FINAL REPORT

GLNG Marine Ecology Technical Report

Prepared for

Santos Ltd

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42626220

URS

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Abbreviations

Abbreviation	Reference
AIMS	Australian Institute of Marine Science
AVTAS	Australian Institute of Marine Science Video Transect Analysis System
CRC	Cooperative Research Centre
DEWHA	Department of Environment, Water, Heritage and the Arts
DPI&F	Department of Primary Industries and Fisheries
EIS	Environmental Impact Statement
EPBC	Environment Protection and Biodiversity Conservation Act 1999
GBRMPA	Great Barrier Reef Marine Park Authority
GLNG	Gladstone Liquefied Natural Gas
GPS	Geographical Positioning System
HSEP	Health, Safety and Environmental Plan
LAT	Lowest Astronomical Tide
LNG	Liquefied Natural Gas
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MOF	Marine Offload Facility
MSL	Mean Sea Level
PPT	Part per thousand
Santos	Santos Limited
SOCI	Species of Conservation Interest
URS	URS Australia

Executive Summary

This report details the results of a marine ecological assessment of Port Curtis conducted by URS Australia. The intertidal and subtidal habitat field survey, conducted between May and June 2008, investigated a range of sites within Port Curtis to provide sufficient information to describe the local and sub-regional intertidal and subtidal environment. During the surveys, forty-five intertidal sites and six subtidal sites were chosen to include representative areas of habitats from locations along the western coastline of Curtis Island (from Boatshed Point to Graham Creek) and in the Kangaroo Island/Friend Point area. Locations such as China Bay, the un-named bay between Hamilton Point and Boatshed Point, Laird Point, Graham Creek and Friend Point were visited to incorporate sites in areas that may potentially be impacted by the proposed Santos Gladstone Liquefied Natural Gas (GLNG) facility and associated infrastructure (e.g. product load out jetty), potential spoil reclamation area, bridge, pipeline and access roads.

Results from the study indicate that the main intertidal habitats in the study area are:

- Extensive areas of mudflats with very fine mud dominated the lower intertidal habitats of almost all sites. Soft mudflats up to 300 m wide were exposed at low tide in areas seaward of the mangrove shoreline at locations such as China Bay and the Kangaroo Bay/Friend Point area.
- Mangrove communities dominated the mid to upper intertidal habitats within the small embayments along the south-west coast of Curtis island. Low dense *Rhizophora stylosa* forests occurred across most of the mangrove zone.
- Rocky shores in between the mangrove embayments that had a high silt content occurred at the mid to upper intertidal zone (e.g. locations such as Hamilton Point).
- Saltflats and salt marshes occurred on tidal flat areas landward of the mangrove zone. High soil salinities precluded macrobiota from living in this habitat except in some shallow drainage lines. While algal mats and sparse areas of halophytic shrubs and grasses (e.g. *Sporobolus virginicus* or salt couch) occurred amongst the salt flats they were largely devoid of vegetation.
- Limited areas of sand beaches and low-tidal sand flats (e.g. Laird Point).

The main subtidal habitats in the study site are:

- Coarse sand channels with shell fragments in between Friend Point and Laird Point;
- silted embayments associated with low-tidal mudflats;
- silt/rubble slope south of China Bay; and
- rocky headlands with rock walls adjacent to deep channels such as Hamilton Point and south of the rubble slope.

Intertidal habitats potentially affected by the proposed LNG infrastructure are widely represented within Port Curtis (and broader regional areas). Mangrove habitats were dominated by low forests and dense thickets of *Rhizophora stylosa* (Stilt Mangrove) which, in most locations, occurred across almost the entire mangrove zone from the seaward edge to its landward margin. In locations where the mangrove zone abuts salt flats, a landward mangrove margin consisted of a narrow zone of shrubland communities dominated by *Ceriops australis* (Smooth-fruited Yellow Mangrove) and *Avicennia marina* (Grey Mangrove). In locations where the mangrove zone abuts the hinterland (usually Eucalypt woodland), a narrow band approximately 2-3 trees wide of mixed species such as *Excoecaria agallocha* (Milky Mangrove), *Aegiceras corniculatum* (River Mangrove), *Lumnitzera racemosa* (White-flowered Black Mangrove), *Bruguiera gymnorhiza* (Large-leafed Orange

Mangrove), *Osbornia octodonta* (Myrtle Mangrove), *Xylocarpus moluccensis* (Cedar Mangrove), *Ceriops australis* and *Avicennia marina* occurred. Of the 14 mangrove species previously recorded from the Port Curtis area, 11 were recorded during the June 2008 survey. The mangrove species recorded from the survey were consistent with those species recorded from other intertidal surveys in the Gladstone area.

The rocky shore fauna was dominated by encrusting oyster and barnacle assemblages in the mid tidal zone. Other species regularly observed included a low diversity assemblage of nerites, littorinids, chitons and grapsid crabs. A total of 57 species or groups of invertebrate fauna were recorded from intertidal habitats, mostly from low-tidal mudflats, mangroves and rocky shores. Molluscs were the most diverse group taxonomically (57 species, including 31 species of gastropods, 25 bivalves and one chiton). Other groups represented were crustaceans (18 species and groups), echinoderms (2 species, each represented by a single individual) and one species of polychaete found at a single site. On the basis of the survey diversity appears to be low. This is attributed to low habitat diversity. In particular, rocky shores had very high silt content, and where they occurred they did not extend into the lower parts of the intertidal region. Instead, the lower intertidal was entirely comprised of very silty mudflats with low biodiversity.

Fifteen species of molluscs and seven species or species groups of crustaceans were found in the mangroves. The actual number of taxa of both groups is in fact higher, as no effort was made to excavate crab holes or undertake destructive sampling of the mangrove trees to record shipworms (bivalve molluscs) that burrow into the trees. Low species diversity was observed and the reasons for low densities of these organisms in the study area are not clear. Three species of the periwinkle genus *Littoraria* were recorded, but only as a few individuals, whereas in other areas they can occur by the hundreds. A single individual each of two species of fiddler crabs (*Uca*) was found. Again, these species can often be found in very high densities on the banks of tidal creeks. Very high numbers were in fact seen on the banks of the Gladstone marina.

Those taxa that have been identified to species are in two biogeographical groups. The majority are widespread Indo-West Pacific species that occur widely in northern Australia. There were a few southern Australian species near their northern geographical limit. No species were found that are limited to the east coast of the continent, occurring in Queensland and New South Wales. None of the invertebrates identified are restricted to the study site; all have widespread distributions outside the Port Curtis area.

Subtidal species distribution and abundance that comprise the benthic communities found within Port Curtis vary according to the substrate type, currents and the prevailing environmental conditions. Macroalgae, soft corals and gorgonians were prevalent at the bridge/pipeline crossing and hydroid zoanthids, sponges and gorgonians dominated the rock wall at Hamilton Point.

The silted embayments of China Bay and the southern side of Hamilton Point towards Boatshed Point contained less number and diversity of species. Pennatulacids and gorgonians were present in very sparse cover. The site was largely devoid of visible marine species however, numerous small and large burrows were apparent.

The Hamilton Point subtidal site contained the highest level of marine species diversity and abundance of all sites surveyed. Percentage cover ranged from approximately 2 – 40% and was dominated by dense stands of stinging hydroid zoanthids. Encrusting sponges and gorgonians were interspersed among the colonies of hydroid zoanthids at Hamilton Point. Colonies of hydroid zonathids were also prevalent at the rubble slope site.

Soft corals and gorgonians were common to both locations, with a higher percentage cover at Hamilton Point. Soft corals often prefer areas that are exposed to stronger currents.

Dugong or turtles were not sighted during the study. A pod of approximately six dolphins identified as Indo-Pacific Humpback dolphins were sighted at Hamilton Point during the survey.

Executive Summary

A total of 45 species of birds were recorded during the survey including four species of shorebirds (includes migratory wading birds), seven species of waterbirds/seabirds, six species of mangrove specialists (i.e. birds mostly confined to mangroves) and 28 other species. The greatest diversity of avifauna was recorded along the mangrove/hinterland margin with mixed terrestrial dwelling species and birds that typically inhabit mangroves. A low diversity and abundance of migratory wading birds (EPBC listed) were recorded on tidal flats.

1.1 Study Background and Objective

URS Australia has been commissioned to coordinate environmental studies related to the Environmental Impact Statement (EIS) being prepared for the LNG project. Infrastructure associated with the GLNG facility includes a road access and bridge/pipeline crossing from the mainland to the proposed GLNG facility site near China Bay. This includes a bridge structure between Friend Point and Laird Point, Curtis Island and a product load out jetty at China Bay. The proposed road, bridge/pipeline crossing and LNG facility are located within the Port of Gladstone, the southern-most port adjacent to the Great Barrier Reef Marine Coastal Park and within the Great Barrier Reef Marine Park (GBRMP) World Heritage Area.

To help evaluate the ecological significance of the area and assess the potential impacts from the project on marine habitats, a survey of intertidal and subtidal habitats was undertaken between May and June in 2008.

This section provides a description of the marine ecological communities and benthic habitat within the proposed Santos GLNG project footprint and surrounding area. The seagrass distribution, mangroves, saltmarsh and mudflat intertidal communities are discussed as well as a description of the subtidal communities and benthic habitats present.

The marine components of the GLNG project include potential impacts arising from:

- construction of the access road and pipeline on the mainland to Friend Point;
- construction of the transmission pipeline marine crossing from Friend Point across 'The Narrows' to Laird Point; and
- construction of the LNG loading jetty and Marine Offload Facility (MOF) at China Bay, Curtis Island.

The objective of this assessment is to describe the marine habitats that may be impacted by the GLNG proposal and how they are represented within Port Curtis and broader regional areas.

An overview of the field surveys conducted, the methods used to describe the existing marine environmental values of the area, results including species descriptions and discussion are provided in this assessment.

The outcomes of this assessment will be applied to:

- describe the potential adverse and beneficial impacts of the proposed project on the identified marine environmental values;
- develop environmental protection objectives for the marine environment, along with the standards and measurable indicators to be achieved; and
- examine viable alternative strategies for managing marine impacts.

1.2 The Study Area

Port Curtis is located on the central Queensland coast just south of the Tropic of Capricorn, eastern Australia and adjacent to Gladstone City. Biogeographically, Port Curtis falls within the Shoalwater Coast bioregion as defined in the *Interim Marine and Coastal Regionalisation for Australia* (IMCRA Technical Group 1998). Port Curtis is a natural deepwater embayment that is protected from the open ocean by Curtis and Facing Islands. Coastal geomorphology in the main study area is characterised by a partially enclosed embayment and shallow estuaries, including small, continental rocky islands, intertidal flats and estuarine islands. Port Curtis estuary is a composite estuarine system that includes the Calliope and Boyne Rivers, The Narrows, Auckland Creek and several smaller creeks and inlets that merge with deeper waters to form a naturally deep harbour protected by southern Curtis Island and Facing Island. Elevated natural turbidity occurs within the shallow marine and estuarine waters with significant input of freshwater and alluvial sediments from the Boyne and Calliope Rivers.

The land adjacent to Port Curtis features over 1,000 km^2 of coastal hinterland, wetlands and estuarine waters with marine and coastal zone wetlands covering an area over 300 km^2 (McKinnon *et. al.* 1995). Mangrove, seagrass, salt marsh, rocky and sandy shoreline, open water and subtidal benthic habitats support varied biological communities. Much of the estuarine near-shore is lined by dense stands of mangrove, mainly *Avicennia marina* and *Rhizophora stylosa* while bare soft sediments cover most of the remaining bedforms (Currie and Small, 2004).

The City of Gladstone has become one of the major industrial centres of Queensland due to its close proximity to the coal fields and deep water access port facilities (McKinnon *et al*. 1994). The area is heavily industrialised along the western shoreline and otherwise surrounded by large tracts of natural intertidal wetlands (Connolly *et al*. 2006). Academic and government research institutions have recently become active in the area resulting in the delivery of current knowledge, however are limited on the values of Port Curtis intertidal wetlands (Connolly *et al.* 2006).

1.2.1 Survey Methodology

The intertidal and subtidal areas within the study site were surveyed between May and June 2008. Baseline marine ecological information was described for the areas potentially impacted by the construction of the bridge/pipeline crossing and LNG facility as part of the GLNG proposal.

The marine habitats and communities are characterised by the following:

- seagrass communities;
- mangrove communities;
- saltmarsh and mudflat communities;
- sand channel communities;
- rocky reef and rubble slope communities; and
- silted embayment habitat.

A helicopter survey of intertidal seagrass distribution at Port Curtis was undertaken on 4 May 2008 at spring low tide. During the survey fixed GPS coordinates using a differential geographic positioning system were taken every 50m along the intertidal and subtidal boundaries of the mainland and Curtis Island. Video footage taken from the helicopter provided information on the zonation of intertidal saltmarsh, mud flats and mangrove communities to assist in the development of the intertidal and subtidal surveys.

The intertidal mangroves, saltmarsh, mudflats and rocky substrate habitats were described using aerial photography, video footage, navigation charts and field survey techniques during June 2008.

Species of conservation and ecological significance sighted within Port Curtis were recorded during the marine assessment.

The subtidal sandy substrate, silted embayment, rubble slope and rocky headland habitats were described using underwater photographs, underwater video footage, navigation charts and marine survey techniques during May 2008.

The methodologies employed to assess the marine habitat were aligned where possible with existing monitoring programs in the areas, such as the Port Curtis Intertidal Monitoring conducted by the Cooperative Research Centre (CRC) for Coastal Zone Estuary and Waterway Management (CRC Coastal) and the Department of Primary Industries and Fisheries (DPI&F).

Section 2 Intertidal Habitats

2.1 Intertidal Habitat Survey

2.1.1 Scope of Work

The intertidal habitat field survey investigated a range of sites along the south-west coast of Curtis Island and adjacent Friend Point area to provide sufficient information to describe the local and sub-regional intertidal environment. An intertidal seagrass survey was conducted by helicopter to investigate seagrass distribution within Port Curtis.

The scope of the survey was restricted to the intertidal zone, i.e. the area between high and low water. Information collected during the field survey provided an indication of the diversity of habitats present and the composition and abundance of the biotic communities and dominant taxa present within each habitat. Seagrass distribution was assessed for Kangaroo Island/Friend Point area and Curtis Island between Laird Point and Hamilton Point during the May helicopter traverse at low spring tide. The information gathered on seagrass distribution and identification provided an indication of the status of seagrass beds at this time of year in relation to the information available from the long term seagrass monitoring program conducted in Port Curtis by the Department of Primary Industries and Fisheries and the Port of Gladstone (Rasheed *et al.*, 2007).

2.1.2 Site Selection

The major habitats and physical features discernible from aerial photography, video footage and navigation charts were identified to develop the survey programme and provisionally select sites for inspection in the field. A range of sites representative of the main habitats was selected for investigation. These sites were visited on foot at mid to low tides to provide sufficient information to describe the local and regional intertidal environment.

During the survey, 45 sites were chosen to include representative areas of intertidal habitats from locations along the western coastline of Curtis Island (from Boatshed Point to Graham Creek) and in the Kangaroo Island/Friend Point area in the north, and included representative areas of the major intertidal habitats (low-tidal mudflats, rocky shorelines, mangroves and salt flats).

Locations such as China Bay, the un-named bay between Hamilton Point and Boatshed Point, Laird Point, Graham Creek and Friend Point were visited to incorporate intertidal sites in areas that may potentially be impacted by the proposed GLNG facility and associated infrastructure (e.g. product load out jetty), bridge, pipeline and access roads. The locations of the sites are shown in Figures 2.1 & 2.2. In addition, boat traverses were made into the tidal creek systems of Targinie Creek and Rawbelle Creek (see Figure 2.2) to obtain an overview of habitats present.

Descriptions and coordinates for each site, together with information collected on habitat characteristics, intertidal communities (invertebrate fauna, flora) and birds are presented in Appendix A.

2.1.3 Survey Techniques

The intertidal survey sites were visited during the 4-5 hour period about low tide, when access to the lower portions of the intertidal zone was possible. Due to their position on the intertidal gradient, many of the landward mangrove and salt flat sites were not subject to tidal inundation from the high tide during daylight hours but were partly wet during the night time high tide.

Seagrass meadows in the Port Curtis area were described during a helicopter survey at spring low tide on 4 May 2008. Helicopter traverses were conducted over the mud flats of Kangaroo Island/Friend Point, the lower reaches of Graham Creek to Laird Point, along the western side of Curtis Island to Hamilton Point and over Tide Island (Figure 2.3). Fixed GPS coordinates were taken along the interface between the intertidal and subtidal zone. Intertidal seagrass distribution was observed and recorded by written description, photography and video footage. The helicopter hovered low over patches of seagrass for closer observation of density and species validation where possible.

Intertidal areas were accessed via small dinghy (tender to the main Capline Charters vessel) and field personnel were dropped at suitable entry/exit locations (e.g. rocky shorelines to avoid soft mudflats) and then traversed on foot to sites.

At some embayments (e.g. China Bay) a number of sites were orientated across the intertidal gradient to form a transect that included the range of habitats (i.e. a transect approximately orientated perpendicular to the shoreline) and thus provided representative examples of the relationship between habitat zonation, geomorphic features, substrate and salinity conditions. Intertidal community and habitat information was recorded in the form of written observations and still photographs. The following information was recorded at each site and is presented in Appendix A:

- Written description and photographs of the intertidal habitats present;
- GPS coordinates and position of transects;
- Substrate characteristics and porewater salinity as determined by auger excavation to approximately 1 m below ground level;
- Diversity and abundance of intertidal biota (predominately marine invertebrates such as molluscs and crustaceans) and flora (mangroves, algae) were examined. In mangrove areas, community structure was noted together with the tree species present within the main mangrove habitats or zones;
- Avifauna - bird observations were made and species identified visually or from calls. The main groups of birds present within intertidal areas were shorebirds (a few migratory wading bird species), seabirds (terns, etc.), waterbirds (egrets, herons, etc.), mangrove residents (birds which are predominantly confined to mangroves) and other species that typically reside in the eucalypt woodland immediately landward of the intertidal zone;
- Invertebrate communities were characterised using molluscs, which are the most diverse group in the marine environment, and, to a lesser extent, crustaceans as indicator groups. The dominant, common marine invertebrates were identified in the field using the following references: Allan & Steene (2003) and Gosliner *et al.* (1996) as general references; Coleman (1994) for echinoderms; George & Jones (1982) and Jones & Morgan (1994) for crustaceans; and Lamprell & Whitehead (1992), Short & Potter (1987) and Wells & Bryce (1986) for molluscs. No biological material was collected for genetic studies and no vertebrate specimens were collected; and
- Seagrass was described from visual observation and photographic records. Identification was conducted using DPI&F/CRC baseline survey information (Rasheed *et. al.* 2003).

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N W E S

0 500 1000m

Scale 1:25 000 (A4)
Datum : GDA 94

Intertidal Habitat Survey Site

Gas Transmission Pipeline

Great Barrier Reef Coast Marine Park

Proposed Bridge/Road Buffer

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Client

Project

GLADSTONE LNG PROJECT
MARINE ECOLOGY ASSESSMENT

Drawn: MG | Approved: JB | Date: 24-02-2009

Job No: **4262 6220** | File No: 42626220-g-520.wor

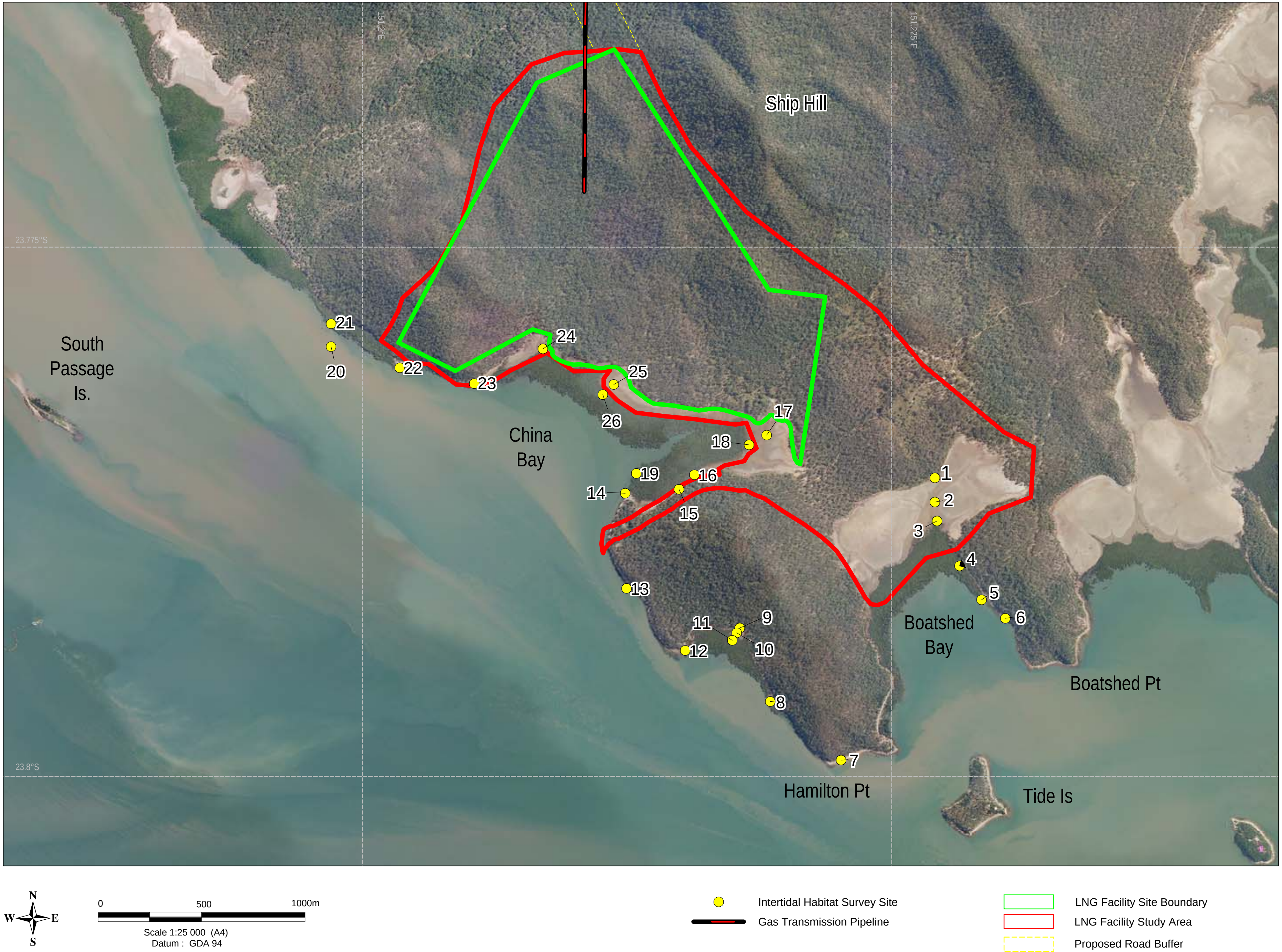
Title

MARINE INTERTIDAL HABITAT SURVEY SITES

Figure: **2.1**

Rev:B

A4



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URS

Client: LNG

Project: GLADSTONE LNG PROJECT
MARINE ECOLOGY ASSESSMENT

Drawn: MG | Approved: JB | Date: 24-02-2009

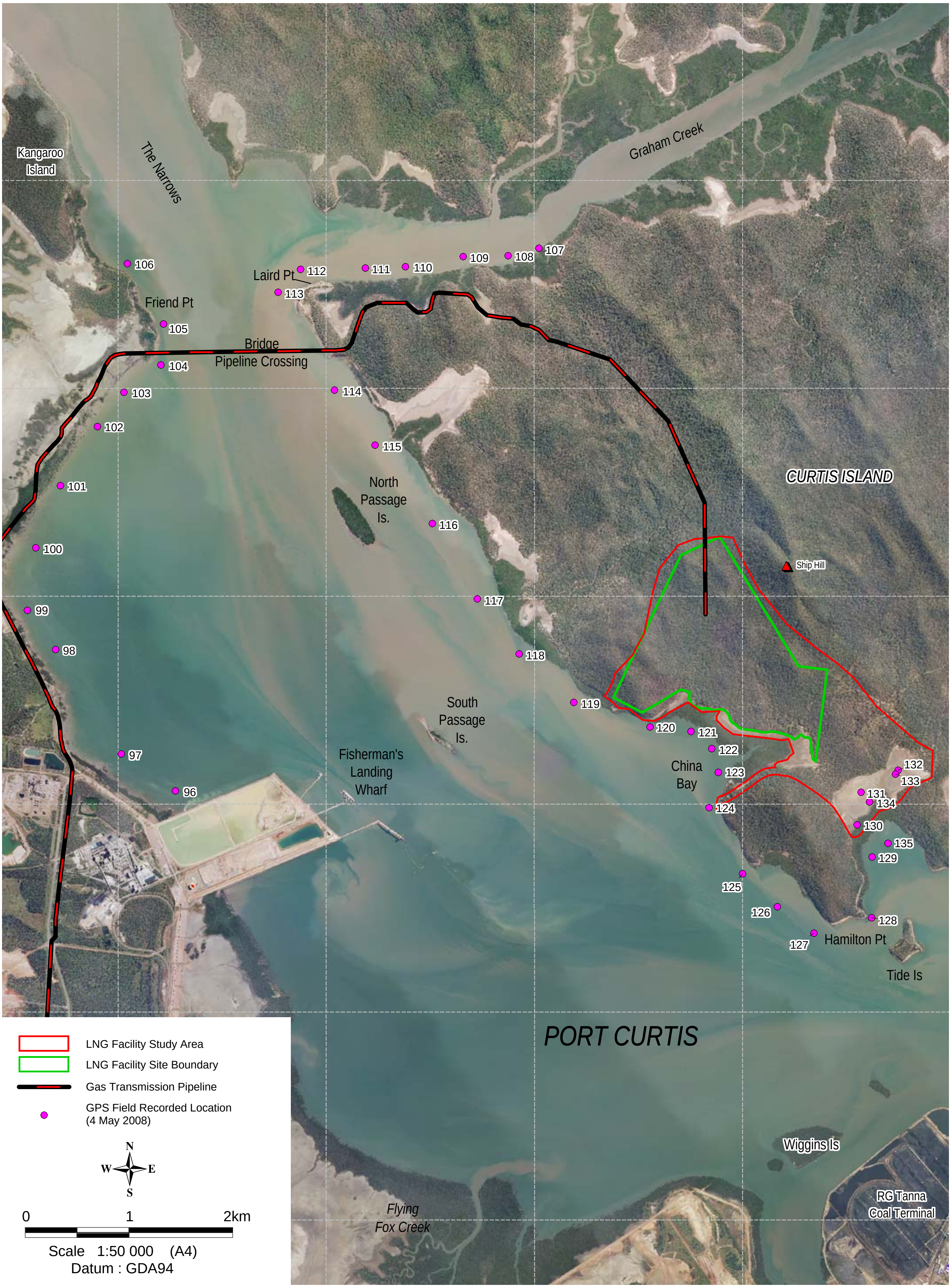
Job No: **4262 6220** | File No: 42626220-g-520.wor

Title: **MARINE INTERTIDAL HABITAT SURVEY SITES**

Figure: **2.2**

Rev:B

A4



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Client	Project	Title
LNG / URS	GLADSTONE LNG PROJECT MARINE ECOLOGY ASSESSMENT	**MARINE SURVEY** **HELICOPTER GPS POINTS**

Drawn: RG	Approved: JB	Date: 03-02-2009	Figure: **2.3**	Rev:B
Job No: **4262 6220**	File No: 42626220-g-554.wor			A4

2.2 Coastal Geomorphology

Intertidal habitats vary according to their orientation within the coastline and the position they occupy on the tidal gradient. The main intertidal habitats in the study area are:

- Low-tidal mudflats (LAT to MSL)
- Mangroves (MSL to ~MHWN-MHWS)
- Rocky shores (MSL to MHWS)
- Salt flats on tidal flat areas landward (~MHWS) of mangroves
- Limited areas of sand beaches and low-tidal sand flats (e.g. Laird Point)

These are convenient categories to use in examining habitats present in the study area, but it should be noted that some are not exclusive. The shorelines can be variable on a small scale and a range of habitats can be present within a localised area. For example, at some sites within a 100 m radius a range of low-tidal mudflat, mangrove and rocky shoreline habitats can occur.

The low-tidal mud flats were generally found at all areas where they occurred further seaward of the mangrove, rocky shore or sandy beach shorelines to varying extents (e.g. ~ 30 to 300 m wide). While mangroves mostly occurred within small embayments and tidal flat settings they also occurred intermittently on rocky shores at mid to upper tidal levels.

2.3 Intertidal Habitats and Communities

The data collected during the June 2008 intertidal habitat survey are presented in summary tables (Tables 2.1, 2.2, 2.3) that allow comparison between the invertebrate fauna and avifauna found in each of the major habitats (Tables 2.1 and 2.2) and the mangrove species recorded and the main coastal sections surveyed (Table 2.3).

