APPENDIX 6

ARROW LNG PLANT

Marine Water Quality - Part B: Marine and Estuarine Ecology Report

arrow energy
go further

Arrow LNG Plant Supplementary Report to the EIS

Part B: Marine & Estuarine Ecology Report

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December 2012

Please note: This report is broken into two sections.

Part A: Marine Water Quality

Part B: Marine and Estuarine Ecology

This section contains Part B only

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Centre for Environmental MANAGEMENT

CQUniversity AUSTRALIA RESEARCH

Arrow LNG Plant Supplementary Report to the EIS

Part B: Marine & Estuarine Ecology Report

Prepared for Coffey Environments (Pty) Ltd on behalf of Arrow CSG (Australia) Pty Ltd (Arrow Energy)

December 2012

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Executive Summary

Baseline marine and estuarine ecology data for the Calliope River and relevant sites in Port Curtis was reported in the Arrow LNG Plant Environmental Impact Statement (EIS). A marine and estuarine ecology additional data analysis and subsequent field surveys were undertaken to inform the Supplementary Report to the EIS (SREIS) for the project. Sampling was focused around the Curtis Island proposed LNG jetty site, Boatshed Point swing basin, access channel, outfall site at Boatshed Point and material offloading facility (MOF) sites, and the mainland location of launch site 1. The sampling also focussed on the associated dredging areas (including the Calliope River) and immediately offshore to the mainland tunnel launch site. The analysis of additional data available since the EIS highlighted that, despite recent reports, there was a need for additional fine scale marine and estuarine ecological surveys, particularly for fish, macroinvertebrates and mangroves, to inform the SREIS.

A marine and estuarine ecology survey was conducted consistent with the methodologies for the previous surveys undertaken for the Arrow LNG Plant EIS. This included investigations of mangrove communities, macroinvertebrate and fish assemblages, benthic communities and sediment analysis, along with general field observations. Based on a preliminary review of available data, six sites were selected within the Calliope River for additional mangrove surveys. Cast nets and gill nets were used to sample both small and large fish species and motile macroinvertebrate fauna from the study area. Sediment grab samples were taken to assess the soft sediment benthic infauna (organisms >1mm) in areas of the Boatshed Point access channel. Due to recent and ongoing third-party mapping of seagrass in the areas of interest for this study in Port Curtis and the Calliope River, and the consistent levels of cover found over this time, further mapping was deemed unnecessary for this study.

Mangrove surveys in the Calliope River showed the red mangrove (*Rhizophora stylosa)* to be the dominant mangrove species; however, the river mangrove (*Aegiceras corniculatum*) was the most abundant species. Sites in the lower Calliope River were dominated by red mangroves (*Rhizophora stylosa*) and were unlike those in the mid to upper Calliope River sections which were dominated by grey mangroves (*Avicennia marina*) and river mangroves (*Aegiceras corniculatum*). Despite this, there were no statistically significant differences in the mangrove parameters measured between sites, except for crabhole counts.

A total of 236 fish and motile macroinvertebrates from 21 species were caught during the study representing common species in the area. Fish species diversity was similar to previous studies, but with lower species abundance, which is likely to be related to the sampling season. Sites in proximity to mangroves had greater fish abundance than those located further from mangroves, potentially as a result of greater juvenile recruitment in the mangrove habitats; however, results were not statistically different.

A total of 1,332 benthic infaunal organisms from 223 species and 9 phyla were recorded. Findings indicate that sediment size class and distribution may influence benthic infauna assemblages with greater diversity occurring in the deeper gravel-dominated areas. Features of the benthic infauna assemblage were similar to those recorded in previous studies.

Twenty-one large marine animals were observed during the study, mostly in the more open waters of Port Curtis and in the mouth of the Calliope River.

The data collected during this marine and estuarine ecology sampling and survey programme adds to the current baseline of information for the areas relevant to the Arrow LNG Plant activities.

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Introduction

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) plant on Curtis Island off the Central Queensland coast, near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project which incorporates the upstream coal seam gas field developments and transmission gas pipelines.

An environmental impact statement (EIS) has been prepared for the project under Part 4 of the *State Development and Public Works Organisation Act 1971* (Qld) (SDPWO Act) and s. 133 of the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act). Coffey Environments Australia Pty Ltd (Coffey Environments), a subsidiary of Coffey International Pty Ltd, was commissioned to assist Arrow Energy in the preparation of the Arrow LNG Plant EIS. The EIS will inform a decision on whether the project should proceed and, if so, under what conditions. The EIS went on public exhibition on 16 April 2012, with submissions closing on 28 May 2012. Arrow Energy is required to prepare a supplementary report to the EIS (SREIS) to respond to comments raised in submissions on the EIS, and to address new data available subsequent to the EIS and changes to the project description.

Coffey Environments has been engaged to prepare the SREIS. The supplementary report will describe material changes made to the project description since the EIS was finalised and assess the implications of the changes on the impacts of the project identified and assessed in the EIS. It will also provide additional information identified in the EIS and respond to comments made in submission to the EIS.

The following report is a response to the brief provided by Coffey Environments that described the relevant works completed to date and the changes in the design, layout and dredging requirements for the MOF, launch site 1, LNG jetty and mainland tunnel entrance. Broadly the following report provides confirmatory marine ecology characterisation in areas associated with the Arrow LNG Plant operations described above, particularly in relation to mangrove and seagrass communities and fish and macroinvertebrate assemblages.

Objectives

The objectives of the study were to update and characterise the estuarine and marine baseline ecology associated with operations of the Arrow LNG plant in Port Curtis, Queensland, to inform the impact assessment undertaken by Coffey Environments. More specifically the objectives were to:

(a) Sample fish, benthic infauna and mobile macroinvertebrates in areas that have not previously been extensively surveyed that will be potentially affected or occupied by the Arrow LNG Plant marine facilities;

(b) Review seagrass and mangrove habitat data, identify where information is lacking in areas where project disturbance may occur and undertake a field survey of such areas;

(c) Map and describe benthic communities and their habitats in the areas proposed for the Boatshed Point access channel and swing basin; and

(d) Characterise fish habitat areas where information is lacking in areas where project disturbance may occur.

Additional Data Analysis

An analysis of existing marine and estuarine ecology data (particularly fish, macroinvertebrates, mangroves and seagrass) was conducted to ascertain the availability of additional data since the completion of the technical studies that informed the EIS. The additional data analysis concentrated on the areas of the LNG jetty site, Boatshed Point swing basin, access channel and MOF sites, launch site 1 and associated dredging areas (including the Calliope River), immediately offshore of the mainland tunnel launch site, and the outfall site at Boatshed Point (Figure 1). The outfall site will discharge hydrostatic test water during the LNG plant commissioning and operations, which will discharge roof and clean surface runoff from within the LNG plant, brine from the desalination plant, process water and, under circumstances exceeding design (e.g., extreme rainfall events), treated sewage effluent.

The Port Curtis Integrated Monitoring Program's Intertidal and Coastal Monitoring 2009 report (Vision Environment 2010) maps and details mangrove and seagrass communities within Port Curtis and nearshore environments. Only minor changes in the distribution of these communities were observed since 2002. Benthic infauna communities were observed to have similar abundance and evenness both spatially and temporally, with an increase in richness and diversity in 2009 when compared to the 2006 period.

Gladstone Ports Corporation initiated a monthly seagrass monitoring program in Port Curtis in September 2011 conducted by Fisheries Queensland. The result from the September 2012 sampling indicated that the current percentage seagrass cover was less than 2% at the Fisherman's Landing and Wiggins Island sites (Davies et al., 2012). This has remained low since the monthly monitoring commenced. The reference sites at Rodds Bay also remained at a low percentage cover (0.05-1.2%), but the outer harbour Pelican Banks sites have persisted at over 10% seagrass cover (Davies et al., 2012).

During marine megafauna monitoring 11 unidentified rays and 4 sharks were observed in aerial surveys in Rodds Bays and north east Curtis Island across both the summer and winter sampling in 2011 (Port of Gladstone Western Basin Strategic Dredging and Disposal Project Environmental Performance Report, CQG Consulting 2011).

Findings

Due to recent mapping of mangrove and seagrass in the areas of interest for this study in Port Curtis and the Calliope River, and the consistent levels of cover found over this time, further mapping was deemed unnecessary for this study. However, as little ecological data has been collected about the mangrove communities in the Calliope River, it was deemed important to provide further baseline data for this area. Little or no seagrass has been observed in the areas immediately around Hamilton Point, Boatshed Point and in the Calliope River. Also, seagrass beds are currently monitored on a monthly basis within Port Curtis (the nearest site of relevance located near Wiggins Island) so further investigation was deemed unnecessary in this study. Any seagrasses found during benthic sampling will, however, be noted and identified. Little data of macroinvertebrate and fish assemblages was found for the intervening time period since publication of the Arrow LNG Plant EIS. Therefore surveys of macroinvertebrate and fish assemblages were deemed necessary to provide further baseline data for the areas where project disturbance may occur. Benthic infauna surveys were conducted where data was lacking, which coincided with the area of greatest disturbance (e.g., Boatshed Point and Hamilton Point).

Methods and Site Locations

Ecological Sampling

A review of recent ecological data (see Additional Data Analysis section above) and a gap analysis was undertaken in relation to the LNG jetty site, Boatshed Point swing basin, access channel and MOF sites, launch site 1 and associated dredging areas (including the Calliope River), immediately offshore the mainland tunnel entrance site, and the outfall site at Boatshed Point. This was used to inform the ecological sampling and field studies component. Figure 1 shows the general area of the Arrow LNG Port Curtis operations.

Mangrove Communities

From a review of recent and existing data (Alquezar 2010, Aurecon Hatch 2012, CQG Consulting 2011, Davies et al. 2012, Vision Environment 2010), six sites were selected via gap analysis within the Calliope River that required additional ground truthing (Table A1; Figure 2). These sites were selected to represent the upper, mid and lower sections of the estuarine portion of the river (2 sites per portion), where either little ecological data exists or where there may be potential zones of disturbance (e.g. near launch site 1). Also, sites were located approximately 1-2 km apart to represent a spatial scale to detect effects in mangroves of potential changes in hydrological patterns. Sampling of mangroves around Boatshed and Hamilton Points and the tunnel entrance site did not occur due to sufficient existing data. Ground truthing consisted of fifty metre transects and/or 25m^2 plots, depending on habitat type, to determine community density and dominant species. Two zones were sampled at each mangrove site location, with Zone 1 located adjacent to the Calliope River and Zone 2 located 50 m landward of the river. In each plot/transect all trees and seedlings were identified and counted and dominant species recorded. The following mangrove parameters were measured in each plot/transect; tree/seedling density, calculated as the number of trees/seedlings per plot area; and Projective Foliage Cover (PFC), calculated as the percentage covered by foliage (canopy density); diameter at breast height (DBH) was measured on mangrove trees with defined trunks (adults) within each plot. Crabhole count (CHC) was recorded within a 0.25m^2 quadrat at each plot/transect (n = 10/site).

Community density was determined by estimates of PFC. Three basic PFC classes were established; open (0-25%), moderate (25-50%) and dense (>50%). Data were then classified into mangrove community classes on the basis of dominant genus present and relative densities for the whole community (Danaher et al. 2005).

Fish and Macroinvertebrate Assemblage

Fish and motile macroinvertebrates were sampled at 9 identified sites (Table A2; Figure 3) using cast nets (Ø3 m x 2.0 m drop x 6 mm mesh size) and gill nets (60 m x 1.5 m x 50 mm, 75 mm and 100 mm panel mesh sizes). Sites were selected based upon proximity to mangrove plot sites or areas of project disturbance. Cast nets (n = 10/site) were used to sample juvenile and small fish and macroinvertebrate fauna, covering a diversity of small scale habitats that are difficult to survey with other netting techniques. Gill nets (n = 2, soak time of 3h) were used at each deep water site to sample larger mobile species that may have been under-represented using other netting technique. Nets were regularly checked for fish in order to reduce mortality. During the gill net soak time, line sampling by hand was also performed within the site location.

All fish collected were identified to species level and measured to 0.1 cm of standard length before being released. If identity was uncertain, a voucher specimen was collected and sent to the laboratory for further analysis.

Benthic Communities and Sediment Grain Size

Replicate grab samples (n = 5/site) were taken to assess soft sediment benthic infauna at 20 identified sites (Table A3; Figure 4) in the Boatshed Point access channel and swing basin area using a Van-Veen grab sampler (0.005 m^3). Samples were returned to the laboratory and sieved to 1 mm, to retain benthic infauna (organisms > 1mm). Retained organisms were preserved, sorted, enumerated and specimens identified to the lowest possible taxonomic level. Species were identified to the CQU database, which has coded species by number (e.g., *Ophiuroidea* 10). Replicates were analysed as separate samples. A sediment sub-sample was taken at each site and sediment grain size was also evaluated to investigate one of the potential factors contributing to any site differences. Sites were selected to provide a representative spatial scale to map the benthic infaunal community (Figure 4). Two Geographic Information System (GIS) layers based on the benthic community abundance and grain size analysis data were mapped (See Results).

