Technical Appendices N3 to N10

Draft Environmental Impact Statement/Environmental Review and Management Programme for the Proposed Wheatstone Project

July 2010

Wheatstone Project

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Title: Draft Environmental Impact Statement/Environmental Review and Management Programme for the Proposed Wheatstone Project: Technical Appendices N3 to N10

Appendix N3 to N10

Appendix N3

Tolerance Limits Report

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Abbreviations

Abbreviation	**Description**
ADCP	Acoustic Doppler Current Profiler
BPP	Benthic Primary Producers
BPPH	Benthic Primary Producer Habitat
CCA	Crustose Coralline Algae
CSD	Cutter Suction Dredger
DEC	Department of Environment and Conservation (WA)
E	Light attenuation coefficient, based on a natural log relationship
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority (WA)
ERMP	Environmental Review Management Programme
GBR	Great Barrier Reef
K_d	Light attenuation coefficient, based on a log relationship
LNG	Liquefied Natural Gas
MEB	Marine Ecosystems Branch (WA DEC)
NTU	Nephelometric Turbidity Units
PAR	Photosynthetically Active Radiation
SBR	Size:Burial ratio
SSC	Suspended Sediment Concentration
TSHD	Trailing Suction Hopper Dredgers
TSS	Total Suspended Solids
WA	Western Australia

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The Wheatstone Project

Tolerance Limits Report

Final Report

July 2010

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1 INTRODUCTION

DHI Water and Environment Pty. Ltd. (DHI Australia) has been appointed by Chevron Australia Pty Ltd (Chevron) via a sub-contract with URS Australia Pty Ltd (URS) to undertake a range of environmental modelling services for Chevron's proposed Wheatstone Project, an LNG (liquefied natural gas) development located in the north west of Western Australia (WA).

Chevron is planning to construct the Wheatstone Project consisting of an LNG plant and export terminal west of Onslow in north west WA. In order to allow vessel access to the LNG export terminal, Chevron is planning to dredge a navigation channel and turning basin. Based on available geotechnical data, the dredged material may not be suitable for onshore placement, so the base case assumption for the impact assessment has been that the dredged material will be placed of at a number of nominated offshore disposal sites. The detailed extent of the dredging area and nominal locations of the offshore disposal sites are shown in Figure 1.1. The location of the disposal areas are yet to be confirmed.

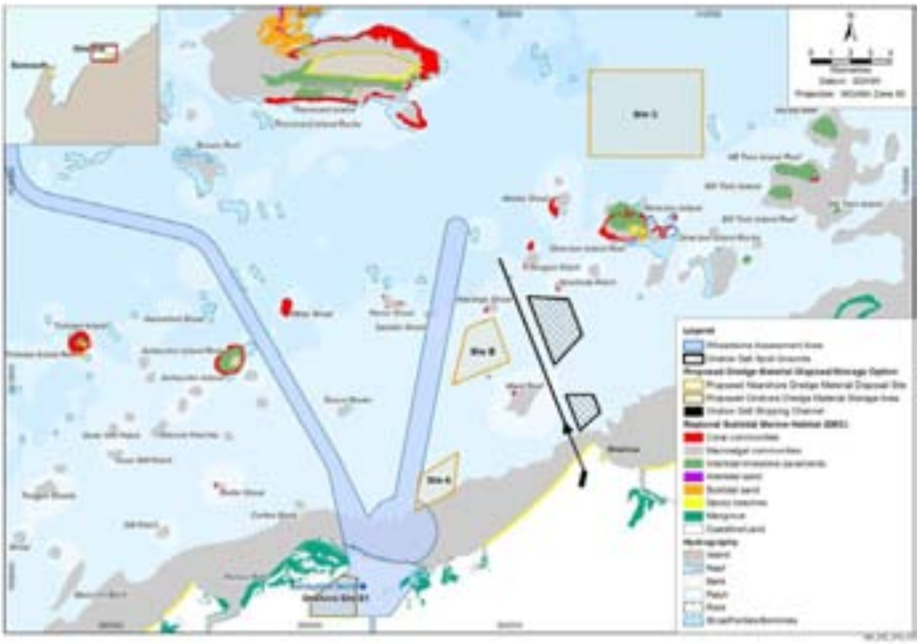

Figure 1.1 General location of the Project area

DHI Water and Environment (S) Pte. Ltd. (DHI Singapore) has been assigned the task of "Development of End Receptor Tolerances". The first phase of this task was to undertake a literature review in order to identify relevant knowledge and summarise the current understanding of the tolerances of relevant receptors to the impacts of suspended sediments, reduced light and sedimentation. The outcomes of the literature review are presented in Appendix A and summarised in Section 5 to Section 9 of this report. The purpose of this report is to combine the findings of the general literature review with DHI's extensive experience of monitoring major dredging and reclamation projects in south east Asia, in order to develop preliminary end receptor tolerance limits for the Wheatstone Project.

These tolerance limits will then be used to interpret the modelling results for the proposed dredging programme for use in the Environmental Impact Assessment / Environmental Review Management Programme (EIA/ERMP).

2 KEY RECEPTORS AND BACKGROUND CONDITIONS

2.1 Key Receptors

URS has provided a habitat map showing the distribution of corals, seagrass, macroalgae and filter feeders across the Project area (Figure 2.1).

Based on discussions with the client and MEB, DHI has identified the following potential key receptors that may be impacted by the proposed dredging, reclamation and offshore disposal activities:

- Corals
- Filter Feeders
- Seagrass
- Macroalgae
- Mangroves

Based on the findings of the literature review (Appendix A) and DHI's previous monitoring experience (Driscoll *et al.* 1997, DHI 1997, DHI 2004, Doorne-Groen 2007), mangroves can be classified as highly tolerant to the magnitude of sedimentation and suspended sediments typically generated from dredging, reclamation and offshore disposal activities, while seagrass and macroalgae can be considered as moderately tolerant, with a relatively short recovery time. However, coral reefs and benthic filter feeder communities are quite sensitive, particularly to suspended sediment and sedimentation loading, and their recovery from impacts is not rapid. Therefore, coral reefs and benthic filter feeder communities are assessed as the most sensitive habitats in the Project area with respect to loading resulting from sediment spill from the proposed dredging, reclamation and offshore disposal activities.

The main focus of this report has therefore been on the sensitivities of corals and filter feeders, as they are the dominant sensitive receptor in the immediate vicinity of the proposed dredging, reclamation and offshore disposal works, and will therefore be the controlling receptor in terms of the acceptable level of impact. However, tolerance limits for the other receptors (seagrass, macroalgae and mangroves) are also proposed.

4

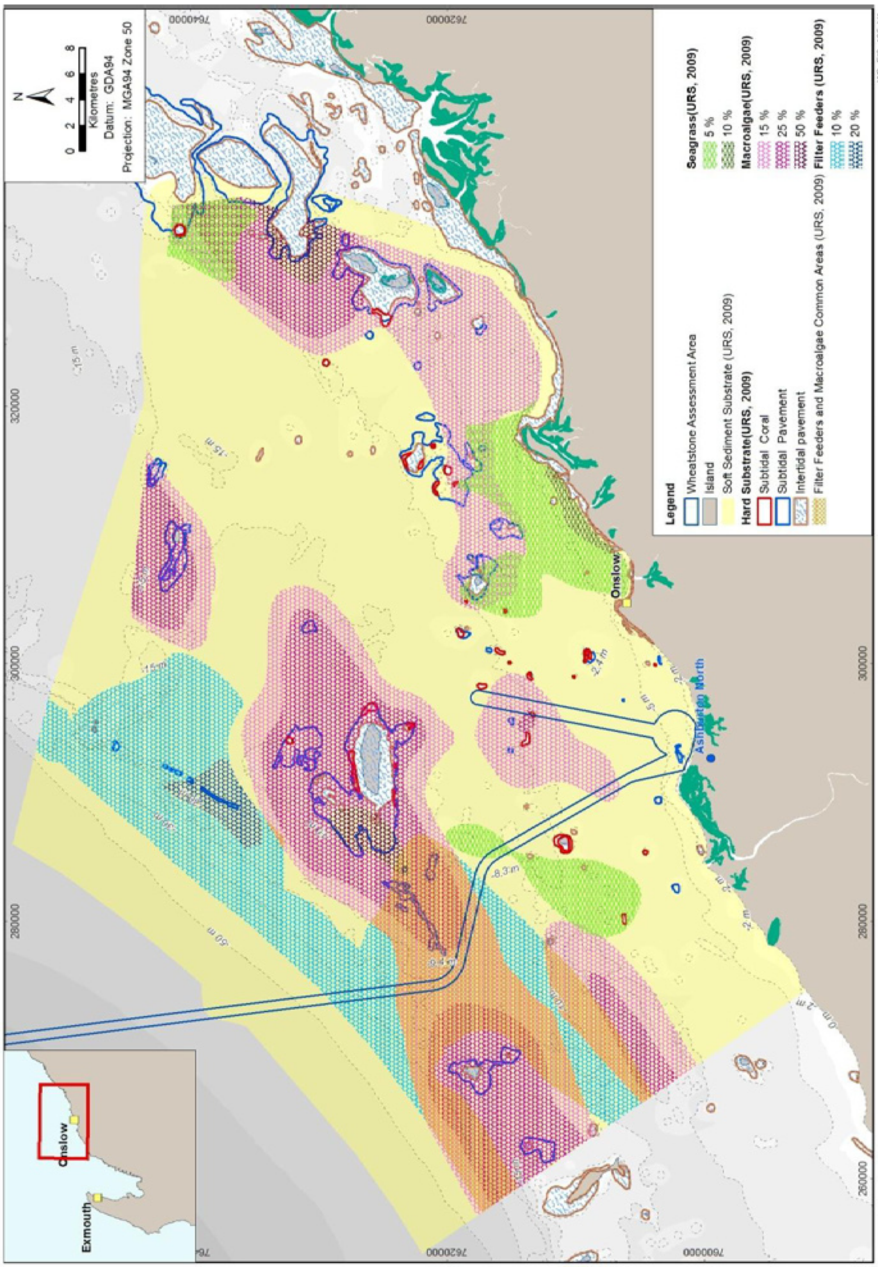

Figure 2.1 Habitat map showing locations of corals, seagrass, macroalgae and filter feeders in the Project area (Source: URS)

SG5240-06/Chevron Wheatstone Tolerance Limits/Final/mjj/07-10

2.2 Background Conditions

DHI's extensive dredge monitoring experience in south east Asia has found that there is a "step-change" in tolerance to suspended sediments and sedimentation between corals from "turbid" environments (which usually comprise species that are more tolerant to elevated total suspended solids (TSS) and sedimentation) and "clear water" environments (which typically comprise species that are less tolerant to elevated TSS and sedimentation). A reliable indicator for this step-change seems to be whether the background TSS concentrations routinely exceed 10 mg/l (DHI unpublished reports). Therefore it is important to understand the background conditions at the Project area in order to determine the appropriate tolerance limits for sensitive receptors at the site.

While available background data are limited at this stage, Chevron plans to continue collecting background data up until works commence. These data will then be used to review and update the tolerance limits (if required) and develop management triggers.

2.2.1 Background Water Quality

MScience (2009a) have undertaken a review of the background water quality conditions of the Project area, using a combined approach of field measurements and remote sensing using four years of MODIS optical satellite images provided by DHI. The conclusions of the study were that the Project area routinely experiences relatively low turbidity, with median turbidity at both nearshore and offshore survey locations ranging from 1–3 Nephelometric Turbidity Units (NTU) and TSS ranging from 2–5 mg/l.

However, the area experiences occasional cyclones and heavy rainfall events during the summer period, which results in elevated turbidity for a number of weeks. Based on turbidity measurements collected by a turbidity sensor deployed in the Project area during Cyclone Dominic in late January 2009, the median turbidity during the 24 hour period when the cyclone passed over was 77 NTU, with the 80th percentile exceeding 143 NTU. Turbidity in the project area remained in excess of 20 NTU for more than ten days after the passage of the cyclone due to strong discharges from the nearby Ashburton River.

Even discounting the periodic effects of cyclones, the median turbidity in the nearshore area (within the 5 m isobath) is generally elevated and more variable during both summer and winter periods, averaging 7–8 NTU, due to strong winds and wave action causing re-suspension in these shallow nearshore areas. Examples of processed MODIS images showing background TSS from summer, transitional and winter periods are shown in Figure 2.2.

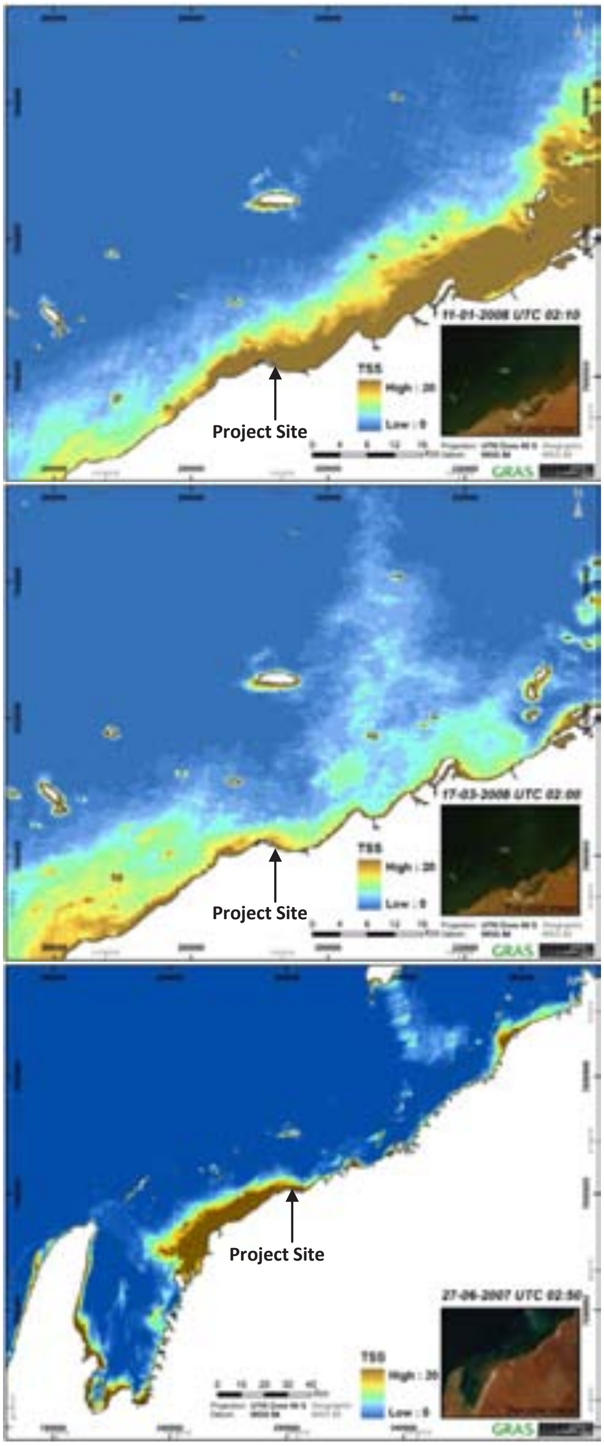

Figure 2.2 *Comparison of background TSS (mg/l) in the study area during summer (top; 11 Jan 2008) during the calm transitional period (middle; 17 March 2008) and during winter (bottom; 27 June 2007), derived from MODIS satellite imagery (Source: GRAS)*

2.2.2 *Background Sedimentation*

MScience (2009a) have also undertaken a review of background sedimentation levels, using field data collected for this Project in combination with data obtained from another project overlapping the Project area. The data were collected from January to June 2009, and therefore represent both summer and winter periods. The sedimentation rates were generally highest during summer (January-March), averaging 10 mg/cm^2/day, compared to 0.7 mg/cm^2/day during March-April, and 1.7 mg/cm^2/day during April-June.

This seasonal pattern is contrary to DHI's expectations, as the stronger wind and wave conditions during the summer period would be expected to result in less net sedimentation (due to higher re-suspension) compared to the winter period. However, the high sedimentation rates recorded during summer across both the nearshore and offshore sites can possibly be explained by Cyclone Dominic, which crossed the coast near Onslow in late January 2009, and generated elevated suspended sediments across the entire Project area for several weeks. Because sediment traps hinder re-suspension, the measurements appear to more closely reflect the high gross sedimentation experienced following the cyclone, rather than the net sedimentation experienced in the reef and seagrass areas, which would be subject to regular periods of extensive re-+suspension during summer. However, DHI notes that overall, the sedimentation conditions can be characterised as highly variable during the summer period.

The spatial distribution was more in line with DHI's expectations, with higher rates of sedimentation (11-21 mg/cm^2/day) recorded in the nearshore areas compared to the offshore areas during both the summer and winter periods. In the nearshore area, the highest sedimentation rate (21 mg/cm^2/day) was recorded during the winter period, which is in line with DHI's understanding of the current and wave conditions during this period.

So, overall the area can be categorised as a generally "clear water" environment, but the corals and seagrass present in the Project area are exposed to periodic elevated turbidity levels, lasting for several weeks, due to occasional cyclones and storm events, and the nearshore areas experience elevated and variable turbidity and sedimentation during the summer months due to wave re-suspension. DHI has taken these background conditions into account in recommending the tolerance limits in Section 5 to Section 9 for the various sensitive receptors. A conservative set of tolerance limits, suitable for "clear water" conditions, is recommended for most of the Project area. However, a less conservative set of tolerance limits has been recommended for the nearshore area (within the 5 m isobaths) during summer, in keeping with the elevated and variable background turbidity and sedimentation experienced in the shallow nearshore areas during summer.

DHI's approach to setting the tolerance limits is described in Section 4.

3 CLASSIFICATION OF IMPACTS

3.1.1 Dredging, Reclamation and Offshore Disposal Related Impacts

The main sources of impact to the receptors described in Section 2.1 in relation to dredging, reclamation and offshore disposal are suspended sediments and sedimentation.

Suspended sediments result in increased turbidity (which is a decrease in water transparency due to the presence of suspended and some dissolved substances, which causes incident light to be scattered, reflected and attenuated rather than transmitted), reduced light penetration and may also cause physical abrasion to soft tissue and interference with filter feeding mechanisms (Philipp and Fabricius 2003, Erftemeijer and Lewis 2006, Erftemeijer and Riegl 2009). Sedimentation results in reduced light via direct shading, increased energy expenditure for those species that actively shed sediment (e.g. through mucous production, ciliary action, etc.) and can interfere with prey capture and/or filter feeding mechanisms, smother benthic fauna, create anoxic conditions near the seabed, and reduce larval recruitment (Fabricius and Wolanksi 2000, Erftemeijer and Lewis 2006, Erftemeijer and Riegl 2009).

Turbidity and light availability (the amount of photosynthetically active radiation (PAR) reaching marine photosynethetic organisms) in the marine environment are measured and expressed in a number of different ways. Common measures include: NTU, Secchi disc readings (m) and water column light attenuation coefficients (K_d or E). Light availability is generally measured directly as PAR (in µmol photons/m^2/day) or expressed as relative measure, for example, minimum light requirement (in % of surface irradiance). Sedimentation is typically measured either as a mass per unit area per time (e.g. kg/m^2/day or mg/cm^2/day) or as a layer thickness per unit time (e.g. mm/14 days), which is an easier unit to visualise.

Traditionally, suspended sediment concentrations (SSC) are based on TSS measurements via collection of water samples, which are then filtered in the laboratory or in the field, to determine the total mass of suspended particulate matter in a given volume of sample. However, it is important to note that SSC is a sub-set of TSS, which also comprises a variable amount of suspended organic matter (e.g. plankton, detritus, etc.).

Turbidity is measured using a nephelometer, which uses an optical backscatter sensor to measure light reflection from the suspended particles. Nephelometers allow results to be obtained *in situ* over a long period of time, and if they are linked via a modem to an online data acquisition programme, then near real time results can be obtained. However, there are considerable limitations to the reliability of results, with frequent calibration required using suspended sediment samples from the area being measured. Fouling is also a common problem with nephelometers, and they require regular maintenance (typically once every two weeks in tropical environments) to minimise the impact of fouling on the data.

Due to recent technological advances, long term *in situ* monitoring of suspended sediments using either laser (e.g. a LISST) or acoustic backscatter (i.e. using an acoustic doppler current profiler (ADCP)) measurements is also possible. While still in their early stages, indications are promising that with further development these approaches may gain widespread acceptance. DHI has used acoustic backscatter measurements extensively in Singapore to monitor SSC, and found very reliable results, providing sufficient calibration samples covering an adequate range of depths are collected.

Turbidity is commonly used as a proxy for either TSS (and/or SSC) or light attenuation, although such comparisons are subject to uncertainty relating to, amongst other factors, particle size distribution and colour, and water depth. Turbidity measurements therefore require calibration against site specific samples collected and analysed for TSS or site specific light attenuation measurements. Light attenuation can also be measured directly. Light measurements are required both at the surface and at varying depths down to the seabed for effective data capture, which makes such monitoring more complex than measurements of turbidity.

Sedimentation is traditionally measured using sediment traps, which are vertical tubes installed near the seabed that capture particles depositing on the seabed. Due to the enclosed nature of the tubes, they provide a conservative maximum measurement of sedimentation, as they do not take account of the re-suspension of settled particles that generally occurs during stronger current or wave conditions. There are various designs for sediment traps, but the most commonly used design comprises a cluster of three tubes, based on the recommended design by English *et al.* (1997), as shown in Figure 3.1. A plastic mesh is used to cover the entrance of the traps, in order to reduce the incidence of marine fauna taking up residence in the tubes, and anti-fouling paint is used to reduce fouling, as both of these issues can interfere with the effectiveness of the traps at measuring sedimentation.

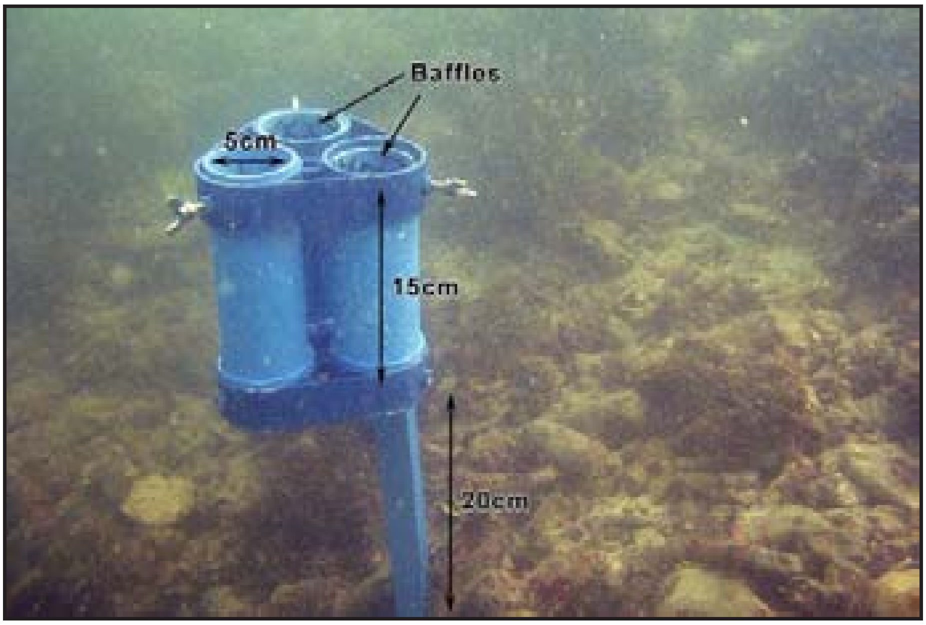

Figure 3.1 Sediment trap design

3.1.2 Classification of Impacts

The classification of impacts will broadly follow the recommended approach of the WA Department of Environment and Conservation's (DEC) Marine Ecosystems Branch (MEB), which uses four categories of classification (Rob Tregonning, pers. comm. 24/08/09):

1. **A Zone of Permanent Loss (or Significant Impact)** – an area within which key receptors (Benthic Primary Producers (BPP) or some other species of concern) are predicted to suffer mortality. This is the area in which mortality and loss of structural function is predicted to occur. This zone should encapsulate the area where "lethal" impacts are predicted. Mortality may occur within the area but it doesn't necessarily indicate that the entire area will experience mortality. The boarder needs to be drawn so that no mortality should occur immediately outside of this zone.

2. **A Zone of Temporary Loss/Damage** – This area, outside the Zone of Permanent Loss, is the area within which sub-lethal impacts on key receptors are predicted (for example for seagrass this may be a reduction in shoot density or some other metric that describes a decline in seagrass health).

3. **A Zone of Influence** – Outside the outer boundary of the Zone of Temporary Loss/Damage there may be influence from the dredge plume at low levels (for example turbidity may be visible or very light sedimentation may occur) but this is predicted to be unlikely to have any material/or measurable impact on the key receptors.

4. Finally, beyond the outer boundary of the Zone of Influence, there will be an unbounded area where there is no detectable influence from the dredging. This area would be suitable for locating a reference site.

It should be noted that the MEBs definition of "permanent loss" comprises both "loss" and "serious damage" as defined in the Environmental Assessment Guideline No. 3 (Environmental Protection Authority (EPA 2009)). "Loss" is defined as direct removal or destruction of Benthic Primary Producer Habitat (BPPH), which is considered to be irreversible, with BPPH not predicted to recover to the pre-impact state. "Serious damage" is defined as damage to BPPH that is effectively irreversible or where recovery, if that can be reasonably predicted at all, would not occur for at least five years.

Based on the information provided by MEB, DHI recommends the following four impact categories shown in Table 3.1. The categories are similar to the MEB categories, except that MEB's "Zone of Permanent Loss" has been subdivided into two zones; reflecting an area of total (or almost total) mortality, which will be confined to a relatively small area within and close to the work area; and an area of partial mortality, which is a larger area where partial mortalities (< 50% of BPP) are expected to occur. Beyond the zone of partial mortality, no mortalities are predicted. The Zone of Temporary Loss/Damage and Zone of Influence have been combined, due to the difficulty in monitoring and detecting "temporary" loss in terms of sub-lethal impacts. This combined zone is referred to as the Zone of Influence, which is consistent with previous dredging EIAs in WA.

Table 3.1 DHI's recommended impact classification categories

Zone	Definitions
Zone of Total Mortality	An area within which key receptors (BPP or some other species of concern) are predicted to suffer total or substantial (more than 50%) mortality, and where loss of structural function is predicted to occur.
Zone of Partial Mortality	An area within which key receptors (BPP or some other species of concern) are predicted to suffer partial mortality (up to 50% loss). Mortality will occur within the area, but will not include all individuals. The outer border will be drawn so that no mortality will be predicted to occur immediately outside of this zone.
Zone of Influence	Outside the outer boundary of the Zone of Partial Mortality there may be influence from the dredge plume at low levels (for example sub-lethal impacts on key receptors, turbidity may be visible or very light sedimentation may occur), but this is predicted to be unlikely to have any material and/or measurable impact on the key receptors.
No Impact	Beyond the outer boundary of the Zone of Influence, there will be an unbounded area where there is no detectable influence from the dredging. This area would be suitable for locating a reference site.

However, it should be pointed that further sub-division of the Zone of Total Mortality is possible, in order to distinguish between areas of permanent habitat loss (e.g. by burial or removal), and areas where BPP total mortality will occur, but the habitat (in terms of the substrate) will remain, so that recolonisation is expected in the longer term. The area of permanent loss is expected to be confined to the marine footprint of the Project (i.e. the navigation channel, the Materials Offloading Facility and Product Loading Facility basins, and the pipeline route), which has been optimised to avoid key marine receptors where possible. The distinction therefore has not been made in DHI's impact categories between these two types of BPPH impact, though it is discussed in more detail in the Dredge Plume Impact Assessment Report (DHI 2010) and the BPPH Loss Assessment (URS 2010).

4 DHI'S APPROACH TO DETERMINING TOLERANCE LIMITS

4.1 Review of Previous Practice in Australia

4.1.1 Overview

The traditional approach to setting management limits for dredging projects in Australia has been to focus on setting trigger levels for parameters that are readily measured in the field, notably turbidity and sedimentation, although light attenuation has also been used. Determining these trigger levels has been undertaken in various ways, traditionally based on literature values, and more recently based on site-specific natural variability (McArthur *et al.* 2002). This has generally been coupled with the use of numerical models to predict SSC and sedimentation due to dredging, in order to predict the level of impact to sensitive receptors (usually corals or seagrass) at various distances from the dredging works. The predicted level of impact is then documented in an EIA report (the terminology and required level of impact assessment varies from state to state and from project to project).

Once the EIA document is reviewed and accepted, an acceptable level of impact is then set by the regulator (e.g. 100% mortality in a certain zone close to the dredging works, with an overall loss in the management area of less than 10% [for example]). Monitoring is then undertaken during and following the dredging works to demonstrate compliance (or otherwise) with the acceptable level of impact set by the regulator. This monitoring typically comprises nephelometers to measure turbidity, light meters to measure light attenuation, sediment traps to measure sedimentation, and biological surveys to document the level of coral or seagrass mortality in the study area. Water quality trigger levels for monitoring (particularly TSS or turbidity limits) are often set based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000), which outlines an approach for developing local trigger levels based on long term (typically 12-24 months) of monitoring data.

Due to the significant degree of uncertainty at the EIA stage, in terms of the site specific tolerances of key receptors (e.g. corals, seagrass, etc.), the physical properties of the dredged material (e.g. sediment particle size distribution, settling velocity, dispersion coefficient, etc.) and the details of the dredging programme (type and capacity of dredgers, daily production rate, timing and duration of dredging, disposal methods, etc.) there has usually been a tendency to take an overly precautionary or conservative approach when setting trigger levels, often resulting in frequent work stoppages, and longer and more costly dredging programmes than may actually be required. Conversely, there have also been instances where trigger levels have been underestimated, resulting in large scale impacts that have halted dredging for many months, once again leading to longer and more costly dredging programmes.

4.2 Examples of Tolerance Limits from Previous Australian Projects

There has been a number of large scale dredging projects undertaken in tropical Australian waters in recent years, particularly in WA. The tolerance limits used for the EIAs of these projects are summarised in Table 4.1.

Table 4.1 Summary of TSS and sedimentation threshold limits used in previous Australian projects

Project	Tolerance Limits	Comments

Gorgon, Chevron Texaco, 2005	The following are the trigger values for cumulative suspended sediment concentrations:
	
	Zone of High Impact:
	• **TSS**
	  ○ ≥ 25 mg/L for 5 in 15 days OR
	  ○ ≥ 10 mg/L for 20 in 60 days OR
	  ○ ≥ 5 mg/L for 80 in 240 days
	• **Sedimentation**
	  ○ ≥ 100 mg/cm^2/day for 1 day
	  ○ ≥ 25 mg/cm^2/day for 5 in 15 days
	  ○ ≥ 10 mg/cm^2/day for 20 in 60 days
	  ○ ≥ 5 mg/cm^2/day for 40 in 120 days
	
	Zone of Moderate Impact:
	• **TSS**
	  ○ ≥ 25 mg/L for 2 in 6 days OR
	  ○ ≥ 10 mg/L for 7 in 21 days OR
	  ○ ≥ 5 mg/L for 20 in 60 days
	• **Sedimentation**
	  ○ ≥ 50 mg/cm^2/day for 1 day
	  ○ ≥ 25 mg/cm^2/day for 2 in 6 days
	  ○ ≥ 10 mg/cm^2/day for 7 in 21 days
	  ○ ≥ 5 mg/cm^2/day for 20 in 60 days
	
	Zone of Visibility:
	• **TSS**
	  ○ ≥ 2 mg/L for 1 day or more
	• **Sedimentation**
	  ○ ≥ 1 mg/cm^2/day for 1 day or more
		Assessed based on total SSC and duration of disturbance.
		
		Based on published data and tolerance limits.

Hay Point Queensland, 2006	**Spring Phase Turbidity Tolerance** • < 20 NTU for the duration of the tidal phase • 20-60 NTU for 6 hours followed by one tidal cycle exchange, in continuous repetition for 3 to 11 days • > 60 NTU for 2 hours **Neap Phase Turbidity Tolerance** • < 11 to < 18 NTU for the duration of the tidal phase • 11 to 60 NTU for 6 hours followed by one tidal cycle exchange, in continuous repetition for 3 to 11 days • > 60 NTU for 2 hours	Assessed based on turbidity (in NTU) measured during a specific time within the tidal cycle. Based on McArthur *et al.* 2002 approach. No division of impact severity. No sedimentation limits developed.

<table>
<tr><th>Project</th><th>Tolerance Limits</th><th>Comments</th></tr>
<tr><td>Pluto, Woodside, 2007</td><td>

Allowable frequency of events exceeding the suspended solid concentration (mg/L) trigger for each specified duration per month:

<table>
<tr><td></td><td>1 hour</td><td>2 hours</td><td>3 hours</td><td>4 hours</td><td>5 hours</td><td>6 hours</td><td>Trigger Level</td></tr>
<tr><td>**Inner Zone**</td><td>16</td><td>8</td><td>5</td><td>2</td><td>1</td><td>0</td><td>35</td></tr>
<tr><td>**Middle Zone**</td><td>10</td><td>2</td><td>1</td><td>1</td><td>1</td><td>0</td><td>10</td></tr>
<tr><td>**Outer Zone**</td><td>4</td><td>2</td><td>2</td><td>1</td><td>1</td><td>0</td><td>10</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Threshold Sedimentation Rates ($mg/cm^2/day$):

<table>
<tr><td></td><td>Medium Term (5 in 15 days)</td><td>Chronic (15 in 30 days)</td></tr>
<tr><td>**Inner Zone**</td><td>60</td><td>36</td></tr>
<tr><td>**Middle-Outer Zone**</td><td>12</td><td>9</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

</td><td>Based on McArthur *et al.* 2002 approach.

Targets set for TSS and sedimentation.</td></tr>
<tr><td>Cape Lambert Dredging, 2007</td><td>

The following are the TSS and sedimentation threshold concentrations for various zones of impact/influence:

Zone of High Impact:
- **TSS**
  - ≥ 19 mg/L for 14 in 21 days
- **Sedimentation**
  - ≥ 300 $mg/cm^2/day$ for 14 in 21 days

Zone of Moderate Impact:
- **TSS**
  - ≥ 11 mg/L for 14 in 21 days
- **Sedimentation**
  - 7–300 $mg/cm^2/day$ for 1 day

Zone of Visibility:
- **TSS**
  - ≥ 2 mg/L for 1 day or more
- **Sedimentation**
  - ≥ 7 $mg/cm^2/day$ for 1 day or more

</td><td>Based on McArthur *et al.* 2002 approach.

Based on at least 6 hours of exposure during daylight hours.</td></tr>
</table>

From this table, it is clear that TSS and sedimentation are the most common parameters used to assess environmental impact of dredging programmes in Australia, though turbidity has also been used. The tolerance limits (also referred to as trigger levels or threshold limits) set for these previous projects are all relatively similar in magnitude, although the allowable duration and frequency of events tends to vary from project to project. They are also similar in magnitude to the limits proposed by DHI for corals for the Project (Section 5). DHI was not able to find any previous TSS or sedimentation limits set for seagrass for WA projects.

4.2.1 Limitations of Using Ambient Water Quality Data to Set Tolerance Limits

There has been a tendency for the more recent WA projects to set TSS limits for dredging based on the approach recommended by McArthur *et al.* (2002), which proposes the development of TSS or turbidity threshold limits based on naturally occurring levels at the project site. The McArthur *et al.* (2002) approach can be summarised as follows:

- Review long-term (at least one year) good quality measurements of TSS or turbidity from the project location.
- Analyse long-term data to determine seasonality (if any) and identify critical seasons.
- Set the 95th percentile value for each season as a threshold concentration, and set the 99th percentile as the highest allowable value.
- Duration of events that exceed the threshold concentration should not exceed the 95th percentile event duration.
- Combined frequency of natural and dredging-related events exceeding the threshold concentration should not be significantly greater than would normally occur (upper 95th percent confidence interval).

The key assumption for this approach is that the coral (and presumably seagrass) communities in the study area in question are adapted to the naturally occurring levels of TSS or turbidity (including low frequency, high concentration events due to storms etc.), and so long as the dredging-related suspended sediments do not result in dose-duration events that significantly exceed the intensity, duration or frequency that the communities are accustomed to, then the dredging programme should not cause any additional stress to the communities. It is essentially a methodology for establishing the natural "no change" limit for specific locations.

This approach is also broadly similar to the ANZECC/ARMCANZ (2000) approach for setting water quality trigger levels, which is also based on the review of a long-term dataset (typically 12-24 months) from a suitable reference site. However, ANZECC/ARMCANZ (2000) uses the 80th percentile of the long-term dataset as the trigger level. This method has been developed for setting a trigger level for water quality monitoring, with comparison of the median value at the monitoring location(s) compared against the 80th percentile value from the reference location(s). However, it can also be adapted to set a trigger level for dredging impact assessment by comparing the 80th percentile of the baseline TSS or turbidity monitoring data at a given location against the median of the concentrations predicted during dredging by numerical modelling for that location.

One of the limitations of both the McArthur *et al.* (2002) approach and the ANZECC/ARMCANZ (2000) approach is that they require a significant duration (at least one year) of good quality data from a range of receptor sites in the study area. Even then, they will still be sensitive to inter-annual variability. Whether the year (or years) of data used for the analysis are "representative", or whether they are higher or lower than a notional long-term "average" year, will have a significant bearing on the thresholds, durations and frequencies that are determined. Whether the dredging programme is carried out in a "representative", "high" or "low" year will also have a significant bearing on how easy or difficult it is for the dredging contractor to comply with the limits.

It is also difficult to apply the these approaches to impact assessment, which is usually based on numerical sediment plume modelling. To the best of DHI's knowledge, no numerical sediment plume modelling studies carried out as part of EIAs of dredging projects to date have included natural variability of background TSS in the models. This is because it is difficult to accurately model background TSS, which is controlled by a large number of variables (e.g. terrestrial runoff, deposition and re-settlement rates, met-ocean conditions, seabed sediment characteristics, bathymetry and shoreline topography), requiring a comprehensive long-term dataset that is usually not available at the EIA stage of a project.

Numerical sediment plume models therefore simulate "excess" SSC, which is the segregated SSC generated by the dredging, reclamation or offshore disposal activities that are being assessed, and which does not include background TSS. In order to assess the model results against the threshold intensity, duration and frequency limits developed under the McArthur *et al.* (2002) approach or the ANZECC/ARMCANZ (2000) approach, an assumption about the baseline TSS must be made (because the "total" TSS will be the "excess" SSC predicted by the model plus whatever background TSS has been assumed). This introduces a significant potential source of variability in the impact assessment, depending on what background conditions are chosen for the assessment.

Another significant limitation when applying the approach for WA projects is that the WA regulator requires that zones of impact be established as part of the impact assessment, so that predictions of the area of BPPH loss can be established. While the McArthur *et al.* (2002) approach or the ANZECC/ARMCANZ (2000) approach appear to provide a robust methodology for determining the "No Impact" limit, they cannot be used to determine zones of influence or mortality. These require field and/or laboratory measurements that correlate different levels of impact (e.g. sub-lethal, partial and total mortality) with the intensity and duration of events. Such measurements can only be obtained from the literature, from field experiments, or from monitoring during the course of a dredging project. However, there is seldom time to conduct detailed field experiments at a project location as part of the EIA stage, and obtaining permission from decision making authorities for field experiments to kill corals would most likely be challenging (and may require its own impact assessment).

This therefore leaves literature values and monitoring from previous dredging projects as the most practical basis for determining the zones of impact. However, most monitoring data from dredging projects are not published or publicly available, and almost all (if they are being managed correctly) do not result in partial or total mortalities that can be correlated with measured water quality or sedimentation levels. An additional challenge in WA is that, due to the sheer length of coastline, new dredging projects may not be undertaken in close proximity to previous dredging projects. This is certainly the case for the Wheatstone Project. The only dredging project undertaken within 100 kilometres of the Project area was the Onslow Salt approach channel, which was dredged more than ten years ago.

DHI therefore recommends basing the Wheatstone Project tolerance limits on a combination of literature values and DHI's previous detailed monitoring experience of dredging and reclamation projects in south east Asia. While the use of data from outside of Australia may seem inappropriate in the first instance, the biogeographic distribution of most coral and seagrass species extends from tropical Australia and throughout south east Asia, and DHI's extensive experience of monitoring corals and seagrass for major long-term dredging and reclamation projects in the region provide a significant enhancement to the available literature values. Based on available data so far, background turbidity levels and sediment properties at the Project area are also comparable to projects in Malaysia, Indonesia and Singapore for which DHI has undertaken extensive monitoring for dredging and reclamation activities.

DHI's recommended approach to developing the tolerance limits for the Project is explained in detail in the next section.

4.3 DHI's Recommended Approach

As discussed above, the McArthur *et al.* (2002) approach or the ANZECC/ARMCANZ (2000) approach do not provide a robust methodology for determining the levels of partial or total mortality. DHI has therefore developed tolerance limits for the key sensitive receptors in the Project area based on available literature and DHI's extensive experience of monitoring dredging and reclamation projects in tropical waters near sensitive receptors. The benefits of this approach are:

- Limits for multiple zones of influence/impact (as required by the WA regulator) can be set in a robust manner, based on literature and previous monitoring experience.
- Methodology is not reliant on having a long-term high quality dataset of water quality measurements from multiple sensitive receptors in the Project area.
- Tolerance limits are initially set using a conservative approach, and then updated and fine-tuned based on ongoing monitoring in the lead up to and during the course of the dredging/reclamation programme.
- Methodology has been specifically developed and optimised for use with numerical sediment plume models, with tolerance limits set for the "excess" SSC generated by the dredging programme, so that no assumptions about the background TSS are required in order to assess the impacts.
- Background TSS and sedimentation conditions are taken into account in setting the tolerance limits by using literature and previous monitoring results from areas with similar background TSS and sedimentation levels.

Chevron will continue to collect baseline water quality data throughout the EIA/ERMP process and in the period leading up to the start of dredging. DHI recommends reviewing these data and using them to update the proposed tolerance limits (if necessary) in the lead up to the start of works.

4.3.1 Setting Preliminary Tolerance Limits

It is DHI's experience, after conducting EIAs and implementing environmental monitoring and management programmes for many large scale dredging and reclamation projects, both in Europe and throughout south east Asia (see Appendix B for case studies), that while it is important to take a conservative approach to setting tolerance limits at the EIA stage, it is important that the values chosen are still realistic, and based on practical experience as well as literature and site-specific data (where possible). It is also DHI's experience that the EIA should be focussed on providing the decision making authorities with sufficient information to determine the acceptable level of environmental impact. However, commitments to specific trigger levels and tolerance limits are not practical at the EIA stage, and should be deferred and included in the final environmental management plan for the Project, which is prepared in the months leading up to the start of works, when sufficient long-term baseline measurements and survey data are available. However, details should be included in the EIA regarding the methodology that will be used to determine the trigger levels and tolerance limits.

DHI's experience from feedback monitoring projects (DHI 1997, Doorne-Groen 2007, Driscoll *et al.* 1997) indicates that tolerance limits are complex, and cannot be described by a single threshold criterion. DHI's recommended tolerance limits are based on a combination of intensity and duration/frequency of impact, and follow the generally accepted principle (e.g. Gilmour *et al.* 2006) that corals and other marine receptors can tolerate a small intensity impact for a relatively long duration/high frequency, or a large intensity impact for a relatively small duration/low frequency, before impacts result in reduced health or mortality. The background conditions (in particular the "average" background and seasonal variability) are also taken into account when setting the preliminary tolerance limits. As described in the subsequent sections of this document, tolerance to various sources of impact can vary considerably depending on the species and life form of the receptor. A conservative approach is therefore taken in determining the tolerance limits, in order to ensure that even the most sensitive receptors are protected.