Table 2-1 Intertidal Invertebrate Species Identified During the Port Curtis Survey

Species	Common name	Low-tidal Flats	Mangroves	Rocky Shores	Sandy Beaches
MOLLUSCA					
Class Polyplacophora					
Plaxiphora sp.	Chiton			✔	
Class Gastropoda					
Monodonta labio	Top shell			✔	
Turbo cinereus	Turban snail			✔	
Telescopium telescopium	Mudwhelk		✔		
Terebralia semistriata	Mudwhelk		✔		
Cerithidea anticipata	Mangrove snail		✔		
Cerithidea largillierti	Mangrove snail		✔		
Cerithidea cingulata	Mangrove snail		✔		
*Pyrazus ebeninus**	Mud snail			✔	
Nerita balteata	Nerite		✔		
Nerita squamulata	Nerite			✔	
Nerita undata	Nerite			✔	
Bembicium auratum	Periwinkle		✔	✔	
Littoraria filosa	Periwinkle		✔		
Littoraria strigata	Periwinkle		✔		
Littoraria scabra	Periwinkle		✔		
Cerithium trailli	Creeper			✔	
Clypeomorus sp.	Creeper			✔	
Clypeomorus batillariaeformis	Creeper			✔	
Clypeomorus zonatus	Creeper			✔	
Polinices sordidus	Moon snail				✔
Bedeva paivae	Thaid whelk			✔	
Cronia cf. *contracta*	Thaid whelk			✔	
Morula marginalba	Mulberry whelk			✔	
*Murex tribulus**	Murex shell	✔			
Nassarius dorsatus	Dog whelk	✔			
*Melo amphora**	Baler shell	✔			
Haminaea sp.	Opisthobranch	✔			
Ellobium aurisjudae	Ellobiid snail		✔		
Ophicardelus ornatus	Ellobiid snail		✔		
Onchidium sp.	Marine slug		✔	✔	
Class Bivalvia					
Brachidontes sp.	Mussel			✔	
*Botula vagina**	Mussel			✔	
Anadara sp.*	Ark shell	✔			
Acrosterigma sp.*	Cockle				✔
Barbatia sp.	Ark shell			✔	
Saccostrea cuccullata	Oyster			✔	
Saccostrea sp. (on trees)	Oyster		✔		
Chlamys sp.	Scallop			✔	
Isognomon isognomum	Rock oyster			✔	

Species	Common name	Low-tidal Flats	Mangroves	Rocky Shores	Sandy Beaches
Pinctada sp.	Pearl oyster			✔	
Chama sp.	Jewel box shell			✔	
Mactra cf. *parkesiana**	Trough clam				✔
*Trisidos tortuosa**	Ark shell				✔
Solen sp.*	Razor clam				✔
*Geloina coaxans**	Mangrove clam		✔		
*Tellina staurella**	Tellin				✔
Tellina sp. (rounded)*	Tellin				✔
Antigona sp.*	Venerid clam			✔	
*Antigona chemnitzii**	Venerid clam			✔	
Gafrarium sp.*	Venerid clam				✔
Paphia cf. *gallus**	Venerid clam				✔
Placamen sp.*	Venerid clam				✔
*Placamen tiara**	Venerid clam				✔
Venerupis sp.*	Venerid clam				✔
Crustacea					
Alpheid sp.	Snapping shrimp			✔	
Balanid spp.	Barnacle			✔	
Chthamalus sp.	Barnacle		✔		
Grapsid spp.	Shore crab			✔	
Macromedaeus cf. *demani*	Xanthid crab			✔	
Macropthalmus sp.	Sentinel crab			✔	
Mictyris sp.	Soldier crab				✔
cf. *Neosartium meinerti*	Shore crab		✔		
Petrolisthes sp.	Porcelain crabs	✔			
Scopimera inflata	Sand bubbler				✔
Scylla holes**	Mud crab		✔		
Sesarma spp.	Mangrove crabs		✔		
Thalassina squamifera mounds**	Mud lobster		✔		
Thalamita sp.	Swimming crab			✔	
Thalamitoides tridens	Swimming crab			✔	
Uca polita	Fiddler crab		✔		
Uca signata	Fiddler crab		✔		
Xanthid sp.	Crab			✔	
Polychaetes					
Diopatra amboinensis	Tubeworm				✔
Echinoderms:					
cf. *Anthenea* sp.	Starfish				✔
Sea urchin test*	Sea urchin			✔	

* species collected only as dead shells. ** crustaceans recorded only from their characteristic holes in the mud.

Table 2-2 Avifauna Recorded from the Intertidal Habitat Survey

		Low-tidal Mud Flats	Mangroves	Rocky Shores	Salt Flats	Hinterland Margin
Shorebirds						
Charadrius ruficapillus	Red-capped Plover	✓			✓	
Numenius phaeopus	Whimbrel	✓	✓	✓		
Haematopus longirostris	Pied Oystercatcher	✓	✓			
Burhinus grallarius	Beach Stone-curlew	✓				
Waterbirds/Seabirds						
Phalacrocorax varius	Pied Cormorant	✓	✓	✓		
Ardea alba	Great Egret	✓				
Egretta novaehollandiae	White-Faced Heron		✓			
Larus novaehollandiae	Silver Gull	✓				
Sterna caspia	Caspian Tern	✓				
Sterna nilotica	Gull-billed Tern	✓	✓	✓		
Sterna bergii	Crested Tern	✓				
Mangrove Birds						
Geopelia humeralis	Bar-Shouldered Dove		✓			
Chrsococcyx minutillus	Little Bronze-Cuckoo		✓			
Todiramphus chloris	Collared Kingfisher		✓	✓		
Gerygone levigaster	Mangrove Gerygone		✓			✓
Lichenostomus fasciogularis	Mangrove Honeyeater		✓			
Myiagra alecto	Shining Flycatcher		✓			
Other Species						
Aviceda subcristata	Pacific Baza					✓
Haliastur indus	Brahminy Kite	✓	✓	✓		
Haliastur sphenurus	Whistling Kite					✓
Pandion haliaetus	Osprey	✓	✓			
Haliaeetus leucogaster	White-bellied Sea-Eagle	✓	✓	✓		
Vanellus miles	Masked Lapwing	✓			✓	✓
Geopelia placida	Peaceful Dove					✓
Cacomantis flabelliformis	Fan-tailed Cuckoo		✓			✓
Centropus phasianinus	Pheasant Coucal					✓
Todiramphus sanctus	Sacred Kingfisher					✓
Dacelo novaguineae	Laughing Kookaburra					✓
Merops ornatus	Rainbow Bee-eater					✓
Pardalotus punctatus	Striated Pardalote					✓
Philemon buceroides	Helmeted Friarbird		✓			✓
Lichenostomus chrysops	Yellow-faced Honeyeater		✓			

		Low-tidal Mud Flats	Mangroves	Rocky Shores	Salt Flats	Hinterland Margin
Lichmera indistincta	Brown Honeyeater		✓	✓		✓
Pachycephala rufiventris	Rufous Whistler					✓
Collurincla megarhyncha	Little Shrike-thrush		✓			✓
Myiagra rubecula	Leaden Flycatcher					✓
Rhipidura leucophrys	Willy Wagtail					✓
Rhipidura fuliginosa	Grey Fantail		✓			✓
Lalage leucomela	Varied Triller					✓
Cracticus nigrogularis	Pied Butcherbird		✓			✓
Gymnorhina tibicen	Australian Magpie				✓	✓
Dicrurus bracteatus	Spangled Drongo					✓
Corvus orru	Torresian Crow					✓
Dicaeum hirundinaceum	Mistletoe Bird		✓			
Hirundo neoxena	Welcome Swallow			✓	✓	✓

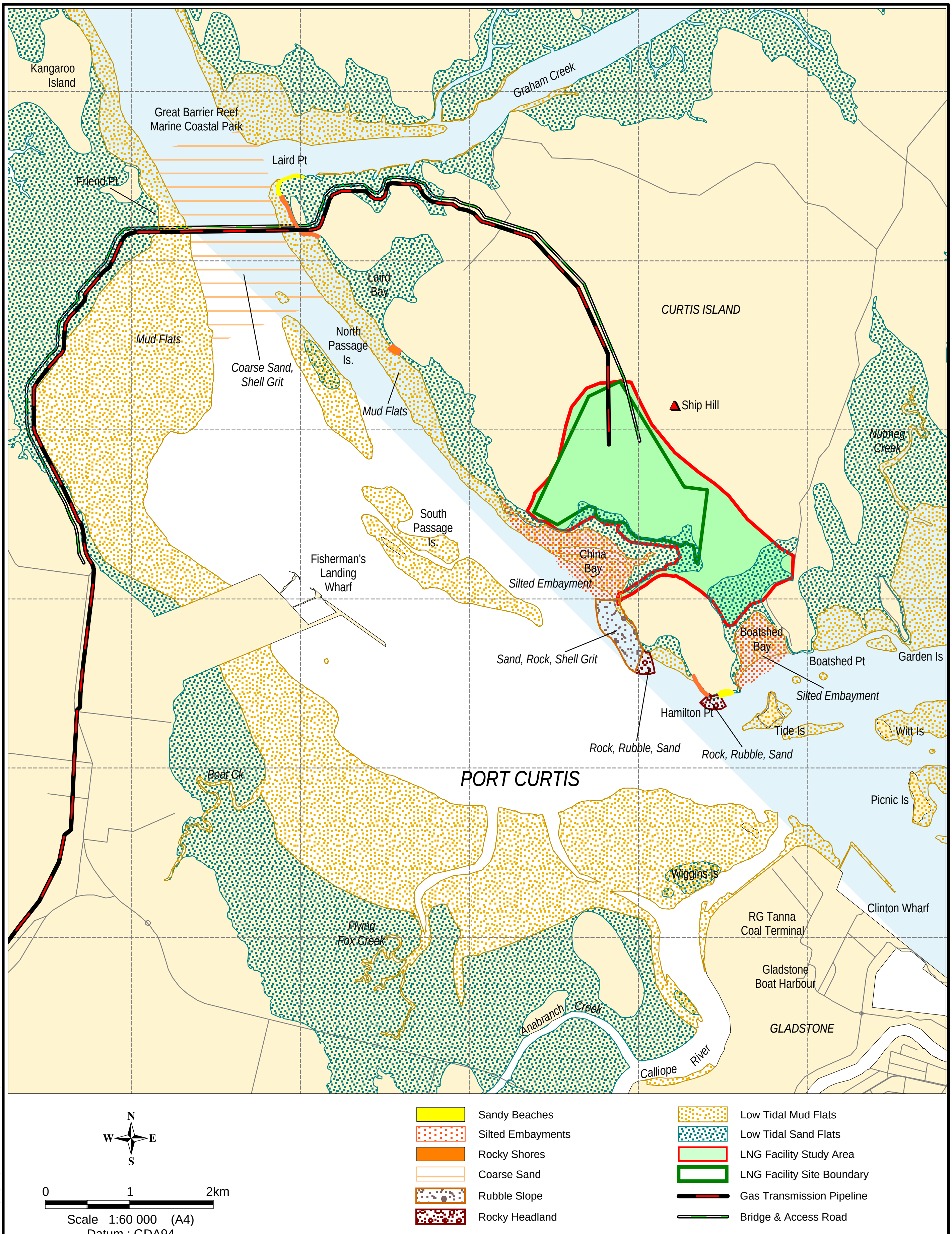
Table 2-3 Mangrove Species Recorded from the Intertidal Habitat Survey

Mangrove Species	Common Name	Boatshed Point to China Bay	China Bay to Laird Point	Laird Point and Graham Creek	Friend Point and Kangaroo Island
Aegialitis annulata	Club Mangrove	✓	✓	✓	✓
Aegiceras corniculatum	River Mangrove	✓	✓	✓	✓
Avicennia marina	Grey Mangrove	✓	✓	✓	✓
Bruguiera gymnorhiza	Large-leaved orange Mangrove	✓	✓	✓	✓
Ceriops australis	Smooth-fruited Yellow Mangrove	✓	✓	✓	✓
Excoecaria agallocha	Milky Mangrove	✓	✓	✓	✓
Lumnitzera racemosa	White-flowered Black Mangrove	✓	✓	✓	
Osbornia octodonta	Mrytle Mangrove	✓	✓	✓	✓
Rhizophora stylosa	Long-style Stilt Mangrove	✓	✓	✓	✓
Xylocarpus granatum	Cannonball Mangrove		✓		
Xylocarpus moluccensis	Cedar Mangrove	✓	✓		✓

Note: Survey sites located within each of the above coastal sections are: Boatshed Point to China Bay (Sites 1-19, 23-26); China Bay to Laird Point (Sites 20-22, 27-32); Laird Point and Graham Creek (Sites 33-35, 43-45); Friend Point and Kangaroo Island (Sites 36-42).

The following section divides the study region into several key intertidal habitats. These habitats are ecologically meaningful, but it should be noted that the shoreline is often complex, and there may be more than one habitat present at each site (see Plate 2-1). Figure 2.4 indicates the location of key intertidal habitat within the study area.

Plate 2-1 Mixed Intertidal Habitats



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Client	Project	Title
LNG / URS	GLADSTONE LNG PROJECT MARINE ECOLOGY ASSESSMENT	**INTERTIDAL & SUBTIDAL SUBSTRATE TYPE**
	Drawn: LL / Approved: JB / Date: 03-02-2009	Figure: **2.4** / Rev:B
	Job No: **4262 6220** / File No: 42626220-g-552.wor	**A4**

2.3.1 Rocky Shores

In between the mangrove embayments, rocky shores with a high silt content occurred at the mid to upper intertidal zone (e.g. locations such as Hamilton Point or immediately south of Laird Point). The shores were mostly composed of small boulders and rubble that were oyster encrusted at mid tide levels (see Plate 2-2).

A low mangrove shrubland community composed mostly of *Aegiceras corniculatum* (with minor species being *Avicennia marina* and *Aegialitis annulata*) also occurred at mid to high tide levels at many rocky shore areas (see Plate 2-3).

A wide variety of biota occurs on rocky shores within the study site (Table 2.1). Most are derived from species which are adapted to live in intertidal regions..The upper areas are exposed to the air for the longest periods and have a restricted number of species. The biota of the upper intertidal zone is often characterized by limpets, littorinid snails and *Leptograpsus* crabs, however, these groups were largely absent at the sites examined in Port Curtis.

An oyster fringe is present at mean sea level on most of the rocky shore areas inspected along the coastline of Port Curtis. As there is less exposure to the air, invertebrate diversity is greater in mid-tidal areas. The mid-tidal accumulations of oysters increase habitat diversity, which in turn further increases the number of other invertebrate species present. Thaid snails (predominantly *Morula marginalba*) were common in this area, and feed on the oysters and other species. Several species of nerites were common, mostly those associated with muddy shorelines. Large chitons (*Acanthopleura*) characteristic of tropical Australian rocky shores were absent. Pulmonate slugs (*Onchidium* sp.) can be abundant shortly after the tide goes out, but soon migrate into crevices where they are protected from desiccation. However, *Onchidium* were uncommon in Port Curtis, even just after the rocks were exposed by a falling tide.

Diversity is generally greatest on the lower portions of rocky shores, but in Port Curtis the habitat at lower levels (~MLWN to MLWS) were largely soft mudflats.

2.3.2 Salt Flats

Salt flats occurred on tidal flats landward of the mangrove zone in areas that only receive tidal inundation during spring tides. High evaporation rates and extreme soil salinities largely preclude macrobiota from living in this habitat except in some shallow drainage lines. While salt flats are largely devoid of vegetation there were sparse areas of halophytic shrubs and grasses (e.g. *Sporobolus virginicus* or salt couch) growing amongst the salt flats. In some areas the salt flat surface was covered with algal mats (cyanobacterial mats) that were in various degrees of desiccation dependent on their location and extent of tidal wetting received. The algal mat combines with the top layer of clay to form a leathery surface which peels back and cracks as the salt flat dries.

Salt flats landward of the mangroves are almost devoid of invertebrates (Wells, 1983; 1984), a feature that was present at the Port Curtis sites. Many of the open salt flats had no molluscs or crab holes (Plate 2-4). Other areas, particularly those closest to mangroves or along small tidal channels had crab holes (Plate 2-5) and isolated individuals of the mud whelk *Telescopium telescopium*.

Plate 2-2 Rocky Shore on Curtis Island

Plate 2-3 Rocky Shore Mangroves

Plate 2-4 Saltflats on Curtis Island

Plate 2-5 Crab Holes

Extensive excavations by feral pigs were noted in several areas along the salt flat/landward mangrove margin (Plate 2-6).

2.3.3 Sand Beaches

Due to the predominance of muddy substrates along the south-west coastline of Curtis Island, sandy beaches were limited to small areas at Hamilton Point (Site 7) and Laird Point.

The shifting sands make upper intertidal sand beaches a difficult environment for invertebrate fauna, and the upper intertidal biota are restricted to a few species of crustaceans and molluscs. There can be extensive wave action that moves the sand rapidly. An organism living on or in the beach sand can be alternately exposed or submerged in the sand during storms by currents and wave action during tides. They must be able to burrow back into the sand if they are exposed or emerge if they are covered over. The lack of ability to move eliminates plants from upper intertidal sand beaches. As on rocky shores, the fauna is zoned, but zonation patterns are subtle as the species are buried into the sand on upper shores.

Plate 2-6 Pig Excavations

Hamilton Point (Site 7; Plate 1) has a sandy beach, though the habitat has a mixture of sandy beach, rocky shore and some mangroves. Invertebrates on the sand beach were impoverished. The upper intertidal areas of sandy beaches in northern Australia are characterised by ghost crabs (*Ocypode*). Many beaches also have burrowing donacid bivalves that can be locally abundant, but neither group was found at Hamilton Point.

There was a small colony of soldier crabs (*Mictyris*) in the midtide region. Single individuals of a sand bubbler crab *Scopimera inflata* and a fiddler crab *Uca polita* were found. These species are usually abundant in similar mid-tidal areas. Lower in the intertidal area several individuals of the mud snail *Nassarius dorsatus* were also observed.

2.3.4 Low-tidal Sand Flats

Low-tidal sand flats are uncommon in Port Curtis. Only one site was investigated during the survey: Site 33 at Laird Point. The sand was relatively coarse, indicating considerable sorting by currents. Few living species were found, but the presence of several species of dead shells suggests other species may occur in the deeper waters offshore.

Colonies of soldier crabs were active during low tide on the sand flat surface at Laird Point (Plate 2-7).

2.3.5 Low-tidal Mud Flats

Extensive areas of mudflats with very fine mud dominated the lower intertidal habitats of almost all sites. Soft mudflats up to 300 m wide were exposed at low tide in areas seaward of the mangrove shoreline at locations such as China Bay and the Kangaroo Bay/Friend Point area (see Plate 2-8).

The very fine mud in the low-tidal mud flats makes observations by foot at low tide extremely difficult and observations were made only along the shoreward margins. At low tide, dense populations of the porcelain crabs *Petrolisthes* sp. were observed on the surface of the mudflat, suggesting the environment is productive. The dense invertebrate populations reported by Wells (1983; 1984; 1986) were on a sandy mudflat that is very different to those found in Port Curtis, so the habitats are not comparable.

Intertidal Habitats

Plate 2-7 Soldier Crabs

Plate 2-8 Low-tidal Mud Flats

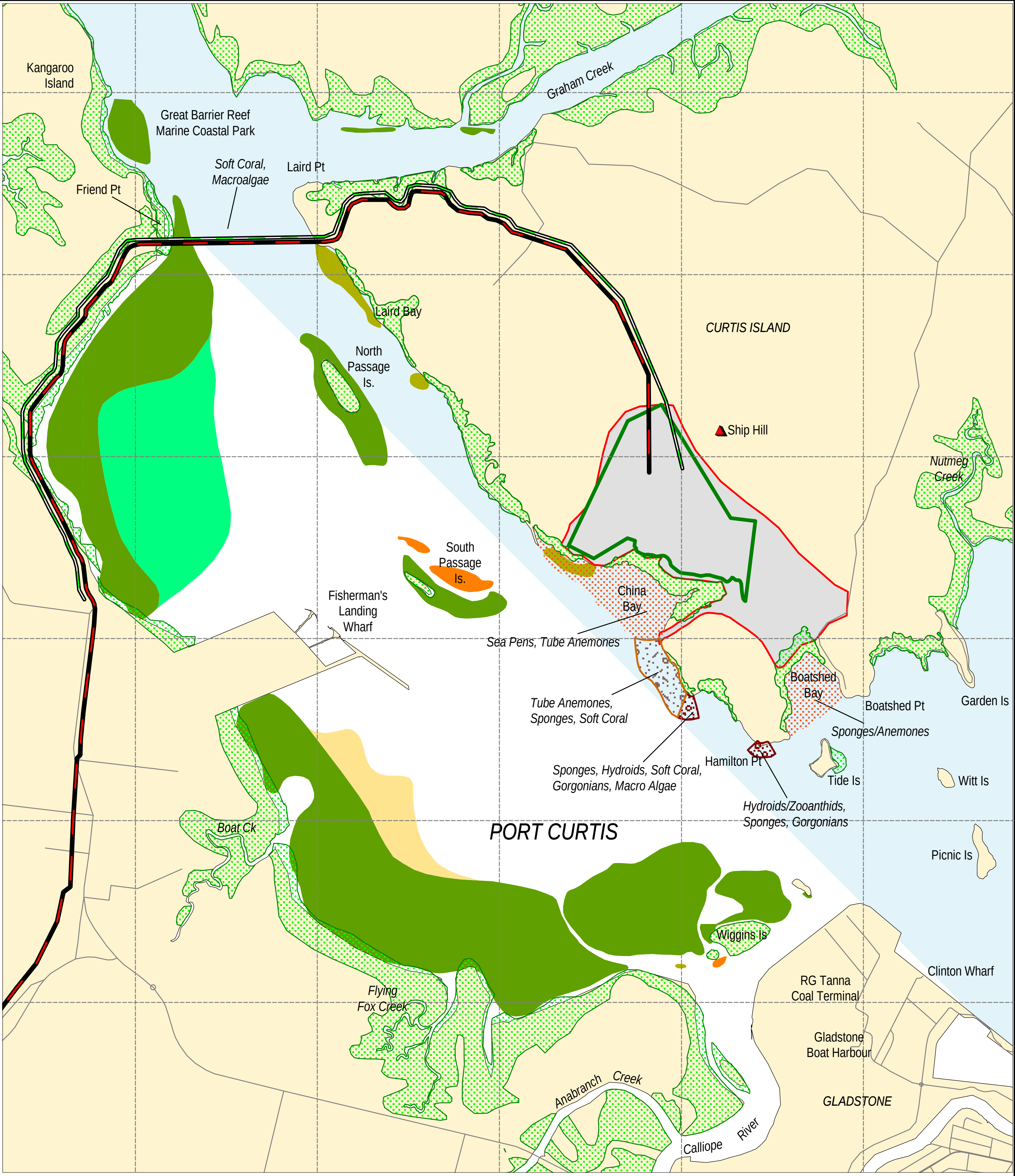
Studies, including investigations of intertidal mudflats, in Port Curtis have illustrated strong links between macrobenthos and environmental and sediment characteristics (Currie & Small 2005). Mudflats lacking conspicuous vegetation may play an important trophic role that is yet to be fully acknowledged. Erfemeijer and Lewis (1999) recognised that intertidal mudflats constitute an important habitat that support a high biodiversity and biomass of benthic invertebrates, sustain productive fisheries and provide important feeding grounds for migratory shorebirds.

A low diversity and abundance of migratory wading birds listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) were recorded on the mudflats during the June 2008 survey (see Table 2.2). This is likely to be due to the survey timing not coinciding with the annual shorebird migration period (~October to April) to Australia that occurs during the winter period in their northern hemisphere breeding grounds. It is expected that the expansive mudflat areas would provide suitable feeding habitat for migratory wading birds. Previous studies have identified the Targinie and Pelican Banks intertidal flats as being the main feeding areas for shorebirds (ANCA/DEWHA).

2.3.6 Mangroves

Mangrove Habitats and Vegetation Communities

The June 2008 survey findings generally confirm the mapping provided in Danaher *et al*. 2005 showing that *Rhizophora* forests dominate the mangrove embayments along the south-west coastline of Curtis Island (Figure 2.5). Due to the 1:25,000 scale of mapping of intertidal wetland community types in Danaher *et al*. (2005) there were some smaller/minor areas of other mangrove communities (i.e. non *Rhizophora* forests) that were recorded in the June 2008 survey but not shown in the 1:25,000 mapping (Sheets 3-5 of Danaher *et al*. 2005). These were typically narrow bands (~ 10 – 30 m wide) of mixed species shrublands or low forests at the landward edge of the mangrove zone or along the margin of cheniers (or beachridges) - ribbon-shaped sand/shell deposits (spits) within the seaward mangrove zone (these are discussed further below).



Scale 1:60 000 (A4)
Datum : GDA94

- Mangroves
- SEAGRASS LEGEND
- Zostera capricorni with Halophila ovalis
- Zostera capricorni
- Halophila decipiens
- Halophila ovalis with Zostera Capricorni
- Halophila decipiens with Halophila ovalis
- Silt Embayment
- Rubble Slope
- Rocky Headland
- LNG Facility Study Area
- LNG Facility Site Boundary
- Gas Transmission Pipeline
- Bridge & Access Road

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Client	Project	Title
LNG / URS	GLADSTONE LNG PROJECT MARINE ECOLOGY ASSESSMENT	**MARINE PLANT AND SUBTIDAL BIOTA**

Drawn: LL	Approved: JB	Date: 03-02-2009	Figure: **2.5**	Rev:B
Job No: **4262 6220**	File No: 42626220-g-553.wor			**A4**

The distribution and zonation of mangrove communities occurs in response to a range of factors such as tidal elevation (i.e. extent of tidal inundation), freshwater input, substrate and porewater (soil/groundwater) conditions that establish physical and chemical gradients across the intertidal area. The zonation across the tidal gradient from the seaward edge to the landward edge of the mangrove zone was:

- **Seaward edge to mid-tidal flat:** mangrove habitats were dominated by low forests and dense thickets of *Rhizophora stylosa* (Stilt Mangrove) which, in most locations, occurred across almost the entire mangrove zone from the seaward edge to the landward edge (see Plates 2-9 & 2-10). For the large part these communities were monospecific *Rhizophora stylosa*, however, minor species included *Aegiceras corniculatum* (as an understorey species along the seaward edge) and *Avicennia marina*.
- **Landward edge to saltflat:** In locations where the mangrove zone abuts saltflats, a landward mangrove margin consisted of a narrow zone (typically 10 -30 m wide) of shrubland communities dominated by *Ceriops australis* (Smooth-fruited Yellow Mangrove) and *Avicennia marina* (Grey Mangrove) (see Plate 2-11). Minor species included *Aegialitis annulata* (Club Mangrove) and *Lumnitzera racemosa* (White-flowered Black Mangrove).
- **Landward edge to hinterland margin** In locations where the mangrove zone abuts the hinterland (usually eucalypt woodland), a narrow (2-3 trees wide) but diverse landward mangrove assemblage occurred consisting of a woodland of mixed species such as *Excoecaria agallocha* (Milky Mangrove), *Aegiceras corniculatum* (River Mangrove), *Lumnitzera racemosa* (White-flowered Black Mangrove), *Bruguiera gymnorhiza* (Large-leafed Orange Mangrove), *Osbornia octodonta* (Myrtle Mangrove), *Xylocarpus moluccensis* (Cedar Mangrove), *Ceriops australis*, *Avicennia marina* and *Rhizophora stylosa* (see Plate 2-12).

In addition to the mangrove communities described above, the presence of cheniers or beachridges (shoe-string shaped sand/shell deposits formed during storm events) has resulted in the development of a species-rich and very localised habitat (see Plate 2-13). The cheniers, which are supra-tidal in elevation, provide localised freshwater seepage at their margins with the surrounding mudflats and, together with a different substrate type (calcareous sands and shell gravel), these conditions have developed narrow mangrove habitats of either a mixed species woodland on the chenier crests (*Excoecaria agallocha, Lumnitzera racemosa*, *Bruguiera gymnorhiza, Xylocarpus moluccensis* and *Xylocarpus granatum*) or a mixed species shrubland on chenier slopes (*Avicennia marina*, *Rhizophora stylosa*, *Ceriops tagal*, *Aegialitis annulata*, *Aegiceras corniculatum, Lumnitzera racemosa* and *Osbornia octodonta*). Coastal dune species and halophytic grasses (*Sprobolus virginicus*) and shrubs (*Sueada* sp.) also occur on the cheniers together with some non-mangrove tree species. Chenier habitats were recorded amongst the seaward mangrove zone at Friend Point (Sites 40 and 41) and at the small mangrove embayment approximately 1.5 km south of Laird Point (Site 30).

Intertidal Habitats

Plate 2-9 Seaward Mangrove Edge

Plate 2-10 Landward Rhizophora sp.

Plate 2-11 Landward Edge Mangroves

Plate 2-12 Hinterland Margin Mangroves

Plate 2-13 Chenier Mangroves

Porewater Salinity

Where growing conditions are favourable, porewater salinity and water content are thought to be the major parameters influencing mangrove habitat zonation. Porewater salinity of sediments is a function of local precipitation, subterranean seepage, terrestrial runoff and tidal inundation (Connolly *et al*. 2006). During the survey, consistent porewater salinity gradients were recorded across a number of transects through the mangrove-saltflat section of the intertidal zone. These are summarised below:

- seaward mangrove zone - salinities were between 39-42 ppt as a result of daily tidal inundation (i.e. inundation by seawater with salinity of ~ 36 ppt).
- landward edge of the mangrove zone (i.e. landward edge with saltflat) where tidal inundation mostly only occurs during spring tides, the salinities were 42-65 ppt.
- landward mangrove edge/hinterland margin - porewater salinity was 33 ppt (i.e. lower than seawater), suggesting some influence of fresh or brackish water seepage from the hinterland.
- Saltflat - extreme salinities ranging from 93 to ~180 ppt were recorded from this habitat where evaporation is high and tidal inundation infrequent.
- Chenier margins – salinities between 34-41 ppt suggesting some localised fresh or brackish water seepage from the chenier.

The porewater salinity gradients described above are consistent with data recorded from previous studies (Connolly *et al*. 2006, LDM 1998) undertaken within tidal flats at Port Curtis.

Natural Mangrove Mortality

Several areas of historical mangrove mortality were encountered during the survey which are most likely related to natural factors and the dynamic environment in which mangroves occur. The types or settings of mortality were:

- Areas of mostly dead *Ceriops* trees located along the margin between the landward mangrove edge and saltflats (see Plate 14, Site 34). Such mortality in these areas is possibly related to changes in tidal flat hydrology that results in progressive increases in soil/porewater salinities, resulting in mangrove dieback.
- In the extensive tidal flat areas south-west of Friend Point (e.g. Sites 36-39) there are several isolated stands of dead and fallen mangroves possibly resulting from storm events and/or shoreline erosion (see Plate 15, Site 39). A more detailed study of the mangroves in this area suggested that the sediment had been undermined from the mangrove fringes as a result of tidal surges receding rapidly through the forest from the extensive Targinie saltflats during spring tides (CQU 1999). Observations made at Site 37 and 38 also indicate that substantial sheet erosion of the tidal flat surface has occurred in this area. At Site 37 this has left the remaining *Ceriops* shrubland on a raised mound approximately 30 cm above the surrounding tidal flat level (see Appendix A).
- Localised areas of mortality from root smothering in areas where mobile sand ridges (cheniers) have moved into mangroves and covered the mangrove aerial breathing root systems.
- Other natural causes or occurrences of mangrove mortality in the broader Port Curtis/Gladstone area are identified in Duke *et al*. (2003) as part of an assessment of historical change to coastal environments at Port Curtis. These include partial defoliation of mangrove canopies or death from insect herbivory, hail damage (Houston 1999) and longer term climate (rainfall) changes in rainfall volumes.

Plate 2-14 Mangrove Dieback

Plate 2-15 Shoreline Erosion

Invertebrate Fauna

A wide variety of invertebrates inhabit mangroves, dominated by molluscs, crustaceans and polychaetes (Wells 1983; 1984; 1986). Invertebrates in mangroves can be divided into two groups: species that are widespread on adjacent rocky and muddy shores and which extend into the margins of the mangroves as simply another suitable habitat; and species characteristic of mangroves, which typically do not occur outside the mangrove zone. The latter category is limited in terms of number of species, but these are often the ones that are numerically dominant. Invertebrates in the Port Curtis mangroves were largely species characteristic of mangroves; there were few species from adjacent shores. The major exception was the periwinkle *Bembicium auratum,* which occurs on rocky shores but was also common in the mangroves.

