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Port Curtis Reef Assessment

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Port Curtis
Reef Assessment – Final Report

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Title :	Port Curtis Reef Assessment – Final Report
Author :	Darren Richardson, Beth Hastie, Craig Morgan
Synopsis :	A technical report detailing the findings of field surveys of reef habitats within Port Curtis. This study considers the habitat characteristics and benthic communities of the Port Curtis area.

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1 INTRODUCTION

1.1 Background

Queensland Gas Company (QGC) is currently preparing environmental investigations and environmental impact assessments to inform their proposed dredging and dredged material disposal activities within and adjacent to Port Curtis. QGC have identified that the potential effect of turbid plumes generated by dredging and dredged material disposal activities on sensitive environmental receptors is a key environmental management issue.

In order to gain an understanding of potential environmental impacts of dredging activities, there is a need to first map and characterise potential environmental receptors within the zone of influence of dredging activities. Seagrasses have been identified as key sensitive environmental receptors within the port area, and studies are in progress to assess potential impacts on seagrass meadows. While many marine plant and animal species may be directly and indirectly impacted by turbid plumes, it is generally acknowledged that in tropical environments, hard corals represent key sensitive environmental receptors given their sensitivity to light deprivation and increased rates of sedimentation.

There is presently little information on the distribution of reef habitats in Port Curtis or the structure of communities that inhabit these reefs. Queensland DPI&F (Rasheed *et al*. 2001) has undertaken surveys of deepwater benthic communities; however the nature of reef communities in intertidal and shallow sub littoral was not examined. GBRMPA has prepared a map of notable reefs within Port Curtis that are identified in the GBRMPA Gazetteer, however this mapping does not identify many of the smaller reefs that occur within Port Curtis.

The present study was commissioned by the QGC to address some of these information gaps. This study involved two main components, namely the characterisation of spatial patterns in:

1) Habitat characteristics of intertidal reef areas;

2) Assessment of benthic communities in intertidal and sub-littoral reef environments.

This information will assist QGC management with future port planning (i.e. understanding impacts and values of reef habitats), and identify information gaps that require further assessments and/or monitoring activities.

1.2 Study Aim and Objectives

The primary aim of this investigation was to assess the spatial characteristics and potential environmental values of shallow water reef communities within Port Curtis. The specific objectives of this study were to:

- Describe spatial patterns in the physical habitat characteristics of the intertidal reef habitats;
- Provide a baseline quantitative assessment of patterns in benthic flora and fauna community structure on shallow sub-tidal reef areas;
- Describe spatial patterns in the structure of shallow water reef communities within Port Curtis;

- Determine whether reef communities are qualitatively different to reef communities elsewhere in the broader region;
- Describe the existing and potential habitat values of the reef communities;
- Provide recommendations on further studies that could further improve an understanding of the impacts and values of marine ecological resources associated with reef habitats and communities.

1.3 Study Area Context

Gladstone Harbour (Port Curtis) is a 30km long deepwater estuary formed behind Curtis and Facing Islands at Latitude 23° South, Longitude 151° East. The harbour has three naturally formed connections with the sea, in order from north to south and of increasing conveyance with the surrounding waters of the Great Barrier Reef Lagoon, these are:

- The Narrows, a narrow intertidal channel between the mainland and Curtis Island which provides a limited exchange of water with Keppel Bay.
- North Entrance , a narrow shallow passage between Curtis Island and Facing Island, and
- South Channel, a broad and deep channel between Facing and Boyne Island.

Since development of the surrounding area began in the 1850's, the harbour has provided sheltered deepwater access for visiting ships via the South Channel. For these same reasons Gladstone is today one of Queensland's major bulk handling Ports with its principal exports being coal, aluminium and cement.

Access to and within the naturally deepwater areas of the Harbour has been enhanced by capital dredging of the South Channel since the 1950's, with major enhancements of channel depths for shipping (to a depth of approximately 16m below datum) in the 1980's and 1990's, resulting in the dredging and removal to sea of approximately 15,000,0000m^3 of sediments.

The harbour is accessed by deep draught vessels from the open waters of the Great Barrier Reef Lagoon via the 24km long dredged South Channel which leads to the first of the protected berths within the Harbour at South Trees Wharf. The inner reaches of the dredged channel continue past Barney Point, Auckland Point, and Clinton Coal Facility up to Fishermans Landing spanning an additional 17km of sheltered waterway.

Title:

Study Location Map

Figure: 1-1

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2 METHODOLOGY

Three assessment methods were used in this study:

- Intertidal reef mapping based on aerial photograph interpretation;
- Rapid intertidal reef assessment survey;
- Quantitative shallow (sublittoral) subtidal reef survey.

2.1 Intertidal Reef Mapping and Field Assessments

The location and extent of intertidal rocky shores was mapped using:

- Existing mapping of reefs and rocky shores, including GBRMPA Gazetteer reef maps and nautical charts; and
- Geo-rectified low-level aerial photography of the study area; geological maps (1: 100 000; Department of Mine and Energy).

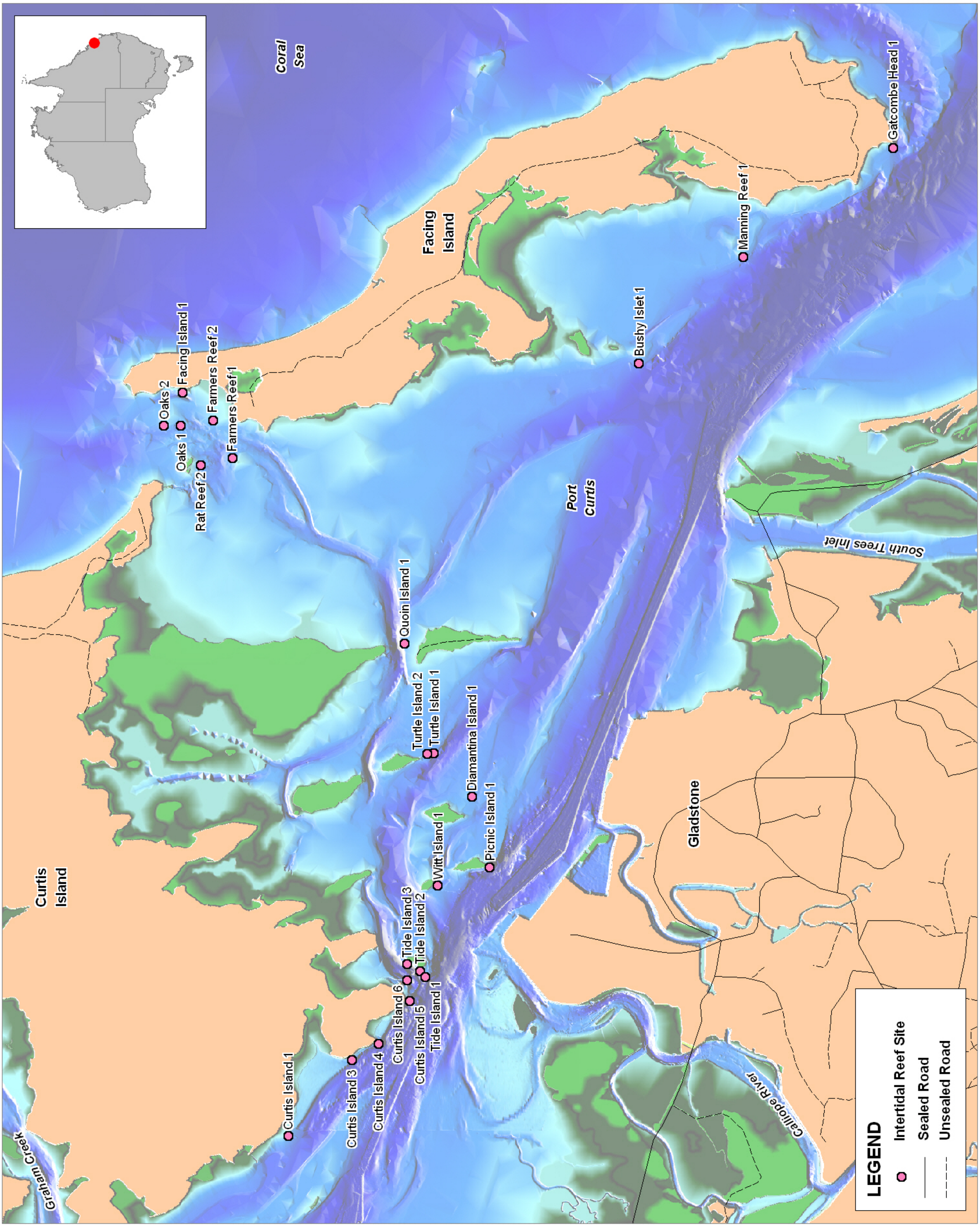
All spatial data were imported into GIS. The extent of visually distinct intertidal rocky shores was then digitised using MapInfo (v9.5) software package. Location names of each reef were derived from boat charts and the GBRMPA Gazetteer.

A total of 23 representative sites were then selected for field-based assessments of intertidal rocky shore habitat characteristics (Figure 2-1). A standardised rapid biological assessment protocol was used to describe the geomorphological and biological habitat characteristics at each site (see Appendix A). The site was visited within two hours either side of spring low water, and a pro-forma was used to document the following:

a) Reef type;

b) Micro-habitat types present and their area/abundance;

c) Dominant life-forms at two replicate pools per micro-habitat type (as described in ‘b’).



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Locations of Intertidal Reef Sites Assessed for Rapid Biological Assessment

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Approx. Scale

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A modified Speight (1984) classification scheme was used to describe reef type. Although principally designed for larger scale landform surveys, the definitions and classifications can be used to describe both relief (the difference in elevation between high and low points) and slope of the landform. Four landform types were identified in this study Table 1-1).

Table 2-1 Landform Classifications

Type	Code	Vertical Height (m)	Slope
High marine cliff	HC	>8	>21º
Low marine cliff	LC	4 to 8	>21º
Outcrop	O	<4	>21º
Wave cut platform	P	<4	<21º

The sediment type(s) present on individual reefs was also used to classify the reef type. Sediment types follow Standards Association of Australian Classifications (in Speight 1984) as shown in Table 1-2.

Table 2-2 Sediment Types on Shores

Category	Code	Particle Diameter (mm)
Slit-Clay	l	<0.6
Sand	s	0.6-2
Gravel	g	2-60
Cobbles	c	60-200
Boulders	b	200-2000

The landform type(s) and sediment type(s) present, and the degree to which the reef was inundated, was then used to classify reefs into structural reef types. In most cases, the landform and sediment types present varied across different tidal zones, and therefore one or more landform types were used in the final classification. Field surveys were also undertaken (at low tide) to determine dominant species present within pools and on the reef platform.

The pro-forma was completed within a 30 minute time period. The information collected during the site assessment was used to provide a qualitative rating of habitat chacteritics and diversity within each site.