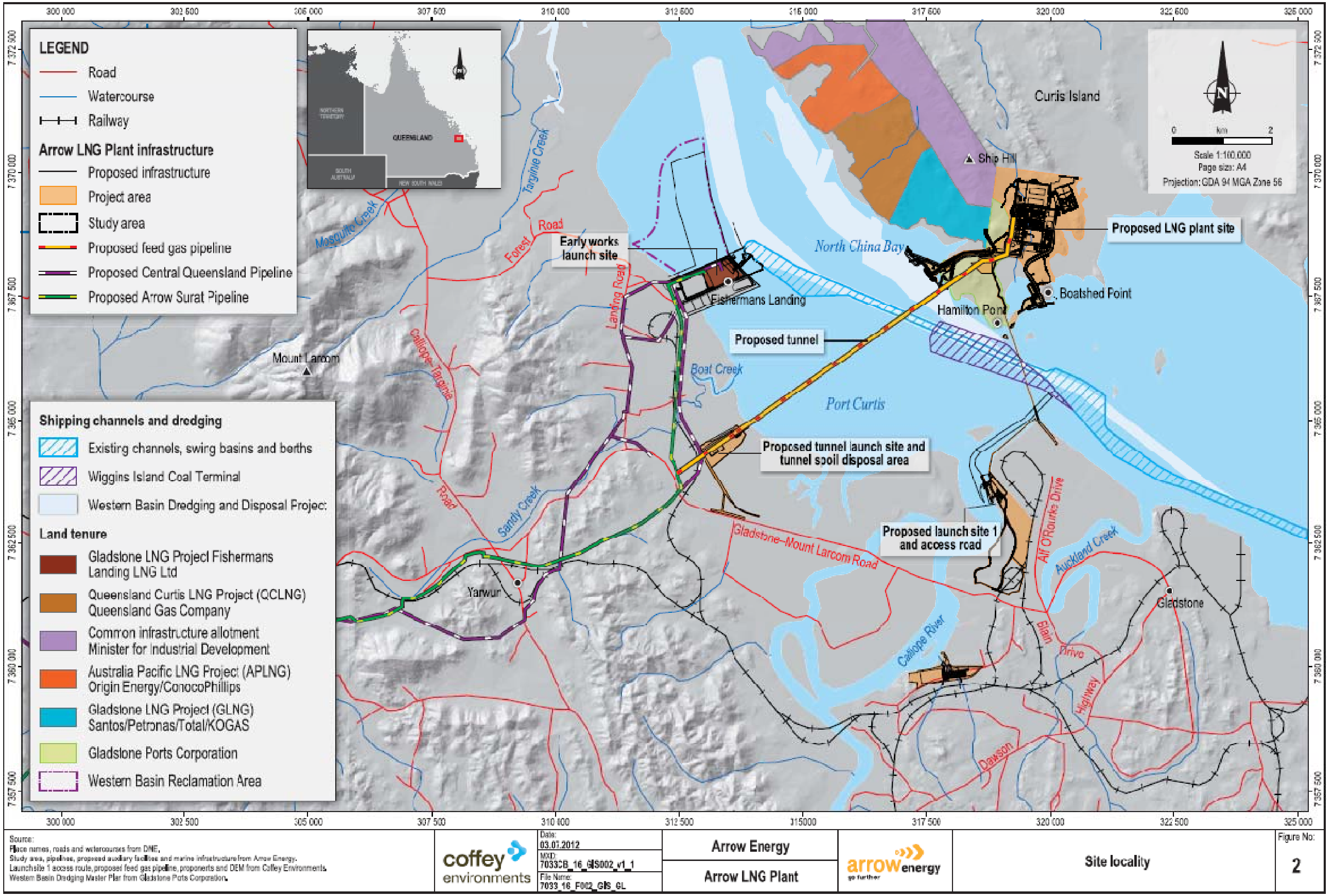

Figure 1: Arrow Energy LNG areas of marine influence

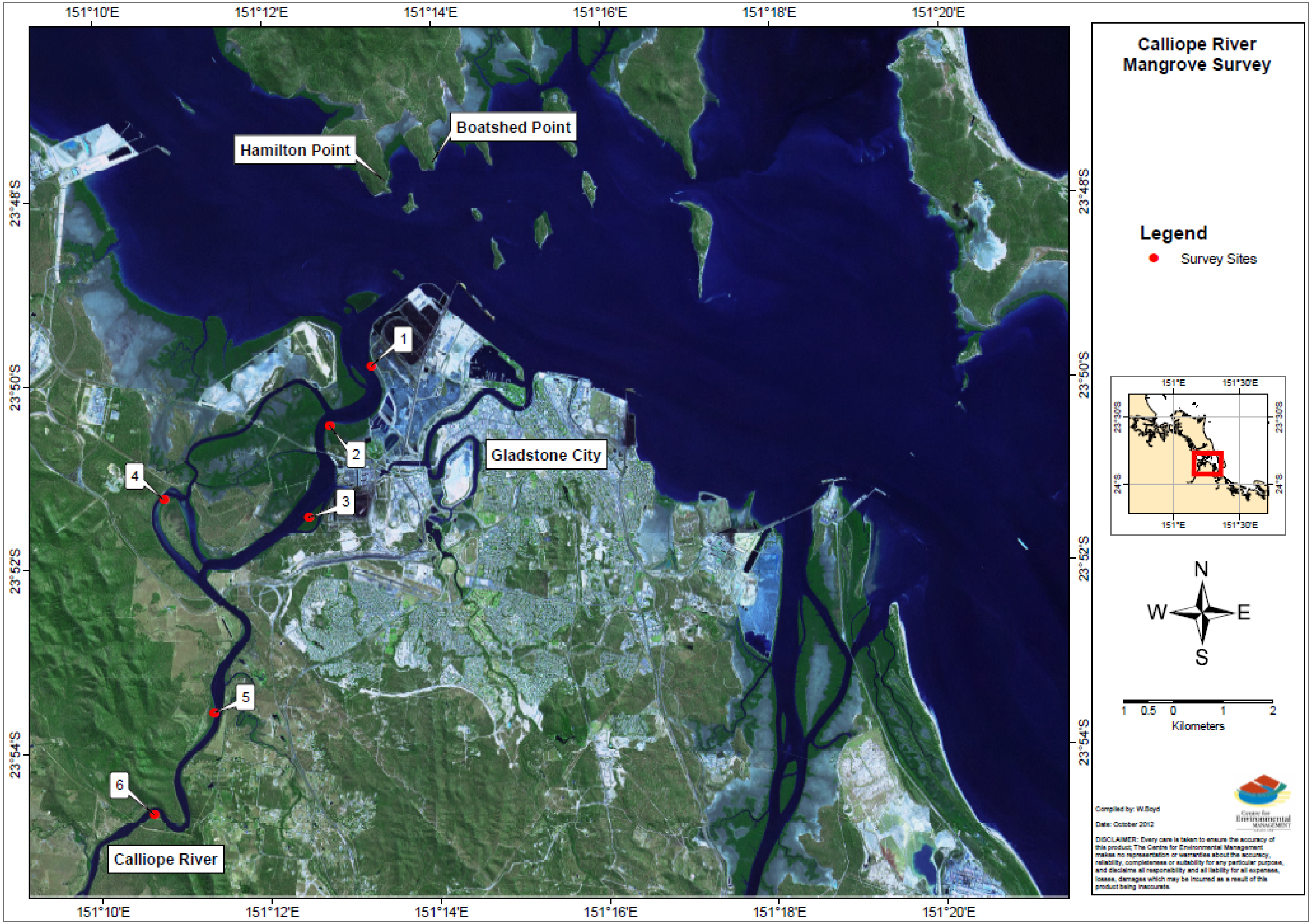

Figure 2: Mangrove Assessment Survey Sites Map

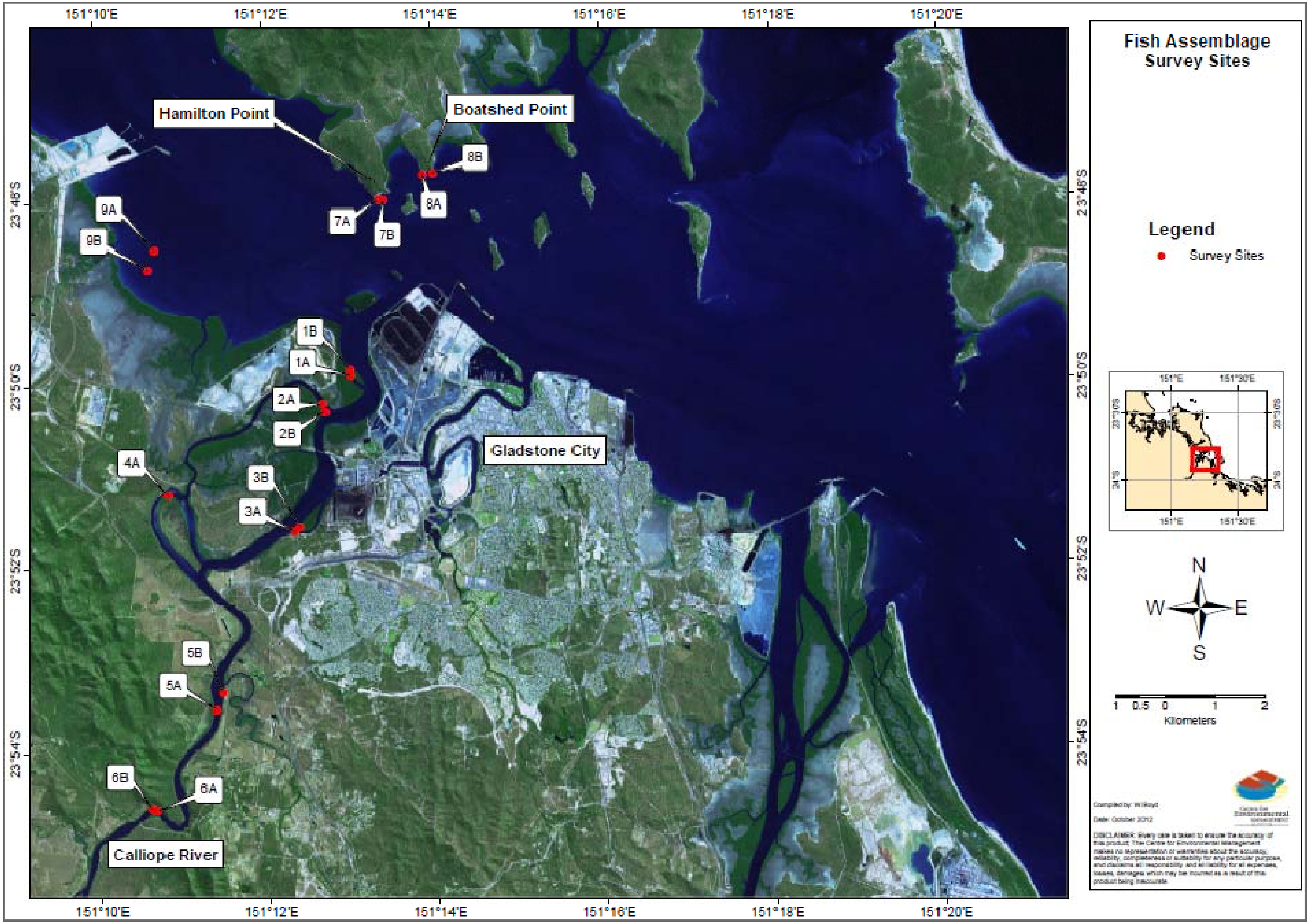

Figure 3: Fish Assemblage Survey Sites Map

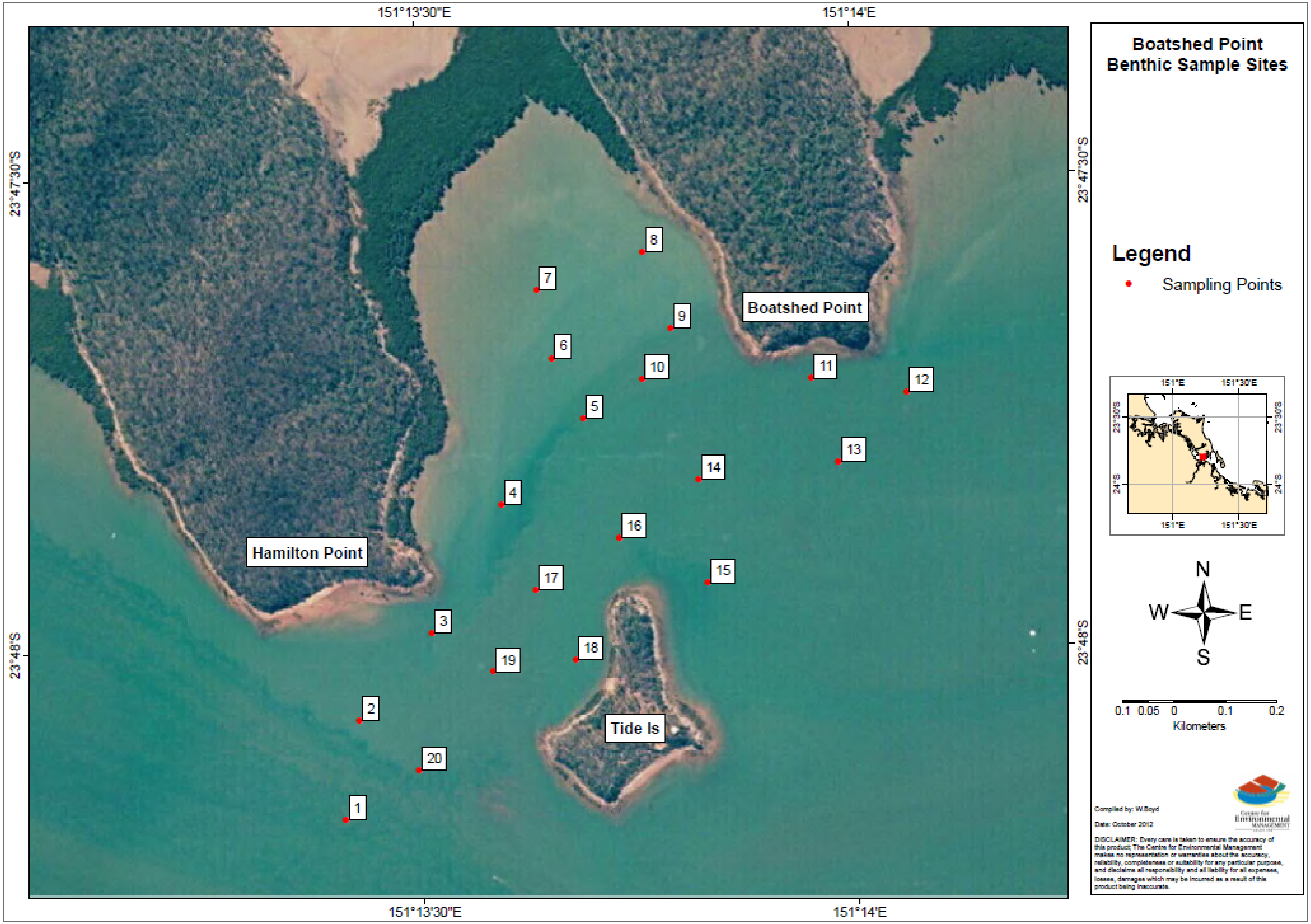

Figure 4: Benthic Communities Sites Map

Marine Megafauna

During all field investigations, a log of large marine animal recordings was maintained. Whenever large marine animals (e.g. marine turtle, dugong or cetacean) was sighted, the date, time, GPS coordinate, animal type or species (where observable) and number of individual animals was recorded.

Data Analysis

Data was analysed across locations and times using multivariate statistics (including ANOVA, multi-dimensional scaling, cluster analysis), where appropriate. Total abundance (number of organisms), species richness (total number of taxa), diversity (Shannon-Weiner; the proportion of individuals per species) and species evenness (how evenly abundance is spread among the various taxa that make up an assemblage) was used for relevant fish/macroinvertebrate and benthic infauna data. Diversity values range from 0 (indicating low community complexity) to 4 (indicating high community complexity). Species evenness is a calculated measure using Pielou's eveness index where values range from 0 (where few species made up the majority of the abundance) to 1 (where each species contributed equally to total abundance) (Hill, 1973; Zar, 1996; McClatchie et al., 1997; Nero & Sealey, 2005; Cai et al., 2006).

Differences ($P < 0.05$, 95% confidence intervals) in mangrove, fish/macroinvertebrate and benthic infauna assemblages 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 homogeneity of variance or normality criteria (Underwood, 1997; O'Neill, 2000).

Fish/macroinvertebrate and benthic infauna community assemblages were plotted using non-metric Multi-Dimensional Scaling (*n*-MDS). This statistical technique applies an ordination algorithm to spatially represent similarity of the data and is used widely including by the US EPA (Barbour et al. 1999). Sample points close to one another signify similar community composition. The more distance between points, the more dissimilar the community composition. Analysis of similarity (ANOSIM) was used to statistically determine dissimilarities in community structure among sites (PRIMER Ver. 6.1; Clarke, 1993). Similarity percentages (SIMPER) were used to determine what organisms best described changes in community assemblages among sampling sites (PRIMER; Clarke, 1993). Fish/macroinvertebrate and benthic infauna community structure was examined using Bray-Curtis (B-C) similarity measures (Clarke, 1993). Bray Curtis was chosen as the preferred similarity matrix because it performs well in preserving 'ecological distance' in a variety of simulations on different types of data sets (Clarke, 1993). Data were weight dispersion corrected and standardized to maintain equal weighting between common and rare species. Mangrove communities were analysed using cluster analysis to determine similarities among sites (PRIMER; Clarke, 1993).

Maps were prepared indicating the sample point localities with reference to the study area. Geo-statistical surface interpolations indicating the average benthic infaunal organism abundance and benthic sediment classes were completed. ESRI® ArcMap™ 9.3.1 with Spatial Analyst extension was the software used for the spatial analyses and for map production (ESRI, 2009). The surface interpolation was carried out using the Natural Neighbour (NN) method (ESRI, 2009). The NN method interpolates values based on only the closest subset of input sample points to each interpolated point and applies weights to them based on proportionate areas. The interpolated values are guaranteed to be within the range of the samples used and the method does not infer trends and does not produce anomalous peaks, pits, ridges or valleys that are not already represented by the input data. The surface passes through the input samples and is smooth everywhere except at locations of the input samples. It adapts locally to the structure of the input data and does not require input from the user with respect to a search radius, sample count, or a shape. The interpolated surfaces were developed as predictive surfaces visually interpreting the potential average abundance spread in relation to potential sediment types relevant to the study area.