Particular attention was given to molluscs, and, to a lesser extent, crustaceans that are characteristic of mangroves. In general, species identified occurred widely in the various parts of the study area. Fifteen species of molluscs and seven species or species groups of crustaceans were found in the mangroves (Table 2.1). The actual number of taxa of both groups is assumed to be higher, as no effort was made to excavate crab holes or undertake destructive sampling of the mangrove trees to record shipworms (bivalve molluscs) that burrow into the trees.

Many groups were less diverse than expected, and many of the species that were present occurred in very low numbers. For example, a few individuals of a single species of the pulmonate family Onchidiidae (slugs) were found, instead of the several that occur in most tropical mangroves. Three species of mud whelks occur in mangroves in eastern Queensland: *Telescopium telescopium* (Plate 2-16)*, Terebralia semistriata* (Plate 2-17) and *Terebralia palustris.* Only isolated individuals of the first two species were found.Three species of *Cerithidea* were also recorded, the most common of which was *C. anticipata* living on mangrove trees (Plate 2-18).

Three species of the periwinkle genus *Littoraria* were recorded, but only as a few individuals, whereas in other areas they can occur by the hundreds. While densities were not measured, the specimens were collected in a single morning and then measured.

A single individual each of two species of fiddler crabs (*Uca*) was found. Again, these species can often be found in very high densities on the banks of tidal creeks. Very high numbers were in fact seen on the banks of the Gladstone marina, and while no density data are provided, a paper by Andersen *et al.* (2004) suggests *U. coarctata* are common in parts of Port Curtis. However, the study sites examined lacked tidal creeks, therefore fiddler crab densities were very low. Two possible reasons are offered for the low densities of molluscs in the mangroves in Port Curtis: the habitat itself and seasonality.

Wells (1983; 1984) examined density, diversity and biomass of four habitats in the Bay of Rest, North West Cape: seaward mudflat, *Avicennia* and *Rhizophora* tree zones and the shoreward saltflat. There was a clear progression from the greatest numbers of all three characteristics on the seaward mudflat, declining in the *Avicennia* zone, reaching very low numbers in *Rhizophora*, and having minimal invertebrate presence on the landward saltflats. The only exception occurred in biomass in the *Avicennia* zone, where modest densities of large *Terebralia semistriata* slightly increased biomass. *Rhizophora* is the dominant mangrove in Port Curtis, in some areas fringed by a narrow zone of *Ceriops* or *Avicennia.* The dominant *Rhizophora* is the type of mangrove that in the Bay of Rest has relatively low invertebrate populations.

Intertidal Habitats

Plate 2-16 Telescopium sp.

Plate 2-17 Terebralia Semistriata

Plate 2-18 Cerithedea Anticipate

Little is known of seasonal variations of invertebrates in mangroves worldwide, including Australia.

Avifauna

Generally the diversity and abundance of avifauna in mangroves was low (Table 2.2). The Brown Honeyeater (*Lichmera indistincta*) was conspicuous in mangroves at most locations, however, the six mangrove resident bird species (i.e. birds mostly confined to mangroves) were only occasionally encountered. Due to the dense nature of mangrove habitats, mangrove birds were recorded on an opportunistic basis.

In areas where mangrove forests or woodlands occurred at the landward edge of the mangrove zone and next to the eucalypt woodland habitat there was considerably more bird activity with birds from both habitats seen moving within the hinterland margin (Table 2.2).

2.3.7 Mangroves at a Regional Scale

At a regional scale, the distribution of mangrove species is determined by a number of factors including temperature, rainfall, catchment and tidal inundation. Mangrove species are limited in their latitudinal distribution by their tolerance to low temperatures (Duke *at al*. 1998) and the majority of mangrove species are limited to tropical environments. Consequently, mangrove species diversity decreases with increasing latitude. In Queensland this phenomenon can be seen clearly along the east coast, with Cape York recording 39 species, the Central Coast region recording 23 species, and the South East region (Curtis Island to Gold Coast) recording 14 species (Duke 2006). Three species (*Acanthus ilicifolius*, *Bruguiera exaristata* and *Xylocarpus* *moluccensis*) are at their southern limits in the Curtis coast region and the most southern occurrence of *Xylocarpus moluccensis* on the eastern Australian coast occurs near Auckland Creek (Connolly *et al*. 2006).

Of the 14 mangrove species previously recorded from the Port Curtis area, 11 were recorded during the June 2008 survey (see Table 2.3).The mangrove species recorded from the survey were consistent with those species noted from other intertidal surveys in the Gladstone area and no new species for the Port Curtis area were found in the June 2008 survey. Species such as *Acanthus ilicifolius* (Spiny Holly Mangrove) and *Acrostichum speciosum* (Mangrove Fern) have previously been recorded from the Gladstone area but were not encountered during the June 2008 survey as suitable habitat for these species (i.e. upper reaches of large creek or river systems) do not occur in the immediate study area. While not considered to be a mangrove, the mistletoe *(Amyema* sp.) was also noted in mangrove canopies at a few sites.

2.3.8 Seagrass

In the Port Curtis estuary, seagrass meadow area and biomass varies seasonally and between years, with peaks in late spring/summer and troughs in winter (McKenzie, 1994; McKenzie *et al.* 1998; Rasheed 1999). Connolly *et al.* (2006) found that seagrass meadows were recorded within the Port Curtis area as existing close to port infrastructure and dredged channels, rendering them highly vulnerable to direct impacts from port developments. Although seagrass meadows were estimated to cover approximately 20% of the Port Curtis area during this study, the authors considered this an overestimate due to the high seasonal variation exhibited at this location (Connolly *et al.* 2006). Results from the baseline monitoring survey of seagrass communities conducted in 2007 by DPI&F also indicate high seasonal variability in the presence and density of seagrass meadows within Port Curtis (Rasheed *et al*, 2008). Figure 2.5 indicates the seagrass beds that are scattered throughout Port Curtis, on both mud and sand banks, as identified during regular monitoring by the Department of Primary Industries and Fisheries (DPI&F).

The drivers of seagrass change in Port Curtis appear to be associated with local and regional climate conditions and factors such as tidal exposure, rainfall, river flows, solar irradiance and temperature (Rasheed *et. al.*, 2008). Despite seagrass meadows being less conspicuous in Port Curtis than in other large estuarine embayments along the Australian east coast, they are considered to contribute significantly to the food webs that sustain fisheries species within Port Curtis, such as whiting, living over mudflats.

Seagrass meadows are considered ephemeral during the winter months (Danaher *et al*, 2005), which may explain the sparse cover found during this survey. The observations recorded from the helicopter survey in May 2008 indicate very sparse cover of seagrass meadows on the mud flats between Fishermans Landing and Friend Point. During this study, no seagrass meadows were found along the western side of Curtis Island or on North Passage Island or South Passage Island. Within the aggregated patches of seagrass on the mainland mud flats, *Zostera capricorni* and *Halophila ovalis* were found towards the high water mark closer to the mainland, and *Halophila ovalis* closer to the low water mark. This is consistent with results from the seagrass baseline survey conducted in 2007 (Rasheed *et al*, 2008).

Results from the most recent survey conducted in late spring (October 2007) by the DPI&F indicate that seagrass meadows in Port Curtis were in the healthiest condition recorded since the inception of the monitoring program (Rasheed *et al*,. 2008). Data from monitoring the seagrass meadows north of Fisherman's Landing, adjacent to Wiggins Island and Pelican Banks are of interest to this study. Due to the time of year of the survey, seagrass meadows were likely to be at their maximum density and distribution in the region. Thirteen meadows from the baseline survey conducted by Rasheed *et al.* (2003) were selected for this long term monitoring program to represent the range of seagrass communities located in areas likely to be vulnerable to impacts from port operations and developments (Rasheed *et al.*, 2008). Seagrass meadows were shown to be patchy north of Fisherman's Landing, whereas cover at Pelican Banks was more consistent with meadows exhibiting a continuous cover of seagrass. The majority of meadows were monitored on sediments dominated by mud and a smaller component of sand and/or shell grit (Rasheed *et al.*, 2008). Results from the 2002 monitoring survey indicate that the intertidal seagrass communities on muddy sediments were dominated by *Zostera capricorni* and were found to be the most widely distributed communities within Port Curtis (Rasheed *et al.* 2003). Connolly *et al.* (2006) found that *Halophila* dominated communities were located adjacent to Fisherman's Landing Wharves and *Halophila decipiens* and *Halophila spinulosa* dominated deeper areas (shallow subtidal and offshore more than 5 m below mean sea level).

In comparison with previous monitoring surveys conducted by DPI&F, the intertidal seagrass meadows that were monitored at Wiggins island had continued to increase in biomass in 2007 from the low levels recorded in 2005 (Rasheed *et al.* 2008). The *Zostera capricorni* dominated meadow at Pelican Banks has been the most stable, with both biomass and area remaining relatively consistent between surveys.

Seagrass meadows were observed to be very sparse and patchy during the helicopter survey of May 2008 with the only seagrass meadows identified on the Friend Point / Kangaroo Island mud flats. As the helicopter reconnaissance was conducted in May (late autumn), seagrass biomass would have been at its lowest. As such, the results from the monitoring survey conducted by DPI&F are a reliable source of information that can be used to identify any significant changes to seagrass biomass and distribution at the locations of interest to this study.

2.3.9 Invertebrate Fauna

A total of 76 species or groups of invertebrate fauna were recorded from intertidal habitats (Table 2.1), mostly from low-tidal mudflats, mangroves and rocky shores. Molluscs were the most diverse group taxonomically (55 species, comprising 30 gastropods, 24 bivalves and one chiton). Other groups represented were crustaceans (18 species and groups), echinoderms (two species, each represented by a single individual) and one species of polychaete found at a single site. On the basis of the suvey, diversity appears to be low. This is attributed to low habitat diversity. In particular, rocky shores had very high silt content, and where they occurred they did not extend into the lower parts of the intertidal region. Instead, the lower intertidal was entirely comprised of very silty mudflats with low biodiversity.

2.3.10 Avifauna

A total of 45 species of birds were recorded during the survey: four species of shorebirds (includes migratory wading birds), seven species of waterbirds/seabirds, six species of mangrove specialists (i.e. birds mostly confined to mangroves) and 28 other species (Table 2.2). The greatest diversity of avifauna was recorded along the mangrove/hinterland margin where terrestrial (i.e. eucalypt woodland) dwelling species were observed in addition to avifauna which typically inhabit mangroves.

Section 3 Subtidal Habitat

3.1 Subtidal Habitat Survey

The survey of the subtidal benthic habitat and communities was undertaken during the neap tide cycle between 25 and 28 May 2008. The subtidal habitat and benthic communities are described for the bridge/pipeline crossing site between Friend and Laird Point and the GLNG MOF jetty, berthing pockets and swing basin sites at China Bay and Hamilton Point. The subtidal survey programme was developed using aerial video footage and photography, navigation charts and design information for the bridge/pipeline crossing and LNG facility. The dive sites were selected to provide a description of the major subtidal habitat types within Port Curtis and to provide sufficient information on the likely impacts. These areas include the proposed bridge/pipeline crossing site from Friend Point to Laird Point (Figure 3.1) and several sites within the proposed GLNG MOF jetty, berthing pocket and swing basin on the western side of Curtis Island (Figure 3.2).

The marine ecological information collected during the survey describes the benthic habitat and benthic communities within the subtidal Port Curtis area. Information collected during the survey is presented to describe the existing marine biodiversity as a result of the proposed bridge/pipeline crossing and LNG facility.

For the purposes of this survey, the subtidal areas were categorised into the following locations:

- Site 1 - Between Friend Point and Laird Point across The Narrows;
- Site 2 - China Bay;
- Site 3 - Rubble slope between China Bay and Hamilton Point;
- Site 4 - Hamilton Point; and
- Site 5 – Between Hamilton Point and Boatshed Point.

3.1.1 Survey Technique

Subtidal habitats within Port Curtis were surveyed using scuba during the neap tide cycle between 25 and 28 May 2008. Diving was conducted from a chartered vessel “Capline Charters” using a dive team consisting of four personnel that included a Dive Officer, Dive Leader and two Divers that acted as Divers Assistant/ Standby Diver. All dives were conducted according to the URS Health, Safety and Environment Plan (HSEP) and Santos inductions. The dive profile was determined according to stage of the tide and depth of each site. The depth range varied from 16.5m at the deepest point of the channel at The Narrows to 5m in the silted embayments of China Bay and between Hamilton Point and Boatshed Point and along the silted rubble slope south of China Bay. Fixed GPS coordinates and depths were recorded for each dive within each site and are provided in Table 3.1.

At each site, divers positioned transects on the seabed using 50m fibreglass tape measures and conducted visual assessment, written observations on underwater paper, underwater video and photography along each transect. In most locations 50m transects were videoed from approximately 0.5m above the sea bed. Several drift dives were undertaken at Hamilton Point and the rubble slope between China Bay and Hamilton Point with fixed GPS coordinates recorded for each dive from the tender vessel by the standby diver.

Compass bearings were recorded for each transect and drift diving was used where possible. The records taken for each dive included the time, location, depth, water temperature, length of dive and marine species sighted including species of conservation interest (SOCI). On several occasions visibility was less than favourable and no underwater video footage was possible. Under these circumstances, observations of benthic habitat and communities were recorded on underwater paper.

Source: This map may contain data which is sourced and Copyright. Refer to Section 18.2 of the EIS for Ownership and Copyright.

Client: URS / LNG

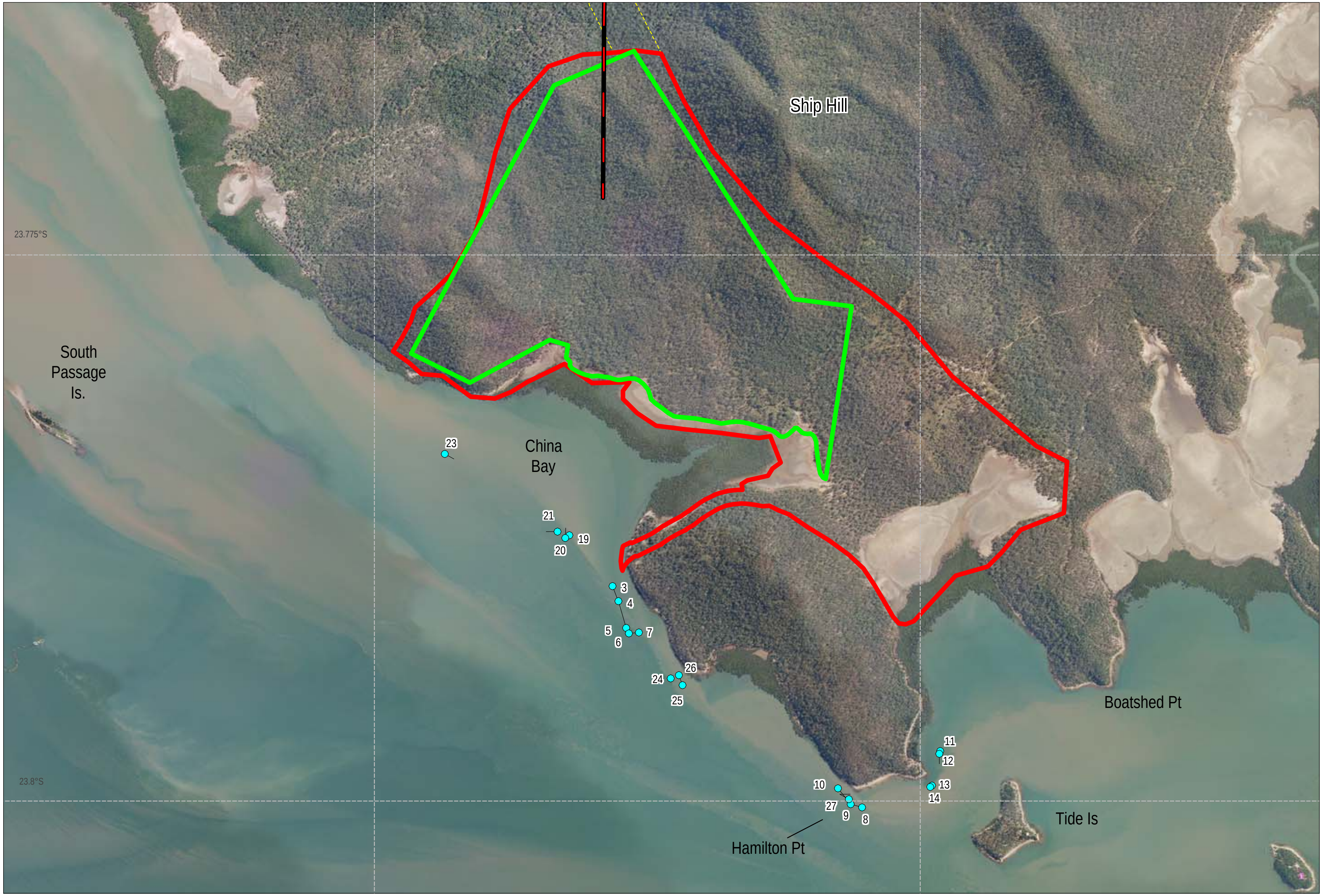
Project: GLADSTONE LNG PROJECT
MARINE ECOLOGY ASSESSMENT

Title: **MARINE SUBTIDAL HABITAT SURVEY SITES**

Drawn: MG | Approved: JB | Date: 24-02-2009

Job No: **4262 6220** | File No: 42626220-g-521.wor

Figure: **3.1** | Rev: B | **A4**



N W E S

0 500 1000m

Scale 1:25 000 (A4)
Datum : GDA94

Great Barrier Reef Coast Marine Park
Subtidal Habitat Survey Site
LNG Facility Site Boundary
LNG Facility Study Area
Gas Transmission Pipeline
Bridge/Road Buffer

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Project: GLADSTONE LNG PROJECT
MARINE ECOLOGY ASSESSMENT

Drawn: MG | Approved: JB | Date: 24-02-2009

Job No: **4262 6220** | File No: 42626220-g-521.wor

Title: **MARINE SUBTIDAL HABITAT SURVEY SITES**

Figure: **3.2** | Rev:B | A4

The following information was recorded at each site and is presented in Appendix B:

- GPS coordinates;
- Substrate characteristics and benthic habitat;
- Subtidal biota descriptions including the dominant, common marine invertebrates (community structure was also noted); and
- Identification of marine species to the lowest taxonomic level using the following references: invertebrates - Allan & Steene (2003); seagrass - DPI&F/CRC (2002).

Note: This was a non-extractive survey and no biological material was collected for identification or genetic studies.

3.1.2 Site Selection

Table 3.1 indicates the position of transects on the seabed. A total of 450m of benthic habitat was surveyed between Friend Point and Laird Point in depths ranging from 5m at Friend Point to 16.5m on the Laird Point side of the channel. Benthic habitat was surveyed along two 50m transects in a north/south direction at Laird Point at 11m depth. Benthic habitat was surveyed in China Bay along three 50m transects at relatively shallow depth (5 - 7m). Two drift dives were conducted along the rubble slope between China Bay and Hamilton Point to survey benthic habitat at approximately 5 – 6m depth. Benthic habitat at Hamilton Point was surveyed during a drift dive and two 50m transects at 8m and 10m depth. At this site the transect position along the rocky wall was at a relatively constant depth of 10m. Benthic habitat was surveyed along two 50m transects at a 5m depth gradient on the southern side of Hamilton Point across the unnamed bay towards Boatshed Point.

Table 3-1 Summary Table of Subtidal Sites Surveyed Within Port Curtis

Site	GPS	Transect length (m)	Transect bearing	Depth (m)
1 – Between Friend Point and Laird Point across The Narrows	16 22 15 18 17 2	50 100 100 100 100 100	240° 70° 260° 270° 255° 180°	5 12 14 13 16.5 11
2 – China Bay	20 21 23	50 50 50	0° 270° 120°	5 5 7
3 – Rubble slope between China Bay and Hamilton Point	3 – 7 24 – 26	Drift Dive Drift Dive		6 5
4 – Hamilton Point	8 – 10 27 27	Drift Dive 50 50	Drift Dive 300° 90°	8 10 10
5 – Between Hamilton Point and Boatshed Point	12 13 - 14	50 50	No bearing No bearing	5 5

3.1.3 Data Analysis

Video footage was analysed in the laboratory using the principles of the Australian Institute of Marine Science (AIMS) Video Transect Analysis System (AVTAS) technology. The video footage of each transect was systematically analysed by identifying the substrate type and marine species at fixed points along each transect. AVTAS analysis involves placing five fixed points on the computer screen. A tape marked with 40 equidistant points was placed at the bottom of the computer screen and the video stopped at each of the forty points for each transect. The benthic habitat type was recorded for each frame and each of the five points resulting in 200 data points for each transect. The data was entered into an Excel spreadsheet using AVTAS habitat codes and the percentage cover of marine biota was estimated for benthic communities at each site. This procedure was repeated for each transect until analysis was complete. Due to time and weather constraints, not all sites were replicated. Some observer bias may have occurred during the data analysis. This was however, not quantified during the scope of this study.

Identification of marine organisms to species level is difficult from photographic evidence therefore marine species were generally grouped into Phylum or Family groups where possible. Table 3.2 indicates the groups of marine species found at each site within Port Curtis during this survey.

Table 3-2 Marine Species Found Within Port Curtis

Species	Common Name	Site 1	Site2	Site 3	Site 4	Site 5
CNIDARIA						
Class Anthozoa						
Order Ceranthidae	Tube Anemone	✓		✓	✓	✓
Order Actiniaria	Anemone				✓	
Order Scleractinia	Hard coral					
Tubastraea sp.	Flower coral				✓	
Subclass Octocorallia						
Order Gorgonacea	Gorgonian - Sea fan / whip	✓		✓	✓	
Order Pennatulacea	Sea pen	✓	✓		✓	✓
Order Alcyonacea	Soft coral	✓		✓	✓	
Class Hydrozoa	Hydroid/zoanthid				✓	
	Hydroid	✓		✓	✓	✓
	Zoanthid	✓				
ECHINODERMATA						
Class Crinoidea	Feather Star				✓	
Class Asteroidea	Sea star	✓		✓	✓	
PORIFERA						
Class Calcarea	Sponge	✓		✓	✓	✓
ECTOPROCTA						
Class Bryozoa	Lace coral	✓		✓	✓	
MOLLUSCA						
Class Bivalvia	Bivalve	✓		✓	✓	
Class Gastropoda						
Order Nudibranchia	Nudibranch				✓	✓
ANNELIDA						
Class Polychaeta	Calcareous tube worm			✓		
CHORDATA						

Species	Common Name	Site 1	Site2	Site 3	Site 4	Site 5
Subphylum Urochordata						
Class Ascidiacea	Ascidian (Tunicate)	✓		✓	✓	
Class Chondrichthyes						
Family Rhincodontidae	Nurse Shark				✓	
MACROALGAE		✓		✓	✓	✓
PHAEOPHYTA	Brown algae					
Dictoya sp.	Y branched algae				✓	✓
Padina sp.		✓				✓
Turbinaria sp.					✓	
CHLOROPHYTA	Green algae					
Halimeda sp.						
RHODOPHYTA	Red algae	✓				✓

3.2 Oceanography and Physical Characteristics

Water temperatures within Port Curtis vary from 18°C in winter to 29°C in summer and evaporation rates are high, generally exceeding mean annual rainfall (878mm) with an average annual evaporation rate estimated at 1748 mm for Gladstone (BOM 2008). The predominant winds are the south-easterly trade winds. Tropical cyclones occur approximately every seven years (BOM 2008).

Water depths in the Port Curtis estuary range between 18m in the southern entrance to 5-9m in the mid to northern sections of the harbour. Water depths surveyed in this study ranged between 5m in the bays to 16.5m in the channel at the bridge/pipeline crossing site.

The estuarine environment receives seasonal supplies of freshwater in the summer months from the adjacent narrow coastal hinterland (Connolly *et al.* 2006; Currie and Small 2004) and a rapid reduction in salinity may occur due to the shallow, semi-enclosed nature of the estuary (Currie and Small, 2004). During the Currie and Small (2004) study, there were marked differences in seawater temperature observed across Port Curtis during the winter of 2002, most pronounced at the mouth of the Calliope River. Elevated water temperatures were due to heated seawater discharges from a coal-fired power station. Currie and Small (2004) indicated that thermal pollution from this source appeared to affect much of the inner harbour.

Water clarity, measured by Secchi disc, was shown to be highly variable across Port Curtis estuary (Currie and Small, 2006). Most fine sediments occur on intertidal banks in the inner harbour at the Narrows, Targinie, southern Curtis Island, and therefore have the highest turbidity (Currie and Small, 2006). Channels adjacent to the intertidal regions of the inner harbour are much less turbid, possibly due to swift tidal currents scouring the bottom and limiting settlement of fine particulate material (Currie and Small, 2006). During this study, turbidity and visibility varied slightly at each site. Visibility in the silted bays was less than at Hamilton Point and The Narrows.

3.3 Subtidal Habitats

3.3.1 Overview

There is limited literature available on the subtidal habitat within the Port Curtis region. Currie and Small (2006) found that bottom sediments in Port Curtis estuary were variable over small distances (<1.5 km) with median size classes ranging from silt and mud to sand, coarse-sand and gravel. Median grain size increased significantly with depth and spatial patterns in sediments broadly reflected patterns in port bathymetry.

Currie and Small (2004) determined there were four sediment types in the port:

- ''Silts and muds'' (<63 µm diam.) were largely restricted to protected intertidal flats in the inner harbour;
- ''Fine sands'' (0.06–0.25 mm diam.) were found in shallow banks between Curtis and Facing Islands and more extensively through much of the outer harbour north of Hummock Island;
- ''Medium sands'' (0.25–0.5 mm diam.) generally flanked channels through much of the inner harbour and also predominated in shelving waters through the outer harbour; and
- ''Coarse-sands and gravels'' (>0.5 mm diam.) were primarily found in the scour holes of arterial channels and entrances, and additionally around fringing reefs (Sable Reef and East Point Ledge) on the eastern side of Facing Island.

The results from the study conducted by URS in May 2008 indicate that the subtidal habitats surveyed consist of coarse sand channels with shell grit, silted embayments, silt / rubble slopes and rocky headlands and walls adjacent to deeper channels.

Marine species that comprise the benthic communities found at the bridge/pipeline crossing site, silted embayments, rubble slopes and rocky walls vary according to the substrate type, currents and prevailing environmental conditions. Table 3.2 indicates the species composition for each site. Coralline algae, soft corals and gorgonians were prevalent at Site 1, whereas hydroids, sponges and gorgonians dominated the Hamilton Point location.

The silted embayments of China Bay and the southern side of Hamilton Point towards Boatshed Point contained lower species diversity. Pennatulacids and gorgonians were present in very sparse cover. The site was largely devoid of marine species however, numerous small and large burrows were apparent.

Hamilton Point contained the highest level of species diversity and abundance of all sites surveyed. Percentage cover ranged from approximately 2 – 30% and was dominated by dense stands of stinging hydroid zoanthids. Encrusting sponges and gorgonians were interspersed among the colonies of hydroid zoanthids at Hamilton Point. Colonies of hydroid zoanthids (see Section 3.4.2) were also prevalent at the rubble slope site.

The colonies of hydroid zoanthids found at Hamilton Point were in thick clumps and appeared to also be living in association with small ascidians. Some species of zoanthids live in association with sponges, hydroids and other invertebrates (Human & Deloach, 2006). The hydroids observed within Port Curtis were most probably Feather Hydroids belonging to the suborder Thecata.

Soft corals and gorgonians were common to both locations, with a higher percentage cover at Hamilton Point. Soft corals often thrive in areas that are exposed to stronger currents.

3.3.2 Coarse Sandy Substrates

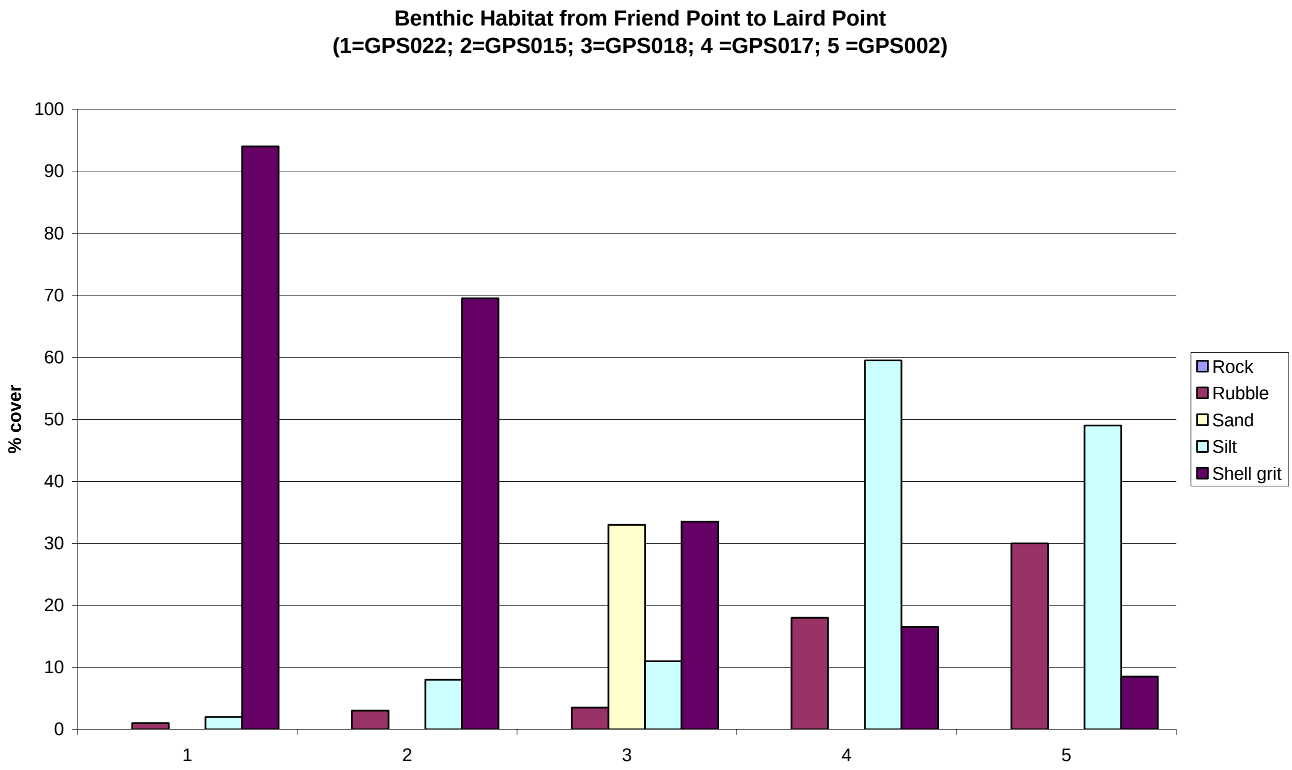
The bridge/pipeline crossing site is located between Friend Point on the mainland and Laird Point on Curtis Island and crosses the channel that separates The Narrows from Port Curtis estuary. Six dives were conducted at this site across the proposed bridge/pipeline crossing (Figure 3.1).