The tolerance limits recommended in Section 5 to Section 9 have been developed for assessment of sediment plume impacts from dredging, reclamation and/or offshore disposal based on short-term scenario modelling. The typical duration of short-term scenario modelling for EIAs that DHI has previously been involved in generally covers one or two 14-day spring-neap tidal cycles. In this case, a one month period (i.e. two spring-neap cycles) has been modelled for each scenario, with the impact assessment carried out on the last 14 days of the simulation (i.e. one spring-neap tidal period). It should be recognized that DHI is not predicting that the levels of impact will necessarily occur within a 14-day period (though in the case of extremely high levels of impact, they most likely will), but if operations continue at the same rate for an extended period (over several months), then these levels of impact are predicted to occur. This short-term scenario-based approach allows DHI to test a broad range of seasonal, climatic and operational conditions in a time-effective fashion, in order to develop conservative impacts zones which are based on an "envelope" of impact zones from the individual scenarios. These impact zones then encompass possible changes to schedule, etc. which are likely to occur during the course of the Project.

The approach is inherently conservative, which is appropriate at the EIA stage, given the broad range of uncertainties associated with dredging projects during these early planning stages. In addition to the "envelope" approach of determining the impact zones, the source of the impact (dredging, reclamation and/or offshore disposal) is assumed to be operating consistently throughout the simulation period (i.e. no allowance is made for planned or un-planned work stoppages, which would allow the receptors time to partially recover from the impact). While an argument can be made that tolerance limits for light-dependent receptors (e.g. corals and seagrass) should only apply during daylight hours, it is DHI's general practice to apply the tolerance limits consistently across the diurnal cycle, as the physical impacts of suspended sediments and sedimentation (e.g. abrasion of soft tissues, clogging of filter feeding apparatus, smothering, etc.) will still occur regardless of the time of day (and may actually be higher at night, particularly for corals which commonly extend their polyps to feed at night).

Overall, DHI characterises the short-term scenario-based approach as "realistically conservative", providing a level of conservatism appropriate to the level of uncertainty at this stage of the Project. Key conservative features built into the tolerance limits include:

- Basing the limits on the most sensitive coral and seagrass species recorded to be present in the Project area (e.g. *Acropora* sp., *Montipora* sp., *Halophila* sp., etc.).
- Basing the limits on the accumulated exposure during both daytime and nighttime over the full simulation period, rather than excluding night time exposure or requiring exposure to last for a specific duration (e.g. six hours) before it is included.
- Setting the limits at a level that is comparable to or lower than limits previously used in the Pilbara region (or by DHI in south east Asia), which have a proven track record of providing effective protection for sensitive receptors.

As the Project progresses, and particularly once dredging commences, much of this uncertainty is removed as decisions on equipment type and size, production rates and the timing of the works are made and implemented. Ongoing monitoring provides a much clearer long-term picture of the background conditions and site specific responses of the receptors to the works. Throughout this period, the inherent conservatism in the approach is reduced, as assumptions are verified or amended. Tolerance limits and management triggers or thresholds should therefore be reviewed and revised periodically in the lead up to and throughout the dredging/reclamation Project, based on the latest available information and data, as outlined below.

4.3.2 Updating Tolerance Limits and Trigger Levels Based on Monitoring

Best environmental outcomes are derived from taking an iterative approach to setting trigger levels and tolerance limits, using conservative but realistic tolerance limits during the EIA stage, and then using site-specific monitoring data in the lead up to and during the course of the dredging works to fine tune and confirm the appropriate values. The key to the process is to ensure that monitoring covers the sources (i.e. the dredger or reclamation discharge) as well as the receptors, in order to enable understanding of the linkages between receptor responses and the dredging/reclamation activities.

These linkages should then be used to periodically review and update the tolerance limits, based on the monitoring results. In this way the tolerance limits and trigger levels are fine tuned, based on the site specific responses and conditions, throughout the duration of the works, and the end goal of not exceeding the maximum acceptable level of impact specified by the decision making authorities, is always firmly in sight. Some case studies of the application of this "feedback" approach are provided in Appendix B.

5 CORALS

5.1 Coral Tolerance to Suspended Sediments

Hard or hermatypic corals (Scleractinia) host unicellular photosynthesising algae, known as zooxanthellae, within their tissue. The photosynthetic activity of the zooxanthellae results in translocation of carbohydrates, which represents a major energy source for the coral host (Muscatine 1990). In turn, corals supply their zooxanthellae with essential nutrients, such as nitrogen and phosphorus (Muscatine 1990). Autotrophic carbon translocation is highly sensitive to light reduction and the quantity and type of deposited materials as a result of increased levels of suspended materials (Philipp and Fabricius 2003, Weber *et al.* 2006).

There is a growing body of evidence from field studies showing that turbidity and sedimentation can degrade coral reefs at local scales (e.g. Anthony and Connolly 2004, Babcock and Smith 2002, Cooper *et al.* 2007, Fabricius 2005, Fabricius *et al.* 2007, Gilmour *et al.* 2006). This was quantified by Hawker and Connell (1992) who found that a 30% increase in average long-term background suspended sediments levels resulted in a 20% reduction in annual growth rates of corals.

However, background turbidity levels vary temporally and at local and regional scales (Cooper *et al.* 2007, Cooper *et al.* 2008, Wolanski *et al.* 2008). In addition, turbidity is strongly influenced by local weather conditions such as wind, waves and tides (Cooper *et al.* 2008). While mean suspended sediment concentrations on coral reefs are typically <5 mg/1 (Pastorok and Bilyard 1985) they may exceed approximately 80 mg/l for 20–30 days per year due to wind re-suspension around some inshore reefs on the Great Barrier Reef (GBR) (Wolanski 1994, Wolanski *et al.* 2005). Hawker and Connell (1992) outlined that corals on the GBR have a tolerance to suspended sediments up to 4 mg/l. However, given the above levels of suspended sediments for inshore reefs on the GBR, such a limit may be considered suitable only for corals on offshore reefs. A wide range of tolerance limits of corals for suspended sediments are found in different geographic regions and tend to be species-specific. These values are presented in Table 5.1.

In the Pilbara region, levels of turbidity are highly variable and driven by local weather conditions (e.g. Forde 1985, Gilmour *et al.* 2006, Simpson 1988). Hence, natural variability in turbidity levels complicates any attempt to determine threshold values for anthropogenic elevated turbidity.

Acceptable levels of turbidity will depend on hydrodynamic conditions, sedimentation rates, and background turbidity and will therefore need to be adjusted to local conditions (Sofonia and Anthony 2008). Preliminary estimates of the tolerance to turbidity of coral in the Pilbara region made by Gilmour *et al.* (2006) are illustrated in Figure 5.1. Gilmour *et al.* (2006) caution that these estimates are based on the limited data presently available from the Pilbara and other regions, and need to be refined and corrected within future research.

Table 5.1 Critical threshold of different species of corals for TSS.

Species/ Types of corals	Location	TSS (mg/l)	Response	Reference
Faviids (e.g. Goniastrea retiformis)	Orpheus Island, GBR, Australia	41	Feeding saturation	Anthony and Fabricius (2000)
Acropora digitifera	Coral Bay, Ningaloo Reef, Australia	≥ 50	Reduced larval settlement and survival	Gilmour (1999)
Acropora millepora	Orpheus Island, GBR, Australia	> 30	Feeding saturation	Anthony and Fabricius (2000)
Acropora millepora	Davis Reef, GBR, Australia	≥ 100	Reduced fertilisation by 50%	Humphrey *et al.* (2008)
Monitpora verrucosa	Kaneohe Bay, Hawaii	8	Reduction of photosynthetic production by 28%	Te (1997)
Pocillopora damicornis	Guam	> 1,000	Reversed metamorphosis "polyps bail-out" by planulae	Te (1992)
Porites cylindrica	Orpheus Island, GBR, Australia	4 - 8	Feeding saturation	Anthony (1999)
Turbinaria mesenterina	GBR, Australia	~ 50	Feeding saturation	Anthony and Connolly (2004)

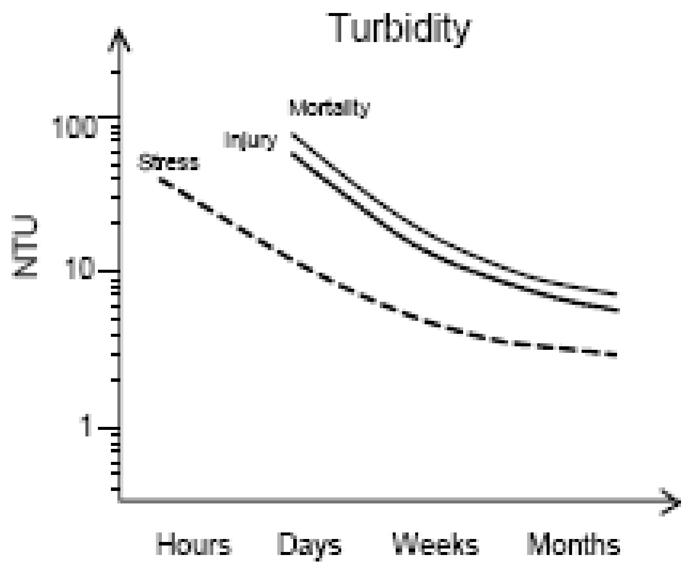

Figure 5.1 Preliminary estimates of the loads and durations of turbidity likely to cause increasing levels of impacts to corals. The curve applies to relatively 'tolerant' species of corals from inshore reefs within the Pilbara, and more susceptible species will have the same levels of impact at lesser loads and/or durations. (Source: Gilmour et al. 2006).

DHI's long-term experience from feedback monitoring projects (DHI 1997, Doorne-Groen 2007, Driscoll *et al*. 1997) indicates that the tolerance levels cannot be described by a single threshold criterion. Rates of primary production and respiration are both sensitive to turbidity, while water depth and the diurnal light cycle also play a critical role. Therefore, the only hard and fast method of establishing tolerance limits for coral is to carry out feedback monitoring, where monitoring of sediment spills is compared against habitat response, leading to tolerance limits updates during the course of the dredging or reclamation project.

Based on the literature presented in this section and in Appendix A, and DHI's previous experience in impact assessment and feedback monitoring of dredging related impacts to corals (Section 4 and Appendix B), DHI's proposed preliminary suspended sediment tolerance limits for corals are shown in Table 5.2 and Table 5.3. The limits for the nearshore area (within the 5 m isobath) during summer and winter have been raised to reflect the increased magnitude and variability of turbidity and suspended sediments experienced in the nearshore zone during these periods, due to rainfall events and frequent re-suspension from wave activity (Section 2.2.1).

Table 5.2 Preliminary matrix of impact zones for suspended sediment impact on corals for assessment of short-term scenario model results: for offshore waters (beyond 5m isobath), and for nearshore waters (within 5 m isobath) during transitional periods only

Zone*	Definitions
Zone of Total Mortality	• Excess SSC > 25 mg/l for more than 10% of the time OR • Excess SSC > 10 mg/l for more than 25% of the time
Zone of Partial Mortality	• Excess SSC > 25 mg/l for 2.5 – 10% of the time OR • Excess SSC > 10 mg/l for 10 – 25% of the time OR • Excess SSC > 5 mg/l for more than 25% of the time
Zone of Influence	• Excess SSC > 25 mg/l for 0.5 - 2.5% of the time OR • Excess SSC > 10 mg/l for 0.5 - 10% of the time OR • Excess SSC > 5 mg/l for 2.5 – 25% of the time
No Impact	• Excess SSC > 25 mg/l for less than 0.5% of the time OR • Excess SSC > 10 mg/l for less than 0.5% of the time OR • Excess SSC > 5 mg/l for less than 2.5% of the time

**Where location meets criteria for multiple zones, highest zone applies*

Table 5.3 Preliminary matrix of impact zones for suspended sediment impact on corals for assessment of short-term scenario model results: for nearshore waters (within 5 m isobath) during summer and winter only

Zone*	Definitions
Zone of Total Mortality	• Excess SSC > 25 mg/l for more than 20% of the time
Zone of Partial Mortality	• Excess SSC > 25 mg/l for 5 – 20% of the time OR • Excess SSC > 10 mg/l for more than 20% of the time OR • Excess SSC > 5 mg/l for more than 50% of the time
Zone of Influence	• Excess SSC > 25 mg/l for 1 - 5% of the time OR • Excess SSC > 10 mg/l for 1 - 20% of the time OR • Excess SSC > 5 mg/l for 5 - 50% of the time
No Impact	• Excess SSC > 25 mg/l for less than 1% of the time OR • Excess SSC > 10 mg/l for less than 1% of the time OR • Excess SSC > 5 mg/l for less than 5% of the time

**Where location meets criteria for multiple zones, highest zone applies*

The values in the tables are for "excess" (i.e. above background) concentrations of suspended sediments generated by the dredging, reclamation or offshore disposal activities, and are used to assess sediment plume model results from the 14-day scenario modelling period. Note that this does not mean that impacts would necessarily be realised within a 14-day period. Rather, if the impact continued at the same level for an extended period (several months), these are the predicted levels of impact. The limits have been developed based on the most sensitive coral species, in order to ensure that the levels of impact predicted are conservative.

Most dredging programmes extend for at least six months, and often for several years, but the durations of exceedence in the tables are not meant to be averaged across the entire period of the dredging programme. An SSC of 25 mg/l at a particular coral reef for 30 days in a row during a two year dredging programme would mean a 4% exceedence of 25 mg/l over the total duration of dredging, but 100% exceedence during a 14-day scenario modelling period. By applying the tolerance limits tables to the results of short-term scenario modelling for this component of the dredging programme, the impact to this particular coral reef would be assessed as Zone of Total Mortality (defined as 50–100% mortality).

The tolerance limits recommended by DHI in Table 5.2 and Table 5.3 are broadly comparable to previous limits adopted for dredging projects in WA (Table 4.1). All of the different projects listed in Table 4.1 take the intensity, duration and frequency of exposure into account, to one extent or another. The magnitude of the suspended sediment limits recommended by DHI are the same as those used for Gorgon (5, 10 and 25 mg/l), and similar to those used for Hay Point (11 to 60 NTU), Pluto (10 to 35 mg/l) and Cape Lambert (2 to 19 mg/l).

DHI's limits are also similar (though generally more conservative) in terms of the duration of exceedence. Under DHI's proposed limits, suspended sediment concentrations above 25 mg/l for more than 10% of the time are predicted to result in total mortality (defined as 50-100% mortality), compared to five in 15 days (33%) for Gorgon's Zone of High Impact. Cape Lambert has also taken a similar approach in terms of the duration of exceedence, with a Zone of High Impact resulting from concentrations above 19 mg/l for 14 out of 21 days (33%).

In terms of setting the triggers for the different levels of impact, Gorgon takes the approach of linking the increased severity of impact to increased duration of exposure (two out of six days is Moderate Impact, but five out 15 days is High Impact). Cape Lambert takes the opposite approach, linking impact severity to increasing concentration (≥ 11 mg/l for 14 in 21 days is Moderate Impact, but ≥ 19 mg/l for 14 in 21 days is High Impact). DHI's proposed limits combine both of these approaches, so that increases in duration and/or increases in concentration results in high levels of severity.

However, it is important to note some key differences in the way that DHI's limits have been applied, compared to the application of previous limits. The limits listed in Table 4.1 have all been applied to water quality measurements of TSS, whereas DHI's limits are for excess SSC (i.e. excluding background TSS). This is because these limits are intended for assessment of model outputs, and the models are predicting excess SSC. However, as the background TSS in the Project area generally range from 2–5 mg/l, particularly beyond the 5 m isobath, the magnitudes of the DHI's proposed tolerance limits are still similar to the trigger levels used by the previous projects. In the longer term, DHI's limits can also be directly applied to measurements of sediment spill from dredging activities (which are also excess SSC, and quite independent of background concentrations), and to the results of hindcast modelling of the actual dredging activities, which DHI is currently applying as a daily management tool for dredge management in Singapore.

DHI's proposed limits have been applied somewhat differently in the dredge plume impact assessment (DHI 2010), compared to the way the limits listed in Table 4.1 are used. The limits for the other projects are applied to assess exceedences on a daily, weekly or even monthly basis, with concentrations required to exceed the trigger levels for relatively long durations (at least six hours per day for Cape Lambert and Hay Point) before they are assessed as having an impact. In contrast, DHI's limits are determined based on the accumulated amount of time that the tolerance limits were exceeded at the end of a 14 day period. So even if the excess SSC at a given coral was above 25 mg/l for two hours every 12 hours (which is a fairly typical exposure pattern for Trailer Suction Hopper Dredgers (TSHD) for the duration of the simulation, as long as this pattern was consistent across the 14 day simulation period, this would be assessed as a 17% exceedence, and the coral would fall within the Zone of Total Mortality.

In practice, the pattern of exposure at a given coral area is unlikely to be so consistent, as diurnal and spring-neap tidal cycles will mean that exposure durations may be higher on some days and lower on others. But the accumulated exposure approach captures these short duration, high concentration events that are typical of TSHD activities in particular, as well as the more consistent exposures typical of Cutter Suction Dredger (CSD) activities, and ensures that the impact assessment is realistically conservative.

5.2 Coral Tolerance to Sedimentation

Sediment traps are commonly used to measure the deposition rate of particulate materials (referred to as sedimentation). They may be moored at particular locations of interest from where they are retrieved after an extended period of time (days–weeks) and analyses of contents can be performed.

Accumulation of sediments on corals is determined by the settling rate and physical characteristics of suspended sediments, the morphology of coral colonies and their ability to rid themselves of deposited particles, as well as the local hydrodynamic conditions. Horizontal foliose, plate-like or tabulate (e.g. *Montipora* and *Acropora*) and encrusting (e.g. *Montipora* and *Pavona*) growth forms present stable surfaces for retention of settling sediments. In contrast, vertical foliose (e.g. *Turbinaria* and *Pavona*) and upright branching growth forms (e.g. *Acropora*) are less likely to retain sediments. Digitate and massive colonies (e.g. *Porites* and *Favia*) typically exhibit intermediate susceptibility to sedimentation as these growth forms are likely to only partially retain sediments (Hawker and Connell 1992, Gilmour *et al.* 2006).

The susceptibility of different coral taxa to sedimentation, as well as the generalised susceptibility of the main coral growth forms, is shown in Table 5.4.

Sediments on corals may be removed by production and release of mucus which lifts particles from the coral tissue (Riegl and Branch 1995). Furthermore, corals may actively trap and reject particles using their tentacles (Anthony and Fabricius 2000). These processes come at an energetic expense to the coral through loss of carbon from mucus release and enhanced respiration (Anthony and Fabricius 2000), and contribute to the compromise of the fitness of the coral. Furthermore, deposition of particles in excess of what may be removed through mucus release or particle trapping may clog the feeding apparatus of the corals and cause elevated mortality (Philipp and Fabricius 2003).

Table 5.4 Groups of corals of varying susceptibility to sedimentation and turbidity (Gilmour et al. 2006)

Relative Susceptibility	Group	Sedimentation and Turbidity
High	Taxa	*Montipora*
		Agaricidae
		Pectinidae
		Acropora (plate)
	Growth Forms	Plating/encrusting corals
Medium	Taxa	*Porites** (massive)
		Favites
		Favia
		Pocillopora
		Acropora (branching)
	Growth Forms	Massive corals
Low	Taxa	*Turbinaria*
		Fungia
		Goniopora
		Galaxea
		Pavona
		Porites (branching)
	Growth Forms	Branching corals

**In some instances massive Porites colonies have displayed variable susceptibility to increased sedimentation*

Stafford-Smith and Ormond (1992) reported that in general, all species with large calices (> 10 mm in diameter) are capable of rejecting influxes of up to at least 50 mg/cm^2, while species with smaller calices (< 2.5 mm in diameter) are poor sediment rejectors. Corals with calices between 2.5 and 10 mm in diameter varied in their responses, although most active rejectors in this size class have strong ciliary mechanisms. The findings from their investigation are summarised below in Table 5.5. Only coral genera which were recorded during site surveys by MScience (MScience 2009b) are reflected in the table.

Table 5.5 Summary of behavioural responses to sediment influxes of Australian scleractinian corals (Source: Stafford-Smith and Ormond 1992)

Species/Types of corals	Calice diameter (mm)	Group no.*	Active-rejection capability
Acropora hyacinthus	0.85	6	Active rejection redundant
Acropora florida	1.1	4	Manipulates silt and fine sand slowly; movement of larger particles often laboured
Favia stelligera	3	3	Easily manipulates silt and fine sand; movement of larger particles often laboured
Favia pallid	8	1A	Easily manipulates all sediment sizes
Favites abdita	9.5	2	Easily manipulates silt, fine and coarse sand
Fungia repanda	200	1A	Easily manipulates all sediment sizes
Goniopora lobata	4	1A	Easily manipulates all sediment sizes
Lobophyllia hemprichii	40	1A	Easily manipulates all sediment sizes
Lobophyllia corymbosa	35	1A	Easily manipulates all sediment sizes
Monitopora danae	0.65	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Montipora foliosa	0.7	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Montipora aequituberculata	0.6	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Platygyra lamellina	4	2	Easily manipulates silt, fine and coarse sand
Pocillopora damicornis	1.1	6	Active rejection redundant
Porites lobata	1.5	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Porites lutea	1.25	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Turbinaria peltata	4	1A	Easily manipulates all sediment sizes
Turbinaria mesenterina	3	3	Easily manipulates silt and fine sand; movement of larger particles often laboured

**Rejection capability decreases with increasing numerical order e.g. Group 6 is the most ineffective active rejector and has the lowest tolerance to sedimentation.*

Recent surveys by MScience (2009b) of the sub-tidal areas in the vicinity of the Project area have recorded average live hard coral cover in the order 30–70%, with the highest cover relating to large (almost mono-specific) stands of large spreading growth forms (e.g. foliose *Montipora* and tabulate *Acropora* species). The highest coral cover was found at north east Koolinda Shoal and Roller Shoal and the lowest at Weeks Shoal and south west Twin Island. The most abundant life-forms were foliose (e.g. *Montipora* and Agaricid species), massive (e.g. Faviid and *Porites* species) and tabulate or branching (e.g. *Acropora* species).

A number of *Turbinaria* juvenile recruits were also documented at a few of the survey sites. *Turbinaria* sp. is a hardy, foliose coral which is particularly resistant to sedimentation. Laboratory experiments carried out on the coral *Turbinaria mesenterina* from the inner GBR lagoon revealed that it is tolerant to sediment loads an order of magnitude higher than most severe sediment conditions *in situ* (Sofonia and Anthony 2008). Other coral species such as *Montipora verrucosa* is also known to be sediment-tolerant and may be covered by sediments for weeks without signs of physiological damage (Hodgson 1990). *Montipora* is prevalent among many turbid coral communities in the Indo-Pacific and can adapt to turbid conditions and enhanced sedimentation by acquiring growth forms that enhance passive sediment shedding (i.e. more branched growth form or vertical orientation) (Bull 1982, Stafford-Smith 1993). Similarly, *Porites* is another highly sediment-tolerant coral species (Stafford-Smith 1993). While the small-polyped *Porites* corals are inefficient sediment rejectors, they may be highly resilient to sedimentation and are known to recover even after complete burial over three days (Sanders and Baron-Szab 2005, Wesseling *et al.* 1999).

Based on open water reef environments with low levels of natural sedimentation Pastorok and Bilyard (1985) have suggested the following criteria:

- 0.01 – 0.1 kg/m^2/day = slight to moderate impacts
- 0.1 – 0.5 kg/m^2/day = moderate to severe impacts
- > 0.5 kg/m^2/day = severe to catastrophic impacts

However, fringing and inshore reef environments are known to experience sedimentation events in exceedence of 0.5 kg/m^2/day (severe to catastrophic) and support flourishing coral communities (Ayling and Ayling 1987). The adoption of a strict criterion for impact assessment based on Pastorok and Bilyard's system therefore may be overly protective in environments where corals assemblages are resilient to periodic or consistently high background rates of sedimentation. Hawker and Connell (1992) have suggested that a value of 0.3 kg/m^2/day is regarded as the absolute limit for sediment deposition in inshore areas. Meanwhile, Rogers (1990) indicated that "normal" sedimentation rates for Caribbean coral reefs appear to be on the order of 0.1 kg/m^2/day. Combined, these studies suggest that there is considerable variation in maximum sedimentation thresholds for corals and highlight that in-depth knowledge of local conditions is important for accurate recommendations.

An overview of values reported in the literature as critical threshold sedimentation rates for different coral species at different locations is presented in Table 5.6.

Table 5.6 Critical threshold of different species of corals for sedimentation (mg/cm^2/day)

Species/Types of corals	Location	Sedimentation (mg/cm^2/day)	Response	Reference
Acropora millepora	Ningaloo Reef, Australia	1-11.7	Reduced recruit survival	Babcock and Smith (2002)
Acropora cervicornls	Jamaica	200	No effect	Dallmeyer (1982)
Acropora palmata	Caribbean	200	Death of underlying tissue	Rogers (1983)
Montipora peltiformis	GBR, Australia	≥ 109	Death	Philipp and Fabricius (2003)
Montastrea annularis	Jamaica	800	Death of underlying tissue	Dallmeyer (1982)
Montastrea cavernosa	Panama	13.8	Death	Lasker (1980)
Porites asteorides (green morphs)	St Croix, United States Virgin Islands	3.6-4.0	Reduction in sediment clearing	Gleason (1998)
Porites asteorides (brown morphs)	St Croix, United States Virgin Islands	5.0-5.4	Reduction in sediment clearing	Gleason (1998)
Porites sp.	Bolinao, Philippines	Experimental burial of 1-5 cm over 68 hour	90% bleached tissue; recovery after 4 weeks	Wesseling *et al.* (1999)
Turbinaria mesenterina	Magnetic Island, GBR, Australia	> 100	Able to clear sediment in ~4-5 hours	Sofonia and Anthony (2008)

Setting threshold values for sedimentation is complex, as responses are species-specific, tend to be dose-dependent and spatially variable (Gilmour *et al.* 2006). This is especially so for corals in the Pilbara region, where background levels of sedimentation vary dramatically over small spatial and temporal scales. It is therefore likely that coral communities on inshore reefs within the Pilbara are able to withstand discrete pulses of relatively high sedimentation.

Acceptable levels of sedimentation will depend on hydrodynamic conditions, background sedimentation rates, re-suspension rates and background turbidity and will therefore need to be adjusted to local conditions (Sofonia and Anthony 2008). Preliminary estimates of tolerance to sedimentation made by Gilmour *et al.* (2006) are illustrated in Figure 5.2. These estimates are based on limited data presently available from the Pilbara and other regions and should be refined and corrected within future research (Gilmour *et al.* 2006).

Based on the literature presented in this section and DHI's previous experience in impact assessment and feedback monitoring of dredging related impacts to corals (Section 4 and Appendix B), DHI's proposed preliminary sedimentation tolerance limits for corals are shown in Table 5.7 and Table 5.8. The limits have been developed based on the most sensitive coral species, in order to ensure that the levels of impact predicted are conservative. The limits for the nearshore area (within the 5 m isobath) during summer and winter have been raised to reflect the increased magnitude and variability of sedimentation experienced in the nearshore zone during these periods, due to rainfall events and frequent re-suspension from strong spring tides and wave activity (Section 2.2.2).

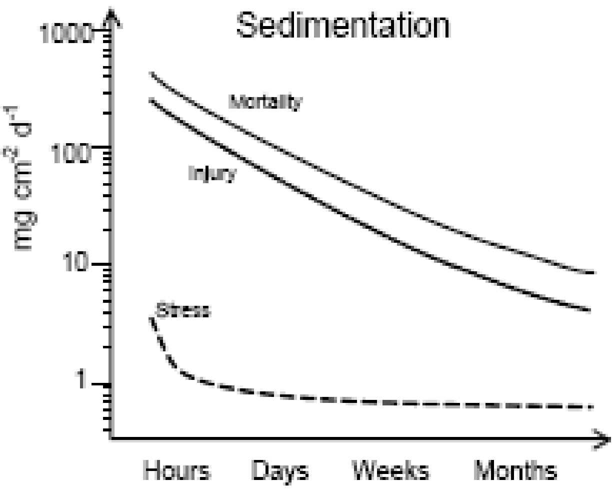

Figure 5.2 *Preliminary estimates of the loads and durations of sedimentation likely to cause increasing levels of impacts to corals. The curve applies to relatively 'tolerant' species of corals from inshore reefs within the Pilbara, and more susceptible species will have the same levels of impact at lesser loads and/or durations (Source: Gilmour et al. 2006)*

Table 5.7 *Preliminary matrix of impact Zones for net sedimentation impact on corals for assessment of short-term scenario model results: for offshore waters (beyond 5 m isobath), and for nearshore waters (within 5 m isobath) during transitional periods only*

Zones	Definitions
Zone of Total Mortality	• Sedimentation > 0.2 kg/m^2/day (> 7.0 mm/14day*)
Zone of Partial Mortality	• Sedimentation 0.05 – 0.2 kg/m^2/day (1.7 – 7.0 mm/14day*)
Zone of Influence	• Sedimentation 0.01 – 0.05 kg/m^2/day (0.3 – 1.7 mm/14day*)
No Impact	• Sedimentation < 0.01 kg/m^2/day (< 0.3 mm/14day*)

** conversion from kg/m^2/day to mm/14 days assumes an initial deposition dry density of 400kg/m^3*

Table 5.8 *Preliminary matrix of impact zones for net sedimentation impact on corals for assessment of short-term scenario model results: for nearshore waters (within 5 m isobath) during summer and winter only*

Zones	Definitions
Zone of Total Mortality	• Sedimentation > 0.5 kg/m^2/day (> 17.5 mm/14day*)
Zone of Partial Mortality	• Sedimentation 0.1 – 0.5 kg/m^2/day (3.5 – 17.5 mm/14day*)
Zone of Influence	• Sedimentation 0.025 – 0.1 kg/m^2/day (0.9 – 3.5 mm/14day*)
No Impact	• Sedimentation < 0.025 kg/m^2/day (< 0.9 mm/14day*)

** conversion from kg/m^2/day to mm/14 days assumes an initial deposition dry density of 400kg/m^3*

The values in the tables are for excess (i.e. above background) rates of net sedimentation generated by the dredging, reclamation or offshore disposal activities, and should be applied to the sediment plume model results from short-term scenario modelling. Note that as discussed previously, this does not mean that impacts would necessarily be realised within the 14-day modelling period. Rather, if the impact continued at the same level for an extended period (several months), these are the predicted levels of impact.

Sedimentation rates in the literature are usually given as mass per unit area per unit time (e.g. kg/m^2/day). However, the layer thickness (e.g. mm/14 days) is often an easier measure to conceptualise, so both measures have been provided in the tables. A density of 400 kg/m^3 has been used to convert between the two measures. The choice of 400 kg/m^3 is based on DHI's extensive monitoring experience of sedimentation, and is a conservative estimate of density for sedimentation during the initial deposition phase.

The tolerance limits recommended by DHI in Table 5.7 and Table 5.8 are broadly comparable but generally more conservative than previous limits adopted for dredging projects in WA (Table 4.1). This is appropriate given the lack of available data on site specific tolerances to sedimentation in the Project area. As detailed in Section 4.3, it is good environmental practice to set conservative but realistic tolerance limits at the EIA stage, and then confirm and optimise these limits in the lead up to the start of work, based on long-term baseline measurements and survey data. The objective at this stage is to provide sufficient details for authorities to determine the acceptable level of environmental impact, but setting concrete trigger levels and final tolerance limits is not appropriate at the EIA stage.

The magnitude of the net sedimentation limits recommended by DHI (equivalent to 1, 5 and 20 mg/cm^2/day) are lower than those used for Gorgon (5 to 100 mg/cm^2/day), Pluto (9 to 60 mg/cm^2/day) and Cape Lambert (7 to 300 mg/cm^2/day). However, is should be noted that DHI's values in Table 5.7 and Table 5.8 are for excess sedimentation (i.e. in addition to background sedimentation). But as background sedimentation at the site ranges from 0.7 mg/cm^2/day to 10 mg/cm^2/day (Section 2.2.2), the magnitudes of DHI's limits can still be regarded as conservative compared to limits previously set for WA projects.

However, DHI's approach to the duration of exceedence is different from the way that sedimentation limits appear to have been applied previously in WA. Previous WA projects have set duration limits apparently based on daily measurements, with a certain number of days with sedimentation above the trigger level resulting in a certain impact category. An exposure duration of five out of 15 days above 25 mg/cm^2/day was assessed as High Impact for Gorgon, while seven out of 21 days above 300 mg/cm^2/day was assessed as High Impact for Cape Lambert.

It should be noted though that in DHI's experience, measuring sedimentation on a very short term basis (daily or even every few days) is logistically very demanding and subject to significant measurement variability due to the small volume of sample. DHI has found that the optimal measurement duration for sedimentation is 14 days, as this covers a full spring-neap tidal cycle, and provides sufficient sample to ensure relatively good measurement accuracy. This is also reflected in data from the literature. While daily rates of sedimentation are reported in the literature, they are typically derived from measurements taken over periods ranging from 7 to 30 days (or sometimes longer). DHI's tolerance limits are comparable to many of the values quoted in the literature (e.g. Pastorok and Bilyard 1985, Ayerling and

Ayerling 1987, Hawker and Connell 1992, Philipp and Fabricius 2003, Gilmour *et al.* 2006).

Therefore, in order to allow for comparison with field measurements of sedimentation, and to cover any temporal variability in sedimentation rates over the spring-neap cycle, DHI's tolerance limits have been based on a 14-day spring-neap period. DHI notes that this is also a biologically relevant duration, as most coral species are able to actively or passively reject sedimentation in the short-term, but would experience stress or some level of impact if sedimentation continued consistently across a 14-day spring-neap cycle.

DHI's net sedimentation tolerance limits are intended for assessment of model outputs for the EIS/ERMP. This is why the limits are set in terms of excess sedimentation, as the models used for the impact assessment are also predicting excess sedimentation. In the longer term, DHI's limits can also be applied to sedimentation measurements during dredging activities, though a long-term baseline (covering a number of spring-neap cycles during winter, summer and calm transitional periods) would be required in order to isolate the incremental sedimentation resulting from the dredging. However, the limits can be directly applied to the results of hindcast modelling of the actual dredging activities, which DHI is currently applying as a daily management tool for dredge management in Singapore.

6 FILTER FEEDERS

6.1 Octocorals (Gorgonians and Soft Corals)

6.1.1 Octocoral Tolerance to Suspended Sediments

Of the 90 known octocoral genera recorded in shallow tropical to sub-tropical Indo-Pacific waters, only 31 genera contain zooxanthellae (Fabricius and Alderslade (2001). The 59 other zooxanthellate-free taxa depend entirely on heterotrophy, such as suspension feeding on small plankton, to cover their carbon demand (Fabricius *et al*. 1995, Fabricius and Klumpp 1995). In addition to heterotrophic energy acquisition, zooxanthellate taxa of octocorals require light to drive photosynthesis and hence carbon fixation to meet their nutritional requirements. Because of this, zooxanthellate taxa are generally found at shallower depths, and are sensitive to light attenuation resulting from increased turbidity, while zooxanthellate-free taxa tend to dominate low-light environments, and are relatively unaffected by suspended sediments (Fabricius and McCorry 2006).

In a recent study in turbid waters (Secchi depth ~2–4 m) of Hong Kong, zooxanthellate-free taxa of octocorals were abundant, averaging 79% of the total octocoral genera recorded per survey (Fabricius and McCorry 2006). In contrast, zooxanthellate octocorals in clear waters of southern Taiwan, situated on the same continental shelf 600 km east of Hong Kong (Dai 1991) were abundant. Low visibility was also found to be strongly related to decreased abundance and richness of zooxanthellate octocorals on the GBR (Fabricius and De'ath 2001b), where zooxanthellate octocoral species richness declined by one genus for each metre reduction in visibility at sites with visibilities of < 10 m. In combination, these studies suggest that water clarity is important for the prevalence of zooxanthellate taxa of octocorals.

Manipulative experiments in the laboratory have also demonstrated a negative correlation between turbidity and the photosynthetic activities of soft corals. In a study by Riegl and Branch (1995), enhanced conditions of suspended sediments were simulated on five species of soft corals. Under turbid conditions corresponding to a 75% reduction in light intensity, all soft coral species, with the exception of *Lobophytum venustum*, demonstrated a decrease in photosynthetic activity, an increase in respiration and subsequent increased loss of carbon through greater mucus output. *Lobophytum venustum* was suggested to be more sediment-tolerant due to the presence of numerous high ridges on the upper surface, hence supporting the importance of morphology in countering the harmful effects of sediments (Fabricius and McCorry 2006, Rogers 1990).

There are no sufficient data on octocoral tolerance to suspended sediments available from the literature to develop the same comprehensive tolerance limits tables that have been proposed for corals, seagrass and mangroves. However, based on the literature that is available and anecdotal evidence from DHI's monitoring experience in south east Asia, it has been assumed that octocoral tolerance to suspended sediments is similar to (or not less than) hard corals. As octocorals often occur at the same depth or deeper than hard corals such as *Turbinaria* that are considered to have a high tolerance for suspended sediments, it seems a reasonable assumption, and it is considered unlikely that octocorals would be more sensitive than the sensitive hard coral species that the coral tolerance limits are based on. Therefore, the preliminary tolerance limits proposed in Table 5.2 and Table 5.3 are also proposed for octocorals.

6.1.2 Octocoral Tolerance to Sedimentation

Numerous studies have described the behavioural and growth responses of scleractinian corals to sedimentation (e.g. Rogers 1990, Sofonia and Anthony 2008, Stafford-Smith 1993). In comparison, only limited studies have been carried out on octocorals. Some studies have suggested that octocorals have a better ability than scleractinians to survive elevated suspended sediment conditions (Anthony and Fabricius 2000, Riegl and Branch 1995). However, a study by Riegl (1995) revealed that although soft corals attempted to remove sediment by inflation of the entire corallum and the formation of mucus sheets, tissue necrosis appeared after one week of continuous sand application (200 mg/cm^2). The dominance of "passive sediment shedder" soft corals in areas of high sedimentation may be attributed to water motion or gravity (when growing on inclined substrata) which would wash off settled sand.

Meanwhile, effects of sedimentation on gorgonians are also poorly studied, with most studies merely inferring the relationship between the composition and abundance of gorgonians to sedimentation (Goh and Chou 1995, Gotelli 1988, Yoshioka and Yoshioka 1989a). Gorgonians growing in the highly sedimented waters (sedimentation rate ~14.1 $mg/cm^2/day$) of Singapore were reported to have growth rates comparable to other regions (Goh and Chou 1995). Another study attributed the differences in composition and overall gorgonian cover on the fore-reef and lagoon to differences in sedimentation, inclination and substratum (Sanchez *et al.* 1997). Furthermore, some studies have found that excessive sedimentation may hinder octocoral recruitment (Gotelli 1988) and growth (Yoshioka and Yoshioka 1989b).

As there are insufficient data on octocoral tolerance to sedimentation available from the literature DHI proposes the same approach as for suspended sediments, based on the assumption that the tolerance of octocorals to sedimentation is similar to hard corals. Therefore, the preliminary tolerance limits proposed in Table 5.7 and Table 5.8 are also proposed for octocorals.

6.2 Sponges

6.2.1 Sponge Tolerance to Suspended Sediments

Sponges are important benthic filter feeders, occupying a wide range of habitats from temperate to tropical areas (Bell 2004). Sponges also include both heterotrophs (filter-feeders) and mixotrophs that may derive > 50% of their nutrition from photosynthesis of their associated zooxanthellae. Many factors are thought to determine the distribution of sponges, including suspended sediments, light availability and sedimentation (Burns and Bingham 2002).

The main detrimental effect of suspended sediments is light reduction, though other detrimental effects of suspended sediments include a reduction or a complete halt in filtration, which would have adverse effects on feeding and respiration. As seen in a study on a tropical sponge, *Verongia lacunosa*, a sediment load in the water as low as > 11 mg/l was enough to cause a reduction in the pumping rate of the sponge (Gerrodette and Flechsig 1979). Meanwhile, an arrest in pumping rates of hexactinellid sponges was also noted in a more recent study by Tompkins-MacDonald and LeysGlass (2008). Continuous input of sediment to two species of hexactinellid sponges resulted in arrested pumping at sediment levels of 15mg/l and 36 mg/l, respectively. This range of tolerance limits suggests a species-specific response to elevated levels of suspended sediments. Hence, some caution should be exercised when assigning absolute values to threshold values of sponges to suspended sediments.

There are insufficient data on the tolerance of sponges to suspended sediments available from the literature to develop the same comprehensive tolerance limits tables that have been proposed for corals, seagrass and mangroves. However, based on the literature that is available and anecdotal evidence from DHI’s monitoring experience in south east Asia, it has been assumed that sponges tolerance to suspended sediments is similar to hard corals. As sponges often occur at the same depth or deeper than hard corals such as *Turbinaria* that are considered to have a high tolerance for suspended sediments, it is considered unlikely that sponges would be more sensitive than the sensitive hard coral species that the coral tolerance limits are based on. Therefore, the preliminary tolerance limits proposed in Table 5.2 and Table 5.3 are also proposed for sponges.

6.2.2 Sponge Tolerance to Sedimentation

Filter feeders such as sponges are actually important water quality indicators since extreme sedimentation can reduce their growth rate by clogging their feeding apparatus (Lohrer *et al.* 2006, Przeslawski *et al.* 2008).

On tropical rocky coasts, increased sedimentation is one of the main factors shaping sponge assemblages, where 69% of variance observed in long term fluctuations of annual patterns of sponge diversity was correlated with sediment deposition (Carballo *et al.* 2008). Increased sedimentation has also been linked to bleaching and necrosis in sponges, likely due to smothering and lowered photosynthetic rates (Fabricius *et al.* 2007).

Several adaptations exist for sponges living in highly sedimented areas. Encrusting or papillate-shaped sponges have been reported to be buried in coarse sand, through which they exploit interstitial water even though their surface is covered with sediments (Ilan and Abelson 1995). In a study carried out in Spermonde Archipelago, Indonesia (de Voogd and Cleary 2007), globular, fan-shaped and fistulose growth forms were associated with sites with poor water transparency, whereas tube and massive-encrusting growth forms were associated with sites with good water transparency. These studies suggest the importance of morphological features in the establishment of sponges in highly sedimented areas (Ilan and Abelson 1995, Rutzler 1997). Morphological adaptation in connection with high sedimentation rates is also documented in temperate regions. In Ireland, the tubular sponge, *Haliclona urceolus*, was found growing up to depths of 24 m while experiencing sedimentation rates of ~30–60 g sediment/m^2/day (Bell 2004). The survival of this sponge in such conditions was attributed to the upward direction of the exhalant water flow (which prevented sediment settlement on upper surfaces), coupled with the angled tubular shaped morphology.

In addition, sponges also grow in selective niches such as on the shells of mobile invertebrates which periodically dislodge sediments (Burns and Bingham 2002) or live on vertical surfaces such as cliff overhangs, which will experience considerably less sediment accumulation than inclined or horizontal surfaces (Bell and Barnes 2000). Sponges may employ both passive and active mechanisms to remove sediment from their surfaces or to prevent sediment settlement in the first place. Although there exist various literature to describe these strategies (e.g. Ilan and Abelson 1995, Bell and Barnes 2000, Burns and Bingham 2002, Bell 2004, and de Voogd and Cleary 2007), there is a lack of information on critical levels of sedimentation that would result in smothering, clogging of the filtering apparatus, or other deleterious effects on sponges.

As there are insufficient data on sponge tolerance to sedimentation available from the literature DHI proposes the same approach as for suspended sediments, based on the assumption that the tolerance of sponges to sedimentation is similar to hard corals. Therefore, the preliminary tolerance limits proposed in Table 5.7 and Table 5.8 are also proposed for sponges.

7 SEAGRASS

7.1 Seagrass Tolerance to Suspended Sediments

The main impact of suspended sediments on seagrass is reduced light availability, although scouring by sediment particles can also have some impact.

Tolerances of seagrass to suspended sediments are also known to be species-specific. A study carried out at several sites in Moreton Bay, Australia documented *Halophila spinulosa* growing in areas where TSS ranged from 1.96 mg/l to 4.25 mg/l (Abal and Dennison 1996). In the same study, *Halophila ovalis* was more tolerant to the effects of turbidity, having been found at a few sampling stations with up to 9.64 mg/l of TSS.