2.2 Benthic Flora and Fauna Survey

2.2.1 Sampling and Analysis Methods

Assessments of benthic flora and fauna communities of shallow, sublittoral reefs were undertaken on the 15th to 19th October 2009, inclusive. Due to the necessity of good water clarity and low current velocities for video transect sampling, data were collected two hours either side of spring low water.

A total of 10 sites were sampled for quantitative assessment of benthic cover. These sites included representative areas throughout Port Curtis, although there was comparatively less sampling effort in western near-shore areas due to poor visibility and strong currents at the time of sampling (see Section 2.3).

Eight sites were sampled using an underwater video operated by a diver. Video imagery was collected using a JVC HD *Everio* hard disc digital video camera in a marine case housing. Two to three randomly placed transects were sampled at each site (depending on reef size). A diver (on snorkel) laid out a fibreglass tape measuring a distance of 25 meters running parallel to the depth contour. A continuous image of the benthic substrate was then recorded by video along the tape. The video camera was held approximately 0.3 m above the substrate. Any notable biota encountered was also noted. When required, specimens were collected to confirm identification.

In addition, two sites were sampled using an underwater video remotely deployed from the vessel. This approach was used where strong currents prevented divers from entering the water. At each of these sites, two to three replicate 25 m video transects were sampled (depending on the size of reef patch). Refer to Figure 2-2 for these locations.

In the laboratory, the recorded video file was downloaded onto a hard drive, and the imagery was displayed on a high definition computer screen. Video footage was paused at five second intervals and the flora, fauna and substrate intersected by randomly placed points on the computer screen were identified and recorded. This method provided a total of 100 sample points per 25 meter transect. The percentage cover of visually distinct taxa or substrate classes (bare, macroalgae, hard coral etc.) on each transect was then calculated based on the methods outlined by Harriott *et al.* (1995).

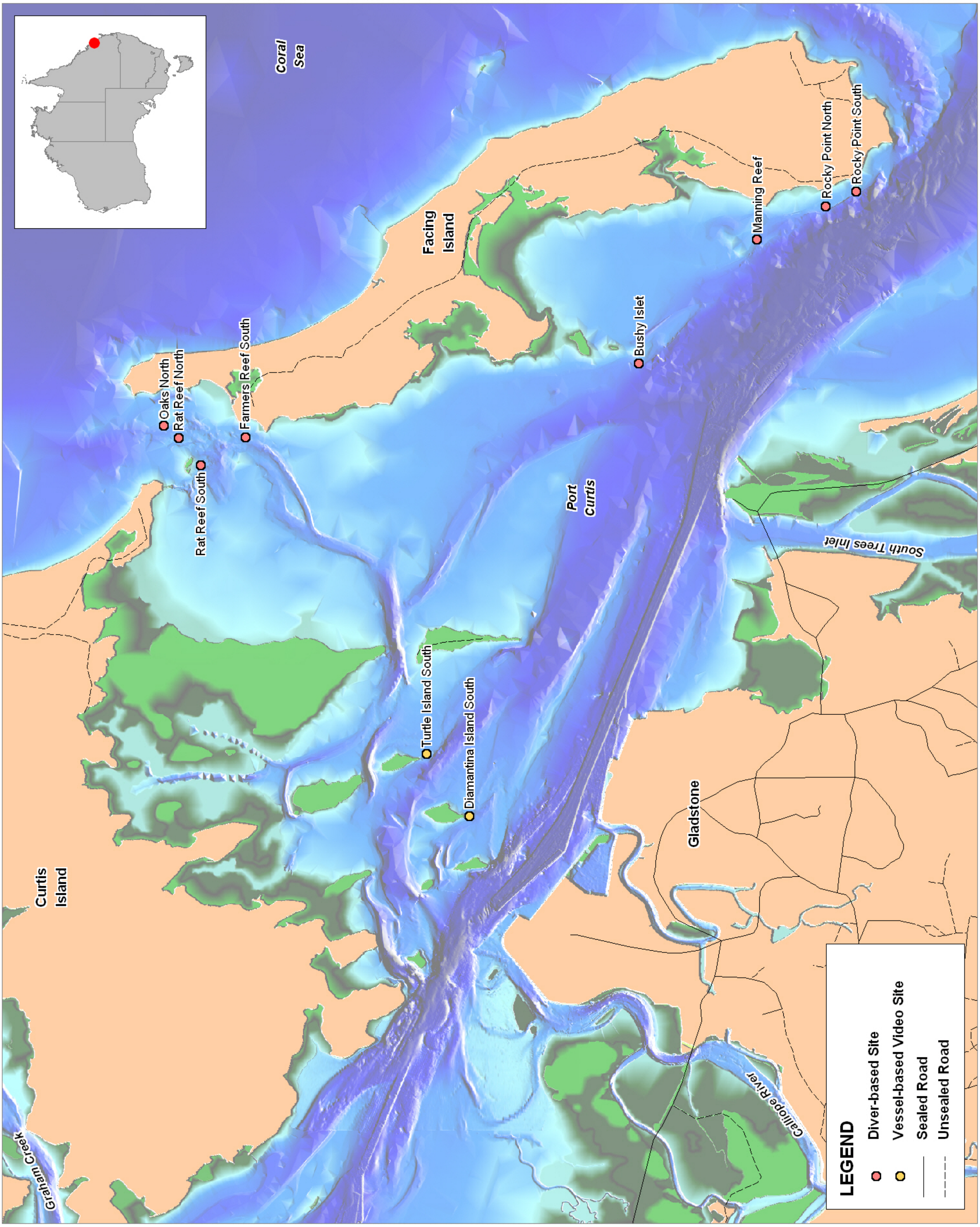
Statistical Analyses

Patterns in community attributes were summarised using simple descriptive statistics (mean, standard error, % cover of different taxa groups), which were plotted and tabulated.

Patterns in assemblage structure at different sites and depth strata were also analysed using a range of multivariate statistical procedures. For all multivariate analyses, raw data were initially double square-root transformed and a similarity matrix was generated using the Bray-Curtis measure of similarity. Based on this similarity matrix, the following tests were performed:

- non-metric multi-dimensional scaling (n-MDS); performed on the similarity matrix to graphically present the similarity of samples based on 2-d and/or 3-d configurations (Clarke 1993).
- Hierarchical cluster analysis was then performed on the similarity matrix using the average linkage method, and groupings were superimposed on MDS plots to check the adequacy and agreement between the two techniques and determine the group membership of samples.

Results of the survey of the reef communities of the study area were semi-quantitatively compared to results from natural reef systems in the broader region to determine the similarities and differences amongst communities in different habitats.



Title:

Location of Quantitative Sub-littoral Reef Sampling Sites

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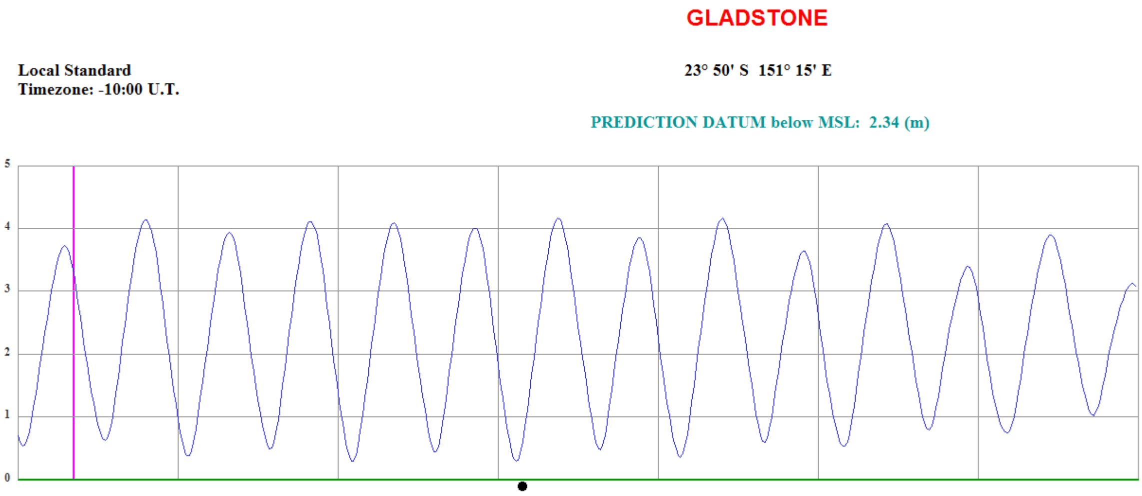
2.3 Survey Conditions and Constraints

Surveys were undertaken at one time only between the 15th to 19th October 2009. Sampling was undertaken during Spring tides, with low water ranging from 0.4 to 0.6 m below MSL. The lower intertidal zone could therefore be visually inspected during low tides.

Wind conditions and turbidity levels were not favourable for visual observations of the seabed over the course of field work. Visibility was typically <0.5 m at the more offshore sites, and <0.3 m nearshore. Tidal current velocities prevented diving except during the period 1 to 1.5 hours either side of the turn of the tide. Due to low water visibility and strong currents, only two sites could be effectively sampled within the nearshore sections of the study area, and no sub-tidal reef sites could be sampled at the southern end of Facing Island.



Oct 15 Th Time	m	16 Fr Time	m	17 Sa Time	m	18 Su Time	m	19 Mo Time	m	20 Tu Time	m	21 We Time	m
0047	0.5	0130	0.4	0209	0.3	0245	0.3	0318	0.4	0349	0.5	0415	0.7
0657	3.7	0740	3.9	0819	4.1	0858	4.2	0935	4.2	1014	4.1	1051	3.9
1301	0.6	1348	0.5	1431	0.4	1514	0.5	1553	0.6	1633	0.8	1712	1.0
1909	4.1	1951	4.1	2030	4.0	2109	3.9	2148	3.6	2227	3.4	2304	3.1

Figure 2-3 Predicted tidal heights during the sampling period (Seafarer tides)

3 RESULTS

3.1 Intertidal Rocky Shores

Table 3-1 is a list of intertidal rocky shores inspected in the present study and the reef classification category. A total of six broad reef types were distinguished on the basis of geomorphological characteristics and dominant biota at mid-low tide level.

Fringing Reefs

Fringing reefs are defined as areas where the supralittoral and upper intertidal zone was predominantly comprised of unconsolidated soft sediment (mud, sand and gravel), and the mid to lower intertidal zone was comprised of reef, either massive/bedrock platform reef, boulder fields or rubble fields. Several fringing reef types were distinguished:

- Oyster dominated reefs (oyster cover >20%);
- Oyster and barnacle dominated reefs;
- Predominantly bare reefs (benthic cover <20%).

Most fringing reefs were rubble flat or boulder field type reefs, with only a small number comprised of massive platform-type reefs. Consequently, fringing reefs generally had few intertidal rock pools or lagoons. Most sites surrounding the small islands and fringing western shoreline of Curtis Island were classified as fringing reefs, with mangroves often dominating in areas with soft sediment. These reefs typically had high macroalgae cover and low coral cover in the sub-littoral zone (see also Section 3.2).