The benthic habitat at 5m depth near Friend Point (GPS016) is primarily silt with numerous small and large burrows. No transect video footage was recorded at this location due to the strong current preventing the tape from staying on the seabed. Gorgonians (Sea fan) and Pennatulacids (Sea pen) were observed at this site. Both belong to the Phylum Cnidaria and are commonly found within the region.

As Figure 3.3 indicates, the benthic substrate in the centre of the channel (GPS022) is coarse sand with a high proportion of shell grit, which may be attributed to a combination of either the hydrodynamics (e.g. strong currents) of the channel between The Narrows and Port Curtis and/or discards of scallop shell from the commercial fishery.

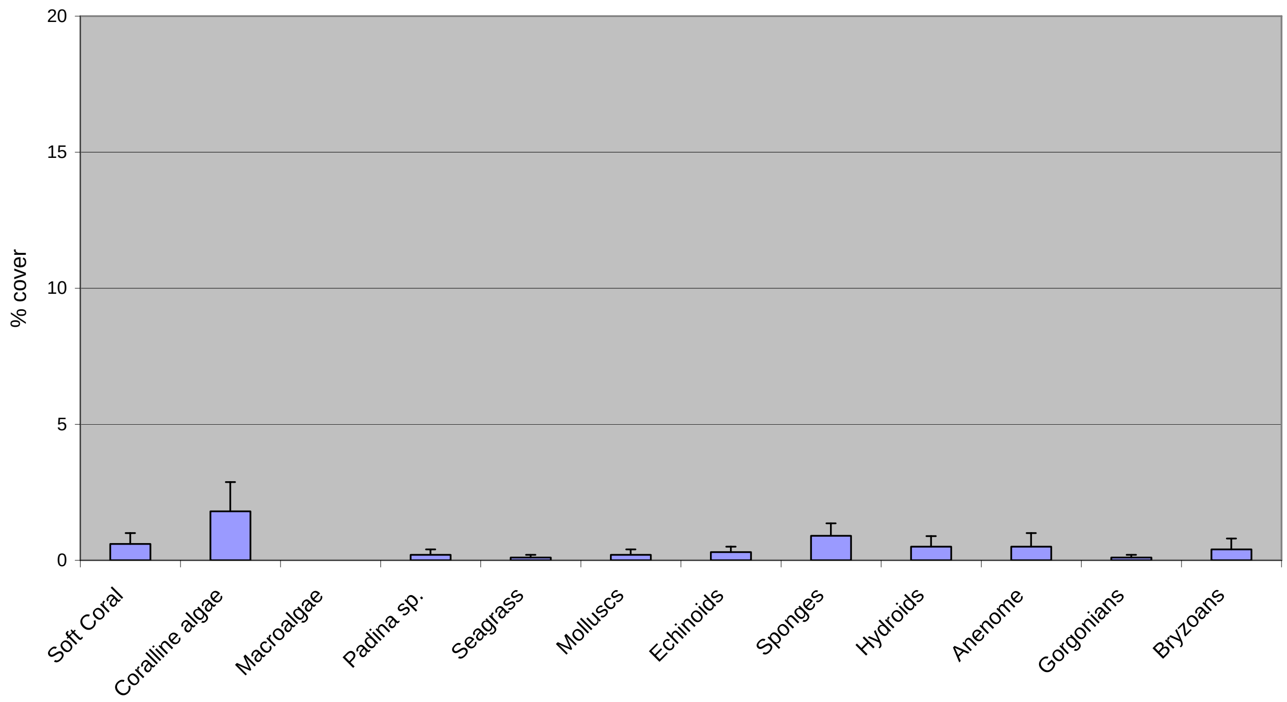
The proportion of silt increases towards Laird Point with lesser amounts of sand and shell grit. Benthic topographic relief across the channel was flat with some small and large burrows present in the softer sediment. Ripples of mud were observed at GPS022. At Laird Point, there were more than two hundred burrows along the 100m transect.

Figure 3-3 Substrate Type at the Bridge/Pipeline Crossing



Percent cover of marine species was low across the channel (Figure 3.4). Soft corals and zoanthids were the most common marine species found at this location. Sea whips and sea fans were scattered throughout the seabed. Razor shells and other bivalves were present, along with clumps of macroalgae such as *Padina sp*. Some sponges were present, but not common, at this site. The zoanthids were approximately 30cm in height, solitary and resembled flower soft corals. The highest cover of marine species at the bridge/pipeline crossing was at GPS015 and GPS018, possibly due to a greater current strength and food source for marine organisms.

Figure 3-4 Benthic Communities at the Bridge/Pipeline Crossing



3.3.3 Silted Embayments

China Bay is a relatively shallow, silted embayment on the south western side of Curtis Island. Gorgonians and Pennatulacids were present in sparse numbers. The benthic habitat on the southern side of Hamilton Point towards Boatshed Point consists of silt with some rubble. The unnamed bay between Hamilton Point and Boatshed Point is a shallow, silted embayment that was dominated by algae with some sponges and hydroids. A feather star, tube anemone and sea pen were sighted at his location.

3.3.4 Rubble Slopes

The slope between China Bay and Hamilton Point consists of silt with some rubble at depths of >6m and some rock at the small headland south of the rubble slope. Although marine species were sparse at this site several tube anemones, sponges, soft corals, tube worms and bivalves were present. Percentage cover was higher at the southern end of the slope where the substrate becomes rockier. This area was dominated by hydroid zoanthids and algae with numerous gorgonians, sponges and soft corals. One hard coral, *Tubastrea sp.* was sighted at this location.

3.3.5 Rocky Headlands

Hamilton Point is a rocky headland that continues down to a rocky wall adjacent to a relatively deep channel. Results of the AVTAS analysis indicate that the substrate is sandy with rubble, rock and some shell grit (Figure 3.5). The hydrodynamics of the channel possibly has a scouring effect on the substrate and provides periodic strong currents suitable for a more complex benthic community.

Colonies of hydroid zoanthids associated with ascidians were recorded as ‘hydroids’ in the AVTAS analysis process and therefore are represented as hydroids at this location. Hamilton Point is dominated by hydroid zoanthids with gorgonians and large areas of sponge gardens (Figure 3.6). This site is by far the most complex in terms of species distribution and abundance. Encrusting and boulder sponges up to 50 x 70cm in dimension were recorded that were often covered in hydroids. Clumps of *Turbinaria sp.* were present either bleached white or a shade of pink. Several soft corals and branching sponges were also present. Percent cover ranged from 2 – 10% in some areas and up to 30% where thick stands of hydroid zoanthids were present. One Nurse Shark was sighted resting in a benthic cave. A Nudibranch (Mollusc) was also sighted at this location.

Figure 3-5 Benthic Substrate at Hamilton Point

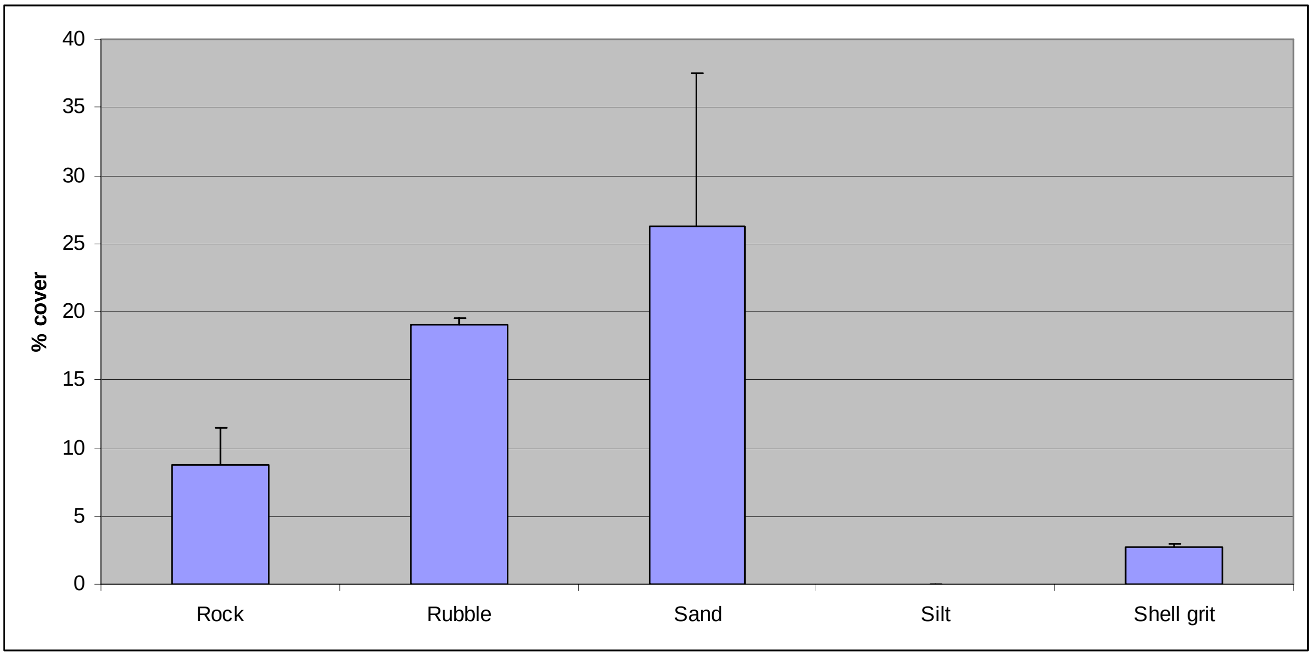
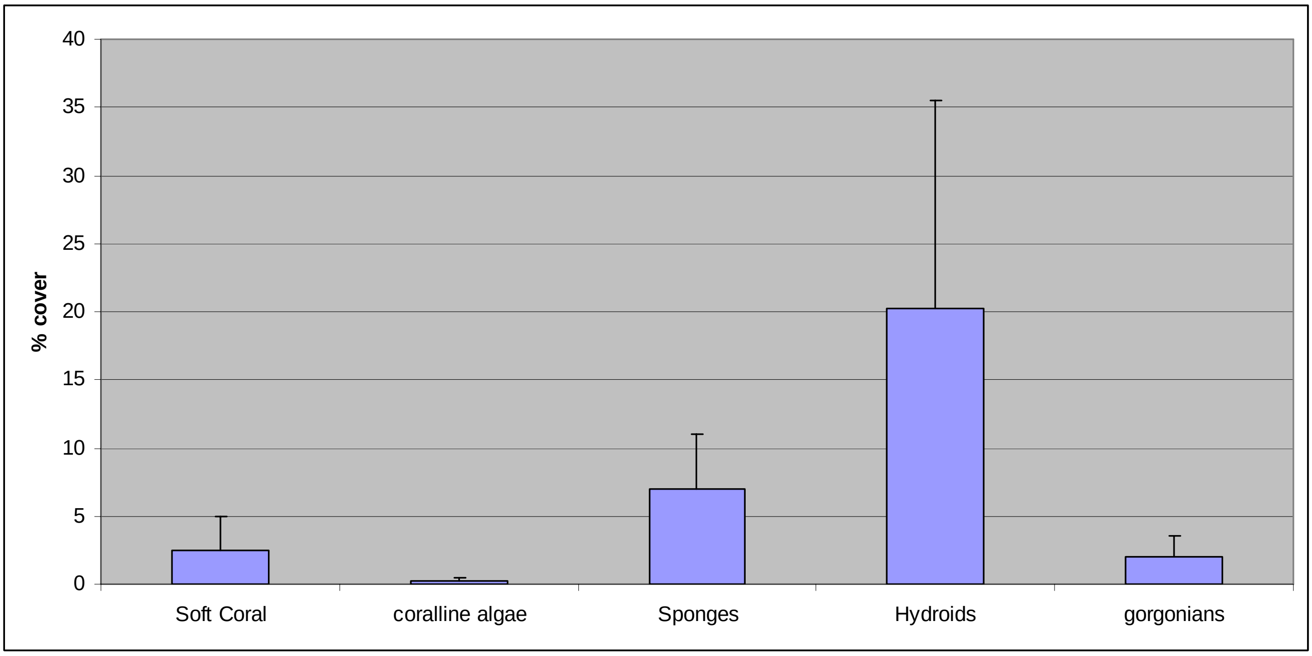


Figure 3-6 Benthic Communities at Hamilton Point



3.4 Subtidal Communities

3.4.1 Sponges

Sponges were prevalent throughout the study site with higher percentage cover at the rubble slope and Hamilton Point (Plate 3-1). Branching sponges were found at the bridge/pipeline crossing site in the coarse sandy substrate. Sponges come in many forms and although they can usually be recognised as a group, individual species are difficult to recognise. Encrusting, leaf and boulder sponges were the more common forms found at Hamilton Point. All sponges are filter feeders on small to extremely small particles and are sedentary as adults. The reproductive ecology of most sponges has not been studied extensively, however sponges prefer periodic currents.

Plate 3-1 Sponges at Hamilton Point

3.4.2 Cnidarians

Hydroid Zoanthids

Hydroids and zoanthids belong to the Phylum Cnidaria, Class Hydrozoa. Zoanthids appear similar to anemones but are smaller and generally colonial or live in close proximity to one another. Zoanthids can live in close association with hydroids as was found within Port Curtis. Hydroids are usually colonial and have a branched skeleton that generally grows in patterns resembling feather or ferns, as were found at Laird Point (Plate 3-2). Individual polyps are attached to this structure. The stinging nematocysts of several hydroids may be toxic to humans. Colonies of hydroids were found at all sites surveyed within Port Curtis. Dense stands of hydroid zoanthids were recorded at Hamilton Point and the rocky headland south of the rubble slope, indicating that this animal prefers rocky substrate in areas that are subject to periodic strong currents. At all other locations within the study site, hydroids and zoanthids were found scattered sparsely through the sand and silt substrates as stand alone hydroid or zoanthid colonies

Plate 3-2 Hydroid Colony

Soft corals and Gorgonians

Soft corals and gorgonians belong to the Subclass Octocorallia and are commonly known as octocorals. Gorgonians are often referred to as soft corals because the colonies lack a rigid skeleton and they can resemble soft corals. Gorgonians include sea fans and sea whips. Most gorgonian colonies are attached to the substrate by a single holdfast at the base of the stem that usually branches (Plate 3-3). Gorgonians are difficult to identify to species in the field and require microscopic examination for accurate identification.

Sea whips were found at all sites surveyed within Port Curtis, with the most common form shown in Plate 3-4. Hamilton Point contained the most impressive stands of gorgonian fans that were sighted during the survey. Soft corals were found throughout the study site at Port Curtis, in the sandy substrate at The Narrows and the rocky substrate at Hamilton Point (Plate 3-5).

Plate 3-3 Gorgonian

Plate 3-4 Sea Whip

Plate 3-5 Soft Coral

Sea pens

Sea pens are quill-like soft corals with a central stalk with either branch-like or leaf-like structures extending in a single plane and they inhabit soft sandy substrate (Human & Deloach, 2006). A primary polyp anchors the animal in the sand and secondary polyps branch out from it. Pennatulacids prefer areas with some current where polyps can catch floating particles of food. Most species extend their bodies at night by hydrostatic pressure to feed. Water is drawn in and discharged through pores in small non-feeding polyps located between the larger feeding polyps. Many species have distinctive shapes and colours, but all have side structures that bear numerous eight tentacled feeding polyps. Colonies of Pennatulicids were found in tall, thin form and in thicker quill-like form.

Feather stars

Feather stars (Crinoids) are the most ancient of echinoderms. Feather stars were prevalent at the Hamilton Point site. They are often found in abundance in areas exposed to periodic strong currents as they feed on plankton. Although the AVTAS analysis did not reveal that echinoderms were present at the Hamilton Point site, numerous feather stars were recorded in the video footage at Hamilton Point, perched on gorgonians closer to currents that bring the planktonic food source they rely on to survive (Plate 3-6 & 3-7).

Plate 3-6 Feather Star and Gorgonian

Plate 3-7 Feather Star and Gorgonian

Sea stars

Sea stars (Asteroids) were found within Port Curtis, at both the Laird Point site and the Hamilton Point site as individuals on the seabed (Plate 3-8). Sea stars are mobile enough to be able to move from one location to another. The one photographed was covered in silt when first discovered, indicating their ability to tolerate silty sediments.

3.4.3 Macroalgae

Marine plants and algae form the base of the oceanic food chain. Several species of green, red and brown algae were found within the Port Curtis sites that were surveyed with green algae dominant at the bridge/pipeline crossing site and red algae dominant at Hamilton Point. Macroalgae need sunlight to photosynthesise and therefore grow to a maximum depth of about 30m.

During a 2007 monitoring program, an unidentified species of filamentous green algae was common on the banks adjacent to Wiggins Island. This was observed on the North and South Passage Islands during URS the helicopter survey in May 2008.

3.5 Marine Megafauna

A pod of Indo-Pacific Humpback dolphins was sighted at the Hamilton Point location. Due to the migratory nature of this species and without longer term monitoring data, it is difficult to assess the frequency and duration of visits made by this species to the Port Curtis area.

Although no dugong were sighted during this survey, dugong feeding activity has been observed on the majority of intertidal seagrass meadows surveyed during the 2007 DPI&F long term monitoring program (Rasheed *et. al.*, 2008). The highest density of dugong feeding trails was observed at the *Zostera capricorni* with *Halophila ovalis* meadow at Wiggins Island with feeding trails recorded at 58% of sampling sites. Dugong feeding trails were also recorded at Pelican Banks and the intertidal meadows to the north and south of Fishermans Landing (Rasheed *et. al.*, 2008). Along the east coast of Queensland dugongs are found on average less than one dugong per square kilometre with large herds sighted in areas such as Moreton Bay, Hervey Bay and the Great Sandy Strait (Seagrass Watch Dugong and Marine Turtle Knowledge Handbook, 2005). Port Curtis or Gladstone Harbour is not indicated as an area where large herds of dugong have been sighted.

No turtles were sighted during this survey within Port Curtis. Turtle nesting sites occur on the beach side of Curtis and Facing Islands and turtles are known to frequent the Port Curtis area, though the frequency and duration of their visits is unknown.

Plate 3-8 Sea Star

4.1 Macrobenthic Fauna Survey

URS commissioned the Centre for Environmental Management at Central Queensland University (CQU) Australia to undertake an investigation on soft sediment macroinvertebrate communities and sediment physical properties within Port Curtis. The report is detailed in Appendix C.

The survey of soft sediment macrobenthic fauna and sediment physical properties was undertaken in July 2008. The survey sites visited during this study are outlined in Figure 4.1.

The aims of this study were to:

- Determine macroinvertebrate assemblages at sites along the proposed pipeline route and adjacent to the Plant;
- Determine sediment carbon content and particle size distribution at all sites; and
- Include any macroinvertebrate biodiversity data available from previous studies.

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Scale 1:60 000 (A4)
Datum : GDA94

- Macrobenthic Fauna Field Survey Locations
- LNG Facility Study Area
- LNG Facility Site Boundary
- Gas Transmission Pipeline

Source: This map may contain data which is sourced and Copyright. Refer to Section 18.2 of the EIS for Ownership and Copyright.

Client	Project	Title
LNG / URS	GLADSTONE LNG PROJECT MARINE ECOLOGY ASSESSMENT	**MACROBENTHIC FAUNA FIELD SURVEY**

Drawn: LL	Approved: JB	Date: 03-02-2009	Figure: **4.1**	Rev:B
Job No: **4262 6220**	File No: 42626220-g-555.wor			A4

5.1 Marine Biogeography

The eastern Australian coastline, from the tip of Cape York to eastern Victoria, incorporates three marine biogeographic regions (Wilson & Allen 1987):

- Tropical Australian Region;
- East Coast Overlap Region; and
- Southern Australian Warm Temperate Region.

The tropical coastline of northern Australia (Tropical Australian Region) is part of the vast Indo-West Pacific Biogeographical Province that extends from the east coast of Africa through the tropical parts of the Indian and Pacific oceans as far east as Hawaii. In broad terms, this region extends from about 30°N to 30°S of the equator. While there is a small proportion of marine species endemic to parts of this region (Wells 2002), most species are widely distributed in the Indo-West Pacific. Some extend over the full range from east Africa to Hawaii, and are even occasionally recorded along the Pacific coast of Central America.

Most marine invertebrates and fish have planktonic larvae that live in the water column for periods ranging from a few days to a year or more. This is a distributional phase in the life cycle during which the larvae are moved about by currents and wave action. Longer-lived larvae are able to travel considerable differences, even across ocean basins. For example, four species of molluscs from South Africa are recorded to have reached the southwestern coast of Australia (Wells & Kilburn 1986) and other species are known to have traveled as planktonic larvae for thousands of kilometres across the Atlantic and Pacific Oceans (Scheltema 1986a; 1986b; 1988). The planktonic distributional phase occurs in both intertidal and subtidal species. Even species that lack a planktonic distributional phase in their life cycle are able to move considerable distances by rafting on floating logs, *Sargassum* mats, etc. In general, marine plants also have mechanisms that allow their widespread distribution.

In a similar way to the tropics, the marine biota of the southern coastline of Australia is widespread, with many species occurring along the entire south coast of the continent, from southern New South Wales to the lower west coast of Western Australia. The biota of the Southern Australian Warm Temperate Region is almost 100% separate from that of the tropical part of the continent. Most temperate species are endemic to southern Australia.

The east and west coasts of the continent are overlap zones where the tropical biota mixes with species from the southern coast of the continent. At the southern part of the overlap zone the biota is almost entirely composed of temperate species. Proceeding northwards the temperate species drop out and are replaced by tropical species, until the biota is almost completely tropical. The replacement of tropical and temperate species is gradual phenomenon, without a distinct boundary. Wilson and Allen (1987) place the southern limit of the East Coast Overlap Zone as Seal Rocks in southern New South Wales (32°28’S) and the northern limit at the latitude of Yeppoon, Queensland (23°08’S).

A feature of both the east and west coast overlap zones, is that they have a small, but important proportion of species that are endemic to either eastern or western Australia. While they may occur north or south of the overlap zone, the species tend to have most of their distribution in the overlap region. There is no firm estimate of the proportion of shallow water species that are east coast endemics. In the west coast the proportion differs in the various phyla, with an average of about 10% being endemic to the region (Wells 1997). A similar percentage would be expected in eastern Australia.

Section 5 Ecological Significance

Port Curtis, located on the Tropic of Capricorn, is near the northern limit of the East Coast Overlap Zone. It has components of all three biotic regions: tropical Indo-West Pacific; southern Australian warm temperate biota; and east coast overlap zone. With its northerly location in the overlap zone, the great majority of the species in the Port Curtis region are tropical, part of the Indo-West Pacific Biogeographical Province. In Table 4 taxa identified to species during the survey have been divided according to their biogeographic affinity. Thirty-six species are tropical, three temperate and three are characteristic of the eastern Australian overlap zone.

Wilson and Allen (1987) point out that the early literature on Australian marine biogeography recognised an inshore Banksian Province in eastern Queensland and an offshore Solanderian Province that included the Great Barrier Reef. While there are substantial differences in the biota inhabiting these two regions, this is an ecological separation, not a biogeographic one.

The key point is that almost all of the marine species found in Port Curtis are widespread species that also occur for thousands of kilometres to the north and south. There are no known marine species that are restricted to the region and are likely to become extinct through industrial development in Port Curtis. Relatively few species in the area would have restricted ranges, and those that do would have ranges on the scale of tens or hundreds of kilometres.

5.2 Regional Perspective

Port Curtis is a major industrial centre that supports aluminium refineries/smelters, cement production works, chemical plants and Queensland's largest power station. The area of state-owned industrial land measures over 10,000 hectares (Duke *et al.* 2003) and the port is a major international and multi-commodity facility. Issues in the region include harbour dredging, port development, industrial development, discharge of effluent and extensive reclamation of intertidal wetlands, including mudflats, mangroves, saltflats and marshes. Although intertidal wetlands are still prevalent along the Port Curtis coastline, they have been extensively cleared, filled or modified around Gladstone City and Auckland Inlet (Duke *et al.* 2003).

Intertidal areas along the south-west coastline of Curtis Island in the vicinity of the proposed LNG site are largely undisturbed. Habitats potentially affected by the proposed LNG infrastructure are widely represented within Port Curtis (and broader regional areas) and it is unlikely that any particular intertidal habitat or individual species would be restricted to areas that would be directly cleared or modified by the project. In the context of significant historical impacts to intertidal habitats in the Port Curtis area from land reclamation projects, the potential direct habitat loss from the LNG project is likely to be small. In Port Curtis, there was a regional loss of mangrove (1470 ha or 38%) and saltmarsh (1340 ha or 34.8%) habitats between 1941 and 1999 (Duke *et al.* 2003). With environmentally sensitive design objectives and the appropriate environmental management measures in place, the proposed LNG plant should affect only a localised area within Port Curtis.

Intertidal mangroves are very productive environments that produce plant material that is used by other organisms *in situ* and is exported to nearby coastal and marine ecosystems (Duke *et al.* 2007). The key habitats found in the study sites at Port Curtis were upper intertidal saltflats, mid intertidal mangroves and rocky shores, and low intertidal mudflats. These habitats are all widespread in the region, and are not unique to the area of the proposed LNG plant.

The upper intertidal saltflats are areas of elevated salinity, too high for mangroves to survive. These are low productivity areas virtually devoid of invertebrates, except for small populations in the small tidal waterways.

Rocky shores are extensive in the study area and other parts of Port Curtis. However, the sites examined were relatively uniform. The rocks were generally small (30 cm or less in diameter), and were covered with oysters.

They were very muddy, with a low diversity of associated invertebrates. Invertebrates present were uniform between the various sites.

Extensive mudflats up to 300 m wide characterise the lower intertidal areas of Port Curtis, both in the study area and other parts of the region.

The marine section of the Calliope River is relatively shallow and muddy with regular large rocky outcrops being a feature of the river bottom (McKinnon *et al.* 1995). Coral reefs were reported in 1994 between Facing and Curtis Islands and south west of Facing Island by the then Queensland Department of Environment and Heritage (1994).

Targinie Creek which is located on the west side of The Narrows and behind Kangaroo Island is distinguished by frequently clear waters that flow across exposed rock, rubble and coarse sandy substrates in several sections of its middle and lower reaches. Results from a subtidal survey in 1995 and 1997 indicate that parts of these substrates at Targinie Creek are colonised by macroalgae, seagrasses, hydroids, grey sponges, tube worms, tunicates and even some small, isolated hard corals (cf. *Goniastrea*) (LDM, cited in Dames & Moore 1998). Other creeks in the area (Boat Creek, Flying Fox Creek and Nutmeg Creek) were shown to not contain any significant areas of corals.

Other subtidal rocky slope and outcrop areas are restricted to small headlands, drop-offs and rocky outcrops off Curtis Island and Facing Island, and off some of the small islands south of Curtis Island (principally Tide and Picnic Islands). Brown algae are the predominant macroalgae on these substrates, with hard coral assemblages restricted to relatively clear, open coastal water sites that are located between Facing Island and Curtis Island (QDEH, 1994, Dames & Moore 1998). Only one hard coral was sighted at the Hamilton Point site during the survey.

Subtidal areas on the western and southern side of Curtis Island near the LNG plant site are relatively undisturbed. The benthic substrate between Friend and Laird Point, at the proposed bridge/pipeline crossing location, is also relatively undisturbed, perhaps with the exception of increased shell fragments discarded from the local commercial scallop fishery. Subtidal habitats potentially affected by the proposed LNG infrastructure are represented at other locations within Port Curtis (and broader regional areas) and it is unlikely that any particular subtidal habitat or individual species would be restricted to areas that would be directly cleared or modified by the project.

