly et al. 1993; [5] Ayling and Ayling 1995b; [6] Ayling and Ayling 1996; [7] van Woesik 1992, na = not available.

| Region | Date | Latitude °S | No. sites | Hard coral cover mean | Hard coral cover sd |
|---|---|---|---|---|---|
| Cape Flattery[1] | Feb 1996 | 14.9 | 5 | **46.2** | 12.2 |
| Cape Tribulation[2] | Nov 1995 | 16.0 | 12 | **60.0** | 12.5 |
| Cairns Section Nth[3] | Jan 1995 | 16.5 | 34 | **81.0** | 7.5 |
| Magnetic Island[4] | Aug 1993 | 19.2 | 36 | **48.4** | 18.8 |
| Middle Reef[4] | Aug 1993 | 19.2 | 5 | **74.6** | 3.9 |
| Hamilton Island[5] | Mar 1995 | 20.3 | 6 | **54.4** | 5.7 |
| Sir James Smith Gp.[7] | 1991 | 20.7 | 56 | **22.0** | na |
| Northumberland Is.[7] | 1991 | 21.5 | 20 | **11.7** | na |
| Shoalwater Bay[6] | Dec 1995 | 22.3 | 34 | **37.8** | 16.2 |
| Keppel Islands[7] | 1991 | 23.2 | 8 | **54.3** | na |

Biodiversity, recorded as the number of coral species encountered at each location, was also lower on the Shoalwater Bay reefs than on most other Great Barrier Reef region fringing reefs. A combined total of only 87 species were recorded over 25 hours of diving in the Shoalwater Bay region, compared with 131 species recorded during two hours of diving around Dent Island in the Whitsunday Group of Islands (Ayling and Ayling 1995b), 120 species from 30 hours of diving on 17 Cairns Section fringing reefs (Ayling and Ayling 1995a), and 143 species from 10 hours of diving around Cape Tribulation fringing reefs (Veron 1987). The number of coral species at each location was also lower than in other areas. In Shoalwater Bay the coral species recorded at each location ranged from 23–58, compared with 35–96 from 17 locations in the Cairns Section, 131 from one location at Dent Island and 93 from one location at Hamilton Island (Ayling and Ayling 1995c). The number of coral species from Shoalwater Bay was, however, comparable to the approximately 90 species recorded from the Keppel Islands by van Woesik (1992).

The biodiversity value proposed by Done (1995) provides a measure of the uniqueness of each reef in a regional context, in this case the Great Barrier Reef region; defining the reefs value in terms of the proportion of unique or rare species that occur there. This uniqueness value was similar for most of the survey reefs because most of the regionally rare species were common throughout the Shoalwater Bay area, and hence it did not provide much guidance for managers in ranking reefs within the Shoalwater Bay area. To look at relative value among the Shoalwater Bay locations the region would need to be redefined as Shoalwater Bay and relative rareness set within this smaller region. This would defeat the purpose of the index, as one-off records of species such as *Acropora tenuis*, *A. millepora* and *Podabacia crustacea* that were rare and unimportant in the Shoalwater Bay area but extremely common on most Great Barrier Reef reefs, would have a disproportionate effect on the biodiversity value compared with common species such as *A. glauca* and *A. solitaryensis* that were very important to managers, being rare on most of the Great Barrier Reef. While the Done biodiversity value may give a ranking of relative value in a Great Barrier Reef wide context this does not necessarily help managers to rank value within a smaller area such as Shoalwater Bay.

In terms of biodiversity and species composition it is the common presence of a number of southern species that are common on fringing reefs south of the Great Barrier Reef region and on southern reefs such as Lord Howe Island, but normally rare on the Great Barrier Reef, that makes these reefs of value to managers. Similarly, the complete absence of a number of groups that are usually common on reefs in other areas is a point of value to managers; it makes these reefs unusual and unique, and suggests that representative examples should be preserved. It is interesting to compare the species composition of the Shoalwater Bay reefs with those from the Keppel Islands and the Northumberland Islands. Van Woesik (1992) records *Acropora glauca* and *A. solitaryensis* from the Keppels but not *Acanthastrea hillae* or *A. bowerbanki*. In terms of species absences he also does not list any *Echinopora*, *Pectinia*, *Merulina*, or *Oxypora* species, but he does record *Fungia* spp. and *Pavona venosa*. In the Northumberland Islands all of the species notably absent in Shoalwater Bay are recorded from at least some sites.

Done (pers. comm.) has suggested that it was his intention that the bioconstruction value be sensitive to the area covered by the various age classes, rather than just reflecting mean age. Hence the value based on proportion of individuals, that gives an approximation of mean colony age, is not a good measure of bioconstruction value. We have maintained the measure of colony age in this report, and as part of the reef ranking process, because we feel it offers another useful piece of information for reef managers.

The percentage cover based bioconstruction value proposed by Done gave a measure of bioconstruction for each reef that was positively correlated to a direct count of large coral colonies from the same reef ($r^2 = 0.31$). Within the Shoalwater Bay area two reefs (Sun and Holt) stood out as having a relatively high bioconstruction value. There were a few cases where the bioconstruction value did not seem to relate to the state of the reef. The Pearl Bay reefs, with a coral cover of only 16.5%, had a bioconstruction value well above that of all other reefs except Sun Island and Holt Island, because coral cover at this location was dominated by a few large, old colonies. While it is true that the time for replacement of such a community is high, it is hard to see the use of ranking it above reefs such as North Ripple that have over 40% coral cover, and a larger number of colonies over 100 centimetres in size, but have a low bioconstruction value because most of the corals are relatively young. Similarly, Clara Island, in spite of having only 7% coral cover and a very few colonies over 100 centimetres, had only the fifth lowest bioconstruction value. The problem here seems to be that while the time for replacement of a community with only a few old colonies is greater than one with large numbers of young colonies the bioconstruction value of lots of small colonies may be equal to or greater than a very few large colonies, but this is not taken into account using Done's measure. However, on the whole this value did appear to provide a useful value ranking for the survey reefs.