In Singapore and Malaysia, DHI has recorded large *Halophila ovalis* meadows growing in water depths of ~2 m, with background TSS concentrations in the order of 10–15 mg/l, and Secchi depths ranging from 0.5–1.5 m.

Most of the literature on seagrass tolerance is related to light reduction, rather than suspended sediment concentration (see Appendix A). However, DHI has developed and successfully applied SSC-based tolerance limits for seagrass over approximately five years of monitoring for various dredging and reclamation projects in south east Asia. As *H. ovalis* is a colonising species, it is often found at or near its depth limit. This, combined with the fact that its small rhizome does not allow for significant energy storage, means that *H. ovalis* can be regarded as one of the most sensitive seagrass species to suspended sediment (and consequent light reduction) impacts. DHI's tolerance limits were therefore based on the tolerance of *H. ovalis* to suspended sediments.

Based on the limited available literature combined with DHI's experience in impact assessment and feedback monitoring of dredging related impacts to seagrass (Appendix B), DHI's proposed preliminary suspended sediment tolerance limits for seagrass are shown in Table 7.1 and Table 7.2. The values in the tables are for excess (i.e. above background) concentrations of suspended sediments generated by the dredging, reclamation or offshore disposal activities, and are used to assess sediment plume model results from a 14-day period. Note that this does not mean that impacts would necessarily be realised within a 14-day period. Rather, if the impact continued at the same level for an extended period (several months), these are the predicted levels of impact. The limits have been developed based on the most sensitive seagrass species, in order to ensure that the levels of impact predicted are conservative.

Table 7.1 Preliminary matrix of impact zones for suspended sediment impact on seagrass for assessment of short-term scenario model results: for offshore waters (beyond 5 m isobath), and for nearshore waters (within 5 m isobath) during transitional periods only

Zone*	Definitions
Zone of Total Mortality	• Excess SSC > 25 mg/l for more than 25% of the time OR • Excess SSC > 10 mg/l for more than 50% of the time
Zone of Partial Mortality	• Excess SSC > 25 mg/l for 2.5 – 25% of the time OR • Excess SSC > 10 mg/l for 10 – 50% of the time OR • Excess SSC > 5 mg/l for more than 25% of the time
Zone of Influence	• Excess SSC > 25 mg/l for 0.5 – 2.5% of the time OR • Excess SSC > 10 mg/l for 0.5 – 10% of the time OR • Excess SSC > 5 mg/l for 2.5 – 25% of the time
No Impact	• Excess SSC > 25 mg/l for less than 0.5% of the time OR • Excess SSC > 10 mg/l for less than 0.5% of the time OR • Excess SSC > 5 mg/l for less than 2.5% of the time

**Where location meets criteria for multiple zones, highest zone applies*

Table 7.2 Preliminary matrix of impact zones for suspended sediment impact on seagrass for assessment of short-term scenario model results: for nearshore waters (within 5 m isobath) during summer and winter only

Zone*	Definitions
Zone of Total Mortality	• Excess SSC > 25 mg/l for more than 50% of the time
Zone of Partial Mortality	• Excess SSC > 25 mg/l for 5 – 50% of the time OR • Excess SSC > 10 mg/l for more than 20% of the time
Zone of Influence	• Excess SSC > 25 mg/l for 1 – 5% of the time OR • Excess SSC > 10 mg/l for 1 – 20% of the time OR • Excess SSC > 5 mg/l for more than 5% of the time
No Impact	• Excess SSC > 25 mg/l for less than 1% of the time OR • Excess SSC > 10 mg/l for less than 1% of the time OR • Excess SSC > 5 mg/l for less than 5% of the time

**Where location meets criteria for multiple zones, highest zone applies*

7.2 Seagrass Tolerance to Sedimentation

Similar to information regarding the tolerance of seagrass species to suspended sediments off the coast of Onslow, WA, little is known of the effects of sedimentation on seagrass in the Project area. Nevertheless, the sedimentation impacts on seagrass meadows arising from dredging and reclamation works are still relevant. This is shown in a literature review compiled by Erftemeijer and Lewis (2006) which reports widespread loss of seagrass meadows in Australia ranging from a few hundred to a few thousand hectares as a result of dredging and associated turbidity and burial effects. Critical thresholds of seagrass for sedimentation are better documented in south east Asia, especially the Philippines (Duarte *et al.* 1997, Vermaat *et al.* 1997, Cabaco *et al.* 2008), and other areas in the Mediterranean as seen below in Table 7.3 and in Table 7.4.

As seen in Table 7.3 and in a review by Vermaat *et al.* (1997), sedimentation rates of 2–13 cm/yr can be coped with by vertical stem elongation. Similar sedimentation levels over shorter periods (weeks to months) can also be tolerated to varying degrees by different species, although with some mortalities (Cabaco *et al.* 2008).

For larger species, growth rates can be high, with growth rates in the order of 1–2 cm per day recorded for *Thalassia* sp. (Driscoll *et al.* 1997) whilst growth rates in the order of 0.9 cm per day have been recorded for *Enhalus* sp. in the Philippines (Estacion and Fortes 1988), enabling them to better cope with partial or full burial. But even for smaller colonising species, such as *Halophila*, growth rates play an important part in coping with sedimentation (Cabaco *et al*. 2008).

Table 7.3 Critical thresholds of sedimentation for seagrass (cm/year)

Species	Location	Sedimentation (cm/yr)	Reference
Cymodocea nodosa	Mediterranean (Spain)	5	Marba and Duarte (1994)
Cymodocea rotundata	Philippines	1.5	Vermaat *et al*. (1997)
Cymodocea serrulata	Philippines	13	Vermaat *et al*. (1997)
Enhalus acoroides	Philippines	10	Vermaat *et al*. (1997)
Halophila ovalis	Philippines	2	Vermaat *et al*. (1997)
Posidonia oceanica	Mediterranean (Spain)	5	Manzanera *et al*. (1995)
Zostera noltii	Mediterranean (Spain)	2	Vermaat *et al*. (1997)

Table 7.4 Details of the experimental design to test the effects of burial on seagrass (burial levels tested, the duration of the experiments, the size:burial ratio (SBR) and the resulting effect on seagrass survival summarised in the experimental burial levels causing 50% and 100% mortality (Source: Cabaco et al. 2008)

Species	Burial levels (cm)	Experimental period (days)	SBR	Burial level (cm)	
				50% Mort.	100% Mort.
C. nodosa	1, 2, 4, 7, 13, 16	35	0.6[c]	4	13
C. rotundata	2, 4, 8, 16	60, 120, 300		2	8
C. serrulata	2, 4, 8, 16	60, 120, 300		2	–
E. acoroides	2, 4, 8, 16	60, 120, 300		4	–
H. uninervis	2, 4, 8, 16	60, 120, 300		4	–
H. ovalis	2, 4, 8, 16	60, 120, 300		2	2
P. australis	10, 15, 20, 30	50	1.3[d]	19.5	–
P. oceanica[a]	5/7, 9/10, 13/14	250	1.4	14	14
P. oceanica[b]	3, 6, 9, 12, 15	45	1.3[e]	10.2	15
P. sinuosa	10, 15, 20, 30	50	1.3[d]	15.4	–
S. filiforme	3.5/4.5, 4/5, 6.5/7.5, 9/10	60	0.8	4.5	10
S. isoetifolium	2, 4, 8, 16	60, 120, 300		8	–
T. hemprichii	2, 4, 8, 16	60, 120, 300		4	–
T. testudinum	3.5/4.5, 4/5, 6.5/7.5, 9/10	60	1.2	5	–
Z. marina	4, 8, 12, 16	12, 24	1.0	4	12
Z. noltii	2, 4, 8, 16	7, 14, 28, 56	< 1[f]	2	8

a: Manzanera *et al*. (1998). b: Ruiz (personal communication).
c: N. Marba` (personal communication). d: Leaf length from Smith and Walker (2002)
e: Leaf length from Manzanera *et al*. (1998). f: Intertidal species, leaves are buried even at low burial levels
"–" indicates that total shoot loss did not occur for the tested burial levels.

In the case of very high sedimentation rates, the short-term survival of larger seagrass species will depend on their anaerobic performance. But such critical sedimentation rates will normally only occur very close to a dredging or reclamation site. If sedimentation is below this short-term critical level, the long-term survivability of the plant will then depend on its aerobic metabolism, which is dominated by oxygen supply through the root system. There are several factors affecting this, including the porosity and organic content of the sediment material.

Duarte *et al.* (1997) conducted a field study in the Philippines to test the effects of different levels of sediment burial on a range of seagrass species. The results of the study are presented in (Table 7.4), and provide a good overview of the tolerance of different seagrass species to sediment burial. However, it should be noted that the findings of the study for the smaller colonising species, such as *Halophila ovalis* and *Halodule uninervis*, were quite different from the results for the larger seagrass.

Duarte *et al.* (1997) conclude that the smaller seagrass species would probably have suffered partial or total mortality after burial with more than 2-4 cm of sediment, as they would have been completed covered. However, the growth rate of *H. ovalis* in particular, which produces a new rhizome inter-node and leaf pair approximately every four days (Vermaat *et al.* 1995), meant that by the time the first round of measurements were taken two months after burial, the *H. ovalis* shoot density had fully recovered, and in fact exceeded the original densities (and the control densities) in most instances (Duarte *et al.* 1997). This concurs with the findings of Supanwanid (1996), who recorded full recovery of *H. ovalis* from dugong feeding within two months, and with Longstaff and Dennison (1999), who conclude that the longer-term sedimentation survival strategy for *Halophila* species is the ability to rapidly re-grow from seed and/or vegetative fragments after burial.

It should be noted that the Duarte *et al.* (1997) study involved immediate burial of the seagrass (analogous to an extreme storm event). In the context of dredging and reclamation, such an immediate burial event is likely to be confined to the immediate vicinity (within 100–500 m) of the work area or offshore spoil placement area. For seagrass further away from the immediate work area, sedimentation is better characterised as an accelerated build-up rather than immediate burial. Given the rapid growth rates of most tropical seagrasses (Vermaat *et al.* 1995) there can be expected to be some capacity to adapt to the risk of accelerated burial due to increased sedimentation rates.

For low sedimentation rates, plant growth is often positively related to increasing sediment nutrient contents supplied by sedimenting material. However, if siltation occurs above a level corresponding to sediment organic matter content of about 5–20% of the dry weight of the seagrass in any given area, it is likely to have a negative impact on seagrass density. This is due to depletion in oxygen availability through decay of the organic matter in the sediments, with the most typical limit being in the order of 10-15% organic matter by dry weight (Duarte 1991, Terrados *et al.* 1999).

A second sedimentation factor potentially affecting seagrass arises from the fact that material remotely deposited from dredging and reclamation activities will generally be finer than the natural material present in the seagrass areas, resulting in a potential reduction in overall porosity of the bottom material. Studies in Thailand and the Philippines have indicated a limiting silt and clay content of 15%, above which species richness and community biomass of seagrass decline sharply

(Terrados *et al*. 1998). Given the location of the seagrass beds in the Project area, it can be expected that the clay content in the existing habitat areas falls below this threshold limit. However, for further reduction in porosity to materialise, incremental sedimentation would have to be concentrated and prolonged in order for consolidation to occur in the face of periodic wave action. This is unlikely, given the remote location of the seagrass beds from the dredging and reclamation area.

The dominant seagrass in the study area are the small colonizing species *Halophila decipiens* and *H. ovalis*. These species are relatively small, usually extending only 2-4 cm above the seabed. However, as discussed above, these small species still seem to be relatively tolerant to elevated sedimentation rates (as long as they don't result in immediate burial) due to their relatively fast growth rates. *H. ovalis* has been documented to produce a new set of two leaves every four days, and to have an annual rhizome horizontal growth of 141 cm (Vermaat *et al*. 1995). This is equivalent to a horizontal rhizome growth rate in the order of 4 mm/day (some of which would presumably be at an angle to the horizontal in order to maintain a preferred depth below the surface), as well as vertical growth in the order of 15 mm/4 days (from the new shoots).

Taking the high growth rate and documented capacity of *Halophila* to cope with relatively high rates of sedimentation, and based on DHI's previous seagrass monitoring results for *Halophila*, the tolerance limits presented in Table 7.5 and Table 7.6 are considered realistically conservative for the small seagrass species known to occur in the Project area. The values in the tables are for excess (i.e. above background) concentrations of sedimentation generated by the dredging, reclamation or offshore dredge material placement activities, and are used to assess sediment plume model results from a 14-day scenario modelling period. Note that this does not mean that impacts would necessarily be realised within a 14-day period. Rather, if the impact continued at the same level for an extended period (several months), these are the predicted levels of impact.

Table 7.5 Preliminary matrix of impact zones for sedimentation impact on seagrass for assessment of short-term scenario model results: for offshore waters (beyond 5 m isobath), and for nearshore waters (within 5 m isobath) during transitional periods only

Zones	Definitions
Zone of Total Mortality	• Sedimentation > 0.7 $kg/m^2/day$ (> 25 mm/14day*)
Zone of Partial Mortality	• Sedimentation 0.2 – 0.7 $kg/m^2/day$ (7 – 25 mm/14day*)
Zone of Influence	• Sedimentation 0.03 – 0.2 $kg/m^2/day$ (1 – 7 mm/14day*)
No Impact	• Sedimentation < 0.03 $kg/m^2/day$ (< 1 mm/14day*)

** conversion from $kg/m^2/day$ to mm/14 days assumes an initial deposition dry density of 400 kg/m^3*

Table 7.6 Preliminary matrix of impact zones for sedimentation impact on seagrass for assessment of short-term scenario model results: for nearshore waters (within 5 m isobath) during summer and winter only

Zones	Definitions
Zone of Total Mortality	• Sedimentation > 1 $kg/m^2/day$ (> 35 mm/14day*)
Zone of Partial Mortality	• Sedimentation 0.3 – 1 $kg/m^2/day$ (10 – 35 mm/14day*)
Zone of Influence	• Sedimentation 0.04 – 0.3 $kg/m^2/day$ (1.5 – 10 mm/14day*)
No Impact	• Sedimentation < 0.04 $kg/m^2/day$ (< 1.5 mm/14day*)

** conversion from $kg/m^2/day$ to mm/14 days assumes an initial deposition dry density of 400 kg/m^3*

8 MACROALGAE

8.1 Macroalgal Tolerance to Suspended Sediments

Recent preliminary surveys of sub-tidal areas in the vicinity of the Project area have documented a diverse range of macroalgal life forms, ranging from filamentous green and brown algae to foliose green algae and coralline red algae (URS 2009). A variety of macrophytes such as *Caulerpa sp*., *Sargassum sp*., *Halimeda sp*. and *Padina sp*. were also recorded around the east side of Thevenard Island and other areas.

Elevated suspended sediments result in light attenuation, reducing photosynthesis-dependent carbon fixation and macroalgal abundance. Research in this area is more widespread in temperate waters as compared to tropical areas. The annual growth and productivity of kelp in the Arctic coast of Alaska was shown to decrease when TSS levels ranged between 18.5 and 24.2 mg/l as a result of reduced irradiance to drive photosynthesis (Aumack *et al*. 2007). In the tropics, information regarding the effects of suspended sediments and light attenuation on macroalgae is limited. Hence, it would be useful to consider experimental studies which describe the light requirements of different macroalgae species in order to develop future threshold values for total suspended matter.

Apart from light reduction, suspended sediments in combination with wave action and/or strong tidal currents have synergistic scouring effects on macroalgal communities (Engledow and Bolton 1994). The elevated shear stress caused by increased water velocity results in increased re-suspension (i.e. elevated suspended sediments) leading to both scouring and light reduction, and can also result in direct removal of macroalgae from the substratum, particularly during strong flow periods (Francoeur and Biggs 2006). Hence, it is often difficult to isolate the effects of light reduction and scouring on macroalgae, as both will tend to occur in tandem during high flow conditions.

In an experimental study by Francoeur and Biggs (2006), it was demonstrated that while increased water velocity alone removed benthic macroalgal biomass, this removal was further enhanced by high concentrations of suspended sediment (concentrations of up to 6,487 mg/l). The same study also showed enhanced biomass losses of unbrushed, loosely attached macroalgal communities, while removal of tightly adherent communities was low. Hence, communities with a tightly adherent cohesive mat physiognomy can be regarded as more resistant to removal.

In a separate investigation carried out in the Galapagos (Kendrick 1991), the biomass of filamentous turf algae as compared to crustose coralline algae was significantly lower under a simulated scour environment. The ability of crustose coralline algae to colonise a variety of marine habitats and persist in highly disturbed environments suggest high importance of different macroalgal growth-forms to the effects of sediment abrasion.

It is also known that submersed macrophytes can greatly improve water quality by dampening wave activity and reducing sediment re-suspension (James *et al.* 2004a). However, the effects of sediment re-suspension dynamics and light attenuation on macroalgae are mainly characterised in temperature climates (James *et al*. 2004b, Fong 2008).

There are insufficient data on macroalgal tolerance to suspended sediments available from the literature to develop the same comprehensive tolerance limits tables that have been proposed for corals, seagrass and mangroves. However, based on the literature that is available and anecdotal evidence from DHI's monitoring experience in south east Asia, it has been assumed that macroalgal tolerance to suspended sediments is similar to (or not less than) seagrass. Macroalgae often occur at the same depth or deeper than seagrass such as *Halophila*, and it is considered unlikely that macroalgae would be more sensitive than the relatively sensitive seagrass species that the seagrass tolerance limits are based on. Therefore, the preliminary tolerance limits proposed in Table 7.1 and Table 7.2 are also proposed for macroalgae.

8.2 Macroalgae Tolerance to Sedimentation

Sedimentation in marine habitats is potentially one of the major factors influencing the structure, biomass and metabolism of benthic assemblages (Aumack *et al.* 2007, Balata *et al.* 2007, Sofonia and Anthony 2008). Although certain varieties of algae have been associated with clean and clear offshore waters, the effects of water quality on algae are little known. Most tropical experimental work on the effects of sedimentation has focused on corals, and little has been done on macroalgae (Schaffelke *et al.* 2000). However, it is a widely-held belief that high rates of sediment deposition and movement are detrimental to the overall richness and diversity of the community through exclusion of less tolerant species (Airoldi and Cinelli 1997, Carpenter 1990). In a 2001 study by Fabricius and De'ath (2001a), no critical threshold limits of sedimentation were given, however, their investigations used a rating scale which determined a strong inverse relationship between cover of crustose coralline algae (CCA) and sedimentary deposits on the GBR. The negative effects of sediment on CCA abundance could be attributed to a reduction in substrate for CCA settlement and a reduction in photosynthesis as a result of shading by the sediments (Fabricius and De'ath 2001a, Klumpp and McKinnon 1992).

Conversely, higher rates of sedimentation have also been reported to increase macroalgal abundance, by either enhancing macroalgal recruitment or survival; or indirectly, by inhibiting competitors or herbivores (Schaffelke and Klumpp 1998). Both physical and biotic factors act together to maintain benthic macroalgae, though Caulerpales may easily out-compete other macroalgae as it is not limited by grazing due to the production of toxic substances (Boudouresque *et al.* 1996, Dumay *et al.* 2002). While physical factors such as light, temperature and sedimentation contribute to regulating the growth of Caulerpales, an experimental study by Piazzi *et al.* (2005) showed that *Caulerpa racemosa* was not affected by an increase in sedimentation rates. This was possibly due to resistance to deposition and burial, coupled with vegetative propagation to grow under disturbed conditions.

Adaptation of macroalgae to disturbance caused by sedimentation is dependent on various factors such as life history traits as well as physiological and morphological differences (Airoldi 2000, Aumack *et al.* 2007, Balata *et al.* 2007). Some filamentous forms benefit from increased sedimentation due to their fast growth, capability to exploit nutrients and ability to trap sediment (Balata *et al.* 2007, Carpenter 1990). Turf algae in particular, appeared more resistant to high sedimentation than erect and encrusting forms (Aumack *et al.* 2007, Gorgula and Connell 2004). In addition, turf algae have a higher sediment tolerance than other benthos occupiers such as corals (Nugues and Roberts 2003). Furthermore, some studies have shown that turf algae are able to trap sediments and pre-empt substrate, hence, facilitating algal overgrowth onto coral colonies (McCook 1999, Fabricius and De'ath 2001a, Aumack *et al.* 2007). Investigations on the effects of sedimentation on algae at various localities are summarised below in Table 8.1.

Sufficient data on macroalgal tolerance to sedimentation are not available from the literature to develop the same comprehensive tolerance limits tables that have been proposed for corals and seagrass. However, based on the literature that is available and anecdotal evidence from DHI's monitoring experience in south east Asia, it has been assumed that macroalgal tolerance to sedimentation is similar to (or not less than) the small colonising seagrass species that the seagrass tolerance limits are based on. Therefore, the preliminary tolerance limits proposed in Table 7.5 and Table 7.6 are also proposed for macroalgae.

Table 8.1 Critical thresholds of algae for sedimentation (g/m²/day)

Species/ Types of algae	Location	Sedimentation (g/m²/day)	Response	Reference
Various species (turf, erect and encrusting)	Vada Shoals, Tuscany	High (~44.3 – 130.9) Low (~6.3 – 49.7)	Turfs more extensive in areas of high sediment deposition Erect and encrusting more extensive in areas of low sediment deposition	Balata *et al.* (2005)
Various species (crustose, filamentous, foliose, corticated-terete and articulated algae)	Tuscany	220	Reduction in diversity Dominance of filamentous species	Balata *et al.* (2007)
Crustose coralline algae	GBR, Australia	N.A.	Sediment negatively affect CCA abundance	Fabricius and De'ath (2001a)
Crustose coralline algae (*Lithothamnion* sp.)	South.west Ireland	2 – 12.5	Sedimentation reduced CCA cover	Maughan (2001)
Turf algae	Livorno, Mediterranean Sea	> 200	Decreased biomass	Airoldi and Virgilio (1998)
Turf algae (*Polysiphonia setacea*)	Livorno, Mediterranean Sea	N.A.	Growth enhanced by reduced sedimentation rates	Airoldi and Cinelli (1997)

Species/ Types of algae	Location	Sedimentation ($g/m^2/day$)	Response	Reference
90 species of macrophytes	Spain	Sediment loading expressed as percentage of substratum covered	Algal cover decrease as sediment loading increase Species richness and diversity show higher values at intermediate sediment loads	Díez *et al.* (2003)
Sargassum microphyllum	GBR, Australia	> 3,580 (x2 ambient sediment deposits)	Decreased rates of recruitment, growth, survival and vegetative regeneration	Umar *et al.* (1998)
Caulerpa racemosa	Tuscan Coast	200 (x4 ambient sediment deposits)	Percentage cover not affected by increase in sedimentation rates	Piazzi *et al.* (2005)

Note: N.A. denotes that information is not available

9 MANGROVES

9.1 Mangrove Tolerance to Suspended Sediments

A study carried out in Cairns, Australia, demonstrated that 80% of suspended sediments brought in to the mangroves from coastal waters at spring flood tide were trapped in the mangroves (Furukawa *et al.* 1997). Sediment particles are carried in suspension into mangrove forests at high tide where they are maintained in suspension due to the turbulence caused by mangrove structures. The particles settle in the mangroves only around low tide, when water turbulence is reduced and when water velocity is not large enough to carry the particles back to the estuary (Kathiresan 2003, Wolanski 1995). However, the vertical accretion of suspended particles also depends on concentration and rare events such as tropical cyclones and floods in nearby rivers (Furukawa *et al.* 1997).

Further observations at Cocoa Creek, a mangrove creek system near Townsville, Australia, suggests a complex but strong relationship exists between tidal hydrodynamics, sediment transport and geomorphology (Bryce *et al.* 2003). Given this complexity, there are no clear estimates of thresholds for sediment fluxes in mangroves. However, mangroves can be considered to be fully tolerant to the range of suspended sediment loads that may be generated outside the work area from dredging and reclamation activities associated with the proposed Project.

9.2 Mangrove Tolerance to Sedimentation

Mangroves are known for their sediment accreting and stabilising properties (Ellison 1999, Furukawa *et al.* 1997, Kitheka *et al.* 2002). Sediment from catchment erosion enters mangrove ecosystems through run-off and transportation in riverine water columns. Sediments deposited in mangrove areas are frequently tainted with particulate pollutants or pollutants adsorbed to clay particles (Dubinski *et al.* 1986, Kehrig *et al.* 2003). It is now recognised that the ability of mangroves to filter water and trap sediment and pollutants is a very important ecosystem service as it improves downstream water quality essential for seagrass and coral growth and stabilises estuarine banks, thereby impeding erosion.

Mangroves are able to withstand gradual sediment accumulation, as this is part of their natural, dynamic state. However, acute increases in sedimentation due to natural or anthropogenic dumping of material can result in burial of pneumatophores, reducing their ability to supply oxygen to the root system (Wolanski 1995). The most sensitive components of the mangrove ecosystem to sedimentation impacts are seedlings and pneumatophores, as both have a relatively small vertical extent, and may therefore be partially or fully buried by high sedimentation rates within a short period of time.

Some field data regarding tolerance levels of mangroves to levels of sedimentation are available. A study by Terrados *et al.* (1997) showed that sediment burial of 8 cm and above retarded growth and increased mortality of *Rhizophora apiculata* seedlings as a result of altered oxygen supply to the hypocotyl root system. Field experimental work in Thailand carried out by Thampanya *et al.* (2002) on seedlings of *Avicennia officinalis, Rhizophora mucronata* and *Sonneratia caseolaris* showed that *Avicennia officinalis* was five times more sensitive to burial than *Sonneratia caseolaris*, whilst *Rhizophora mucronata* showed no significant difference between the control and burial treatments (0, 4, 8, 16, 24 and 32 cm). There was 100% mortality in *Avicennia officinalis* after 225 days at 32 cm burial, and almost 90% mortality at 24 cm.

There are numerous accounts of sedimentation as a result of human disturbance causing problems in mangroves, but generally few quantitative details. Anecdotally, DHI is aware of a case in Bali where mangroves adjacent to a reclamation area were subjected to sedimentation of approximately 30 cm when a bund wall failed. This resulted in complete defoliation of the mangroves, but subsequent site visits reported that the mangroves had re-foliated within about six months, with few if any mortalities. Ellison (1999) has documented a few areas in Australia where deposition of dredge material smothered the roots and caused the deaths of mangroves (Table 9.1).

Table 9.1 Summary of mangrove burial events and consequences (Source: Ellison (1999))

Location	Species	Burial	Effect
Mud Island	• *Avicennia marina* • *Rhizophora stylosa*	N.A	Death
Princess Charlotte Bay	• *Rhizophora* • *Avicennia*	70 cm 70 cm	Death Survived
Port Samson	• *Avicennia marina*	20 cm	Death
King Bay	N.A	N.A	2 Ha dead
Gladstone	• *Avicennia marina* • *Avicennia marina* • *Rhizophora stylosa*	5 cm 50 cm 50 cm	Stressed Dead Stressed
Bowen	• *Avicennia marina*	12 cm	0.5 Ha dead

Note: N.A. denotes that information is not available

Closer to the Project area, Ellison (1999) documented smothering of *Avicennia marina* roots by > 20 cm of sediment at Port Samson in north WA, and the subsequent death of the trees. The closest mangrove stands to the Project area appear to be located near the Ashburton River which opens into the Indian Ocean and is located 55 km west south west of Onslow. Approximately 3 km^2 of mangrove areas were identified in a 2001 estuary assessment of the river (DEH and FRDC 2000).

Seven species of mangroves are known to occur along the Pilbara coast (EPA 2001). Of these, six species were recorded from the Ashburton Delta area from the surveys undertaken for this Project (URS 2009). The six mangrove species are:

- *Aegialitis annulata* (Club Mangrove)
- *Aegiceras corniculatum* (River Mangrove)
- *Avicennia marina* (Grey Mangrove)
- *Bruguiera exaristata* (Ribbed Mangrove)
- *Ceriops australis* (Spurred Mangrove)
- *Rhizophora stylosa* (Spotted-leaved Red Mangrove)

Within the Project area *Avicennia marina* (Grey mangrove) was a widespread and dominant species that occurred within the majority of mangrove associations present. It was found growing monospecifically in many areas and in a range of structural forms (e.g. from dense low forests to open shrubland) but also occurred in association with the other five species in particular locations. The local dominance by *A. marina* reflects the broader regional pattern with this species being the most widespread and abundant mangrove species in the Pilbara coastal region (Semeniuk 1999). A summary of the tolerance of the six mangrove species occurring in the Project area to sedimentation /burial is provided in Table 9.2.

Table 9.2 Summary of tolerance to sedimentation/burial of mangrove species occurring in the Project area

Species	Sedimentation Tolerance	Reference
Aegialitis annulata	N.A.	N.A.
Aegiceras corniculatum	*A. corniculatum* is more tolerant to burial than *R. stylosa* and *B. gymnorrhiza* and less tolerate than *A. marina.*	Youssef and Saenger (1998)
Avicennia marina	Will usually die when pneumatophores are covered (~10 cm sediment), though death by burial can still occur below this level. Have been known to survive when buried in at least 70 cm when sediment pore holes are large, e.g., with shells. May be able to extend pneumatophores several centimetres to cope with burial.	Ellison (1998)
Bruguiera exaristata	Trees may die when knee roots are completely buried (confirmed for *B. gymnorrhiza*, not tested on this species specifically)	Ellison (1998)
Bruguiera	Burial of knee roots usually causes death	Ellison (1998)
Rhizophora stylosa	Greater burial tolerance under some circumstances than *A. marina*, showed signs of stress under 50 cm and died under 70 cm burial depth	Ellison (1998)

Note: N.A. denotes that information is not available

The Ashburton River has been described as a wave dominated delta with low sediment trapping efficiency, naturally low turbidity, salt wedge/partially mixed circulation, with a consequently low risk of habitat loss due to sedimentation (DEH and FRDC 2000). It is considered unlikely, given the distance from the Project area, that the proposed dredging and reclamation works can generate sedimentation rates that would be high enough to introduce stress on the mangroves found around this area. However, DHI has developed preliminary tolerance limits, based on the above literature and extensive monitoring experience in south east Asia. Table 9.3 shows the proposed tolerance limits for mangroves based on the 14-day scenario modelling.

This does not mean that the predicted level of impact would necessarily occur within a 14-day period (although this might be possible in extreme situations), but rather that if operations continue at the same rate for an extended period (several months), then these levels of impact are predicted to result.

Two types of limits are provided, a mass of sediment per unit area (which is how sedimentation is commonly reported in the literature), and a thickness of the sediment layer (which is often more useful in relating to field observations). In order to convert from the mass per unit area to the thickness, the density of the sediment has been assumed to be approximately 400 kg/m^3, which from DHI's previous monitoring experience is a suitable "typical" density of settled fine material from dredging or reclamation. The limits have been developed based on the most sensitive mangrove species (*A. marina*), in order to ensure that the levels of impact predicted are conservative.

Table 9.3 Preliminary matrix of impact zones for sedimentation impact on mangroves, for assessment of short-term scenario model results

Zone*	Definitions
Zone of Total Mortality	• Sedimentation > 3 $kg/m^2/day$ (> 100 mm/14day*)
Zone of Partial Mortality	• Sedimentation 1.5 – 3 $kg/m^2/day$ (50 – 100 mm/14day*)
Zone of Influence	• Sedimentation 0.03 – 1.5 $kg/cm^2/day$ (1 – 50 mm/14day*)
No Impact	• Sedimentation < 0.03 $kg/m^2/day$ (< 1 mm/14day*)

** assuming an initial deposition dry density of 400 kg/m^3*

9.3 Mangrove Tolerance to Erosion

While erosion is a natural process, it may be exacerbated by human influence. Dredging and reclamation works both alter tidal flow patterns and it is important to distinguish their impact from the natural rate of erosion. However, few studies have been carried out on erosion in mangroves, and earlier works suggest highly variable erosion rates on a temporal and spatial scale (Paling *et al.* 2003, Semeniuk 1980).

A study carried out on mangroves situated at creeks in and around Port Hedland, WA, recorded mangrove mortality in certain areas. However, it was concluded that the development within the harbour did not have any significant impacts on creek erosion since the greatest mortality was experienced far from human habitation (Paling *et al.* 2003).

DHI has undertaken a number of studies assessing erosion impacts on mangroves at various locations throughout south east Asia. Mild to moderate erosion may expose pneumatophores, which will affect the respiration of mangroves, but is not likely to result in mortalities. Based on DHI's previous monitoring experience in south east Asia, mortalities generally result once an erosion berm of more than 50–100 cm has formed, undercutting the mangroves trees along the shoreline and causing trees to lean or fall into the water.

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APPENDIX A

Literature Review

SG5240-05/Chevron Wheatstone Tolerance Limits/Final/mjj/05-10

A. LITERATURE REVIEW

A.1 Corals

A.1.1 Coral Tolerance to Suspended Sediments

There is a growing body of evidence from field studies showing that turbidity and sedimentation can degrade coral reefs at local scales (e.g. Anthony and Connolly 2004, Babcock and Smith 2002, Cooper *et al.* 2007, Fabricius 2005, Fabricius *et al.* 2007, Gilmour *et al.* 2006).

Turbidity in the marine environment can be measured directly in terms of nephelometric turbidity units (NTU), which are measured by a nephalometer, or as the concentration of total suspended solids (TSS, mg/l). Turbidity can also be measured indirectly as light attenuation from Secchi disk readings (cm) or water column attenuation coefficients (K_d or E).

Hard or hermatypic corals (Scleractinia) host unicellular photosynthesising algae, known as zooxanthellae, within their tissue. The photosynthetic activity of the zooxanthellae results in translocation of carbohydrates, which represents a major energy source for the coral host (Muscatine 1990). In turn, corals supply their zooxanthellae with essential nutrients, such as nitrogen and phosphorus (Muscatine 1990). Autotrophic carbon translocation is highly sensitive to light reduction and the quantity and type of deposited materials as a result of increased levels of suspended materials (Philipp and Fabricius 2003, Weber *et al.* 2006). This was quantified by Hawker and Connell (1992) who found that a 30% increase in average long-term background suspended sediments levels resulted in a 20% reduction in annual growth rate.

However, background levels vary temporally and at local and regional scales (Cooper *et al.* 2007, Cooper *et al.* 2008, Wolanski *et al.* 2008). In addition, turbidity is strongly influenced by local weather conditions such as wind, waves and tides (Cooper *et al.* 2008). While mean suspended sediment concentrations on coral reefs are typically <5 mg/1 (Pastorok and Bilyard 1985) they may exceed approximately 80 mg/l for 20–30 days per year due to wind resuspension around some inshore reefs on the GBR (Wolanski 1994, Wolanski *et al.* 2005). Hawker and Connell (1992) outlined that corals on the GBR have a tolerance to suspended sediments up to 4mg/l. However, given the above levels of suspended sediments for inshore reefs on the GBR, such a limit may be considered suitable only for corals on offshore reefs. A wide range of tolerance limits of corals for suspended sediments are found in different geographic regions and tend to be species-specific. These values are presented below in Table A.1.

In the Pilbara region, levels of turbidity are highly variable and driven by local weather conditions (e.g. Forde 1985, Gilmour *et al.* 2006, Simpson 1988). Hence, natural variability in turbidity levels complicates any attempt to determine threshold values for anthropogenically elevated turbidity.

Table A.1 Critical threshold of different species of corals for total suspended matter/TSM (mg/l)

Species/ Types of corals	Location	TSM (mg/l)	Response	Reference
Faviids (e.g. Goniastrea retiformis)	Orpheus Island, GBR, Australia	41	Feeding saturation	Anthony and Fabricius (2000)
Acropora digitifera	Coral Bay, Ningaloo Reef, Australia	≥50	Reduced larval settlement and survival	Gilmour (1999)
Acropora millepora	Orpheus Island, GBR, Australia	> 30	Feeding saturation	Anthony and Fabricius (2000)
Acropora millepora	Davis Reef, GBR, Australia	≥100	Reduced fertilisation by 50%	Humphrey *et al.* (2008)
Monitpora verrucosa	Kaneohe bay, Hawaii	8	Reduction of photosynthetic production by 28%	Te (1997)
Pocillopora damicornis	Guam	>1000	Reversed metamorphosis "polyps bail-out" by planulae	Te (1992)
Porites cylindrica	Orpheus Island, GBR, Australia	4 - 8	Feeding saturation	Anthony (1999)
Turbinaria mesenterina	Australia	~ 50	Feeding saturation	Anthony and Connolly (2004)

Acceptable levels of turbidity will depend on hydrodynamic conditions, sedimentation rates, and background turbidity and will therefore need to be adjusted to local conditions (Sofonia and Anthony 2008). Preliminary estimates of tolerance to turbidity made by Gilmour *et al.* (2006) are illustrated in Figure A.2. These estimates are based on limited data presently available from the Pilbara and other regions and will need to be refined and corrected within future research (Gilmour *et al.* 2006).

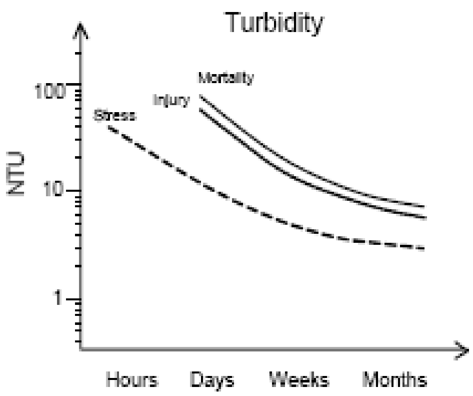

Figure A.1 Preliminary estimates of the loads and durations of turbidity likely to cause increasing levels of impacts to corals. The curve applies to relatively 'tolerant' species of corals from inshore reefs within the Pilbara, and more susceptible species will have the same levels of impact at lesser loads and/or durations. Source: Gilmour et al. *2006).*

In addition, recent experience from feedback monitoring projects (DHI 2007, Doorne-Groen 2007, Driscoll *et al.* 1997) indicates that the tolerance levels cannot be described by a single threshold criterion. Rates of primary production and respiration are both sensitive to turbidity, while water depth and the diurnal light cycle also play a critical role, such that the only hard and fast method of establishing tolerance limits for coral is to carry out feedback monitoring, where hindcast of sediment spills is compared against habitat response, leading to tolerance limits updates during the course of the dredging or reclamation project.

A.2 Coral Tolerance to Reduced Light Levels

Light availability is generally measured directly as photosynthetically active radiation (PAR), expressed either as µmol photons/m^2/s or µE/m^2/s, or as a relative measure (e.g. % of surface irradiance). Light in water is absorbed by water itself, by dissolved organic carbon (DOC) and by suspended particles (phytoplankton, organic and inorganic solids). Suspended particles furthermore scatter the light which contributes to an increased light attenuation (Kirk, 1994). Light decreases exponentially according to Lambert-Beer's Law:

$$\mathbf{I_z = I_o e^{-zK_d}}$$

where: I_z is the irradiance (µE/m^2/s) at water depth z (m)
I_o is the irrandiance just below the surface, and
K_d is the diffuse attenuation coefficient (per m)

This diffuse attenuation coefficient can be estimated from measurements of light intensity at two depths (e.g. at surface and seabed):

$$\mathbf{K_d = -\frac{\ln(I_{seab}/I_{surf})}{\Delta z} \quad = \quad K_o + K_1.C}$$

where
K_o is the background absorption rate
K_1 is the absorption rate for suspended sediments, and
C is the concentration of suspended sediments

It is therefore possible to estimate K_o and K_1 by using a linear regression of measured TSS concentration against K_d (determined from surface and seabed light measurements).

Light-dependent photosynthetic activity of the zooxanthellae is a key driver of coral growth and survival (Muscatine *et al.* 1990). Corals are, therefore, highly sensitive to increases in suspended sediment and the corresponding reduction in light penetration (Yentsch *et al.* 2002). It has been shown that corals require a minimum amount of light corresponding to approximately 2–8 % of surface irradiance (e.g. Cooper *et al.* 2007, Titlyanov and Latypov 1991, Table A.2). Although such a limit allows the maintenance of corals, it might be insufficient to support active reef growth (Cooper *et al.* 2007).

Reduced light is known to, at least temporarily, reduce photosynthesis by zooxanthellae, leading to lower carbon gains, slower calcification (reef-accretion) and thinner tissues in corals (Anthony and Fabricius 2000, Fabricius 2005). The optimal quality of light (spectral composition) light intensity may be specific to some corals, and has also been shown to be important for the settlement and metamorphosis of some coral planulae (Mundy and Babcock 1998). For *Oxypora lacera* planulae, optimum light intensities of approximately 100-400 µmol photons/m^2/s have been established (Babcock and Mundy 1996, Mundy and Babcock 1998).

Scleractinian corals have developed several ways to increase their light-capturing and light regulating abilities at low light intensities in order to maintain high carbon fixation rates. Corals are known to expand their motile parts (polyp and tentacles) to enhance light exposure of zooxanthellae and thereby influence their photosynthetic activity (Ulstrup *et al.* 2006, Varesehi *et al.* 2007). Meanwhile, a majority of corals can adjust to light reduction by increasing the size and amount of chloroplasts in zooxanthellae within 5 to 10 days (Anthony and Fabricius 2000, Anthony and Hoegh-Guldberg 2003, Fabricius 2005). Corals are also known to regulate their host pigmentation composition in order to enhance guidance of light to chlorophyll *a* (Dove *et al.* 2008). In other instances of light reduction, corals compensate by preferentially growing in a certain depth range where they can survive or maintain active reef growth. The maximum depth range for corals diminishes as a direct function of turbidity from >40m in low turbidity environments to <4m water depth in highly turbid environments.

While autotrophy (photosynthesis) is an important avenue for carbon fixation, in particular in shallow well-lit water, heterotrophy (e.g. filter feeding) is a means by which corals supplement their nutrient requirements and source important nutrients (Porter 1976). Various studies have demonstrated that corals can feed on a variety of food sources, including dissolved and particulate organic matter (e.g. Al-Moghrabi *et al.* 1993, Anthony 1999) and suspended sediments (Rosenfeld *et al.* 1999). Heterotrophy has been shown to account for between 0 and 66% of fixed carbon incorporated into corals (Muscatine *et al.* 1989, Grottoli and Wellington 1999). In addition to providing carbon, heterotrophic feeding is important, since nitrogen, phosphorus, and other nutrients cannot be supplied from zooxanthellar photosynthesis but must come from capture of zooplankton, particulate matter or dissolved compounds (e.g. Muscatine and Porter 1977).

Although corals may compensate for loss of autotrophic carbon fixation by increasing their feeding activity (Anthony and Fabricius 2000), feeding saturation has in one study been shown to occur at very low levels (4–8mg/l) of suspended particulate matter, suggesting that an increase in concentrations above this level may not be metabolically beneficial (Anthony 1999). Rather, high concentrations of suspended particles have been shown to result in intensified physical disturbance and energy loss through respiration and exertion (Telesniki and Goldberg 1995, Anthony 1999). Nevertheless, enhanced feeding activity and thereby maintenance of lipid energy stores under turbid conditions has been shown to benefit corals' nutritional condition and therefore their resilience (e.g. Anthony and Fabricius 2000, Saunders *et al.* 2005).

Importantly, increases in photosynthetically active tissue, chlorophyll *a*, have been widely documented in symbiotic organisms exposed to heterotrophic enrichment, specifically nitrogen compounds (Stambler *et al.* 1991, Muller-Parker *et al.* 1994). Houlbreque *et al.* (2003) found that chlorophyll *a* concentrations were 4 to 7-fold greater and rates of photosynthesis 2–10 times higher in fed than in unfed corals. This suggests that autotrophic and heterotrophic feeding modes act in concert for the benefit of the whole organism (coral + zooxanthellae).

Table A.2 presents available information on the responses of different corals to the effects of light reduction.