Results

Mangrove Communities

During the survey, a total of five mangrove species was observed within the six Calliope River study sites, with a total of 585 adult trees and 322 seedlings recorded (Table 1; Table 2). Two zones were sampled at each mangrove site location, with Zone 1 located adjacent to the Calliope River and Zone 2 located 50 m landward of the river. Overall, the river mangrove (*Aegiceras corniculatum)* (67% of all adult mangrove trees) had the greatest abundance of adult trees. The red mangrove (*Rhizophora stylosa*), grey mangrove (*Avicennia marina*) and yellow mangrove (*Ceriops tagal*) were also well represented with 17%, 10% and 6% of all adult mangrove trees, respectively. The black mangrove (*Lumnitzera racemosa*) was also present, but with an overall abundance of less than 1% of all adult mangrove trees recorded in all study plots.

The greatest abundances of seedlings recorded were the grey mangrove (*Avicennia marina*), red mangrove (*Rhizophora stylosa*) and river mangrove (*Aegiceras corniculatum*) at 40%, 36% and 23% of all seedling mangrove trees, respectively. Yellow mangrove (*Ceriops tagal*) and black mangrove (*Lumnitzera racemosa*) were also recorded, with numbers making up a total of less than 1%.

Combining the total number of adult and seedling plants surveyed throughout each site, Sites 1 and 2 were dominated by red mangroves (*Rhizophora stylosa*), whereas Sites 5 and 6 were dominated by grey mangroves (*Avicennia marina*) (Figure 5). Sites 3 and 4 had river mangroves (*Aegiceras corniculatum*) as the dominant species in one plot but red mangroves (*Rhizophora stylosa*) and yellow mangroves (*Ceriops tagal*) as the dominant species in the second plot. Despite the large number of river mangroves (*Aegiceras corniculatum*) surveyed overall, they were not the most abundant species (tree/seedling counts combined) in any of the six plots (Table 1; Table 2).

Figure 5: Example of *Rhizophora stylosa* stand in a typical intertidal habitat

Table 1: Mangrove tree abundance per 25m^2 plot

Species	Common name	Site 1	2	3	4	5	6
		Zone 1 (0 m)					
Aegiceras corniculatum	river mangrove			67	61	13	53
Avicennia marina	grey mangrove		2		12	5	11
Ceriops tagal	yellow mangrove	5					
Lumnitzera racemosa	black mangrove		5				
Rhizophora stylosa	red mangrove	12	4		23	5	
	Total	17	11	67	96	23	64
		Zone 2 (50 m)					
Aegiceras corniculatum	river mangrove				46	8	142
Avicennia marina	grey mangrove				8	4	15
Ceriops tagal	yellow mangrove	4		26			
Rhizophora stylosa	red mangrove	8	13	12	21		
	Total	12	13	38	75	12	157

Table 2: Mangrove seedling abundance per 25 m^2 plot

Species	Common name	Site 1	2	3	4	5	6
		Zone 1 (0 m)					
Aegiceras corniculatum	river mangrove				5	26	
Avicennia marina	grey mangrove					6	88
Ceriops tagal	yellow mangrove						
Lumnitzera racemosa	black mangrove		1				
Rhizophora stylosa	red mangrove	12					
	Total	12	1	0	5	32	88
		Zone 2 (50 m)					
Aegiceras corniculatum	river mangrove				13		29
Avicennia marina	grey mangrove					34	2
Ceriops tagal	yellow mangrove			3			
Rhizophora stylosa	red mangrove	6	1	86		10	
	Total	6	1	89	13	44	31

Sites 1 and 2 had a higher abundance of yellow mangroves (*Ceriops tagal*) and red mangroves (*Rhizophora stylosa*) as well as an absence of river mangroves (*Aegiceras corniculatum*) (Table 1; Table 2). Site 3 had a more even spread of the three species, whereas Sites 4, 5 and 6 were dominated by the river mangrove (*Aegiceras corniculatum*).

Diameter at breast height (DBH) was only measured on adult trees with defined trunks. The most mature trees were located at Site 2 and Site 5 which had the highest mean DBH of all sites (Table 3). Of all species, grey mangrove (*Avicennia marina*) had the largest overall mean DBH of 175 ± 125 mm and was recorded at Site 2.

Sites 3, 4 and 6 showed higher tree density (52.5 ± 14.5, 85.5 ± 10.5 and 110.5 ± 46.5, respectively), than Sites 1, 2 and 5 (14.5 ± 2.5, 12 ± 1 and 17.5 ± 5.5, respectively), however, there was no statistical difference among sites ($P > 0.05$) (Figure 6) There was also no statistical differences ($P > 0.05$) observed among sites for species richness, species diversity, species evenness or projective foliage cover (Figure 6). Crabhole counts (CHC) were conducted at all six sites with Sites 2, 4 and 5 (115-133 CHC) being significantly different ($P < 0.01$; $F = 11.84$; *df* 5) from Sites 1, 3 and 6 (59-74 CHC) (Table 4; Figure 6).

Table 3: Mean diameter at breast height (cm) per 25m^2 plot

		Site					
		1	2	3	4	5	6
Species	**Common name**	***Zone 1 (0 m)***					
Avicennia marina	river mangrove		175 ± 125		34.3 ± 6.7	84 ± 16	55.5 ± 7.3
Ceriops tagal	yellow mangrove	24.8 ± 2.2					
Lumnitzera racemosa	black mangrove		26.8 ± 4.7				
Rhizophora stylosa	red mangrove	30.2 ± 2.3	66.25 ± 11.4		14.4 ± 2.1	88 ± 24.2	
		Zone 2 (50 m)					
Avicennia marina	river mangrove				54.8 ± 14.9	82.5 ± 4.8	41.3 ± 4
Ceriops tagal	yellow mangrove	41 ± 9.3		47 ± 8.8			
Rhizophora stylosa	red mangrove	27.5 ± 5.1	60.8 ± 7.4	16.6 ± 2.1	17.4 ± 1.6		

Mean diameter at breast height (cm) is shown as mean ± SE.

Table 4: Comparisons of statistical differences in crabhole counts among sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Site 1		*		*	*	
Site 2	*		*			*
Site 3		*		*	*	
Site 4	*		*			*
Site 5	*		*			*
Site 6		*		*	*	

* Denote significant difference ($P < 0.05$) between sites.
Grey boxes denote no significant difference between sites.

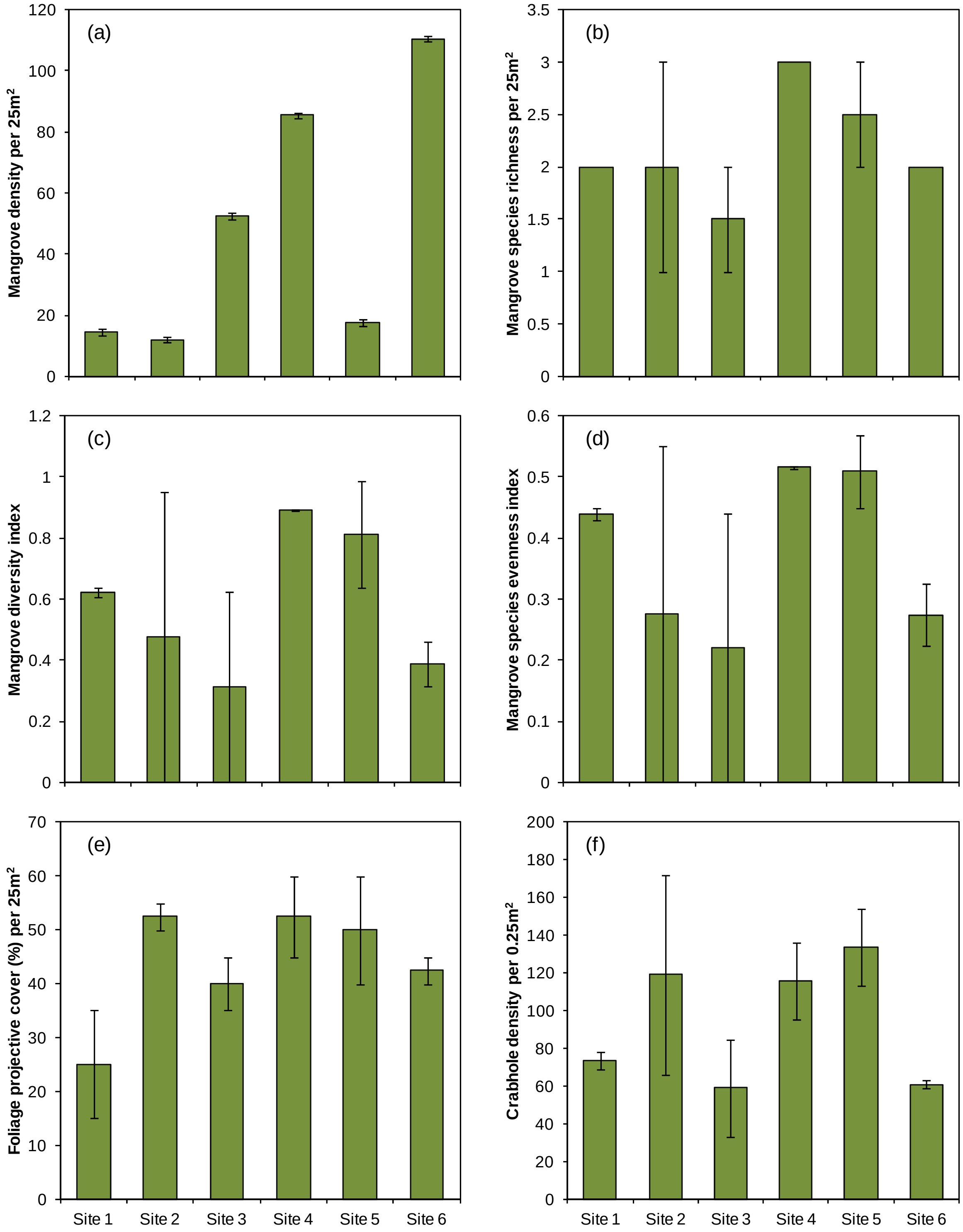

Figure 6: Mean (±se) (a) mangrove density, (b) species richness, (c) diversity, (d) species evenness, and (e) projective foliage cover (%) per 25m^2 plots, and (f) crabhole counts per 0.25m^2 quadrats (n = 2) at six locations.

Figure 7: Example of canopy cover near mouth of the Calliope River

Site 1, located closest to the mouth of the Calliope River showed less projective foliage cover (PFC) than all other sites surveyed (Figure 7). Sites 2 through 6 had PFC of almost 50% coverage; whereas Site 1 had an average of 25% PFC. Site 1 recorded an open canopy, whereas Site 2 was the only site to record a dense canopy over both plots (Table 5).

Overall, the mangrove populations were most similar between Sites 4 and 5 with approximately 90% similarity (Figure 8). Sites 1 and 2 were the most dissimilar of the six sites surveyed, with only an approximate 55% similarity to each other and 30% similarity to the remaining four sites (Figure 8).

Table 5: Projective foliage cover (%), dominant species, and overstory cover per 25m^2 plot and mean crabhole counts per 0.25m^2 quadrat

Zone	Site					
	1	2	3	4	5	6
Projective foliage cover (%)						
Zone 1 (0 m)	35	55	35	45	60	45
Zone 2 (50 m)	15	50	45	60	40	40
Overstory cover						
Zone 1 (0 m)	M	D	D	M	M	M
Zone 2 (50 m)	M	D	M	O	O	M
Dominant species						
Zone 1 (0 m)	*R*	*R*	*Ae*	*Ae*	*Av*	*Av*
Zone 2 (50 m)	*R*	*R*	*R + C*	*R*	*Av*	*Av*
Crabhole counts per 0.25m^2 quadrat						
Zone 1 (0 m)	78.1 ± 10.1	171.7 ± 13.9	33.3 ± 2.2	136.1 ± 12.4	154.1 ± 17.6	62.8 ± 7.3
Zone 2 (50 m)	69.2 ± 9.8	66.2 ± 5.9	84.5 ± 12	95 ± 10	113.3 ± 11.8	58.7 ± 5.6

Average crabhole count/0.25m^2 quadrat is shown as mean ± SE.
O = Open
M = Moderate
D = Dense

Ae = *Aegiceras corniculatum*
Av = *Avicennia marina*
C = *Ceriops tagal*
R = *Rhizophora stylosa*

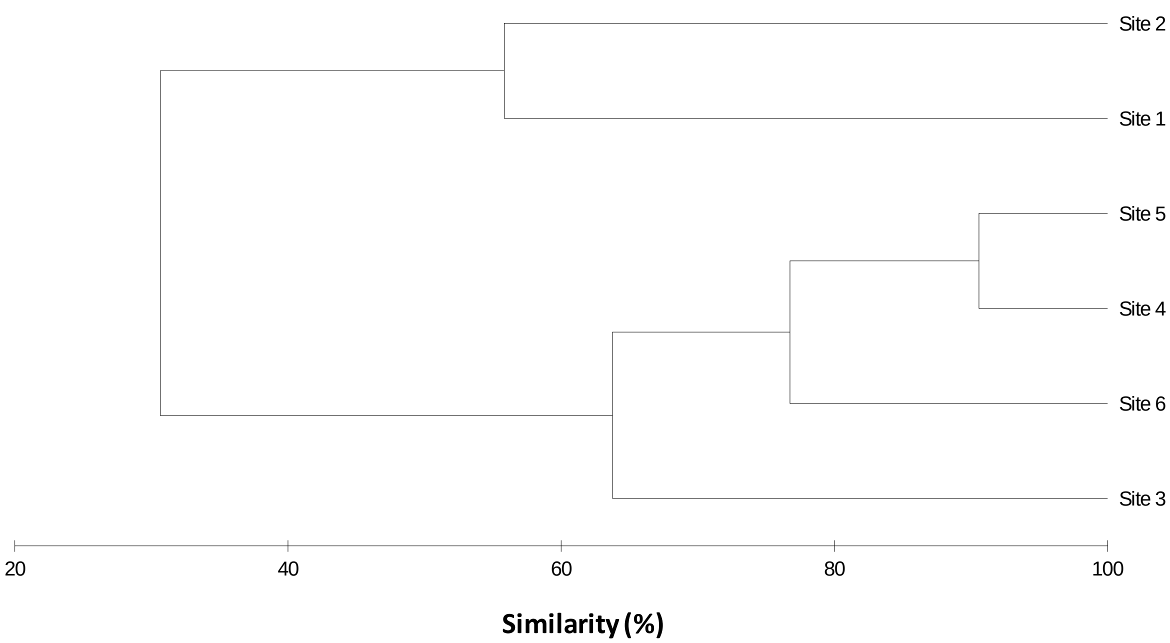

Figure 8: Cluster analysis of mangrove community assemblages (Bray-Curtis similarity) at different sites (n = 2/site). Data were standardized.

Fish and Macroinvertebrate Assemblages

Within Port Curtis, a total of 148 fish and mobile macroinvertebrates from 15 species were collected from nine sites, using a cast net (Figure 9). These species were representative of shallow soft sediment habitats, mangroves and other areas with vegetation lined banks. The most common species recorded were the banana prawn (*Fenneropenaeus merguiensis*), the greenback mullet (*Liza subviridis*) (35%), the common ponyfish (*Leiognathus equulus*) (7%), and the common toadfish (*Tetractenos hamiltoni*) (3%). See Table 6 for a list of species recorded at all sites for the current monitoring program.