Although our measure of mean colony age gives an underestimate due to bias in the size frequencies constructed from the line intersect data, it is clear that mean age of corals on the Shoalwater Bay reefs was low. Our biased estimate of grand mean age was only 12.4 years (excluding Pearl Bay). This suggests either that these reefs are subjected to major disturbance on a relatively short return period, or that the corals are growing very slowly as a result of high siltation rates, low water clarity and/or low temperatures. Cyclones could cause extensive damage in these shallow waters, both from wave action and from flooding and silt resuspension, and the relatively enclosed shallow waters of Shoalwater Bay are probably conducive to surface water warming and hence major bleaching events. The relative lack of exceptionally large coral colonies which are usually a feature of fringing reefs (Ayling and Ayling 1995a) also suggests that the reefs are subject to regular disturbance. Assuming normal growth rates, the oldest coral we measured in Shoalwater Bay was probably only between 100 and 200 years old. The largest massive poritid measured during this survey was only around two and a half metres diametre; heads of over five metres diametre are frequently encountered in other fringing reef areas. Acroporids over 10 metres across are also frequently encountered on fringing reefs in other areas, whereas in Shoalwater Bay we only measured 16 acroporid colonies over five metres diametre and only one of around 10 metres across. Colonies of *Goniopora* species over five metres across are also usually frequently encountered on fringing reefs, but none over two metres were measured on these survey reefs. There were many large corymbose plate and tabulate acroporids between one to five metres in diameter on the north-east sector Shoalwater Bay reefs. While large tabulate colonies are a conspicuous feature of many Central and Capricorn Section offshore reefs they are not usually so abundant on fringing reefs.

Our impression was that the Shoalwater Bay reefs were no more silty or turbid than fringing reefs in other areas we have surveyed. The occurrence of dense algal forests down to depths of about 10 metres below AHD also suggests that the water clarity in Shoalwater Bay is not unusually turbid compared with other fringing reefs; dense algal forests are rarely found below five metres depth on most fringing reefs. Corals on some extremely turbid fringing reefs, e.g. Middle Reef off Townsville, appear to grow at normal or above normal rates (Kaly et al. 1993), and it is unlikely that corals in Shoalwater Bay are growing at below normal rates for this reason. It is also unlikely that water temperatures are significantly lower in Shoalwater Bay than in the Whitsunday Island Group where fringing reef development is more 'normal'. While it is possible that these factors are slowing coral growth in the Shoalwater Bay area, it seems more likely that a high disturbance regime is responsible for the observed patterns.

The ranking of reef value within the Shoalwater Bay region was done by combining a number of reef attributes, and, at least subjectively, appeared to give a biologically meaningful and useful result. The wide range in the overall ranking value is interesting: the 18 reefs ranged from 1.83 to 4.36 on a scale of 0–5. This extreme variability has not been a feature in other surveys of fringing reefs. As an example, in the Cairns Section survey of 17 reefs, coral cover ranged from 65 to 93% (Ayling and Ayling 1995a), compared with 7–66% for this survey. Around Hamilton and Dent Islands coral cover at nine sites ranged from 32 to 71% (Ayling and Ayling 1991b), and on 12 sites in the Cape Tribulation region cover ranged from 40 to 74% (Ayling and Ayling 1991a). Similarly, aesthetic value on the Shoalwater Bay reefs ranged from 1 to 4.5 on a scale of 0-5. Although aesthetic estimates have not been made from other fringing reef surveys, my post-hoc opinion is that most would rate between three and five. This variability may result from the Shoalwater Bay area being marginal for the development of fringing reefs.

**Implications for Management**

The Great Barrier Reef Marine Park Authority was interested in determining the status of fringing reefs within the Shoalwater Bay and Byfield Coast area as a prerequisite for preparing a management plan for these areas. Although these reefs generally have less coral cover, lower biodiversity, and fewer large coral colonies than fringing reefs in regions of the Great Barrier Reef outside the strong tide region between Mackay and Port Clinton, they have a number of unique features, notably the abundance of a number of coral species that are rare or absent on the rest of the Great Barrier Reef (note that some of these species also occur on fringing reefs to the south of Shoalwater Bay such as around the Keppel Islands). Within the above mentioned strong tide area the Shoalwater Bay reefs appear to have a relatively high cover of corals. They are also unusual in the absence of many species that are common on most other fringing reefs. Thus although these reefs are generally not true reefs, and may be subject to high levels of disturbance, the reef type they represent is probably worthy of some protection.

It was suggested that some ranking of the reefs on values that would be meaningful for management would assist with this process. The value ranking we have provided could be used by managers in a number of ways. They might choose to protect the reefs with high or above average value, or they might choose clusters of reefs that incorporate the high value reefs along with other reefs with average or below average value.

Given that there were a number of differences in coral community composition between northern reefs (north of Collins Island) and southern reefs, it may be most appropriate to choose two clusters of reefs for protection. In the northern sector the adjacent reefs of Mumford, Ten Pin Rock, Holt and Unnamed includes one reef of above average value along with three average reefs. Note that it is reefs in this northern sector that include the greatest abundance of the unique *Acropora* species mentioned above. In the southern sector the cluster of Swan, Osborne, Sun and Clara includes the reef with the highest value, along with two average reefs and the lowest value reef.

Given the variability of the reefs in this region, and the suggestion that disturbance levels are high, the current value ranking is not likely to remain stable in the medium to long term and it may be prudent to include a variety of rankings in any protected areas.

While the Done biodiversity value gives a ranking of relative value within the larger Great Barrier Reef region, it did not appear to provide a very useful value ranking for reefs within a limited area such as Shoalwater Bay. Done's proposed bioconstruction value was more useful in this local context, although there were some cases where the calculated values seemed at variance with empirical estimates of reef value. Note that in future surveys of this type a more determined attempt should be made to collect data in a way that would make calculation of these values easier and less affected by biases. These methodological changes would almost certainly add considerably to field time on each reef but the increased value of the data may offset this. Trials would need to be made to check on the most cost effective methods to use.