Table A.2 Critical threshold of corals for light availability ('minimum light requirements' expressed as photosynthetically active radiation, PAR)

Species/ Types of corals	Location	PAR (µmol photons/m²/s)*	Response	Reference
Acropora valida	GBR, Australia	200	Rate of photosynthesis four times lower than *T. mesenterina*	Anthony & Connolly (2004)
Fungia paumotensis (mushroom coral)	Gulf of Siam	2 – 9% surface irradiance	Minimum light requirements for growth	Tityanov & Latypov (1991)
Goniastrea rectiformis	Orpheus Island, GBR, Australia	140	- Photoacclimate - More than doubled rate of particle feeding	Anthony & Fabricius (2000)
Lobophyllia hemprichii	Gulf of Siam	2 – 9% surface irradiance	Minimum light requirements for growth	Tityanov & Latypov (1991)
Montipora peltiformis	GBR, Australia	30% surface irradiance	Photosynthetic activity of zooxanthellae negatively affected	Philipp & Fabricius
Platygyra daedalea	Gulf of Siam	2 – 9% surface irradiance	Minimum light requirements for growth	Tityanov & Latypov (1991)
Plerogyra sinuosa	Eilat Sea, Israel	20% surface irradiance	Expansion of globular tentacles in daytime to maximise light exposure	Varesehi & Frieke (1986)
Pocillopora damicornis	Gulf of Siam	2 – 9% surface irradiance	Minimum light requirements for growth	Tityanov & Latypov (1991)
Porites cylindrica	Orpheus Island, GBR, Australia	140	- Did not photoacclimate - Feeding rate four-eight folds lower than *G. rectiformis*	Anthony & Fabricius (2000)
Turbinaria mesenterina	GBR, Australia	200	Rate of photosynthesis four times higher than *A. valida*	Anthony & Connolly (2004)
Turbinaria mesenterina	GBR, Australia	370	Steady-state saturation irradiance and maximum growth occurs	Anthony & Hoegh-Guldberg (2003)
Coastal and outer reefs	Whitsunday Islands, GBR, Australia	≥ 104 115	Minimum amount of light for coral reef establishment	Cooper *et al.* (2007)

**Units in µmol photons/m²/s unless stated otherwise*

A.3 Coral Tolerance to Sedimentation

Sediment traps are commonly used to measure the deposition rate of particulate materials (referred to as sedimentation). They may be moored at particular locations of interest from where they are retrieved after an extended period of time (days–weeks) and analyses of contents can be performed.

Accumulation of sediments on corals is inherently determined by the settling rate of suspended solids as well as the morphology of coral colonies and their ability to rid themselves of deposited particles. Horizontal foliose, plate-like or tabulate (e.g. *Montipora* and *Acropora*) and encrusting (e.g. *Montipora* and *Pavona*) growth forms present stable surfaces for retention of settling solids. In contrast, vertical foliose (e.g. *Turbinaria* and *Pavona*) and upright branching growth forms (e.g. *Acropora*) are less likely to retain sediments. Digitate and massive colonies (e,g. *Porites* and *Favia*) typically exhibit intermediate susceptibility to sedimentation as these growth forms are likely to only partially retain sediments (Hawker and Connell 1992, Gilmour *et al.* 2006).

The susceptibility of different coral taxa to sedimentation, as well as the generalised susceptibility of the main coral growth forms, are shown in Table A.3.

Table A.3 Groups of corals of varying susceptibility to sedimentation and turbidity (Gilmour et al. 2006).

Relative Susceptibility	Group	Sedimentation and Turbidity
High	Taxa	*Montipora*
		Agaricidae
		Pectinidae
		Acropora (plate)
	Growth Forms	Plating/encrusting corals
Medium	Taxa	*Porites** (massive)
		Favites
		Favia
		Pocillopora
		Acropora (branching)
	Growth Forms	Massive corals
Low	Taxa	*Turbinaria*
		Fungia
		Goniopora
		Galaxea
		Pavona
		Porites (branching)
	Growth Forms	Branching corals

**In some instances massive* Porites *colonies have displayed variable susceptibility to increased sedimentation*

Sediments on corals may be removed by production and release of mucus which lifts particles from the coral tissue (Riegl and Branch 1995). Furthermore, corals may actively trap and reject particles using their tentacles (Anthony and Fabricius 2000). These processes come at an energetic expense to the coral through loss of carbon from mucus release and enhanced respiration (Anthony and Fabricius 2000), and contribute to compromise the fitness of the coral. Furthermore, deposition of particles in excess of what may be removed through mucus release or particle trapping may clog the feeding apparatus of the corals and cause elevated mortality (Philipp and Fabricius 2003).

Stafford-Smith and Ormond (1992) reported that in general, all species with large calices (>10mm in diameter) are capable of rejecting influxes of up to at least

50 mg/cm^2, while species with smaller calices (<2.5mm in diameter) are poor sediment rejectors. Corals with calices between 2.5 and 10mm in diameter varied in their responses, although most active rejectors in this size class have strong ciliary mechanisms. The findings from their investigation are summarised below in Table A.4. Only coral genera which were recorded during the URS site survey (URS, 2009) are reflected in the table.

Table A.4 Summary of behavioural responses to sediment influxes of Australian scleractinian corals (Source: Stafford-Smith and Ormond 1992)

Species/Types of corals	Calice diameter (mm)	Group no.*	Active-rejection capability
Acropora hyacinthus	0.85	6	Active rejection redundant
Acropora florida	1.1	4	Manipulates silt and fine sand slowly; movement of larger particles often laboured
Favia stelligera	3	3	Easily manipulates silt and fine sand; movement of larger particles often laboured
Favia pallid	8	1A	Easily manipulates all sediment sizes
Favites abdita	9.5	2	Easily manipulates silt, fine and coarse sand
Fungia repanda	200	1A	Easily manipulates all sediment sizes
Goniopora lobata	4	1A	Easily manipulates all sediment sizes
Lobophyllia hemprichii	40	1A	Easily manipulates all sediment sizes
Lobophyllia corymbosa	35	1A	Easily manipulates all sediment sizes
Monitopora danae	0.65	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Montipora foliosa	0.7	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Montipora aequituberculata	0.6	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Platygyra lamellina	4	2	Easily manipulates silt, fine and coarse sand
Pocillopora damicornis	1.1	6	Active rejection redundant
Porites lobata	1.5	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Porites lutea	1.25	5	Manipulates silt; movement of fine sand is slow; little rejection of large particles
Turbinaria peltata	4	1A	Easily manipulates all sediment sizes
Turbinaria mesenterina	3	3	Easily manipulates silt and fine sand; movement of larger particles often laboured

**Rejection capability decreases with increasing numerical order e.g. Group 6 is the most ineffective active rejector and has the lowest tolerance to sedimentation.*

Turbinaria sp. is a hardy, foliose coral which is particularly resistant to sedimentation. Laboratory experiments carried out on the coral *Turbinaria mesenterina* from the inner GBR lagoon revealed that it is tolerant to sediment loads an order of magnitude higher than most severe sediment conditions *in situ* (Sofonia and Anthony 2008). Other coral species such as *Montipora verrucosa* is also known to be sediment-tolerant and may be covered by sediments for weeks without signs of physiological damage (Hodgson 1990). *Montipora* is prevalent among many turbid coral communities in the Indo-Pacific and can adapt to turbid conditions and enhanced sedimentation by acquiring growth forms that enhance passive sediment shedding (i.e. more branched growth form or vertical orientation) (Bull 1982, Stafford-Smith 1993). Similarly, *Porites* is another highly sediment-tolerant coral species (Stafford-Smith 1993). While the small-polyped *Porites* corals are inefficient sediment rejectors, they may be highly resilient to sedimentation and are known to recover even after complete burial over three days (Sanders and Baron-Szab 2005, Wesseling *et al.* 1999).

Based on open water reef environments with low levels of natural sedimentation Pastorok and Bilyard (1985) have suggested the following criteria:

- 0.01 – 0.1 $kg/m^2/day$ slight to moderate impacts;
- 0.1 – 0.5 $kg/m^2/day$ moderate to severe; and
- > 0.5 $kg/m^2/day$ severe to catastrophic.

However, fringing and inshore reef environments are known to experience sedimentation events in exceedence of 0.5 $kg/m^2/day$ (severe to catastrophic) and support flourishing coral communities (Ayling and Ayling 1987). The adoption of a strict criterion for impact assessment based on Pastorok and Bilyard's system therefore may be overly protective in environments where corals assemblages are resilient to periodic or consistently high background rates of sedimentation. Hawker and Connell (1992) have suggested that a value of 0.3 $kg/m^2/day$ is regarded as the absolute limit for sediment deposition in inshore areas. Meanwhile, Rogers (1990) indicated that 'normal' sedimentation rates for Caribbean coral reefs appear to be on the order of 0.1 $kg/m^2/day$. Combined, these studies suggest that there is considerable variation in maximum sedimentation thresholds for corals and highlight that in-depth knowledge of local conditions is important for accurate recommendations.

An overview of values reported in the literature as critical threshold sedimentation rates for different coral species at different locations is presented below in Table A.5.

Table A.5 Critical threshold of different species of corals for sedimentation ($mg/cm^2/day$)

Species/Types of corals	Location	Sedimentation ($mg/cm^2/day$)	Response	Reference
Acropora millepora	Ningaloo Reef, Australia	1-11.7	Reduced recruit survival	Babcock and Smith (2002)
Acropora cervicornls	Jamaica	200	No effect	Dallmeyer (1982)
Acropora palmata	Caribbean	200	Death of underlying tissue	Rogers (1983)

Species/Types of corals	Location	Sedimentation (mg/cm²/day)	Response	Reference
Montipora peltiformis	GBR, Australia	≥109	Death	Philipp and Fabricius (2003)
Montastrea annularis	Jamaica	800	Death of underlying tissue	Dallmeyer (1982)
Montastrea cavernosa	Panama	13.8	Death	Lasker (1980)
Porites asteorides (green morphs)	St Croix, US Virgin Islands	3.6-4.0	Reduction in sediment clearing	Gleason (1998)
Porites asteorides (brown morphs)	St Croix, US Virgin Islands	5.0-5.4	Reduction in sediment clearing	Gleason (1998)
Porites sp.	Bolinao, Philippines	Experimental burial of 1-5 cm over 68 hr	90% bleached tissue; recovery after 4 wk	Wesseling *et al.* (1999)
Turbinaria mesenterina	Magnetic Island, GBR, Australia	>100	Able to clear sediment in ~4-5 hr	Sofonia and Anthony (2008)

Setting threshold values for sedimentation is complex, as responses are species-specific, tend to be dose-dependent and spatially variable (Gilmour *et al.* 2006). This is especially so for corals in the Pilbara region, where background levels of sedimentation vary dramatically over small spatial and temporal scales. It is therefore likely that coral communities on inshore reefs within the Pilbara are able to withstand discrete pulses of relatively high sedimentation.

Acceptable levels of sedimentation will depend on hydrodynamic conditions, sedimentation rates, and background turbidity and will therefore need to be adjusted to local conditions (Sofonia and Anthony 2008). Preliminary estimates of tolerance to sedimentation made by Gilmour et al. (2006) are illustrated in Figure A.2. These estimates are based on limited data presently available from the Pilbara and other regions and will need to be refined and corrected within future research (Gilmour *et al.* 2006).

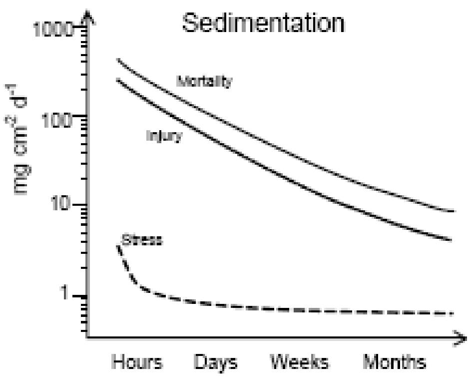

Figure A.2 *Preliminary estimates of the loads and durations of sedimentation likely to cause increasing levels of impacts to corals. The curve applies to relatively 'tolerant' species of corals from inshore reefs within the Pilbara, and more susceptible species will have the same levels of impact at lesser loads and/or durations. Source: Gilmour* et al. *2006).*

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A.4 Filter Feeders

A.4.1 Octocorals (Gorgonians and Soft Corals)

Octocoral Tolerance to Suspended Sediments

Of the 90 known octocoral genera recorded in shallow tropical to sub-tropical Indo-Pacific waters, only 31 genera contain zooxanthellae (Fabricius and Alderslade (2001). The 59 other zooxanthellate-free taxa depend entirely on heterotrophy, such as suspension feeding on small plankton, to cover their carbon demand (Fabricius *et al.* 1995, Fabricius and Klumpp 1995). In addition to heterotrophic energy acquisition, zooxanthellate taxa of octocorals require light to drive photosynthesis and hence carbon fixation to meet their nutritional requirements. Because of this, zooxanthellate taxa are generally found at shallower depths, and are sensitive to light attenuation resulting from increased turbidity, while zooxanthellate-free taxa tend to dominate low-light environments, and be relatively unaffected by suspended sediments (Fabricius and McCorry 2006).

In a recent study in turbid waters (secchi depth ~2–4 m) of Hong Kong, zooxanthellate-free taxa of octocorals were abundant, averaging 79% of the total octocoral genera recorded per survey (Fabricius and McCorry 2006). In contrast, zooxanthellate octocorals in clear waters of southern Taiwan, situated on the same continental shelf 600 km east of Hong Kong were abundant (Dai 1991). Low visibility was also found to be strongly related to decreased abundance and richness of zooxanthellate octocoralson the GBR (Fabricius and De'ath 2001b), where zooxanthellate octocoral species richness declined by one genus for each metre reduction in visibility at sites with visibilities of <10m. In combination, these studies suggest that water clarity is important for the prevalence of zooxanthellate taxa of octocorals.

Manipulative experiments in the laboratory have also demonstrated a negative correlation between turbidity and the photosynthetic activities of soft corals. In a study by Riegl and Branch (1995), enhanced conditions of suspended sediments were simulated on five species of soft corals. Under turbid conditions corresponding to a 75% reduction in light intensity, all soft coral species, with the exception of *Lobophytum venustum,* demonstrated a decrease in photosynthetic activity, an increase in respiration and subsequent increased loss of carbon through greater mucus output. *Lobophytum venustum* was suggested to be more sediment-tolerant due to the presence of numerous high ridges on the upper surface, hence supporting the importance of morphology in countering the harmful effects of sediments (Fabricius and McCorry 2006, Rogers 1990).

Octocoral Tolerance to Sedimentation

Numerous studies have described the behavioural and growth responses of scleractinian corals to sedimentation (e.g. Rogers 1990, Sofonia and Anthony 2008, Stafford-Smith 1993). In comparison, only limited studies have been carried out on octocorals. Some studies have suggested that octocorals have a better ability than scleractinians to survive elevated suspended sediment conditions (Anthony and

Fabricius 2000, Riegl and Branch 1995). However, a study by Riegl (1995) revealed that although soft corals attempted to remove sediment by inflation of the entire corallum and the formation of mucus sheets, tissue necrosis appeared after one week of continuous sand application (200 mg/cm^2). The dominance of “passive sediment shedder” soft corals in areas of high sedimentation may be attributed to water motion or gravity (when growing on inclined substrata) which would wash off settled sand.

Meanwhile, effects of sedimentation on gorgonians are also poorly studied, with most studies merely inferring the relationship between the composition and abundance of gorgonians to sedimentation (Goh and Chou 1995, Gotelli 1988, Yoshioka and Yoshioka 1989a). Gorgonians growing in the highly sedimented waters (sedimentation rate ~14.1 mg/cm^2/day) of Singapore were reported to have growth rates comparable to other regions (Goh and Chou 1995). Another study attributed the differences in composition and overall gorgonian cover on the fore-reef and lagoon to differences in sedimentation, inclination and substratum (Sanchez et al. 1997). Furthermore, some studies have found that excessive sedimentation may hinder octocoral recruitment (Gotelli 1988) and growth (Yoshioka and Yoshioka 1989b).

A.5 Sponges

A.5.1 Sponge Tolerance to Suspended Sediments

Sponges are important benthic filter feeders, occupying a wide range of habitats from temperate to tropical areas (Bell 2004). Sponges also include both heterotrophs (filter-feeders) and mixotrophs that may derive >50% of their nutrition from photosynthesis of their associated zooxanthellae. Many factors are thought to determine the distribution of sponges, including light availability and sedimentation (Burns and Bingham 2002).

Sponges on the inner-shelf reefs of the GBR are known to be mainly heterotrophic whilst those on middle- and outer-shelf reefs are predominantly mixotrophic (Cheshire and Wilkinson 1991, Whalan *et al.* 2007, Wilkinson and Trott 1985). Cheshire and Wilkinson (1991) found that zooxanthellate sponges on the fore-slope of Davies Reef, GBR, grow to a depth of 30m (corresponding to 8% of surface light). In contrast, zooxanthellate sponges in lagoon environments (with increased suspended sediments and decreased light availability) grew to a maximum depth of 22m. Meanwhile, a study conducted in the Torres Straits Archipelago (between northern Queensland and Papua New Guinea) (Duckworth et al. 2008), documented zooxanthellate species that are also found on the GBR, such as *Carteriospongia flabellifera, Phyllospongia lamellosa* and *P. papyracea*, at shallower depths of 5–10m. Year-round water visibility at Torres Straits was lower than the middle- and outer-shelf reefs of the GBR, resulting in zooxanthellate sponges occupying shallower habitats. Hence, the availability of light and correlated factors such as suspended sediments are important in determining the distribution of zooxanthellate sponges. As a result, these sponges are generally flattened with a high surface to volume or weight ratio to enhance light-capturing efficiency (Cheshire and Wilkinson 1991, Wilkinson and Trott (1985). In addition, some studies predict that the turbid conditions of the inner reefs at the GBR are likely to be a contributing factor to reduced reproductive output for inner shelf reef sponges (Whalan *et al.* 2007).

Other detrimental effects of suspended sediments include a reduction or a complete halt in filtration, which would have adverse effects on feeding and respiration. As seen in a study on a tropical sponge, *Verongia lacunosa*, a sediment load in the water as low as >11mg/l was enough to cause a reduction in the pumping rate of the sponge (Gerrogett and Flechsig 1979). Meanwhile, an arrest in pumping rates of hexactinellid sponges was also noted in a more recent study by Tompkins-MacDonald and LeysGlass (2008). Continuous input of sediment to two species of hexactinellid sponges resulted in arrested pumping at sediment levels of 15mg/l and 36mg/l, respectively. This range of tolerance limits suggests a species-specific response to elevated levels of suspended sediments. Hence, some caution should be exercised when assigning absolute values to threshold values of sponges to suspended sediments.

A.5.2 Sponge Tolerance to Sedimentation

Filter feeders such as sponges are actually important water quality indicators since extreme sedimentation can reduce their growth rate by clogging their feeding apparatus (Lohrer *et al.* 2006, Przeslawski *et al.* 2008).

On tropical rocky coasts, increased sedimentation is one of the main factors shaping sponge assemblages, where 69% of variance observed in long term fluctuations of annual patterns of sponge diversity was correlated with sediment deposition (Carballo *et al.* 2008). Increased sedimentation has also been linked to bleaching and necrosis in sponges, likely due to smothering and lowered photosynthetic rates (Fabricius *et al.* 2007).

Several adaptations exist for sponges living in highly sedimented areas. Encrusting or papillate-shaped sponges have been reported to be buried in coarse sand, through which they exploit interstitial water even though their surface is covered with sediments (Ilan and Abelson 1995). In a study carried out in Spermonde Archipelago, Indonesia (de Voogd and Cleary 2007), globular, fan-shaped and fistulose growth forms were associated with sites with poor water transparency, whereas tube and massive-encrusting growth forms were associated with sites with good water transparency. These studies suggest the importance of morphological features in the establishment of sponges in highly sedimented areas (Ilan and Abelson 1995, Rutzler 1997). Morphological adaptation in connection with high sedimentation rates is also documented in temperate regions. In Ireland, the tubular sponge, *Haliclona urceolus*, was found growing up to depths of 24m while experiencing sedimentation rates of ~30–60g sediment/m^2/day (Bell 2004). The survival of this sponge in such conditions was attributed to the upward direction of the exhalant water flow (which prevented sediment settlement on upper surfaces), coupled with the angled tubular shaped morphology.

In addition, sponges also grow in selective niches such as on the shells of mobile invertebrates which periodically dislodge sediments (Burns and Bingham 2002) or live on vertical surfaces such as cliff overhangs, which will experience considerably less sediment accumulation than inclined or horizontal surfaces (Bell and Barnes

2000). Sponges may employ both passive and active mechanisms to remove sediment from their surfaces or to prevent sediment settlement in the first place. Although there exist various literature to describe these strategies (e.g. Ilan and Abelson 1995, Bell and Barnes 2000, Burns and Bingham 2002, Bell 2004, and de Voogd and Cleary 2007,), there is a lack of information on critical levels of sedimentation that would result in smothering, clogging of the filtering apparatus or other deleterious effects on sponges.

A.6 Seagrass

A.6.1 Seagrass Tolerance to Suspended Sediments

The main impact of suspended sediments on seagrass is reduced light availability, although scouring by sediment particles can also have some impact.

Tolerances of seagrass to suspended sediments are also known to be species-specific. A study carried out at several sites in Moreton Bay, Australia documented *Halophila spinulosa* growing in areas where total suspended solids (TSS) ranged from 1.96mg/l to 4.25mg/l (Abal and Dennison 1996). In the same study, *Halophila ovalis* was more tolerant to the effects of turbidity, having been found at a few sampling stations with up to 9.64mg/l of TSS.

Most of the literature on seagrass tolerance is related to light reduction, rather than suspended sediment concentration. Details of seagrass tolerance to light reduction is summarised below.

A.6.2 Seagrass Tolerance to Reduced Light Levels

Productivity of seagrass can be limited by reduced light penetration resulting from the presence of algal blooms and suspended sediments. Some of the best documented losses of seagrass due to light limitation have occurred in Australia (Dennison *et al.* 1993, Ralph *et al.* 2007, Walker and McComb 1992). Localised declines in seagrass cover have occurred in the Whitsunday and Hervey Bay areas, where sewage effluents led to nutrient enrichment of the waters, resulting in algal blooms and subsequent events of light deprivation (Longstaff and Dennison 1999, Preen *et al.* 1995).

The sensitivity of seagrass to reductions in light availability is attributed to their high minimum light requirements (Dennison *et al.* 1993). Seagrass requirements for light penetration have been well described, with the habitat being confined to water depths where light levels are 4.4–29% of surface irradiance (SI) for different species (Erftemejer and Lewis 2006, Ralph *et al.* 2007) and 5–20% within a species (Dennison 1987). On average, the light requirement of seagrass as a group of plants has been calculated to be 11% of SI (Duarte 1991). Such a large range is caused by:

- inter-specific differences;
- morphologic and physiologic adaptation within a species (i.e. elongation of leaves to reach higher in the water column, increased amount of chlorophyll *a* per unit leaf area);

- presence of epiphytes on seagrass leaves reducing the light availability; and
- other confounding factors such as wave exposure and sediment composition.

Seagrass species recorded by URS (2009) in the study area included *Halophila ovalis, Halophila decipiens* and *Halophila spinulosa.*

Halophila ovalis is known to have a very limited tolerance to light deprivation caused by anthropogenic changes. Longstaff *et al.* 1999 showed that complete darkness for more than 30 days would result in complete die off of *Halophila ovalis*. In general, the survival period of seagrass below its minimum light requirement is shorter in smaller species, which have a low carbohydrate storage capacity, as compared to larger species (e.g. *Posidonia* or *Enhalus* spp.). Hence, it has been suggested that the long-term survival strategy of *Halophila* species would rely on the ability to rapidly regrow from seed and/or vegetative fragments after light deprivation, once light conditions have improved (Terrados *et al.* 1998, Longstaff and Dennison 1999).

A study carried out in Moreton Bay, Australia, documented the growth of *Halophila spinulosa* in areas where the water transparency averaged 1.30m, based on secchi disc depth readings (Abal and Dennison 1996). In the same study, *Halophila ovalis* was found to be growing in waters of only 0.65 m transparency and thus appeared to be more tolerant to light attenuation. Overall, the minimum light requirements of most *Halophila* spp. have been reported to be as low as 3–8% SI (Erftemejer and Lewis 2006).

Table A.6 shows the minimum light requirements for different species of *Halophila*.

Table A.6 Critical thresholds of light availability for seagrass (minimum light requirement is expressed as % of surface irradiance, SI)

Species	Location	% SI	Reference
Halophila decipiens	Hobe Sound, Florida, USA	2.5	Dennison (1987)
Halophila decipiens	St. Croix, Caribbean	4.4	Williams and Dennison (1990)
Halophila decipiens	Northwest Cuba	8.8	Duarte (1991)
Halophila ovalis	Zanzibar, Tanzania	16	Schwartz *et al.* (2000)
Halophila spp.	Sub tropical seas	5	Dennison *et al.* (1993)

The minimum light requirements for seagrass species have been derived from empirical determinations of the percentage of surface irradiance at the maximum colonisation depth (Dennison *et al.* 1993, Ralph *et al.* 2007). As a result, we have a better understanding about the minimum amount of light required for seagrass growth, but little information exists about the association between plant survival and light availability (Ralph *et al.* 2007, Schaffelke *et al.* 2000).

A.6.3 Seagrass Tolerance to Sedimentation

Similar to information regarding the tolerance of seagrass species to suspended sediments off the coast of Onslow, not much is known of the effects of sedimentation on seagrass in the project area. Nevertheless, the environmental impacts on seagrass meadows arising from dredging and reclamation works are still relevant. This is shown in a literature review compiled by Erftemeijer and Lewis (2006) which reports widespread loss of seagrass meadows in Australia ranging from a few hundred to a few thousand hectares as a result of dredging and associated turbidity and burial effects. Critical thresholds of seagrass for sedimentation are better documented in South-East Asia, especially the Philippines (Duarte *et al.* 1997, Vermaat *et al.* 1997, Cabaco *et al.* 2008), and other areas in the Mediterranean as seen below in Table A.7 and in Table A.8.

Table A.7 Critical thresholds of sedimentation for seagrass (cm/year)

Species	Location	Sedimentation (cm/yr)	Reference
Cymodocea nodosa	Mediterranean (Spain)	5	Marba and Duarte 1994
Cymodocea rotundata	Philippines	1.5	Vermaat *et al.* 1997
Cymodocea serrulata	Philippines	13	Vermaat *et al.* 1997
Enhalus acoroides	Philippines	10	Vermaat *et al.* 1997
Halophila ovalis	Philippines	2	Vermaat *et al.* 1997
Posidonia oceanica	Mediterranean (Spain)	5	Manzanera *et al.* 1995
Zostera noltii	Mediterranean (Spain)	2	Vermaat *et al.* 1997

As seen in Table A.7 and in a review by Vermaat *et al.* (1997), sedimentation rates of 2–13cm/yr can be coped with by vertical stem elongation. Similar sedimentation levels over shorter periods (weeks to months) can also be tolerated to varying degrees by different species, although with some mortalities (Table A.8). For larger species, growth rates can be high, with growth rates in the order of 1–2cm per day recorded for *Thalassia* sp. (Driscoll *et al.* 1997) whilst growth rates in the order of 0.9cm per day have been recorded for *Enhalus* sp. in the Philippines (Estacion and Fortes 1988), enabling them to better cope with partial or full burial. But even for smaller colonising species, such as *Halophila*, growth rates play an important part in coping with sedimentation (Cabaco *et al.* 2008).

In the case of very high sedimentation rates, the short-term survival of larger seagrass species will depend on their anaerobic performance. But such critical sedimentation rates will normally only occur very close to a dredging or reclamation site. If sedimentation is below this short-term critical level, the long-term survivability of the plant will then depend on its aerobic metabolism, which is dominated by oxygen supply through the root system. There are several factors affecting this, including the porosity and organic content of the sediment material.

Duarte *et al.* (1997) conducted a field study in the Philippines to test the effects of different levels of sediment burial on a range of seagrass species. The results of the study are presented in (Table A.8), and provide a good overview of the tolerance of different seagrass species to sediment burial. However, it should be noted that the findings of the study for the smaller colonising species, such as *Halophila ovalis* and *Halodule uninervis*, were quite different from the results for the larger seagrass.

Table A.8: Details of the experimental design to test the effects of burial on seagrass (burial levels tested, the duration of the experiments, the size:burial ratio (SBR) and the resulting effect on seagrass survival summarised in the experimental burial levels causing 50% and 100% mortality. Total shoot loss did not occur for the tested burial levels. Source: (Cabaco et al. *2008)*

Species	Burial levels (cm)	Experimental period (days)	SBR	Burial level (cm)	
				50% Mort.	100% Mort.
C. nodosa	1, 2, 4, 7, 13, 16	35	0.6c	4	13
C. rotundata	2, 4, 8, 16	60, 120, 300		2	8
C. serrulata	2, 4, 8, 16	60, 120, 300		2	–
E. acoroides	2, 4, 8, 16	60, 120, 300		4	–
H. uninervis	2, 4, 8, 16	60, 120, 300		4	–
H. ovalis	2, 4, 8, 16	60, 120, 300		2	2
P. australis	10, 15, 20, 30	50	1.3d	19.5	–
P. oceanicaa	5/7, 9/10, 13/14	250	1.4	14	14
P. oceanicab	3, 6, 9, 12, 15	45	1.3e	10.2	15
P. sinuosa	10, 15, 20, 30	50	1.3d	15.4	–
S. filiforme	3.5/4.5, 4/5, 6.5/7.5, 9/10	60	0.8	4.5	10
S. isoetifolium	2, 4, 8, 16	60, 120, 300		8	–
T. hemprichii	2, 4, 8, 16	60, 120, 300		4	–
T. testudinum	3.5/4.5, 4/5, 6.5/7.5, 9/10	60	1.2	5	–
Z. marina	4, 8, 12, 16	12, 24	1.0	4	12
Z. noltii	2, 4, 8, 16	7, 14, 28, 56	< 1f	2	8

a Manzanera *et al*. (1998).
b Ruiz (personal communication).
c N. Marba` (personal communication).
d Leaf length from Smith and Walker (2002) 0 for the same area.
e Leaf length from Manzanera *et al*. (1998).
f Intertidal species, leaves are buried even at low burial levels.

Duarte *et al.* (1997) conclude that the smaller seagrass species would have suffered initial (probably) total mortality after burial with more than 2-4cm of sediment, as they would have been completed covered. However, the growth rate of *H. ovalis* in particular, which produces a new rhizome inter-node and leaf pair approximately every four days (Vermaat *et al.* 1995), meant that by the time the first round of measurements were taken two months after burial, the *H. ovalis* shoot density had fully recovered, and in fact exceeded the original densities (and the control densities) in most instances (Duarte *et al.* 1997). This concurs with the findings of Supanwanid (1996), who recorded full recovery of *H. ovalis* from dugong feeding within two months, and with Longstaff and Dennison (1999), who conclude that the longer-term sedimentation survival strategy for *Halophila* species is the ability to rapidly regrow from seed and/or vegetative fragments after burial.

It should be noted that the Duarte *et al.* (1997) study involved immediate burial of the seagrass (analogous to an extreme storm event). In the context of dredging and reclamation, such an immediate burial event is likely to be confined to the immediate vicinity (within 100–500m) of the work area or offshore disposal area. For seagrass further away from the immediate work area, sedimentation is better characterised as an accelerated build-up rather than immediate burial. Given the rapid growth rates of most tropical seagrasses (Vermaat *et al.* 1995) there can be expected to be some capacity to adapt to the risk of accelerated burial due to increased sedimentation rates.

For low sedimentation rates, plant growth is often positively related to increasing sediment nutrient contents supplied by sedimenting material. However, if siltation occurs above a level corresponding to sediment organic matter content of about 5–20% of the dry weight of the seagrass in any given area, it is likely to have a negative impact on seagrass density. This is due to depletion in oxygen availability through decay of the organic matter in the sediments, with the most typical limit being in the order of 10-15% organic matter by dry weight (Duarte 1991, Terrados *et al.* 1999).

A second sedimentation factor potentially affecting seagrass arises from the fact that material remotely deposited from dredging and reclamation activities will generally be finer than the natural material present in the seagrass areas, resulting in a potential reduction in overall porosity of the bottom material. Studies in Thailand and the Philippines have indicated a limiting silt and clay content of 15%, above which species richness and community biomass of seagrass decline sharply (Terrados *et al.* 1998). Given the location of the seagrass beds in the study area, it can be expected that the existing habitat areas fall above this threshold limit. However, for further reduction in porosity to materialise, incremental sedimentation would have to be concentrated and prolonged in order for consolidation to occur in the face of periodic wave action.

A.7 Macroalgae

A.7.1 Macroalgal Tolerance to Suspended Sediments

Elevated suspended sediments result in light attenuation, reducing photosynthesis-dependent carbon fixation and macroalgal abundance. Research in this area is more widespread in temperate waters as compared to tropical areas. The annual growth and productivity of kelp in the Arctic coast of Alaska was shown to decrease when TSS levels ranged between 18.5 and 24.2 mg/l as a result reduced irradiance to drive photosynthesis (Aumack *et al.* 2007). In the tropics, information regarding the effects of suspended sediments and light attenuation on macroalgae is limitied. Hence, it would be useful to consider experimental studies which describe the light requirements of different macroalgae species in order to develop future threshold values for total suspended matter. In general, leathery macroalgae are known to have light requirements of about 0.5 % SI (surface irradiance), while foliose and delicate macroalgae require approximately 0.10 % SI, and encrusted macroalgae have the lowest light requirements, extending down to depth limits with about 0.01 % SI (Markager and Sand-Jensen 1992).

Apart from light reduction, suspended sediments in combination with wave action have synergistic scouring effects on macroalgal communities (Engledow and Bolton 1994). The elevated shear stress caused by increased water velocity can result in direct removal of macroalgae from the substratum (Francoeur and Biggs 2006). But both sediment suspension and mobilisation of large substrata (resulting in sediment abrasion) are dependent on increased water velocity. Hence, it is often difficult to isolate the effects of suspended sediments and scouring on macroalgae.

In a 2006 experimental study by Francoeur and Biggs (2006), it was demonstrated that while increased water velocity alone removed benthic macroalgal biomass, this removal was further enhanced by high concentrations of suspended sediment (concentrations of up to 6,487mg/l). The same study also showed enhanced biomass losses of unbrushed, loosely attached macroalgal communities, while removal of tightly adherent communities was low. Hence, communities with a tightly adherent cohesive mat physiognomy can be regarded as more resistant to removal.

In a separate investigation carried out in the Galapagos (Kendrick 1991), the biomass of filamentous turf algae as compared to crustose coralline algae was significantly lower under a simulated scour environment. The ability of crustose coralline algae to colonise a variety of marine habitats and persist in highly disturbed environments suggest high importance of different macroalgal growth-forms to the effects of sediment abrasion.

It is also known that submersed macrophytes can greatly improve water quality by dampening wave activity and reducing sediment resuspension (James *et al.* 2004a). However, the effects of sediment resuspension dynamics and light attenuation on macroalgae are mainly characterised in temperature climates (James *et al.* 2004b, Fong 2008).

A.7.2 Macroalgae Tolerance to Sedimentation

Sedimentation in marine habitats is potentially one of the major factors influencing the structure, biomass and metabolism of benthic assemblages (Aumack *et al.* 2007, Balata *et al.* 2007, Sofonia and Anthony 2008). Although certain varieties of algae have been associated with clean and clear offshore waters, the effects of water quality on algae are little known. Most tropical, experimental work on the effects of sedimentation has focused on corals and little has been done on macroalgae (Schaffelke *et al.* 2000). However, it is a widely-held belief that high rates of sediment deposition and movement are detrimental to the overall richness and diversity of the community through exclusion of less tolerant species (Airoldi and Cinelli 1997, Carpenter 1990). In a 2001 study by Fabricius and De’ath (2001a), no critical threshold limits of sedimentation were given, however, their investigations used a rating scale which determined a strong inverse relationship between cover of crustose coralline algae (CCA) and sedimentary deposits on the GBR. The negative effects of sediment on CCA abundance could be attributed to a reduction in substrate for CCA settlement and a reduction in photosynthesis as a result of shading by the sediments (Fabricius and De’ath 2001a, Klumpp and McKinnon 1992).

Nevertheless, higher rates of sedimentation have also been reported to increase macroalgal abundance, by either enhancing macroalgal recruitment or survival; or indirectly, by inhibiting competitors or herbivores Schaffelke and Klumpp 1998). Both physical and biotic factors act together to maintain benthic macroalgae, though Caulerpales may easily out-compete other macroalgae as it is not limited by grazing due to the production of toxic substances (Boudouresque *et al.* 1996, Dumay *et al.* 2002). While physical factors such as light, temperature and sedimentation contribute to regulating the growth of Caulerpales, an experimental study by Piazzi *et al.* (2005) showed that *Caulerpa racemosa* was not affected by an increase in sedimentation rates, possibly due to both resistance to deposition and burial, coupled with vegetative propagation to grow under disturbed conditions.

Adaptation of macroalgae to disturbance caused by sedimentation is dependent on various factors such as life history traits as well as physiological and morphological differences (Airoldi 2000, Aumack *et al.* 2007, Balata *et al.* 2007). Some filamentous forms benefit from increased sedimentation due to their fast growth, capability to exploit nutrients and ability to trap sediment (Balata *et al.* 2005, Carpenter 1990). Turf algae in particular, appeared more resistant to high sedimentation than erect and encrusting forms (Aumack *et al.* 2007, Gorgula and Connell 2004). In addition, turf algae have a higher sediment tolerance than other benthos occupiers such as corals (Nugues and Roberts 2003). Furthermore, some studies have shown that turf algae are able to trap sediments and pre-empt substrate, hence, facilitating algal overgrowth onto coral colonies (McCook 1999, Fabricius and De'ath 2001a, Aumack *et al.* 2007). Investigations on the effects of sedimentation on algae at various localities are summarised below in Table A.9.

Table A.9: Critical thresholds of algae for sedimentation (g/m²/day)

Species/ Types of algae	Location	Sedimentation (g/m²/day)	Response	Reference
Various species (turf, erect and encrusting)	Vada Shoals, Mediterranean Sea	High (~44.3 – 130.9) Low (~6.3 – 49.7)	Turfs more extensive in areas of high sediment deposition Erect and encrusting more extensive in areas of low sediment deposition	Balata *et al.* (2005)
Various species (crustose, filamentous, foliose, corticated-terete and articulated algae)	Mediterranean Sea	220	Reduction in diversity Dominance of filamentous species	Balata *et al.* (2007)
Crustose coralline algae	GBR, Australia	-	Sediment negatively affect CCA abundance	Fabricius & De'ath (2001)
Crustose coralline algae (*Lithothamnion* spp.)	S.W Ireland	2 – 12.5	Sedimentation reduced CCA cover	Maughan (2001)
Turf algae	Livorno (Mediterranean Sea)	>200	Decreased biomass	Airoldi & Virgilio (1998)
Turf algae (*Polysiphonia setacea*)	Livorno (Mediterranean Sea)	-	Growth enhanced by reduced sedimentation rates	Airoldi & Cinelli (1997) 0
90 species of macrophytes	Spain	Sediment loading expressed as % of substratum covered	Algal cover decrease as sediment loading increase Species richness and diversity show higher values at intermediate sediment loads	Díez *et al.* (2003)
Sargassum microphyllum	GBR, Australia	> 3580 (x2 ambient sediment deposits)	Decreased rates of recruitment, growth, survival and vegetative regeneration	Umar *et al.* (1998)
Caulerpa racemosa	Mediterranean Sea	200 (x4 ambient sediment deposits)	% cover not affected by increase in sedimentation rates	Piazzi *et al.* (2005)

A.8 Mangrove

A.8.1 Mangrove Tolerance to Suspended Sediments

A study carried out in Cairns, Australia, demonstrated that 80% of suspended sediments brought in to the mangroves from coastal waters at spring flood tide were trapped in the mangroves (Furukawa *et al.* 1997). Sediment particles are carried in suspension into mangrove forests at high tide where they are maintained in suspension due to the turbulence caused by mangrove structures. The particles settle in the mangroves only around low tide, when water turbulence is reduced and when water velocity is not large enough to carry the particles back to the estuary (Kathiresan 2003, Wolanski 1995). However, the vertical accretion of suspended particles also depends on concentration and rare events such as tropical cyclones, floods in nearby rivers (Furukawa *et al.* 1997).

Further observations at Cocoa Creek, a mangrove creek system near Townsville, Australia suggest a complex but strong relationship that exist between tidal hydrodynamics, sediment transport and geomorphology (Bryce *et al.* 2003). Given this complexity, there are no clear estimates of thresholds for sediment fluxes in mangroves. However, mangroves can be considered to be fully tolerant to the range of suspended sediment loads that may be generated outside the work area from dredging and reclamation activities associated at waters off Onslow.

A.8.2 Mangrove Tolerance to Sedimentation

Mangroves are known for their sediment accreting and stabilising properties (Ellison 1999, Furukawa *et al.* 1997, Kitheka *et al.* 2002). Sediment from catchment erosion enters mangrove ecosystems through run-off and transportation in riverine water columns. Sediments deposited in mangrove areas are frequently tainted with particulate pollutants or pollutants adsorbed to clay particles (Dubinski *et al.* 1986, Kehrig *et al.* 2003). It is now recognised that the ability of mangroves to filter water and trap sediment and pollutants is a very important ecosystem service as it improves downstream water quality essential for seagrass and coral growth and stabilises estuarine banks, thereby impeding erosion.

Mangroves are able to withstand gradual sediment accumulation, as this is part of their natural, dynamic state. However, acute increases in sedimentation due to natural or anthropogenic dumping of material can result in burial of pneumatophores, reducing their ability to supply oxygen to the root system (Wolanski 1995). The most sensitive components of the mangrove ecosystem to sedimentation impacts are seedlings and pneumatophores, as both have a relatively small vertical extent, and may therefore be partially or fully buried by high sedimentation rates within a short period of time.

Some field data regarding tolerance levels of mangroves to levels of sedimentation are available. A study by Terrados *et al.* (1997) showed that sediment burial of 8 cm and above retarded growth and increased mortality of *Rhizophora apiculata* seedlings as a result of altered oxygen supply to the hypocotyl root system. Field experimental work in Thailand carried out by Thampanya *et al.* (2002) on seedlings of *Avicennia officinalis*, *Rhizophora mucronata* and *Sonneratia caseolaris* showed that *Avicennia officinalis* was five times more sensitive to burial than *Sonneratia caseolaris*, whilst *Rhizophora mucronata* showed no significant difference between the control and burial treatments (0, 4, 8, 16, 24 and 32cm). There was 100% mortality in *Avicennia officinalis* after 225 days at 32cm burial, and almost 90% mortality at 24cm.

There are numerous accounts of sedimentation as a result of human disturbance causing problems in mangroves, but generally few quantitative details. Ellison (1999) pointed out a few areas in Australia where deposition of dredge spoil smothered the roots and caused the deaths of Mangroves. While the critical threshold of sedimentation was not indicated for Mud Island, off Brisbane and King Bay, values for a few other localities are further indicated below in Table A.10.

Table A.10 Summary of mangrove burial events and consequences. Source: Ellison (1999)

Location	Species	Burial	Effect
Mud Island	• *Avicennia marina* • *Rhizophora stylosa*	N.A	Death
Princess Charlotte Bay	• *Rhizophora* • *Avicennia*	70 cm 70 cm	Death Survived
Port Samson	• *Avicennia marina*	20cm	Death
King Bay	*N.A*	N.A	2 ha dead
Gladstone	• *Avicennia marina* • *Avicennia marina* • *Rhizophora stylosa*	5cm 50cm 50cm	Stressed Dead Stressed
Bowen	• *Avicennia marina*	12cm	0.5 ha dead

Closer to the project area, Port Samson in North Western Australia documented smothering of *Avicennia marina* roots by >20cm of sediment and subsequent death of the trees Ellison (1999). The closest mangrove stands to the project area appear to be located near the Ashburton River which opens into the Indian Ocean and is located 55km WSW of Onslow. Approximately 3km^2 of mangrove areas were identified in a 2001 estuary assessment of the river (DEH, FRDC 2000).