Figure 9: Example of cast net used for nekton surveys

A further 86 fish from 8 species were collected using two gill nets (Figure 10) in order to sample species representative of larger sized fish assemblages in deeper water channels. The most common species recorded were the giant leatherskin queen fish (*Scomberoides commersonianus*) (37%), the white-eyed shark, (*Rhizoprionodon acutus*) (22%), and the bull shark (*Carcharhinus leucas*) (19%). Other species collected in the gill nets included the blue catfish (*Arius graeffei)*, the blue threadfin salmon (*Eleutheronema tetradactylum*), and the beach salmon (*Leptobrama muelleri*). Frequent checking of the nets ensured that organisms could be released without harm.

Figure 10: Example of gill net deployment

An additional 2 fish were collected via line sampling by hand: the blue catfish (*Arius graeffei*), and the blue threadfin salmon (*Eleutheronema tetradactylum*). This technique proved to be less effective in comparison to other used field techniques due to the limited ability to sample a large area within the marine and estuarine environment, in comparison with the gill and cast nets, which are designed to sample a widespread area. Total numbers of all fish caught at the nine sites using the various techniques during the current sampling program can be found in Table 6.

Table 6: Fish abundance per location

Family	Species Name	Common Name	Site 1	2	3	4	5	6	7	8	9
Penaeidae	*Fenneropenaeus merguiensis*	banana prawn	1	41	4	5	6	5			2
Portunidae	*Scylla serrata*	mud crab								1	1
Carcharhinidae	*Carcharhinus leucas*	bull shark									16
Carcharhinidae	*Rhizoprionodon acutus*	white-eyed shark									19
Sparidae	*Acanthopagrus australis*	yellowfin bream					2		1		
Sparidae	*Acanthopagrus berda*	black/pikey bream								1	
Ambassidae	*Ambassis marianus*	estuary perchlet			1						
Terapontidae	*Amniataba percoides*	barred grunter	1		2						
Ariidae	*Arius graeffei*	blue catfish			1	3	1				
Hemiramphidae	*Arrhamphus sclerolepis*	snub-nosed garfish							1		
Tetraodontidae	*Chelonodon patoca*	milk-spotted puffer		1							
Polynemidae	*Eleutheronema tetradactylum*	blue threadfin salmon				1					9
Leiognathidae	*Leiognathus equulus*	common ponyfish	2	3	4				1		
Leptobramidae	*Leptobrama muelleri*	beach salmon		1	1					1	1
Mugilidae	*Liza subviridis*	greenback mullet	24	21	3	2	1				
Mugilidae	*Liza vaigiensis*	diamondscale mullet				2					
Echeneididae	*Remora remora*	remora suckerfish									1
Carangidae	*Scomberoides commersonianus*	giant leatherskin queen fish	27	1	1	1					2
Sillaginidae	*Sillago ciliata*	sand whiting	1		1						
Batrachoididae	*Tetractenos hamiltoni*	common toadfish		1						3	
Engraulidae	*Thryssa aestuaria*	estuary anchovy								1	
		Total:	56	69	18	14	10	5	3	7	51

Sites: 1-6: Calliope River 7: Hamilton Point 8: Boatshed Point
9: Tunnel Entrance

There were no statistically significant differences ($P > 0.05$) in species richness, evenness, or diversity in nekton assemblages between sites, both in the Port Curtis harbour and the Calliope River. Nekton refers to free-swimming organisms that are generally independent of currents. Total species abundance varied among sites, but there were no significant differences ($P = 0.170$), with site abundance ranging from 3 (Site 7) to 69 (Site 2) (Table 6; Figure 6).

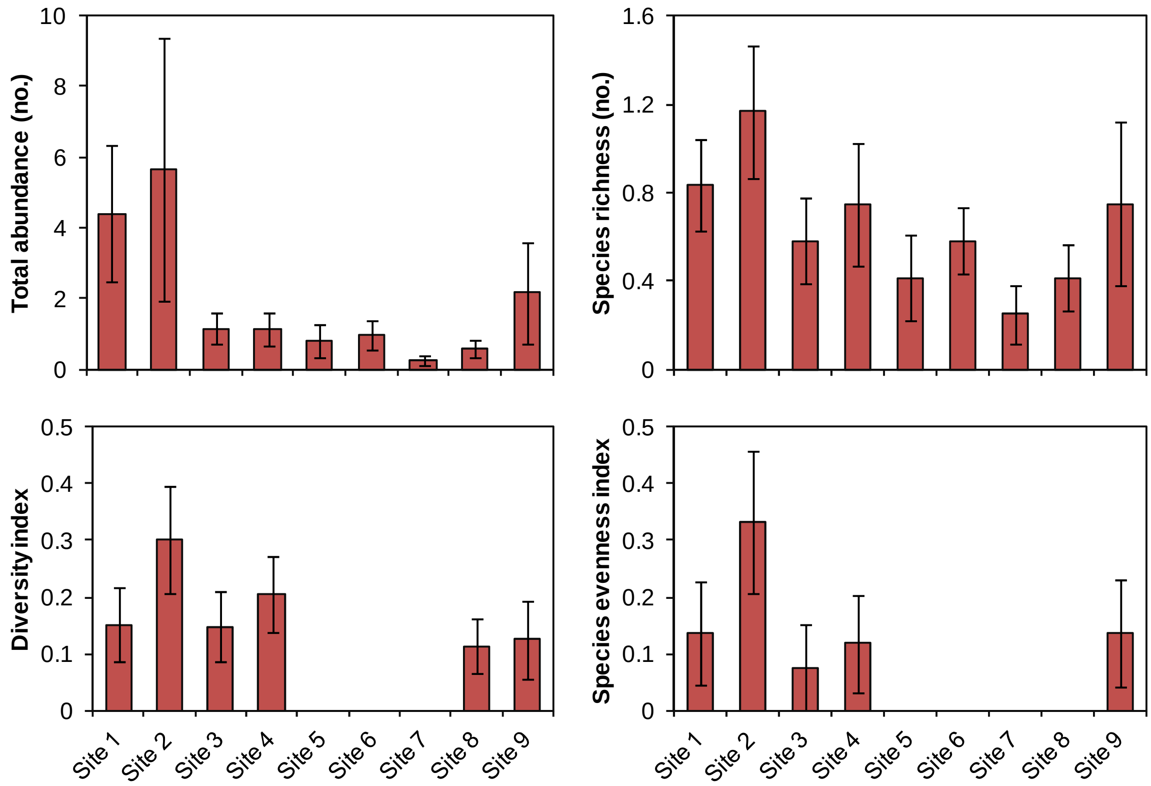

Figure 11: Mean (±se) total abundance, species richness, diversity, and species evenness of nekton surveyed using cast and gill nets (n = 12) at nine study locations. Sites 1-6: Calliope River, Site 7: Hamilton Point, Site 8: Boatshed Point, Site 9: Tunnel Entrance.

Site 2, in the lower Calliope River, displayed the overall highest figures out of all sites, showing the largest and most diverse population of fish and evenly distributed. There was a clear trend with lower diversity and evenness at Sites 5 to 7, although these were not statistically significant. Variance was shown in the levels of species richness across all sites ranging from 0.2 to 1.2 (Figure 11).

The greenback mullet (*Liza subviridis*), giant leatherskin queen fish (*Scomberoides commersnianus*) and the banana prawn (*Fenneropenaeus merguiensis*) (Figure 12) were the most commonly found species across all sites, with no substantial variation evident between each of the sites mean fish length (Table 7).

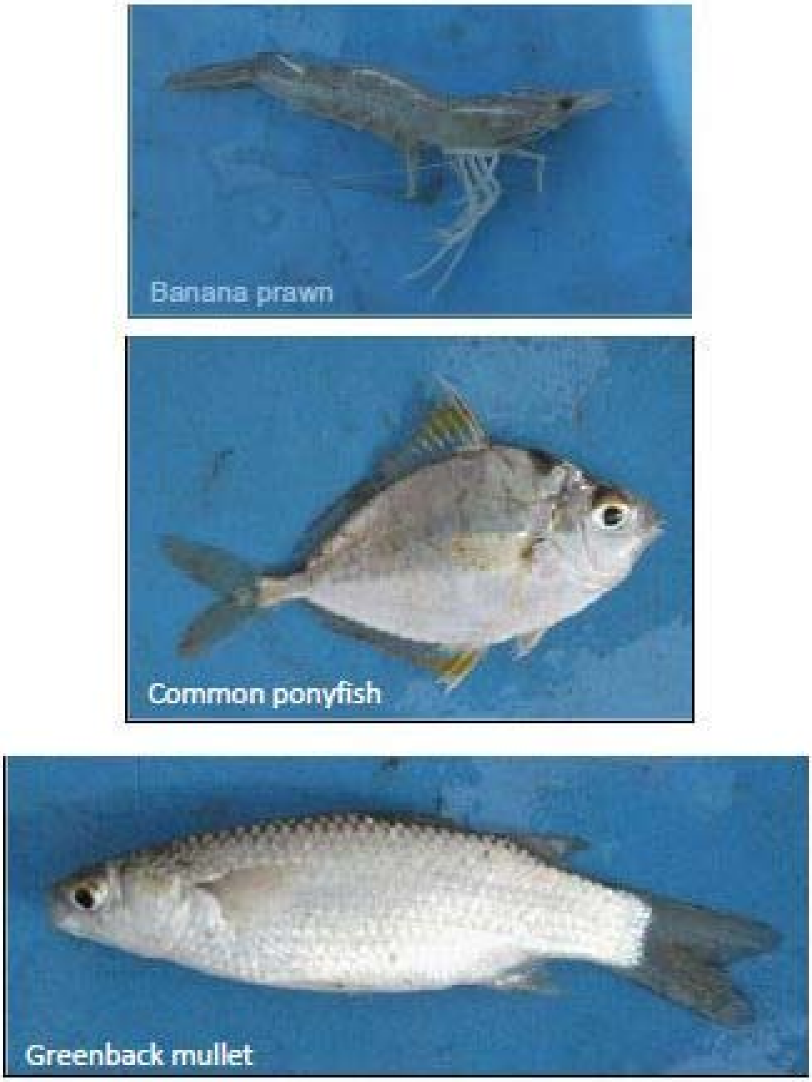

Figure 12: Example of fish and macroinvertebrate species caught in Port Curtis

Analysis of similarity indicated that there was a significant relationship in fish assemblages between most sites (ANOSIM Global R-statistic = 0.13, P = 0.05; Figure 13 & Figure 14). The plots represent the replicated fish diversity at each site and show that most sites were clustered together indicating similar species diversity. The species that contributed highest to the dissimilarity (SIMPER analysis) of each of the sites were the greenback mullet (*Liza subviridis*), the banana prawn (*Fenneropenaeus merguiensis*) and the common pony fish (*Leiognathus equulus*). Outliers can be seen relating to Sites 7 and 8, meaning the highest levels of dissimilarity were most likely caused by the notable absence of species diversity and evenness (Figure 13). Figure 14 displays the same data but with these outliers removed. It must also be noted that two out of the three outliers were from Site 8.

Table 7: Mean fish standard length (mm) per location

Family	Species Name	Common Name	Site								
			1	2	3	4	5	6	7	8	9
Penaeidae	*Fenneropenaeus merguiensis*	banana prawn	50	29.10 ± 0.73	28.75 ± 4.73	28 ± 4.64	29.67 ± 1.33	36.4 ± 7.16			32.5 ± 2.5
Portunidae	*Scylla serrata*	mud crab								6	81
Carcharhinidae	*Carcharhinus leucas*	bull shark									864.69 ± 36.86
Carcharhinidae	*Rhizoprionodon acutus*	white-eyed shark									632.12 ± 35.79
Sparidae	*Acanthopagrus australis*	yellowfin bream					85		290		
Sparidae	*Acanthopagrus berda*	black/pikey bream								196	
Ambassidae	*Ambassis marianus*	estuary perchlet			55						
Terapontidae	*Amniataba percoides*	barred grunter	55		95 ± 5						
Ariidae	*Arius graeffei*	blue catfish			280	521.67 ± 15.90	350				
Hemiramphidae	*Arrhamphus sclerolepis*	snub-nosed garfish							185		
Tetraodontidae	*Chelonodon patoca*	milk-spotted puffer		135							
Polynemidae	*Eleutheronema tetradactylum*	blue threadfin salmon				620					463.33 ± 41.25
Leiognathidae	*Leiognathus equulus*	common ponyfish	52.5 ± 2.5	56.67 ± 4.41	67.5 ± 3.23				60		
Leptobramidae	*Leptobrama muelleri*	beach salmon		495	360					270	250
Mugilidae	*Liza subviridis*	greenback mullet	90.3 ± 2.20	105.80 ± 5.97	100	89 ± 19	95				
Mugilidae	*Liza vaigiensis*	diamondscale mullet				315 ± 35					
Echeneididae	*Remora remora*	remora suckerfish									20
Carangidae	*Scomberoides commersonianus*	giant leatherskin queen fish	438.89 ± 9.37	495	370	575					590 ± 140
Sillaginidae	*Sillago ciliata*	sand whiting	115		125						
Batrachoididae	*Tetractenos hamiltoni*	common toadfish		70						61.67 ± 1.67	
Engraulidae	*Thryssa aestuaria*	estuary anchovy								127	

Sites: 1-6: Calliope River 7: Hamilton Point 8: Boatshed Point 9: Tunnel Entrance

Mean standard length (mm) is shown as mean ± se.

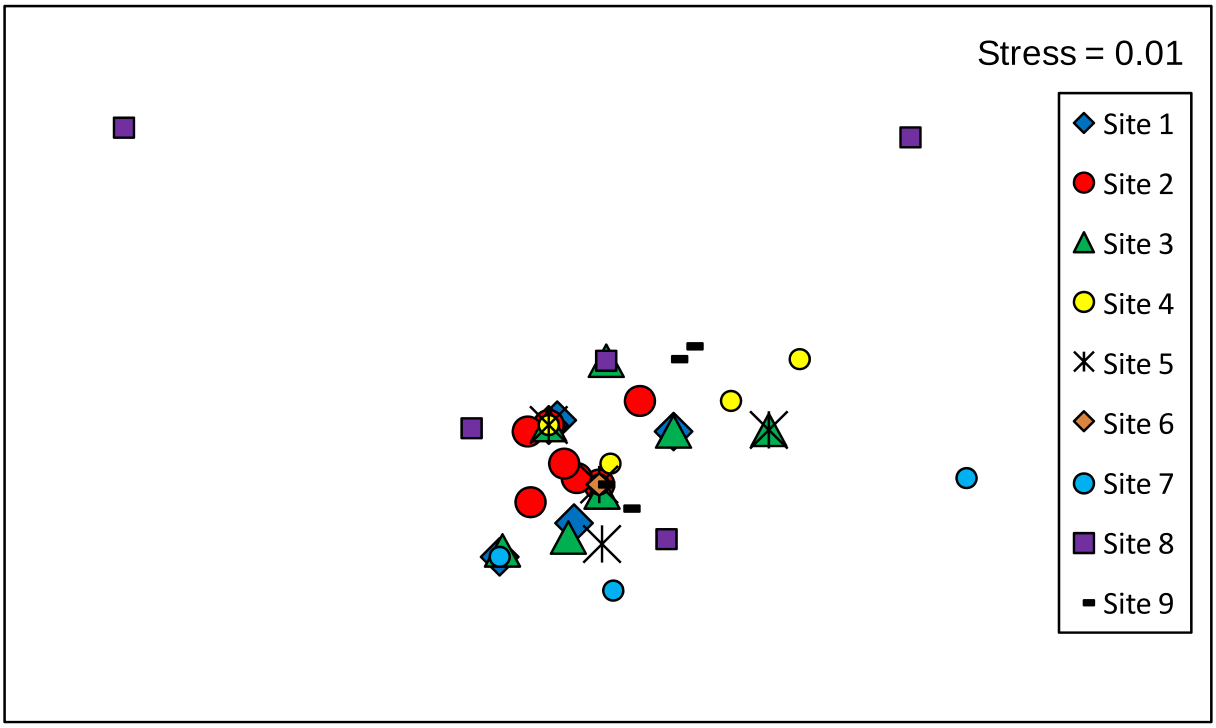

Figure 13: 2D Ordination plots (n-MDS) of fish assemblages surveyed using cast and gill nets (n = 12/site). Data were standardized and weight dispersion corrected, based on Bray-Curtis similarity matrices. Sites 1-6: Calliope River, Site 7: Hamilton Point, Site 8: Boatshed Point, Site 9: Tunnel entrance.