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Limitations Section 7

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Intertidal Habitat Summary Results

Appendix A

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
1 14/6/08 0845 hrs	7368343 N	319369 E	Mangrove fringed bay adjacent to Tide Island. Landward edge of salt flats at the salt flat/hinterland margin. A few scattered mangroves (*Lumnitzera racemosa* and *Avicennia marina* shrubs, 1-2 m high) and patches of *Sporobolus* grass (salt couch). Auger excavation: brown/grey muddy sands – groundwater sample (Salinity = 62 ppt) **Birds:** Willie Wagtail **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds. **Other:** Feral pig tracks on salt flats. Horses seen on salt flat/hinterland margin.
2 14/6/08 0910 hrs	7368209 N	319347 E	Mangrove fringed bay adjacent to Tide Island. Salt flat habitat ~70 m landward of main mangrove zone. Mostly bare salt flat with sparse low mangroves, *Avicennia marina* (0.5 m), and patches of *Sporobolus* grass. Small shallow drainage lines running across salt flat (pools in drainage lines). Auger excavation: grey-brown muds – groundwater sample (Salinity = 93 ppt) **Molluscs: Gastropods:** *Telescopium telescopium, Terebralia semistriata.*
3 14/6/08 0930 hrs	7368119 N	319354 E	Mangrove fringed bay adjacent to Tide Island. Landward edge of mangroves - narrow zone (~ 20 m wide) of *Avicennia marina* shrubland (2-3 m) with an understorey of *Ceriops australis* and *Rhizophora stylosa* shrubs. Low recumbent *Avicennia marina* extending out into salt flats. Auger excavation: grey-brown peaty muds – groundwater sample (Salinity = 52 ppt). **Birds:** Bar-shouldered Dove, Brown Honeyeater, Mangrove Honeyeater, Mangrove Gerygone **Molluscs: Gastropods:** *Telescopium telescopium, Terebralia semistriata.* **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds. **Other:** Feral pig excavations amongst landward edge of mangrove zone.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
4 14/6/08 1000 hrs	7367794 N	319552 E	Mangrove fringed bay adjacent to Tide Island. Seaward mangrove zone - dense low *Rhizophora stylosa* forest. Auger excavation: dark brown muds – groundwater sample (Salinity = 40 ppt). **Birds:** Brahminy Kite, Shining Flycatcher, Helmeted Friarbird, Brown Honeyeater **Molluscs: Gastropods:** *Cerithidea anticipata, Ellobium aurisjudae,* both dead. **Crustaceans:** *Sesarma* spp.
5 14/6/08 1030 hrs	736785 N	319568 E	Mangrove fringed bay adjacent to Tide Island. Mudflats seaward of mangroves exposed at low tide. Oyster encrusted rocks amongst very soft mud. **Birds:** Caspian Tern, Whimbrel (4), Silver Gull. **Molluscs: Gastropods:** *Nerita balteata, Nerita squamulata, Monodonta labio, Bembicium auratum, Cerithium trailli, Nassarius fraudator, Haminea* sp. **Bivalves:** *Tellina staurella, Anadara* sp., *Saccostrea cuccullata, Placamen tiara, Mactra* cf. *parkesiana.* **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** Alpheid, grapsid spp., *Macropthalmus* sp., *Petrolisthes* sp., *Thalamita* sp., *Macromedaeus* cf. *demani.*
6 14/6/08 1045 hrs	7367594 N	319704 E	Mangrove fringed bay adjacent to Tide Island. Rock rubble shoreline on east side of bay. Low shrubland of *Aegiceras corniculatum* (1 m) mangroves at mid to upper tide levels of the rocky shoreline. Soft muds exposed seaward of the rocky shoreline at low tide. Occasional low *Osbornia octodonta, Rhizophora stylosa, Ceriops australis* and *Aegialitis annulata* amongst shrubland **Gastropods:** *Nerita balteata, Nerita squamulata, Nerita undata, Monodonta labio, Turbo cinereus, Littoraria strigata, Littoraria scabra, Bembicium auratum, Saccostrea cuccullata, Isognomon isognomum, Pinctada* sp. **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** Grapsid spp., *Petrolisthes* sp., cf. *Neosartium meinerti.*

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
7 14/6/08 1200 hrs	7366849 N	318924 E	Hamilton Point. Small sandy beach (medium grained shelly sand) with scattered low rocky outcrops and some low mangroves within beach at mid-upper levels. Mangroves were mostly an *Aegiceras corniculatum* shrubland (1 m) with occasional *Osbornia octodonta, Rhizophora stylosa, Ceriops australis* and *Aegialitis annulata*. A few taller *Excoecaria agallocha* trees at high tide level amongst *Sporobolus* grass. **Birds:** Caspian Tern, White-faced Heron. **Gastropods:** *Turbo cinereus, Nerita balteata, Nerita squamulata, Nerita undata, Monodonta labio, Bembicium auratum, Littoraria strigata, Clypeomorus batillariaeformis, Clypeomorus zonatus, Cerithium trailli, Bedeva paivae, Morula marginalba, Nassarius dorsatus, Onchidium* sp. **Bivalves:** *Chlamys* sp., *Placamen tiara, Mactra* cf. *parkesiana, Saccostrea cuccullata, Brachidontes* sp., *Isognomon isognomum, Trisidos tortuosa.* **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., grapsid spp., *Scopimera inflata, Mictyrs* sp., *Chthamalus* sp., *Uca polita.*
8 14/6/08 1245 hrs	7367168 N	318590 E	Hamilton Point – narrow mangrove embayment on south west side of point. Narrow fringe (~ 40 m wide) of low *Rhizophora stylosa* forest between hinterland and mudflats that extend seaward from mangroves. Landward edge of mangroves is a shrubland of *Aegiceras corniculatum* with some *Osbornia octodonta, Excoecaria agallocha* and *Aegialitis annulata*. Auger excavation within *Rhizophora stylosa* forest: gravels/shelly muds – groundwater sample (Salinity = 39 ppt). **Birds**: White-bellied Sea Eagle. Striated Pardalote. **Crustaceans:** *Sesarma* spp., *Mictyrs* sp.
9 14/6/08 1320 hrs	7367546 N	318429 E	Hamilton Point – narrow mangrove embayment on south west side of point. Narrow (~ 15 m wide) hinterland mangrove fringe of *Lumnitzera racemosa* (3-4 m high) with occasional *Bruguiera gymnorhiza* and *Rhizophora stylosa.* Auger excavation: gravelly muds – groundwater sample (Salinity = 33 ppt). **Birds:** Brown Honeyeater **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
10 14/6/08 1335 hrs	7367519 N	318429 E	Hamilton Point – narrow mangrove embayment on south west side of point. Small area of salt flat between hinterland mangrove fringe (Site 9) and main *Rhizophora stylosa* mangrove zone (Site 11). Shrubland of *Ceriops australis* borders the salt flat. Auger excavation: dark brown/grey – groundwater sample (Salinity = 112 ppt). **Crustaceans:** *Sesarma* spp.
11 14/6/08 1345 hrs	7367506 N	318409 E	Hamilton Point – narrow mangrove embayment on south west side of point. Dense *Rhizophora stylosa* thicket (~3-4 m) at landward edge of the main mangrove zone. Auger excavation: grey/brown muds – groundwater sample (Salinity = 47 ppt). **Birds:** Brown Honeyeater, Mangrove Honeyeater. **Molluscs: Gastropods:** *Littoraria strigata.* **Crustaceans:** *Thalassina squamifera* mounds.
12 14/6/08 1410 hrs	7367438 N	318164 E	Hamilton Point – narrow mangrove embayment on south west side of point. Mudflats seaward of *Rhizophora stylosa* forest -soft mudflats with mudwhelk (*Telescopium*) colony grazing mudflat surface. Rocky shoreline west of mudflats has scattered *Rhizophora stylosa, Aegialitis annulata* and *Aegiceras corniculatum* with one large *Xylocarpus moluccensis* tree at high tide level. **Birds:** Great Egret. **Molluscs: Gastropods:** *Telescopium telescopium, Nerita squamulata, Nerita undata, Bembicium auratum, Cerithium trailli.* **Bivalves:** *Saccostrea cuccullata.* **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** Grapsid spp., *Thalamita* sp.
13 14/6/08 1430 hrs	7367746 N	317925 E	Hamilton Point – western shoreline. Rocky rubble shoreline with *Aegiceras corniculatum* shrubland (~ 1 m high) at mid-upper tide levels, also scattered *Osbornia octodonta, Excoecaria agallocha and Avicennia marina*. **Molluscs: Gastropods:** *Nerita squamulata, Nerita undata, Monodonta labio, Turbo cinereus, Bembicium auratum, Cerithium trailli, Morula marginalba.* **Bivalves:** *Barbatia* sp. **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., *Macromedaeus* cf. *demani.*

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
14 14/6/08 1500 hrs	7368212 N	317853 E	China Bay – southern shoreline where the rock rubble shoreline abuts the main mangrove system that extends north around China bay. *Aegiceras corniculatum* shrubland on the rocky shoreline and low dense *Rhizophora stylosa* forest extending around the China Bay shoreline. **Birds:** Brahminy Kite, Brown Honeyeater, Australian Magpie. **Molluscs: Gastropods:** *Nerita squamulata, Nerita undata, Monodonta labio, Bembicium auratum, Littoraria strigata, Cerithium trailli.* **Bivalves:** *Saccostrea cuccullata.* **Polyplacophora:** *Plaxiphora* sp.
15 15/6/08 0800 hrs	7368198 N	818001 E	China Bay - southern part of mangrove system. Landward edge of mangroves – *Ceriops australis* shrubland (2-4 m) with scattered *Avicennia marina, Lumnitzera racemosa* forming a narrow (~ 30 m wide) landward edge with low dense *Rhizophora stylosa* forest extending seaward. Auger excavation: *Ceriops australis* shrubland gravelly – muds, groundwater sample (Salinity = 46 ppt); *Rhizophora stylosa* forest grey muds, groundwater sample (Salinity = 41 ppt). **Birds:** Whistling Kite, Rufous Whistler, Leaden Flycatcher, Grey Fantail, Mangrove Gerygone, Brown Honeyeater, Pied Butcherbird. **Molluscs: Gastropods:** *Telescopium telescopium, Nerita balteata.* **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds.
16 15/6/08 0845 hrs	7368334 N	318175 E	China Bay - southern part of mangrove system. Landward edge of mangrove zone – narrow band of *Excoecaria agallocha* and *Ceriops australis* woodland with an *Ceriops australis* shrubland (~ 30 m wide) extending to the *Rhizophora stylosa* forest zone. **Birds:** Peaceful Dove, Rainbow Bee-eater, Varied Triller, Helmeted Friarbird, Brown Honeyeater, Spangled Drongo, Pheasant Coucal, Sacred Kingfisher, Australian Magpie. **Molluscs: Gastropods:** *Telescopium telescopium.* **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
17 15/6/08 1000 hrs	7368485 N	318515 E	China Bay - southern part of mangrove system. Salt flat that extends from mangroves to hinterland. Algal mat on salt flat. Auger excavation: grey-brown muddy sands and clays (Salinity = 102 ppt). **Birds:** Red-capped Plover (4). **Crustaceans:** *Sesarma* spp.
18 15/6/08 1010 hrs	7368500 N	318462 E	China Bay - southern part of mangrove system. Landward edge of mangroves adjacent to Site 17. Dense Rhizophora stylosa thickets (~ 2m) with a fringe of *Ceriops australis, Avicennia marina, Aegialitis annulata* heath extending out towards salt flat habitat. Auger excavation: grey-brown muds (Salinity = 44 ppt). **Birds:** Brown Honeyeater. **Molluscs: Gastropods:** *Telescopium telescopium.* **Crustaceans:** *Sesarma* spp., *Chthamalus* sp.
19 15/6/08 1035 hrs	7368291 N	317883 E	China Bay - southern part of mangrove system. Seaward edge of mangroves – dense low *Rhizophora stylosa* forest (4-5m). Soft mudflats extending seaward of mangroves. Auger excavation: gravelly muds (Salinity = 39 ppt). **Molluscs: Gastropods:** *Telescopium telescopium, Nerita balteata.* **Crustaceans:** *Sesarma* spp., *Chthamalus* sp., *Thalassina squamifera* mounds.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
20 15/6/08 1150 hrs	7368944 N	316422 E	Shoreline 1 km north west of China Bay. Rocky gravel spit extending out (~ 50m) into low tidal zone from the mangrove shoreline. Oyster encrusted rocks. On low tide extensive soft mudlflats are exposed both north and south of rock/gravel spit. **Birds:** Silver Gull, Red-capped Plover (4). **Gastropods:** *Nerita balteata, Bembicium auratum, Clypeomorus zonatus, Morula marginalba, Cronia* cf. *contracta, Nassarius dorsatus, Onchidium* sp., *Littoraria scabra, Littoraria filosa, Littoraria strigata*. **Bivalves:** *Saccostrea cuccullata, Gafrarium* sp., *Chama* sp., *Antigona chemnitzii, Pinctada* sp., *Tellina staurella, Tellina* sp. (rounded), *Barbatia* sp., **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., grapsid spp., *Chthamalus* sp., *Thalamita* sp., xanthid sp., balanid spp., *Scylla* holes.
21 15/6/08 1215 hrs	7369123 N	316447 E	Shoreline 1 km north west of China Bay. Narrow band of mangroves (low *Rhizophora stylosa* forest) landward of Site 20. Auger excavation: gravel and shelly muds (Salinity = 40 ppt). Landward edge of mangrove zone between Sites 21 and 22 is narrow (~ 10 m wide) fringe of mixed *Rhizophora stylosa, Ceriops australis, Excoecaria agallocha, Avicennia marina, Lumnitzera racemosa* and occasional *Xylocarpus moluccensis*. **Birds:** Mistletoe Bird (female) in a small clump of mangrove mistletoe (*Ameya* sp.) in canopy of a *Rhizophora stylosa* tree. Along hinterland fringe between Sites 21 and 22: Laughing Kookaburra, Pheasant Coucal, Crested Hawk (4). **Molluscs: Gastropods:** *Nerita balteata, Bembicium auratum.* **Crustaceans:** *Sesarma* spp., *Chthamalus* sp., *Scylla* holes.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
22 15/6/08 1300 hrs	7368907 N	316772 E	Shoreline ~ 0.5 km north west of China Bay. Narrow band (~ 40 m wide) of mangroves – low *Rhizophora stylosa* forest (4-5 m) with an understorey of scattered *Aegiceras corniculatum* shrubs, occasional *Excoecaria agallocha* and *Ceriops australis* at landward edge of mangroves. **Birds:** Brahminy Kite. **Gastropods:** *Nerita balteata, Bembicium auratum, Littoraria strigata, Morula marginalba.* **Bivalves:** *Saccostrea cuccullata, Tellina* sp., *Anadara* sp. **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., grapsid spp., *Chthamalus* sp., *Thalassina squamifera* mounds, *Macropthalmus* sp., small balanids, *Sesarma* spp., *Thalamita* sp.
23 15/6/08 1325 hrs	7731502	678242	China Bay – western shoreline. Rocky shoreline with extensive soft mudflats extending seaward (~ 200 m wide mudflats exposed at low tide). Amongst the rocky shoreline is a narrow (~ 20 m wide) band of low *Rhizophora stylosa* forest with *Aegiceras corniculatum* shrub understorey. **Birds:** Gull-billed Tern, White-bellied Sea Eagle, Whimbrel (4). **Gastropods:** *Monodonta labio, Nerita balteata, Nerita squamulata, Bembicium auratum, Littoraria strigata, Cerithidea cingulata, Telescopium telescopium, Morula marginalba.* **Bivalves:** *Saccostrea cuccullata, Tellina* sp., *Anadara* sp. **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., grapsid spp., *Chthamalus* sp., *Thalassina squamifera* mounds, *Macropthalmus* sp., small balanids, *Sesarma* spp., *Thalamita* sp., *Uca signata.*

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
24 15/6/08 1400 hrs	7368987 N	317461 E	China Bay - northern part of mangrove system. Landward edge of mangrove zone – narrow margin of *Ceriops australis, Avicennia marina* shrubs and then dense *Rhizophora stylosa* thickets (2-3 m) extend seaward across main mangrove zone. **Birds:** White-bellied Sea Eagle, Little Shrike Thrush, Brown Honeyeater, Striated pardalote. **Molluscs: Gastropods:** *Nerita balteata, Cerithidea largillierti, Telescopium telescopium, Terebralia semistriata.* **Bivalves:** *Geloina coaxans* (dead). **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds. **Other:** Feral pig excavations at landward edge of mangroves.
25 15/6/08 1430 hrs	7368837 N	317787 E	China Bay - central part of mangrove system. Salt flat habitat landward of mangrove zone (algal mat on salt flats). Auger excavation: grey-brown muds/clays (Salinity = 95 ppt). **Crustaceans:** *Sesarma* spp.
26 15/6/08 1450 hrs	7368802 N	317740 E	China Bay - central part of mangrove system. Landward edge of mangrove zone – narrow margin of *Ceriops australis, Avicennia marina, Aegialitis annulata* shrubs. Dense *Rhizophora stylosa* thickets (3-4 m) extend seaward across main mangrove zone. Auger excavation: grey-brown muds (Salinity = 47 ppt). **Birds:** Brown Honeyeater **Molluscs: Gastropods:** *Telescopium telescopium.* **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
27 16/6/08 0830 hrs	7371017	315095	Curtis Island shoreline adjacent to Passage Island. Low cliffs behind a rocky shoreline. Sparse low *Rhizophora stylosa* forest (3-4 m) with a low shrubland of *Aegiceras corniculatum, Ceriops australis, Aegialitis annulata, Osbornia octodonta* at the landward margin. **Molluscs: Gastropods:** *Littoraria strigata, Bembicium auratum, Nerita balteata, Cerithidea anticipata, Telescopium telescopium, Terebralia semistriata.* **Crustaceans:** *Chthamalus* sp., *Sesarma* spp.
28 16/6/08 0915 hrs	7371781	315134	Mangrove embayment ~1.5 km south of Laird Point. Salt flat habitat – algal mat on salt flat, also some areas of low scattered *Avicennia marina* in shallow drainage lines. Auger excavation: grey-brown clays (Salinity = 94 ppt). **Crustaceans:** *Sesarma* spp.
29 16/6/08 0920 hrs	7371748	315079	Mangrove embayment ~1.5 km south of Laird Point. Landward edge of mangroves adjacent to Site 28. Dense *Rhizophora stylosa* thickets (3 m) with a landward margin of mixed *Ceriops australis, Avicennia marina, Aegialitis annulata* shrubland. Auger excavation: grey muds (Salinity = 43 ppt). **Birds:** White-faced Heron, Brown Honeyeater, Pied Butcherbird **Molluscs: Gastropods:** *Nerita balteata, Telescopium telescopium.* **Crustaceans:** *Sesarma* spp.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
30 16/6/08 0945hrs	7371589	314647	Mangrove embayment ~1.5 km south of Laird Point. Seaward edge of mangrove zone - a narrrow sand chenier runs parallel to the shoreline amongst the mangrove zone. Chenier is composed of coarse sand, gravel and shell material and is ~ 10 m wide and ~2-3 m higher than the surrounding tidal flat level. On the upper levels and cfrest of the chenier, scattered mangrove trees occur amongst coastal terrestrial species on the chenier (mangrove species include *Bruguiera gymnorhiza, Rhizophora stylosa, Xylocarpus granatum & moluccensis* and *Osbornia octodonta*). Chenier/tidal flat margin supports a mangrove shrubland (*Ceriops australis, Osbornia octodonta, Avicennia marina, Lumnitzera racemosa, Aegiceras corniculatum*). Dense low *Rhizophora stylosa* forest (4-5 m) between chenier and low tidal mudflats extending further seaward. Auger excavations: Slope of chenier – shelly-gravels over muds (Salinity = 34 ppt), *Rhizophora stylosa* forest – grey/brown muds (Salinity = 40 ppt). **Birds:** Pied Cormorant, Collared Kingfisher, Fan-tailed Cuckoo, Helmeted Friarbird, Brown Honeyeater, Mangrove Honeyeater. **Molluscs: Gastropods:** *Littoraria strigata, Bembicium auratum, Nerita balteata, Cerithidea anticipata, Telescopium telescopium.* **Bivalves:** *Geloina coaxans.* **Crustaceans:** *Chthamalus* sp., *Sesarma* spp.
31 16/6/08 1050 hrs	7372016	314436	Mangrove embayment ~1.5 km south of Laird Point. Northern end of bay where the chenier finishes within mangrove zone. Site is located in salt flat and mangrove habitat between the chenier and hinterland. Dense *Rhizophora stylosa* forests occur next to the chenier and further landward, mangroves become *Ceriops australis* thickets (3-4 m) with a low *Avicennia marina* shrubland fringing the salt flat habitat. At hinterland margin scattered *Xylocarpus moluccensis* trees occur amongst *Lumnitzera racemosa* and *Excoecaria agallocha* shrubs. **Birds**: Little Shrike-thrush, Brown Honeyeater. **Molluscs: Gastropods:** *Nerita balteata, Telescopium telescopium, Ellobium aurisjudae.* **Crustaceans:** *Chthamalus* sp., *Sesarma* spp., cf. *Neosartium meinerti.*

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
32 16/6/08 1100hrs	7372392	313975	Rocky shoreline ~0.5 km south of Laird Point (approx. bridge crossing location). Moderate sloping rocky shoreline with oyster encrusted rocks at mid to low tide levels. Low scattered *Aegiceras corniculatum* shrubland amongst rocky substrate at mid to high tide levels. At 1330 hrs approx. 100 m of soft mudflats were exposed seaward of the rocky shoreline (at 1330 hrs low tide was 1.0 m CD). **Birds:** White-bellied Sea Eagle, Pied Cormorant, Collared Kingfisher, Striated Pardalote. **Gastropods:** *Nerita squamulata, Nerita undata, Littoraria strigata, Bembicium auratum, Telescopium telescopium, Pyrazus ebeninus, Clypeomorus* sp., *Bedeva paivae*, *Nassarius dorsatus, Melo amphora.* **Bivalves:** *Tellina staurella, Chlamys* sp., *Antigona chemnitzii, Trisidos tortuosa, Pinctada* sp., *Isognomon isognomum, Saccostrea cuccullata, Saccostrea* sp. (on trees). **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., *Thalamitoides tridens*, grapsid spp., balanid sp.
33 16/6/08 1300 hrs	7372829	313748	Laird Point – sand flats and mud flats exposed at mid to low tide levels. Narrow mangrove fringe of *Avicennia marina* and *Aegiceras corniculatum* shrubland at mid to high tide levels behind sand flats (eroding shoreline amongst mangrove shrubland). Landward of mangroves is a shallow saline lagoon and salt flat – *Sporobolus* grass, *Halosarcia* sp. and other halophytic low shrubs (e.g. *Suaeda* sp.) fringe the saline lagoon. **Birds:** Pied Cormorant, White-bellied Sea Eagle, Brahminy Kite, Masked Lapwing, Red-capped Plover, Beach Stone-curlew, Pied Oystercatcher, Crested Tern, Gull-billed Tern, Helmeted Friarbird. **Molluscs: Gastropods:** *Polinices sordidus, Bedeva paivae*, *Murex tribulus, Nassarius dorsatus, Nassarius fraudator, Melo amphora, Ophicardelus ornatus.* **Bivalves:** *Tellina staurella, Chlamys* sp., *Antigona chemnitzii, Venerupis* sp., *Placamen* sp., *Paphia* cf. *gallus, Botula vagina, Solen* sp., *Acrosterigma* sp., *Trisidos tortuosa, Antigona* sp., *Barbatia* sp., *Pinctada* sp., *Isognomon isognomum. Saccostrea cuccullata.* **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Mictrys* sp., cf. *Neosartium meinerti.* **Polychaetes:** *Diopatra amboinensis* **Echinoderms:** cf. *Anthenea* sp., sea urchin test.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
34 16/6/08 1400 hrs	7372670	3144236	Small mangrove embayment immediately east of Laird Point. Site is in salt flat habitat landward of mangroves (algal mat on salt flat surface). Extensive band of dead mangroves (mostly *Ceriops australis*) in landward mangrove areas around embayment. Auger excavation: muddy sands and gravels, compact layer at 0.6m BGL (Salinity = 94 ppt). **Crustaceans:** *Sesarma* spp.
35 16/6/08 1415 hrs	7372713	314211	Small mangrove embayment immediately east of Laird Point. Landward edge of mangroves adjacent to Site 34. Low dense forest of *Rhizophora stylosa* with a narrow (~ 20 m wide) landward fringe of *Avicennia marina* shrubland with some *Ceriops australis*. Auger excavation: muddy sands and muds (Salinity = 42 ppt). **Birds:** White-faced Heron, Helmeted Friarbird, Brown Honeyeater. **Molluscs: Gastropods:** *Nerita balteata, Cerithidea anticipata, Cerithidea largillierti, Telescopium telescopium.* **Crustaceans:** *Chthamalus* sp., *Sesarma* spp., cf. *Neosartium meinerti, Thalassina squamifera* mounds.
36 17/6/08 0930 hrs	7372202	311497	Friend Pt area: Salt flats ~ 1 km northwest of Friend Point. Auger excavation: brown-grey clays with old root (mangrove ?) matter and peat amongst clays (Salinity = ~180 ppt). **Molluscs: Gastropods:** *Telescopium telescopium,* numerous individuals, all long dead. *Ellobium aurisjudae,* also dead. **Crustaceans:** *Sesarma* spp.
37 17/6/08 0945 hrs	7372067	311529	Friend Pt area (~ 1 km northwest of Friend Point): landward band of mangroves adjacent to Site 36. Dense *Ceriops australis* shrubland (2-3 m) with scattered *Avicennia marina* on margins. Mangroves occur on a raised surface (low mound) that is ~ 30 cm above level of the surrounding salt flats. Extensive mortality of mangrove trees/shrubs in some areas within this mangrove band (mostly on landward side). Auger excavation: grey clays (Salinity = 65 ppt). **Birds:** Mangrove Honeyeater, Mangrove Gerygone **Invertebrates:** None.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
38 17/6/08 1015 hrs	7371898	311665	Friend Pt area (~ 1 km northwest of Friend Point): Bare mudflat area with dead mangroves (old stumps) between landward band (Site 37) and seaward band (Site 39) of mangroves. Stumps are of both *Rhizophora stylosa* and *Ceriops australis*. Auger excavation: grey/brown muds and clays (Salinity = 97 ppt). **Birds:** Whimbrel (2), Gull-billed Tern (25). **Invertebrates:** None. In situ cockles exposed by sheet erosion of tidal flat surface.
39 17/6/08 1030 hrs	7371835	311731	Friend Pt area: Seaward band of mangroves ~ 1km northwest of Friend Pt. Eroding shoreline with a mud cliff (~1m high) separating the remaining tall *Ceriops australis* shrubland (on landward side of cliff) from the eroded *Rhizophora stylosa* zone. Stands of alive *Rhizophora stylosa* still occur immediately to west of Site 39. Auger excavation: grey/brown muds (Salinity = 43 ppt). **Birds:** Osprey, Brahminy Kite, Whimbrel, Pied Cormorant, Gull-billed Tern, Mangrove Honeyeater, Little Bronze-Cuckoo. **Molluscs: Gastropods:** *Telescopium telescopium,* numerous individuals, all long dead. **Crustaceans:** *Sesarma* spp., *Chthamalus* sp.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
40 17/6/08 1130 hrs	7372383	312257	Friend Point: Seaward mangrove zone - mangroves extending from a small chenier (sand/shell deposit) to low tidal mudlflats. Chenier habitat: the crest of the chenier supports *Suaeda* sp and the ground cover *Canavalia* sp?? (a coastal dune species) and on the chenier slope scattered mangroves occur, *Xylocarpus moluccensis* and *Avicennia marina* trees. Auger excavation: shelly gravels (Salinity = 41 ppt). Mangrove habitat: tall shrubland of *Avicennia marina, Ceriops australis, Rhizophora stylosa* between seaward *Rhizophora stylosa* forest zone and chenier. Auger excavation: grey/brown muddy sands (Salinity = 51 ppt). Seaward mangrove zone is a *Rhizophora stylosa* forest (6 m) and mudflats extend seaward from mangrove zone. Auger excavation: brown muddy sands (Salinity = 42 ppt). **Birds:** Brahminy Kite, Mangrove Honeyeater, Brown Honeyeater. **Molluscs: Gastropods:** *Nerita balteata, Telescopium telescopium, Terebralia semistriata, Cerithidea cingulata, Littoraria strigata.* **Crustaceans:** *Chthamalus* sp., *Sesarma* spp.
41 17/6/08 1205 hrs	7372541	312333	Friend Point: Site is ~ 200 m north of Site 40. A small chenier occurs within the seaward mangrove zone. Chenier slopes support *Bruguiera gymnorhiza, Rhizophora stylosa*, *Xylocarpus moluccensis*, *Osbornia octodonta, Aegiceras corniculatum, Avicennia marina, Excoecaria agallocha* mangroves with *Sprobolus* grass. Seaward mangrove zone is low *Rhizophora stylosa* forest (4-5 m) with an understorey of scattered *Aegiceras corniculatum*. Auger excavation: shelly muds (Salinity = 41 ppt). **Birds:** Yellow-faced Honeyeater, Brown Honeyeater. **Molluscs: Gastropods:** *Bembicium auratum.* **Crustaceans:** *Chthamalus* sp., *Sesarma* spp., *Scylla* holes.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
42 17/6/08 1210 hrs	7372522	312413	Friend Point: Rocky rubble shoreline with oyster encrusted rocks extending seaward of mangroves (Site 41) into low tidal levels. At low tide the rubble shoreline extended ~ 100m out from seaward mangroves edge - this made this location the only suitable site for low tide access to Friend Point as other surrounding low tidal flats were soft mud. **Birds:** Pied Oystercatcher, Gull-billed Tern, White-bellied Sea Eagle. **Molluscs: Gastropods:** *Littoraria strigata, Onchidium* sp. **Bivalves:** *Saccostrea cuccullata.* **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** Grapsid spp.
43 17/6/08 1415 hrs	7373200	315452	Graham Creek ~ 1.5 km upstream from Laird Point. Narrow mangrove fringe (~ 20 m wide) on a moderate sloping shoreline. Oyster encrusted rocks and rubble in front of mangroves at mid to lower tide levels. Low dense *Rhizophora stylosa* forest with a landward edge of *Ceriops australis* shrubland with scattered *Excoecaria agallocha, Lumnitzera racemosa* and *Avicennia marina*. **Birds:** Pied Oystercatcher, Gull-billed Tern. **Molluscs: Gastropods:** *Littoraria strigata, Littoraria scabra, Nerita balteata, Bembicium auratum, Onchidium* sp. **Bivalves:** *Pinctada* sp., *Saccostrea cuccullata.* **Polyplacophora:** *Plaxiphora* sp. **Crustaceans:** *Petrolisthes* sp., cf. *Neosartium meinerti, Sesarma* spp.
44 17/6/08 1430 hrs	7372901	315503	Mangrove embayment 1.5 km upstream from Laird Point. Salt flat habitat landward of mangroves. Sparse low *Avicennia marina* on salt flat. Auger excavation: gravelly muds (Salinity = 67 ppt). **Birds:** Australian Magpie. **Crustaceans:** *Sesarma* spp.

INTERTIDAL HABITAT FIELD SURVEY SITES			
SITE	**LATITUDE**	**LONGITUDE**	**COMMENTS**
45 17/6/08 1445 hrs	7372901	315460	Mangrove embayment 1.5 km upstream from Laird Point. Landward edge of mangrove zone (adjacent to Site 44). Low dense *Rhizophora stylosa* forest with a narrow (30 m wide) landward edge of *Avicennia marina* shrubalnd with occasional *Ceriops australis*. Auger excavation: grey/brown muds (Salinity = 43 ppt). **Birds:** Grey Fantail. **Molluscs: Gastropods:** *Nerita balteata, Telescopium telescopium, Littoraria strigata.* **Crustaceans:** *Sesarma* spp., *Thalassina squamifera* mounds.