Seven species of mangroves are known to occur along the Pilbara coast (EPA 2001). Of these, six species were recorded from the Ashburton delta area from the surveys undertaken for this project (URS 2009). The six mangrove species are:

- *Aegialitis annulata* – Club Mangrove
- *Aegiceras corniculatum* - River Mangrove
- *Avicennia marina* – Grey Mangrove
- *Bruguiera exaristata* – Ribbed Mangrove
- *Ceriops australis* – Spurred Mangrove
- *Rhizophora stylosa* – Spotted-leaved Red Mangrove

Within the study area *Avicennia marina* (Grey mangrove) was a widespread and dominant species that occurred within the majority of mangrove associations present. It was found growing monospecifically in many areas and in a range of structural forms (e.g. from dense low forests to open shrubland) but also occurred in association with the other five species in particular locations. The local dominance by *A. marina* reflects the broader regional pattern with this species being the most widespread and abundant mangrove species in the Pilbara coastal region (Semeniuk 1999). A summary of the tolerance of the six mangrove species occurring in the study area to sedimentation /burial is provided in Table A.11.

Table A.11 Summary of tolerance to sedimentation/burial of mangrove species occurring in the study area

Species	Sedimentation Tolerance	Reference
Aegialitis annulata	No information available	
Aegiceras corniculatum	*A. corniculatum* is more tolerant to burial than *R. stylosa* and *B. gymnorrhiza* and less tolerate than *A. marina*	Youssef and Saenger, 1998
Avicennia marina	Will usually die when pneumatophores are covered (~10cm sediment), though death by burial can still occur below this level. Have been known to survive when buried in at least 70cm when sediment pore holes are large, eg, with shells May be able to extend pneumatophores several centimetres to cope with burial	Ellison, 1998
Bruguiera exaristata	Trees may die when knee roots are completely buried (confirmed for *B. gymnorrhiza*, not tested on this species specifically)	Ellison, 1998
Bruguiera	Burial of knee roots usually causes death	Ellison, 1998
Rhizophora stylosa	Greater burial tolerance under some circumstances than *A. marina*, showed signs of stress under 50cm and died under 70cm burial depth	Ellison, 1998

The Ashburton River has been described as a wave dominated delta with low sediment trapping efficiency, naturally low turbidity, salt wedge/partially mixed circulation, with a consequently low risk of habitat loss due to sedimentation (DEH, FRDC 2000). It is therefore considered unlikely that the proposed dredging and reclamation works can generate sedimentation rates that are high enough to introduce stress on the mangroves found around this area.

A.8.3 Mangrove Tolerance to Erosion

While erosion is a natural process, it may be exacerbated by human influence. Dredging and reclamation works both alter tidal flow patterns and it is important to distinguish their impact from the natural rate of erosion. However, few studies have been carried out on erosion in mangroves, and earlier works suggest highly variable erosion rates on a temporal and spatial scale (Paling *et al.* 2003, Semeniuk 1980).

A study carried out on mangroves situated at creeks in and around the Port Hedland area, Western Australia, recorded mangrove mortality in certain areas. However, it was concluded that the development within the harbour did not have any significant impacts on creek erosion since the greatest mortality was experienced far from human habitation (Paling *et al.* 2003).

A.9 Visual Impact

A.9.1 Visual Impact and Detection Levels

Coastal waters off Onslow are characteristically turbid due to resuspension of fine sediment due to the windy conditions (URS 2005). The Australian and New Zealand Environment Conservation Council (ANZECC) have produced water quality guidelines to protect and manage the environmental values supported by the water resources (ANZECC 2000). These guidelines include criteria for visual impacts, in order to protect waters for recreational activities such as swimming and boating, and to preserve the aesthetic appeal of water bodies. Relevant aspects of the ANZECC guidelines are presented below in Table A.12 and Table A.13.

Table A.12 Water quality characteristics relevant to recreational uses.

Characteristics	Primary contact (e.g. swimming)	Secondary contact (e.g. boating)	Visual use (no contact)
Microbiological guidelines	x	x	
Nuisance organisms (e.g. algae)	x	x	x
Physical and chemical guidelines:			
Aesthetics	x	x	x
Clarity	**x**	**x**	**x**
Colour	**x**	**x**	**x**
pH	x		
Temperature	x		
Toxic chemicals	x	x	
Oil, debris	x	x	x

Table A.13 Summary of water quality guidelines for recreational waters.

Parameter	Guideline
Physical and chemical	
Visual clarity & colour	To protect the aesthetic quality of a waterbody: • the natural visual clarity should not be reduced by more than 20%; • the natural hue of the water should not be changed by more than 10 points on the Munsell Scale; • the natural reflectance of the water should not be changed by more than 50%. • To protect the visual clarity of waters used for swimming, the horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m.

A.10 References

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APPENDIX B

DHI Case Studies

B.1 Case Study: Øresund Link, Denmark and Sweden

This Feedback Monitoring approach was pioneered by DHI during the construction of the Øresund Link, a 16km fixed link joining Denmark and Sweden, which ran from 1995–2000 (Møller *et al.* 1994). The works comprised construction of a tunnel, an artificial island and a bridge for the various stages of link (Figure B.1), and involved 7 million cubic metres of dredging (Photo B.1), with a 2.2km^2 reclamation. Large seagrass meadows (predominantly *Zostera*, Photo B.2), extensive mussel beds, important seabird foraging areas and herring migration routes were within the potential impact area of the project, and there was intense public and regulatory scrutiny from both Denmark and Sweden to ensure that the project was managed to avoid or minimise environmental impacts.

Extremely strict targets were set for acceptable levels of impacts, with an overall target of zero long-term impacts, with some temporary (less than 5 years) and local (within 7km) changes acceptable during construction. The following specific targets were set:

- **Herring Migration:** SSC less than 10mg/l over at least two thirds of the Øresund during migratory periods.
- **Foraging Birds:** SSC less than 28mg/l (1m visibility) during April and July-**August** in 90% of forage area for at least 70% of the time. Reduction in Eider population on Saltholm not more than 15% total population, or 10% of breeding population. Full recovery of number of breeding pairs required within 5 years.
- **Seagrass:** Distribution and biomass not reduced by more than 25%, full recovery required within 2-5 years.
- **Mussel Beds:** Sedimentation rate less than 15kg/m^2/month and less than 60g/m^2/day for at least 20% of the time during June-August, when mussel larvae settle. Distribution and biomass not reduced by more than 25%, full recovery required within 2-5 years.
- **Other Benthic Fauna:** Biomass of benthic fauna at less than and greater than 6m not reduced by more than 25%, full recovery required within 2-5 years.
- **Bathing Water:** SSC less than 28mg/l for at least 80% of the time, and at least 95% of the time during July (peak summer vacation period).
- **Sediment Spill:** Total sediment spill by end of construction must not exceed 5% of total dredge volume

In order to meet these targets, DHI carried out high frequency Feedback Monitoring of the dredging works and the various environmental receptors throughout the construction period. Despite the significant scale of dredging and reclamation works undertaken, DHI was able to manage the project to achieve full compliance with the very strict environmental standards that had been set.

Figure B.1 Location and components of the Øresund Link (Image Source: NASA)

Photo B.1 Large sediment plume from cutter suction dredger Castor*, 7 August 1997. Inset shows cutter head*

Photo B.2 DHI marine biologist monitoring Zostera *shoot density and biomass during the Øresund Link construction*

B.2 Case Study: Bali Turtle Island, Indonesia

B.2.1 Background

DHI subsequently transferred the Feedback Monitoring approach from temperate to tropical waters in 1996 with the Bali Turtle Island project (Driscoll *et al.* 1997). Turtle Island or Pulau Serangan is located to the southeast of Bali, just outside Benoa Bay (Figure B.2), and was being developed in connection with the expanding tourism industry of the area. The location of the island close to the international airport of Denpasar made the island ideal for hotels and a golf course, but the feasibility of the project depended on improvements of the access to the island and an extension of the existing island by a 3.7 km^2 dredge and fill reclamation.

Dredging was undertaken using a large cutter suction dredger, the *Suez No. 5*, with a typical daily production of 20,000m^3. Analysis of sediment samples from the dredging area found that the seabed material had a fine material content in the order of 20%, indicating relatively large spill rates could be expected.

B.2.2 Environmental Receptors

The key receptors in the vicinity of the works were corals (predominantly *Acropora* spp.), seagrass (mainly *Thalassia* spp.) and mangroves (predominantly *Sonneratia* spp., with some *Rhizophora* spp.). The water in the project area was relatively clear, ranging from 0 to 5 mg/l, so corals occurred on the reef slope from 5–6m until 10–15m below MSL along the east coast of Turtle Island. Seagrass meadows extended over most of the area between the reef fringe and the shoreline on the east coast of Turtle Island and the surrounding mainland of Bali. Mangroves were present in varying density along most of the fringe of Benoa Bay, but were confined to a small area on the south east coast of Turtle Island, as well as a thin band along the central part of the west coast.

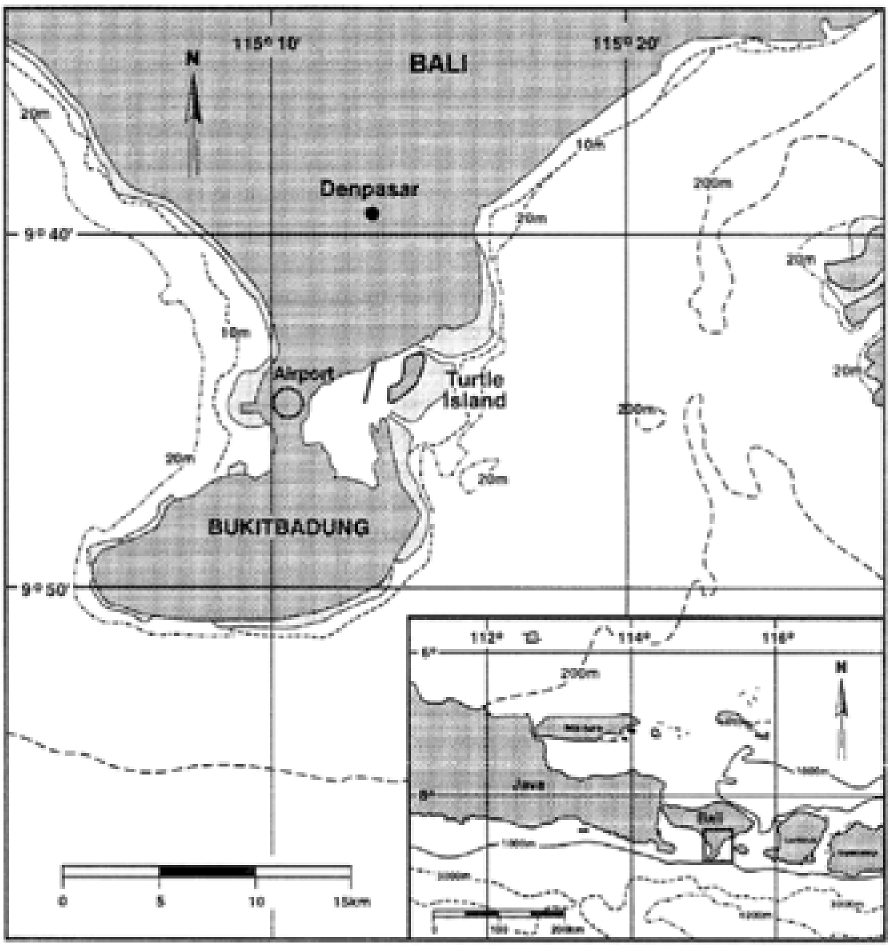

Figure B.2 Location of Turtle Island, Bali

Unfortunately, the decision to engage DHI to apply the Feedback Monitoring approach to the management of the dredge and fill reclamation for Turtle Island wasn't made until after the project had commenced construction, so for the first three months of construction, no environmental monitoring or management of the dredging and reclamation works took place. DHI then undertook a detailed biological survey to establish the "baseline" conditions at the start of monitoring, comprising:

Coral Monitoring at five stations:

- key species *Acropora* spp.
- Determination of areal coverage of different hard coral growth forms via transect and quadrat techniques.
- Documentation of observed frequency of bleached hard corals.
- Measurement of growth rates of hard coral colonies via skeletal staining of specimens with the dye Alizarin Red.
- Determination of recolonisation rates via recruitment of reef organisms on settling plates.

Seagrass monitoring at four stations:

- key species *Thalassia* spp. comprising 75–95% of the seagrass cover.
- Measurement of leaf and rhizome biomass, via harvesting and weighing.
- Measurement of height and density of shoots.
- Determination of growth rate of leaves and turnover of shoots via marking and later harvesting of younger shoots.
- Documenting concentration of soluble carbohydrates in rhizomes via measurement with a field refractometer.

Mangroves monitoring at five stations:

- key species: *Sonneratia* spp. and *Rhizophora* spp.
- Measurement of height and spatial density of pheumatophores.
- Determination of growth and survival rates of seedlings.
- Recording of sediment level.

B.2.3 Tolerance Limits

Based on available literature and initial monitoring results, preliminary tolerance limits were set for SSC and sedimentation. The preliminary limit for SSC was set as 10mg/l above ambient levels, averaged over the daylight hours. The reduction in irradiance (ambient light intensity) due to an additional 10mg/l of SSC will be in the order of 20% at a depth of 1m, and in the order of 80% at a depth of 10m. The biological monitoring frequency for the project was once every two months, so the consequence of light reduction associated with an excess SSC of 10mg/l over a two month period was predicted as:

- A measureable, but within two months not irreversible, change in shoot density, leaf growth and sugar content of the rhizomes of seagrasses

- A measureable but not fatal reduction in the growth of hard corals

As photosynthesis only occurs during daylight hours, this concentration limit was relaxed to 25mg/l averaged over night time hours.

A preliminary limit for sedimentation of 100g/m^2/day was set for corals, which are the most sensitive receptor to sedimentation. Seagrass were found to be less sensitive to sedimentation, especially given their location on the reef flats, where periodic wave action helps to clear the sedimentation. A preliminary limit of 250g/m^2/day was therefore set for seagrass. As corals and seagrass are also sensitive to short-term sedimentation, occurring over the space of hours, which may be subsequently resuspended by wave and current action, preliminary short-term limits for sedimentation were also set. For corals, a preliminary limit of 4.2g/m^2/hr was set, while for seagrass, the limit was 10.4g/m^2/hr.

In order to determine the scale of impact from the dredging works undertaken during the first three months before monitoring commenced, DHI undertook a hindcast sediment plume modelling study of the three month construction period, based on daily dredging data provided by the contractor (Figure B.3).

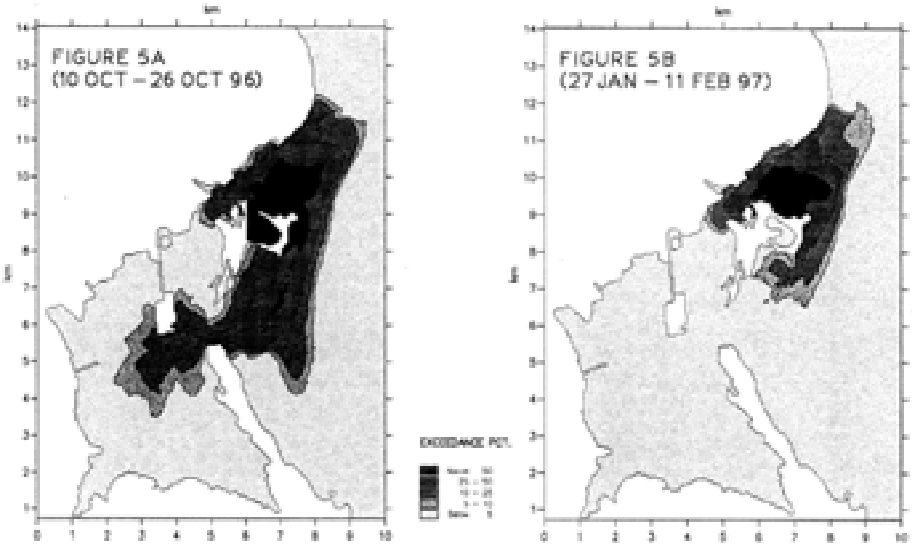

Figure B.3 Effect of modifying dredging practice to reduce spill - shown in terms of the % exceedence of the daylight suspended sediment concentration limit of 10 mg/l before and after the change in dredging practice

During the period 10 October 1996 to 26 October 1996, which included a relatively high spillage associated with the early construction sequence, the maximum daily sediment plume excursion (defined by the 10% exceedence contour of 10mg/l) extended 2km north and 5km south of the dredging area. During the period 27 January to 11 February 1997, following modifications of dredging practices recommended by DHI, including the application of a no-dredge policy during daylight ebb tide, this impact area was reduced to 2km north and 1.5km south.

B.2.4 Impacts to Corals

The effect of the uncontrolled dredging and reclamation works during the first three months of construction was clearly seen in a change in mean live hard coral cover, particularly closest to the dredging area. From DHI's qualitative assessment, no dead corals were observed during the October 1996 survey, but sedimentation on the corals was observed to be 1-5cm thick, and likely to result in mortalities if prolonged. DHI recommended stopping the reclamation discharge at this location after the first survey, and this recommendation was implemented in November 1996. By February 1997, the sedimentation near the reclamation area had reduced to 1–3mm, and a few of the corals were observed to be showing signs of growth.

Monitoring showed a decrease in live hard coral cover as a result of the first three months of uncontrolled dredging at some sites, with a number of dead corals recorded during the December 1996 survey. A comparison of coral growth rates from October to December 1996 and December 1996 to February 1997 showed that coral growth rates increased significantly once DHI's management measures were implemented. The hindcast modelling showed that impacted stations had the highest sediment loading from the dredging during the October to December period, and growth rates at the two stations that were most impacted more than tripled once DHI's management measures were introduced.

B.2.5 Impacts to Seagrass

There was no clear pattern of change in seagrass cover due to the dredging and reclamation works during the course of the monitoring, though a large number of linear cuts were noted at some stations, which appeared to be related to boats and jet skis from nearby resorts.

There was also no clear pattern of change in the dry weight of seagrass due to the dredging and reclamation works during the course of the monitoring, While a decrease in biomass was observed at one station between the first and second campaigns, this was due to a shift in the size classes of the seagrass, with a much higher proportion of shorter, younger shoots recorded during the December 1996 monitoring period. The mean shoot density also increased during the same period. There were no clear changes in shoot density at the other monitoring locations.

While there were no clear impacts to seagrasses in terms of mortalities due to the dredging and reclamation works, there was some evidence that growth rates were affected. The growth rates of *Thalassia* spp. were significantly lower at three of the stations than the growth rates recorded at the reference station, which was outside of the dredging plume (confirmed via the hindcast modelling). It is therefore considered likely that this decrease in growth rate was a sub-lethal response to the reduced light conditions resulting from the construction works.

B.2.6 Impacts to Mangroves

In order to determine any sedimentation or erosion impacts to mangroves as a result of the construction works, sediment level markers were established at each of the five monitoring locations during the initial survey in October 1996. The change in sediment height, relative to the level established in October was then determined during the two subsequent surveys. The monitoring indicated a slight decrease (1-2cm) in sediment height at most stations, but a slight increase (2cm) at one station. Observations of the marker as well as markers on seedlings at the station confirm that approximately 2cm of siltation occurred at the station between October and December 1996, most likely due to the nearby dredging and reclamation works. However, no further change was observed at this location from December 1996 to February 1997, indicating that DHI's recommended changes in dredging practice were effective in controlling sedimentation at this location. The small decreases at the other stations are thought to be part of the natural variability in sediment level in this area.

The average density and mean height of pneumatophores at each of the monitoring locations did not show any statistically significant changes between the October and December 1996 surveys, indicating no impacts to pneumatophores resulting from the dredging and reclamation works, even at the station which recorded some siltation.

However, the survey found pronounced differences between stations, which seemed to reflect the sediment conditions at each site. Sites with coarser sediments and a relatively thick layer of oxidised top sediment had a higher pneumatophore density but a relatively small mean height, while sites with more anaerobic and softer sediments had a lower pneumatophore density, but a relatively high average height.

The *Rhizophora* spp. seedlings marked during the initial survey in October showed a steady growth throughout the subsequent two monitoring periods, with no indication of any effects on growth rates due the dredging or reclamation works, apart from at one station, which had a reduced growth rate between the October and December 1996 surveys. As this coincided with the period of siltation recorded at this station, the reduced growth rate at this station was most likely related to the dredging and reclamation activities.

B.2.7 Conclusions

The results of the three monitoring campaigns showed the effectiveness of DHI's recommended management measures, and provided confirmation via the Feedback Monitoring approach that the preliminary tolerance limits established for corals, seagrass and mangroves were realistically conservative.

Despite suspended sediment levels that exceeded the preliminary tolerance limit of 10mg/l set for both corals and seagrass for a major portion of the time during the first three months of construction, prior to DHI's engagement in the project, the impacts to corals were mostly sub-lethal, with coral mortalities only recorded at two stations immediately adjacent to the reclamation discharge. Only sub-lethal impacts (reduced growth rates) were recorded for seagrass and mangroves.

The hindcast modelling showed that DHI's recommended management measures significantly reduced the area affected by sediment plumes. By the third survey campaign in February 1997, only one bleached and one recently dead coral were recorded across all five coral monitoring locations, and no impacts (in terms of mortalities) were detected at any of the seagrass or mangrove monitoring stations. Impacts that were detected were sub-lethal (affecting growth rates), and in line with the predicted level of impact. This indicated that the preliminary limits chosen were suitably conservative for the start of the project, and the limits were then progressively relaxed during the subsequent stages of the works, as part of the Feedback Monitoring process. It was also clear that corals were the most sensitive to the increased suspended sediments and consequent sedimentation resulting from the dredging and reclamation works. Corals are generally regarded as the "limiting receptor" when determining the acceptable level of impact.

DHI regards the Bali Turtle Island Feedback Monitoring programme to be an example of best practice environmental management for marine construction projects at that time. Unfortunately, the Asian Financial Crisis hit in July 1997, and this resulted in financing for the project becoming extremely limited. As a consequence, DHI's contract to undertake the Feedback Monitoring for the project was cancelled, and the contractor reverted to extremely high production rates (and consequently high spill rates) in order to complete the project as quickly and cheaply as possible. Without monitoring, it is not possible to know the extent of the resulting impacts, but DHI understands that many of the corals surrounding Turtle Island did not survive the construction works. However, once construction was completed, it is likely that corals recolonised the reef areas, and certainly the resort is now operational.

B.3 Background Context for Large Scale Reclamation and Dredging Projects in Singapore

B.3.1 Background

The land mass of Singapore, which is currently approximately 640km^2, has been increased by more than 20% by numerous reclamation projects over the past 40 years, including several extremely large reclamations. Because of the confined nature of Singapore, and the presence of a large number of patch reefs, reclamation and associated dredging works often take place in very close proximity to coral reef and seagrass areas. In addition, increasing industrial development results in reclamation and dredging works often occurring near sensitive industrial water intakes. But perhaps most critical was the proximity of the works to the international boundaries between Singapore and its neighbours, Malaysia and Indonesia.

B.3.2 ITLOS Dispute

In response to claims made by Malaysia relating to the potential impacts arising from reclamation works being undertaken by the Singapore authorities at Tuas View Extension and Pulau Tekong (Figure B.4), the International Tribunal for the Law of the Sea (ITLOS) ordered the governments of Singapore and Malaysia (in October 2003) to conduct a joint third party study of the possible impact of these reclamation works on the environment. DHI was jointly commissioned in March 2004 by the Ministry of Foreign Affairs (Malaysia) and Ministry of National Development (Singapore) as the independent consultant to undertake the detailed studies.

The outcome of the ITLOS proceedings was that Singapore instituted a mandatory requirement for detailed environmental impact assessment studies based on hydrodynamic and sediment plume modelling prior to approval of any future dredging and/or reclamation projects, to confirm that there would be no trans-boundary issues associated with the works. They also instituted a mandatory requirement for strict daily environmental management of all large dredging and reclamation projects, to confirm compliance with the requirement of no trans-boundary impacts.

Figure B.4 Location and extent of Tuas View Extension (TVE) and Pulau Tekong (PT). Reclamation areas are shown in grey.

B.3.3 Marine Habitat Status in Singapore

The tropical waters of Singapore provide excellent conditions for marine life, due to relatively constant tropical water temperatures and frequent fresh ocean throughflow from both the South China Sea and Melaka Straits. Coral, seagrass and mangrove habitats have been found to be relatively rich in Singapore. For corals, 55 of the 106 coral genera existing worldwide (Veron *et al*. 2000) are documented in Singapore waters alone (Tun *et al*. 2004), compared to 13 genera found in the Caribbean. For seagrass habitats, 12 species out of 57 known species are found in Singapore (Waycott *et al*. 2004), while 24 out of the 54 true and minor mangrove species have been found in Singapore so far (Thomlinson 1999).

The total area of coral reef habitat in Singapore has been estimated to range from 100km^2 (Spalding *et al.* 2001) to 54km^2 (Burke *et al.* 2002). However, these area estimates included large inter-tidal reef flats that do not actually support coral communities in Singapore, leading to a recent revised estimate of sub-tidal coral reef area in the order of <5km^2 (Wilkinson 2008). A more accurate estimation of the remaining coral reef habitat in Singapore, based on detailed GIS mapping, has found the total sub-tidal coral reef area in Singapore to be only approximately 1.4km^2 (Tun *et al.* in prep).

Singapore has relatively high suspended sediment concentrations and sedimentation rates. Based on DHI's long-term monitoring in Singapore, average Total Suspended Solids (TSS) levels range from 8–10mg/l and sedimentation rates range from 0.05–0.2 kg/m^2/day in the southern waters of Singapore, where most of the remaining corals and seagrass are located.

These conditions have strongly influenced the dominant coral life forms over the past twenty years. The dominant coral life forms are massive and foliose corals (Figure B.5) with Acroporiids generally absent. Hard corals are generally confined to a maximum depth of between 5m and 7m below chart datum (CD), and are most abundant along the reef crest (0m below CD) and upper reef slope (down to 3m below CD). The lower reef slopes are dominated by filter feeders (particularly gorgonians and sponges). There are generally only occasional isolated small coral colonies on the reef flats of Singapore.

Figure B.5 Massive and foliose life forms that are typical of Singapore reefs.

B.3.4 Acceptable Level of Impact

Based on the high diversity and low remaining area of coral habitat in Singapore, the Singapore government has placed a very high priority on preserving the remaining coral, seagrass and mangroves habitats and biodiversity in Singapore, with corals in particular seen as a vital biomedical resource in addition to their environmental value. This has translated into very strict levels of acceptable impact being set for dredging and reclamation projects over the past five years. A level of "slight impact" is generally allowed immediately adjacent to the work area (usually defined as within 500m), while "no impact" is required for all environmental receptors more than 500m from the work area. The definitions of the levels are impact are:

- *No Impact:* Changes are significantly below physical detection level and below the reliability of numerical models, so that no change to the quality or functionality of the receptor will occur.

- *Slight Impact:* Changes can be resolved by numerical sediment plume models, but are difficult to detect in the field as they are associated with changes that cause stress or sub-lethal impacts, not mortality, to marine ecosystems. Slight Impacts may be recoverable once the stress factor has been removed.

The acceptable level of impact is defined for each receptor, and are collectively referred to as the Environmental Quality Objectives (EQOs) for the project.

If any areas of coral reef are directly impacted by the project (i.e. within the footprint of the dredging or reclamation area) it is presently common practice in Singapore for the Singapore government to require compensation for this habitat loss in the form of a coral relocation exercise, undertaken prior to the start of works.

B.4 Case Study: Pulau Ular Reclamation, Singapore

B.4.1 Background

The Pulau Ular project involved a nine million m^3 reclamation from March 2006 to February 2007 (an 11 month period) to join three existing islands (Pulau Ular, Pulau Busing and Pulau Bukom Kechil, Figure B.6) in order to provide space for a new petrochemical project. It is immediately adjacent to Pulau Bukom, which is one of Shell's largest oil refineries in the world, and only 300m north of Pulau Hantu, which is Singapore main recreational diving area, featuring both coral reef and inter-tidal seagrass areas. It is also approximately 1km north of one of the major seagrass areas in southern Singapore, covering approximately 25Ha along the west coast of Pulau Semakau, 2km south of Cyrene Reefs (Terumbu Pandan) which is also a major seagrass habitat, and approximately 1km east of Pempang Reefs, a large chain of patch reefs with relatively high live hard coral cover.

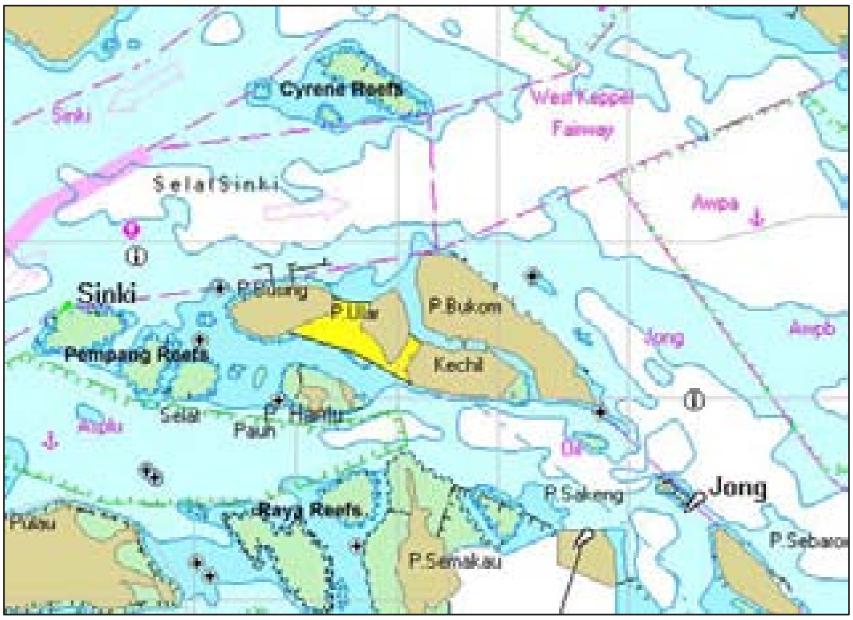

Figure B.6 Location and extent of Pulau Ular reclamation (shown in yellow)

B.4.2 Tolerance Limits

DHI's Feedback Monitoring approach was applied to this reclamation, with an initial spill budget (prior to the start of works) being set based on preliminary tolerance limits for corals, seagrass and mangroves. The preliminary tolerance limits were based on previous monitoring works undertaken by DHI in Singapore and Malaysia, and were based on five escalating categories of impact. The definitions of these five categories of impact are provided in Table B.1. The levels set for the preliminary tolerance limits were the subject of extensive discussions with the regulator (Singapore National Parks Board, generally abbreviated as NParks), before the limits were accepted by the regulator. The limits were then cross-checked against monitoring results throughout the duration of the project, and updated if required as part of the feedback process.

Table B.1 Impact Definitions

Severity	Definitions
No Impact	Changes are significantly below physical detection level and below the reliability of numerical models, so that no change to the quality or functionality of the receptor will occur
Slight Impact	Changes can be resolved by numerical sediment plume models, but are difficult to detect in the field as they are associated with changes that cause stress, not mortality, to marine ecosystems. Slight Impacts may be recoverable once the stress factor has been removed
Minor Impact	Changes can be resolved by numerical models and are likely to be detected in the field as localized mortalities, but to a spatial scale that is unlikely to have any secondary consequences
Moderate Impact	Changes can be resolved by numerical models and are detectable in the field. Moderate impacts are expected to be locally significant
Major Impact	Changes can be detected in the field and are likely to be related to complete habitat loss. Major impacts are likely to have secondary influences on other ecosystems

Coral Tolerance to Suspended Sediments

The tolerance limits presented in Table B.2 were based on DHI's findings from extensive monitoring data from multiple projects in Singapore (where changes in reef health, measured as a function of live hard coral cover and diversity, have been compared to measured and predicted suspended sediment and sedimentation levels). The key finding of this monitoring has been that it is the duration of exposure as well as the intensity of exposure that will determine the level of impact. Corals can tolerate high incremental suspended sediment concentrations for short periods of time, and low incremental suspended sediment concentrations for longer durations. It is possible that a given occurrence may meet the criterion for multiple severity levels, in which case the highest severity is taken as the resultant impact severity.

The limits presented in Table B.2 are excess concentrations (i.e. in addition to the ambient background concentrations). They are based on a 14 day spring-neap cycle, which is the duration of the numerical sediment plume scenario modelling used to determine the maximum dredging or reclamation production rate that will still comply with the EQOs, in order to set the spill budget.

Table B.2 Impact Severity Matrix for suspended sediment impact on coral reefs in environments with high background concentrations

Severity	Definitions
No Impact	• Excess Suspended Sediment Concentration > 5mg/l for less than 5% of the time
Slight Impact	• Excess Suspended Sediment Concentration > 5mg/l for less than 20% of the time • Excess Suspended Sediment Concentration > 10mg/l for less than 5% of the time
Minor Impact	• Excess Suspended Sediment Concentration > 10mg/l for less than 20% of the time • Excess Suspended Sediment Concentration > 5mg/l for more than 20% of the time
Moderate Impact	• Excess Suspended Sediment Concentration > 10mg/l for more than 20% of the time • Excess Suspended Sediment Concentration > 25mg/l for more than 5% of the time
Major Impact	• Excess Suspended Sediment Concentration > 25mg/l for more than 20% of the time • Excess Suspended Sediment Concentration > 100mg/l for more than 1% of the time

The limits refer to daylight hours only, as the impact of suspended sediments on light availability is not a controlling factor during night-time hours. However, because elevated suspended sediment concentrations may have other impacts to corals during the night time (including abrasion and clogging of coral polyps when they are feeding at night), in order to assure a conservative assessment of impact, the daytime tolerance limits presented in Table B.2 were also applied to the assessment of night-time reclamation activities.

Coral Tolerance to Sedimentation

Tolerance limits for sedimentation were also derived based on DHI's extensive monitoring of background sedimentation levels and monitoring during multiple dredging and reclamation projects in Singapore of coral responses to sedimentation levels. Based on these datasets, the limits presented in Table B.3 are considered to be conservative for coral reefs with naturally high background sedimentation levels.

Table B.3 Impact Severity Matrix for sedimentation impact on coral reefs in environments with high background sedimentation rates

Severity	Definitions
No Impact	Sedimentation < 0.05kg/m^2/day (< 1.7mm/14 days*)
Slight Impact	Sedimentation < 0.1kg/m^2/day (<3.5mm/14 days*)
Minor Impact	Sedimentation < 0.2kg/m^2/day (< 7.0mm/14 days*)
Moderate Impact	Sedimentation < 0.5kg/m^2/day (< 17.5mm/14 days*)
Major Impact	Sedimentation > 0.5kg/m^2/day (> 17.5mm/14 days*)

*Assuming an initial deposition density of 400kg/m^3

Seagrass Tolerance to Suspended Sediments

DHI's findings from previous monitoring studies in Singapore, as well as the Bali Turtle Island project described in Section B.2, have clearly indicated that corals are more sensitive to both suspended sediments and sedimentation that either seagrass or mangroves. The tolerance limits for seagrass are therefore less stringent that those applied to corals. Based on DHI's extensive monitoring datasets, the tolerance limits in Table B.4 were adopted for the project.

Table B.4 Impact Severity Matrix for suspended sediment impact on seagrass in environments with high background concentrations

Severity	Definitions
No Impact	• Excess Suspended Sediment Concentration > 5mg/l for less than 20% of time
Slight Impact	• Excess Suspended Sediment Concentration > 5mg/l for more than 20% of time • Excess Suspended Sediment Concentration > 10mg/l for less than 20% of time
Minor Impact	• Excess Suspended Sediment Concentration > 10mg/l for more than 20% of time • Excess Suspended Sediment Concentration > 25mg/l for more than 5% of time
Moderate Impact	• Excess Suspended Sediment Concentration > 25mg/l for more than 20% of time • Excess Suspended Sediment Concentration > 75mg/l for more than 1% of time
Major Impact	• Excess Suspended Sediment Concentration > 75mg/l for more than 20% of time

The limits provided in Table B.4 are for daylight hours only, as photosynthesis only occurs during daylight hours. However, in order to be conservative, these limits were also applied for night time dredging as well.

Seagrass Tolerance to Sedimentation

Seagrass are generally not impacted significantly by sedimentation (especially in tropical waters where growth rates are relatively high, and high tidal amplitudes and strong currents help to reduce net sedimentation) unless it gets to the point of starting to bury the leaves, which requires quite a high sedimentation rate. Such high sedimentation rates will usually only occur very close to the dredging or reclamation works. DHI's tolerance limits for seagrass, which were based on extensive monitoring from previous projects, are presented in Table B.5.

Table B.5 Impact Severity Matrix for sedimentation impact on seagrass in environments with high background sedimentation rates

Severity	Definitions
No Impact	• Sedimentation < 0.1kg/m^2/day (< 3.5mm/14 days*)
Slight Impact	• Sedimentation < 0.25kg/m^2/day (<8.8mm/day)
Minor Impact	• Sedimentation < 0.5kg/m^2/day (< 17.5mm/day)
Moderate Impact	• Sedimentation < 1.0kg/m^2/day (< 35mm/day)
Major Impact	• Sedimentation > 1.0kg/m^2/day (> 35mm/day)

*Assuming an initial deposition density of 400kg/m^3

It should be noted that other impacts to seagrass that may result from increased sedimentation, such as changes in the substrate composition, are also important to the overall impact levels experienced by a seagrass bed. However, such detailed impacts are difficult to quantify, and were therefore captured via the habitat monitoring component of the project instead, which included regular collection of sediment samples from the seagrass meadows for sediment grading analysis.

Mangrove Tolerance to Suspended Sediments and Sedimentation

Based on the literature and DHI's extensive previous monitoring experience, mangroves can be considered to be very tolerant to the range of suspended sediment loads that may be generated from dredging and reclamation activities. Of the various mangrove species, those with pheumatophore root systems (e.g. *Avicennia* spp.) are more sensitive to sedimentation, but they are only likely to be stressed when prolonged sedimentation reaches levels of 10–30cm. This level of sedimentation is unlikely to occur outside the immediate work area, so mangroves are thus were considered as sensitive receptors for this project. However, due to the relative scarcity of mangrove habitat remaining in Singapore, mangrove monitoring was included in the scope of the monitoring programme to confirm the predictions of no impact.

Visual Impact Detection Limits

In the turbid background conditions that occur around Singapore, low concentration sediment plumes are generally not visible (based upon the results of long-term remote sensing analysis) if the excess concentration (above background) does not exceed 5mg/l. A realistic measureable visual detection limit for non-recreational areas (in the Singapore high background turbidity context) would be a recurring plume present for 30–40 minutes per 12 hour daylight period (i.e. an exceedence of about 5% per day). For recreational areas, a limit of 2.5% exceedence of 5mg/l has proved to be appropriate in Singapore, based on previous projects.

B.4.3 Monitoring Outcomes

While the monitoring results for the project are proprietary to the client, DHI was able to confirm that the 11 months of monitoring during the reclamation, together with three additional months of monitoring during the post-reclamation audit period, confirmed that the EQOs for the project were met. There were no cross-border impacts, no impacts to corals (outside of the immediate reclamation footprint), seagrass or mangroves, no water quality impacts, no change in sediment composition or sediment levels at receptor sites (apart from the natural level of accretion expected over the time period), no impacts to the sensitive intakes near the reclamation area (including the Shell refinery intake), and no current impacts detected by the three ADCPs deployed across southern Singapore.

The active use of the feedback EMMP approach was clearly responsible for this outcome. During the project, there were a number of occasions when spill budgets and/or tolerance limits were exceeded during the short-term (several days) and management actions were undertaken (including temporary lowering of production rates, and restriction of works during certain phases of the tide) to bring the project back into compliance before any impacts were realised.

The initial spill budgets set for the project were found to be conservative, and were progressively relaxed during the course of the project in line with the feedback approach that forms the basis of the EMMP. The habitat monitoring confirmed the tolerance limits that had been set for the various receptors, including the corals and seagrass which were in close proximity to the reclamation area.

B.5 Pasir Panjang Container Terminal Phases 3 and 4 Reclamation, Singapore

B.5.1 Background

The Pasir Panjang container terminal (PPT) is one of the busiest container terminals (by volume) in the world. In order to expand the port's capacity and keep pace with the increasing size and number of container vessels visiting the port, a long-term six year) dredging and reclamation project to construct Phases 3 and 4 of the container terminal commenced in 2006. The location and proposed layout of the port expansion is shown in Figure B.7. It is estimated that the project will involve approximately 33 million cubic metres of reclamation fill (mostly from sand source dredging in Singapore waters), and seven million cubic metres of capital dredging.

The port expansion is immediately adjacent to Labrador Nature Reserve, which is one of the few remaining natural coastal coral reef areas in Singapore, and also features a sandy beach area with inter-tidal seagrass. Next to this is Labrador Park, a highly utilised recreational parkland area. The reclamation is located approximately 2km east of Cyrene Reefs, which are one of the main seagrass areas in southern Singapore, and approximately 2–3km west of coral reefs and recreational beaches along the western coastline of Sentosa, and the sensitive Underwater World intake on the northwest coast of Sentosa. It is also located approximately 3km north of Pulau Bukom, which is one of Shell's largest oil refineries in the world.

Figure B.7 Location and extent of Pasir Panjang Phases 3 and 4 reclamation (shown in green)

B.5.2 Tolerance Limits

DHI's Feedback Monitoring approach was applied to this reclamation, with an initial spill budget (prior to the start of works) being set based on preliminary tolerance limits for corals, seagrass and mangroves. The preliminary tolerance limits were based on previous monitoring works undertaken by DHI in Singapore and Malaysia (including the Pulau Ular reclamation described in Section B.4), and were based on five escalating categories of impact. The definitions of these five categories of impact were the same as those used for the Pulau Ular project (provided in Table B.1). The limits were then cross-checked against monitoring results throughout the duration of the project, and updated if required as part of the feedback process.

The tolerance limits used for the project were the same as those listed in Section B.4 for the Pulau Ular project.

B.5.3 Monitoring Outcomes

The reclamation is currently in its third year, and approximately 50% complete. While the monitoring results for the project are proprietary to the client, DHI is able to confirm that the three years of monitoring undertaken so far during the reclamation and dredging activities have affirmed that the EQOs for the project had been fully met thus far. There have been no cross-border impacts, no impacts to corals (outside of the immediate reclamation footprint), seagrass or mangroves, no water quality impacts, no change in sediment composition or sediment levels at receptor sites (apart from the natural level of accretion expected over the time period), no impacts to the sensitive intakes near the reclamation area (including the Shell refinery intake and the Underwater World intake at Sentosa), and no current impacts detected by the four ADCPs deployed across southern Singapore.

The active use of the feedback EMMP approach has clearly been responsible for this outcome. Due to the very complex dredging and reclamation schedule, and the variety of sediment conditions in the dredging areas, regular (sometimes weekly) updating of spill budgets has been required in order to ensure that the EQOs continue to be met. The feedback loop, where every sediment plume has been modelled in hindcast mode based on the actual sediment characteristics and production from each dredging activity and compared against tolerance limits for each receptor has been invaluable in understanding and managing the dynamic nature of the project.

The habitat monitoring has so far confirmed that the tolerance limits that had been set for the various receptors, including the corals and seagrass which were in close proximity to the reclamation area, were appropriately conservative, and no revision of tolerance limits has been required.