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**APPENDIX 1. Summary of Abundance of Benthic Organisms from the Survey Reefs.**

Reefs are grouped into NE, NW, SW and SE sectors of Shoalwater Bay. Figures show mean percentage cover for each benthic group from two groups of five 20 m line intersect transects on each reef, along with standard deviations in italics, and the grand mean from each group of reefs. Reef abbreviations are from table 1.

**A. NE Sector Reefs.**

| Reef: | NR | | Ho | | Un | | Mu | | TP | | Grand mean | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Encrusting group | mean | *sd* | mean | *sd* | mean | *sd* | mean | *sd* | mean | *sd* | mean | *sd* |
| *Sargassum* spp. | 17.3 | *7.4* | 12.9 | *7.1* | 12.1 | *6.6* | 16.1 | *8.3* | 19.1 | *5.3* | 15.5 | *7.2* |
| Turfing algae | 20.9 | *6.2* | 22.7 | *5.9* | 21.1 | *6.9* | 23.4 | *3.4* | 28.5 | *8.5* | 23.3 | *6.7* |
| Seagrasses | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* |
| Sponges | 0.2 | *0.6* | 0.6 | *1.0* | 0.2 | *0.5* | 1.4 | 2.2 | 0.3 | *0.5* | 0.6 | *1.2* |
| Total hard coral | 46.2 | *18.5* | 53.8 | *12.2* | 60.7 | *13.4* | 41.2 | *10.9* | 24.0 | *7.1* | 45.2 | *17.7* |
| Pocilloporidae | 2.4 | *2.0* | 3.0 | *2.6* | 0.6 | *1.0* | 11.4 | *4.5* | 2.4 | *1.6* | 2.2 | *2.4* |
| Acroporidae | 35.3 | *20.5* | 31.2 | *9.2* | 55.0 | *15.2* | 6.1 | *6.0* | 8.7 | *5.4* | 29.5 | *20.2* |
| *Montipora* | 17.6 | *13.8* | 17.7 | *6.3* | 20.4 | *7.3* | 2.6 | *3.6* | 5.2 | *2.6* | 14.5 | *9.4* |
| *Acropora* | 17.7 | *11.7* | 13.5 | *7.1* | 34.6 | *17.6* | 17.5 | *7.1* | 3.4 | *2.6* | 15.1 | *15.0* |
| Poritidae | 1.4 | *1.6* | 1.5 | *1.4* | 0.6 | *1.3* | 2.5 | *1.4* | 0.5 | *0.5* | 1.3 | *1.4* |
| Siderastreidae | 0.9 | *1.6* | 2.1 | *1.8* | 0.1 | *0.2* | 0.5 | *0.7* | 0.8 | *1.7* | 0.8 | *1.5* |
| Mussidae | 0.4 | *0.6* | 0.3 | *0.7* | 0.2 | *0.3* | 1.1 | *2.5* | 0.5 | *0.5* | 0.5 | *1.2* |
| Faviidae | 3.8 | *3.2* | 3.5 | *2.8* | 2.6 | *2.1* | 6.7 | *2.8* | 4.0 | *2.9* | 4.1 | *3.0* |
| Dendrophylliidae | 1.4 | *1.7* | 11.8 | *13.5* | 1.3 | *1.4* | 9.3 | *6.5* | 5.3 | *5.4* | 5.8 | *8.1* |
| Total soft coral | 4.2 | *4.0* | 4.1 | *3.9* | 2.2 | *2.5* | 2.1 | *2.1* | 1.7 | *1.4* | 2.9 | *3.0* |

**B. NW Sector Reefs.**

| Reef: | Co | | FT | | Li | | WR | | Grand mean | |
|---|---|---|---|---|---|---|---|---|---|---|
| Encrusting group | mean | *sd* | mean | *sd* | mean | *sd* | mean | *sd* | mean | *sd* |
| *Sargassum* spp. | 24.8 | *5.7* | 24.0 | *8.4* | 31.3 | *4.1* | 19.8 | *6.4* | 25.0 | *7.4* |
| Turfing algae | 16.3 | *4.0* | 17.5 | *5.5* | 14.0 | *2.2* | 22.6 | *5.5* | 17.6 | *5.4* |
| Seagrasses | 0.7 | *1.4* | 0.0 | *0.0* | 7.1 | *8.1* | 0.6 | *1.7* | 2.1 | *5.0* |
| Sponges | 1.2 | *1.2* | 0.8 | *1.6* | 0.3 | *0.4* | 0.5 | *0.7* | 0.7 | *1.1* |
| Total hard coral | 16.1 | *6.4* | 23.2 | *9.6* | 21.6 | *6.8* | 43.1 | *11.2* | 26.0 | *13.3* |
| Pocilloporidae | 0.5 | *0.7* | 2.3 | *1.7* | 2.1 | *1.2* | 1.4 | *1.9* | 1.6 | *1.6* |
| Acroporidae | 5.9 | *5.7* | 9.1 | *6.6* | 9.7 | *5.1* | 21.0 | *9.7* | 11.4 | *8.9* |
| *Montipora* | 4.7 | *4.3* | 6.3 | *6.7* | 6.5 | *3.7* | 8.2 | *5.3* | 6.4 | *5.1* |
| *Acropora* | 1.2 | *2.3* | 2.8 | *2.7* | 3.2 | *3.9* | 12.8 | *8.1* | 5.0 | *6.5* |
| Poritidae | 2.1 | *2.5* | 1.0 | *1.1* | 2.4 | *1.7* | 0.7 | *1.0* | 1.6 | *1.8* |
| Siderastreidae | 0.2 | *0.5* | 0.7 | *1.0* | 1.1 | *1.2* | 1.4 | *1.5* | 0.9 | *1.2* |
| Mussidae | 0.0 | *0.0* | 0.4 | *0.7* | 0.1 | *0.2* | 0.9 | *1.5* | 0.3 | *0.9* |
| Faviidae | 2.4 | *1.7* | 3.3 | *2.2* | 3.4 | *2.0* | 5.3 | *2.4* | 3.6 | *2.3* |
| Dendrophylliidae | 4.7 | *3.1* | 5.7 | *3.2* | 2.0 | *2.3* | 11.0 | *6.4* | 5.8 | *5.1* |
| Total soft coral | 2.6 | *2.0* | 1.8 | *1.4* | 1.2 | *1.0* | 2.2 | *2.2* | 2.0 | *1.7* |