Two fringing reef sites were also recorded in the southern sector of Port Curtis (along the south-western shoreline of Facing Island). These reefs had high hard coral cover in the sub-littoral zone.

Platform Reefs

Unlike fringing reefs, platform reefs had limited soft sediment cover within the intertidal zone. Most reefs in the North Passage sector were platform reefs. Platform reefs typically had high oyster cover in the mid to lower intertidal zone, often in association with barnacles. As discussed in section 3.2 below, hard corals often dominated the shallow sub-littoral zone of these reefs.

Steep Headland Reefs

The southern headland of Facing Island (Gatcombe Head) was comprised of a steep sloping rocky escarpment. Benthic cover within the intertidal zone was relatively sparse, although oysters were abundant in places.

Table 3-1 Intertidal rocky shore classifications

Name	Classification	Sub-classification
Western sites		
South Passage Is. (Curtis Island 1)	Fringing oyster reef at mid-low tide	Soft sediment + Platform reef (bare + oysters)
Curtis Is. 3	Fringing reef at mid-low tide	Soft sediment + Rubble flat (bare - oysters)
Curtis Is. 4	Fringing oyster reef at mid-low tide	Soft sediment + Rubble flat (bare + oysters)
Curtis Is. 5	Fringing oyster reef at mid-low tide	Soft sediment + Rubble flat (bare + oysters)
Curtis Is. 6	Fringing reef at mid-low tide	Soft sediment + Boulder Field (bare - oysters)
Tide Is. 1	Oyster reef	Platform reef (bare + oysters - barnacles)
Tide Is. 2	Fringing oyster/barnacle reef at mid-low tide	Soft sediment + Boulder Field (bare + oysters + barnacles)
Tide Is. 3	Fringing oyster/barnacle reef at mid-low tide	Soft sediment + Rubble flat (bare + oysters + barnacles)
Witt Is.	Fringing oyster/barnacle reef at mid-low tide	Soft sediment + Boulder field (bare + oyster + barnacle)
Picnic Is.	Fringing reef at mid-low tide	Soft sediment + Boulder Field (bare - oysters)
Diamantina Is.	Fringing reef at mid-low tide	Soft sediment + Rubble flat (bare - oysters)
Turtle Is. 2 North	Fringing reef at mid-low tide	Soft sediment + Rubble flat (bare - oysters)
Turtle Is. South	Fringing reef at mid-low tide	Soft sediment + Platform reef (bare - oysters)
Quoin Is.	Fringing reef at mid-low tide	Soft sediment + Rubble flat
North Passage sites		
Rat 2 (South)	Oyster reef	Rubble flat + Platform reef (oyster)
Facing Is. 1	Bare platform reef	Platform reef (bare)
Oaks	Oyster reef	Platform reef (bare + oyster)
Oaks 2	Oyster-barnacle reef	Platform reef (bare + oyster + barnacle - coral)
Farmers Reef no. 1	Oyster reef	Boulder field (bare + oyster - barnacle)
Farmers Reef no. 2	Oyster-barnacle reef	Platform reef (bare + oyster + barnacle)
South Facing Is. sites		
Bushy Islet	Fringing oyster/barnacle reef at mid-low tide	Soft sediment + Platform reef (bare + oyster + barnacle)
Manning Reef	Fringing oyster reef at mid-low tide	Soft sediment + Platform reef - rubble flat (bare + oyster - barnacle)
Gatcombe Head	Steep headland	Steeply inclined headland (bare - oysters)

3.2 Sub littoral Reef Assessment

A total of 26 fauna and 12 flora benthic habitat groups were recorded on video transects, and consisted of the following:

- 18 Cnidaria groups (hard coral, soft coral, sea whips/fans and hydroids);
- 3 Mollusca groups (gastropods and bivalves); and
- one group within each of the fauna phyla Chordata (ascidians); Echinodermata (feather stars); Annelida (polychaete worms); Porifera (sponges); Arthropoda (crustaceans);
- 2 Phaeophyta (brown) algae groups;
- 5 Rhodophyta (red) algae groups;
- 4 Chlorophyta (green) algae groups; and
- a broad 'turfing' algae group, which typically comprised a combination of small macroalgae, epiphytic algae and silts.

The average percentage cover of each benthic group is summarised in Table 3-2, and Figure 3-1 summaries the average proportion of aggregated benthic groups at each site. Trends in reef assemblage structure among sites are described in the following sections.

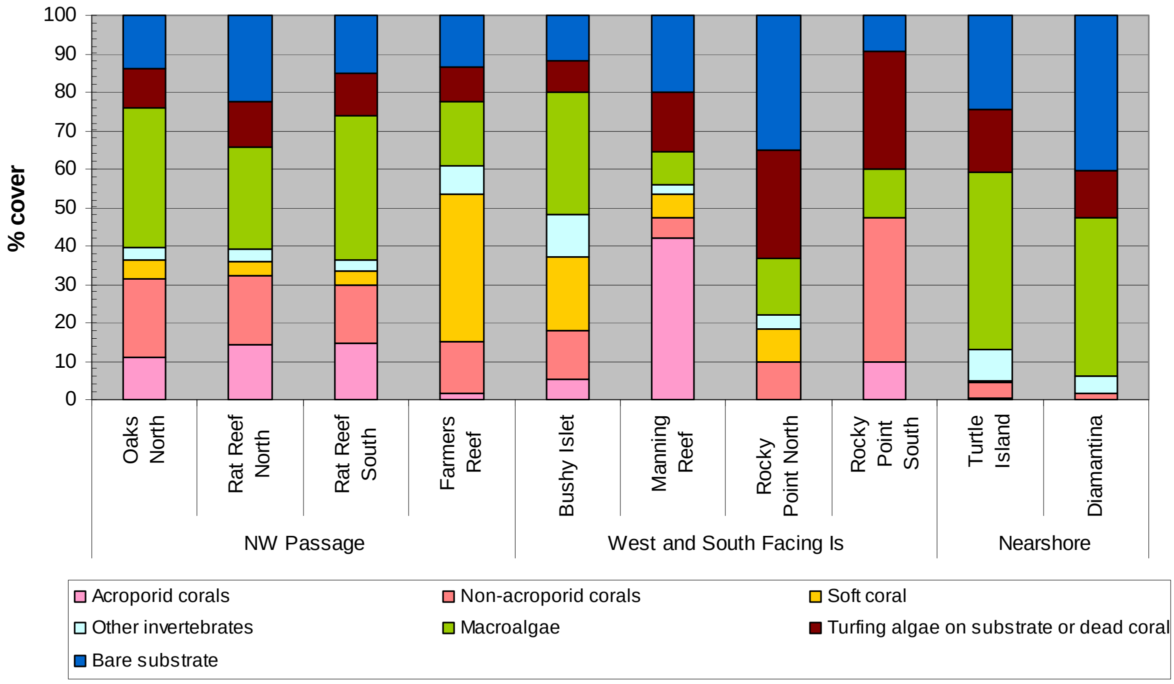


Figure 3-1 Summary of the percentage cover of broad taxa groups at each site

Table 3-2 Average benthic cover (% occurrence) of fauna, flora and bare substrate at each site

Group				Oaks North	Rat Reef North	Rat Reef South	Farmers Reef	Bushy Islet	Manning Reef	Rocky Point North	Rocky Point South	Turtle Island	Diamantina
Fauna	Cnidaria	Hard coral	*Acropora* - branching (*A. robusta* dominant)	3.5	9.0	3.5	1.5	0.0	37.7	0.0	4.0	0.0	0.0
			Acropora. - Digitate	1.0	1.7	0.0	0.0	1.3	3.3	0.0	4.0	0.3	0.0
			Acropora. - Tabulate	6.5	0.7	4.5	0.0	2.0	1.0	0.0	2.0	0.0	0.0
			Acropora millepora	0.0	3.0	6.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0
			Total Acroporids	11.0	14.3	14.5	1.5	5.3	42.0	0.0	10.0	0.3	0.0
			Encrusting spp.	3.5	1.3	0.0	0.0	2.7	0.0	0.0	4.5	0.0	0.0
			Pocillopora spp.	0.5	0.3	0.5	7.0	0.7	1.7	2.7	7.0	0.7	0.0
			Porites spp.	0.5	0.3	2.0	0.5	4.7	0.0	0.7	0.0	0.0	0.0
			Favites spp.	0.5	4.3	1.5	0.0	2.0	2.3	2.3	1.5	3.0	0.0
			Goniopora spp.	0.0	1.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0
			Turbinaria spp.	15.5	9.3	11.0	6.0	2.3	1.3	4.0	24.5	0.3	1.5
			Cyphastrea spp.	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
			Goniastrea spp.	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			Total Non-Acroporids	20.5	18.0	15.5	13.5	12.7	5.3	10.0	37.5	4.0	1.5
		Soft Coral	Soft coral	4.0	3.0	3.5	33.0	18.7	4.3	2.0	0.0	0.0	0.0
			Xenia spp.	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
			Alcyonium spp.	0.5	0.7	0.0	5.5	0.0	1.7	4.3	0.0	0.7	0.0
			Dendronephthya	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
			Total Soft coral	5.0	3.7	3.5	38.5	19.0	6.0	8.3	0.0	0.7	0.0
		Other Cnidaria	Gorgonian	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.7	1.0
			Hydroids (sea firs)	0.5	0.0	0.0	2.5	1.3	0.0	0.0	0.0	0.7	0.5
	Chordata		Ascidian (sea squirt)	0.5	1.0	0.0	0.5	1.7	1.0	1.0	0.0	2.0	0.5
	Crustacea	Cirripedia	Barnacle	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	1.0	0.0
	Mollusca	Gastropods	Nudibranch	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			Sea snails	0.0	0.0	0.0	0.0	0.7	0.3	0.3	0.0	0.0	0.0
		Bivalvia	Bivalve	0.0	0.0	0.0	0.5	0.3	0.3	1.0	0.0	0.0	0.0
	Echinodermata		Feather star	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
	Annelida	Polychaeta	Tube or fan worm	0.0	0.3	0.0	0.0	1.7	0.0	0.3	0.0	0.7	0.0
	Porifera		Sponges	2.0	2.0	2.5	3.5	3.3	1.0	0.7	0.0	3.0	2.5
			Total non-coral invertebrates	3.0	3.3	3.0	7.5	11.3	2.7	3.7	0.0	8.0	4.5