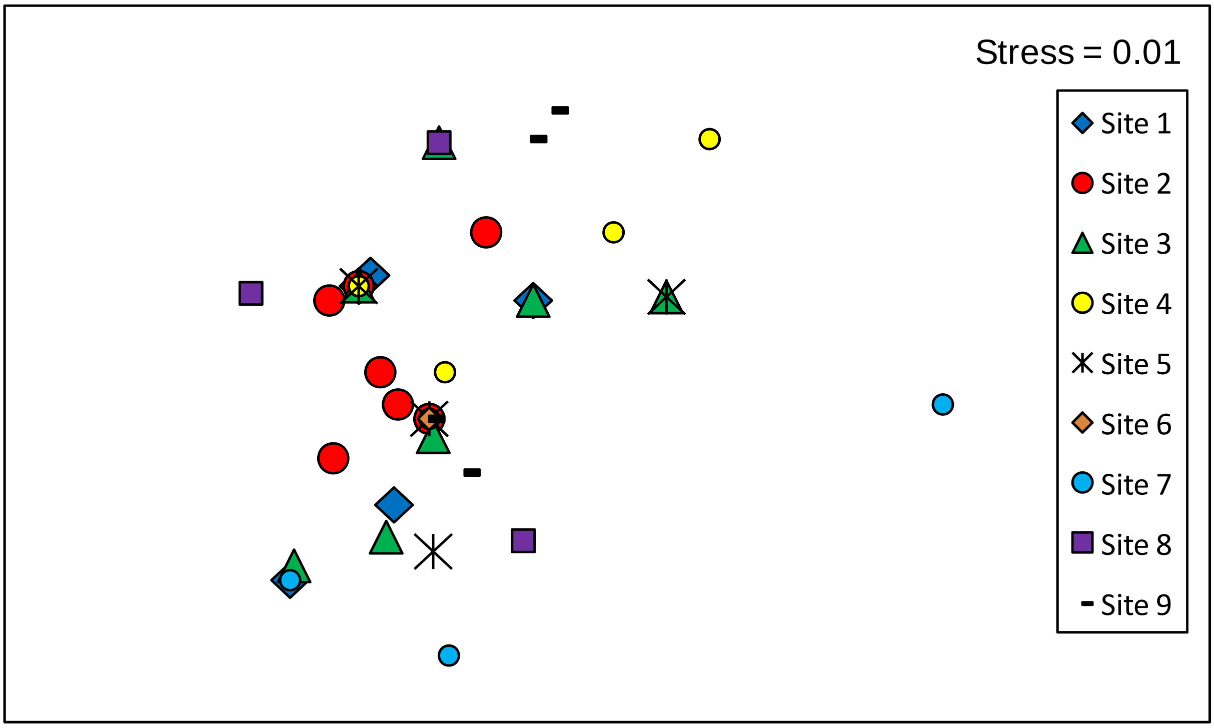

Figure 14: 2D Ordination plots (n-MDS) of fish assemblages (excluding outliers) surveyed using cast and gill nets (n = 12/site). Data were standardized and weight dispersion corrected, based on Bray-Curtis similarity matrices. Outliers were established by comparison with interquartile range. Sites 1-6: Calliope River, Site 7: Hamilton Point, Site 8: Boatshed Point, Site 9: Tunnel entrance.

***MDS plots**: Sample points close to one another signify similar community composition. The more distance between points, the more dissimilar the community composition.*

Sediment Grain Size

Sediments were collected by the same grab sampling technique and at the same sites used for the benthic infauna sampling. The grain size sampling was undertaken to inform the benthic infaunal sampling and was not designed to assess the sediment characteristics of the area. For ease of reporting for sediment grain size, benthic communities sites were split into northern (Sites 5 to 14) and southern (Sites 1 to 4 & 15 to 20). Notable differences were evident within the sediment composition between the northern and southern sites (Figure 15; Figure 16). The northern sites showed an average of 60 to 70% silts and mud. Fine sands also represented 25 to 35% of the sediment structure, with the remainder (<5%) being comprised of coarse sands and gravel (Figure 15). Site 13 differed in comparison to the other northern sites, showing a composition of 80% coarse sand and gravel, 15% fine sands and 0.5% of the sediment structure being silts and mud (Figure 15).

The southern sites in Boatshed Point were not uniform in composition. Sites 4, 15 and 19 presented varying mud and silt balances ranging from 70 to 95 % (Figure 16), with sands and gravel attributing to the rest of the sediment formation (5 to 30%), which were more like those found at northern sites. Site 1 revealed fine sand (60%) to be the dominant grain size at this particular site. Silt and mud (35%) followed, with the remaining sediment of Site 1 being made up of coarse sand and gravel (5%). Fine sand was also the dominant grain size for Site 17 (50%), followed by gravel and coarse sand (35%) with the remnant of the sediment structure attributed to silt and mud (5%). The rest of the southern sites (Figure 16), showed average mud and silt percentages ranging from 5 to 15% which was followed by fine sand, again showing varying averages of 5 to 15%. Coarse sand and gravel made up the remainder of the sediments with averages ranging from 70 to 90% (Figure 16). Deeper water sites (Sites 1 to 3, 13 to 14 and 16 to 17) have higher gravel content than the shallower sites which were seen to have a higher silt and sand content overall (Figure 17).

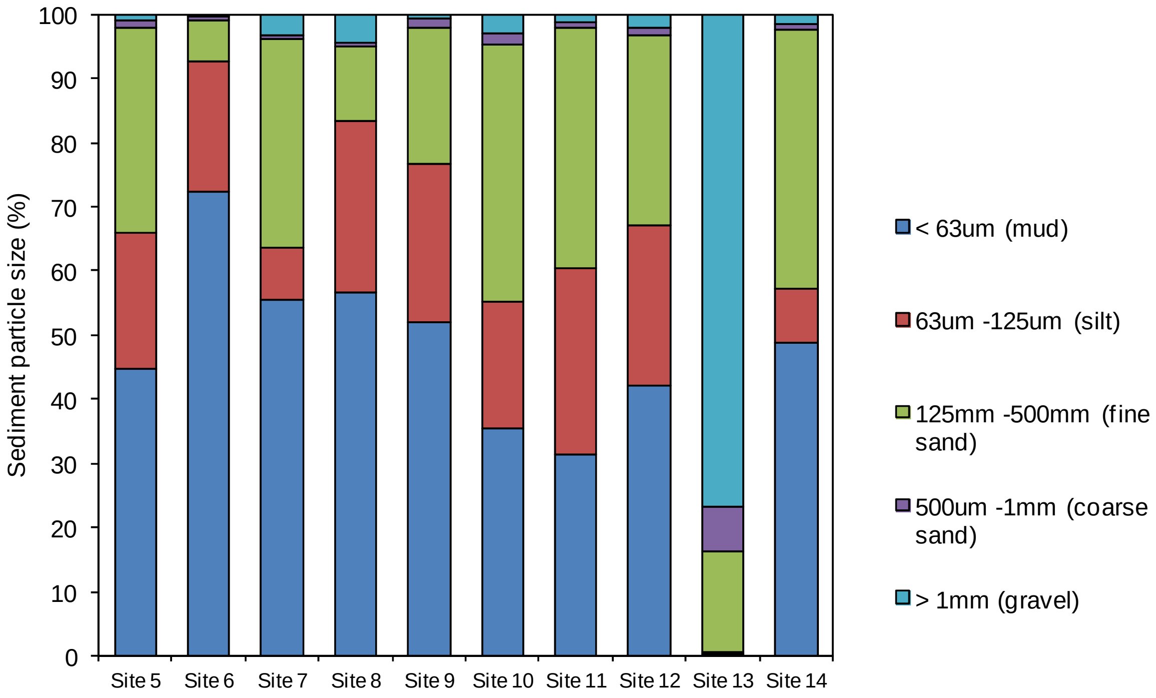

Figure 15: Sediment Grain Size Percentages for Benthic Sites 5 – 14 in the Northern Vicinity of Boatshed Point.

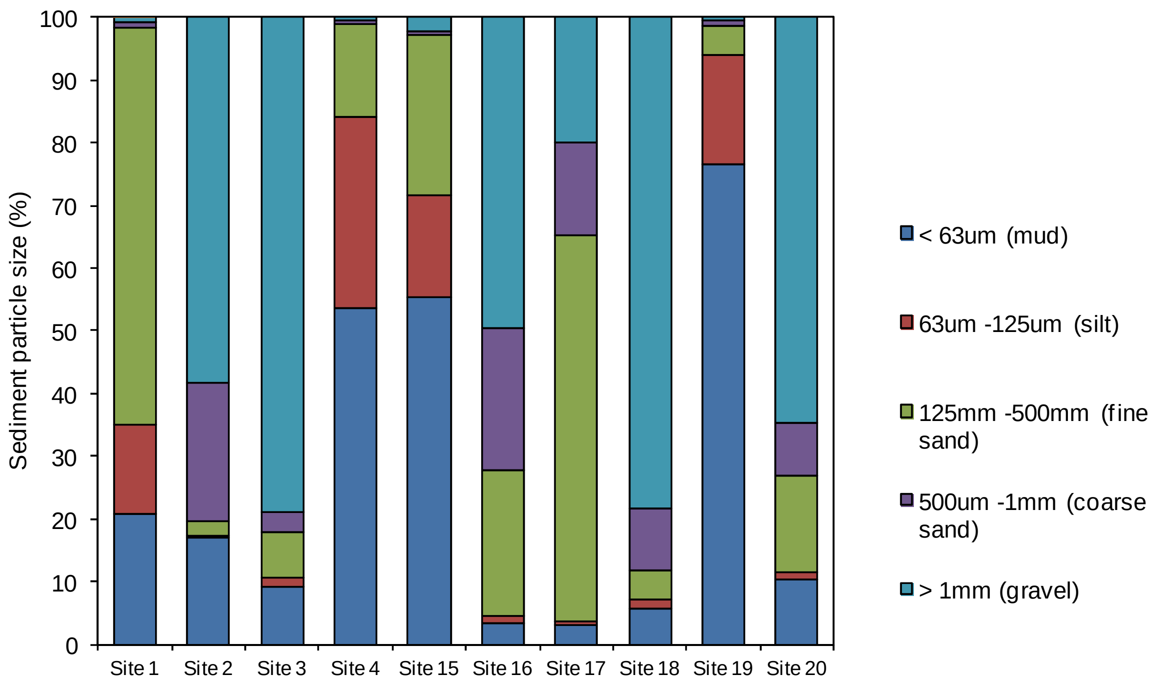

Figure 16: Sediment Grain Size Percentages for Benthic Sites 1 – 4 & 15 – 20 in the Southern Vicinity of Boatshed Point.

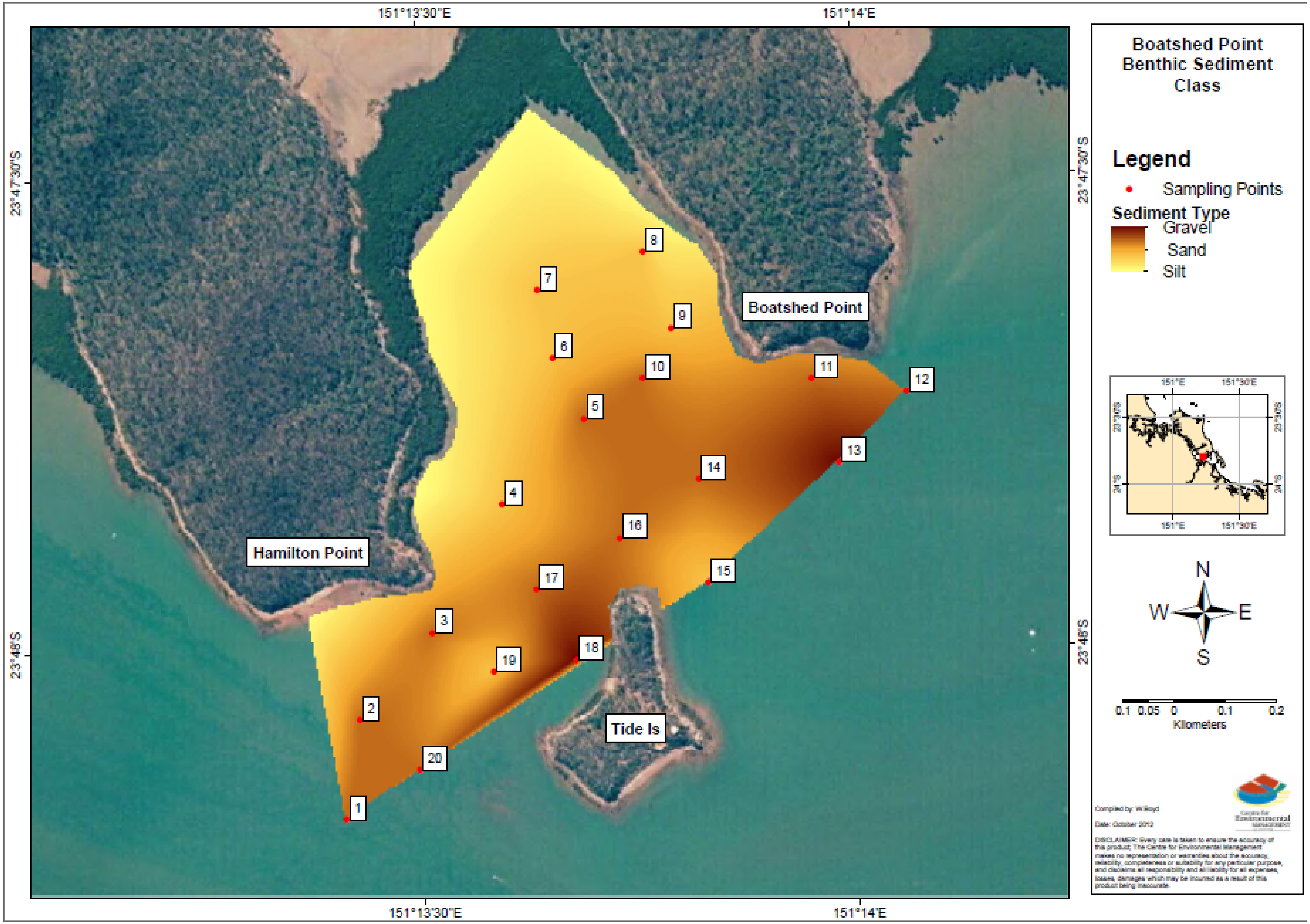

Figure 17: Boatshed Point Benthic Sediment Class Map

Benthic Communities

A total of 1,332 benthic infaunal organisms from 223 species and 9 different phyla were collected in August 2012 from 20 sites. Species were identified to the CQU database, which has coded species by number (e.g., *Ophiuroidea* 10). The most common organisms recorded across all sites included the brittle stars *Ophiuroidea* 10 (3%) and *Ophiuroidea* 18 (4%), the gastropods *Epitonium* sp. 3 (4.5%), Gastropoda 184 (6%) and *Rissoidae* sp. 1 (5%), and the bamboo-worm *Maldanidae* 9 (19%) (Figure 18). The most common phyla included polychaetes (40%), molluscs (38%), crustaceans (12%) and echinoderms (8%), with chordates, cnidarians, pycnogonids and sipunculids being the least common phyla (< 0.5%). Table A4 and Table A5 provide lists of species recorded within all study sites. There were no seagrass leaves or rhizomes recorded in any of the sediment/benthic infauna samples from study sites in the bay adjacent to Boatshed Point and Tide Island.