### C. SW Sector Reefs.

| Reef: Encrusting group | Os mean | Os sd | Cl mean | Cl sd | Sw mean | Sw sd | Sn mean | Sn sd | Ed mean | Ed sd | Grand mean mean | Grand mean sd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sargassum* spp. | 20.0 | *8.0* | 42.0 | *7.9* | 22.0 | *5.9* | 17.0 | *12.3* | 20.6 | *7.8* | 24.3 | *12.3* |
| Turfing algae | 17.9 | *3.2* | 16.0 | *8.4* | 7.4 | *3.0* | 7.9 | *1.9* | 19.6 | *5.6* | 13.7 | *7.0* |
| Seagrasses | 0.0 | *0.0* | 17.7 | *20.1* | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* | 3.5 | *11.2* |
| Sponges | 0.6 | *0.5* | 0.2 | *0.3* | 0.3 | *0.5* | 0.1 | *0.3* | 0.2 | *0.4* | 0.3 | *0.4* |
| Total hard coral | 44.8 | *8.6* | 7.3 | *4.9* | 51.2 | *9.6* | 66.2 | *21.1* | 38.2 | *10.1* | 41.5 | *22.9* |
| Pocilloporidae | 1.1 | *1.0* | 0.3 | *0.7* | 0.9 | *1.2* | 0.8 | *1.0* | 0.8 | *0.6* | 0.8 | *0.9* |
| Acroporidae | 25.1 | *9.8* | 1.7 | *2.7* | 38.1 | *11.7* | 51.4 | *21.3* | 18.1 | *7.7* | 26.9 | *20.8* |
| *Montipora* | 16.4 | *6.1* | 1.7 | *2.7* | 33.1 | *11.2* | 44.1 | *25.1* | 14.4 | *6.7* | 21.9 | *19.5* |
| *Acropora* | 8.6 | *6.9* | 0.0 | *0.0* | 5.0 | *6.8* | 7.4 | *7.2* | 3.7 | *3.4* | 4.9 | *6.2* |
| Poritidae | 1.6 | *1.4* | 1.1 | *1.4* | 2.3 | *2.8* | 1.2 | *1.2* | 2.0 | *2.3* | 1.6 | *1.9* |
| Siderastreidae | 1.3 | *0.9* | 0.1 | *0.2* | 1.1 | *1.3* | 0.6 | *1.0* | 1.1 | *1.5* | 0.8 | *1.1* |
| Mussidae | 1.2 | *2.0* | 0.1 | *0.3* | 0.2 | *0.4* | 0.0 | *0.0* | 0.0 | *0.0* | 0.3 | *1.0* |
| Faviidae | 3.8 | *3.6* | 1.3 | *1.4* | 2.4 | *1.4* | 3.2 | *2.5* | 5.1 | *3.3* | 3.2 | *2.8* |
| Dendrophylliidae | 9.7 | *5.4* | 2.7 | *1.9* | 5.8 | *3.0* | 8.4 | *9.1* | 9.7 | *5.4* | 7.3 | *5.9* |
| Total soft coral | 5.3 | *2.7* | 3.5 | *2.8* | 1.8 | *1.2* | 0.8 | *1.2* | 8.2 | *4.6* | 3.9 | *3.8* |

### D. SE Sector Reefs.

| Reef: Encrusting gp. | Ba mean | Ba sd | Cn mean | Cn sd | Bl mean | Bl sd | Grand mean mean | Grand mean sd | PB mean | PB sd |
|---|---|---|---|---|---|---|---|---|---|---|
| *Sargassum* spp. | 17.3 | *6.1* | 11.1 | *4.5* | 0.0 | *0.0* | 11.4 | *8.6* | 28.3 | *14.1* |
| Turfing algae | 14.4 | *2.5* | 23.6 | *5.5* | 8.8 | *1.6* | 15.3 | *6.3* | 17.7 | *4.1* |
| Seagrasses | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* | 0.0 | *0.0* |
| Sponges | 0.3 | *0.8* | 0.4 | *0.5* | 1.6 | *1.0* | 0.6 | *0.9* | 1.3 | *1.8* |
| Total hard coral | 32.7 | *13.1* | 34.3 | *12.9* | 54.8 | *14.6* | 38.6 | *15.9* | 16.5 | *10.8* |
| Pocilloporidae | 1.1 | *1.1* | 1.1 | *1.1* | 0.2 | *0.2* | 0.9 | *1.0* | 2.8 | *4.6* |
| Acroporidae | 16.1 | *6.3* | 10.6 | *11.6* | 25.8 | *13.3* | 17.1 | *10.8* | 2.9 | *3.8* |
| *Montipora* | 13.8 | *5.3* | 6.9 | *6.7* | 18.4 | *9.5* | 13.2 | *7.7* | 2.9 | *3.8* |
| *Acropora* | 2.3 | *3.2* | 3.7 | *5.2* | 7.4 | *11.4* | 3.9 | *4.4* | 0.0 | *0.0* |
| Poritidae | 2.0 | *1.6* | 1.6 | *2.0* | 2.8 | *3.7* | 2.1 | *2.3* | 2.6 | *4.3* |
| Siderastreidae | 1.6 | *1.9* | 2.5 | *1.6* | 3.9 | *1.9* | 2.4 | *2.0* | 0.7 | *1.2* |
| Mussidae | 0.1 | *0.1* | 0.8 | *0.8* | 0.7 | *1.0* | 0.4 | *0.7* | 0.1 | *0.3* |
| Faviidae | 3.9 | *3.3* | 6.7 | *3.0* | 10.4 | *3.6* | 6.2 | *4.1* | 1.6 | *2.4* |
| Dendrophylliidae | 6.9 | *8.8* | 9.0 | *3.3* | 9.7 | *4.8* | 8.1 | *6.7* | 5.7 | *3.0* |
| Total soft coral | 9.1 | *5.0* | 15.3 | *4.4* | 24.4 | *6.6* | 14.5 | *8.1* | 0.9 | *2.6* |