Subtidal Habitat Summary Results

Appendix B

SUBTIDAL HABITAT FIELD SURVEY SITES				
SITE	**GPS numbers**	**EASTING**	**NORTHING**	**COMMENTS**
1	GPS016 GPS022 GPS015 GPS018 GPS017 GPS002	312563 312762 312988 313126 313359 313454	7372747 7372733 7372714 7372767 7372782 7372663	**The Narrows between Friend Point and Laird Point** **Substrate characteristics:** Coarse sand with silt at Friend Point and Laird Point. Deep channel with high proportion of shell grit at GPS022. Substrate relatively flat with some rippling of the sea bed and burrows. **Benthic Communities:** GPS016 – silt with numerous burrows; one Pennatulacid (Sea pen) and one sea fan (Gorgonian) GPS022 – 100m transect - coarse sand and shell grit with lots of shell fragments; ripples of silt; dominated by sponges and hydroids, algae, two gorgonians, one soft coral, one zoanthid GPS015 – 100m transect – rubble/shell grit/sand substrate; flat coarse sand, sea fan (12), sea whip (17), bivalve (8), zoanthids (12), soft coral (5), sea pen (1), clumps of algae, hydoids, sponges (4), tube anemone (1) GPS018 – 100m transect – silt/sand/some shell grit – sea whip (34), sea fan (7), sponge weed, zoanthid (8), macroalgae, bivalve (razor shell), soft coral, algae, sea pen (2), *Padina sp*., bryzoan (2), ascidian (2), sponge, sea snake GPS017 – 100m transect – silt with shell grit to fine silt with some rubble, red algae, sponge (3), sea star (1), sea fan (1), tube anemone (2), algae, sea whip (7), bivalve (1), school of juvenile fish GPS002 – 100m transect – silt with some shell grit and over 200 small burrows – dominated by algae, hydroid, sea star
2	GPS020 GPS021 GPS023	317493 317455 316925	7368099 7368129 7368518	**China Bay** **Substrate characteristics:** silted embayment with fine silt and numerous burrows. **Benthic communities:** one sea pen (Pennatulacid)

SUBTIDAL HABITAT FIELD SURVEY SITES				
SITE	**GPS numbers**	**EASTING**	**NORTHING**	**COMMENTS**
3	GPS003 GPS004 GPS005 GPS006 GPS007 GPS024 GPS025 GPS026	317716 317745 317783 317795 317842 317993 318049 318032	7367856 7367780 7367645 7367617 7367623 7367393 7367359 7367409	**Rubble slope and rocky headland between China Bay and Hamilton Point** **Substrate characteristics:** The rubble slope is silted with sparse cover of marine species. The rocky headland to the south of the slope has higher proportion of rock with silt and some sand. **Benthic Communities:** Rubble slope has tube anemones (3), sponge (5), soft coral (1), bivalve (2), algae, ascidian (1), bryzoan and 5 small tube worms. The rocky headland contained a higher percentage cover dominated by hydroid zoanthids and algae. Gorgonians (26), sponges (18) , sea fans (3), one hard coral *Tubastrea sp.*, soft coral (17), algae, sea star (1).
4	GPS008 GPS009 GPS010 GPS027	318895 318840 318780 318832	7366748 7366764 7366844 7366789	**Hamilton Point** **Substrate characteristics:** rocky wall adjacent to a deep channel, sandy substrate with rock, rubble and shell grit. **Benthic Communities:** Drift dive – dominated by hydroid zoanthids, gorgonians and sponges. Large areas of sponge gardens. Encrusting and boulder sponges (50 x 70cm) covered in hydroids. Clumps of sponge with gorgonians and feather stars on top. Clumps of *Turbinaria sp*. Bleached and pink. Several soft corals and branching sponges within the sponge gardens and hydroid zoanthid stands. Percentage cover ranging from 2 -10% and up to 30% in patches. Highest species diversity and abundance of all sites surveyed during this study. One Nurse Shark seen resting in a cave and a Nudibranch was sighted.
5	GPS012 GPS013 GPS014	319251 319219 319211	7367025 7366864 7366856	**Southern side of Hamilton Point towards Boatshed Point** **Substrate characteristics:** silt with rubble, numerous small burrows and patches of algae. Silted embayment with rocky edges towards Hamilton Point **Benthic Communities:** Dominated by algae with some sponge and hydroids. Feather star (1), tube anemone (1) and sea pen(1)

Macroinvertebrate and Sediment Assessment for the Curtis Island Gas Pipeline EIS

Appendix C

BE WHAT YOU WANT TO BE.

CQUniversity AUSTRALIA

Macroinvertebrate and sediment assessement for the Curtis Island gas pipeline EIS

Ralph Alquezar

August 2008

URS

Centre for Environmental MANAGEMENT

GLADSTONE

Macroinvertebrate and sediment assessment for the Curtis Island gas pipeline EIS

URS

2008

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Executive summary

Port Curtis is a shallow, semi-enclosed estuarine system situated on the central coast of Queensland approximately 500 kilometres north of Brisbane. Macrobenthic assemblages (community structure) were assessed by investigating abundance, species richness, diversity and species evenness in subtidal benthos at twenty four sites within Port Curtis in July 2008. Data from previous studies were also used to determine changes in macroinvertebrate biodiversity among years within sites, where available. Sediment samples were also collected for particle size analysis and carbon content at the 24 sites in July 2008.

A total of 656 organisms from 129 taxa were collected throughout the 24 sites. Polychaetes, molluscs and crustaceans accounted for more than 85 % of individuals. There were significant differences in macroinvertebrate biodiversity among the 24 sites in 2008. Where data was available, macroinvertebrate biodiversity was significantly different among years, within sites. In general, highest macroinvertebrate abundance and diversity was observed in 1995-96 & 2003. Macroinvertebrate community assemblages were also different among sites in 2008. A number of environmental factors such as freshwater inputs, salinity, sediment grain, size and organic content may contribute to differences in macrobenthic biodiversity and assemblage composition. In Port Curtis, environmental variables such as sediment size, water depth and carbon content appeared to have an influence on macrobenthic assemblages among sites, however, other environmental factors that were not investigated in the present study, such as freshwater output and potential contamination, can influence macrobenthic community assemblages.

Estuarine intertidal mud-flats are highly productive habitats and crucial breeding grounds for a diverse array of macroinvertebrates and are important trophic components for detrital-based and other higher order food webs, hosting energy transfer among consumer and predator organisms.

Macrobenthic organisms are associated with physical and chemical properties linked to sediments, thus, changes in sediment and water quality can have detrimental effects on macrobenthic community structure, making them suitable bioindicators of ecosystem health.

1.0 Introduction

Port Curtis is a shallow, semi-enclosed estuarine system situated on the central coast of Queensland approximately 500 kilometers north of Brisbane. There are two large offshore islands (Curtis Island and Facing Island) that surround the waters of Port Curtis forming a narrow coastal embayment approximately 200 km^2 in area. Freshwater flows from two major rivers (Boyne and Calliope) and numerous creeks discharging into the port. Strong tidal currents and a 5m tidal range also have major influences on the area's marine and intertidal ecosystems. The area supports a wide range of marine habitats including mangroves, seagrass meadows, salt-marshes, coral reefs, and extensive mudflats and subtidal soft-sediments.

Many of the regions coastal environments are considered significant in terms of conservation value. The Great Barrier Reef World Heritage Area commences at the low water mark on the mainland side of the Narrows and includes Curtis Island, while the offshore areas east of Curtis Island are included within the Mackay/Capricorn Section of the Great Barrier Reef Marine Park (GBRMPA 1998). Areas in and around Port Curtis also provide important feeding grounds for the endangered species *Dugong dugong* and have been declared part of the Rodd's Bay Dugong Sanctuary (GBRMPA 1998).

Industrial growth in the Port Curtis hinterland over the last 40 years has resulted in the development of several foreshore manufacturing, processing and bulk handling facilities. These include major alumina and aluminium processing plants, a coal-fired power station, a cement works, several chemical refineries, and an extensive network of shipping wharves and storage facilities. Other significant industries within the region include mining, agriculture, fishing and tourism.

Estuarine intertidal mud-flats are highly productive habitats and crucial breeding grounds for a diverse array of macroinvertebrate organisms (MacFarlane and Booth 2001). Macrobenthic communities are important trophic components for detrital-based and other higher order food webs, hosting energy transfer among consumer and predator organisms (Connolly and Guest 2004; Coull 1999). Macrobenthic community assemblages (macroinvertebrates) have been used in the past as bioindicators of ecosystem health (Stewart *et al.* 2000), and are associated with physical and chemical properties linked to sediments, thus, changes in sediment and water quality can have detrimental effects on overall community structure (Kanandjembo *et al.* 2001; Nanami *et al.* 2005; Stewart *et al.* 2000). There are a number of studies that have investigated macrobenthic community assemblages associated with environmental variables (Hirst 2004; Kanandjembo *et al.* 2001; MacFarlane and Booth 2001; Munari *et al.* 2003; Nanami *et al.* 2005).

URS commissioned the Centre for Environmental Management at CQUniversity Australia to undertake an investigation on soft sediment macroinvertebrate communities in the Port Curtis Region and sediment physical properties as background information for a proposed pipeline from the Gladstone mainland to Curtis Island.

The following aims were proposed;

1) To determine macroinvertebrate assemblages at sites along the proposed pipeline route and adjacent to the Plant;
2) To determine sediment carbon content and particle size distribution at all sites;
3) To include any macroinvertebrate biodiversity data available from previous studies.

2.0 Material and Methods

A detailed assessment of macroinvertebrate community assemblages and sediment physical properties was undertaken at 24 sites in July 2008 (Table 1; Figure 1).

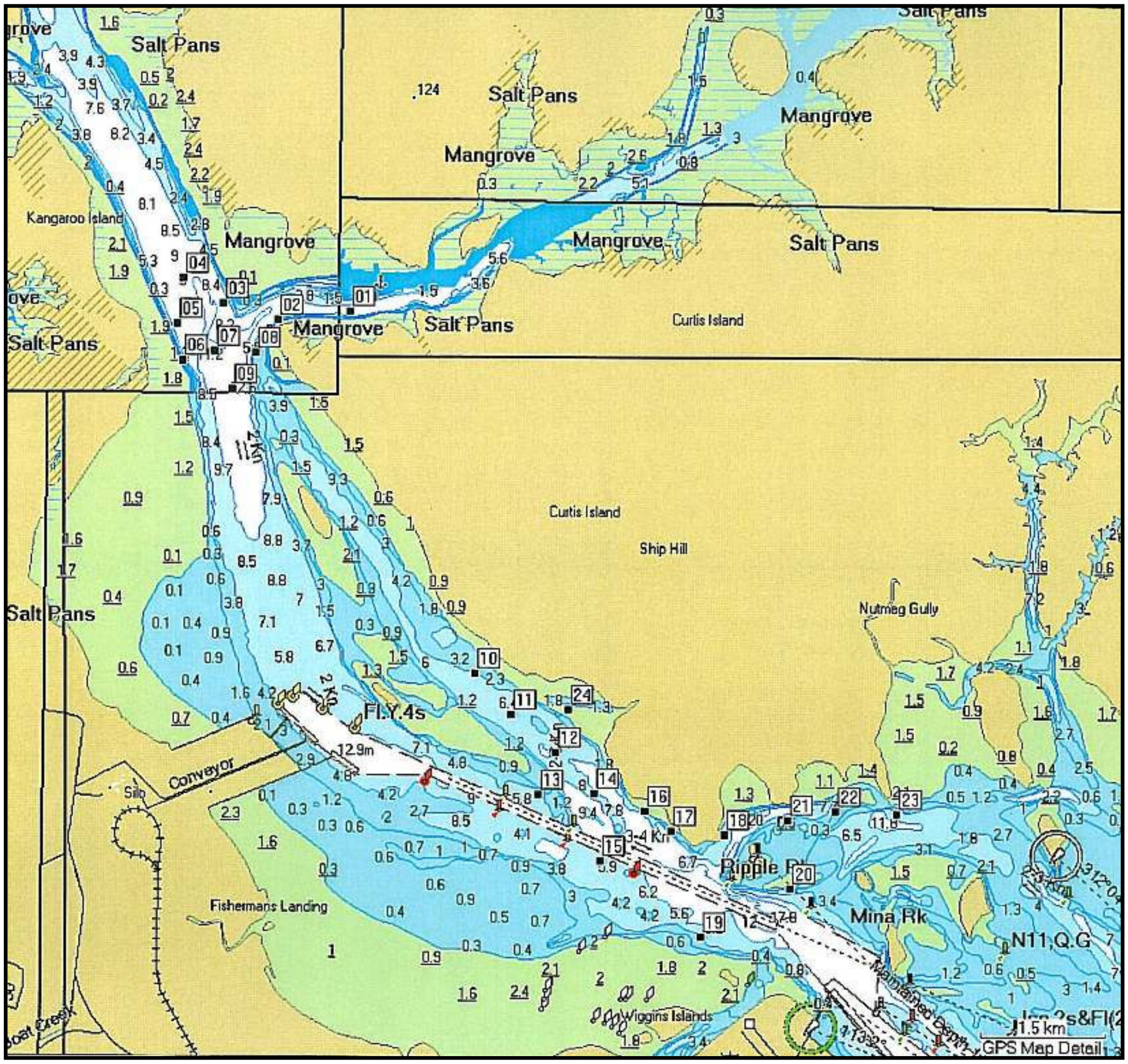

Figure 1. Map of 24 sites along Grahams Creek and Targinnie Channel.

Three replicate grab samples were collected at each site using a van-Veen grab sampler to determine macroinvertebrate community assemblages. Sediments and associated macroinvertebrates were bagged and sent to the laboratory for further analysis. Samples were sieved through a 1mm mesh and the retained organisms were preserved, sorted and identified to the lowest taxonomic level (species level).

Three replicate surface sediment samples were also collected at each site using acid-washed polyethylene corers and stored on ice before being transported to the laboratory for further analysis.

Sediments were taken from each site for carbon content and particle size analysis. Sediment samples were oven dried to a constant temperature of 40˚C. Sediments were sieved to < 2mm particle size to remove large shell grit and gravel. Sediment organic content was measured as percent Loss on Ignition (%LOI) using a muffle furnace at 550 ˚C for 3h. Sediment particle sizes were determined gravimetrically by wet sieving sediments on an agitated stack of Endecott test sieves with apertures of 2mm, 1mm, 500µm, 250µm, 125µm and 63µm and expressed as a percent of the total sample weight.

Macrobenthic biodiversity was measured as total abundance (total number of organisms), species richness (total number of taxa), diversity (Shannon-Weiner; the proportion of macroinvertebrates per species) and species evenness (how evenly abundance is spread among the various taxa that make up an assemblage). Diversity values ranged from 0 (indicating low community complexity) to 4 (indicating high community complexity). Species evenness values were between 0 (few species make up the majority of the abundance) and 1 (even number of species making up the total abundance) (Cai *et al.* 2006; Hill 1973; McClatchie *et al.* 1997; Nero and Sealey 2005; Zar 1996).

Differences ($P < 0.05$, 95% confidence intervals) in (a) macrobenthic biodiversity and (b) sediment carbon content among sites were determined using one-way Analysis of Variance (ANOVA). Data were tested for homogeneity of variance and normality. Significance levels were increased ($P < 0.01$, 99% confidence intervals) where data did not meet that criteria (O'Neill 2000; Underwood 1997).

Macrobenthic community assemblages were plotted using *non-metric* Multi Dimensional Scaling (*n*-MDS). Certain outliers in the sample matrix of individual samples caused high unacceptable stress values (> 0.2), therefore, mean assemblages were used to test among sites for *n*-MDS. Sample points close to each other signify they are similar in community composition. The further the sample points are away from each other, the more dissimilar they are. Analysis of Similarity (ANOSIM) was used to statistically determine dissimilarities in community structure among sites (PRIMER; Clarke, 1993). Due to the large number of sites and the number of pair wise comparisons, Cluster analysis was used to determine macrobenthic community similarity among groups of sites. Similarity percentages (SIMPER) were used to determine what organisms best described changes in community assemblages among sites (PRIMER; (Clarke 1993)). Macrobenthic community structure was examined using Bray-Curtis (B-C) similarity measures (Clarke 1993). Bray Curtis was chosen as the preferred similarity matrix because it performed well in preserving 'ecological distance' in a variety of simulations on different types of data sets. No transformations were made to the data to maintain equal weight among common and rare species. Data were standardised and weight dispersion corrected.

Macroinvertebrate biodiversity data was included, where available, from 1995-2003 at sites 1-3, 8, 21-23 based on a report from CQPA Alquezar and Small (2006) (Table 1), to determine change in macroinvertebrate biodiversity over time.

Table 1. GPS coordinates (Datum WGS 84) for all sites at the proposed gas pipeline route, sampling depths and reported chart datum depths. Underlined values indicate intertidal at low water mark. Sites with CQPA code indicate previous year's data available.

Site number	South	East	Depth (m)	Datum Depth (m)	CQPA site
1	S23 44.521	E151 10.887	8.4	6.4	CQPA 16
2	S23 44.577	E151 10.372	10.5	6.5	CQPA 13
3	S23 44.477	E151 09.982	8.9	6.6	CQPA 14
4	S23 44.312	E151 09.704	11.5	9.0	-
5	S23 44.607	E151 09.660	9.2	7.7	-
6	S23 44.842	E151 09.695	5.3	3.5	-
7	S23 44.781	E151 09.921	13.5	11.2	-
8	S23 44.790	E151 10.217	5.5	1.6	CQPA 15
9	S23 45.025	E151 10.052	17.2	12.6	-
10	S23 46.851	E151 11.774	8.8	7.9	-
11	S23 47.120	E151 12.026	12.1	5.2	-
12	S23 47.364	E151 12.348	10.8	6.7	-
13	S23 47.633	E151 12.217	8.8	5.8	-
14	S23 47.625	E151 12.618	11.0	8.0	-
15	S23 48.069	E151 12.660	7.5	5.9	-
16	S23 47.746	E151 12.978	15.4	6.7	-
17	S23 47.873	E151 13.166	5.9	<u>1.2</u>	-
18	S23 47.900	E151 13.546	12.5	5.2	-
19	S23 48.560	E151 13.379	10.5	3.5	-
20	S23 48.247	E151 14.015	6.5	0.3	-
21	S23 47.799	E151 14.001	3.6	<u>0.2</u>	CQPA 9
22	S23 47.738	E151 14.331	5.6	0.3	CQPA 10
23	S23 47.757	E151 14.766	3.0	0.8	CQPA 11
24	S23 47.091	E151 12.430	2.6	<u>1.2</u>	-

BIO-ENV was used to analyse relationships between macrobenthic community assemblages by relating similarity matrices with environmental variables (particle size analysis, carbon content – CC and water depth). Note that linking environmental variables with biological patterns using BIO-ENV is purely observational and not causative. Cause and effect can only be demonstrated using manipulative field experiments (Clarke and Gorley 2001; Clarke and Green 1988).

3.0 Results and discussions

3.1 Sediments

Sediment carbon content was significantly ($P < 0.01$) elevated at sites 3, 6, 10, 17, 18 and 24, with lowest sediment carbon content at sites 8, 12-16 and 19-22 (Figure

2). Interestingly, sites 3, 6, 17, 18 & 24 also expressed the highest silt mud fraction (< 63µm) with sites 19-22 showing the highest sand/gravel fractions (Figure 3).

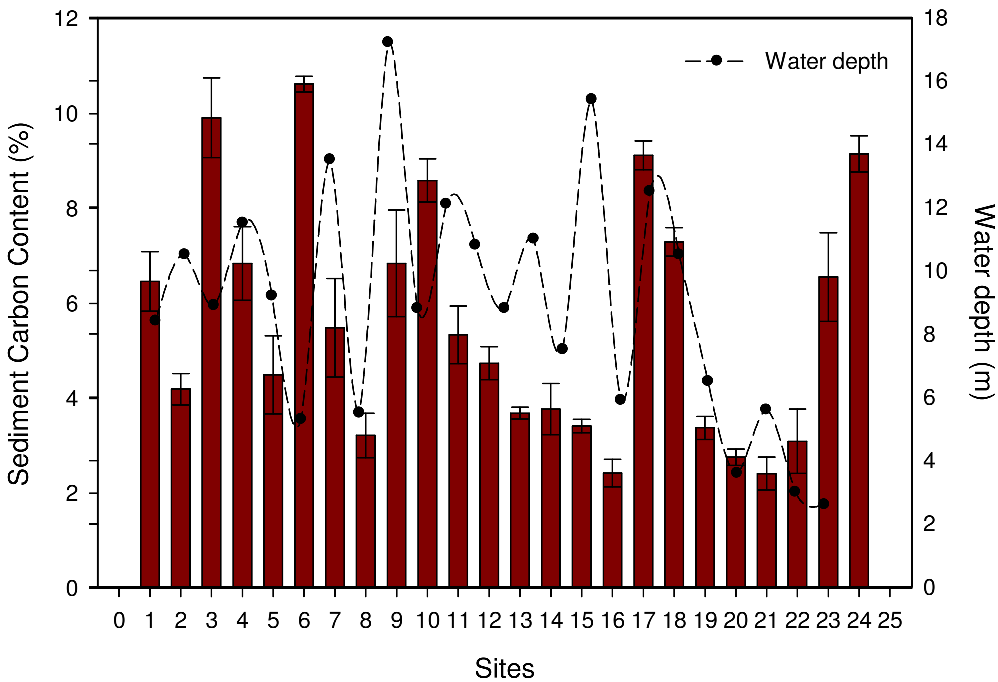

Figure 2. Mean (±se) percent sediment carbon content at 24 sites within Port Curtis. Solid lines indicate water depths (m) at which samples were taken from.

Studies have shown that systems with low water flow velocity have higher deposition rates of carbon content and finer sediments of high cohesive properties including silts and clays (mud). Systems with relatively high water flow rates have sediments mainly composed of sands and gravels, hence, low cohesive properties (McAnally and Mehta 2002; Sakamaki and Nishimura 2007). Changes in water depths (Table 1) and currents within the Port Curtis estuary may explain why some sites had significantly elevated carbon content and finer particle sizes (increased deposition) and other sites with increased water movements having lower carbon content and larger grain sizes. See appendix I for post Hoc results among sites.

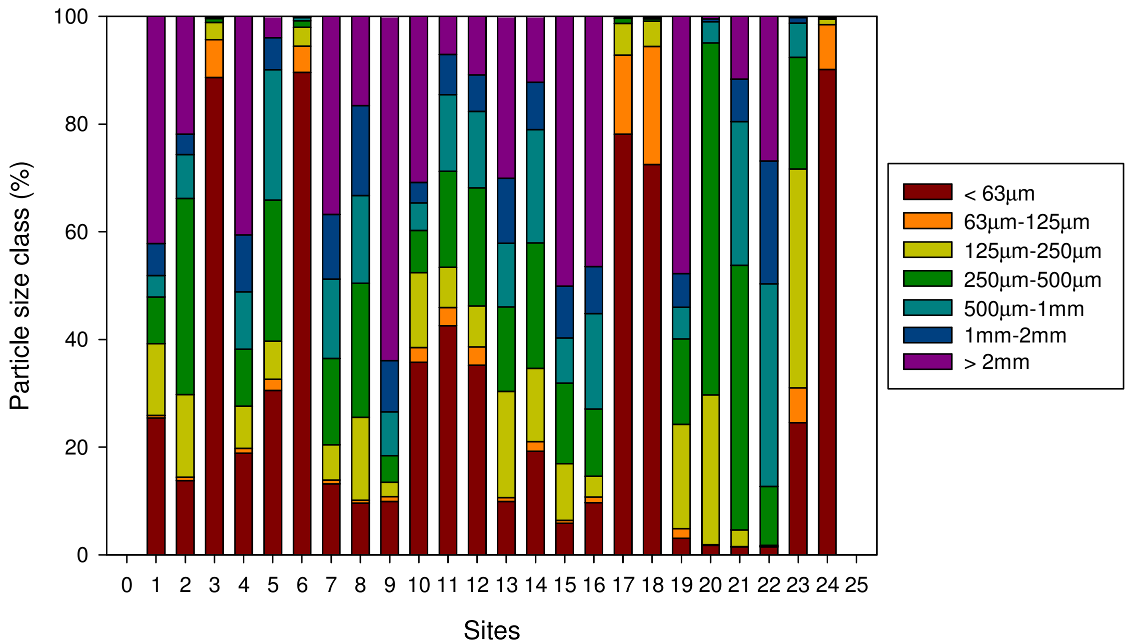

Figure 3. Mean sediment particle size classes at 24 sites within Port Curtis.

3.2 Macroinvertebrates

A total of 656 macroinvertebrate organisms were collected from 129 taxa. The most common organisms included *Maldanidae* sp. *2, Carditella (Carditellona) torresi, Ceriantharia* sp. *2,* and *Ascidia sydneiensis.* Polychaetes made up the highest percentage of taxa (39%) followed by molluscs (30%) and crustaceans (15%) (Figure 4). See appendix IV & V for species lists and photo libraries.

There were significant (P < 0.01) differences among sites in macroinvertebrate biodiversity (Figure 5 & 6). In general, sites 9, 12, 13, 19 and 23 had the highest abundance (> 17 individuals), species richness (> 9 taxa) and diversity (Figures 5 & 6) with lowest biodiversity at sites 6, 17, 21 & 22. Conversely, highest species evenness was encountered at sites 6, 7, 14, 17 & 24, with lowest evenness at sites 9, 13 & 22. See appendix II for post Hoc results.

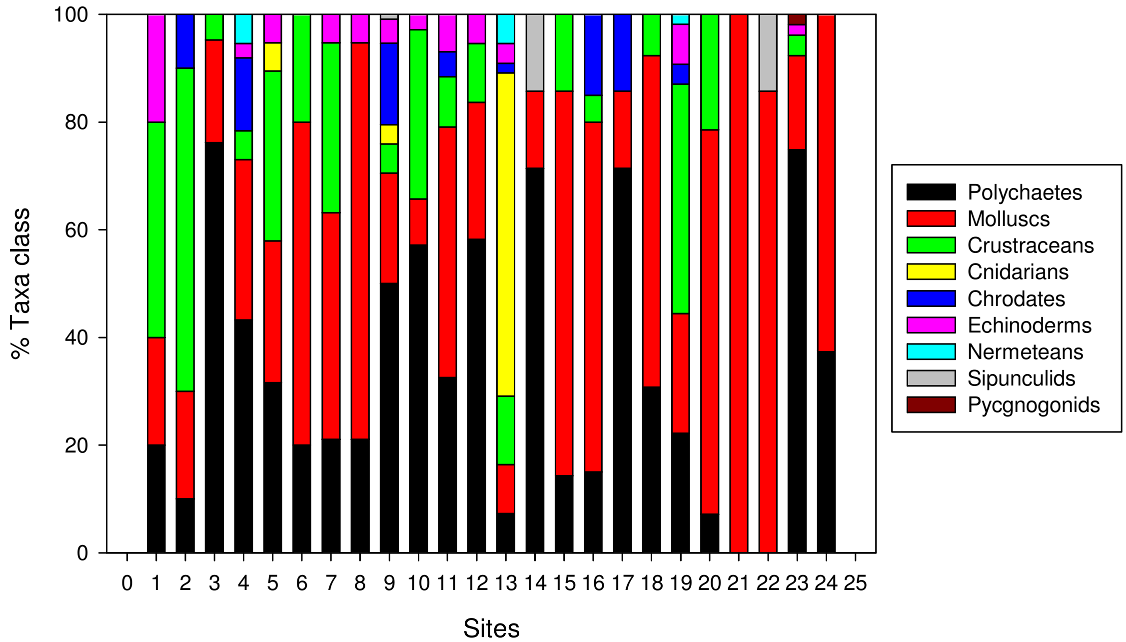

Figure 4. Average percent (%) taxa composition at each of 24 sites, *n* = 3.

Table 2. Correlation coefficients from BIO-ENV analysis for comparisons among macrobenthic assemblages and environmental parameters (sediment particle size, sediment carbon content (CC) and water depth (m), at Port Curtis. Data were normalized and mean corrected.

Single variable	**R**	**Best combination**	**R**
Mud	0.348	Mud, Depth	0.304
CC	0.209	Mud, CC	0.296
Sand	0.149	Mud, Gravel	0.277
Gravel	0.088	Mud, CC, Depth	0.276

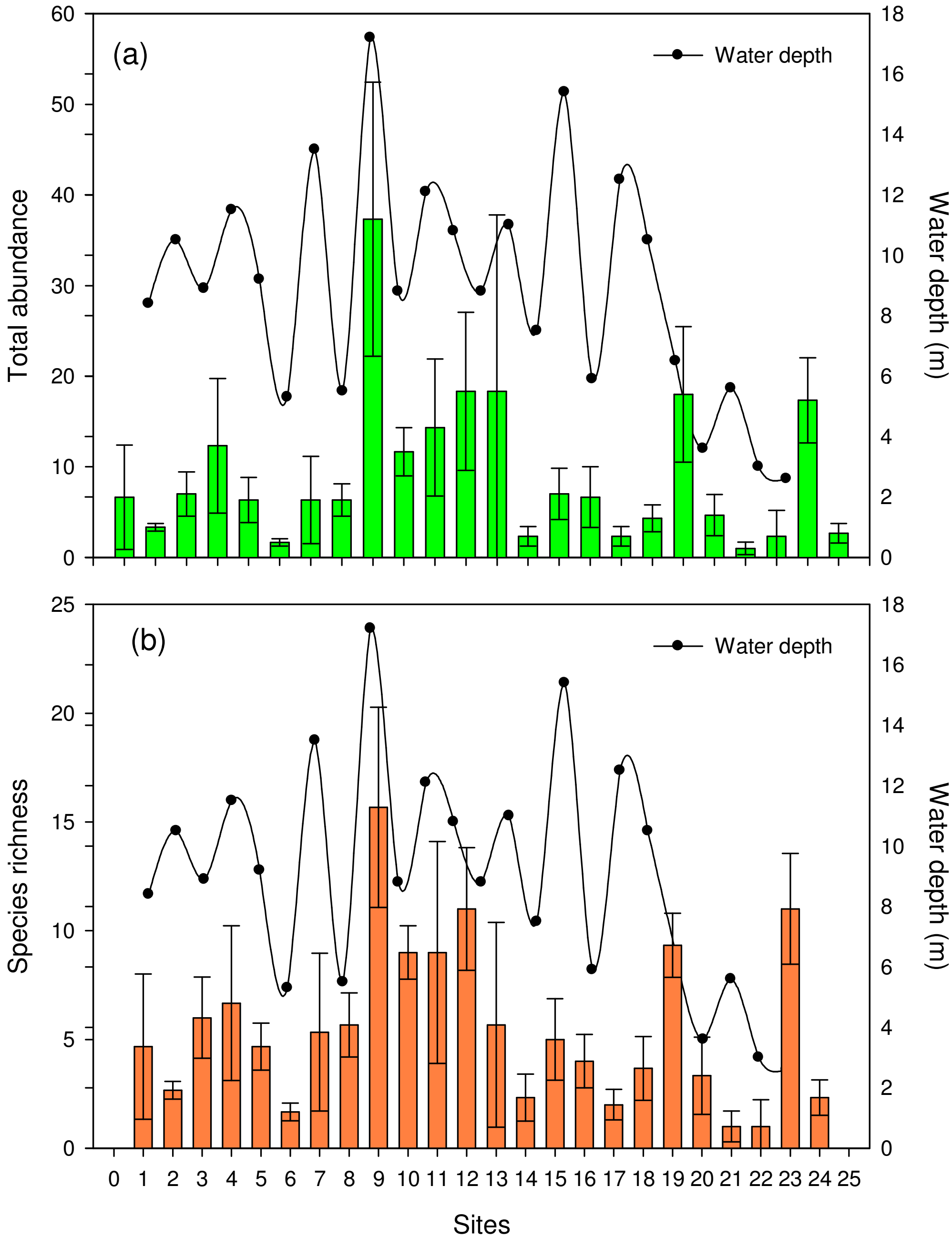

Figure 5. Macroinvertebrate mean (±se) (a) total abundance, and (b) species richness at the 24 sites in Port Curtis. Solid lines indicate water depths (m) at which samples were taken from.