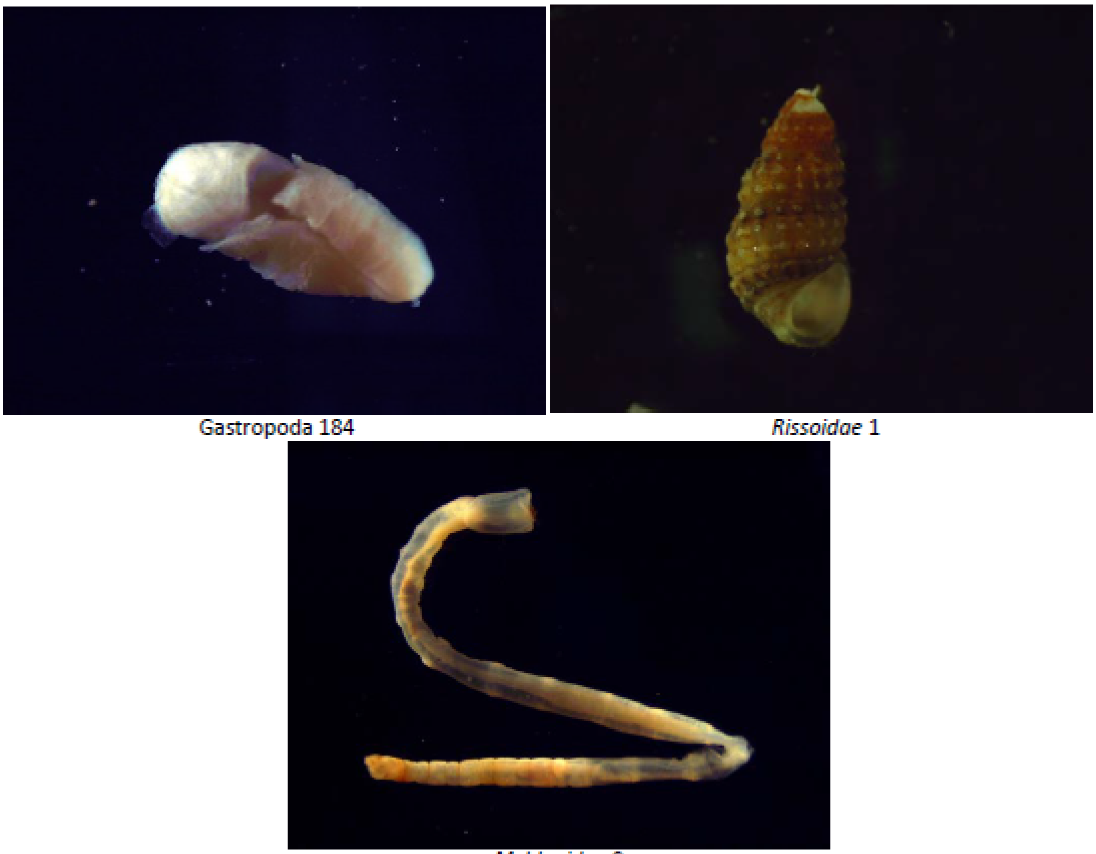

Figure 18: Three most common organisms recorded across all sites: Maldanidae 9 (19%), Gastropoda 184 (6%) and Rissoidae sp. 1 (5%).

Benthic infaunal abundance appeared to follow sediment grain size distributions (Figure 17; Figure 19). Sites 5, 12, 14 & 20 showed relatively high abundances while Sites 1, 2, 3, & 15 showed relatively lower abundances (Figure 19; Figure 20). There were significant differences between sites in benthic infauna total abundance ($P < 0.01$; $F = 6.559$; *df* 19), species richness ($P < 0.01$; $F = 7.047$; *df* 19), diversity ($P < 0.01$; $F = 4.392$; *df* 19) and species evenness ($P = 0.01$; $F = 2.135$; *df* 19) (Figure 20). Site 20 was significantly different from the majority of sites in benthic infauna total abundance, species richness and diversity. Highest number of organisms, species richness and diversity were also observed at Site 20 (Figure 20a-c). Conversely, Sites 1 to 4 and 15 had the lowest number of organisms, species richness and diversity compared with other sites. In general, sites with higher number of organisms had similarly higher species richness and diversity compared with other sites. The exception, Site 12, had the second highest number of organisms and diversity but the fifth lowest species richness. Species evenness was variable among all sites (Figure 20d).

Benthic infauna community assemblages were significantly dissimilar among all sites (ANOSIM Global R-statistic 0.318; P = 0.01; Figure 21). The organisms that mostly contributed to assemblage dissimilarity among sites included the gastropod *Rissoidae* 1, the bamboo-worm *Maldanidae* 9 and the brittle star *Ophiuroidea* 10 (SIMPER analysis). Outliers in Sites 1, 7, 15, 19, and 20 slightly exacerbated dissimilarity in benthic infauna assemblages among all sites. Outliers were established by comparison with interquartile range. Removal of outliers slightly improved similarity in benthic infauna assemblages among all sites (ANOSIM Global R-statistic 0.372; P = 0.01; Figure 22). Organisms that best contributed to site similarities included the bamboo-worm *Maldanidae* 9 and the gastropods *Trichobranchidae* 1 and Gastropoda 184 (SIMPER analysis). Excluding outliers, highest assemblage similarity was between Sites 7 to 9 and Sites 10 to 12.

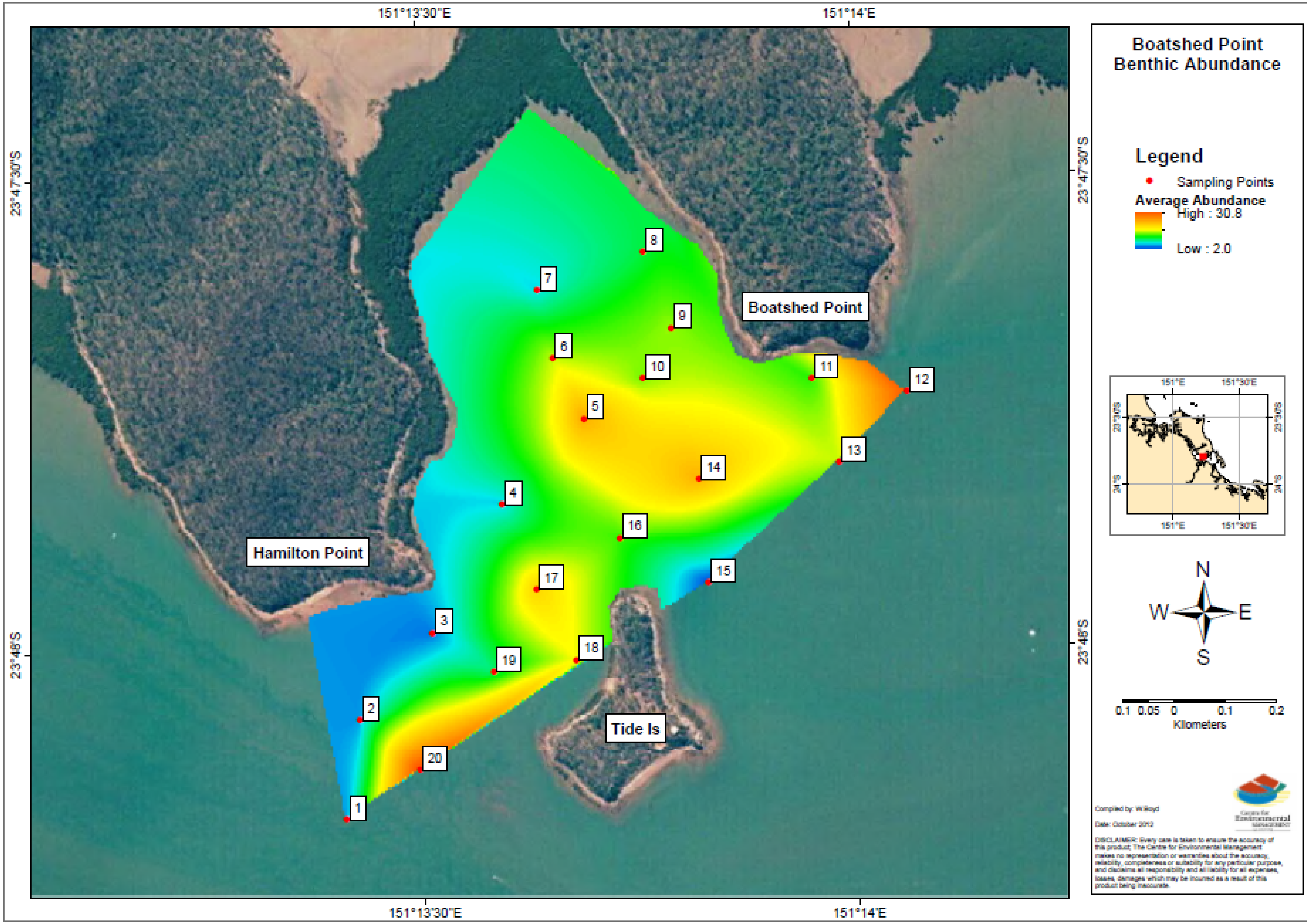

Figure 19: Boatshed Point Benthic Abundance Map

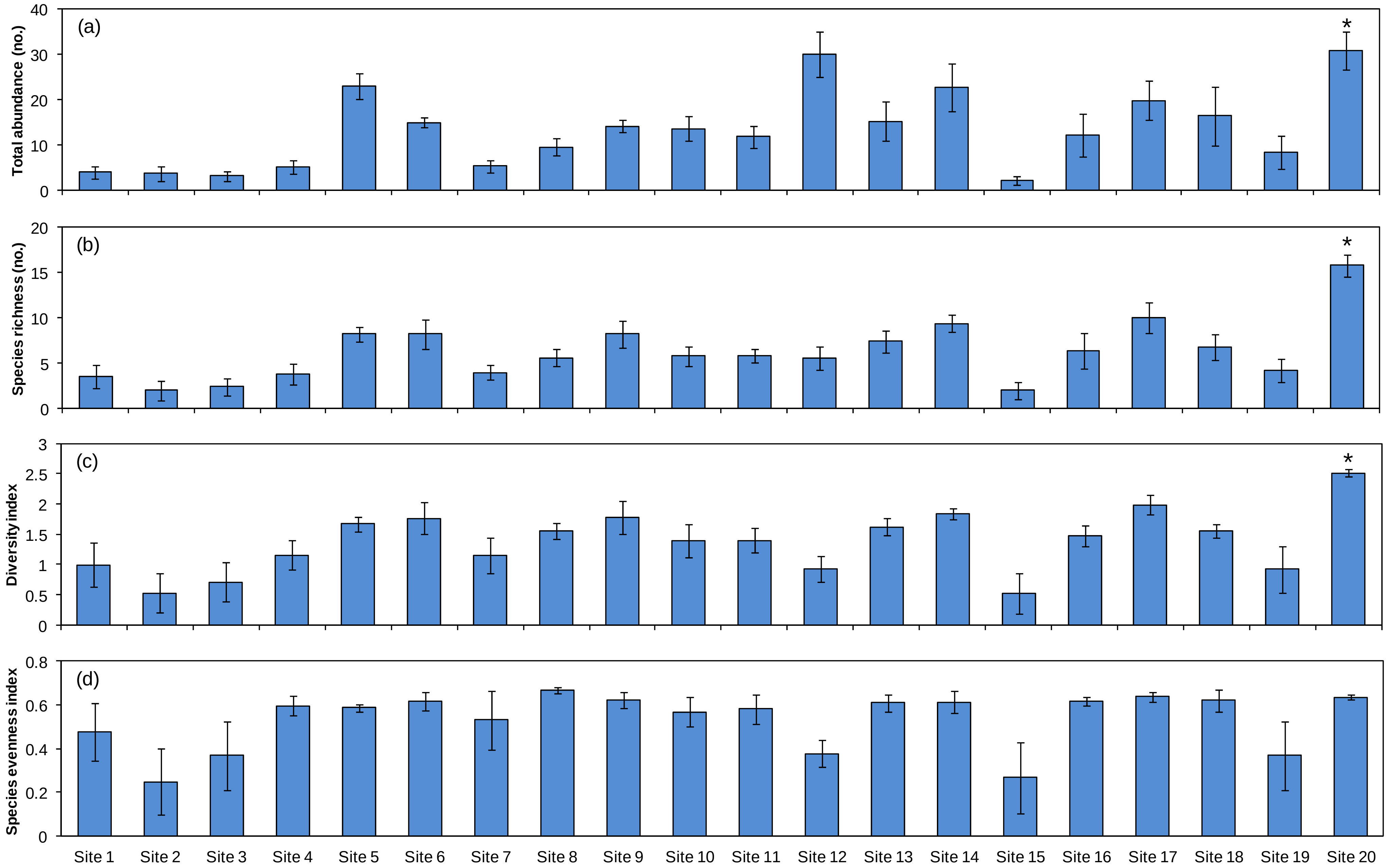

Figure 20: Mean (±se) benthic infauna (a) total abundance, (b) species richness, (c) diversity, and (d) species evenness (n = 5) at twenty locations.

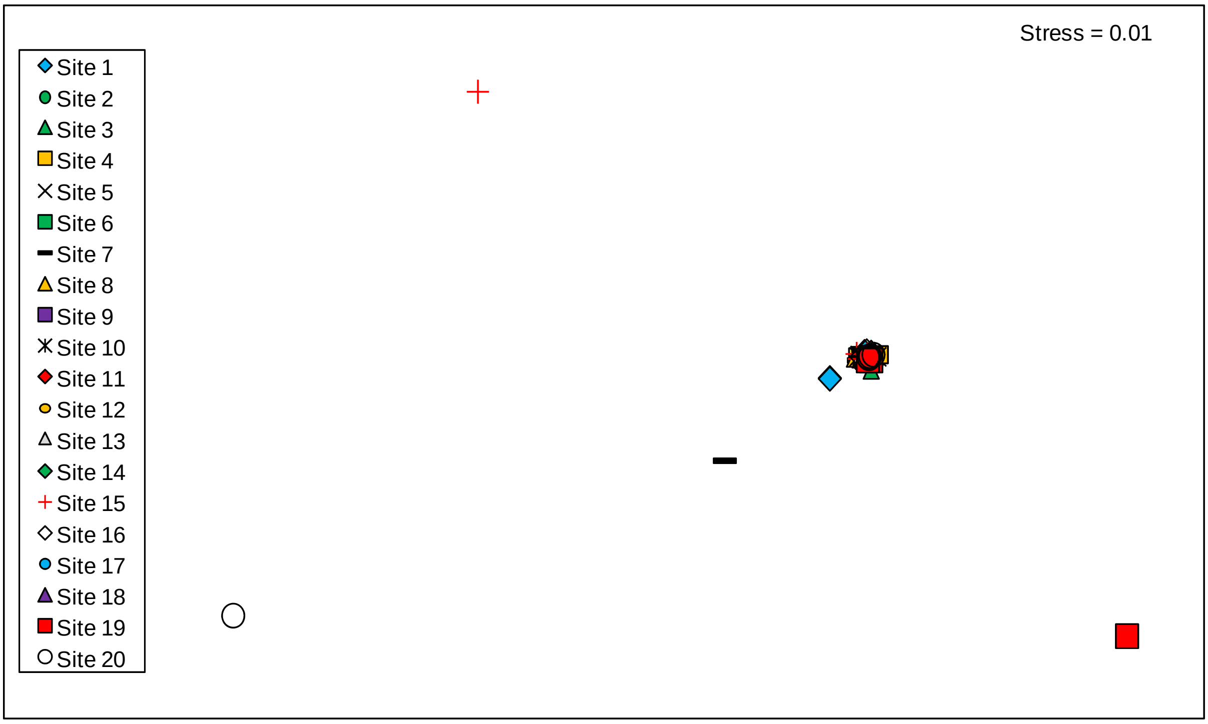

Figure 21: 2D Ordination plots (n-MDS) of benthic infauna assemblages surveyed using sediment grab samples (n = 5/site). Data were standardized and weight dispersion corrected, based on Bray-Curtis similarity matrices.