Group				Oaks North	Rat Reef North	Rat Reef South	Farmers Reef	Bushy Islet	Manning Reef	Rocky Point North	Rocky Point South	Turtle Island	Diamantina
Flora	Macroalgae	Red algae (Rhodophyta)	Foliose coralline	1.5	1.3	1.5	1.0	2.3	0.0	7.0	0.0	0.0	1.5
			Encrusting coralline	1.0	0.0	0.0	0.5	3.7	0.0	0.0	0.0	0.0	0.0
			Segmented red	1.5	1.7	0.0	0.0	0.3	0.0	0.0	9.0	0.0	3.5
			Asparagopsis taxiformis	4.5	11.7	8.5	7.5	17.0	0.7	3.0	1.0	24.3	28.5
			Other fleshy red	0.5	0.0	0.0	1.5	2.3	1.0	0.0	0.0	0.0	0.0
		Green algae (Chlorophyta)	*Halimeda* sp.	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	1.7	6.0
			Caulerpa taxifolia	2.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			Caulerpa brownii	0.5	0.7	1.5	0.0	0.7	0.3	1.7	1.0	0.7	0.0
			Other fleshy green	4.5	1.0	10.0	0.0	0.3	0.0	3.0	1.5	7.0	0.0
		Brown algae (Phaeophyta)	*Padina* sp.	16.0	8.3	11.5	1.5	0.0	3.7	0.0	0.0	7.3	0.0
			Other fleshy brown	4.0	1.3	4.0	4.5	5.0	3.0	0.0	0.0	5.0	2.0
			Total macroalgae	36.5	26.3	37.5	16.5	31.7	8.7	14.7	12.5	46.0	41.5
	Smaller "turfing" algae		Rock with turfing	6.0	7.0	7.5	6.5	7.0	2.3	23.7	26.5	16.7	12.0
			Dead coral/turfing	4.0	5.0	3.5	2.5	1.3	13.0	4.7	4.0	0.0	0.0
			Total turfing algae	10.0	12.0	11.0	9.0	8.3	15.3	28.3	30.5	16.7	12.0
Bare substrate			Sand/silt/shell grit	13.0	17.0	14.0	13.5	7.7	20.0	33.7	9.5	24.3	40.5
			Bare rock/rubble	1.0	5.3	1.0	0.0	4.0	0.0	1.3	0.0	0.0	0.0
			Total bare substrate	14.0	22.3	15.0	13.5	11.7	20.0	35.0	9.5	24.3	40.5

a) Acropora (branching)

b) Acropora (digitate) with feather star

c) Turbinaria

d) Favites

e) Soft coral

f) Red algae (*Asparagopsis taxiformis*)

g) Sponge (orange) surrounded by coral and algae

Figure 3-2 Examples of corals and other biota observed during underwater video surveys

3.2.1 Benthic Flora

Macroalgae numerically dominated the reef benthos at most sites (refer to Table 3-2 and Figure 3-3). Highest macroalgae cover was recorded at the two fringing nearshore reef sites (Turtle and Diamantina Islands: 46 and 41% cover, respectively). Macroalgae assemblages at these two sites, as well as Bushy Islet and Rat Reef North, were comprised mostly of the red alga *Asparagopsis taxiformis*.

Oaks North (located in North Passage) was the only other site where macroalgae cover exceeded 20% cover, but unlike the above mentioned sites, macroalgae assemblages were numerically dominated by he brown alga *Padina* (16% cover), together with a wide variety of other macroalgae taxa.

Small 'turf' algae was abundant at Rocky Point North and Rocky Point South (28-30% cover), and to a lesser extent Turtle Island and Diamantina Island (17 and 12% respectively). At these four sites, turfing algae was mostly recorded in association with rocky substrate. Manning Reef had moderate cover of turfing algae in association with dead coral (13% cover). Sites with high coral cover, particularly Acroporid corals, also had high turfing algae-dead coral cover (regression of Acroporid cover and turfing algae on dead coral cover: $r^2 = 0.87$, p <0.05).

3.2.2 Benthic Fauna

Hard corals comprised >30% of total benthic cover at five sites: Oaks North, Rat Reef North and South (North Passage) and Manning Reef and Rocky Point South (West and South Facing Island). The hard coral assemblages at these sites were numerically dominated by different taxa, as summarised below:

- Manning Reef, which had the highest recorded coral cover with in the study area, was numerically dominated by *Acropora robusta*, a large branching species. Other hard coral species together represented <10% cover at this site. Coral colony size at this site was >5m, and large proportion of dead coral with turfing algae (13%) was recorded in association with these colonies;
- Rat Reef North and Rat Reef South had moderate cover of Acroporid corals, with *A. robusta* dominated at Rat Reef North, and *A. millepora* and tabulate *Acropora* co-dominant at Rat Reef South. These two sites also had a wide variety of other non-Acroporidae corals, with *Turbinaria* species co-dominant;
- Rocky Point South and Oaks North had moderate high cover of *Turbinaria* (24% and 15% cover, respectively), ~10% cover of Acroporid corals, and a variety of other hard coral taxa sub-dominant;
- Farmers Reef and Bushy Islet had hard coral assemblages comprised of a variety of non-Acroporid corals (14 and 13%, respectively), with *Pocillopora/Turbinaria* species most abundant at Farmers Reef, and *Porites* species most abundant at Bushy Islet;

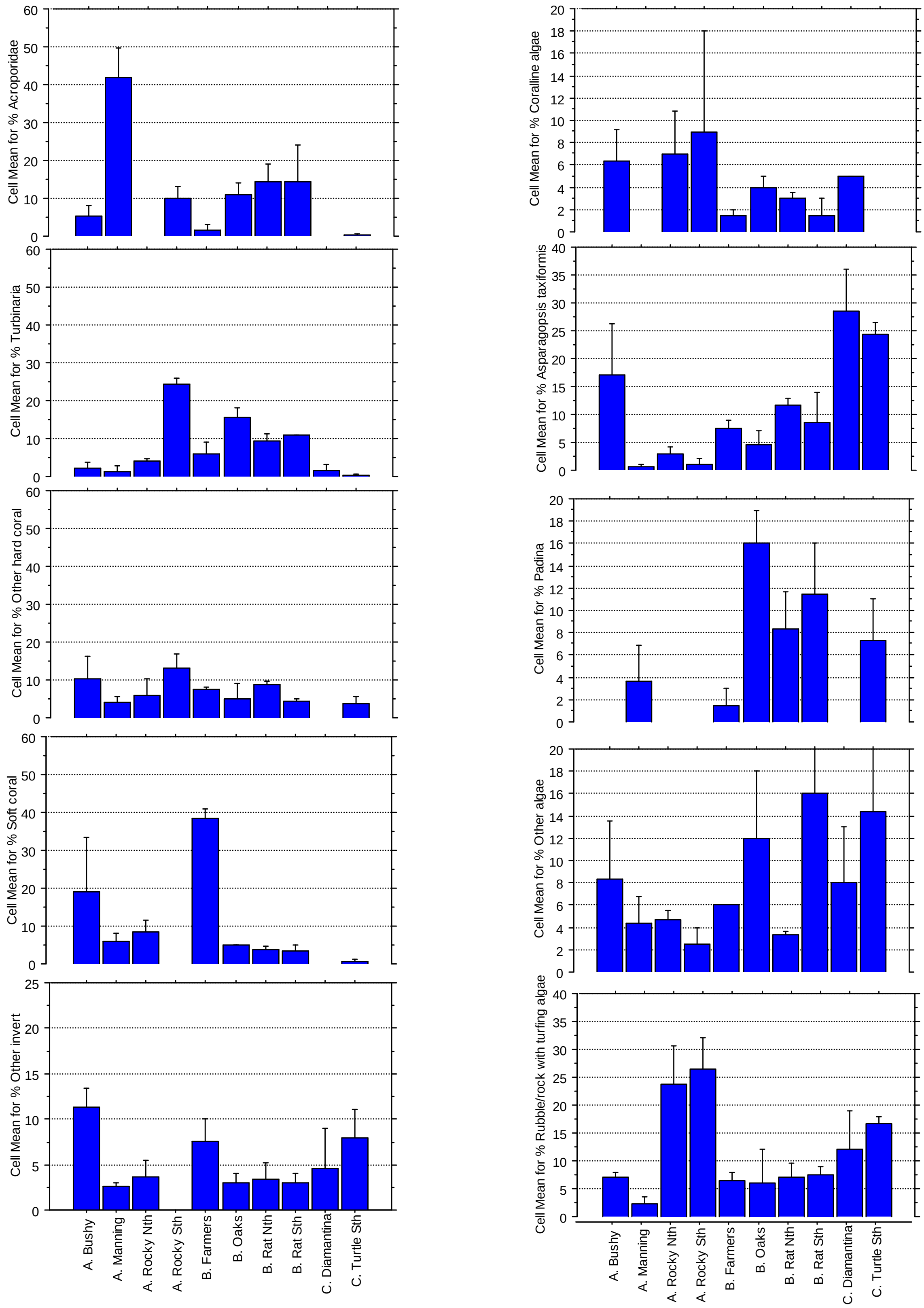


Figure 3-3 Mean percentage cover (±S.E.) of benthic habitat groups at each site

- Turtle Island had 4.3% hard coral cover, which was comprised almost exclusively of *Favites*. Nearby Diamantina Island had 1.5% cover of *Turbinaria*, but no other hard coral taxa were recorded on transects. Coral colonies at these sites were small (typically <20 cm diameter) and had a patchy distribution.

Soft coral cover at Farmers Reef and Bushy Islet was high (38% and 19%, respectively). At all other sites soft coral cover was <10%. In terms of total coral cover (hard + soft coral cover), all sites except Turtle Island and Diamantina Island had >10% cover.

Total percentage cover of non-coral macroinvertebrate taxa ranged from 0 to 11%. Sponges were recorded at most sites (except Rocky Point South), but in low abundance (0.7 to 3% cover). Hydroid cover at Farmers Reef was 2.5% and feather star (crinoids) cover at Bushy Islet was 2%. All other fauna taxa represented <2% cover within sites.

3.2.3 Taxa Diversity

Figure 3-4 illustrates the number of mean number of benthic habitat groups recorded at each site. This provides a simple, gross measure of the diversity of life-forms recorded at each site. Overall, Bushy Islet, Oaks and Rat Reefs North and South had the highest number of benthic habitat groups (17 to 20 groups). The remaining sites had <15 life-form groups, with the lowest number of life-forms recorded at Diamantina Island (eight groups).

Figure 3-4 shows that the mean number of hard coral taxa groups ranged from one at Diamantina Island, to seven taxa groups at Rat Reef North and South. Sites with high Acropoid cover also tended to have high hard coral cover (r = 0.82, p = 0.001). There was a significant positive correlation between % cover and number of coral groups (r = 0.61, p = 0.001), indicating that sites with high hard coral cover also tended to have a higher number of hard coral groups. Removal of Manning Reef, a site dominated by large colonies of *Acropora robusta*, from the analysis greatly improved the strength of this association (r = 0.86, p = 0.001).