## APPENDIX 2. Shoalwater Bay Fringing Reef Hard Coral Species Lists.

Table lists species recorded during surveys of ten 20 m transects, plus those seen during a 30 min haphazard swim covering the depth range present in the survey areas. X - indicates species present at that location; a number indicates number of species recorded in a genus or group. For location abbreviations see table 1. Note: R indicates species that are rare in the GBR region.

| Location: | PB | NR | Ho | Un | Mu | TP | FT | Co | Li | WR | Os | Cl | Sw | Sn | Ed | Ba | Cn | Bl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total No. Species** | **41** | **55** | **55** | **44** | **53** | **53** | **37** | **42** | **56** | **49** | **58** | **23** | **52** | **51** | **48** | **56** | **36** | **50** |
| **FAMILY - Species:** | | | | | | | | | | | | | | | | | | |
| POCILLOPORIDAE | | | | | | | | | | | | | | | | | | |
| *Pocillopora damicornis* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Seriatopora hystrix* | | X | X | X | X | X | X | X | X | | | | | X | | | | X |
| *Stylophora pistillata* | | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| ACROPORIDAE | | | | | | | | | | | | | | | | | | |
| *Montipora* (no. species) 2R | 3 | 8 | 6 | 5 | 5 | 6 | 4 | 4 | 6 | 5 | 6 | 3 | 6 | 7 | 6 | 6 | 4 | 6 |
| *Acropora palifera* | | X | X | X | X | X | | | | | | | | | | | | |
| *A. brueggemanni* | | | | | | X | | | X | | | | | | | | | |
| *A. samoensis* R | | | X | | | X | | | X | | X | | | X | | | | |
| *A. digitifera* | | | X | | | | | | | | | | | | | | | |
| *A. glauca* R | | X | X | X | X | X | X | X | | X | X | X | | X | X | | X | X |
| *A. nobilis* | | X | X | X | | | | | | X | | | | | | X | | |
| *A. formosa* | | | X | X | | X | | | X | | X | | X | X | | X | | |
| *A. microclados* | | | X | X | | X | | | | | | | | X | | | | |
| *A. latistella* | | | X | | X | | | X | X | X | X | | | | | | | X |
| *A. millepora* | | | | | | | | | | | X | | | | | | | |
| *A. tenuis* | | | | | X | | | | | | | | | | | | | |
| *A. cytherea* | | X | X | X | X | X | | | | X | X | | | | X | | X | X |
| *A. hyacinthus* | | X | X | X | | X | | | | | | | | | | | | |
| *A. subulata* | | | X | | X | X | | | X | X | X | | | | | X | | X |
| *A. cerialis* | | | | | | | | | | | | | | X | X | X | | |
| *A. nasuta* | | X | | X | X | X | | | | X | X | | | | | | | |
| *A. valida* | X | X | X | X | X | X | | | X | X | X | | X | X | X | X | | |
| *A. divaricata* | X | X | X | X | X | X | | | X | X | | | | X | X | | | X |
| *A. secale* | | | X | | | | | | | | | | | | | | | |
| *A. paniculata* R | | X | X | | X | X | | | | | | | | | | | | |
| *A. solitaryensis* R | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *A.streopora myriophthalma* | | X | | | X | X | X | X | X | X | X | | | | X | | X | X |
| PORITIDAE | | | | | | | | | | | | | | | | | | |
| *Porites* massive (no. species) | 2 | 1 | 1 | | 1 | | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 |
| *P. lichen* | | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| *Goniopora* (no. species) | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 4 | 3 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 4 |
| *Alveopora* (no. species) | | | | | 1 | | | | 1 | 1 | 2 | | 2 | 1 | 1 | 2 | | |
| SIDERASTREIDAE | | | | | | | | | | | | | | | | | | |
| *Psammocora contigua* | | X | X | | | | | | | | | | X | | | X | | |
| *P. superficialis* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Coscinarea columna* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| AGARICIIDAE | | | | | | | | | | | | | | | | | | |
| *Pachyseris speciosa* | | | | | X | X | | | | | X | | X | X | X | X | | |
| FUNGIIDAE | | | | | | | | | | | | | | | | | | |
| *Podabacia crustacea* | | | | | | | | | X | | X | | | X | | | | |
| OCULINIDAE | | | | | | | | | | | | | | | | | | |
| *G. fascicularis* | X | | X | | | | | X | | | | | X | X | X | X | | |
| PECTINIIDAE | | | | | | | | | | | | | | | | | | |
| *Echinophyllia aspera* | X | | | | X | | | | X | | | | | X | X | | | |
| *E. orpheensis* | | | | | | | | | X | | | | X | | | X | | |
| *Mycedium elephantotus* | | X | X | X | X | X | | | X | X | X | | X | X | X | X | X | X |