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Appendix N4

Ashburton River Delta Mangrove System:
Impact Assessment Report

Tables

Figures

Charts

Plates

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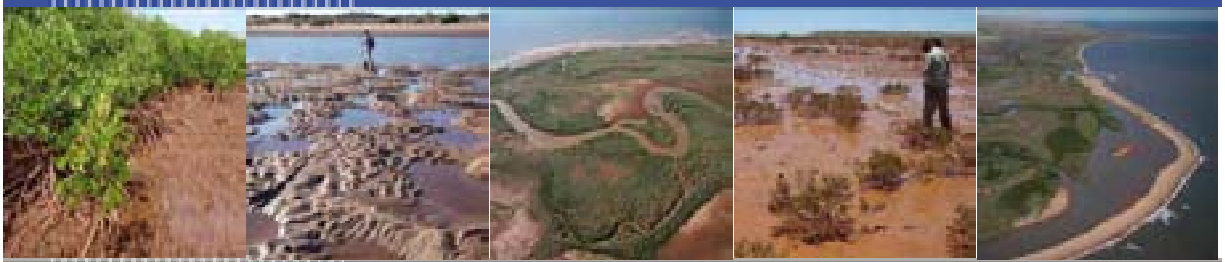

Report

Wheatstone Project

Ashburton River Delta Mangrove System: Impacts Assessment Report

14 MAY 2010

Prepared for

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Executive Summary

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara coast. The LNG and Domgas plants will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and future yet-to-be determined gas fields. The Project is referred to as the Wheatstone Project and "Ashburton North" is the proposed site for the LNG and Domgas plants.

The Project site is immediately adjacent to the Ashburton River Delta, an accretionary sedimentary structure occupying about 9 km of the coastline from the mouth of the Ashburton River to an area east of Entrance Point. The delta supports an extensive area of mangroves (526 ha) and a diversity of mangrove assemblages and is considered by the EPA to be of high conservation value and deserving of the "highest level of protection" (EPA 2001). The location of the proposed Wheatstone LNG Project immediately adjacent to the Ashburton River Delta gives rise for concern regarding potential impacts on the delta arising from the Wheatstone Project. The report below has been prepared to address the concerns regarding protection of the delta by:

- developing a conceptual model to guide the assessment of potential cumulative impacts to the Ashburton delta arising from construction and operation of the Wheatstone project
- undertaking an assessment of the key processes responsible for maintenance of the ecosystem and the potential for the project to affect these processes
- assessing the potential for the mangrove system to be adversely affected in the long term as a result of the operation of the LNG project.

Workshops were conducted with various specialists to gain an understanding of the Ashburton Delta system and relevant project design information. These workshops identified a range of potential indirect and direct impacts that were subsequently used to confirm the range and scope of studies required to undertake the assessments relating to the potential impacts on the mangrove system. The impacts assessed in this report are:

- Modification to the key processes of tidal inundation, freshwater flood flows of the Ashburton River and coastal sediment transport.
- Potential direct impacts related to the construction of the infrastructure (e.g. pipeline shore crossing and the onshore dredge material placement area).
- Potential indirect impacts related to turbidity and sediment deposition from dredging, seepage from the onshore dredge material placement area, stormwater management, hydrocarbon spills and emissions (atmospheric, noise and light).

A summary of these assessments are:

- Recognition of the ecological importance and conservation significance of the Ashburton Delta mangrove system has resulted in the design of a project footprint that aims to avoids any direct impact to intertidal Benthic Primary Producer Habitat within the Delta (e.g. mangroves, bioturbated mud flat with samphires).
- The only potential for direct impact on the Ashburton Delta mangroves arises from trenching the pipeline shore crossing. Whilst this is not Chevron's preferred option, were it to eventuate, it would temporarily disturb an area of relatively barren intertidal sand flat which currently supports a very low density of mangrove seedlings. The first such trenching activity is therefore unlikely to result in the loss of mature mangroves. However, future trenching activities may well do so (as seedlings would have grown) and therefore, may not satisfy the EPA's guidance to this area.

URS

Executive Summary

- None of the key processes identified for maintaining the Delta will be modified to the extent that indirect impacts are expected to occur and no adverse impacts to the Delta mangrove ecosystem are anticipated.
- No direct impacts or longer term indirect impacts to mangrove habitats are expected to occur under the normal operating conditions of the project.
- Should it be required, the onshore placement of dredge material into a bunded area in the southwest section of the project site has the potential to cause localised water table mounding and seepage of seawater in areas immediately adjacent to (but outside of) the onshore placement area footprint. Modelling studies show that the majority of seepage is predicted to occur into the salt flat habitat next to the southern perimeter and southwest corner of the placement area and away from mangrove areas. A low rate of seepage may occur at the dune/tidal flat margin near the northwest perimeter of the placement area. This is adjacent to the landward most occurrence of mangroves that are fringing the upper reaches of a small tidal creek. When considering the low rates of seepage in combination with high evaporation rates it is unlikely that the seepage will result in any impacts to mangroves fringing the small creek and any changes will be very localised to the dune/tidal flat margin.
- The assessment has identified the potential for condensate spills from the Product Loading Facility and, to a lesser extent, diesel spills from the Materials Offloading Facility to adversely affect the mangroves of the Ashburton Delta. It is recognised that spills are rare events but, should they occur in particular conditions, the potential for substantial mangrove mortality is high. Therefore management actions are necessary to ensure such events do not occur. Such management actions are documented in the Chevron Marine Oil Pollution Plan.

Based on the above assessments and historical experience indicating minimal impacts occurring from existing LNG plants and associated port infrastructure in Australia which occur either adjacent to, or amongst, mangrove habitats (e.g. Burrup Peninsula, Darwin Harbour), it is expected that the potential indirect impacts from the operation of the Wheatstone Project would constitute a low risk of adversely impacting the ecological integrity of the Ashburton Delta mangrove system.

Introduction

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara coast. The LNG and Domgas plants will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and future yet-to-be determined gas fields. The Project is referred to as the Wheatstone Project and "Ashburton North" is the proposed site for the LNG and Domgas plants. The Project will require the installation of gas-gathering, export and processing facilities in Commonwealth and State Waters, and on land. The LNG plant will have a maximum capacity of 25 million tonnes per annum (MTPA) of LNG.

The Wheatstone Project has been referred to the Western Australia Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this report have been conducted to support the environmental impact assessment process.

The Ashburton River Delta is an accretionary sedimentary structure occupying about 9 km of the coastline from the mouth of the Ashburton River to an area east of Entrance Point (located at the western boundary of the Wheatstone Project site (see Figure 1-1). The delta supports an extensive area of mangroves (526 ha) and a diversity of mangrove assemblages.

The Ashburton River Delta mangrove ecosystem is considered by the EPA to be of high conservation value and deserving of the “highest level of protection” (EPA 2001). The location of the proposed Wheatstone LNG Project immediately adjacent to the Ashburton River Delta gives rise for concern regarding potential impacts on the delta arising from the Wheatstone Project. During a visit to the Wheatstone site in October 2009, the EPA expressed concern that the values of the Ashburton Delta would be protected and indicated that they would expect the proponent to demonstrate that there would be no long-term irreversible loss of mangrove habitat, no impact on its geomorphic formation processes and nutrient flow to the estuary, and no adverse indirect impacts arising from the project.

The report below has been prepared to address the EPA’s concerns regarding protection of the delta by:

- developing a conceptual model to guide the assessment of potential cumulative impacts to the Ashburton delta arising from construction and operation of the Wheatstone project;
- undertaking an assessment of the key processes responsible for maintenance of the ecosystem and the potential for the project to affect these processes; and
- assessing the potential for the mangrove system to be adversely affected in the long term as a result of the operation of the LNG project.

The structure of the document is as follows:

1. Provide an assessment of the conservation significance of the Ashburton Delta on the basis of survey work undertaken for the Wheatstone Project, existing literature and relevant EPA guidance statements (Section 2).
2. Characterise the relevant biological, geomorphological and hydrological attributes and processes of the Ashburton Delta mangrove system (Sections 3 to 5).
3. Present a conceptual model describing the key processes maintaining the delta system and how these processes operate and influence the mangrove systems under both prevailing conditions and extreme, ephemeral events (e.g. floods and cyclones) (Section 6).
4. Undertake an assessment of the potential impacts to the delta from the Project, initially at the level of the key processes identified in Section 6 and then investigating specific direct and

1 Introduction

potential indirect impacts related to the project (Section 7). These assessments have considered a range of studies that are relevant to the particular impacts and, where applicable, any management or mitigation measures proposed.

In October 2009, workshops were held with various specialists to gain an understanding of the Ashburton Delta system and relevant project design information. These workshops identified a range of potential indirect and direct impacts that were subsequently used to confirm the range and scope of studies required to undertake the assessments relating to the potential impacts on the mangrove system. The impacts assessed in this report are:

- Modification to the key processes of tidal inundation, freshwater flood flows of the Ashburton River and coastal sediment transport.
- Potential direct impacts related to the construction of the infrastructure (e.g. pipeline shore crossing and the onshore dredge material placement area).
- Potential indirect impacts related to turbidity and sediment deposition from dredging, seepage from the onshore dredge material placement area, stormwater management, hydrocarbon spills and emissions (atmospheric, noise and light).

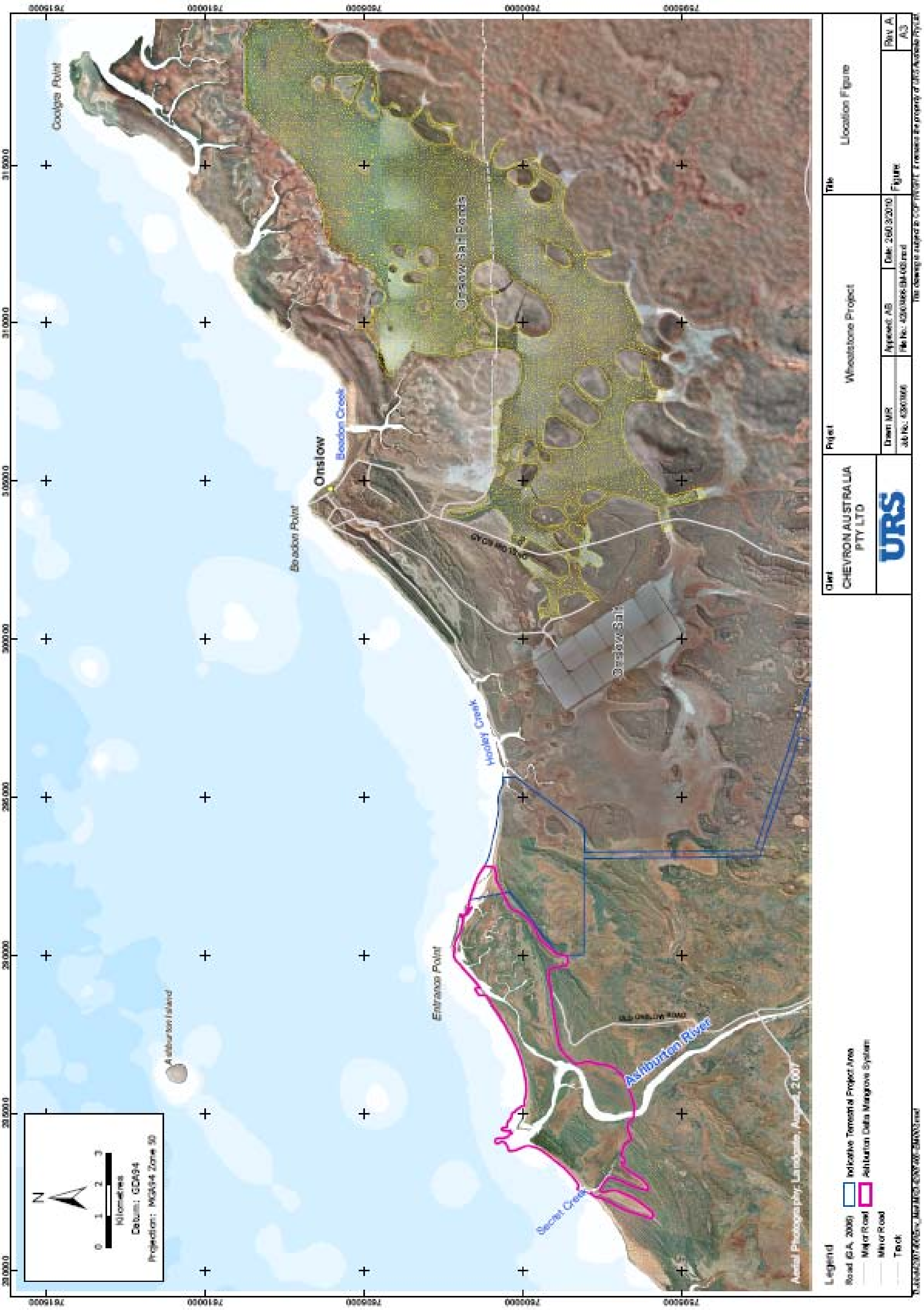

Figure 1-1 **Locality diagram**

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Conservation Significance of the Ashburton Delta

2.1 Assessment of conservation significance using Principles of Environmental Protection

An assessment of conservation significance of the Ashburton Delta with respect to EPA Position Statement No. 7 - Principles for Environmental Protection (EPA 2004a) was undertaken as part of an assessment of intertidal habitats of the Onslow coastline (URS 2010a). Of the five Principles of Environmental Protection adopted by the EPA, the third is "*The principle of the conservation of biological diversity and ecological integrity*" which "… *should be a fundamental consideration*" (EPA 2004a). This was used as the guiding principle when considering the conservation significance of the intertidal ecosystems of the project study area.

Biological diversity is defined by the EPA to encompass three levels – ecosystem diversity, species diversity and genetic diversity. Ecological integrity is said to be maintained "when key indicators of the system's structure and function remain within ranges that are unlikely to pose significant risk of incremental or irreversible damage" (EPA 2004a, Position Statement 29). Primary and secondary production are two of the most fundamental ecosystem functions that maintain ecological integrity.

When applying the principles of the EPA Position Statement No. 7 the conservation significance of the mangrove/mud flat habitats within the Ashburton Delta was regarded as:

- low (species-richness and genetic diversity) to high (ecosystem diversity) in terms of biodiversity, and
- high to very high in terms of primary and secondary productivity.

Biodiversity

The biodiversity significance, expressed in species-richness terms, is low on global and regional scales. These are not biodiverse ecosystems. In fact in some respects they are restricted, even when compared with other mangrove habitats of the Pilbara (nearshore) Bioregion. The intertidal surveys undertaken for the Wheatstone Project revealed no intertidal species that are abundant within the study area but rare elsewhere or in need of special protection.

The biodiversity significance expressed in terms of local endemicity is low. Although there is a high proportion of regional (North West Shelf) endemic species in the fauna, endemics of the study area are representative of the North West Shelf biogeographic province, nor is there any evidence of any local distinctive genetic forms.

The Ashburton Delta is unique as a biogeomorphic unit and in that respect it has high conservation value in terms of regional ecosystem diversity. The Ashburton Delta is characterised by sinuous river channels and tidal creeks bordered by moderately dense mangrove forests, almost enclosed behind beach/dune barriers. The delta is active and growing, contains an array of mangal habitat types and is unique as a biogeomorphic feature on the Western Australian coast.

Productivity

The Ashburton Delta and other mangrove/high tidal mud flat habitats in the wider study area (i.e. tidal embayments in the Turbridgi Point to Coolgra Point area) are assumed to have high primary and secondary productivity, important to the adjacent coastal ecosystems, though this is not quantified. Accordingly, they are assessed as having high to very high conservation significance. In the case of the Ashburton Delta, this is already acknowledged by the status given to it as a "Regionally Significant" mangrove area (EPA Guidance Statement 1) as discussed below.

The mangrove/mud flat habitats in the Onslow study area are likely to exhibit productivity processes and pathways that are different to those of the better researched wet tropics. In this regard they are representative of arid zone mangrove systems of the Pilbara (nearshore) Bioregion. Whether their productive output is greater or less than mangrove ecosystems in the wet tropics is unknown.

2.2 EPA Guidance

The EPA Guidance Statement (GS No. 1) for protection of tropical mangroves along the Pilbara coastline (EPA 2001) identifies areas that support arid zone mangroves that have special conservation significance. It also sets out the EPA's expectations for the protection of mangroves, while recognising current and potential future development areas.

The guidelines contained in GS No. 1 are based on a study by Semeniuk (1997a) to identify areas of regionally significant mangrove areas. This study recognised the "diversity of coastal types, diversity of habitats within a given coastal setting and diversity within habitat as factors leading to the heterogeneity of mangrove types along the Pilbara Coast and thus explicitly linked mangroves to geomorphic setting and habitats as a basis for their selection for conservation" (Brocx 2008). In the report 'Selection of Mangrove Stands for Conservation in the Pilbara Region of Western Australia - A Discussion', the following information about the Ashburton Delta is provided:

The Ashburton River Delta is one of the three largest deltas in the Pilbara region, encompassing the area between Rocky Point and Entrance Point. As a system, the Ashburton River Delta is a sand and mud delta, and hence contains a range of habitats such as sand ridges and associated swales, barred lagoons, mud flats, tidal creeks, spits, cheniers, tributaries and abandoned tributaries. The delta is active and important regionally in that it exhibits a coastal history of dynamic channel changes and complexity of mangrove assemblages. The dominant mangroves in the system are Avicennia marina and Rhizophora stylosa, and these occur in most of the commonly occurring habitats. The full range of habitats in the delta at the small scale result in some diversity of vegetation, with six species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (Aegialitis annulata, Aegiceras corniculatum, Avicennia marina, Bruguiera exaristata, Ceriops australis, Rhizophora stylosa). The mangroves in the system vary from extensive and wide in local inter-ridge areas, to fringing tidal creeks, cheniers and sand ridges (Semeniuk 1997a).

The five criteria below were used by Semeniuk (1997a) to select "Category A" (i.e. high conservation) areas and the key features of selected areas were assessed with respect to these criteria. The Ashburton River Delta was assessed as satisfying criteria one and four.

1. Representation of a coastal type and its accompanying mangroves.
2. Globally unique mangrove habitats and their assemblages.
3. Scientifically explicit mangrove/habitat relationships.
4. Clear and distinct examples of mangrove assemblages floristically.
5. Clear and distinct examples of mangrove assemblages structurally.

Within the GS No. 1 framework, the Ashburton River Delta is identified as being a Guideline 1 area of very high conservation value and "regionally significant" (Area 4 in Figure 2-1). It should be noted that the boundary of the delta (Area 4) within GS No. 1 is only broadly defined and was based on the source document (Semeniuk 1997a) which provided a map at a scale of 1:1,000,000 showing the Pilbara coast and approximate boundaries of the 22 areas selected as "Category A" (i.e. high conservation) areas. A more defined boundary of the Ashburton Delta mangrove system is shown in Figure 1-1 of this report.

The EPA's operational objectives for Guideline 1 areas such as the delta are:

- No development should take place that would adversely affect the mangrove habitat, the ecological function of these areas and the maintenance of ecological processes which sustain the mangrove habitats.
- The EPA will give these mangrove formations the highest degree of protection with respect to geographical distribution, biodiversity, productivity and ecological function.
- Proponents should be aware that where developments are proposed in these areas the EPA will adopt a presumption against finding the proposals environmentally acceptable.

In addition, the EPA Environmental Assessment Guideline 3 (Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment) (EPA 2009) links the above advice to EAG 3 Category A and provides the guidance that "No development activities should take place in these areas, nor should there be any development elsewhere, that would cause direct or indirect damage/loss of benthic primary producer habitat (e.g. mangroves) or ecological integrity of these areas. (Cumulative Loss Guideline = no loss of BPPH)"

It should be noted that while the above guidance information outlines the likely EPA expectations regarding the protection of mangrove habitats, the EAG 3 recognises the complexity associated with determining the ecological significance of loss of BPPH and hence the loss guidelines are not considered as rigid limits. The environmental acceptability of any potential damage/loss of BPPH will be a judgement of the EPA on its consideration of the overall risk to the ecological integrity of the delta. With respect to project design and management, the expectation of EAG 3 is that "Proponents will need to demonstrate 'best practicable' design, construction methods and environmental management aimed at minimising further damage/loss of BPPH through indirect impacts."

2.3 Geoheritage Significance

Geoheritage and geoconservation are concepts concerned with the preservation of landforms, natural and artificial exposures of rocks, and geological sites where geological features can be seen (Doyle et al. 1994). A further definition of geoheritage was provided by Brocx (2008);

Globally, nationally, state-wide, to local features of geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, palaeontologic, geomorphic, pedologic, and hydrologic attributes, at all scales, that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference.

2 Conservation Significance of the Ashburton Delta

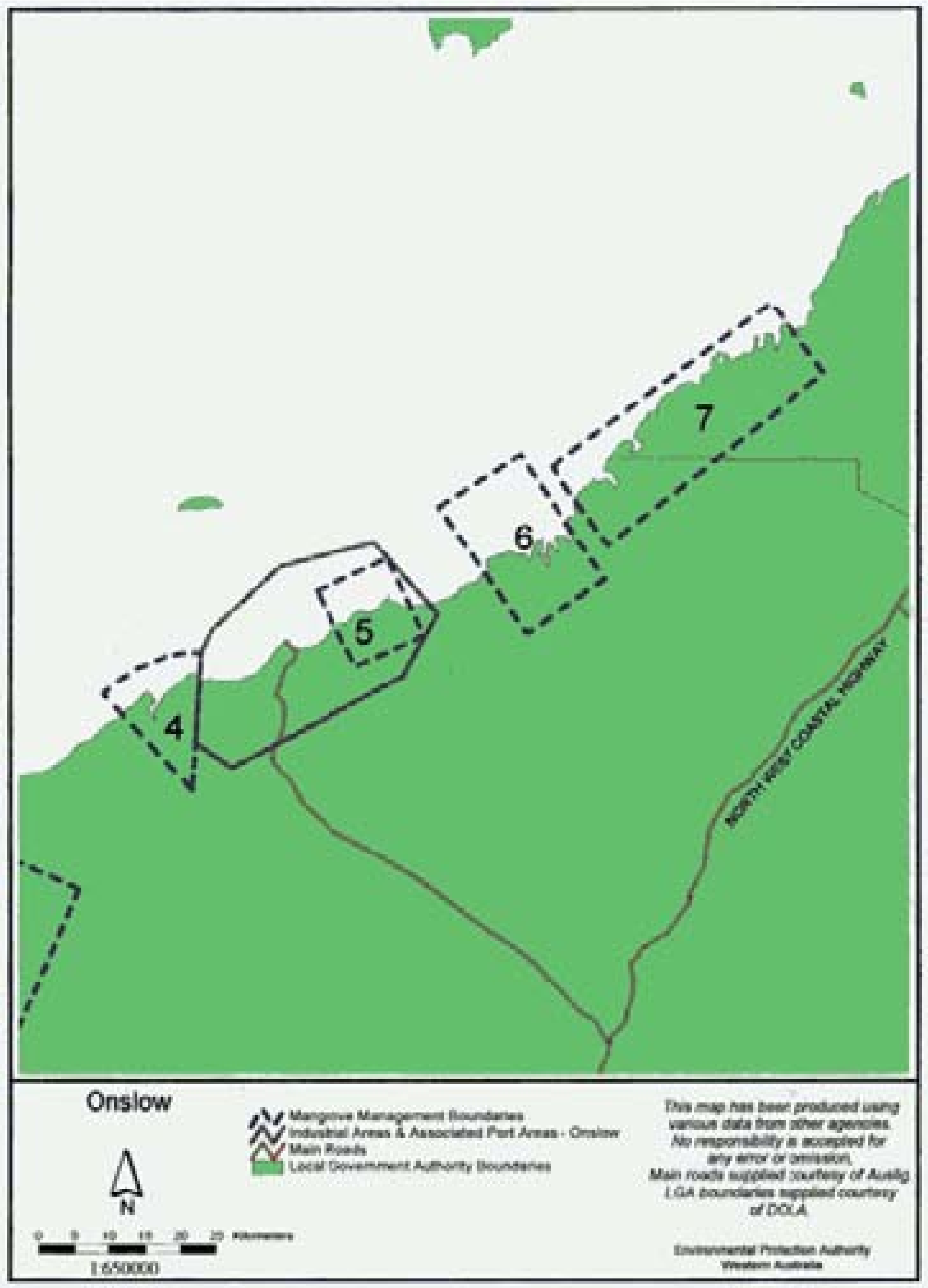

Figure 2-1 Mangrove management area boundaries identified for the study area by EPA Guidance Statement No 1. Source: EPA 2001

2 Conservation Significance of the Ashburton Delta

Within Australia the recognition and protection of geoheritage significance in terms of regulatory processes is still being developed and in Western Australia there is no State legislation, or formal legislation, or formal systematic process for the identification, conservation and management of sites of geoheritage significance (Brocx 2008). Rationale for the conservation of geodiversity due to its linkage with the conservation of biodiversity is provided by Semeniuk (1997b). This work identifies that while many current conservation principles and policies are based on biological attributes (e.g. at a species or biological community level), the biodiversity values of a particular region are inherently linked to that region's geodiversity. Hence, the conservation of the natural history values of a region is best achieved by the combined consideration of biological and earth science features (e.g. geologic and geomorphic features).

A preliminary assessment of geoheritage values of the Ashburton Delta is provided in the Damara report 'Coastal Geomorphology of the Ashburton River Delta and adjacent areas' (Damara 2010). The significance of the deltaic complex of the Ashburton River including the suite of geologic features and landforms comprising the shoreface, coastal dunes, chenier plains, mudflats, upper deltaic floodplains and palaeochannels relate to the degree to which the landforms: (a) collectively and individually provide essential life services; and/or (b), are recognised by experts within the geological disciplines for inclusion within the Register of the National Estate.

Potential examples include:

- The chenier plain comprising the eastern delta of the Ashburton River, which is remarkable for the rapidity of landform change and its state of preservation.
- The last interglacial platform identified through radiometric analyses of embedded coral and shell is intermittent and cut by the Ashburton River. The feature has been observed to extend from Urala Station to Onslow. Such landforms are poorly preserved in WA.
- An interglacial shoreline on Urala Station, including 120,000+ yr BP landforms backed by coastal dunes. Both have been crossed by younger linear desert dunes.
- Biogeography of the system, with its sub-fossil shell taxa. The biogeography is of considerable scientific interest and potential engineering interest in terms of landscape stability. It contrasts with the younger components of recent chenier development on the eastern delta. The range of species preserved is of considerable biogeographic interest. Additionally, complexity in the mix of materials and landforms on the modern surface provides evidence of extreme events in the region.
- High level wrack deposits of the 700 year old storm or tsunami on the western part of the coastal dune ridge provide evidence of the low-frequency high-magnitude events affecting the Ashburton River Delta.

In combination, these elements have considerable conservation significance on the basis of geoheritage (Damara 2010). Further studies are planned to provide a greater understanding of the evolution and development of the delta and adjacent landforms.

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Mangrove Systems of the Ashburton Delta

Intertidal habitat surveys conducted for the Wheatstone Project have visited a range of sites in the Tubridgi Point to Coolgra Point area to document the intertidal habitats and associated biological communities and collect information on the distribution and conservation significance of intertidal habitats. Particular focus was placed on the two main intertidal systems located adjacent to the proposed Wheatstone North development site, these being the Hooley Creek to Four Mile Creek tidal embayment and the Ashburton River Delta. The results of these surveys are provided in URS (2010a).

Mangroves in the Onslow area occur mostly within river mouth and tidal creek systems where they form a nearly continuous ribbon of vegetation fringing the creek channels. These mangroves are protected and partially isolated from the sea by barrier dune systems through which tidal creeks have breached narrow channels. At the tidal creeks which occur from Hooley Creek, Middle Creek, Four Mile Creek, Beadon Creek, and Second and Third Creeks, mangroves are confined to a narrow fringe adjacent to the creek channel that is typically only 10-20 m wide. More expansive mangrove areas are found at the Ashburton River Delta and Coolgra Point where a far greater area and diversity of habitats exist that are suitable for mangrove colonisation. Estimates of mangrove areas and species diversity recorded from these locations are provided in Table 3-1.

Table 3-1 Mangrove species and areas for each mangrove system in the Onslow area

Species	Ashburton Delta	Hooley Creek	Middle Creek	Four Mile Creek	Beadon Creek	Second Creek	Third Creek	Coolgra Creek
Aegialitis annulata	✓	✓	✓					✓
Aegiceras corniculatum	✓	✓	✓		✓		✓	✓
Avicennia marina	✓	✓	✓	✓	✓	✓	✓	✓
Bruguiera exaristata	✓							✓
Ceriops australis	✓	✓	✓		✓		✓	✓
Rhizophora stylosa	✓	✓	✓	✓	✓	✓	✓	✓
Mangrove area (ha)	526	66	13	4	133	30	161	515

The complex geomorphology of the Ashburton Delta consisting of a system of spits, cheniers, tidal flats, distributary channels and coastal dune barriers is reflected by the distribution of intertidal habitats including an extensive mangrove system. The distribution of the various intertidal habitats and adjacent supratidal areas is shown in Figure 3-1.

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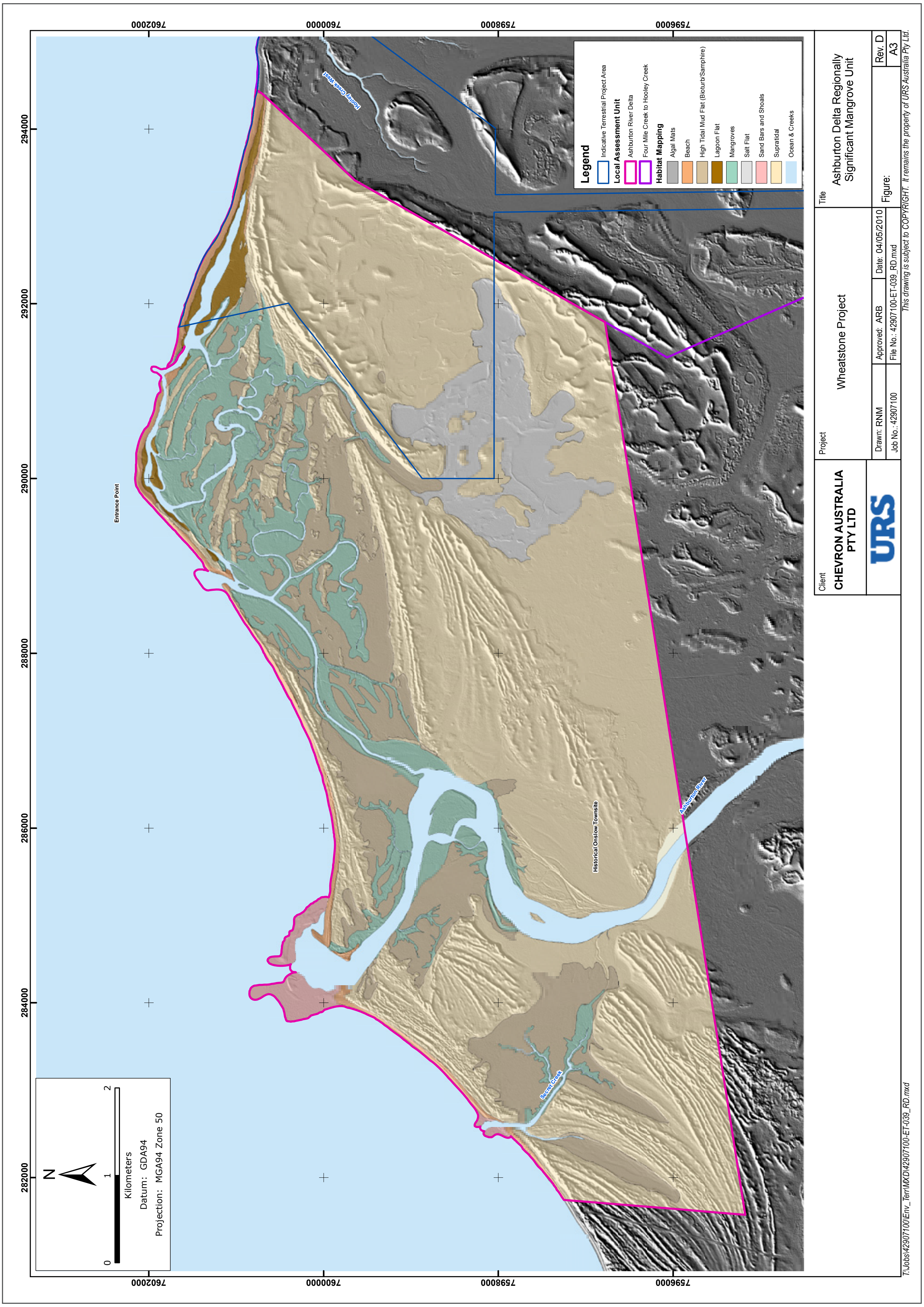

Legend
Indicative Terrestrial Project Area
Local Assessment Unit
Ashburton River Delta
Four Mile Creek to Hooley Creek
Habitat Mapping
Algal Mats
Beach
High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Mangroves
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
Entrance Point
Historical Onslow Townsite
Ashburton River
Secret Creek
Hooley Creek West
Kilometers
0
1
2
N
Datum: GDA94
Projection: MGA94 Zone 50
282000
284000
286000
288000
290000
292000
294000
7596000
7598000
7600000
7602000
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Ashburton Delta Regionally Significant Mangrove Unit
Drawn: RNM
Approved: ARB
Date: 04/05/2010
Job No.: 42907100
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The intertidal habitats present in the Ashburton Delta are:

- sandy beaches
- sand bars and shoals at the mouth of tidal creeks and the Ashburton River
- mangroves
- lagoon flat
- high tidal mud flat (supporting areas of bioturbated mud flats with samphire communities)
- supratidal salt flats.

3.1 Mangrove Associations and Their Distribution

Tidal exchange and flows are the dominant and prevailing processes that maintain Pilbara mangroves as they regulate many of the physical, chemical and biological functions. Groundwater and sediment salinity gradients are established across the tidal flats in response to decreasing frequencies of seawater (tidal) recharge with increasing tidal flat elevation, and these gradients have produced recognisable structural and physiognomic zones or associations within the mangroves (URS 2010a). Five main mangrove associations were recognised as occurring within the delta and distribution of mangrove associations in the eastern section of the Delta is shown in Figure 3-2. The mangrove associations and the area they occupy within the Ashburton Delta are shown in Table 3-2. Codes used to denote the various associations reflect the dominant mangrove species.

Table 3-2 Mangrove distribution

Code	Association	Ashburton Delta (ha)
Am1	Tall dense *Avicennia marina* fringing major tidal creeks and seaward margins	70
Am2	Low to moderate, dense *Avicennia marina* shrubland	257
Am3	Low, open to very open *Avicennia marina* on landward margins	146
AmRs	Mixed, tall *Avicennia marina/Rhizophora stylosa* low forests and thickets	38
Rs	Mixed, dense *Rhizophora stylosa* low forests and thickets	15
Total		**526**

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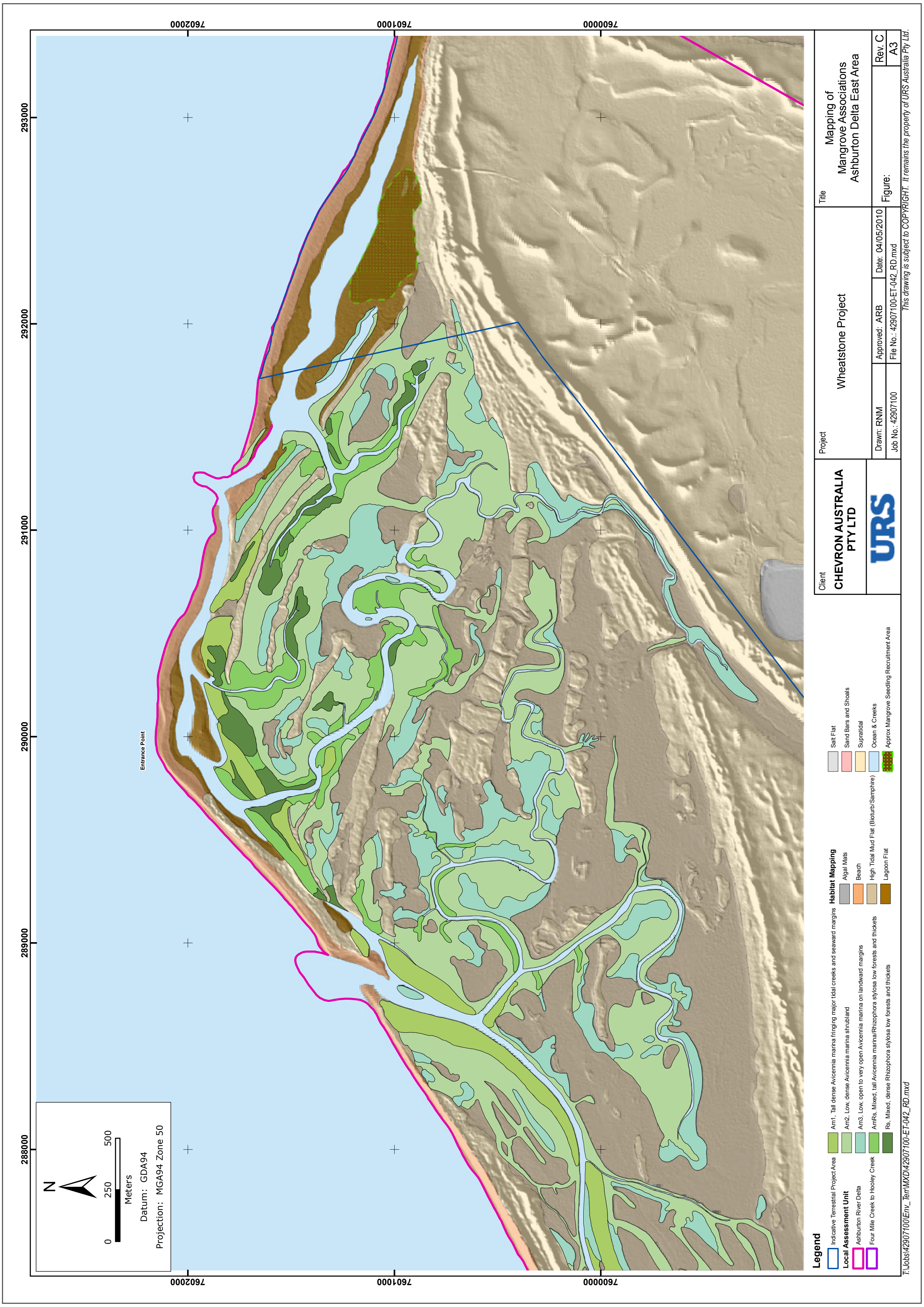
Entrance Point
N
0 250 500
Meters
Datum: GDA94
Projection: MGA94 Zone 50
Legend
Local Assessment Unit
Indicative Terrestrial Project Area
Ashburton River Delta
Four Mile Creek to Hooley Creek
Am1, Tall dense Avicennia marina fringing major tidal creeks and seaward margins
Am2, Low, dense Avicennia marina shrubland
Am3, Low, open to very open Avicennia marina on landward margins
AmRs, Mixed, tall Avicennia marina/Rhizophora stylosa low forests and thickets
Rs, Mixed, dense Rhizophora stylosa low forests and thickets
Habitat Mapping
Algal Mats
Beach
High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
Approx Mangrove Seeding Recruitment Area
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Mapping of Mangrove Associations Ashburton Delta East Area
Drawn: RNM
Approved: ARB
Date: 04/05/2010
Figure:
Rev. C
Job No.: 42907100
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3 Mangrove Systems of the Ashburton Delta

Tall dense Avicennia marina (thickets and low forests) fringing the major creek systems and seaward margins (Am1)

This association was typically limited to occurring along the major tidal creeks and the river channel of the Ashburton Delta (Plate 3-1). The structure of this association varied from dense thickets (2-4 m high) to low forests (4-5 m high).

Low to moderate height, dense Avicennia marina shrubland (Am2)

Together with the more open shrubland unit (Am3), this association was the most widespread in the study area. It occured as a fringe along the mid-upper reaches of the tidal creek systems and in some areas also extended landward across tidal flats from behind the taller associations (units Am1, AmRs, Rs) (Plate 3-1). This association was predominantly monospecific *A. marina*, approximately to 2 m in height and with a variable moderate to dense canopy cover. It was often backed by, and intergrades with, the open scrub unit (Am3) described below (Plate 3-2).

Low, open to very open Avicennia marina scrub on the landward margins (Am3)

Extensive areas of this unit occurred along the uppermost reaches of the tidal creeks and at the landward extent of the mangrove zone on tidal flat areas (Plate 3-2). As tidal elevation increases and the frequency of inundation decreases, the density of trees within these areas becomes generally low to scattered and they grow in a stunted, recumbent form due to high soil salinities that are approaching (or at) the threshold level tolerated by mangroves. Areas of low open *A. marina* scrub mangroves are often interspersed with the high tidal mud flat habitat (samphire and bioturbated mud flat zone) described in Section 3.5.

Plate 3-1

Plate 3-2

Plate 3-1 **Low dense *Avicennia marina* forests (Am1) along main channel in the Ashburton Delta. Further away from the channel the mangroves grade into dense *Avicennia marina* shrubland (Am2)**

Plate 3-2 **Open *Avicennia marina* scrub interspersed with samphire communities**

Mixed, tall Avicennia marina/Rhizophora stylosa thickets and low forests (Am/Rs)

This association was limited in extent and occurred in the lower reaches and more seaward areas of the more major creek systems and the Ashburton Delta. Dense thickets and low forests of mixed *A. marina* and *R. stylosa* were observed in areas adjacent to units Am1 and Rs.

3 Mangrove Systems of the Ashburton Delta

Tall dense Rhizophora stylosa thickets or low forests (Rs)

Low forests and dense thickets of monospecific *R. stylosa* were observed in the seaward or lower sections of the larger tidal creek systems and in the north-eastern sector of the Ashburton Delta (Plate 3-3). Within the tidal range occupied by mangroves, the dense *R. stylosa* stands usually occurred close to the lower limit of mangrove occurrence and in areas of muddy substrates. This is typical of the position occupied by *R. stylosa* in the Pilbara region (Semeniuk 1983).

Plate 3-3 Entrance Point area showing dense *Rhizophora stylosa* (dark green areas) amongst dense *Avicenna marina* (lighter green areas)

Other mangrove habitats

Other less frequently occurring mangrove habitats included dense to open shrubland of *Ceriops australis* (fringing the mid to upper reaches of creek channels and on tidal flats) and areas of the river mangrove (*Aegiceras corniculatum*) colonising newly-formed sand bars within the larger creek channels. In addition to the above assemblages, the presence of cheniers amongst the tidal flats has resulted in the development of a species-rich and very localised habitat. The cheniers, which are supratidal in elevation, provide localised freshwater seepage at their margins with the surrounding mud flats (which contain hypersaline groundwater) and, together with a different substrate type (calcareous sands), these conditions have developed narrow fringing mangrove habitats that can support *A. marina*, *R. stylosa*, *C. australis*, *A. annulata*, *A. corniculatum* and *B. exaristata* (i.e. all the Pilbara mangrove species expected to occur in the Onslow area).

High tidal mud flats

Landward of the mangrove zone, areas of bioturbated mud flats with samphire communities typically extended across the tidal flats to the hinterland margin or they merged with the supratidal salt flats. These high tidal mud flat areas occur in the upper or higher sections of the intertidal zone and hence are not regularly inundated by tides.

Together with the mangrove and algal mat habitats, this habitat was been considered as Benthic Primary Producer Habitat (BPPH) for the purposes of the Wheatstone environmental assessment (URS 2010b). The samphire plants and algal mats, like mangrove trees, are primary producers in the strict sense while the bioturbated mud flats are areas of high secondary production essential to the output of nutrients by the plants in the ecosystem. The bioturbated/samphire zone was a mappable

3 Mangrove Systems of the Ashburton Delta

habitat, however, the boundaries between samphire communities and bioturbated areas were often indistinct (or often interspersed within the same area) and hence they have been mapped together.

At locations where the extent of mud flat development was limited or truncated by the hinterland or low islands, the bioturbated/samphire mud flat habitat occupied the full extent of the mud flat zone between the landward edge of the mangroves and the hinterland margin. During both ground and helicopter-based surveys it was noted that high tides above 2.2 m Chart Datum (0.7 m Australian Height Datum) were required to inundate these areas. In many locations this habitat was hundreds of metres wide, while in others the bioturbated/samphire mud flat habitat zone was only a few metres wide and abutted the base of supratidal sandy cheniers or dunes with a well-defined high tide mark.