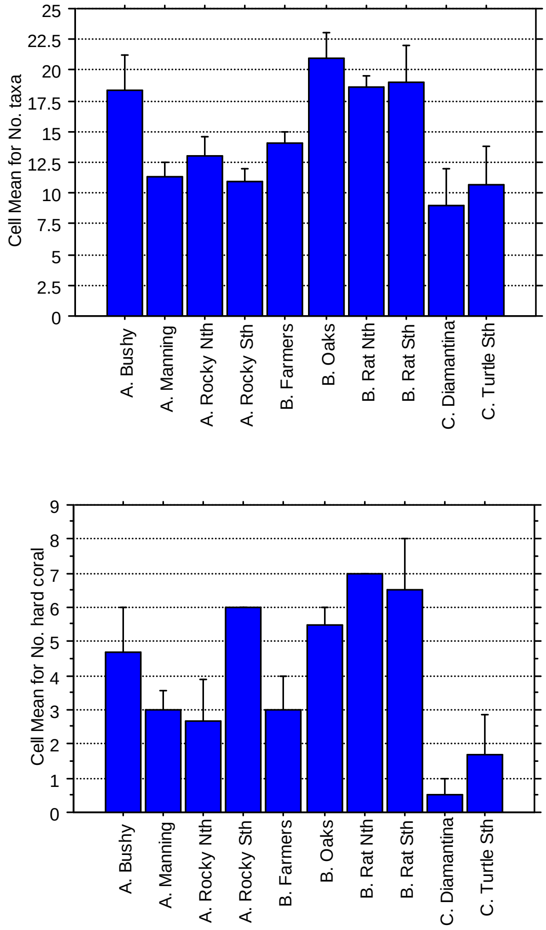


Figure 3-4 Mean number of benthic groups and hard coral groups (±S.E.) at each site

3.2.4 Multivariate Patterns in Assemblage Structure

Patterns in similarity of reef assemblages among sites are shown in Figure 3-5 (n-MDS ordination[1]) and Figure 3-6 (cluster analysis dendrogram). These plots both indicate that transects within sites tended to group together, indicating that differences within sites were generally (but not always) less than differences among sites.

The ordination and dendrogram also indicate that the two western nearshore reef sites (Turtle and Diamantina Islands) had reef assemblages that differed from other sites sampled in the study area. One transect from Turtle Island did however group together with Rocky Islet North at the 60% similarity level, indicating that assemblages were not always consistently different between areas of Port Curtis (i.e. between North Passage and nearshore sectors of Port Curtis).

There was a high degree of similarity in assemblage structure among reefs within North Passage (see blue coloured sites in the ordination). By contrast, reef sites along western and south-western

[1] Refer to text box in Appendix B for advice on how to interpret the n-MDS ordination

Facing Island varied greatly from each other, and were generally more similar to North West Passage sites than to each other.

Trends in assemblage structure among sites were further explored based on an n-MDS ordination generated from site-averaged data (Figure 3-7). This ordination shows that Turtle and Diamantina Islands separated from other sites at the 50% similarity level. North Passage sites (except Farmers Reef) formed a grouping with Bushy Islet at the 60% similarity level, whereas the south and western Facing Island sites formed separate site groupings at the 60% similarity level. This again shows that south and western Facing Island sites did not form a distinctive community, unlike the assemblages recorded around Turtle and Diamantina (red algae – *Halimeda* - bare substrate dominated) and North Passage (*Padina* – *Acropora* – Soft Coral – *Turbinaria* dominated). This is consistent with patterns in the abundance of individual taxa groups described in Section 3.2.1 and 3.2.2.

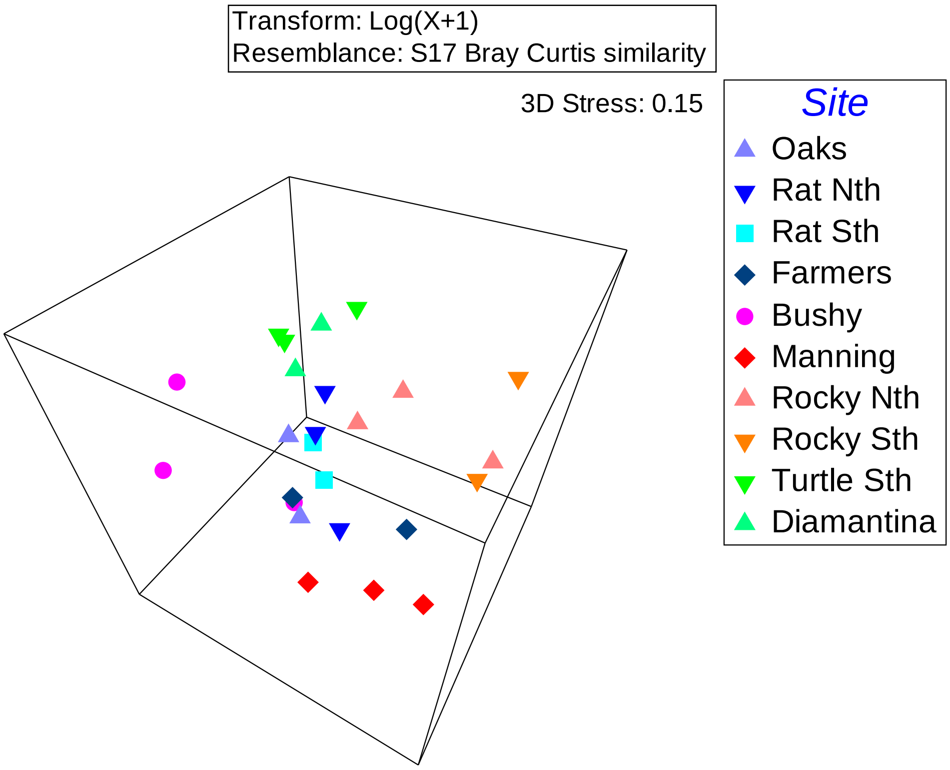


Figure 3-5 Three-dimensional n-MDS ordinations (using Bray-Curtis similarity on a log x+1 transformation) showing patterns in similarity of assemblages

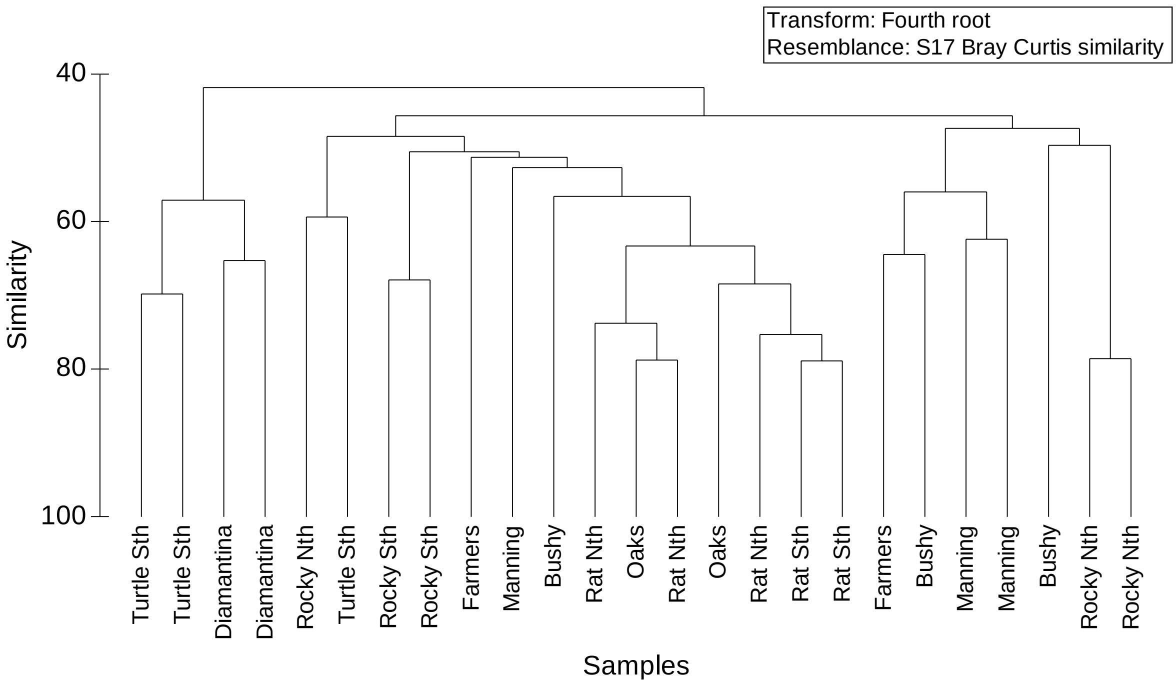


Figure 3-6 Dendrogram (using Bray-Curtis similarity on a log x+1 transformation) showing patterns in similarity of assemblages among sites

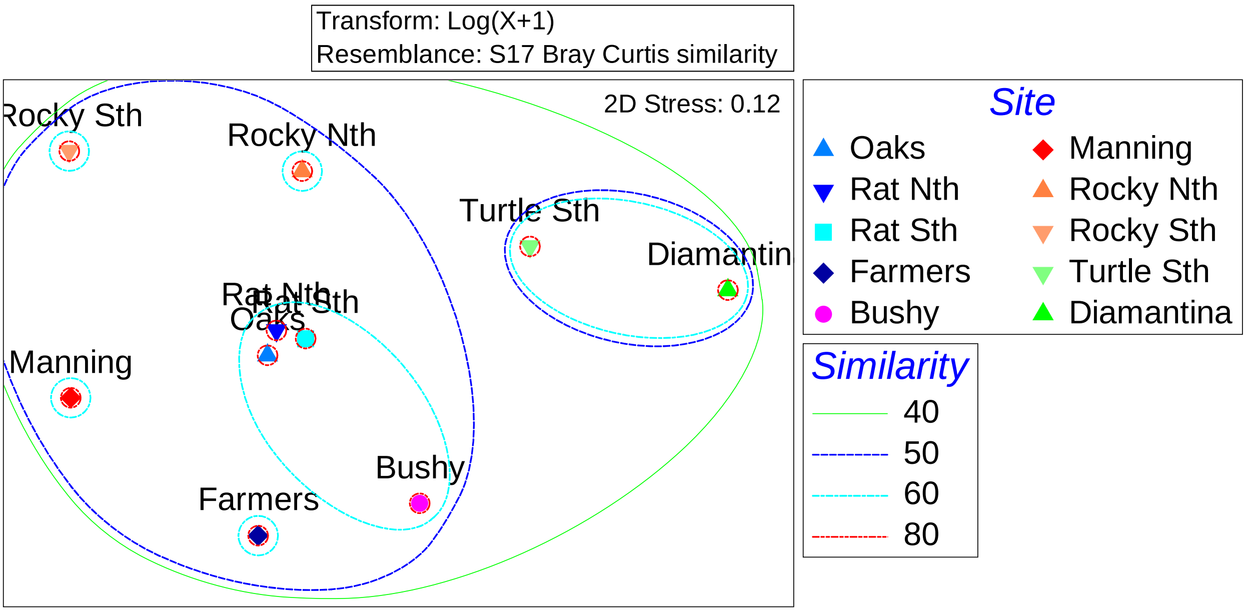


Figure 3-7 Two-dimensional n-MDS ordinations (using Bray-Curtis similarity on a log x+1 transformation) showing patterns in similarity of assemblages using site averaged data. Groupings from cluster analysis are superimposed on the ordination

4 DISCUSSION

4.1 Distribution and Extent of Reefs

Port Curtis is a marine embayment that is fringed by two major barrier islands on its east side: Curtis and Facing Islands. These two islands contain a number of bed rock outcrops, headlands and boulder/rubble fields that presently form intertidal rocky shores and reefs. Port Curtis also contains many smaller islands that are generally the remnants of elevated topography inundated during the last sea level rise, and also contain extensive areas of intertidal rocky shores and reef areas.