| Location: | PB | NR | Ho | Un | Mu | TP | FT | Co | Li | WR | Os | Cl | Sw | Sn | Ed | Ba | Cn | Bl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FAMILY - Species:** | | | | | | | | | | | | | | | | | | |
| MUSSIDAE | | | | | | | | | | | | | | | | | | |
| *Acanthastrea echinata* | | X | X | | | | | | | | X | | | | | | | |
| *A. hillae* R | X | X | X | X | X | X | X | | X | X | X | | | | X | X | | X |
| *A. bowerbanki* R | X | X | X | X | X | X | X | | X | X | X | | X | | | X | | X |
| *Lobophyllia hemprichii* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *L. corymbosa* | | | | | | | | | | | | | X | | | | | |
| MERULINIDAE | | | | | | | | | | | | | | | | | | |
| *Hydnophora exesa* | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| *H. microconus* | X | X | | X | | | | | | X | | | | | | | | |
| FAVIIDAE | | | | | | | | | | | | | | | | | | |
| *Favia* (no. species) 1R | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 5 | 5 | 4 | 2 | 3 | 3 | 3 | 4 | 3 | 5 |
| *Favites* (no. species) | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 3 | | 1 | 1 | 2 | 3 | 2 | 3 |
| *Goniastrea* (no. species) | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | | 1 | 1 | 3 | 2 | 1 | 1 |
| *Platygyra* (no. species) | 3 | 3 | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 |
| *Leptoria phrygia* | X | | | | | | | | | | | | | | | | | |
| *Plesiastrea versipora* R | X | | X | | X | X | | X | X | | X | X | X | | X | X | X | X |
| *Leptastrea transversa* | X | | | X | X | X | | X | X | | X | X | X | X | X | X | | X |
| *Cyphastrea serailia* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Moseleya latistellata* | X | X | X | | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| CARYOPHYLLIIDAE | | | | | | | | | | | | | | | | | | |
| *Euphyllia ancora* | X | X | | | | X | | X | X | | X | | X | | | X | | X |
| *E. glabrescens* | | X | X | | X | | | | | | | | X | | | X | | |
| *E. divisa* | | | | | | | | | X | X | X | | X | X | | X | | |
| *E. cristata* | | | | | | | | | | | | | X | X | | | | |
| DENDROPHYLLIIDAE | | | | | | | | | | | | | | | | | | |
| *Turbinaria peltata* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *T. patula* R | X | | | | | | | | X | | X | | X | | X | X | X | X |
| *T. frondens* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *T. mesenterina* | X | | | | | | | X | | | | | X | | | | | |
| *T. stellulata* | X | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X |
| *T. bifrons* R | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

**APPENDIX 3. Colour Scenes from the Shoalwater Bay Fringing Reefs.**

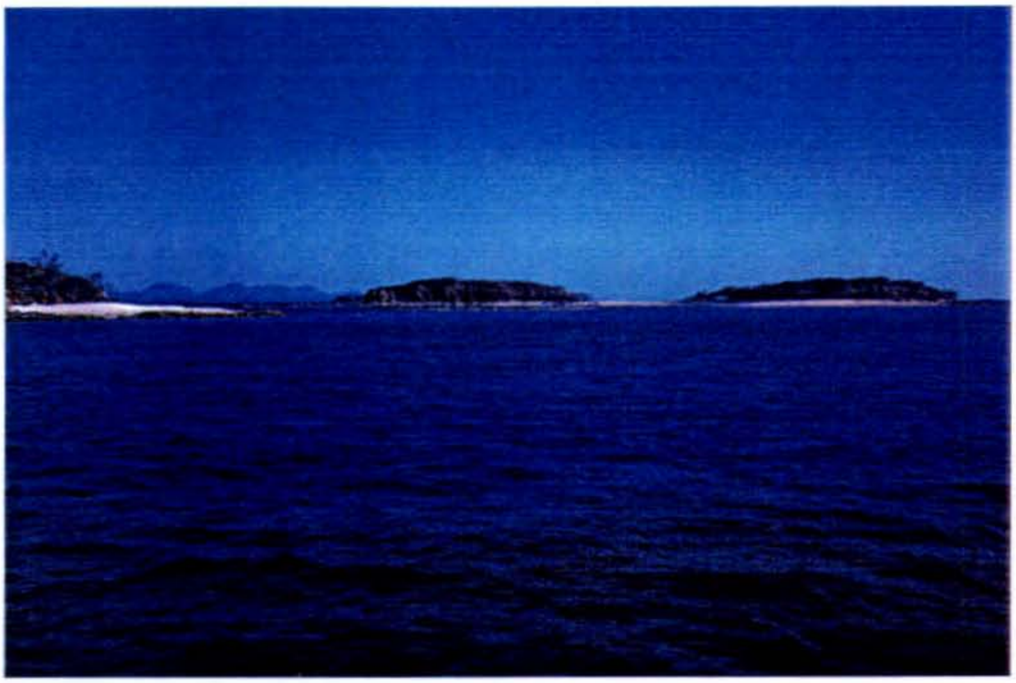

**Plate 1.** Mumford Island is typical of most of the islands in Shoalwater Bay being made up of a series of granite/basalt islets with small beaches and relatively low diversity fringing reef coral communities