Within the bioturbated/samphire mud flat habitat a patchy and often complex zonation or mosaic was evident in the following sub-habitats:

- bioturbated mud flats - devoid of macro-vegetation but heavily worked over by burrowing crabs (Plate 3-4)
- samphire flats and/or discrete patches of samphires - dominated by halophytic shrubs but with some crab burrows (Plate 3-5).

Vegetation communities within samphire areas were dominated by two species, *Halosarcia halocnemoides* and *H. pruinosa*. Other species that were commonly found in areas where the samphire flats abutted the hinterland or low islands located amongst the tidal mud flats were *Muellerolimon salicorniaceum*, *Frankenia ambita*, *Noebassia astrocarpa*, *Hemichroa diandra* and the perennial grass *Sporobolus virginicus* (marine couch).

Plate 3-4

Plate 3-5

Plate 3-4 Bioturbated mud flats showing numerous crab burrows
Plate 3-5 Patches of samphire plants amongst bioturbated mud flats

In several locations in the Onslow area there were expansive areas of mud flats that extended for several kilometres landward of the mangrove lined tidal creek systems and landward of the bioturbated/samphire mud flat habitat described above. In these more expansive areas there were areas of cyanobacterial mats, also referred to as algal mats. The distribution of algal mats was limited in terms of tidal elevation but, due to the flatness of the tidal flat terrain, they could occupy large spatial areas (as is evident by the dark colouration of this zone on aerial photographs). Such expansive areas of mud flats with algal mats were observed at Tubridgi Point (Urala Creek), the Hooley Creek-Four

Mile Creek system and the Second Creek-Coolgra Point system. Such expansive areas of mud flats did not occur in the Ashburton Delta and there were no large spatial areas of algal mat detected from the habitat mapping.

Supratidal salt flats

Supratidal mud flats in the Pilbara bioregion are highly saline and are referred to here as salt flats. Where they occur they do not provide habitat for marine invertebrate fauna due to the hostile conditions produced by high surface temperatures and high evaporation rates. However, they are part of the drainage catchments of the mangrove ecosystem and are included here for that reason. An area of salt flat habitat occured in the south-east section of the delta (see Figure 3-1). Salt flats are inundated only on rare occasions by either extreme sea levels events (e.g. cyclone-induced storm surges) or by freshwater during flood periods.

Salt flats were predominantly devoid of vegetation; however areas of samphire shrubs were present in some locations, particularly at the interface of salt flats with the hinterland and terrestrial vegetation communities that may also support samphire communities.

3.2 Mangrove Flora

Seven species of mangroves are known to occur along the Pilbara coast (EPA 2001). Of these, six species were recorded from the Onslow area, both from the surveys undertaken for this Project and also from an earlier study conducted in 1990 (LEC 1991) as part of environmental studies for the Roller Oilfield Development. The six mangrove species are listed in Table 3-1.

Within the study area, *Avicennia marina* was a widespread and dominant species that occurred within the majority of mangrove associations present. It was found growing monospecifically in many areas and in a range of structural forms (e.g. from dense low forests to open shrubland) (Plates 3-1 and 3-2), but also occurred in association with the other five species in particular locations. The local dominance of *A. marina* reflects the broader regional pattern with this species being the most widespread and abundant mangrove species in the Pilbara coastal region (Semeniuk 1993b).

Rhizophora stylosa was the next most common mangrove species and typically formed dense stands (thickets and low forests) in the lower reaches or more seaward sections of the tidal creek systems, which provided a muddy protected environment that was subject to regular tidal inundation (Plate 3-3). *Ceriops australis* typically occurred in association with *A. marina* to form open scrub along the landward margin of the mangrove zone in locations either where the mangrove zone intergraded with the high tidal mud flat or along the mangrove - hinterland fringe or along the margins of cheniers. Both *R. stylosa* and *C. australis* are relatively widespread along the Western Australian coastline, occurring from the Kimberley to Exmouth Gulf.

On the basis of Western Australian Herbarium records, the specimen-based distribution for the remaining three species (*Aegialitis annulata, Aegiceras corniculatum* and *Bruguiera exaristata*) shows Karratha as the southern limit for these species. However, previous surveys in the Onslow area (LEC 1991), the eastern side of Exmouth Gulf (Biota 2005) and as documented in Johnson (1990) and Semeniuk (1993b) show that these species reach their southern range limit at the bottom of Exmouth Gulf. The field surveys undertaken for the Wheatstone Project recorded these three species at Coolgra Point and in the Ashburton Delta.

Stands of the river mangrove (*A. corniculatum*) were locally common in some parts of the Ashburton Delta, particularly the central and north-eastern sectors where it formed a narrow band (~ 2-5 m wide) along the tidal creeks. The meandering pattern of channel development evident in many of the tidal creeks and tributaries in the Delta (Figure 3-2) has led to differences in species composition between opposite banks. Thus the gently shelving, prograding banks of the 'point bar' generally displayed a higher species diversity compared with the steep and eroding edges of the opposite shore (i.e. on the cut bank). In these circumstances *A. corniculatum* were usually present on the shallower slopes of the prograding bank and typically absent from the cut bank. The club mangrove (*A. annulata*) occurred as an understorey species to *A. marina* on some locations but was not widespread.

The ribbed mangrove (*Bruguiera exaristata*) was recorded from one site in the Ashburton Delta where it occurred as a minor species amongst a dense *A. marina* dominated tall shrubland. In addition, *B. exaristata* was also recorded during a 1990 survey of the Ashburton Delta in a similar locality within the north-east sector of the delta (LEC 1991). In these cases *B. exaristata* occurred only as isolated stands consisting of approximately 10-15 trees.

Salt tolerant halophytic shrubs (i.e. non-mangrove species) were a conspicuous component of the vegetation within sections of the mangrove zone. Where present, these shrubs were established at varying degrees across the tidal gradient. Close to tidal creeks, they usually comprise a single species such as *Hemichroa diandra* occurring as an understory or heath amongst *A. marina* mangroves. Sometimes *H. diandra* extended beyond the mangrove shrubs and partly down the slope of the tidal creek bank. Halophytic vegetation within the mangrove zone was common amongst the more landward *A. marina* open shrubland and consisted of a mixture of species (e.g. *H. diandra, Halosarcia halocnemoides* and *Halosarcia pruinosa*). Like the mangroves, the halophytic shrubs recorded in the delta were typical of those found in similar habitats in other mangrove environments on the Pilbara coast (Craig 1983; Biota 2005) and have been recorded for the Onslow area in previous surveys (Paling 1990; LEC 1991).

3.3 Mangrove Fauna

Many species of animals can move into or out of mangroves on a tidal, seasonal, or other basis. The fauna of mangroves can be divided into three components (URS 2010c):

- species that enter mangroves at high tide and depart on the falling tide
- species that enter mangroves at low tide and depart on the rising tide
- species that remain in mangroves throughout the tidal cycle.

The mixture of species entering and leaving mangroves every tidal cycle makes mangroves a dynamic environment with a broad range of community attributes.

3.3.1 Species distributions

Species that enter mangroves at high tide and depart on the falling tide

A wide variety of organisms enter the mangroves on the rising tide, primarily to feed within them including fish, some crabs, reptiles including sea snakes, saltwater crocodiles and turtles, and even mammals such as dugong. These are all marine species that leave the mangroves on the falling tide. A portion of the populations of these species may remain in water retained in larger creeks or intertidal pools at low tide. Some species exhibit a mixture of responses. For example, some mud crabs leave the mangroves as the tide falls, some may remain in the tidal creeks and others retreat into burrows that retain seawater at low tide.

Fish surveys undertaken in tidal creek habitats at Hooley Creek and the north-eastern Ashburton lagoon in recorded a moderate degree of fish diversity in the systems; 344 individuals of 34 species were recorded; only one individual each of the mudcrab *Scylla serrata* and the swimmer crab *Portunus* sp. were collected (URS 2010d). Further fish surveys are planned for November 2010.

Species that enter mangroves at low tide and depart on the rising tide

A smaller group of species exhibits the reverse cycle: entering the mangroves at low tide, then leaving as the tide returns. These are terrestrial species from adjoining environments and include mammals, reptiles such as lizards, and a variety of birds. Again a portion of the population may remain in the upper foliage of taller mangroves at high tide, particularly birds and bats.

Species that remain in mangroves throughout the tidal cycle

A large group of invertebrates and some fish, such as mudskippers, remain in the mangroves throughout the tidal cycle. These animals often have a planktonic larval stage in their life cycle that allows them to be widely distributed between mangrove systems. However, once they settle to the bottom, the animals are restricted to the local area.

This group of species can be divided into species that occur on adjacent shores, such as rocky and sandy shores and include mangroves as simply one of the habitats in which they live, and species that typically occur only in mangroves. Most of the species in mangroves are there incidentally; only a relatively small proportion is restricted to mangroves. URS (2010a) provided a list of mangrove obligate species from the Onslow area, including the Ashburton Delta and Hooley Creek: only seven gastropod molluscs, 10 crabs and one barnacle were considered to be largely restricted to mangroves. Similarly, Metcalfe and Glasby (2008) recorded 76 species of intertidal worms from mangrove habitats in Darwin Harbour, only seven of which (all polychaetes) appeared to be restricted to the mangroves.

3.3.2 Invertebrate fauna

Mangroves and associated mud flats have a high organic content, support high microbial activity and large densities of invertebrate fauna that remain in the mangroves throughout the tidal cycle. These organisms perform the critical ‘secondary production’ role of breaking down organic material into forms that become available to the mangrove ecosystem and beyond. Within that upper intertidal zone, much of the mud flat areas are heavily burrowed by ocypodid and sesarmid crabs, generally in vast numbers. The burrowers have very important functions in maintaining favourable geochemical conditions in the substrate. Ocypodid crabs (fiddler crabs - genus *Uca*) feed mainly on the micro-epibenthos on the substrate surface, while the sesarmids (marsh crabs – genera *Neosarmatium, Perisesarma, Parasesarma*) feed on detrital material they gather from the mud flat surface (URS 2010a). The sesarmids play a particularly important role as they drag the plant material into their burrows where they shred it, thereby resizing and redistributing organic material throughout the soil profile.

3.3.3 Vertebrate fauna

The results of terrestrial fauna surveys undertaken in the vicinity of the Project area indicated that key terrestrial vertebrate fauna known or likely to be present in mangrove habitats in the Wheatstone Project area included (Biota 2010a):

- nine species of mangrove specialist avifauna
- herpetofauna including two mangrove snake species (*Ephalophis grayae* and *Hydrelaps darwiniensis*), and low frequency potential for individual saltwater crocodiles *Crocodylus porosus* (listed as a Schedule 4 species at State level)
- the little northern free-tail bat *Mormopterus loriae coburgensis* (listed as a Priority 1 species by the Department of Environment and Conservation).

During marine and intertidal survey work in 2009, survey teams sighted sawfish in the north-eastern lagoon of the Ashburton Delta and in Hooley Creek. Sawfish (family *Pristidae*) are highly modified rays with a shark-like appearance but the head is flattened, with an elongated rostrum, known as the saw, which gives rise to the common name of sawfish. The saw has a number of pairs of rostral teeth that extend laterally. Without a specimen, the identification of the sawfish sighted in the study area could not be confirmed. Four species occur in Western Australian waters, and all are protected under legislation such as the *Environment Protection and Biodiversity Conservation Act 1999* and the *Western Australian Fish Resources Management Act 1994* (URS 2010d).

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Coastal Geomorphology

A detailed assessment of coastal geomorphology undertaken by Damara (2010) identified recent historical changes to the geomorphology of the proposed Ashburton North site, established them in the broad contexts of Late Holocene coastal evolution and projected future changes, including the construction of Project infrastructure.

Specific objectives of the Damara study were to :

6. Describe the landform assemblages and geomorphic components of the coastal lowlands along the coast between the mouths of the Ashburton River and Middle Creek, and extending inshore from low water to the approximate landward limit of spring tidal inundation.
7. Describe active coastal and marine processes, with particular reference to the shoreline, over the period for which historical aerial photography and any survey information is available.
8. Develop a conceptual model of coastal development during the Late Holocene based on the superficial geology and geomorphology and which may be refined by stratigraphic and chronologic investigation.
9. Identify areas of relative instability and potentially subject to risk in response to projected environmental change, particularly areas in which bioproductivity may be significantly affected.
10. Determine the sensitivity of (a) proposed infrastructure to environmental conditions and (b) the environment to establishment of the proposed infrastructure.
11. Identify potential future quantitative studies and monitoring programs, should these be required.

4.1 Coastal Geomorphology of the Ashburton Delta

A geomorphic map covering the study area has been developed by Damara (2010) through analysis of aerial imagery and LIDAR topography subsequent to field inspection (Figure 4-1).

Over a geologically long period, the Ashburton River has delivered a substantial amount of sandy sediment to the coast from the Precambrian hinterland (Semeniuk 1993a, 1996). The sediment has accumulated to form a riverine plain with up to 25 m of unconsolidated red sand and muddy-sand overlying an early Pleistocene or older limestone pavement. A more recently formed pavement of marine origin commonly sits above the deep red sand and outcrops at the surface. The pavement has a variety of lithified geomorphic features associated with fluvio-deltaic and nearshore marine processes. These include the landforms of mid-delta environments: channel gorges, topographic rises and basins. Delta front features such as beach rock, beach ramps and low bluffs are also present as small islets with fringing coral reefs and are apparent close to the modern shore. In places the limestone features are overlain by recently deposited, unconsolidated dune and beach sands, as well as sediments characteristic of supratidal and intertidal flats.

Throughout the Quaternary at least, the shifting Ashburton River has built a suite of coalescing deltas with the deltaic plain consisting of overlapping and inter-fingering delta lobes against a northwest trending rocky shore. The switching pattern has commonly resulted from channel avulsion with one of the few distributaries present at any time carrying the majority of water and sediment discharge. Judging by the formation of recorded changes to Entrance Point, the active channel rapidly progrades seaward, while secondary channels are clearly less active and may be blocked by deposition from the main channel.

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Legend
Geomorphology Boundaries (Damara, 2009)
Active delta of the Ashburton River (Includes remnant chenier plain and coastal dune ridge)
Deltaic Foreland (Includes lithified and active cheniers, tiidal creeks and mudflats)
Geomorphology (Damara, 2009)
B, Basin; wetland in Backbarrier flats or riverine plain
Cheniers, Beaches & Spits
Ca, Active chenier, beach and spits
Cl, Chenier with lithified core; may be in part overlain with unconsolidated sand
Cp, Exposed rock pavement, inplaces supporting chenier ridge
Cu, Unconsolidated chenier landward of the active shore
Dunes
Db, Beach
Dbf, Backbarrier flats landward of dune ridge
Dbr, Remnant beach ridge or chenier plain
Dcf, Backbarrier flats landward of the coastal dune ridge: remnant washover fans may be present
Dcr, Coastal dune ridge
Df, Foredune ridge
Ds, Inactive spit
Dsf, Salt flats fringing outwash or beach ridge plain
Dtf, Backbarrier flats associated with dunes away from the present coast
Dtr, Terrestrial dune ridge
Mudflat & Mangal
Mb, Basin in mudflats
Mf, Undifferenciated mud flats and salt flats
Mi, Residual Island
Msr, Salt flat, fringing dunes and or fringing pavements
Mtm, Tidal creeks and mangroves without evidence or recent deposition
Mto, Tidal creeks with and depositional fans and mangroves
River
OCL, Ocean, Creeks & Lakes
Rcb, Marginal shoal or sand bank in channel
Rop, Riverine outwash plain
Rt, River terrace
N
0 500 1,000 1,500
Meters
Datum: GDA94
Projection: MGA94 Zone 50
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
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Geomorphology Mapping
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4 Coastal Geomorphology

In several places, particularly where the channel has been driven parallel to shore, presumably under the influence of winds and waves from the west and flowing in a north-east direction, the delta is asymmetrical with the river feeding chenier spits on the eastern side of its mouth (Figure 4-2). This is a feature of coastal environments subject to strong littoral transport along the lower swash zone of sandy beaches.

Presently, the main channel is approximately seven km west of Entrance Point and its delta has a more symmetrical form than that present in the early 1900s. This is a very recent change of channel position. It resulted from the main river mouth switching from Entrance Point to its present position after siltation of the channel in the vicinity of the Old Wharf, which was abandoned in 1921. Channel avulsion, the change in channel position associated with extreme flood events, is typically associated with river systems bearing a high sediment load, under relatively low wave and tide conditions (Coleman & Wright 1975). At the site of the active channel, a local salient and shoal structure commonly occurs, which may be rapidly destabilised if the river flow subsequently switches to an alternate channel. This feature is locally apparent at the existing Ashburton Channel entrance, with only residual shoals remaining at Entrance Point. Such changes have occurred in the geologic past, throughout the Holocene in particular. Changes in channel position are apparent as palaeochannels on the floodplains form elongate depressions that may carry fluvial flood waters, contain tidal creeks along part of their length or form billabongs in wet seasons. The channels may be reactivated by tidal creek incursion or avulsion of the main river channel. Shoals at the abandoned river mouths are rapidly reworked by ocean processes and moved into the littoral transport system to form beaches, chenier spits and foredune ridges as is currently occurring at Entrance Point.

Entrance Point delta is a geologically controlled cuspate foreland with its asymmetrical shape apparently determined by a limestone pavement on older deltaic landform, comprising the main body of the feature, as well as by wave refraction around offshore structures such as Curlew Bank, Roller Shoal and Ashburton Island. In this report, the foreland is referred to as the eastern delta to distinguish it from the small developing delta at the current mouth of the Ashburton River. At present a distributary arm of the Ashburton River, formerly the main channel, flows northeast along the western margin of the limestone pavement. A sequence of lithified ridges is apparent and includes cheniers linearly oriented WNW to ESE. Swales between the ridges support tidal creeks and mangals. The most recently formed cheniers separate tidal creeks flowing onto the northeast shore of the cuspate feature or which have been blocked by sediment drift across their entrances (as shown by the red arrows in Figure 4-3). Further south the tidal creeks drain into the old Ashburton River channel or onto the eastern flank of the foreland. One drains low-lying land in the Saddle Hill dune complex. The cheniers and sand spits of the foreland constitute a substantial store of sediment that is highly unstable and could easily be remobilised by fluctuation in the intensity of fluvio-marine processes. The age structure of the cheniers has been examined to provide insight into development of the sequence and the likelihood of remobilisation.

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Figure 4-2 Geomorphology of the Ashburton River deltaic complex. Source: Damara 2010.

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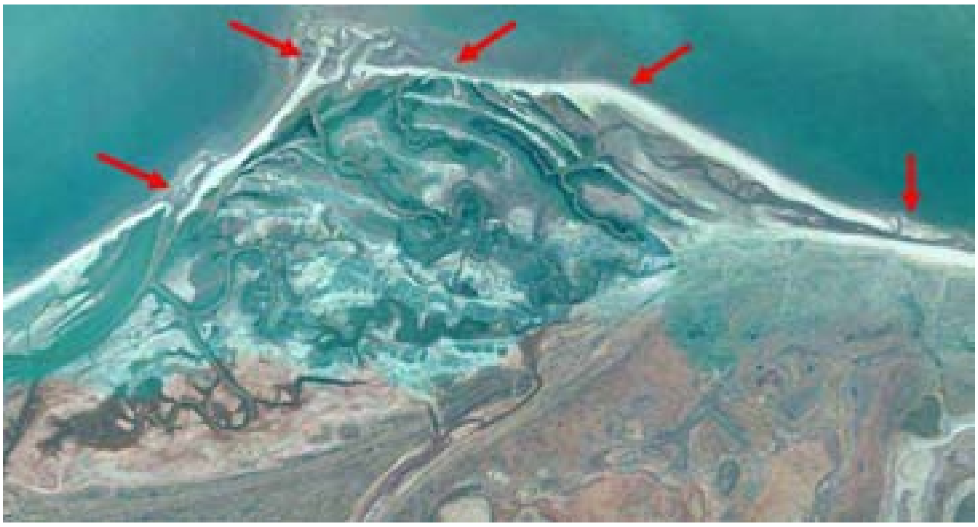


Figure 4-3 Sedimentation blocking the mouths of tidal creeks. Source: Damara 2010

4.2 Late Holocene dynamics

Rapid sea level rise associated with the post-glacial transgression causes a break point in coastal evolution, with modern geomorphic coastal features typically having an age of less than 6,000 years. These features overlie an older coastal structure developed during the Pleistocene relative sea level highstand. Pleistocene features can typically be distinguished from modern formations by their lithified nature, although indurated beach rock structures may be comparatively modern.

Figure 4-4 Apparent Planform Formations. Source: Damara 2010

The presence of lithified cheniers within the Ashburton eastern and western deltas confirms that the deltaic complex is comprised of both modern and older formations. Available dating, historical nautical records and more recent aerial imagery allow approximate distinction of four formations, corresponding to different eras of development (Figure 4-4). The relative accretion rate suggested by each of these formations has been estimated using rough estimates of accumulation depth based upon existing adjacent bathymetry and indicative depth to underlying rock (Table 4-1).

Table 4-1 Estimated Accretion Rates for Planform Formations

Formation	Age	Area	Est. Depth	Accretion
Holocene Delta	c. 6000 yrs	860 ha	1-3 m	1,500-4,500 m^3 p.a.
Eastern Delta	c. 1000 yrs	360 ha	1-3 m	3,500-10,000 m^3 p.a.
River Mouth	c. 100 yrs	180 ha	2-8 m	50-200,000 m^3 p.a.
Barrier Spit (east of Entrance Point) 1963-2009	c. 40 yrs	60 ha	3-5 m	45-75,000 m^3 p.a.
Barrier Spit (east of Entrance Point) 2001-2009	c. 10 yrs	6 ha	3-5 m	20-40,000 m^3 p.a.

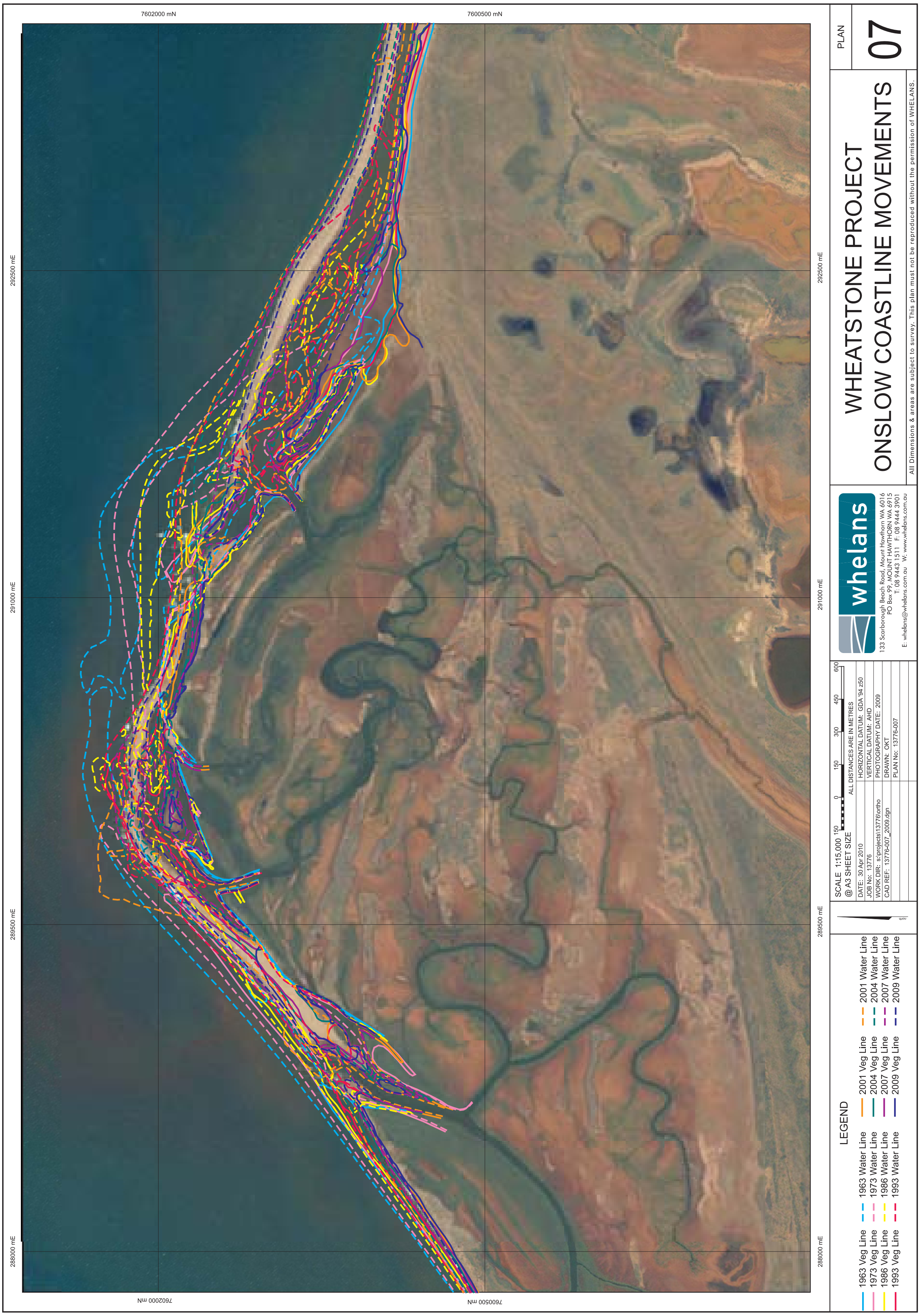
4.3 Historic Coastline Movements

Shoreline movements in the vicinity of the proposed development site were examined by Damara (2010) using photogrammetric analysis of historic aerial imagery from 1973, 1993, 2001 and 2004 (Figure 4-5). Despite very high variability of forcing conditions, historic photographs show that the Ashburton coast has generally maintained a similar shoreline position for decades, with only local features experiencing significant change, including the deltas, cheniers and spits at the mouths of tidal creeks. Observed coastal movements between the Ashburton River entrance and Hooley Creek suggest discrete coastal components that have persisted from 1973 to 2009, but have each evolved in different ways (Figure 4-6).

In terms of the overall stability of the Ashburton Delta mangrove system, the historical aerial photographs indicate that any significant changes to mangrove distribution in the last 30-40 years have been limited to the seaward margins of the delta as a band of maximum width of approximately 200 m and the remainder of the mangrove system has been relatively stable.

The characteristic behaviour of constrained dynamic zones is developed by the geologic framework underpinning much of the Pilbara coast, with rocky features providing strong structural control over shoreline position (Semeniuk 1996). In this situation, coastal dynamics are appropriately interpreted using a source-sink conceptual framework which is applicable to a largely controlled or engineered coast.

The Ashburton River Delta is comprised of an extended area of generally low-lying land, within which is an array of channels and ridges. Some of the channels actively transport river flows, others are active only during flood events, and some of the channels are characteristic in structure of tidal inlets and apparently bear little flood runoff. Historical movements of the Ashburton River Delta include internal channel movements and external coastal evolution.


WHEATSTONE PROJECT
ONSLOW COASTLINE MOVEMENTS
PLAN
07
whelans
LEGEND
1963 Veg Line
1973 Veg Line
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SCALE 1:15,000
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ALL DISTANCES ARE IN METRES
7602000 mN
7600500 mN
288000 mE
289500 mE
291000 mE
292500 mE
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4 Coastal Geomorphology

The main flow path of the Ashburton River across the delta has switched between channels historically, as the river previously exited near Entrance Point (Australian Pilot 1921, cited in Damara 2010). The old channel silted up and switching of the channel to its present position occurred between 1921 and 1973.

Figure 4-6 Coastal Components near Ashburton River Entrance. Source: Damara 2010

The north-west facing coastline between the Ashburton River entrance and Entrance Point appears to have receded by 50 m between 1973 and 2004. Imagery from 1993 and 2001 shows a reasonably consistent trend of shoreline erosion in the order of 1.5 m/yr. Concurrent accretion of a barrier spit occurred on the coast eastwards of Entrance Point, which gradually elongated before eventually welding to the coast in 2005. This behaviour is consistent with an eastwards migration of the delta sediments.

The 2009 site inspection identified two creek entrances east of the main Ashburton River entrance. Historic imagery shows there are three historic creek entrance sites that intermittently migrate, close up and break open (Table 4-2).

Table 4-2 Position of Ashburton Delta Creek Entrances

Date	Ashburton East	Entrance Point West	Entrance Point East
Entrance Position	7601200N; 288800E	7602000N; 290000E	7601750N; 291200E
1973	Closed	Open	Open
1993	Closed	Open	Closed
2001	Open	Open	Closed
2004	Closed	Open	Closed
2009	Open	Closed	Open

4 Coastal Geomorphology

The following features of the creek entrance and bars are noted:

- Ashburton East entrance closed between 2001 and 2004 (Plate 4-1). There were no significant flow events during this period and it is assumed the littoral drift overwhelmed the tidal flow.
- The Entrance Point western spit, evident in 2009, has historically been the site of a reasonably complex entrance bar complex, with the bar configuration suggesting eastwards littoral drift. This spit has migrated eastward by about 700 m since 2004.
- The Entrance Point western spit was located 300 m offshore of the 2004 coastline in 1973.
- The Entrance point eastern spit migrated eastwards by about 2.2 km between 1973 and 2009. The rate of eastward migration since 1993 has been in the order of 100 m/yr. This spit welded to the coastline after 2004, about the time when the current entrance to the west appears to have opened (Plate 4-2). The entrance spit is welded to the shore about 500 m west of the Project site. The present rates of eastward migration are uncertain, however historic rates have been very high.
- The coastline at the salient has been relatively stable, but remains vulnerable to the influence of the eastward migration of the Ashburton delta.

Plate 4-1 Entrance Point looking west

4 Coastal Geomorphology

Plate 4-2 Entrance Point looking east

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Ashburton River Flood Flows

The Ashburton River is characterised by:

- A large catchment area.
- Ephemeral flows (recorded discharge varies between nil and greater than 12,600 m^3/s; Department of Water (DoW) at the Nanutarra Gauging Station).
- Climatic conditions which are characterised by long dry periods and high intensity rainfall events, which generate significant stream flows.
- The magnitude of stream flow is predominantly determined by the Average Recurrence Interval (ARI) of the rainfall events.

The Ashburton River catchment is approximately 78,777 km^2 in area with many smaller sub-catchments. Overland flow is channelled in the upstream portion of the catchment, due to greater topographic relief in its upper reaches. At the coast, the river discharges through a network of tributaries within a delta system. Rainfall distribution, occurrence and intensity are known to vary widely across the Ashburton River catchment, due both to the size of the catchment and nature of the cyclonic rainfall events. There is a trend observed from rainfall records of decreasing rainfall intensity further from the coast reducing from hundreds of millimetres at the coast to tens of millimetres of rain further inland.

5.1 Historical Flows and Flood Events

Flow in the lower reaches of the Ashburton River (Charts 5-1 and 5-2) has been monitored since 1972 through the DoW Gauging Station at the Nanutarra Bridge, approximately 100 km inland from the river mouth. The annual flow volumes in the Ashburton River are widely variable, being known to range from 3 GL in 2007 to 4,500 GL in 1997.

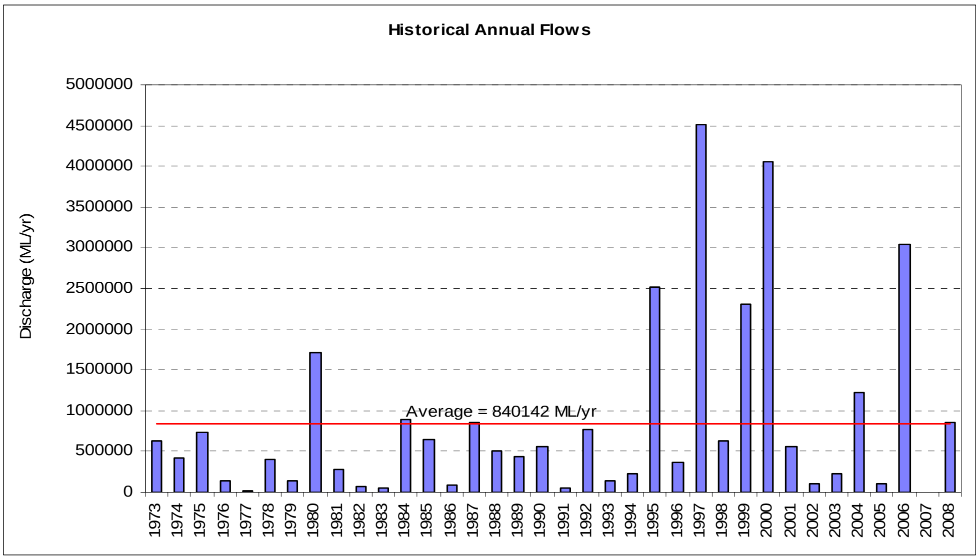

Chart 5-1 Ashburton River Annual Flow Volumes (1973-2008). Source: URS 2010e

5 Ashburton River Flood Flows

The maximum flow rates on the Ashburton River (Chart 5-2) were obtained for every year using the annual maximum stream flow values.

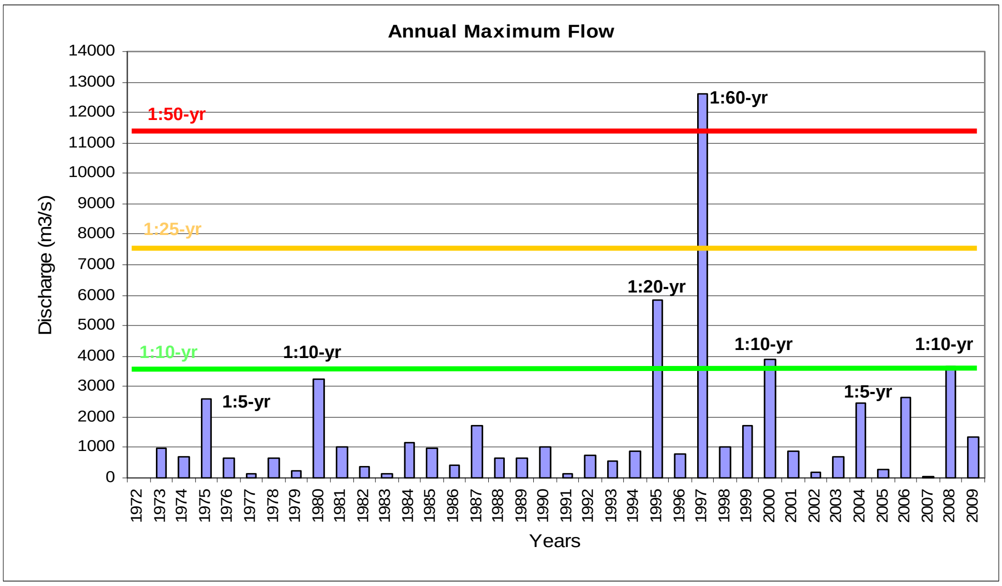

Chart 5-2 Ashburton River Annual Maximum Flow Rates (1973 to 2009). Source: URS 2010e

5.2 Flood Frequency

A Flood Frequency Analaysis (FFA) was undertaken on the annual maxima flow data recorded at the DoW Nanutarra Gauging Station, the closest gauging station to the Project Area. The Nanutarra gauge has 37 years of flow record and gauges the majority of the Ashburton River catchment. A complete annual maxima flow data set has been used in the FFA. The results of the analysis with the 90% probability limits are shown in Chart 5-3.

5 Ashburton River Flood Flows

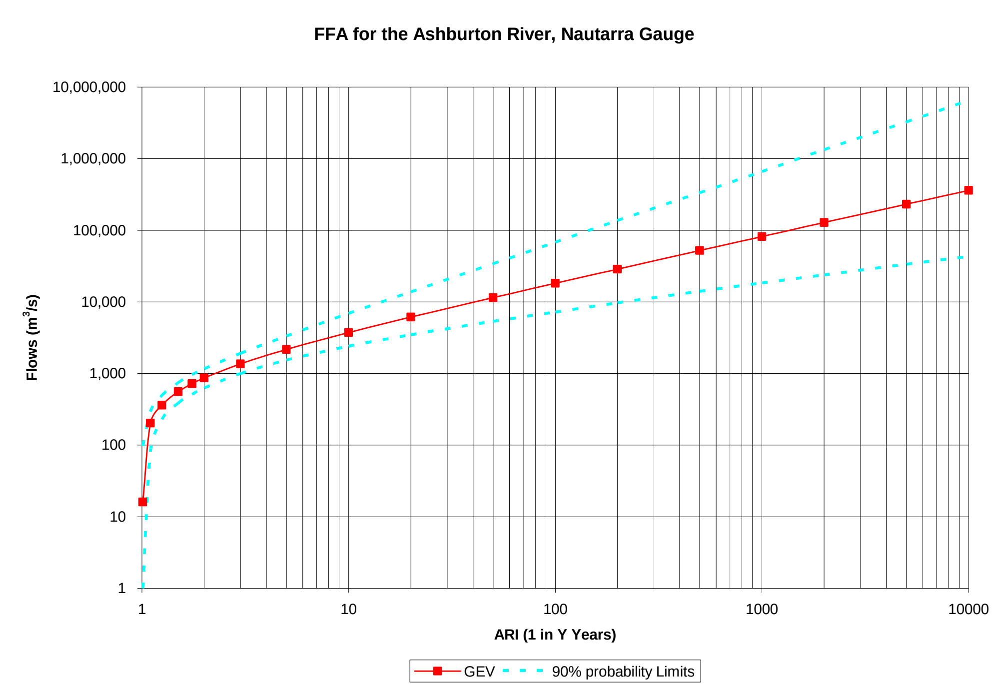

Chart 5-3 Ashburton River Flood Frequency Analysis. Source: URS 2010e

The derived flows for various ARI events at the Nanutarra Gauging Station are shown in Table 5-1.

Table 5-1 Estimated peak discharges for varying ARI

ARI	Flows (m^3/s)
5	2,168
10	3,730
20	6,134
50	11,469
100	18,187

5.3 Sediment Loads

Total annual estimated sediment discharge from the Ashburton River at Nanutarra Bridge is provided in Chart 5-4.

5 Ashburton River Flood Flows

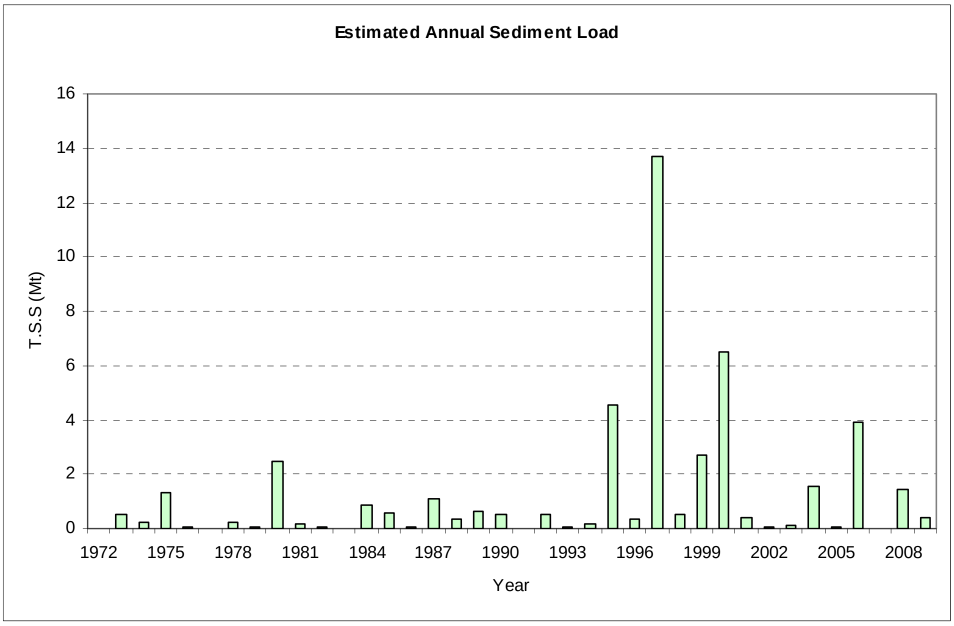

Chart 5-4 Estimated annual TSS discharge in Ashburton River at Nanuturra Bridge over 37 year period, based on daily flows. Source: URS 2010d

The estimated average sediment load entering the ocean each year will be highly variable as sediment loading is dependent on river flow, which in turn is highly dependent on the intensity and duration of rainfall across the catchment area. The Ashburton River is ephemeral and therefore the sediment load and transport volume are highly variable.

Using the estimated annual sediment discharge, the recurrence interval of annual sediment load entering the Ashburton River Delta area has been determined and is shown in Chart 5-5.

5 Ashburton River Flood Flows

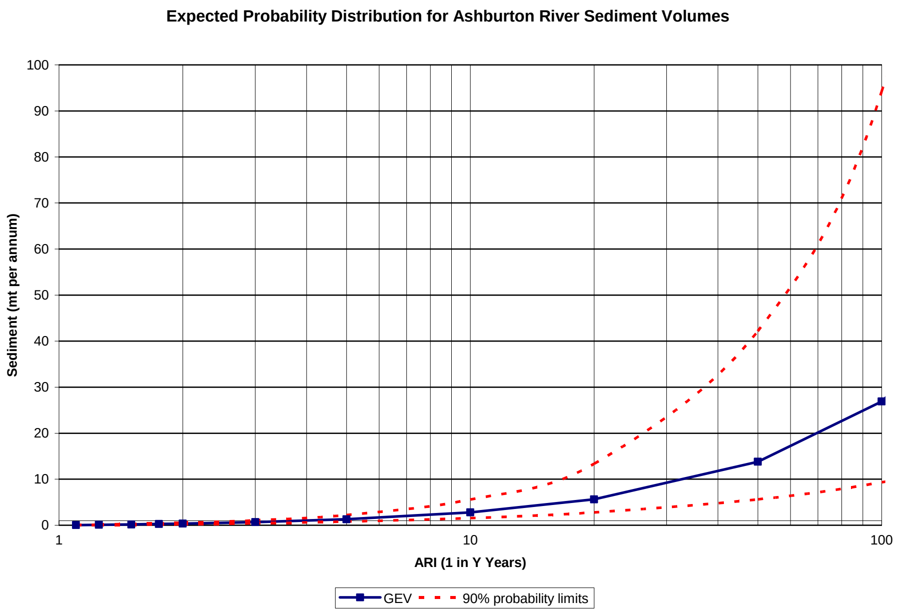

Chart 5-5 Ashburton River Sediment Load Frequency Analysis. Source: URS 2010d

The derived sediment loads are shown in Table 5-2.

Table 5-2 Estimated sediment load for varying ARI

ARI	Sediment load (Mt/annum)
5	1.3
10	2.8
20	5.6
50	13.8
100	26.9

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Development of a Model of Key Processes Maintaining the Delta

This section describes the development of a model to describe the key processes maintaining the delta system. The characteristic features of the delta have been described previously in relation to the mangrove habitats (Section 3), coastal geomorphology (Section 4) and surface water hydrology (Section 5). In this section, the terms 'model' and 'processes' are more or less interchangeable because the primary focus is upon sediment movement and stability, rather than a complex set of interactions which are less useful in elucidating the primary drivers for mangrove habitats in this system. To justify the focus on sediment, the first section gives a general description of the processes that maintain mangrove systems and concludes with the aspects likely to be important in the project environment. It is followed by a summary of the geomorphological units that occur within the scope of the project area and how these influence mangroves under normal conditions and extreme events.

6.1 Generic Information on Processes Maintaining Mangrove Systems

There exists a complex series of factors that influence the nature of where mangroves occur and the types of habitat that will dominate in each location. At the largest scale, the distribution of mangroves around the Earth is most predominantly affected by temperature (Figure 6-1), as mangroves do not usually grow outside of the 18°C isotherm or typically above the latitudes of 25^0 south and north. The next major factor, at the scale of km^2, is the geomorphological setting (Semeniuk 1986). This is quite important for the following discussion because the two major mangrove systems in the west Onslow region are based upon at least four different geomorphological settings or landform components (Damara 2010). Hydrology and topography will influence mangrove habitats at the scale of square kilometres to hectares, while at the hectare to metre scale, soil characteristics will become increasingly important (Figure 6-1).