Most of the smaller islands (Tide, Witt, Picnic, Diamantina, Turtle, Quoin, Compigne, Chinaman and Rat Islands) are located to the south of Curtis Island and are evidenced as an extension of the elevated ridge lines on Curtis Island as they intersect the waters of Port Curtis. The smaller islands are generally characterised by steeply sloping rocky shorelines consisting of boulders and ridges of the underlying parent rock material. In places, the rocky shores have been covered by littoral drift deposits of sand, shell and fine mud materials. Examples of this occur at Quoin and between Witt and Diamantina Islands. The Passage Islands west of Curtis Island, also appear to have resulted from the littoral deposition of muddy sediments over a submerged former ridge line.

By contrast the intertidal foreshores of the barrier islands (Curtis and Facing Islands) within Port Curtis are often gently sloping with broad expanses of sandy or muddy intertidal flats backed by mangroves and separated by pronounced rocky headlands or points consistent with the major topographic ridge lines of each island. These represent structurally complex intertidal habitats that contain a mosaic of habitat patches for marine flora and fauna communities. Gatcombe Head, located on the southern tip of Facing Island, differs from all other intertidal rocky shores in the study area in that it is steeply sloping and has limited mud/sand deposits. This headland is exposed to strong tidal currents and oceanic swells from the south and east.

Overall, exposed intertidal rocky shores within Port Curtis cover 297 ha, which represents ~1.4% of the total intertidal wetland area of the Port Curtis region (Danaher *et al*. 2005; Table 4-1). As shown in Table 4-1, 'unvegetated' mud and sand banks (24%), mangroves (~25%), saltpan (18%) and to a seagrass meadows (~21%) formed the largest intertidal habitat areas in the Port Curtis area. The Port Curtis area is a depositional environment and consequently intertidal rocky shores were generally restricted to areas that experience relatively strong tidal currents and wave action (i.e. the lower intertidal zone).

Table 4-1 Summary of intertidal wetland habitat areas within Port Curtis (Danaher *et al*. 2005)

Community	Area (ha)	% of Total
Closed *Rhizophora*	4396.02	20.69%
Closed *Avicennia*	100.20	0.47%
Open *Avicennia*	85.40	0.40%
Closed *Ceriops*	309.10	1.45%
Open *Ceriops*	35.23	0.17%
Closed *Avicennia/Ceriops*	744.67	3.50%
Open *Avicennia/Ceriops*	12.57	0.06%
Closed *Rhizophora/Avicennia*	350.39	1.65%
Open *Rhizophora/Avicennia*	0.56	0.00%
Closed *Aegiceras*	95.55	0.45%
Closed *Aegiceras/Rhizophora*	37.61	0.18%
Closed *Aegiceras/Avicennia*	22.87	0.11%
Closed mixed mangroves	520.35	2.45%
Dead *Rhizophora*	3.44	0.02%
Dead *Ceriops*	13.97	0.07%
Dead *Ceriops* with emergent *Avicennia*	8.21	0.04%
Saltpan	3894.30	18.33%
Samphire dominated saltpan	485.66	2.29%
Saline grass	193.21	0.91%
Exposed mud and sand banks (non-vegetated)	5143.87	24.21%
Exposed rocky substrates	296.69	1.40%
Isolated *Zostera* patches	107.83	0.51%
Aggregated *Zostera* patches	1806.69	8.50%
Continuous *Zostera* cover	626.26	2.95%
Isolated *Halodule* patches	24.82	0.12%
Aggregated *Halodule* patches	1299.36	6.11%
Continuous *Halodule* cover	244.96	1.15%
Isolated *Halophila* patches		
Aggregated *Halophila* patches	390.97	1.84%
Continuous *Halophila* cover		
Total	**21 250.78**	**100.00%**

Many of these rocky shores extend into subtidal waters to form rocky reefs/rubble banks. Baseline deepwater benthic habitat assessments in Port Curtis (Rasheed *et al*. 2002) recorded nine reef habitat classes on the basis of density, diversity and types of epifauna (Table 4-2; Appendix D). The dominant habitat classes were:

1. Medium density benthic community on rubble substrate, dominated by bryozoans, hard coral, hydroids, echinoids (1984 ± 1612 ha). This habitat class was recorded south of East Banks and Facing Island;

2. High density benthic community – scallop/rubble substrate dominated by a bivalves with a mix of reef biota (1456 ± 832 ha). This habitat class was recorded in deepwater areas (coincident with navigation channels between Fishermans Landing and west Facing Island, as well as a patch south of Gatcombe Head (south of Facing Island);

3. High density benthic community on rubble substrate dominated by sponges, soft coral, hard coral, hydroids, bryozoans, gorgonians and a mix of other benthic taxa (915 ± 352 ha). This habitat class was interspersed with community 2 above to the west of Facing Island;

4. High density benthic community on rubble substrate dominated by bryozoans, sponges, low numbers of other taxa (944 ± 337 ha). This habitat class occurred east of Boyne Island.

Based on mapping undertaken by Rasheed *et al.* (2002), rubble reefs (with overlying soft sediment in places) were found to represent the dominant deep-water (>5 m) habitat type within Port Curtis. The bed sediments are typified by occasional rocky outcrops with silty sand or gravel deposits. The sub-tidal faunal communities in these areas include encrusting reef communities comprising bivalves, tunicates and filter feeding hydroids, gorgonians and soft corals (Rasheed *et al*. 2002; BMT WBM pers. obs.). The dominance of filter-feeding biota on these rubble reefs is probably a consequence of high tidal current velocities providing an on-going supply of algae and other fine particulate organic matter. The presence of hard corals in the deep water areas is notable given the low ambient light conditions likely to be experienced in these areas. It is possible that these corals derive their most of their nutritional requirements from zooplankton and other organic matter rather then symbiotic algae. The ecology of these coral (and other reef) assemblages, and the effect of ambient turbidity conditions, represents an information gap from a dredging and port management perspective.

It should be noted that the Rasheed *et al*. (2002) study only considered waters >5 m water depth, hence areas between 5 m and the intertidal zone presently remain unmapped. This sub-littoral zone represents the area with the highest densities and diversity of hard and soft coral, particularly in the eastern sections of Port Curtis. Section 4.2 below provides a discussion on patterns in reef community structure in these areas.

4.2 Patterns in Sub-Littoral Reef Community Structure

Key Driving Factors

The water quality of Port Curtis is characterised by high suspended sediment loads at most times of the year. This is due to the typically large tidal range (mean tidal range of 3.3 m), with strong tidal (ebb and flood) currents in all channels in the Harbour, which resuspends bed sediments. There are also typically turbid outflows from the surrounding catchment (via Boyne and Calliope Rivers) during the summer months. Sediments are also often mobilised into the water column at times when the wind direction and strength is sufficient to result in waves breaking onto the broad intertidal flats west of Facing Island and south and west of Curtis Island, thereby mobilising fine muddy bed sediments. As a result, there is commonly a noticeable gradient in the water clarity, which improves towards the sea (South Channel and North Entrance) and reduces further into the harbour towards The Narrows.

Table 4-2 Summary of the extent of deepwater benthos habitat areas within Port Curtis and Rodds Bay – density, number of sites recorded, and area (Rasheed *et al.* 2002)

R = mapping reliability estimate

Density category	Benthic macro-invertebrate region description	Region No.	No. of sites	Area ± R (ha)
Open substrate, occasional individual	Open substrate with isolated benthic individuals	7	47	8,193 ± 5,499
		11	1	206 ± 101
		15	6	1,477 ± 1,101
Low density benthic community	Dominated by open substrate with low density of varied benthic taxa	6	4	1,383 ± 1,111
		8	2	308 ± 147
		10	1	116 ± 58
		12	4	882 ± 605
		13	3	583 ± 404
		19	14	3,766 ± 3,487
		20	7	401 ±337
		21	7	1,167 ± 893
Medium density benthic community	Mostly open substrate interspersed with small rubble dominated by echinoids and gastropods - low numbers of other taxa	1	2	532 ± 347
	Rubble substrate dominated by bryozoans and Hydroids - low numbers of other taxa	2	10	715 ± 442
	Rubble substrate dominated by bryozoans, hard coral, hydroids, echinoids - low numbers of other taxa	14	10	1,984 ± 1,612
	Rubble reef and coral bommies interspersed with open substrate dominated by bryozoans, hydroids, sponges, soft coral, hard coral, gastropods and bivalves	17	3	424 ± 281
	Rubble reef dominated by bivalves, ascidians, bryozoans and hard corals- low numbers of other taxa	9	2	444 ± 270
High density benthic community	Rubble reef dominated by sponges, soft coral, hard coral, hydroids, bryozoans, gorgonians with a mix of other benthic taxa	16	4	915 ± 352
		23	5	944 ± 337
	Rubble substrate dominated by bryozoans, sponges, ascidian, bivalves and hard coral - low number of other benthic taxa	5	1	157 ± 64
	Scallop / rubble reef community dominated by bivalves with mix of reef taxa	18	6	1,456 ± 832
		22	2	461 ± 217
	Rubble reef and coral bommies interspersed with open substrate – mixed coral reef community	3	1	98 ± 93
		4	1	158 ± 105
TOTAL ALL AREAS		**23**	**143**	**26,770 ± 11,560**

The benthic reef fauna and flora assemblages of Port Curtis live within the constraints imposed by variable water (and air) temperature range, large tidal range, strong tidal currents and low light levels and associated high suspended solid concentrations. Most light dependant reef building corals, seagrass and seaweed species therefore occur from the lower intertidal to a depth not usually exceeding 2 m below low water datum.

Coral Community

These environmental conditions have a strong influence on spatial (and likely temporal) patterns in reef community structure within Port Curtis. Reefs located in North Passage and along the western side of Facing Island typically had high hard coral cover, with a maximum value of >47% cover (mean = 39%). However, at the two turbid fringing reef sites hard coral was low (average = 4%), and anecdotal observations indicated that coral colony size was typically low (<15 cm diameter). This suggests that reefs in these areas may be subject to major disturbances on a relatively regular basis, which could include for example floods and physical disturbance due to storms and cyclones. It is also possible that the low cover and colony size is a consequence of low growth and/or recruitment rates in response to rates, possibly in response to high sedimentation rates, low light levels and /or low water temperatures (e.g. Ayling *et al*. 1998).