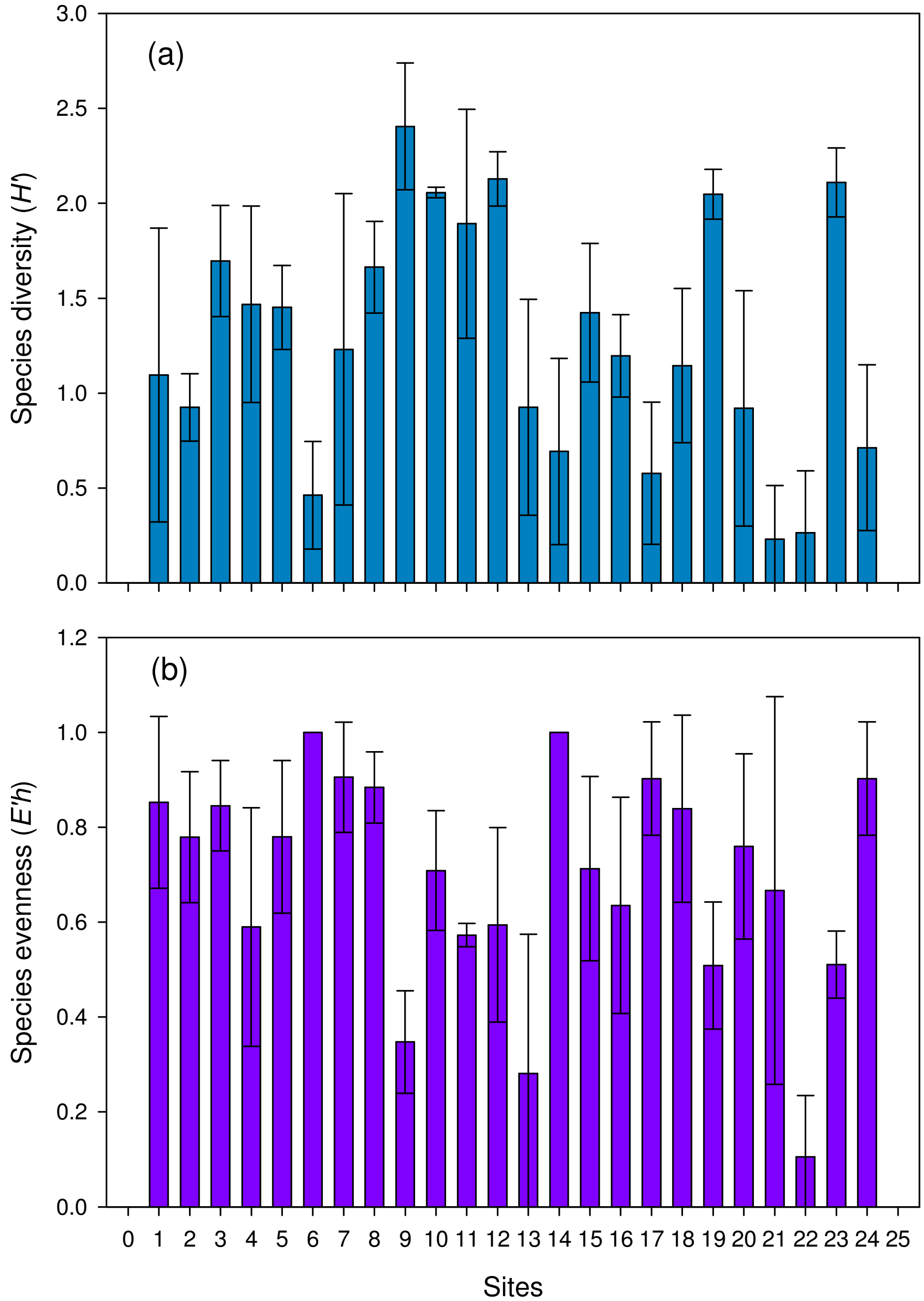

Figure 6. Macroinvertebrate mean (±se) (a) diversity, and (b) species evenness at the 24 sites in Port Curtis.

There were significant community assemblage dissimilarities among sites (Figure 7; Global R-statistic 0.283, $P < 0.001$). In general, site 17 showed the greatest community dissimilarity among other sites. Sites 8 & 11, 4 & 16, and 1 & 21 showed the highest community similarity among all sites (Figure 8).

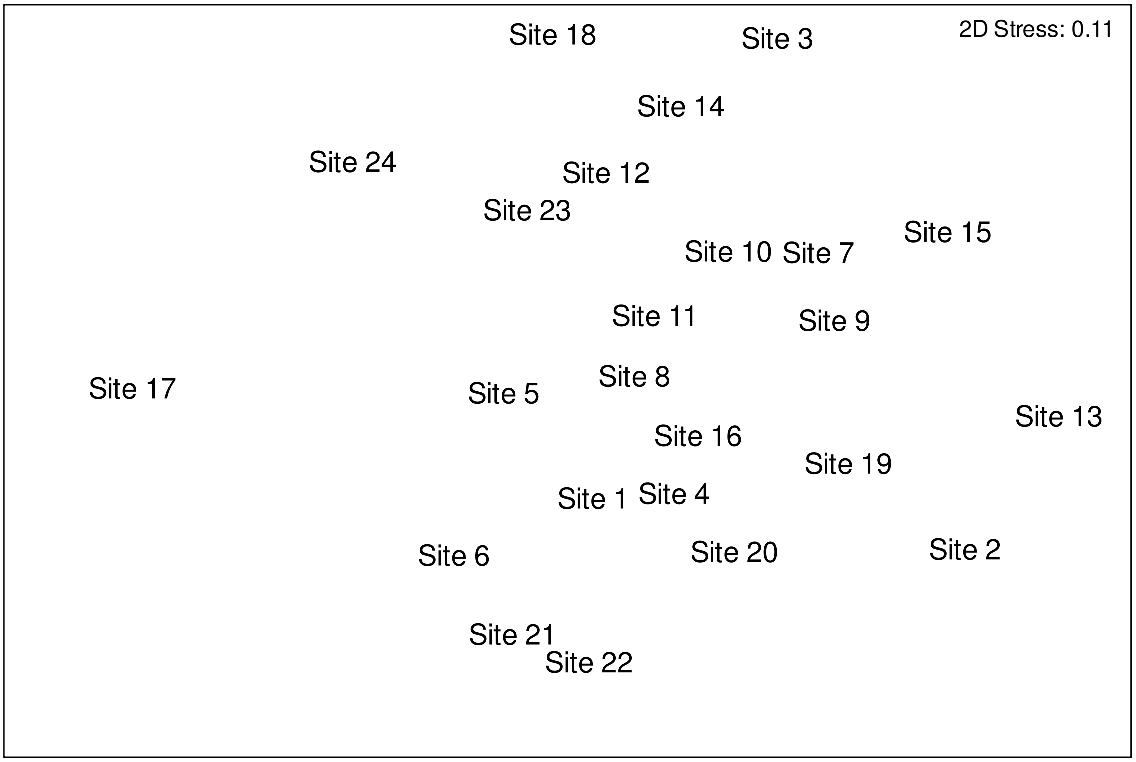

Figure 7. 2D ordination plot (*n*-MDS) of macroinvertebrate assemblages at the 24 different sites in June 2008. Data were normalized, weight dispersion corrected and mean corrected to site.

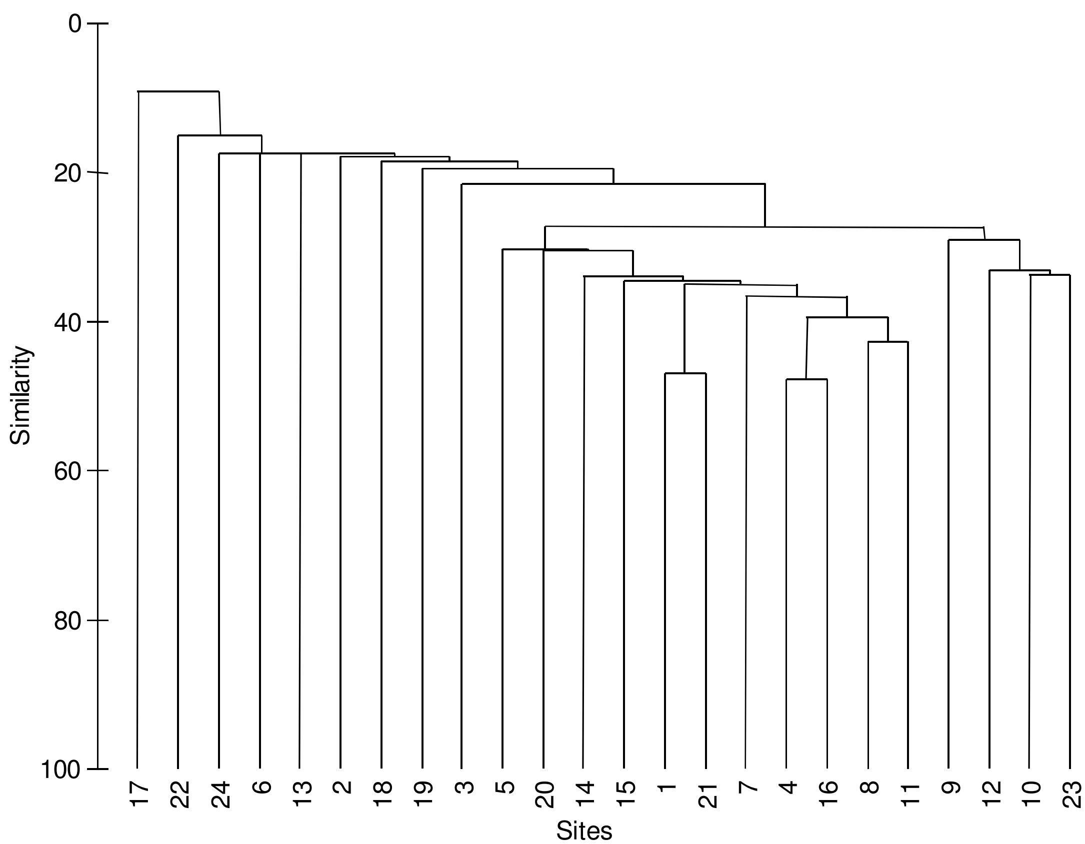

Figure 8. Cluster analysis of macroinvertebrate community assemblages among sites, $n = 3$.

The main species that contributed to differences in community structure among sites (SIMPER analysis) included *Carditella (Carditellona) torresi* (up to 45%), *Maldanidae* sp. 2 (up to 30%) and *Placamen tiara* (up to 10%).

Macrobenthic communities can vary over space and time due to changes in salinity, temperature fluctuations, increased pollution loads and seasonal freshwater flows (Carvalho *et al.* 2005; Clarke and Gorley 2001; Clarke and Green 1988; Munari *et al.* 2003; Voelz *et al.* 2000). For example, a study by (Yong *et al.* 1997) investigated macrobenthic community changes along a pollution gradient in the River Trend (UK), with a considerable loss in numbers and species diversity in the more polluted sites. However, Yong et al. (1997) also established that although there were considerable amounts of species loss, there were an increased number of tolerant species that thrived in the more polluted sites. In the present study, there were significant ($P < 0.01$) differences in macroinvertebrate biodiversity among years (Figures 9-12), with significantly higher macroinvertebrate abundance and species richness in 1995, 2001-2002 at most sites. Lowest macroinvertebrate biodiversity was in 1997, 98, 99, 2003 & 2008 (Figures 9-12). See appendix III for post Hoc results. Although the suite of environmental parameters mentioned above were not measured as part of this study, changes in water/sediment quality can affect changes to macrobenthic community structure, since all sites were within the shallow semi-enclosed Port Curtis estuary.

Community fluctuations over space and time could be attributed to natural occurrences such as flood events or severe storms, or may be influenced by human (anthropogenic) activities in the adjacent coastland. A study by Alquezar and Boyd (2008) found a significant reduction in macroinvertebrate biodiversity following a localised dredge disturbance with observed successional ecosystem recovery over time. It is important to note that both broad scale processes (diffusive) as well as point source impacts may affect macroinvertebrate community structure over time (Alquezar *et al.* 2006; Parr and Mason 2003; Peeters *et al.* 2004; Stewart *et al.* 2000; Wang *et al.* 2007).

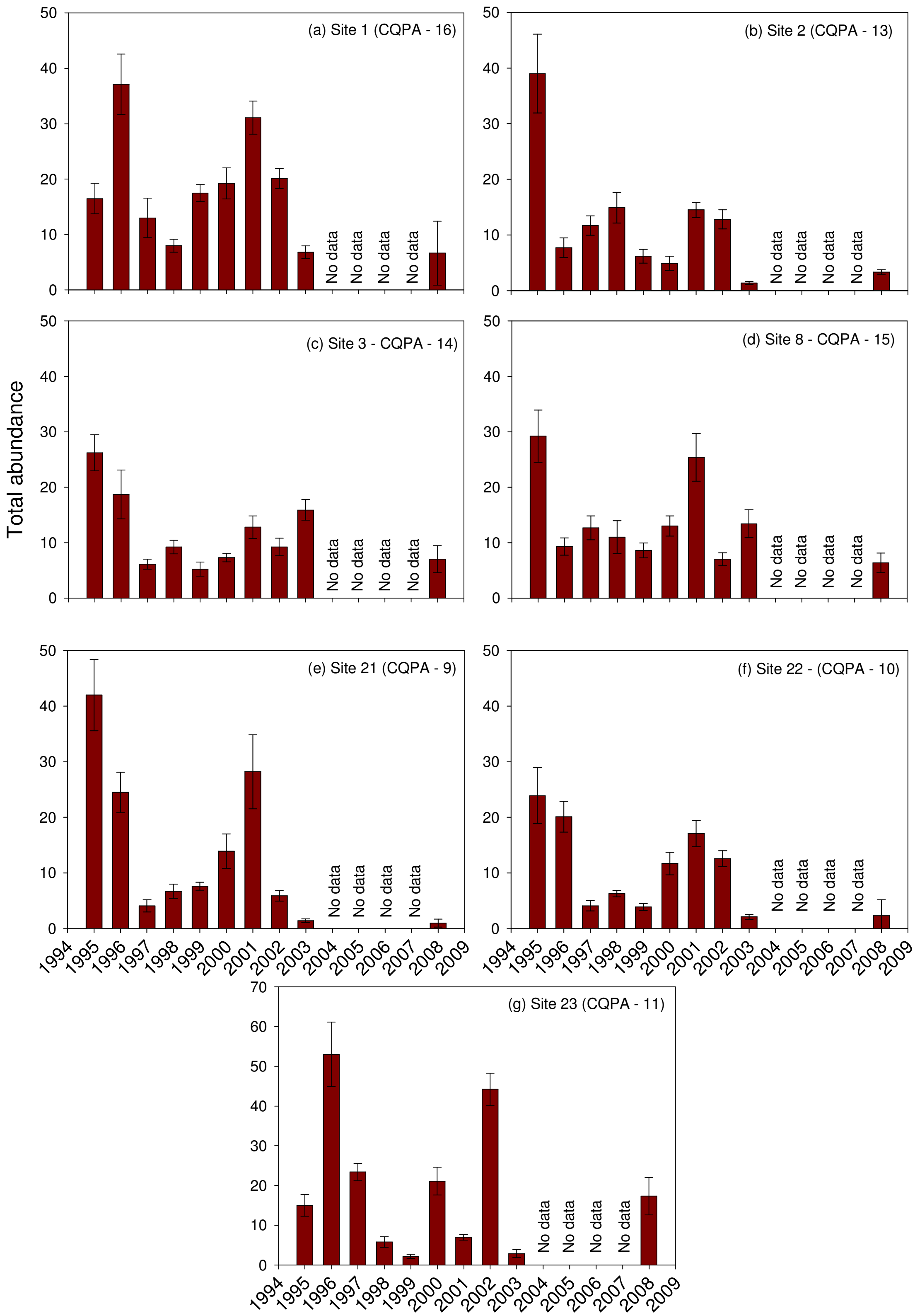

Figure 9. Mean (± SE) macroinvertebrate abundance at different sites from 1995-2003 & 2008. No data available from 2004-07. Data collected from other sources (Alquezar and Small 2006) (*n* = 10, 94-03; *n* = 3, 2003).

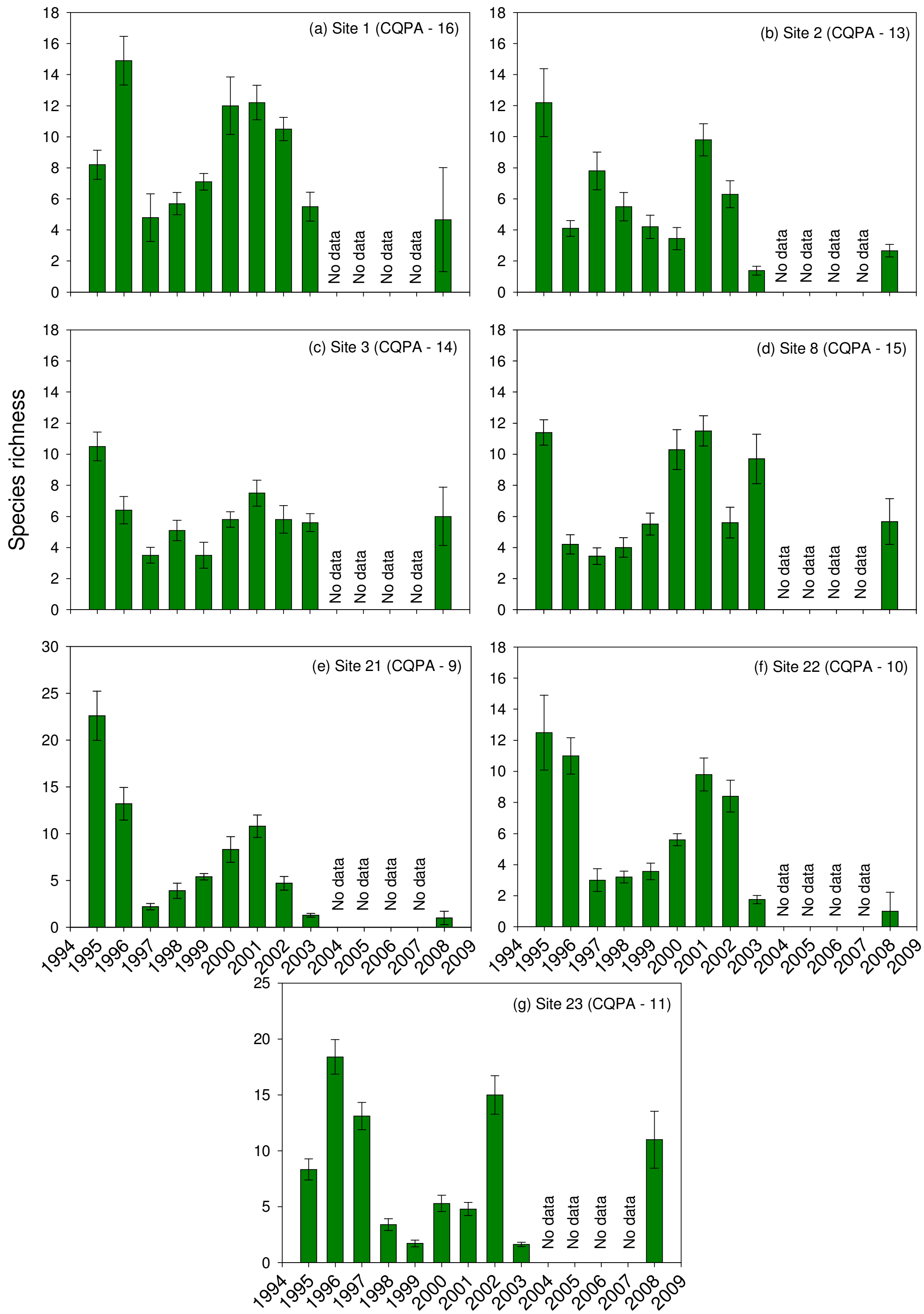

Figure 10. Mean (± SE) macroinvertebrate species richness at different sites from 1995-2003 & 2008. No data available from 2004-07. Data collected from other sources (Alquezar and Small 2006) (n = 10, 94-03; n = 3, 2003).

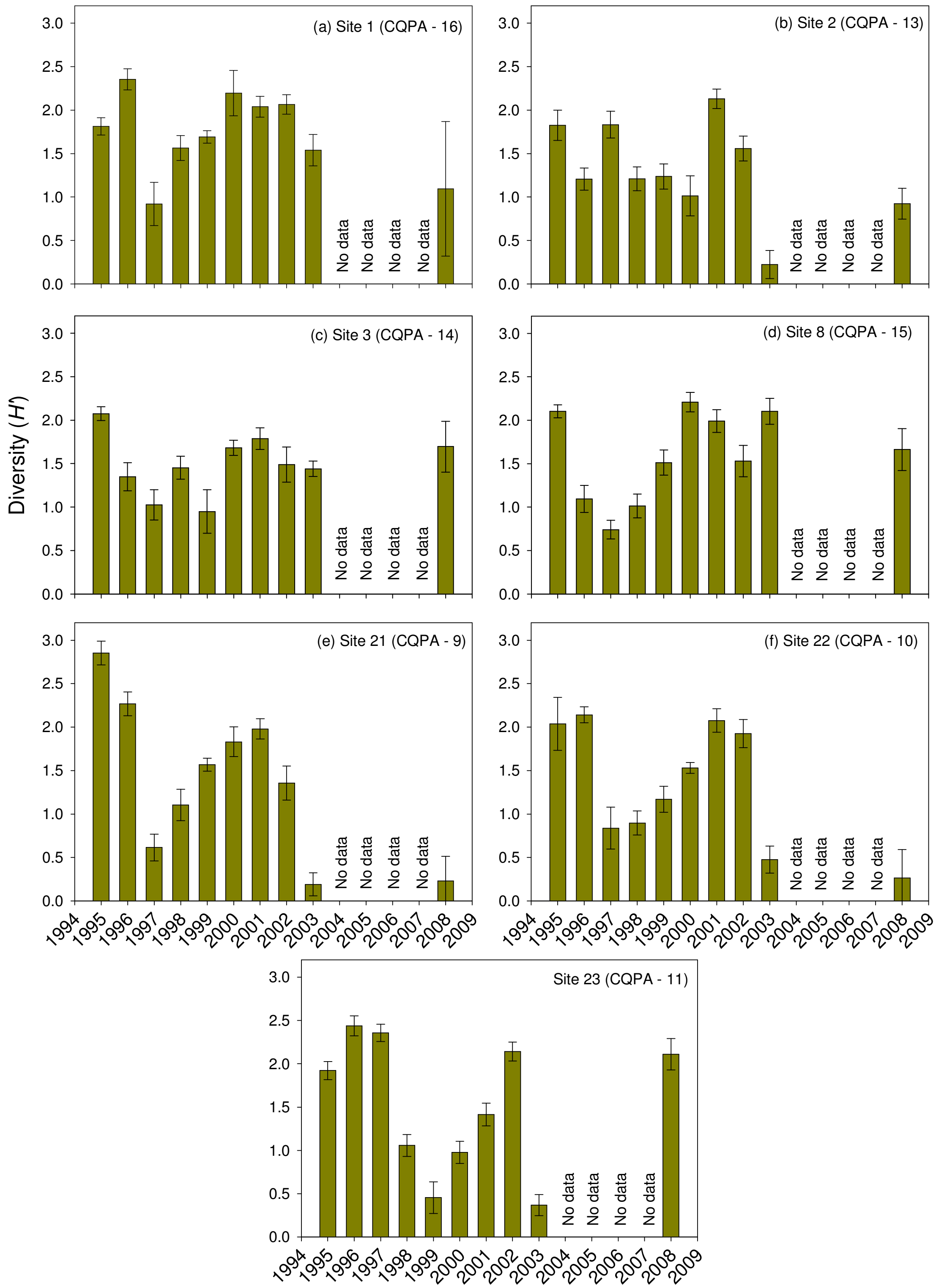

Figure 11. Mean (± SE) macroinvertebrate diversity at different sites from 1995-2003 & 2008. No data available from 2004-07. Data collected from other sources (Alquezar and Small 2006) (*n* = 10, 94-03; *n* = 3, 2003).

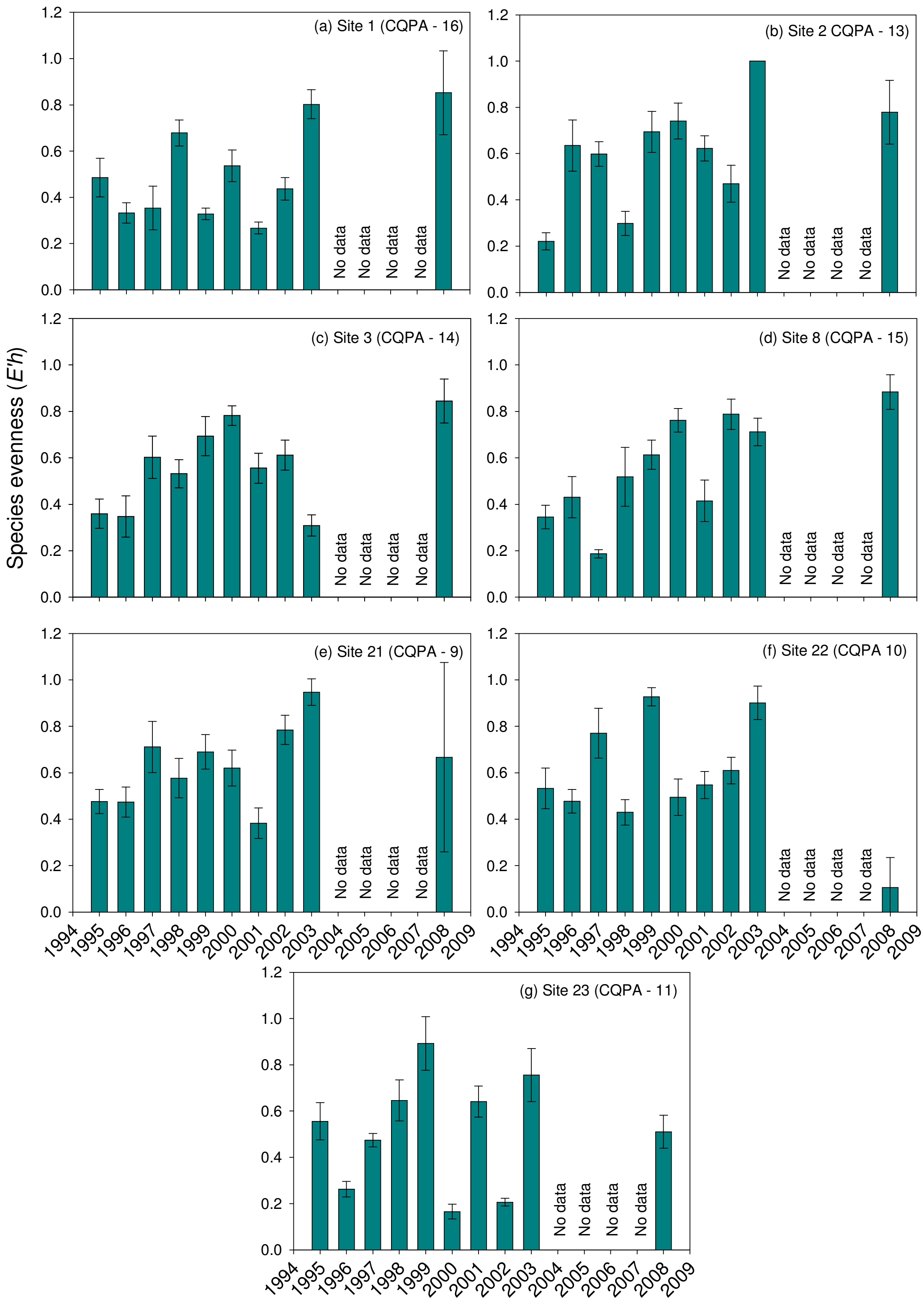

Figure 12. Mean (± SE) macroinvertebrate species evenness at different sites from 1995-2003 & 2008. No data available from 2004-07. Data collected from other sources (Alquezar and Small 2006) (*n* = 10, 94-03; *n* = 3, 2003).

Furthermore, other studies have shown that spatial and seasonal changes in macrobenthic assemblages have been attributed to other ecological stressors such as predator/competitor density dependence, organic matter (& particle size), seagrass/algae biomass and shoot/frond density, with increased vegetation in the hotter months promoting greater soft bottom stabilisation and habitat structure and thus increasing the availability of microhabitats (Dauvin *et al.* 2004; Rueda and Salas 2003). In the present study, a significant correlation was observed among macroinvertebrate community assemblages with sediment particle sizes and water depth (Table 2), however, this trend is purely observational and not causative as there are a number of other variables that were not investigated in the current study.

Benthic succession following a significant environmental disturbance can have an effect on macrobenthic recolonisation (Long *et al.* 1996; Skilleter *et al.* 2006). A review by Bolam and Rees (2003) reported that macrobenthic invertebrate community assemblages in systems that were periodically (frequently) exposed to disturbances recovered at a faster rate (up to 9 months) than invertebrate communities that resided in relatively unstressed marine environments (between 1-4 years).

In ecological succession, organisms fall under two distinct categories. There are r-selected organisms or r-strategists with characteristics of high fecundity and being able to reproduce rapidly, small body sizes, short generation times and the ability to disperse offspring widely. K-selected organisms are organisms that dominate in stable or predictable environments, have larger bodies, longer life spans and produce fewer offspring (Haybach *et al.* 2004; MacArthur and Wilson 1967; Pianka 1970). In environments with a high frequency and/or intensity of disturbances, r-strategists usually dominate due to their opportunistic behavior and ability to reproduce at faster rates, however, as time succeeds, r-selected organisms are gradually replaced with K-selected organisms, which are better suited to competition and limited resources (Haybach *et al.* 2004; Pianka 1970).

The recovery/reversibility potential for an ecosystem may be governed by time and ecosystem connectivity, however, the strength of a local disturbance can also influence ecological processes affecting the distribution of species and ultimately change community structure.

4.0 Conclusions

- There were significant differences in sediment carbon content among sites within Port Curtis

- Sediment size classes were significantly different among sites, possibly due to water depth and hydrodynamic influences (currents, tides).

- Macroinvertebrate abundance, species richness, diversity and species evenness (biodiversity) was significantly different among sites in 2008.

- Macroinvertebrate community assemblages were significantly dissimilar among sites within Port Curtis in 2008.

- Macroinvertebrate biodiversity was significantly different among years, within sites, based on previous year’s data.

- Changes in biodiversity and assemblage composition among sites and years may be attributed to differences in water depth, sediment carbon content loads and sediment particle sizes.

- Other biotic (ecological) and abiotic (anthropogenic disturbance, contamination, freshwater inputs etc.) influences may also affect macroinvertebrate biodiversity and assemblage composition.