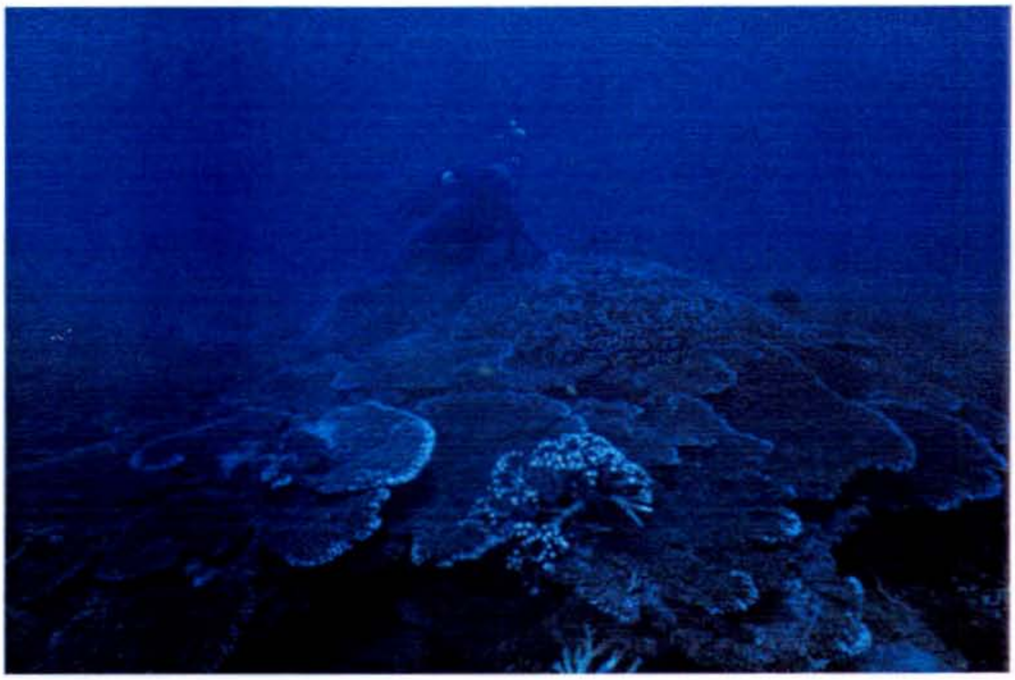

**Plate 2.** Like most of the fringing reefs in north-east Shoalwater Bay, Reef 22-047 had relatively clear water with good coral cover, composed mainly of plating and staghorn *Acropora* species. Aesthetic value of these north-east reefs was generally high.

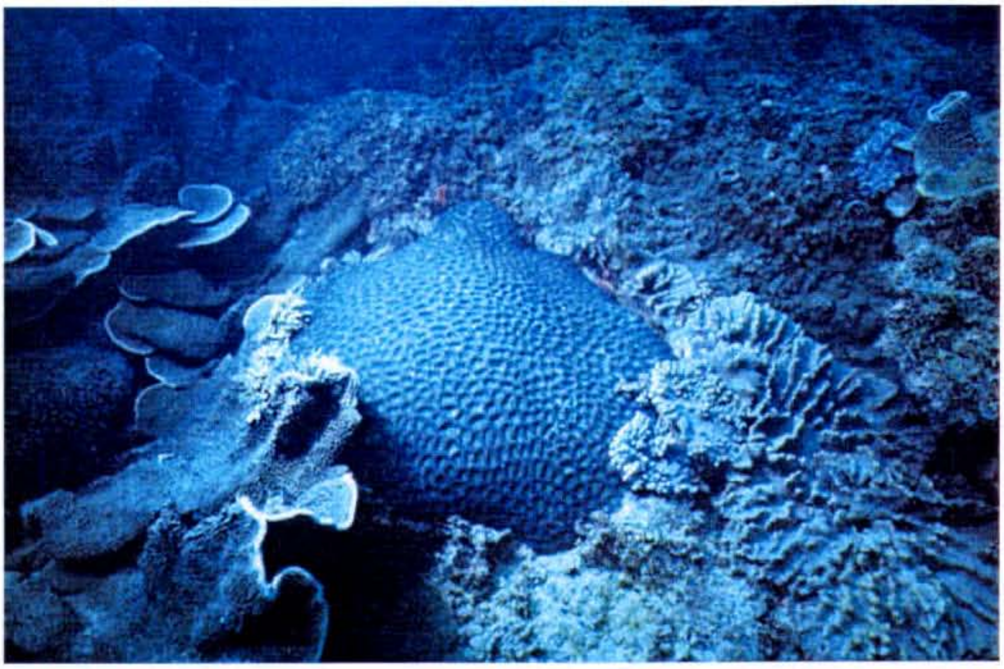

**Plate 3.** *Acanthastrea hillae*. Members of the coral genus *Acanthastrea* were conspicuous and common on Shoalwater Bay reefs, but are usually found in temperate waters south of the Great Barrier Reef

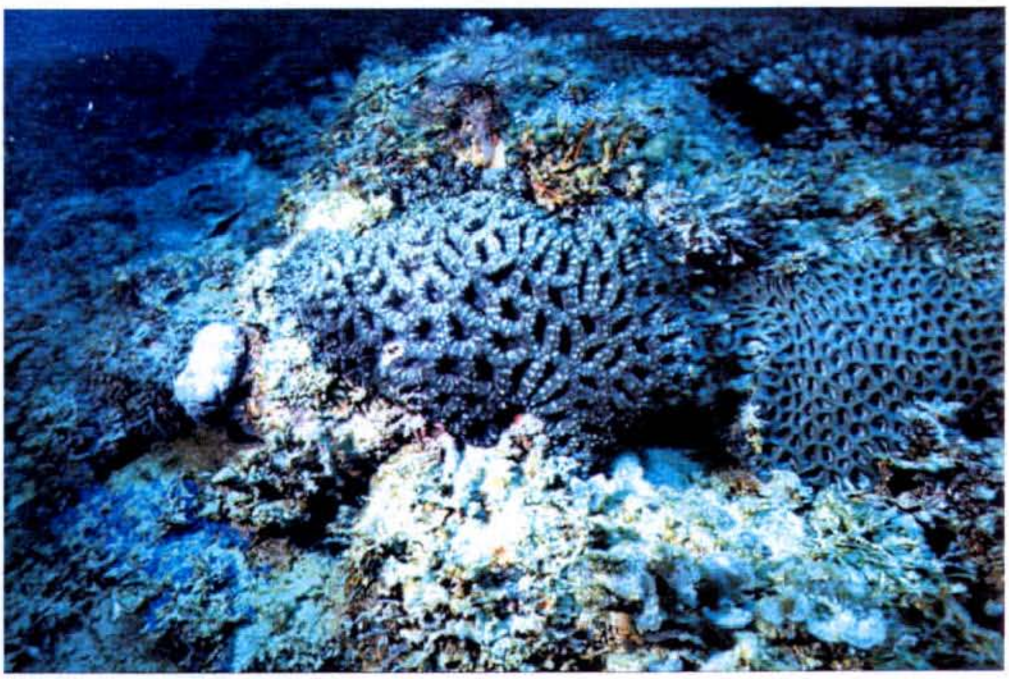

**Plate 4.** *Acanthastrea bowerbanki* is considered rare, except at Lord Howe Island, but was common on Shoalwater Bay reefs