Table 4-3 is a comparison of hard coral cover on Port Curtis reefs with other fringing reefs in the southern sections of the Great Barrier Reef. The overall average hard coral cover of Port Curtis reefs was similar to that recorded at Shoalwater Bay (located north of Rockhampton), but higher than recorded at the Sir James Smith Group and Northumberland Island. These reefs lie within the area between Mackay and Port Clinton, which experiences a maximum tidal range of >5 m, compared to a maximum tidal range of ~4 m at Port Curtis. Ayling *et al*. (1998) argue that sediment movement and mobilisation within the 'strong tide zone' of the central Queensland coast is more likely to be responsible for the low coral cover in this area than lower ambient water temperatures.

Hard coral cover within Port Curtis was also consistent with patterns observed in the broader region at an individual reef scale. For example, surveys by van Woesik (1992) at 12 locations in the broader bioregion recorded hard coral cover values ranging from 5.3% around Percy Islands, to 41% at Prudloe Island. Shoalwater Bay, which like Port Curtis is a nearshore turbid water environment, had hard coral cover values ranging from 7.3% to 66.2%, with 10 of the 17 sites sampled having an average hard coral cover of >40% (Ayling *et al*. 1998). At Port Curtis, two of the 10 sites sampled had hard coral cover >40%, and minimum and maximum hard coral cover values were less than recorded at Shoalwater Bay (1.5 to 47.5%).

There were also differences in the types of corals dominating on reefs. Acroporids dominated at only one of the sites sampled in Port Curtis (Manning Reef), whereas *Turbinaria* dominated or-co-dominated at seven of the 10 sites. *Pocillopora* was not common, but did dominate or co-dominate at two sites. *Faviid* corals were also uncommon, but did occur at most sites within the study area. At Shoalwater, Acroporids were found to dominate on all but one reef, and Turbinaria was had a grand mean cover of 6.8% compared to 7.6% at Port Curtis. Two other hard coral taxa were recorded in moderate to high numbers at Shoalwater but not recorded at Port Curtis, namely *Seriatopora* and *Montipora* species.

Table 4-3 Hard coral cover on Great Barrier Reef fringing reefs (modified after Ayling *et al*. 1998)

Region	Date	Latitude °S	No. sites	Hard coral cover	
				Mean	SD
Hamilton Island	Mar 1995	20.3	6	54.4	5.7
Sir James Smith Group	1991	20.7	56	22.0	n/a
Northumberland Island	1991	21.5	20	11.7	n/a
Shoalwater Bay	Dec 1995	22.3	34	37.8	16.2
Keppel Islands	1991	23.2	8	54.3	n/a
Port Curtis	Oct 2009	23.8	10	31.7	19.64
North Passage	Oct 2009		4	39.4	11.45
West and South Facing Island	Oct 2009		4	38.3	17.86
Western islands	Oct 2009		2	3.6	3.78

Macroalgae Community

Macroalgae cover, which is also regulated by ambient light levels, varied greatly among sites from 24 to 63% (mean = 42.5% ± 11.71 s.d.). Macroalgae numerically dominated the reef benthos at most sites, with highest macroalgae cover recorded at the two most turbid sites. However incidental observations indicated that the macroalgae zone at these sites was restricted to the upper few meters of the water column.

Assemblages were comprised of a range of brown (predominantly *Padina*), green (*Caulerpa, Halimeda*) and red (commonly *Asparagopsis,* as well as foliose and encrusting coralline species) macroalgae species. *Asparagopsis taxiformis* was recorded at all sites and numerically dominated or co-dominated at eight of the 10 sampled sites. This is a relatively common species in nearshore turbid environments in Queensland (Cribb 1996; Huismann 2000). One site (Oaks North) was numerically dominated by the brown alga *Padina* (16% cover), together with a wide variety of other macroalgae taxa. Small 'turf' algae was moderately abundant at most sites, most notably Rocky Point North and Rocky Point South (28-30% cover).

It is notable that the brown alga *Sargassum* was not a conspicuous element of the benthic flora of Port Curtis. On fringing reefs elsewhere in the bioregion, *Sargassum* is typically the most abundant macroalgae species (e.g. McCook 1996; 1997; Ayling et al. 1998; EHMP 2006), and is thought to have a strong influence on reef assemblage structure (McCook 1996; 1997). It is unclear why *Sargassum* was not a distinctive feature of the Port Curtis reef flora given the apparent presence of suitable habitat here, but may be a consequence of herbivory.

Other Taxa

A range of other soft corals and other epifauna species typical of reef environments in the broader region (e.g. Ayling *et al*. 1998; Rasheed *et al*. 2003) were recorded in Port Curtis. Most of these taxa were heterotrophic filter-feeders, and are not entirely reliant on light (autotrophs) to meet their energy requirements. The periodic low light levels associated with resuspended particles, together with periodic freshwater inflows, is likely to prevent extensive development of reef building corals and other autotrophic species. By contrast, the high phytoplankton biomass would provide a plentiful food resource for heterotrophic particle feeders.

The major influences on reef community structure within Port Curtis have not been examined to date. However, grazing (e.g. by sea urchins), inter-species competition and potentially nutrient availability could have a strong influence on these spatial patterns of macroalgae and other reef components. Further work would be required to assess the proximal controls of reef communities, and the spatial and temporal scales at which that these controls operate.

4.3 Management Implications

Deepwater rubble reef assemblages occur throughout Port Curtis, including areas within and directly adjacent to navigation channels. Maintenance and capital dredging would result in both direct (i.e. physical removal of reef habitat and assemblages) and indirect disturbance (i.e. turbid plume generation and associated reduced light and increased sedimentation and suspended solid concentrations) to reef assemblages. Potential stress mechanisms associated with turbid plume generation include:

- Reduced ambient light levels resulting in reduced photosynthesis in plants (including symbiotic algae in some hard corals);
- High rates of sedimentation leading to smothering of benthic flora and fauna; and
- High suspended solid concentrations resulting in physiological stress to filter-feeding organisms and gill clogging.

Despite this, Rasheed *et al*. (2003) recorded high density benthic macroinvertebrate communities around the maintained channels within the port from South Channel to Targinie Channel near Fishermans Landing. Rasheed *et al*. (2003) described these communities as “some of the most diverse and densest mapped in the deepwater survey area”. In the absence of a pre-Port development baseline it is not possible to determine how these reefs habitats and assemblages have been altered by dredging activities. However, in gross terms, it is apparent that dredging has not resulted in broad-scale loss of reef habitats or assemblages from the Port area.

The sensitivity of reef environments and assemblages to dredging-related impacts has not been studied in Port Curtis to date. Reefs immediately adjacent to maintained channels contain a range of taxa that are typically considered to be sensitive to turbid plume impacts, including low density hard and soft coral assemblages, as well as shallow water macroalgae beds. It is also evident however that these areas represent marginal habitat for many of these species. As discussed, the low hard coral cover and small size of coral colonies are likely to be a consequence of periodic disturbance and high turbidity levels. However, it is probable that prolonged exposure of corals, macroalgae and other reef taxa to dredge plumes, particularly during periods of naturally high turbidity, could lead to stress and possibility mortality of some species.

Reef environments in comparatively less turbid areas of Port Curtis, such as those around North Passage and fringing the western and southern margins of Facing Island, are likely to be at more sensitive to turbid plume impacts than the naturally turbid nearshore areas. These areas contain large areas of hard coral, including many species that are intolerant of prolonged exposure to high turbidity.

There are some available data describing tolerances of a small number of the more common nearshore coral species to elevated turbidity levels (e.g. Cooper *et al*. 2008). The likelihood of dredge-generated turbid plumes at these concentrations reaching the shallow water reefs of Port Curtis is presently under investigation.

5 CONCLUSIONS AND RECOMMENDATIONS

This study represents the first evaluation of the biological characteristics of nearshore reef assemblages of Port Curtis. This study constitutes a baseline dataset which could be used to assess future changes in reef habitats, communities and ecological values. The key findings of the present study are:

- The benthic reef fauna and flora assemblages of Port Curtis live within the constraints imposed by variable water (and air) temperature range, large tidal range, strong tidal currents and low light levels and associated high suspended solid concentrations. Most light-dependant reef building corals, seagrass and seaweed species therefore occur from the lower intertidal to a depth not usually exceeding 2 m below low water datum.
- Reefs located in North Passage and along the western side of Facing Island typically had high hard coral cover, with a maximum value of >47% cover (mean = 39%).
- At the two nearshore turbid fringing reef sites (Turtle and Diamantina Islands) hard coral was low (average = 4%), and incidental observations indicated that coral colony size was typically low (<15 cm diameter). This is possibly a consequence of frequent disturbance (floods, storms), as well as low growth and/or recruitment rates due to high sedimentation rates, low light levels and /or low water temperatures.
- Hard coral cover within Port Curtis was consistent with patterns observed at other fringing reefs within the broader region (e.g. Shoalwater, Percy Islands, and Prudloe Island).
- Macroalgae cover, which is also regulated by ambient light levels, varied greatly among sites from 24 to 63% (mean = 42.5% ± 11.71 s.d.). Macroalgae numerically dominated the reef benthos at most sites, with highest macroalgae cover recorded at the two most turbid sites. However incidental observations indicated that the macroalgae zone at these sites was restricted to the upper few meters of the water column.
- A range of other soft corals and other epifauna species typical of reef environments in the broader region were recorded in Port Curtis. Most of these taxa were heterotrophic filter-feeders, and are not entirely reliant on light (autotrophs) to meet their energy requirements. The periodic low light levels associated with resuspended particles, together with periodic freshwater inflows, is likely to prevent extensive development of reef building corals and other autotrophic species.
- Deepwater rubble reef assemblages occur throughout Port Curtis, including areas within and directly adjacent to navigation channels. Maintenance and capital dredging would result in both direct and indirect disturbance to reef assemblages. In gross terms, it is apparent that dredging has not resulted in broad-scale loss of reef habitats or assemblages from the Port area.

The sensitivity of reef environments and assemblages to dredging-related impacts has not been studied in Port Curtis to date. This remains a significant information gap from an impact assessment perspective.

It is also important to note that this study represents a one-off snap-shot of communities at one point in time, and that there is likely to be changes in community structure in response to (i) seasonal changes in communities; (ii) episodic events such as floods or storms; and (iii) natural, successional changes in structure. It is recommended that monitoring be undertaken at 2-4 year intervals to assess long-term changes in community structure.