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Appendix I

Carbon content (CC)

Site	21	16	20	22	8	19	15	13	14	2	5	12	11	7	1	23	4	9	18	10	17	24	3	6
	2.4	2.4	2.8	3.1	3.2	3.4	3.4	3.6	3.8	4.2	4.5													
			2.8	3.1	3.2	3.4	3.4	3.6	3.8	4.2	4.5	4.7												
					3.2	3.4	3.4	3.6	3.8	4.2	4.5	4.7	5.3											
						3.4	3.4	3.6	3.8	4.2	4.5	4.7	5.3	5.5										
												4.7	5.3	5.5	6.5	6.5								
													5.3	5.5	6.5	6.5	6.8	6.8	7.2					
																	6.8	6.8	7.2	8.6				
																				8.6	9.1	9.2	9.9	
																							9.9	10

**Student-Newman-Keuls Post Hoc test for carbon content (CC) at all sites. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among sites. Sites are placed in order from lowest to highest percentage of carbon content.*

Appendix II

Total abundance

Site	21	6	14	17	22	24	2	18	20	5	7	8	1	16	3	15	10	4	11	23	19	12	13	9
	1.0	1.6	2.3	2.3	2.3	2.6	3.3	4.3	4.6	6.3	6.3	6.3	6.6	6.6	7.0	7.0	11	12	14	17	18	18	18	
																				17	18	18	18	37

Species Richness

Site	21	22	6	17	14	24	2	20	18	16	1	5	15	7	8	13	3	4	10	11	19	12	23	9
	1.0	1.0	1.7	2.0	2.3	2.3	2.7	3.3	3.6	4.0	4.6	4.6	5.0	5.3	5.6	5.6	6.0	6.7	9.0	9.0	9.3	11	11	
																			9.0	9.0	9.3	11	11	16

Diversity

Site	21	22	6	17	14	24	20	2	13	1	18	16	7	15	5	4	8	3	11	19	10	23	12	9
	0.2	0.3	0.5	0.6	0.7	0.7	0.9	0.9	0.9	1.1	1.1	1.2	1.2	1.4	1.5	1.5	1.7	1.7	1.9					
																				2.0	2.1			
																					2.1	2.1	2.1	
																							2.1	2.4

Evenness

Site	22	13	9	19	23	11	4	12	16	21	10	15	20	2	5	18	3	1	8	17	24	7	6	14
	0.1	0.3	0.3	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8									
		0.3	0.3	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	1.0	1.0

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity at all sites. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences ($P < 0.01$) among sites. Sites are placed in order from lowest to highest biodiversity.*

Appendix III

Site 1 (CQPA 16)

Total abundance

Year	2008	2003	1998	1997	1995	1999	2000	2002	2001	1996
	6.7	6.8	8.0	13.0	16.5	17.5	19.2	20.1		
						17.5	19.2	20.1	31.1	
									31.1	37.1

Species Richness

Year	2008	1997	2003	1998	1999	1995	2002	2000	2001	1996
	4.6	4.8	5.5	5.7	7.1	8.2	10.5			
					7.1	8.2	10.5	12.0	12.2	
							10.5	12.0	12.2	14.9

Diversity

Year	1997	2008	2003	1998	1999	1995	2001	2002	2000	1996
	0.9	1.1	1.5	1.6	1.7					
		1.1	1.5	1.6	1.7	1.8				
			1.5	1.6	1.7	1.8	2.0	2.1	2.1	2.4

Evenness

Year	2001	1999	1996	1997	2002	1995	2000	1998	2003	2008
	0.3	0.3	0.3	0.4	0.4	0.5	0.5			
					0.4	0.5	0.5	0.7		
							0.5	0.7	0.8	
								0.7	0.8	0.9

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Site 2 (CQPA 13)

Total abundance

Year	2003	2008	2000	1999	1996	1997	2002	2001	1998	1995
	1.4	3.3	4.9	6.2	7.7	11.7	12.8	14.5	14.9	
										39.0

Species Richness

Year	2003	2008	2000	1996	1999	1998	2002	1997	2001	1995
	1.4	2.7	3.4	4.1	4.2	5.5	6.3			
		2.7	3.4	4.1	4.2	5.5	6.3	7.8		
						5.5	6.3	7.8	9.8	
								7.8	9.8	12.2

Diversity

Year	2003	2008	2000	1996	1998	1999	2002	1995	1997	2001
	0.2									
		0.9	1.0	1.2	1.2	1.2	1.6			
				1.2	1.2	1.2	1.6	1.8	1.8	
							1.6	1.8	1.8	2.1

Evenness

Year	1995	1998	2002	1997	2001	1996	1999	2000	2008	2003
	0.2	0.3	0.5							
		0.3	0.5	0.6	0.6	0.6				
			0.5	0.6	0.6	0.6	0.7	0.7	0.8	
							0.7	0.7	0.8	1.0

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Site 3 (CQPA 14)

Total abundance

Year	1999	1997	2008	2000	1998	2002	2001	2003	1996	1995
	5.2	6.1	7.0	7.3	9.2	9.2	12.8	15.9		
			7.0	7.3	9.2	9.2	12.8	15.9	18.7	
									18.7	26.2

Species Richness

Year	1997	1999	1998	2003	2000	2002	2008	1996	2001	1995
	3.5	3.5	5.1	5.6	5.8	5.8	6.0	6.4	7.5	
										10.5

Diversity

Year	1999	1997	1996	2003	1998	2002	2000	2008	2001	1995
	0.9	1.0	1.3	1.4	1.5	1.5	1.7	1.7	1.8	
			1.3	1.4	1.5	1.5	1.7	1.7	1.8	2.1

Evenness

Year	2003	1996	1995	1998	2001	1997	2002	1999	2000	2008
	0.3	0.3	0.4	0.5	0.6	0.6	0.6			
		0.3	0.4	0.5	0.6	0.6	0.6	0.7		
				0.5	0.6	0.6	0.6	0.7	0.8	0.8

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences ($P < 0.01$) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Site 8 (CQPA 15)

Total abundance

Year	2008	2002	1999	1996	1998	1997	2000	2003	2001	1995
	6.3	7.0	8.6	9.3	11.0	12.6	13.0	13.4		
						12.6	13.0	13.4	25.4	
									25.4	29.2

Species Richness

Year	1997	1998	1996	1999	2002	2008	2003	2000	1995	2001
	3.4	4.0	4.2	5.5	5.6	5.7				
				5.5	5.6	5.7	9.7	10.3		
							9.7	10.3	11.4	11.5

Diversity

Year	1997	1998	1996	1999	2002	2008	2001	2003	1995	2000
	0.7	1.0	1.1							
		1.0	1.1	1.5	1.5	1.6				
				1.5	1.5	1.6	2.0	2.1	2.1	2.2

Evenness

Year	1997	1995	2001	1996	1998	1999	2003	2000	2002	2008
	0.2	0.3	0.4	0.4	0.5					
		0.3	0.4	0.4	0.5	0.6	0.7			
			0.4	0.4	0.5	0.6	0.7	0.8	0.9	
					0.5	0.6	0.7	0.8	0.9	0.9

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Site 21 (CQPA 9)

Total abundance

Year	2008	2003	1997	2002	1998	1999	2000	1996	2001	1995
	1.0	1.4	5.9	6.7	7.6	13.9				
						13.9	24.5	28.2		
								28.2	42.0	

Species Richness

Year	2008	2003	1997	1998	2002	1999	2000	2001	1996	1995
	1.0	1.3	2.2	3.9	4.7	5.4				
			2.2	3.9	4.7	5.4	8.3			
					4.7	5.4	8.3	10.8		
							8.3	10.8	13.2	
										22.6

Diversity

Year	2003	2008	1997	1998	2002	1999	2000	2001	1996	1995
	0.2	0.2	0.6							
			0.6	1.1						
				1.1	1.4	1.6				
					1.4	1.6	1.8	2.0		
						1.6	1.8	2.0	2.3	
									2.3	2.8

Evenness

Year	2001	1996	1995	1998	2000	2008	1999	1997	2002	2003
	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	
						0.7	0.7	0.7	0.8	0.9

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Site 22 (CQPA 10)

Total abundance

Year	2003	2008	1999	1997	1998	2000	2002	2001	1996	1995
	2.1	2.3	3.9	4.1	6.3	11.7	12.6			
					6.3	11.7	12.6	17.1		
						11.7	12.6	17.1	20.1	
								17.1	20.1	23.9

Species Richness

Year	2008	2003	1997	1998	1999	2000	2002	2001	1996	1995
	1.0	1.8	3.0	3.2	5.6	5.6				
			3.0	3.2	5.6	5.6	8.4			
						5.6	8.4	9.8		
							8.4	9.8	11.1	12.5

Diversity

Year	2008	2003	1997	1998	1999	2000	2002	1995	2001	1996
	0.3	0.5	0.8	0.9						
		0.5	0.8	0.9	1.2					
				0.9	1.2	1.5				
					1.2	1.5	1.9			
						1.5	1.9	2.0	2.1	2.1

Evenness

Year	2008	1998	1996	2000	1995	2001	2002	1997	2003	1999
	0.1									
		0.4	0.5	0.5	0.5	0.5	0.6	0.8		
							0.6	0.8	0.9	0.9

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Site 23 (CQPA 11)

Total abundance

Year	1999	2003	1998	2001	1995	2008	2000	1997	2002	1996
	2.1	2.9	5.8	7.0	15.0	17.3	21.1			
			5.8	7.0	15.0	17.3	21.1	23.4		
									44.2	53.0

Species Richness

Year	2003	1999	1998	2001	2000	1995	2008	1997	2002	1996
	1.6	1.7	3.4	4.8	5.3					
			3.4	4.8	5.3	8.3				
						8.3	11.0			
							11.0	13.1	15.0	
									15.0	18.4

Diversity

Year	2003	1999	2000	1998	2001	1995	2008	2002	1997	1996
	0.4	0.5								
			1.0	1.0	1.4					
						1.9	2.1	2.1	2.4	2.4

Evenness

Year	2000	2002	1996	1997	2008	1995	2001	1998	2003	1999
	0.2	0.2	0.3	0.5						
		0.2	0.3	0.5	0.5					
			0.3	0.5	0.5	0.6				
				0.5	0.5	0.6	0.6	0.6	0.8	
						0.6	0.6	0.6	0.8	0.9

**Student-Newman-Keuls Post Hoc test for macroinvertebrate biodiversity for all available years. Values are means for groups in homogeneous subsets. Lines at the same level indicate no significant differences (P < 0.01) among years. Years are placed in order from lowest to highest biodiversity (n = 10, 1995-2003; n = 3, 2008. Data source(Alquezar and Small 2006).*

Appendix IV

Species list.

Alpheus pacifica	Isopoda 4	Placamen tiara
Amphinomidae 1	Leanira sp. 1	Polychaete 2
Amphipoda 42	Leionuculana superba	Polychaete 42
Amphipoda 43	Leocratides filamentosa	Polychaete 43
Anodontia omissa	Leptochela sydniensis	Polynoidae 14
Anthozoa 11	Leucothoe sp.	Polynoidae 2
Anthozoa 17	Limaria sp. 1	Pomacuma australiae
Anthozoa 5	Lucinidae 2	Pycnogonida sp. 2
Armandia sp. 1	Lucinidae 3	Rhaphidopus ciliatus
Ascidia sydneiensis	Lumbrineris sp. 2	Sabellaridae 2
Ascidiacea 21	Mactra (Mactra) queenslandica	Sabellidae 15
Azorinus sp. 2	Mactra abbreviata	Sabellidae 2
Azorinus sp. 3	Maera sp. 1	Saccostrea sp.
Bivalvia 17	Maldanidae 1	Samytha sp. 1
Callianassa cf orientalis	Maldanidae 2	Serpulidae 1
Capitellidae 1	Maldanidae 5	Sipuncula 17
Capitellidae 8	Marphysa bifurcata	Sipuncula 5
Cardita incrassala	Melampus striatus	Solecurtidae 1
Carditella (Carditellona) torresi	Mimachlamys gloriosa	Solen sp. 1
Ceriantharia 2	Modiolus sp. 1	Speocarcinus sp.1
Chama limbula	Mytilidae 1	Spionidae 1
Cirratulidae 8	Nassarius sp. 1	Spionidae 4
Cleistostoma wardi	Natatolana angula	Sternapis scutata
Corbula (Notocorbula) tunicata	Nematoneris unicornis	Sthenelais sp. 1
Corbula (Serracorbula) crassa	Nemertea 16	Streblosoma sp. 1
Corophiidae sp. 5	Nemertea 17	Syllidae 12
Diopatra dentata	Nemertea 18	Syllidae 2
Donax sp. 1	Nephtys sp. 1	Talabrica sp.
Dorvilleidae 1	Nereididae 3	Tanaidacea 1
Elasmopus sp. 1	Nuculana corbuloides	Tanaidacea 2
Epitonium sp. 3	Nuculana darwini	Tawera subnodulosa
Eunice sp. 1	Nudibranchia 12	Tellina sp. 14
Eunice vittata	Nursia sinuata	Tellina sp. 15
Eupolymnia sp. 1	Ophelina sp. 1	Tellina sp. 4
Gafrium transversarium	Ophiuroidea 15	Tellina sp. 6
Glycera sp. 1	Ophiuroidea 27	Terebellidae 1
Gobiidae 2	Ophiuroidea 32	Terebellidae 6
Grandidierella sp. 1	Orbiniidae 2	Timoclea lionata
Halicreion sp. 1	Paphia exarata	Trichobranchidae 1
Haploscloplos sp. 1	Paphia sp. 1	Trichobranchidae 2
Haplostylus cf queenslandensis	Paphies heterodon	Urochaustorius halei
Holothuroidea 3	Parelasmopus ya	Waldeckia sp. 1
Isolda pulchella	Pista typha	Xenocheira fasciata

Appendix V

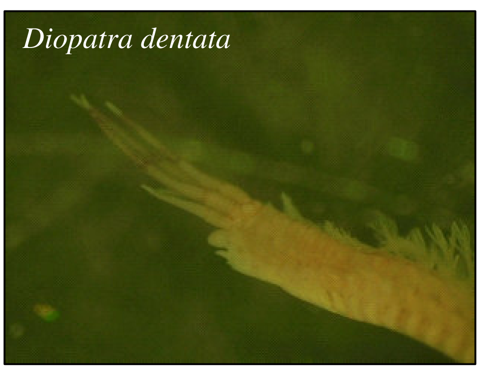
Polychaetes


Amphinomidae sp. 1


Armandia sp.1


Capitellidae sp. 1


Capitellidae sp.8


Diopatra dentata


Dorvilleidae sp. 1


Eunice sp. 1


Eunice vittata

Eupolymnia sp. 1

Glycera sp.1

Haploscoloplos sp.1

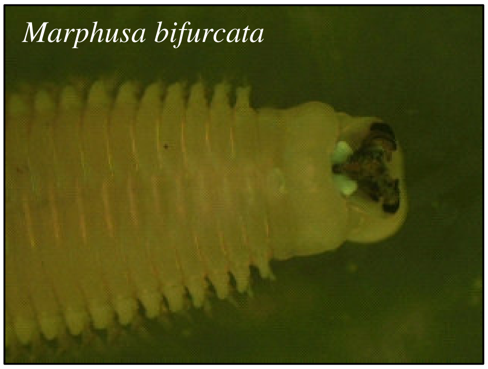
Isolda pulchella

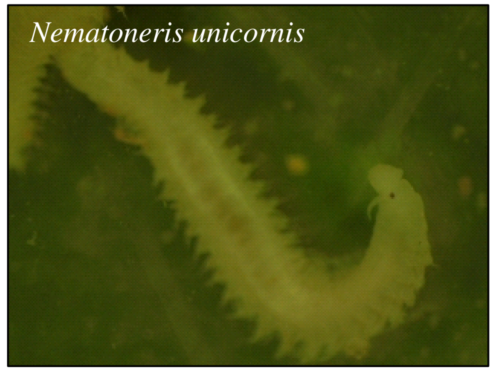
Leanira sp. 1

Leocratides filamentosa

Lumbrineris sp. 2

Maldanidae sp. 2


Marphusa bifurcata


Nematoneris unicornis


Nepthys sp. 1


Nereidae sp. 3


Ophelina sp. 1


Orbinidae sp. 2


Pista typha


Polychaete sp. 2

Polychaete sp. 42

Polychaete sp. 43

Polynoidae sp. 2

Polynoidae sp. 10

Sabellaridae sp. 2

Sabellidae sp. 2

Sabellidae sp. 15

Samytha sp. 1

Serpulidae sp. 1

Spionidae sp. 1

Spionidae sp. 4

Sternapis scutata

Sthenelasis sp. 1

Syllidae sp. 2

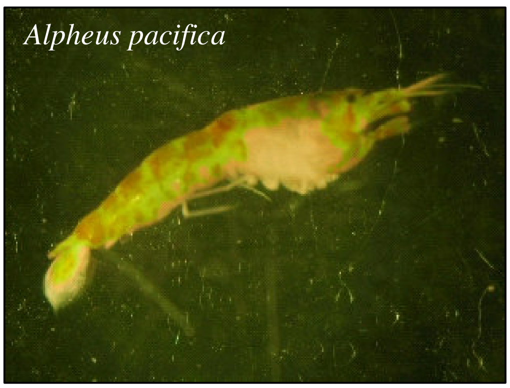
Syllidae sp. 12

Terebellidae sp. 1


Terebellidae sp. 6


Trichobranchidae sp. 1

<u>*Crustaceans*</u>

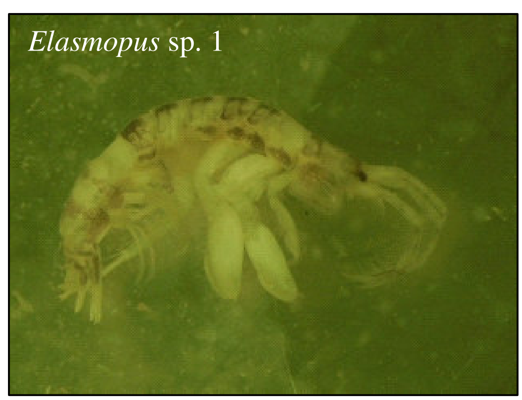

Alpheus pacifica


Amphipoda sp. 42


Amphipoda sp. 43


Callianassa orientalis


Corophidae sp. 5


Elasmopus sp. 1

Grandiderella sp. 1

Halicreions sp. 1

Haplostylus queenslandensis

Isopoda sp. 4

Leptochela sydniensis

Leucothoe sp. 1

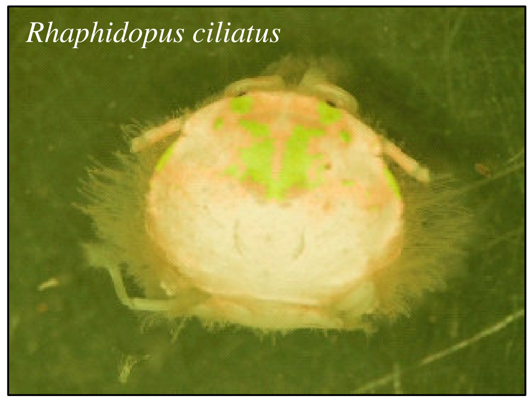
Natatolana angula

Nursia sinuata

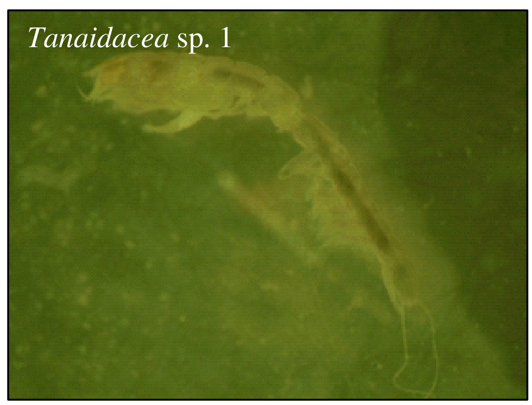

Oygrides deilli


Parelasmopus ya


Pomacuma australiae


Rhaphidopus ciliatus

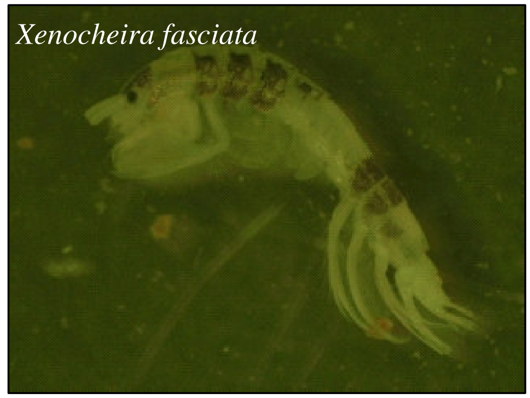

Speocarcinus sp. 1


Tanaidacea sp. 1


Tanaidacea sp. 2


Urohaustarius halei

Waldeckia sp. 1



Xenocheira fasciata

__Bivalves & Molluscs__

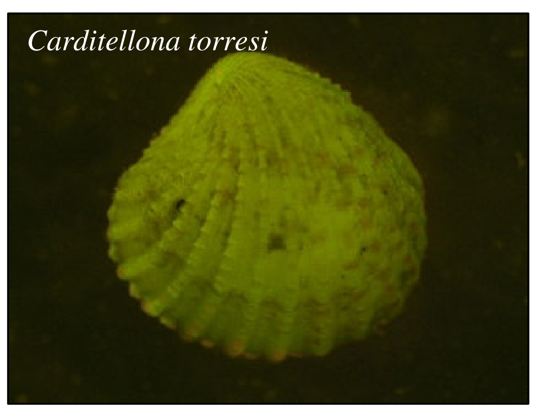
Anodantia omissa

Azorinus sp. 2

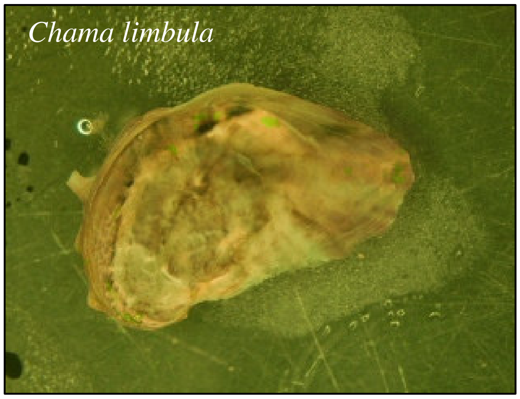
Azorinus sp. 3

Bivalvia sp. 17

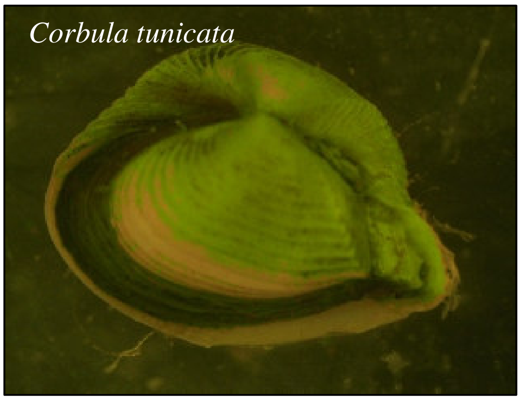
Bivalvia sp. 53



Carditellona torresi


Chama limbula


Corbula serracorbula crassa

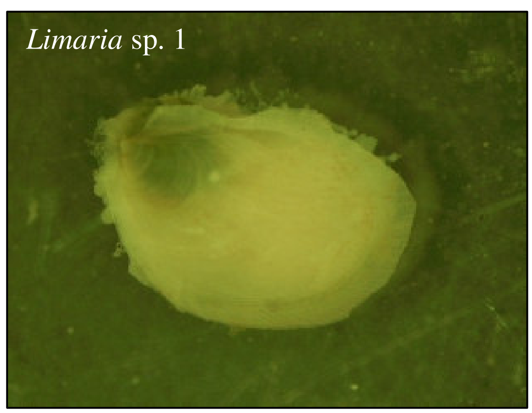

Corbula tunicata


Donax sp. 1

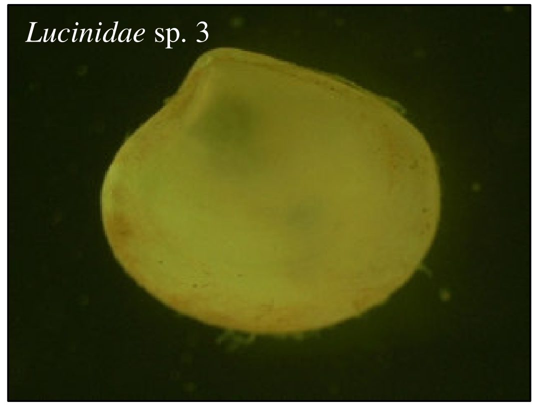

Epitonium sp. 3


Gafrium transversarium


Leionuculana superba


Limaria sp. 1


Lucinidae sp. 2


Lucinidae sp. 3


Mactra abbreviata


Mactra queenslandica


Massarius sp. 1


Melampus striatus


Mimachlamys

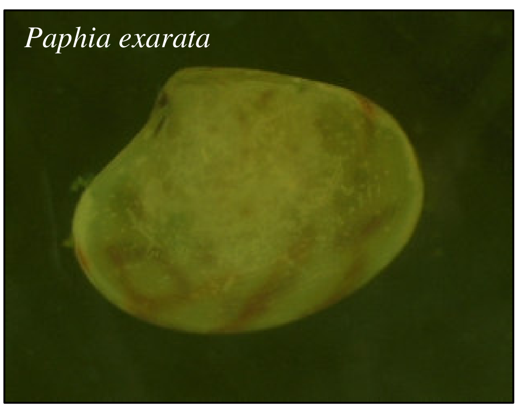

Modiolis sp. 1

Nuculana

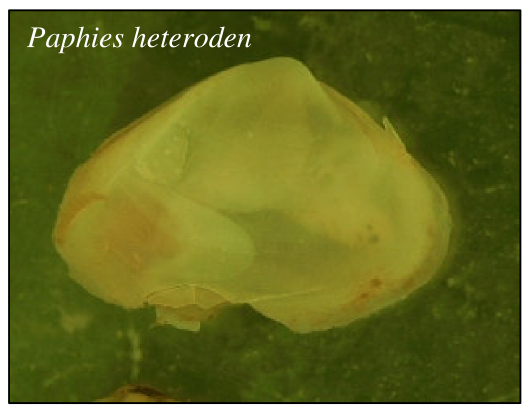
Nuculana darwini

Pacamen tiara

Pahpia sp. 1



Paphia exarata

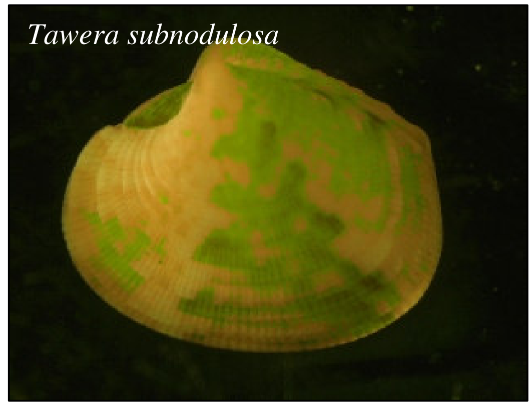


Paphies heteroden

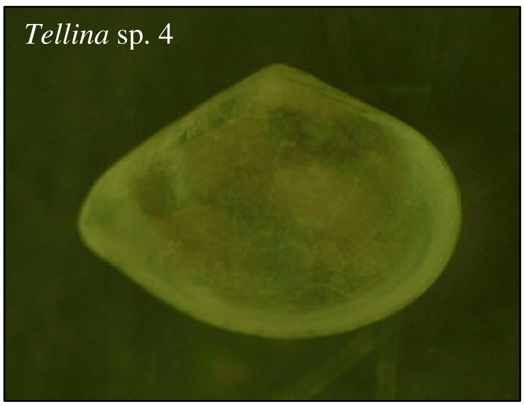
Solecurtidae sp. 1

Solen sp. 1

Talabrica sp. 1

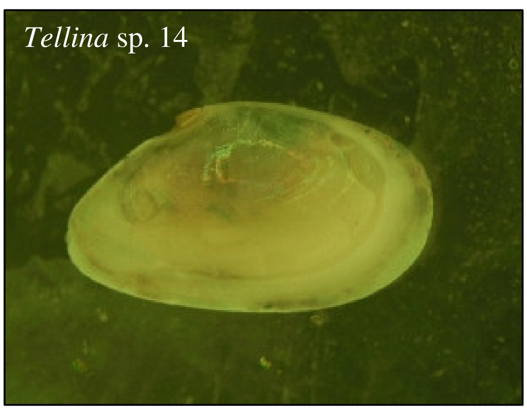


Tawera subnodulosa



Tellina sp. 4

Tellina sp. 6



Tellina sp. 14

Tellina sp. 15

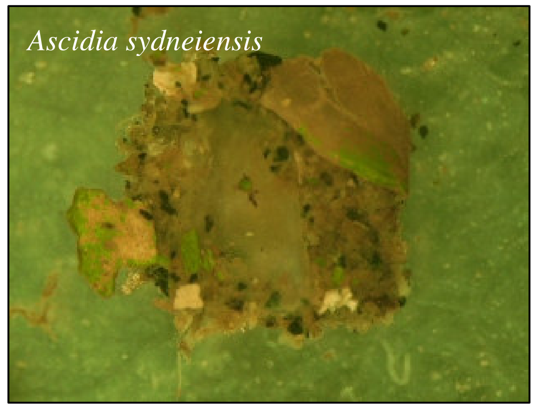
Timoclea lionata

<u>*Miscellaneous*</u>


Anthozoa sp. 5


Anthozoa sp. 11


Anthozoa sp. 17


Ascidia sydneiensis


Ceriantharia sp. 2


Gobiidae sp. 2


Holothuroidea sp. 3


Nemertea sp. 16


Nemertea sp. 17


Nemertea sp. 18


Nudibranchia sp. 12

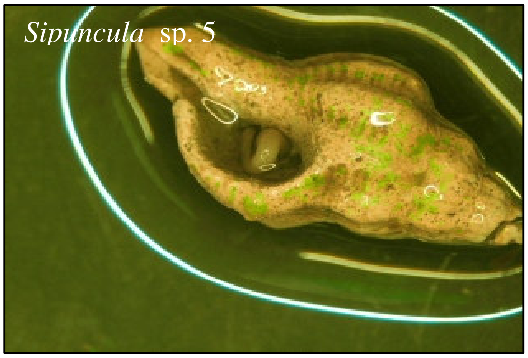

Ophur sp. 1


Ophuroidea sp. 15


Ophuroidea sp. 27


Ophuroidea sp. 32


Pycnogonida sp. 2


Sipuncula sp. 5


Sipuncula sp. 17

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