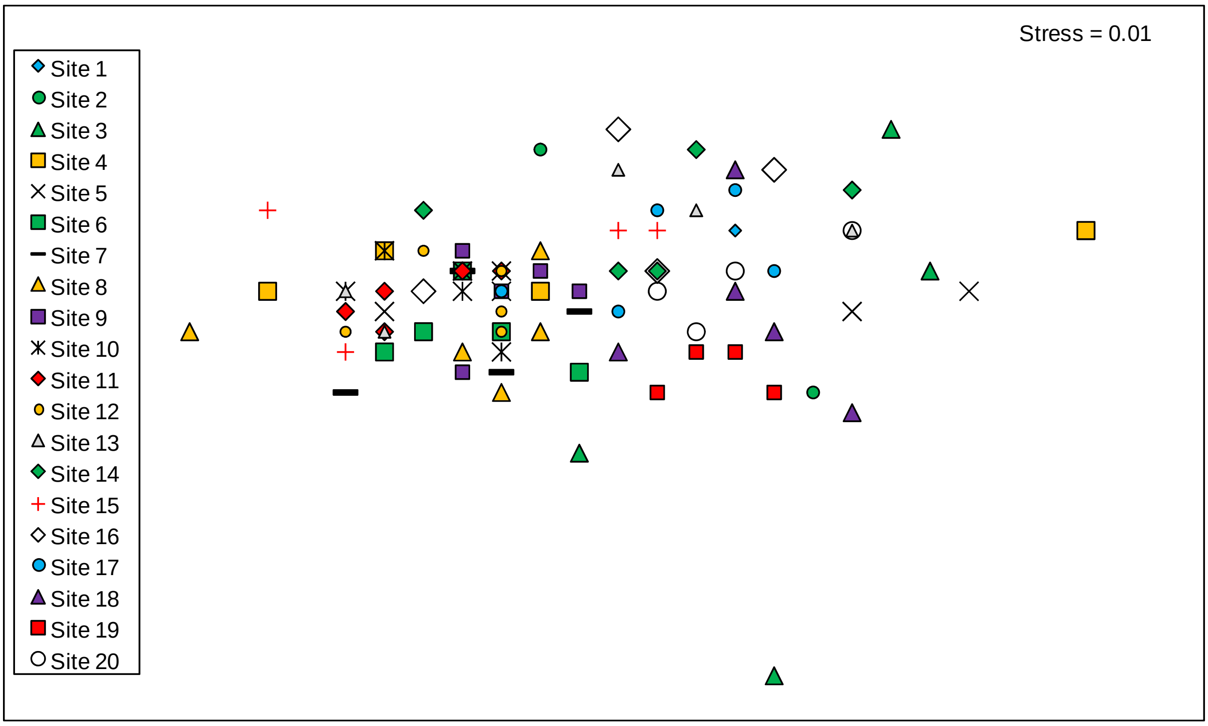

Figure 22: 2D Ordination plots (n-MDS) of benthic infauna assemblages (excluding outliers) surveyed using sediment grab samples (n = 5/site). Data were standardized and weight dispersion corrected, based on Bray-Curtis similarity matrices. Outliers were established by comparison to the interquartile range.

***MDS plots**: Sample points close to one another signify similar community composition. The more distance between points, the more dissimilar the community composition.*

Marine Megafauna

A total of twenty-one large marine animals was spotted during the course of the study (Table 8), all of which were located either in the open waters of the Port Curtis or towards the mouth of the Calliope River. Most sightings were of individuals, however two green turtles were observed together on 23 August and a pod of five bottlenose dolphins was observed on 24 August. The observed animals were: green turtles (*Chelonia mydas*) (total 12), bottlenose dolphins (*Tursiops truncatus*) (total 5), a bull shark (*Carcharhinus leucas*), and a sea snake. One dolphin was observed on 23 August that could not be identified to species level. A single deceased dugong (*Dugong dugon*) was observed in mangroves near Site 4 (in the mid Calliope River), which was reported to Queensland Parks and Wildlife Service.

Table 8: Large Marine Animal Log

Date	Time	Taxa	Number	Latitude	Longitude	Notes
21/08/2012	11:00AM	Dugong	1	-23.8543	151.1792	Calliope River, Remains in mangroves at high tide - Young adult, no external marks
22/08/2012	9:07AM	Brown sea snake	1	-23.8558	151.2069	Calliope River, 300mm in Length
22/08/2012	3:12PM	Green turtle	1	-23.8520	151.1838	Calliope River, South end of Anabranch
23/08/2012	6:47AM	Green turtle	1	-23.8743	151.1907	Calliope River
23/08/2012	7:05AM	Green turtle	1	-23.7958	151.2308	Boatshed Point
23/08/2012	7:50AM	Green turtle	1	-23.7983	151.2252	Hamilton Point
23/08/2012	8:20AM	Dolphin	1	-23.7983	151.2252	Hamilton Point
24/08/2012	6:21AM	Green turtle	2	-23.7904	151.2334	Adjacent to Boatshed Point - Sighted twice
24/08/2012	8:37AM	Bottlenose dolphin	5	-23.7910	151.2250	Near Boatshed Point
24/08/2012	8:40AM	Green turtle	1	-23.7930	151.2219	Adjacent to Hamilton Point
24/08/2012	8:48AM	Green turtle	1	-23.8004	151.2207	Adjacent to Hamilton Point
24/08/2012	8:30AM	Green turtle	1	-23.8071	151.1730	Near Mainland Tunnel Launch Site
27/08/2012	4:15PM	Bull shark	1	-23.8071	151.1730	Near Mainland Tunnel Launch Site
30/08/2012	2:12PM	Green turtle	1	-23.7958	151.2308	Near Boatshed Point
30/08/2012	2:51PM	Green turtle	1	-23.7958	151.2308	Near Boatshed Point
31/08/2012	10:15AM	Green turtle	1	-23.8071	151.1730	Near Mainland Tunnel Launch Site

Discussion

Mangrove Communities

Mangroves were prevalent throughout the Calliope River study area. These communities provide coastal protection, nursery habitat for fish and invertebrates, and are of economic and conversation value as fisheries resources and for ecosystems services. Mangroves are protected as marine plants under the *Fisheries Act 1994* (Qld) and Port Curtis is listed in the Directory of Important Wetlands in Australia (Environment Australia 2001).

Notable differences were recorded in the mangrove community structure in the present study, most notably the abundance of the river mangrove (*Aegiceras corniculatum*). Although high numbers of river mangroves (*Aegiceras corniculatum*) were found during the current study (67% of total trees, 23% of total seedlings), previous studies in other stretches of the Calliope River and elsewhere within Port Curtis found that the river mangrove (*Aegiceras corniculatum*) made up less than 1% of the total number of trees and saplings combined (Alquezar 2011).

Differences in mangrove assemblages within the current study, as well as between the current study and previous studies (Alquezar, 2011), may be affected by salinity ranges, as salinity is an important determinate of mangrove community structure (Hutchings & Saenger, 1987). According to Lovelock (1993), the river mangroves (*Aegiceras corniculatum*) are found along river banks across a wide range of salinities. Species found to be more dominant within Port Curtis previously, such as *Ceriops sp.* and *Rhizophora sp.*, are generally found in more intertidal zones with a more consistent salinity (Lovelock, 1993), such as that within the generalised intertidal habitat of Port Curtis. This is supported by the differences in salinity levels between Sites 1-2 and Sites 3-6 (see Figure 2 for site locations). Salinity ranged from 35.17 to 15.92 ppt during spring tide and 33.99 to 23.44 ppt during neap tide at Sites 3-6 (Water Quality Report A). River mangroves (*Aegiceras cornicualatum*), which are naturally found over a wide range of salinities, are the dominant species at these sites. These values contrast to the high and relatively uniform salinities found at Sites 1 and 2 (Spring Tide: 36.11 to 32.82 ppt; Neap Tide: 34.1 to 32.78 ppt) (Water Quality Report A), in which river mangroves (*Aegiceras cornicualatum*) were absent.

Differences observed between Zone 1 (adjacent to river) and Zone 2 (50 m from river) can be attributed to the natural zonation of mangrove communities. Mangrove community structure is affected by many factors including proximity to a freshwater source, light intensity and wind (Hutchings & Saenger, 1987). As such, it is common to find differences in mangrove numbers, maturity level and assemblage structure between communities bordering a freshwater source and those farther away from the same freshwater source, commonly referred to as natural zonation.

Crabhole densities were significantly different at Sites 1, 3 and 6 compared to Sites 2, 4 and 5 (Table 4; See Figure 2 for site locations). Tidal exposure, food availability and sediment size are known to affect the distribution of crabs (Hutchings & Saenger, 1987). Variation in crabhole counts can potentially be attributed to similar factors, such as the proximity of the site to a water source and mangrove community assemblage. Although there are no clear trends among sites within the present study, it is evident across all sites that crabhole density was higher near the edge of the river (Zone 1) compared to those 50 m from the edge of the water (Zone 2), excluding Site 3.

Fish and Macroinvertebrate Assemblages

There were no statistically significant differences between survey sites in species richness, evenness, or diversity relating to the nekton assemblages both in the Port Curtis harbour and the Calliope River.

The greenback mullet (*Liza subviridis*), giant leatherskin queen fish (*Scomberoides commersnianus*) and the banana prawn (*Fenneropenaeus merguiensis*) were the most commonly found species across all sites. The size class of the most abundant species, the greenback mullet (*Liza subviridis*), in this study (90-109 mm) was comparable to the more common size classes found previously (100-119 mm) for the lower Calliope River sites Alquezar (2011). Fish size depends on factors such as predation, food availability, habitat type, connectivity, age class, seasonality and depth of water (Sheaves, 2006; Harvey & Stewart, 1991). Despite the low catch rate, the population spread (i.e., size class grouping) of the greenback mullet (*Liza subviridis*) implies a similar population structure to previous years. The low number of specimens caught is likely to be responsible for the degree of variance found during this study and low statistical power of the data.

Overall, there were noticeable differences in fish assemblage abundance in comparison to previous sampling events. However, of the nine sites only three were common to that sampled in Alquezar (2011) (Boatshed Point, Hamilton Point, launch site 1, Calliope River). At these locations total abundance (density) was up to 10 times lower than previously recorded. Richness and evenness were slightly lower, but diversity was similar. This could be due to several factors such as, ambient water temperatures, tidal phases, increased boating movement within the harbour within recent years, previous large flood events, and/or methodological issues such as net placement. However, the most likely cause is seasonal factors. Sampling by Alquezar (2011) was conducted in February and May while the current study was conducted in late August. Sheaves (2006) found that fish assemblages in tropical Queensland estuaries sampled in July were different to those in the wet season due to a high recruitment at the latter time.

Mangrove environments are recognised to play an important role in the life cycle of many fish and macroinvertebrate species. *Rhizophora stylosa* dominated mangrove habitats have been shown to be a source of food, shelter and as a nursery habitat for nekton with 42 species including those of commercial importance found in subtropical communities (Halliday and Young 1996). These mangrove habitats are however lower in fish abundances than other mangroves communities. The level of use varies with species and is dependant on how transient or sedentary the species is. Laegdsgaard & Johnson (2001) have shown a strong positive relation between juvenile fish species and mangrove presence and complexity (i.e., root and trunk structure) and that the stage of the life cycle influences the reasons for mangrove use.

The current study showed that 77% of total fish abundance caught was categorised as offshore spawners that used the mangrove communities of the Calliope River as a nursery habitat. This compares favourably to 53% found in 2011 (Alquezar 2001). A further 19% of the nekton assemblage was classified as estuarine based species that spend their entire life history in the immediate proximity of the mangrove community and use these mangroves as a nursery habitat. Estuarine and freshwater breeders made up approximate 4% of the nekton assemblage in relation to mangrove community use. This compared to 3% in 2011 (Alquezar 2011). These estuarine and freshwater species will spend their entire life in a particular system. The presence of fresh water species such as the blue catfish (*Arius graeffei)* in an estuarine environment (diadromus fish), such as the Calliope River anabranch provides an indication of the dynamics and interconnectivity between the various tracts of the Calliope River relating to fish abundance. The banana prawn and greenback mullet were found to be the most common juvenile species that utilised the mangrove habitat within the Calliope River system. Overall, there is a general trend whereby sites with lower mangrove distribution (e.g., the upper Calliope River, Boatshed and Hamilton Points) had lower fish richness and abundance.

Observed fish and macroinvertebrates species of recreational and commercial value include: the banana prawn (*Fenneropenaeus merguiensis*), the mud crab (*Scylla serrata*), and sand whiting (*Sillago ciliata*), as well as the mullet and bream species.

Sediment Grain Size

Deeper water sites tended to have higher gravel content than the shallower sites which were seen to have a higher silt and sand content overall. This is likely due to a lower flowing depositional condition at the shallow sites as opposed to the deeper waters where greater flow and settlement of fine particles is unlikely (Herzfeld, 2004). This is supported by the supplementary coastal processes study completed by BMT WBM Pty Ltd (attached as an appendix to the main supplementary report to the EIS) which shows that in general shallower sites have slower currents and hence are a depositional environment as opposed to the deeper waters that have faster currents and hence settling of fine particles is less likely to occur.

Benthic Communities

The significantly greater total abundance, species richness and diversity at Site 20 are difficult to interpret. Although a higher than average (across all sites) number of organisms, species richness, and diversity were recorded on all five replicates, these values do not correlate with particle size or location. Other sites at similar locations (relative to Tide Island, Curtis Island) or with similar particle sizes had variable total abundance, species richness and diversity compared to Site 20 (Figure 20). Therefore, a combination of these two factors, unique to Site 20, or an unmeasured parameter may explain the statistically significant differences observed at Site 20.