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APPENDIX A: WAYPOINTS FOR SAMPLING LOCATIONS

WGS 84

Location	**Northing**	**Easting**
Bushy 1	330431	7362637
Manning 1	332367	7360732
Manning 2	332693	7360483
Gatcombe 1	334355	7358002
Bastard Reef	333711	7358214
Rocky 3	333286	7359228
Rocky 1	333517	7358669
Rocky 2	333557	7358676
Facing 1	329901	7370933
Farmers 2	329399	7370375
Farmers 1	328705	7370023
Oaks 1	329305	7370966
Oaks 2	329297	7371269
Rat 1	329076	7371003
Farmers 3	329089	7369785
Farmer 4	328721	7370083
Bommie	328740	7370096
Rat 2	328584	7370598
Turtle 1	323333	7366367
Turtle 2	323328	7366477
Turtle 3	323315	7366653
Turtle 4	323223	7366519
Turtle 5	323051	7367450
Quoin Island 1	325339	7366890
Diamantina 1	322543	7365661
PICNIC IS 1	321257	7365345
Witt Is 1	320929	7366294
Curtis Island 1	316376	7369008
Curtis Island 2	316577	7368812
Curtis Island 3	317753	7367853
Curtis Island 4	318048	7367368
Curtis Island 5	318831	7366801
Tide Island	319269	7366520
Curtis Island 6	319210	7366850
Tide Island 2	319377	7366609
Tide Island 3	319502	7366844
Reef	319889	7367012
Knoll1	316871	7368328
Knoll 2	316912	7368274
Knoll3	316966	7368173
Knoll 4	318793	7366676

APPENDIX B: MDS ORDINATION INTERPRETATION

Box 1 – Interpreting a n-MDS ordination or plot

A Non-metric Multidimensional Scaling (n-MDS) plot provides a visual representation of patterns in similarity in assemblages between samples (transects in this case). The analysis provides the 'best' representation of patterns in the similarity of assemblages in a simple, two-dimensional plot.

In simple terms, the closer samples (the coloured points) are together within the ordination space, the more similar they are to each other. Conversely, samples that are far apart tend to have different assemblages. In the ordination, samples have been coded according to the site (coloured dots). Coding samples provides a simple visual tool for exploring patterns in similarity (and dissimilarity) in assemblage structure among samples, sites and depths.

In interpreting the n-MDS the main things we consider are:

(i) Whether there is a tendency for samples to group by factor (site or location). This provides a means of determining the degree of small-scale variations in assemblages within sites or depths. This is useful for examining the degree of patchiness among samples, and also the adequacy of the sampling methodology in reducing errors produced by small-scale patchiness.

(ii) The degree of variation (similarity dissimilarity) between different factors (sites). This provides a means for determining, for example, whether there is a gradient in assemblage structure among different sites or locations. This also allows an examination of the spatial scale that differences in assemblages operate, i.e. whether the largest differences in assemblages occurred among sites, or small-scale differences among samples within sites.

(iii) The plot also shows a 'stress' value which ranges from 0 to 0.3. This value provides a means of assessing how well the plot represents patterns in higher dimensional space. A stress value of <0.15 is optimal, whereas stress values >0.25 indicate that the plot is probably not a good representation patterns in higher dimensional space, and should be used with caution.

APPENDIX C: SIMPER ANALYSIS RESULTS

	Group Facing North	Group Facing West				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Padina sp.	2.13	0.39	3.02	2.21	7.11	7.11
Acropora - branching (often A. robusta)	1.56	1.32	2.36	1.71	5.55	12.65
Soft coral	2.01	1.44	2.06	1.15	4.85	17.51
Asparagopsis taxiformis	2.16	1.37	1.99	2.05	4.69	22.2
Turbanaria sp.	2.39	1.72	1.84	2.41	4.32	26.52
Other fleshy green algae	1.2	0.65	1.67	1.4	3.93	30.45
Other fleshy brown algae	1.44	0.79	1.55	1.31	3.64	34.09
Pocillopora sp	0.79	1.22	1.47	1.43	3.46	37.55
Rubble/rock with turfing algae	2.05	2.45	1.47	1.67	3.45	41
Acropora - Tabulate	1.06	0.72	1.47	1.64	3.45	44.45
Acropora millepora	0.85	0.27	1.42	1.02	3.35	47.8
Foliose coralline algae	0.84	0.82	1.42	2.32	3.34	51.13
Segmented red algae	0.47	0.65	1.4	1.01	3.3	54.43
Acropora - Digitate	0.42	0.98	1.38	1.34	3.24	57.67
Alcyonium sp.	0.7	0.66	1.37	1.26	3.23	60.91
Encrusting hard coral	0.59	0.75	1.32	1.13	3.1	64
Bare rock/ rubble (no sediment)	0.81	0.61	1.28	1.27	3.02	67.02

	Group Facing North	Group West Bay				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Soft coral	2.01	0	3.87	1.85	7.86	7.86
Turbanaria sp.	2.39	0.6	3.32	4.94	6.76	14.62
Acropora - branching (often A. robusta)	1.56	0	2.9	3.25	5.9	20.52
Dead coral with turfing algae	1.54	0	2.89	9.38	5.87	26.39
Padina sp.	2.13	1.06	2.64	1.32	5.37	31.76
Halimeda	0.1	1.46	2.62	2.2	5.33	37.09
Asparagopsis taxiformis	2.16	3.31	2.18	3.3	4.43	41.52
Other fleshy green algae	1.2	1.04	2.11	1.21	4.3	45.82
Acropora - Tabulate	1.06	0	1.95	1.19	3.96	49.78
Acropora millepora	0.85	0	1.57	0.9	3.2	52.98
Bare rock/ rubble (no sediment)	0.81	0	1.47	1.15	3	55.98

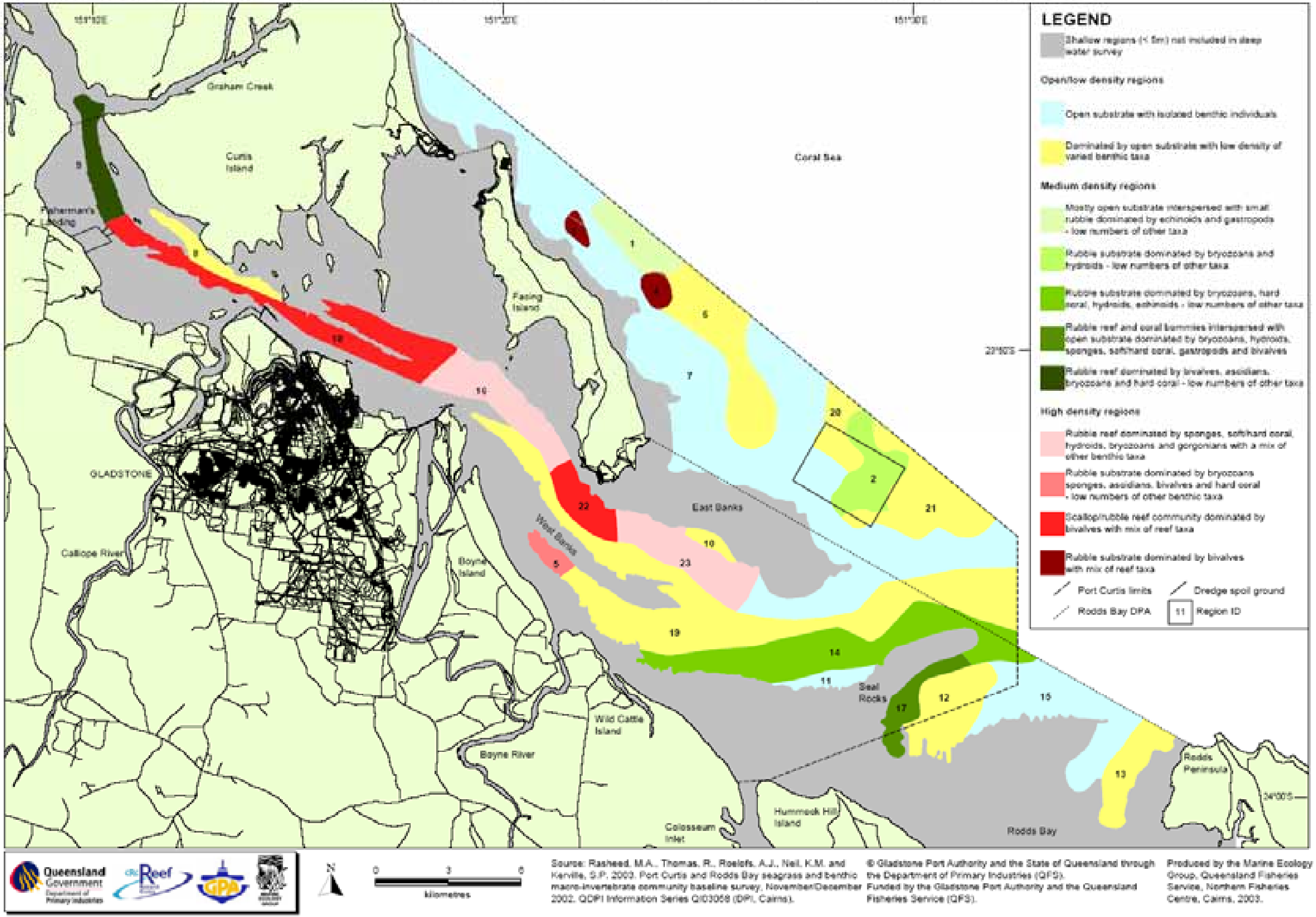
	Group Facing West	Group West Bay				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Asparagopsis taxiformis	1.37	3.31	4.13	1.79	7.39	7.39
Dead coral with turfing algae	1.71	0	3.58	2.21	6.4	13.79
Halimeda	0	1.46	3.05	2.38	5.45	19.24
Acropora - branching (often A. robusta)	1.32	0	2.86	0.82	5.11	24.34
Soft coral	1.44	0	2.78	1.35	4.96	29.31
Turbanaria sp.	1.72	0.6	2.37	1.07	4.23	33.54
Padina sp.	0.39	1.06	2.09	1.06	3.74	37.28
Other fleshy green algae	0.65	1.04	2.08	1.49	3.72	41
Pocillopora sp	1.22	0.26	2.08	1.34	3.71	44.71
Segmented red algae	0.65	0.75	2.01	1.14	3.59	48.29
Acropora - Digitate	0.98	0.14	1.91	1.4	3.41	51.71
Other fleshy brown algae	0.79	1.45	1.86	1.36	3.33	55.04
Rubble/rock with turfing algae	2.45	2.72	1.68	1.62	3	58.04

APPENDIX D: SUBTIDAL BENTHOS MAP

(Source: Rasheed *et al*. 2002)

Map Overpage

MAP 10. Deep water benthic macro-invertebrate regions in Port Curtis and Rodds Bay, November/December 2002



Source: Rasheed, M.A., Thomas, R., Roelofs, A.J., Neil, K.M. and Kerville, S.P. 2003. Port Curtis and Rodds Bay seagrass and benthic macro-invertebrate community baseline survey, November/December 2002. QDPI Information Series QI03058 (DPI, Cairns).

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