**Plate 5.** Colonies of the corymbose-plating *Acropora glauca* were common at most sites in Shoalwater Bay, but are considered extremely rare on the Great Barrier Reef

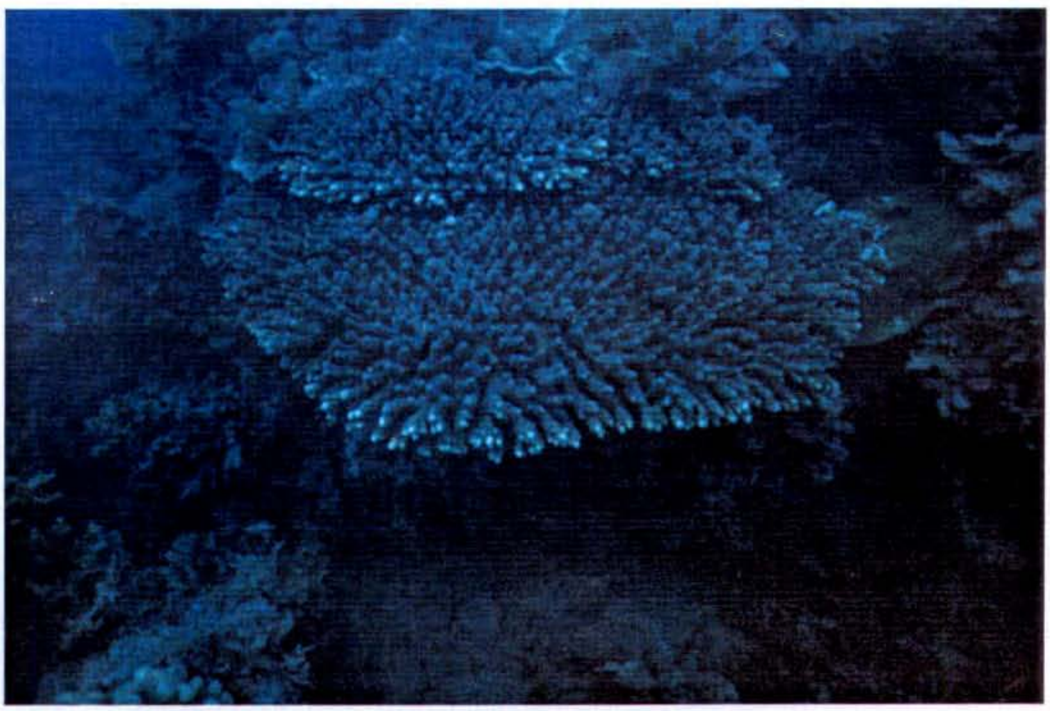

**Plate 6.** *Acropora solitaryensis*. This species is also considered extremely rare on the Great Barrier Reef, but occurred at most sites in Shoalwater Bay

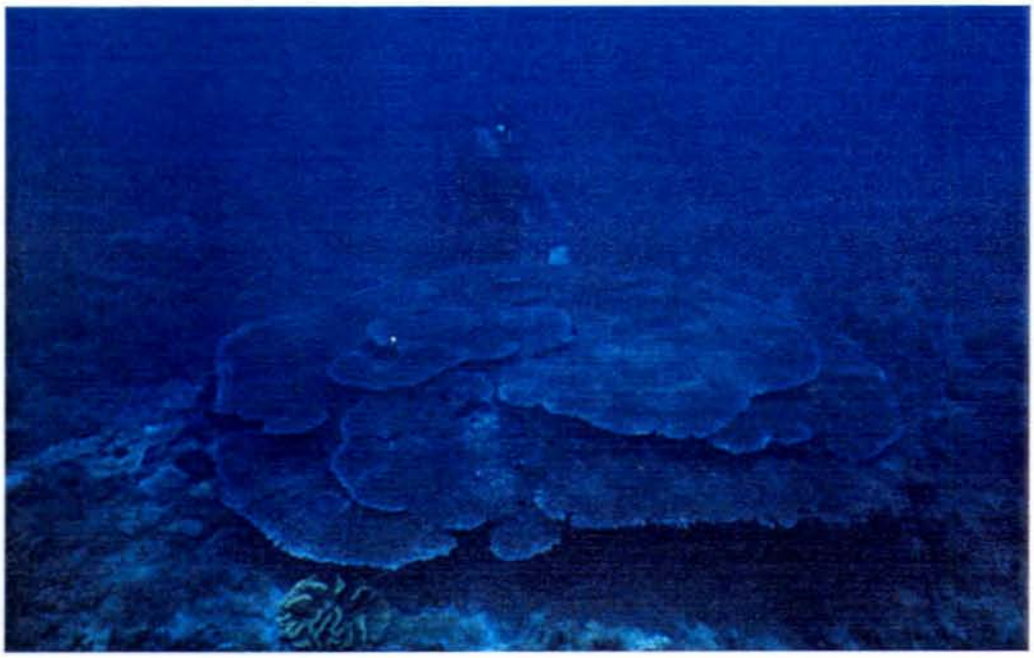

**Plate 7.** Fringing reefs in the northern Cannibal group are dominated by corymbose plate-forming acroporas. Plates up to 4.9 metres in diameter were recorded.

**Plate 8.** Lingham Island. Fringing reefs in the southern Cannibal group were dominated by macroalgae on hard substrates and by seagrass on soft substrates with a patchy distribution of corals, including this species, *Turbinaria bifrons*.