Although benthic infauna total abundance, species richness and diversity generally illustrated a positive relationship *within* each site, excluding Site 12, benthic infauna total abundance, species richness and diversity were variable among all sites. Substrate structure has been known to influence benthic infauna community assemblages (Kaller & Hartman, 2004). Studies demonstrate a higher total abundance and diversity of benthic infauna in gravel substrates compared to sand or silt-dominated substrates (Grubaugh et al., 1996; Vuori & Joensuu, 1996; Kaller & Hartman, 2004). This was apparent in the current study as a general trend is evident between higher total abundance and coarser sediment types (Figure 17; Figure 19); however, closer examination of sediment class distribution shows variable results and are highly heterogeneous inline with that commonly found (Simpson et al. 2005). Although the substrate at Site 20 was composed of approximately 60% gravel and had the greatest total abundance, species richness and diversity, sites with a greater proportion of gravel showed diminished benthic infauna total abundance, species richness and diversity. For instance, Sites 3 had low indice values while Sites 13 and 18 had mid-ranged indice values despite substrates composed of approximately 80% gravel (Figure 20). Similar variable results encompass much of the data; however, sites with the highest assemblage similarity (Sites 7-9 and Sites 10-12) had similar substrate types (Figure 15; Figure 22; See Figure 4 for site locations). In addition to being in close proximity, Sites 7-9 were composed of approximately 50-55% mud, 5-20% silt and 5-20% fine sand whereas Sites 10- 12 were composed of 35-40% mud, 20-30% silt and 35-40% fine sand. Sediment particle size and its relationship with food play a role in determining benthic infauna assemblages (Peeters *et al.*, 2004). Similar substrate compositions may provide distinctive and corresponding habitats and food sources and thus may explain the high benthic infauna assemblage similarity seen between Sites 7-9 and Sites 10-12 (See Figure 4 for site locations). Other factors such as sediment pH, redox, moisture content, organic carbon content, porewater constituents and contaminant loads can also affect benthic infaunal assemblage (Simpson et al. 2005) as well as water physico-chemical characteristics such as dissolved oxygen, salinity and temperature (Dauer et al., 2000).

While earlier studies encompassed a wider range of environments, the present study intensely sampled benthic infauna from one location, the bay adjacent to Boatshed Point. Despite temporal differences between previous studies (Alquezar, 2008; Alquezar, 2010) and the present study, Boatshed Point showed increased benthic infauna total abundance and similar species richness, diversity, and species evenness across all three studies (Table 9). As with previous studies (Alquezar, 2008; Alquezar, 2010), the present study represented Boatshed Point as the mean (±se) of the nearest site, which was Site 11 (n = 5).

Table 9: Mean (±se) benthic infauna total abundance, species richness, diversity and species evenness at Boatshed Point in 2008, 2010 (previous studies; (Alequezar, 2008; Alequezar, 2010)), and 2012 (current study).

	2008[a]	2010[a]	2012[b]
Total abundance	4.3 ± 1.2	7.6 ± 1.4	11.8 ± 2.5
Species richness	3.7 ± 1.2	5.2 ± 0.6	5.8 ± 0.7
Diversity	1.1 ± 0.3	1.5 ± 0.1	1.4 ± 0.2
Species evenness	0.8 ± 0.2	0.7 ± 0.1	0.6 ± 0.1

[a] Shown as mean (±se) of subtidal samples from that year.
[b] Shown as mean (±se) of nearest site to Boatshed Point (Site 11).

Since 2008, benthic infauna density has nearly tripled while species richness is slightly higher and the other two factors have remained uniform at Boatshed Point. Similar benthic infaunal ecological indices at Boatshed Point across the three studies imply that the structure of the benthic infauna community assemblage has remained relatively unchanged over the last four years. Changes in hydrology, currents and water quality of surrounding marine and freshwater systems may be responsible for the increases in benthic infauna abundances through habitat modification, food availability, turbidity or sediment composition changes (Koel and Stevenson, 2002; Peeters *et al.*, 2004; Angonesi *et al.*, 2006; Bishop *et al.*, 2006).

Marine megafauna

The incidental field observations of marine megafauna imply that suitable habitats exist in the project area. Therefore, their presence is a factor for designing measures to manage and mitigate potential construction and operation impacts of the LNG plant and associated infrastructure.

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Conclusions

Species of national and international importance were observed during this study implying that suitable habitats are available within Port Curtis and the Calliope River.

In the current study, mangrove communities supply significant habitat structure and refuge as well as providing food to numerous commercially and recreationally important macro-invertebrate and fish communities. Furthermore, mangroves promote sediment stability and reduce erosion. The presence of mangroves in the area appeared to influence the degree of fish abundance and richness so sites where the mangrove population was low or absent may be a factor in the observed finding due in part to the reduced habitat complexity. Mangrove species distribution appeared to be influenced by salinity as well as zonation along the Calliope River. Crabhole counts were a good indicator for site differences, though highlighted the lack of spatial trends within the study area.

Fish and macroinvertebrates species of recreational and commercial importance were present throughout the study area. Overall, there were few differences in macroinvertebrate and fish biodiversity among sites surveyed; however, catch rates were low. The few site differences observed and the differences to the data previously recorded are most likely attributed to natural seasonal conditions and variations plus the spatial differences between sites (e.g., upper Calliope River versus harbour sites at Boatshed and Hamilton Points).

Differences in particle size distribution were recorded among the sampled sites around Boatshed and Hamilton Points, potentially due to surrounding water currents and water depth. A general trend was also evident between higher total abundance of benthic infauna and coarser sediment types. Furthermore, a number of sites showed a relationship between sediment particle size and benthic infauna richness. Sediments around Boatshed Point appear to be a major contributor to benthic infaunal assemblages of the area. Trends since 2008 showed increased benthic infaunal abundance and relatively constant species richness, diversity and species evenness. Water and sediment type and quality, habitat type and food availability may be influencing factors in these trends. Although seagrass has been recorded within Port Curtis in the past, there was no evidence of seagrass at any of the study sites for the current sampling and survey program. The nearest permanent beds were located around Wiggins Island.

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Glossary

ANOSIM - Analysis of Similarity

ANOVA - Analysis of Variance

Benthic infauna - Fauna which live within the sediments of the seafloor

Diadromous – organisms that migrate between fresh and marine waters

CHC – Crabhole Count

DBH - Diameter at Breast Height

Diversity (Shannon-Weiner) - The proportion of organisms per species calculated as an index

EIS - Environmental Impact Statement

GIS - Geographic Information System

MOF - Material Offloading Facility

Motile - able to move spontaneously and actively

Nekton – free swimming aquatic organisms able to move independently of currents

n-MDS - non-metric Multi-Dimensional Scaling

PFC - Projective Foliage Cover

SIMPER - Similarity Percentages

Soak time - Time gill net spent in water

Species evenness - How evenly the abundance is spread among the various taxa that make up and assemblage

Species richness - Total number of taxa

SREIS - Supplementary Report to the EIS

Total abundance - Total number of organisms

Appendix

Table A1: Mangrove Sites GPS Locations in WGS84

Site	Location	Latitude	Longitude
Site 1	Calliope River	-23.8303	151.2209
Site 2	Calliope River	-23.8410	151.2126
Site 3	Calliope River	-23.8576	151.2082
Site 4	Calliope River	-23.8540	151.1797
Site 5	Calliope River	-23.8928	151.1891
Site 6	Calliope River	-23.9111	151.1771

Table A2: Macroinvertebrate and Fish Assemblage Sites GPS Locations

Site	Location	Latitude	Longitude
Site 1A	Calliope River	-23.8318	151.2169
Site 1B	Calliope River	-23.8308	151.2168
Site 2A	Calliope River	-23.8370	151.2114
Site 2B	Calliope River	-23.8384	151.2117
Site 3A	Calliope River	-23.8601	151.2055
Site 3B	Calliope River	-23.8592	151.2064
Site 4A	Calliope River	-23.8533	151.1806
Site 5A	Calliope River	-23.8922	151.1897
Site 5B	Calliope River	-23.8893	151.1910
Site 6A	Calliope River	-23.9106	151.1779
Site 6B	Calliope River	-23.9102	151.1768
Site 7A	Hamilton Point	-23.8000	151.2227
Site 7B	Hamilton Point	-23.8001	151.2237
Site 8A	Boatshed Point	-23.7953	151.2315
Site 8B	Boatshed Point	-23.7951	151.2336
Site 9A	MainlandTunnel Launch Site	-23.8087	151.1784
Site 9B	Mainland Tunnel Launch Site	-23.8123	151.1771

Table A3: Benthic Communities Sites GPS Locations

Site	Location	Latitude	Longitude
Site 1	Boatshed Point	-23.8030	151.2236
Site 2	Boatshed Point	-23.8012	151.2239
Site 3	Boatshed Point	-23.7997	151.2253
Site 4	Boatshed Point	-23.7974	151.2266
Site 5	Boatshed Point	-23.7959	151.2282
Site 6	Boatshed Point	-23.7949	151.2276
Site 7	Boatshed Point	-23.7937	151.2274
Site 8	Boatshed Point	-23.7930	151.2294
Site 9	Boatshed Point	-23.7944	151.2299
Site 10	Boatshed Point	-23.7952	151.2294
Site 11	Boatshed Point	-23.7953	151.2326
Site 12	Boatshed Point	-23.7955	151.2344
Site 13	Boatshed Point	-23.7967	151.2331
Site 14	Boatshed Point	-23.7970	151.2304
Site 15	Boatshed Point	-23.7989	151.2306
Site 16	Boatshed Point	-23.7981	151.2289
Site 17	Boatshed Point	-23.7989	151.2273
Site 18	Boatshed Point	-23.8002	151.2280
Site 19	Boatshed Point	-23.8004	151.2264
Site 20	Boatshed Point	-23.8021	151.2250

Table A4: List of benthic infauna organisms encountered across all sites

Chordates	**Crustaceans cont…**	**Molluscs cont…**
Arius graeffei	*Paranthuridae 1*	*Dentalium sp. 1*
Gobiidae 2	*Paratanaidae 1*	*Donacidae 1*
Cnidarians	*Pomacuma australiae*	*Donax sp. 1*
Anthozoa 1	*Rhaphidopus ciliatus*	*Ellobium sp. 1*
Crustaceans	*Synalpheus sp. 1*	*Epitonium sp. 2*
Alpheus pacificus	*Talitrus sp.1*	*Epitonium sp. 3*
Alpheus polyxo	*Tanaidacea 1*	*Epitonium sp. 4*
Alpheus sp. 2	*Tanaidacea 2*	*Epitonium sp. 5*
Amphipoda 39	*Tanaidacea 10*	*Gari anomula*
Amphipoda 40	*Tanaidacea 11*	*Gari sp. 2*
Amphipoda 42	*Thoracia 1*	*Gastropoda 24*
Amphipoda 43	*Xanthidae 10*	*Gastropoda 46*
Amphipoda 44	*Zoea 2*	*Gastropoda 69*
Ancylocheles gravelei	*Zoea 3*	*Gastropoda 72*
Caprellidae 2	**Echinoderms**	*Gastropoda 108*
Cerapus sp. 1	*Holothuroidea 1*	*Gastropoda 123*
Cerapus sp. 2	*Holothuroidea 11*	*Gastropoda 156*
Ceratoplax lutea	*Ophiuroidea 5*	*Gastropoda 184*
Copepoda 1	*Ophiuroidea 10*	*Limaria sp. 1*
Corophiidae 5	*Ophiuroidea 18*	*Littorinidae 2*
Cumacea 5	*Ophiuroidea 27*	*Littorinidae 4*
Dexaminidae 2	*Ophiuroidea 32*	*Macoma (Psammacoma) sp.*
Diogenes dubius	**Molluscs**	*Mactra abbreviata*
Diogenes guttatus	*Acteoncina fusiformis*	*Mimachlamys gloriosa*
Grandidierella cf. gilesii	*Austrocochlea constricta*	*Modiolus sp. 1*
Grandidierella sp. 1	*Azorinus sp. 2*	*Nassarius sp. 2*
Grandidierella sp. 2	*Azorinus sp. 3*	*Nassarius sp. 3*
Haplostylus cf. queenslandensis	*Bivalvia 79*	*Nassarius sp. 5*
Ilyograpsus paludicola	*Callista (Costacallista) sp.*	*Nassarius sp. 6*
Leptochela sydniensis	*Carditella (Carditellona) torresi*	*Nuculana corbuloides*
Leucothoe sp. 1	*Carditella torresi*	*Nuculana darwini*
Macrophthalmus telescopicus	*Collumbellidae 1*	*Nuculana novaeguiensis*
Maera sp.1	*Collumbellidae 2*	*Nuculanidae 1*
Mallacoota sp.1	*Collumbellidae 3*	*Paphia undulata*
Natatolana sp.1	*Corbula (Notocorbula) tunicata*	*Placamen retroversum*
Ocypoda 3	*Corbula (Serracorbula) crassa*	*Polyplacophora 3*
Ogyrides delli	*Corbula sulcata*	*Potamididae 2*
Oratosquillina stephensoni	*Cyclichna sp. 1*	*Potamididae 3*
Ostracoda 2	*Cyclostremiscus sp. 2*	*Pyramidellidae 3*
Ostracoda 6	*Cyclostremiscus sp. 4*	*Pyramidellidae 4*

Table A5: List of benthic infauna organisms encountered across all sites (cont...)

Molluscs cont…	Polychaetes cont…	Polychaetes cont…
Pyramidellidae 5	*Eunice sp. 6*	*Poecilochaetus sp.* 1
Ringicula sp. 1	*Eunice sp. 8*	*Polynoidae* 4
Rissoidae 1	*Eunice vittata*	*Polyodontes australiensis*
Strigilla sp. 1	*Glycera sp. 1*	*Progoniada sp.* 1
Strigilla sp. 2	*Haploscloplos sp. 1*	*Sabellidae* 8
Syrnola sp. 1	*Hydroides sp. 1*	*Samytha sp.* 1
Syrnola sp. 2	*Idanthyrsus pennatus*	*Sigambra tenticulata*
Talabrica sp.	*Leanira sp. 1*	*Spionidae* 1
Tawera subnodulosa	*Lumbrineris sp. 1*	*Spionidae* 3
Tellina (Cadella) diluta	*Lumbrineris sp. 5*	*Spionidae* 4
Tellina sp. 2	*Lumbrineris sp. 6*	*Spionidae* 10
Tellina sp. 7	*Lumbrineris sp. MoV324*	*Stenelais sp.*
Tellina sp. 13	*Magelona sp. 1*	*Sternapis scutata*
Tellina sp. 14	*Maldanidae 2*	*Sthenelais sp.* 1
Tellinidae 1	*Maldanidae 5*	*Streblosoma sp.* 2
Tellinidae 3	*Maldanidae 9*	*Syllidae* 1
Trigonostoma obliquata	*Marphysa sp. 6*	*Syllidae* 2
Trisidos tortuosa	*Mellinna sp. 1*	*Terebellidae* 5
Turbinidae 3	*Nematoneris sp.*	*Trichobranchidae* 1
Turridae 3	*Nephtys sp. 1*	*Trichobranchidae* 2
Turritella sp. 3	*Nereididae 3*	**Pycgnogonids**
Veneridae sp. 3	*Nereididae 8*	*Pycnogonida* 4
Polychaetes	*Nereididae 16*	**Sipunculans**
Ampharete sp. 1	*Nereididae 17*	*Sipuncula* 5
Arabella longipedata	*Nereididae 22*	*Sipuncula* 8
Arabellidae 4	*Nereididae 23*	*Sipuncula* 11
Armandia sp. 1	*Nereis sp. 1*	*Sipuncula* 16
Bispira sp.	*Ninoe sp. 1*	**Urochordates**
Capitellidae 2	*Nothria sp. 1*	*Ascidia sydneiensis*
Capitellidae 6	*Notomastus sp. 1*	
Capitellidae 8	*Ophelina sp. 1*	
Cirratulidae 5	*Ophelina sp. 3*	
Cirratulidae 7	*Orbiniidae 1*	
Diopatra aciculata	*Orbiniidae 2*	
Diopatra sp. 2	*Orseis sp. 1*	
Dorvilleidae 1	*Pectinaria kanabinos*	
Dorvilleidae 4	*Pectinaria sp.*	
Eteone siphadonta	*Phyllodocidae 5*	
Eunice gracilis	*Pisione sp. 1*	
Eunice sp. 1	*Pista typha*	