Thus many factors influence mangroves regardless of scale and a complex interaction occurs between factors. Tidal characteristics, climate, geomorphology and biotic factors are major and combine to affect the nature of a mangrove community (Figure 6-2). This is reflected in characteristics that include zonation, life form, species structure and productivity. One example of this complexity is the interactions between tidal frequency and temperature that ultimately dictate groundwater table height and salinity. This is further influenced by rainfall, freshwater seepage and runoff. Water table height, combined with habitat slope and erosional/depositional processes, in turn influences the oxygen content of the soil. These factors and their interactions are quite complex. Figure 6-2 combines most, if not all, of the natural factors affecting a mangrove and the nature of its community. The various summation/interactions of these factors then dictate the habitat type and diversity of mangrove species in a particular environment. It should be noted that the present discussion is not intended to be a detailed examination of how these factors affect mangroves, which can be gained from works such as Tomlinson (1986), Hutchings & Saenger (1987) and Hogarth (1999).

In modelling terms, most mangrove systems are very much 'self-contained'. In other words, the bulk of the nutrient and energy (i.e. carbon) flow is cycled within the system (including the mangrove trees and any secondary producers). In the Pilbara this system includes the adjacent nearshore marine region, rather than upland sources. Dissolved inorganic carbon, derived largely from the bacterial breakdown of particulate material within the mangroves, returns on incoming tides, along with any nutrients. The mangrove habitats in the project area and their carbon and nutrient cycles have been adequately explained elsewhere (URS 2010a) and within a region such as the Pilbara, the productivity and nutrient cycles within any mangrove habitat are essentially similar. Therefore, the primary question remains is what factors affect mangrove distribution in specific locations such as the project area.

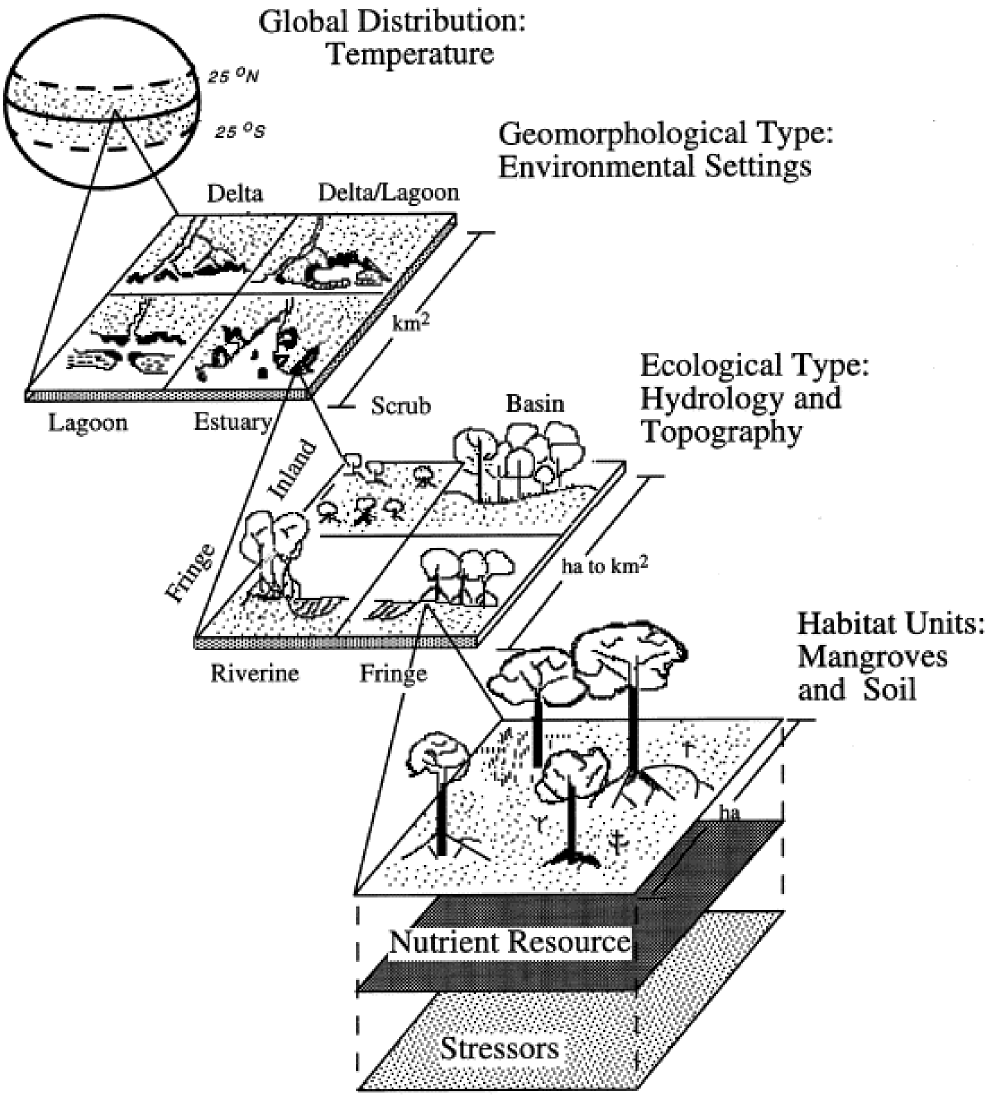


Figure 6-1 Scale of factors effecting mangrove habits (from Twilley et al. 1998)

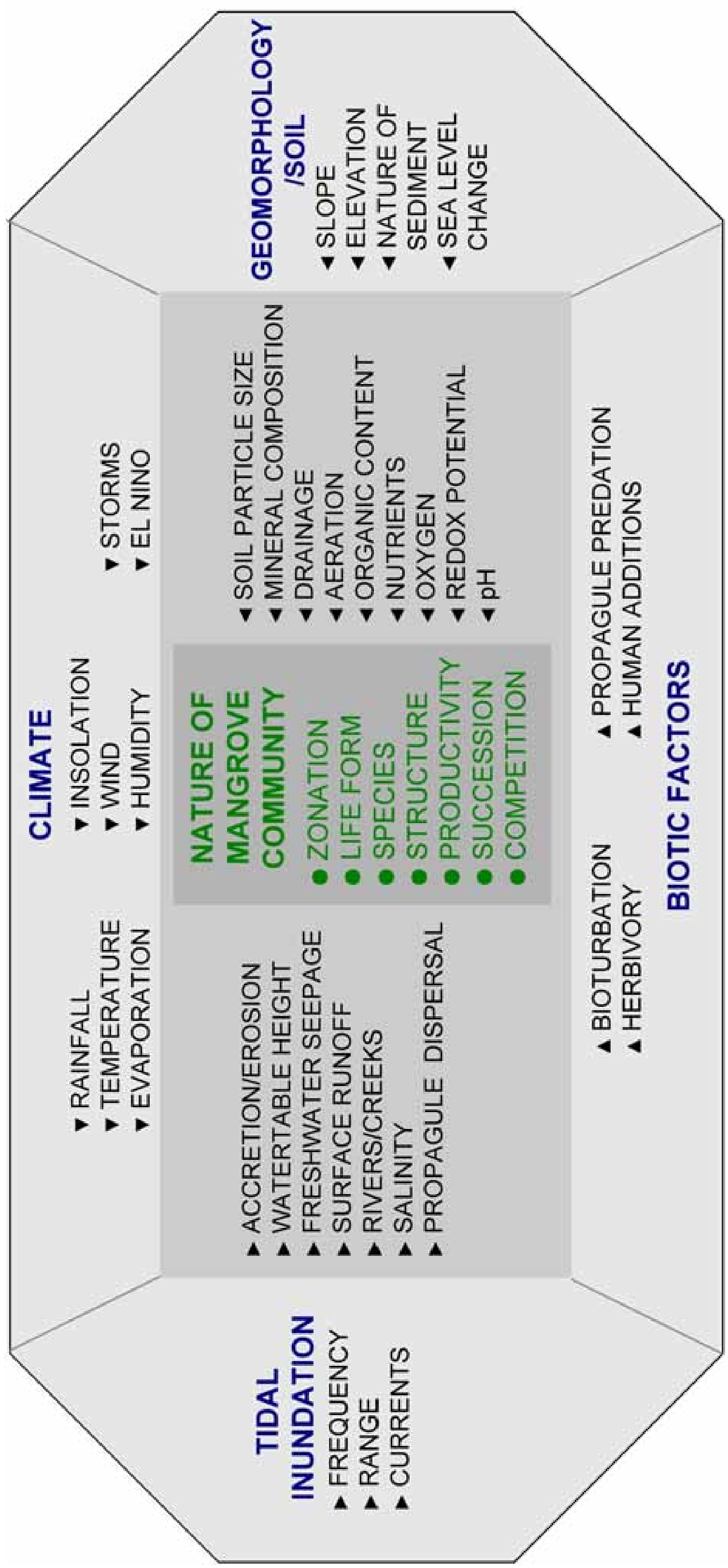


Figure 6-2 The major tidal, climatic, geomorphological and biotic factors that affect the nature of mangrove communities. Note that the 'mangrove community' refers specifically to the mangrove trees, rather than other flora or associated fauna within mangrove habitat

6 Development of a Model of Key Processes Maintaining the Delta

In the right climatic conditions, regardless of the geomorphological setting and taking into account the factors mentioned above, the key factor for mangrove presence is simply having a suitable substrate on which to actually grow. 'Suitable' is defined here as substrate that is relatively stable and of the appropriate groundwater and soil salinity. Under normal conditions, the rates of erosion and deposition are likely to be 'slow' and influenced by the mangroves themselves (Figure 6-3). Human factors also influence the hydrological conditions which may lead to enhanced deposition or erosion (e.g. dredging). In contrast, under 'catastrophic' conditions (such as storms, floods and cyclones) these rates are likely to be rapid and it has been shown that tens of metres of shoreline substrate can recede in several hours. Deposition is also more intense under these conditions (e.g. Paling et al. 2008).

Once a suitably stable substrate is present, the next important attribute is groundwater and soil salinity. There are a number of factors that affect this soil property and mangroves in the Pilbara typically only grow between 35 ppt and 90 ppt. Thus any interaction of topography and elevation, along with tidal inundation and climate (i.e. Figure 6-2), that produces a suitable range of salinity will have mangroves present. Predominantly these factors are: the salinity of tidal water; time interval between inundations; rainfall; evaporation rate; soil retention properties and run-on minus run-off. Unlike many other mangrove habitats worldwide, mangrove communities in the Pilbara do not have (under normal conditions) appreciable upland sources of either nutrients or freshwater (Figure 6-4). Hence, unlike mangroves in tropical northern Australia, there are no mangrove zones occurring at the landward margin of the mangrove belt that are reliant on regular seasonal freshwater input from hinterland sources to maintain the appropriate groundwater and soil salinities required for their survival. This results in the occurrence of largely bare salt flats behind (or landward of) the mangrove belt due to the prevailing highly saline conditions (Semeniuk 1983, Paling & McComb 1994).

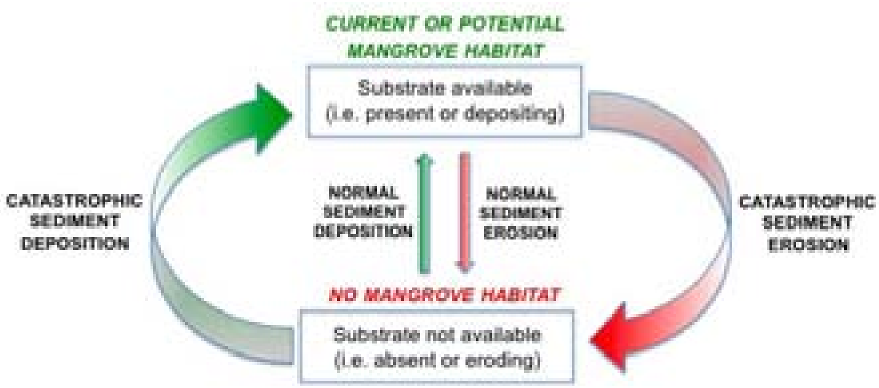


Figure 6-3 Representation of sediment deposition and erosion in the project area mangroves under normal and catastrophic conditions.

6 Development of a Model of Key Processes Maintaining the Delta

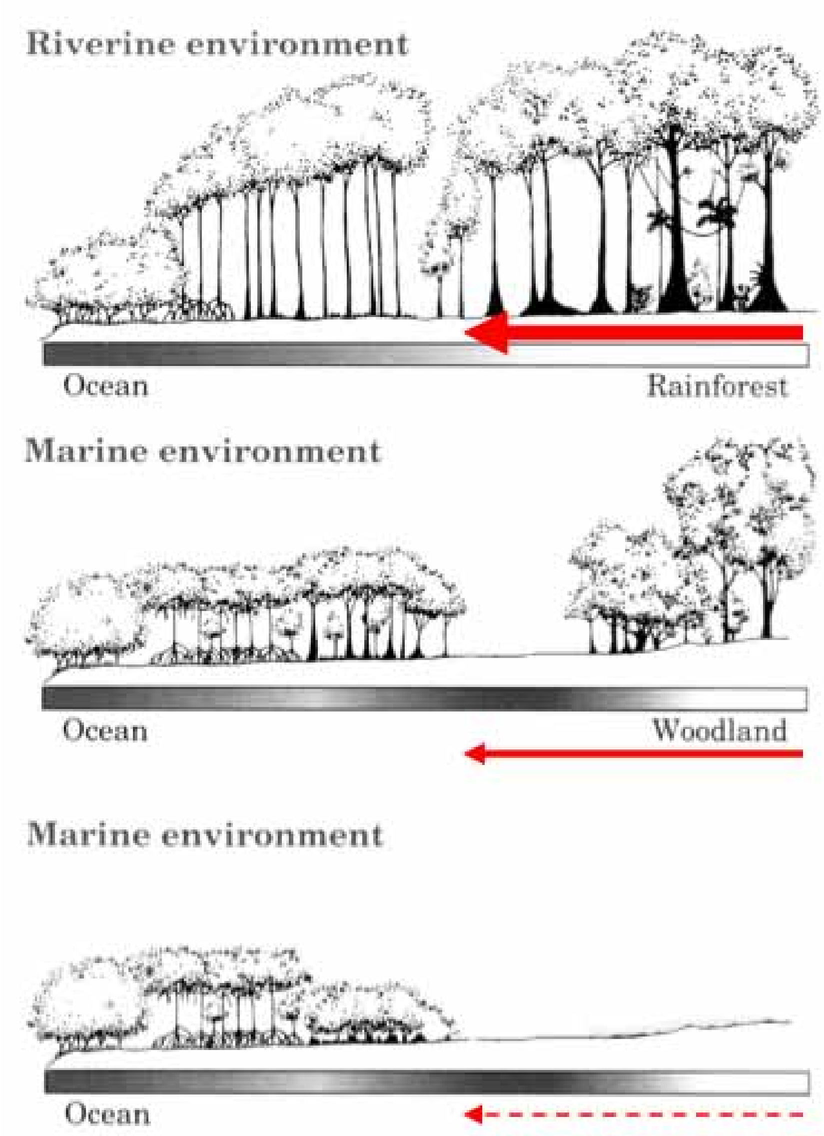


Figure 6-4 Hinterland sources of freshwater and nutrients that occur in various mangrove environments. The Pilbara conforms to the bottom figure with, under normal conditions, few upland sources. In this instance there is no vegetation on the zone between mangroves and the hinterland due to the extremely saline conditions.

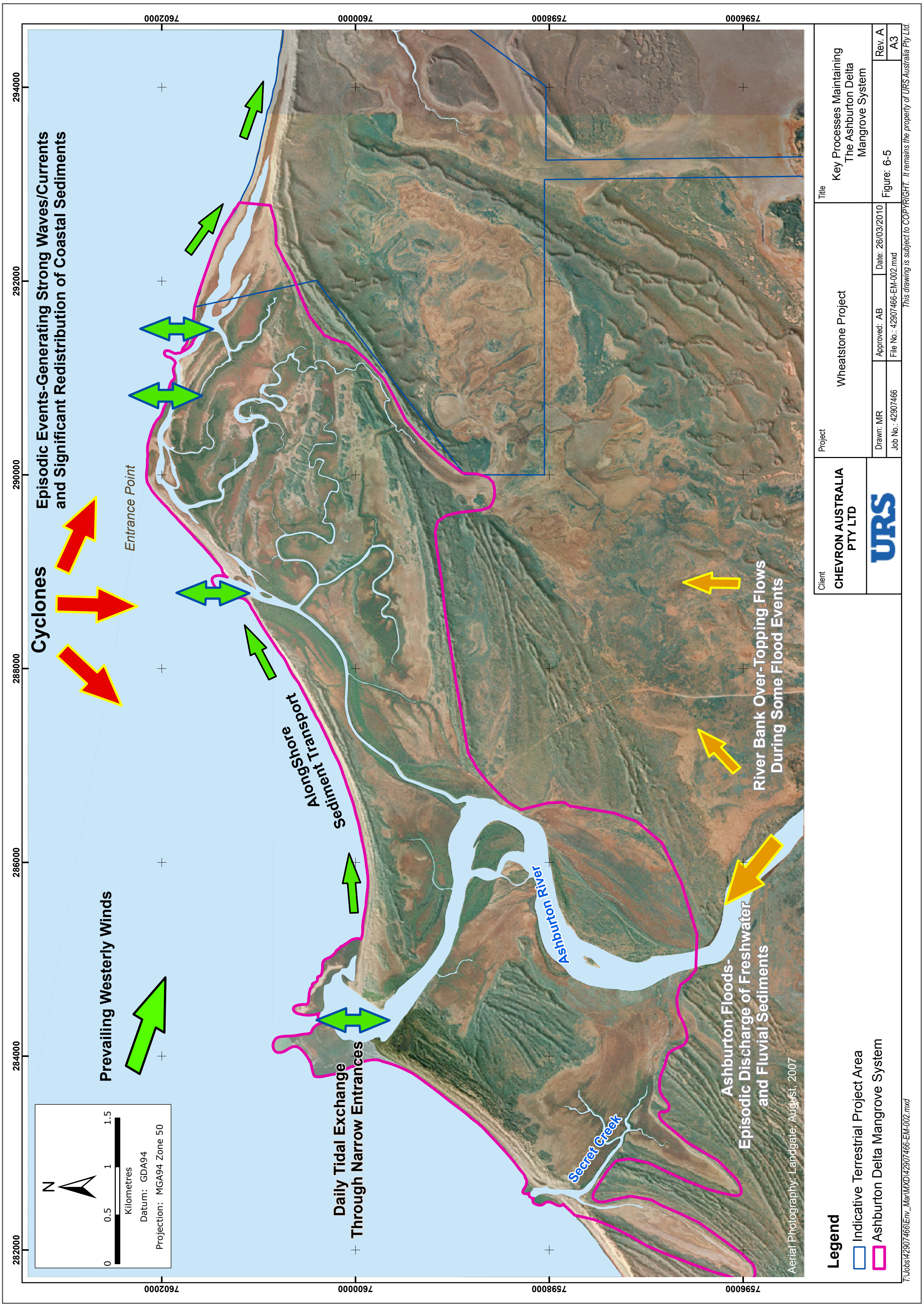
6.2 Key Processes Maintaining the Ashburton River Delta

Having briefly discussed the generic processes that allow mangrove systems to be maintained in particular environments, particularly in the Pilbara, it is now useful to examine characteristics specific to the mangrove communities occurring in the Ashburton River Delta and adjacent areas. Figure 6-5 presents a schematic diagram of the key processes maintaining the delta. These processes are:

- Tidal exchange – daily exchange of tidal waters into the delta mangrove system through the main Ashburton River mouth and the narrow tidal creek mouths in the Entrance Point area.
- Coastal sediment transport processes - prevailing westerly winds generating a net eastward longshore sediment movement. These processes are partly responsible for the development of coastal features such as beaches, sand soils and cheniers which form the outer barriers of the delta that provide protection to the mangrove system.
- Ashburton River flows/floods – periodic major input of sediment and freshwater from flood events.
- Cyclones – rapid high energy events that may result in a significant redistribution of sediment along the coastline.

The delta (and the cuspate deltaic foreland) forms a particularly complex geomorphological formation, the seaward end of which is active in terms of sedimentation and erosion (i.e. changes have occurred between 10 and 100 years BP). The river mouth has changed over the last 80 years and active channel avulsion has adjusted the position of coalescing deltas (see Section 3.1). Damara (2010) noted that channel avulsion is typically associated with river systems bearing a high sediment load under relatively low wave and tide conditions and that the cheniers and sand spits present constitute a store of highly unstable sediment that could be remobilised by river and marine processes. In the interim, mangroves have colonised any stable (suitable) environment and can be observed actively colonising relatively recent sediment deposits on the newer cheniers (URS 2010a). It should be noted that most of the changes in coastline, deposition and mangrove presence have occurred within 200 to 300 m of the current coastline (see Section 4-3 and Figure 4-5), particularly in the eastern delta area (areas of both mangrove loss and gain in this area is evident from historical aerial photography). Landward of this coastal fringe the mangroves appear to be relatively stable in their extent and distribution. As the delta progrades over time, more stable sediment will become available for mangrove colonisation.

Under prevailing conditions, mangrove communities in this complex will be influenced by two processes, tidal exchange and continued progradation of the Delta (Figure 6-6A). Normal tidal sediment movement (i.e. erosion and deposition) is usually a ‘slow’ process and allows a relatively stable environment for mangroves to be maintained (Figure 6-3). The continual sediment deposition associated with the delta growth will provide new habitat for mangrove colonisation as it has done in the past. These mangroves will also be stable and it is expected that as landward topography elevates due to the delta progradation, the environment will become less suitable for mangroves and the system will move slowly seaward at the same rate as the colonisation of newly deposited material. Mangrove communities will follow this basic pattern until disturbed by extreme events.



Cyclones
Episodic Events-Generating Strong Waves/Currents and Significant Redistribution of Coastal Sediments
Entrance Point
Prevailing Westerly Winds
AlongShore Sediment Transport
Daily Tidal Exchange Through Narrow Entrances
Ashburton River
Secret Creek
Ashburton Floods- Episodic Discharge of Freshwater and Fluvial Sediments
River Bank Over-Topping Flows During Some Flood Events
Aerial Photography: Landgate, August, 2007
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Legend
Indicative Terrestrial Project Area
Ashburton Delta Mangrove System
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7602000
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7598000
7596000
Client
CHEVRON AUSTRALIA PTY LTD
Project
Wheatstone Project
Title
Key Processes Maintaining The Ashburton Delta Mangrove System
Drawn: MR
Approved: AB
Date: 26/03/2010
Job No.: 42907466
File No.: 42907466-EM-002.mxd
Figure: 6-5
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6 Development of a Model of Key Processes Maintaining the Delta

Two extreme, ephemeral events can occur in this area (and are often related to each other): floods from the Ashburton River; and cyclones or storms. Evidence suggests that mangroves to landward remain relatively stable in this complex and most changes will occur within 200 – 300 m of the coast, regardless of extreme events (Figure 6-6B). Two major effects are likely from floodwaters: radically increased water flow (causing erosion in the current channel and elsewhere if overtopping occurs); and a large sediment load which would likely end up at the eastern part of the delta. It would be expected that nutrients would be associated with the sediments and it should be noted that the flows would consist of fresher water. It is difficult to predict the impact of these nutrients on mangroves, save to say that it will be mildly positive (i.e. will enhance growth), because the water containing them will flow into the sea extremely rapidly, dilute and predominantly be lost to the mangrove habitats. It is also possible, as in the past (Damara 2010), that the Ashburton River entrance may change its location.

Cyclones predominantly have erosive power and the ability to radically alter the current coastline (Damara 2010), particularly at the eastern end of the delta which is exposed to the east. Any mangroves that have colonised the area within a few hundred metres of the coast also have the potential to be lost when the sediment is removed. Sediments from erosion or flood events are unlikely to deposit in the same way as they did at the eastern side of Exmouth Gulf following Cyclone Vance and therefore are unlikely within the Ashburton Delta to cause problems for already well-established mangroves further inland (Paling et al. 2008). This conclusion is based upon past observations available from the geomorphological data made available by Damara (2010).

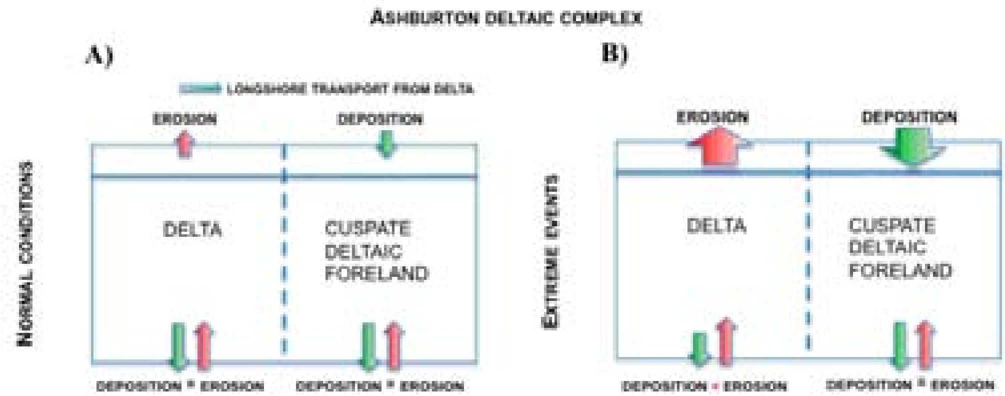

Figure 6-6 Sediment movement in mangrove environments under normal prevailing conditions (A) and extreme events (B) in the Ashburton River delta.

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Assessment of Potential Impacts of the Project on the Delta

The information provided in Section 6 regarding key processes and factors that are likely to influence and maintain the delta mangrove system is used in this section to direct an assessment of the potential impacts to the delta from the project. Initially this assessment is undertaken at the "key process" level and then specific direct and potential indirect impacts are addressed.

7.1 Potential Changes to Key Processes

Damara (2010) identified that the Ashburton deltaic complex is quite dynamic in terms of sediment movement and identified a number of key processes that would need to be considered by any development. These included;

- Continuing progradation of the Ashburton Delta system and its expansion.
- Cyclones and their effect on enhancing or reducing the current eastward sediment transport mechanism from the Delta.
- The effects of significant variations in flow and sediment supply from the Ashburton River.

The proposed development avoids direct impacts on the Ashburton Delta mangroves and construction and operation of the project is unlikely to modify key processes maintaining the system. Construction within intertidal areas will be limited to an area of salt flats in the south-west section of the project site for the onshore placement area (although this may not be required) and the shallow lagoon at the eastern edge of the delta. The normal processes of prevailing tidal flow and periodic flooding from the Ashburton River will thus be allowed to continue. It is likely that under extreme events the extent of natural change (both positive and negative) in mangrove habitat in the deltaic complex will far exceed the four hectares being removed by the current development in the adjacent Hooley Creek system. For example, the mangrove colonisation currently occurring on the eastern cuspate deltaic foreland in the two decades is likely to have already exceeded this figure. The transport of sediment from the delta to the east may be affected by shore crossing structures and this would be expected to influence sediment movement on the coastline in the area of the Hooley Creek entrance.

Sections 7.1.1 to 7.1.3 below further assess the potential for the project to modify key processes related to tidal inundation, Ashburton River flows and floods and coastal sediment transport.

7.1.1 Effects on surface water processes – tidal inundation and freshwater flood flows

The key surface water processes responsible for the maintenance of the delta mangrove ecosystem are tidal inundation and freshwater flood flows. The following is an assessment of the potential impact of the development of the Wheatstone Project on these processes.

The assessment comprises the use of the predictive hydraulic model of the Ashburton River Delta to establish the baseline surface water characteristics of the delta area in terms of inundation extent, hydro period, predicted flood water levels and peak flows. The potential impact of the Wheatstone Project has been assessed by comparing the simulated surface water level characteristics of the existing baseline environment with those predicted to occur after development of the Wheatstone Project infrastructure.

7 Assessment of Potential Impacts of the Project on the Delta

Tidal Inundation

Tidal data from the tide gauge at Beadon Creek was used for the assessment of the impact of the Wheatstone Project on the tidal characteristics of the Ashburton River Delta area. The standard tide variation is shown in Chart 7-1. The extent to which the tide inundates the Ashburton River Delta area was assessed using several days of observed tidal records in the hydraulic model. The input data is associated with a period of spring tides (maximum tide elevation 1.24 m AHD) recorded at the Onslow Tidal Gauge during January 2009 (note that Mean High Water Springs tidal level for the Onslow area is 1.0 m AHD). This data has been identified as the typical tidal water levels for the area, by the Department of Planning and Infrastructure.

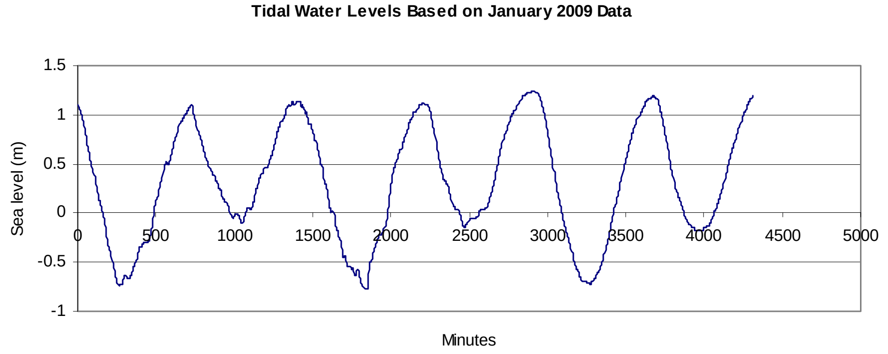


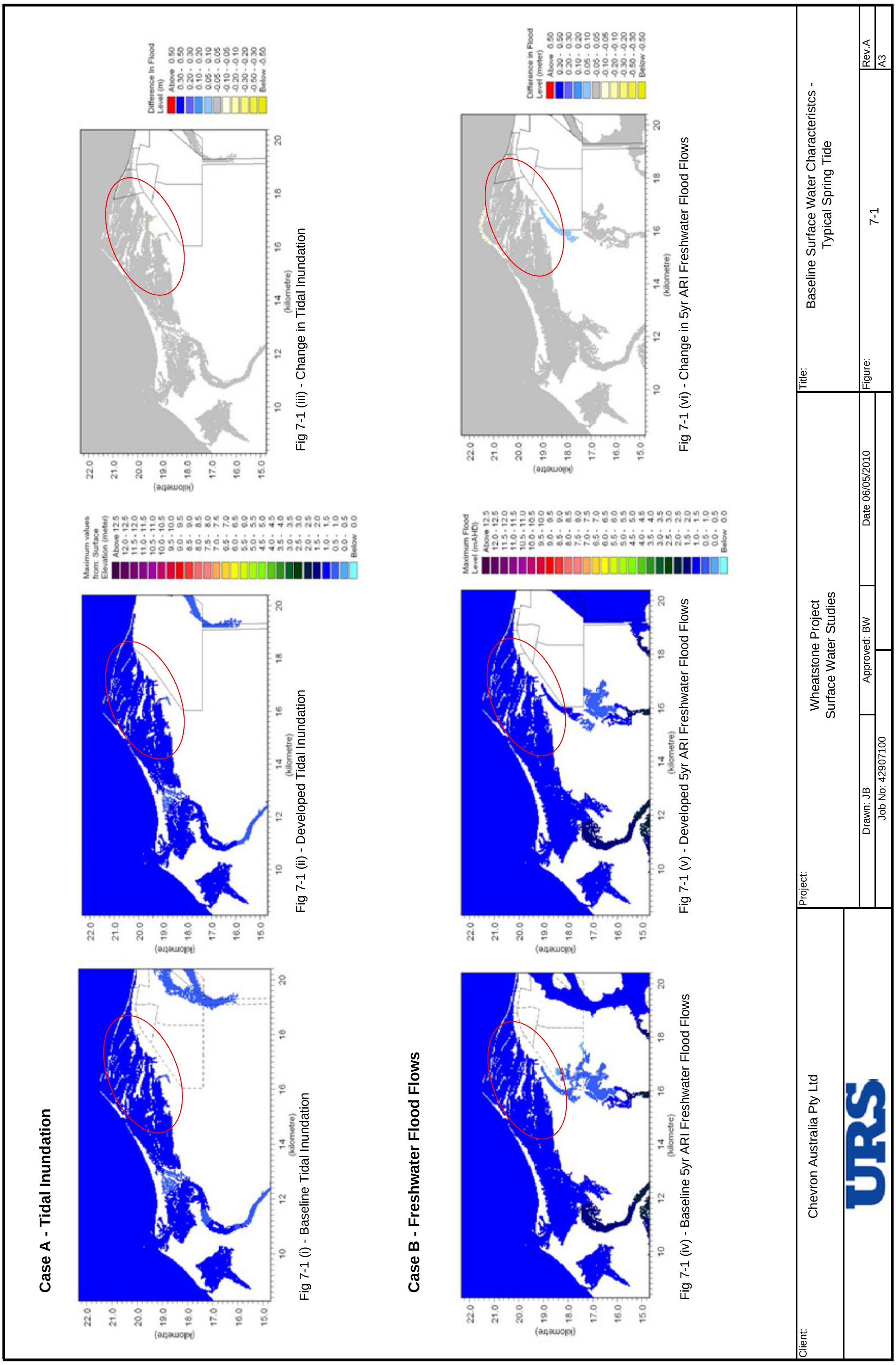
Chart 7-1 Tidal Water Levels for January 2009

The impact of the development of the Wheatstone Project on the area subject to tidal inundation, was assessed by comparing the simulated area of inundation before and after the development of the Wheatstone Project, (Figure 7-1 Case A). The impact of the Wheatstone Project on the tidal inundation is shown as the difference in the maximum water depth before and after development of the Wheatstone Project.

The baseline conditions are presented in Figure 7-1 (i). The area of interest in this study is shown in red. This figure shows that for a typical spring tide the water level rises to just reach cross section B in Figure 7-2(i) but does not reach as far as cross section A.

The simulated water levels following the development of the Wheatstone Project are presented in Figure 7-1 (ii). This figure shows that for a spring tide the water levels and inundation areas are the same as in the baseline.

The impacts of the Wheatstone Project development on tidal inundation was assessed using the difference between the baseline and developed water levels presented in Figure 7-1 (iii). The results show that the proposed Wheatstone Project does not obstruct (flood level difference of less than ± 5 cm) the tidal flows into and out of the Ashburton River Delta area and therefore would cause no significant change in the tidal inundation characteristics of the mangrove area.


Case A - Tidal Inundation
Fig 7-1 (i) - Baseline Tidal Inundation
Fig 7-1 (ii) - Developed Tidal Inundation
Fig 7-1 (iii) - Change in Tidal Inundation
Case B - Freshwater Flood Flows
Fig 7-1 (iv) - Baseline 5yr ARI Freshwater Flood Flows
Fig 7-1 (v) - Developed 5yr ARI Freshwater Flood Flows
Fig 7-1 (vi) - Change in 5yr ARI Freshwater Flood Flows
Client:
Chevron Australia Pty Ltd
URS
Project:
Wheatstone Project
Surface Water Studies
Title:
Baseline Surface Water Characteristics -
Typical Spring Tide
Drawn: JB
Approved: BW
Date 06/05/2010
Job No: 42907100
Figure:
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7 Assessment of Potential Impacts of the Project on the Delta

Freshwater flood flows

The impact of the Wheatstone Project on the fresh water flood flows in the coastal mangrove areas of the Ashburton River Delta is assessed by comparing flood depths/elevations before and after development of the Wheatstone Project, and by comparing the flow characteristics of the drainage channel (upper reaches of a small tidal creek) along the north-western boundary of the proposed Plant Pad footprint. This drainage channel is a narrow tidal creek fringed by a small band (~ 10 m wide) of low mangroves. These mangroves represent the landward limit of mangrove distribution in this section of the delta and are the mangroves closest to the Project and hence potentially, most likely to be impacted by the Project.

The impact of the development of the Wheatstone Project on the hydrology of the mangrove area was assessed by comparing the simulated maximum water levels as a result of a 5yr ARI flood event, before and after the development of the Wheatstone Project, (Figure 7-1 Case B). The impact of the Wheatstone Project on the flood water levels is shown as the difference in the maximum water depth before and after development of the Wheatstone Project.

The baseline conditions are presented in Figure 7-1 (iv). This figure shows that for a 5yr ARI flood event the Ashburton River floods the Delta area north-west of the dunes, causing water flood water and tidal water to flow through the channel into the catchment south-west of the proposed plant foot print. Further upstream, a portion of the flood waters in the Ashburton River spill over in the Southwest catchment from the southwest. Both flows fill up the storage in the salt pans of the Southwest catchment before spilling through the channel passing cross sections A and B into the northeast mangrove area of the Ashburton river delta.

The simulated water levels following the development of the Wheatstone Project are presented in Figure 7-1 (v). This figure shows that for the area of interest, the same flooding mechanism applies. However, due to the reduction in baseline storage in the Southwest catchment, water levels in the southwest catchment are shown to be marginally higher, as more water is predicted to flow through the channel.

The impacts of the Wheatstone Project development on the 5yr ARI flood characteristics of the coastal mangrove area of the Ashburton River Delta is presented in Figure 7-1 (vi). The results are shown as the difference in the maximum water level before and after development of the Wheatstone Project. The results show that the Wheatstone Project does not cause a significant change in the fresh water flood characteristics (flood level differences of less than ± 10 cm) of the mangrove area and therefore would cause no significant change in the freshwater flood flow characteristics of the mangrove area.

The only potential impact of the Wheatstone Project development is that the onshore dredge material placement area will remove an area of the salt flat in the south west corner of the plant footprint, thereby reducing the flood storage capacity of the salt flat and consequently causing a relatively small increase in the volume of flood water into the tidal creek which drains into the north east end of the Delta. This increase in freshwater flow will only occur over a short period of time and may potentially of minor benefit to the mangroves by providing additional freshwater to an environment that, for the majority of time, is subject to harsh arid conditions and high salinities.

Figure 7-2 (i) shows the location of two cross sections in the drainage channel along the western boundary of the proposed Plant Pad footprint. The simulated peak discharge rates for the two cross sections for a standard tidal variation and the 5 yr ARI flood event before and after the development of the Wheatstone Project are shown on Figure 7-2(ii) for Cross section A and on Figure 7-2 (iii) for Cross section B.

These Figures compare the discharge rate through the channel at both cross sections A and B for a 5yr ARI flood event under baseline and developed conditions. It shows that the initial flow through the channel is negative which means that the flow direction is from the delta area into the Southwest catchment. This flow contributes to filling up the storage capacity in the Southwest catchment. On reaching the storage capacity of the Southwest catchment the flow through the channel reverses and continues to flow towards the Ashburton Delta area (i.e. positive flow direction). The variation in flow rate is caused by the tidal variation during the flood event.

The comparison between the baseline and developed discharge rates for cross sections A and B shows that the discharge characteristics are largely the same, with only minor differences, which are well within the tolerances of the hydraulic model.

The development of the Wheatstone Project has no significant impact on the runoff from the Ashburton River and the sediment load in the River. The proposed Project would not cause a significant change in the flood flow characteristics of the Ashburton River Delta area, and consequently no significant change in the sediment regime of the area.

7.1.2 Effects on coastal sediment transport processes

Damara (2010) has undertaken an assessment of the potential impacts from the proposed development on coastal sediment transport processes. The proposed MOF breakwaters, shipping basin and dredged channel provide an interruption to shoreface sediment transport patterns, particularly in close to the coast (Figure 7-3).

- Construction of the proposed MOF basin and breakwaters will cause a "near-field" impact, developed through sedimentation within the capture zones of the proposed facility. Some accretion is likely to occur on either side of the harbour, with a greater volume accreting on the western side, estimated to be capable of capturing from 100,000 to 400,000 m^3. This accretion will be more rapid than long-term rates of littoral drift and is counterbalanced in the short-term by erosion from the adjacent coast, which is likely to cause destabilisation of the outer chenier adjacent to the Ashburton eastern delta.
- Interruption of ongoing littoral drift is likely to cause updrift accretion on the western side and downdrift erosion on the eastern side of the harbour, modulated by seasonal, inter-annual and episodic fluctuations in the direction of sediment transport. This may be partially mitigated through bypassing works, although the discrete nature of such works, either spatially or temporally, is likely to affect the coastal dynamics, and increase local shoreline variability.
- The effect of wave sheltering adjacent to Hooley Creek tidal spit will produce a local imbalance in sediment transport and is likely to cause erosion of the spit. Marginal increase in the water level exchange through to Hooleys Creek West is anticipated due to the more open entrance, including exposure to greater wave action.
- Deeper waters provided by the dredged channel and shipping basin will provide a trap for any sediment bedload transport passing in either direction. This accumulation may be managed by incorporating siltation allowances and sediment traps to the basin design and undertaking maintenance dredging.

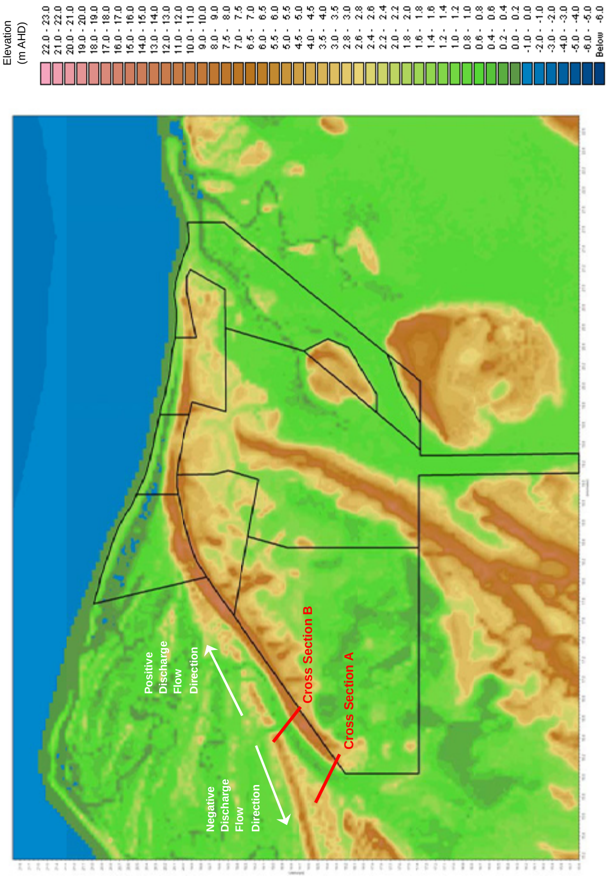

Fig 7-2 (i) - Site Topography and Cross Sections Locations

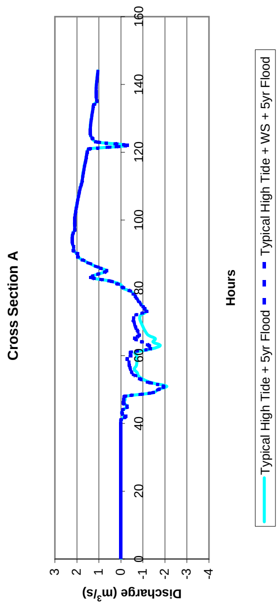

Fig 7-2 (ii) - Simulated Peak Discharge Rates for Cross Section A

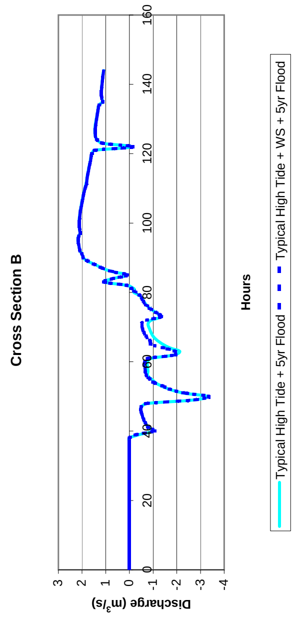

Fig 7-2 (iii) - Simulated Peak Discharge Rates for Cross Section B

Client: Chevron Australia Pty Ltd

Project: Wheatstone Project Surface Water Studies

Title: Baseline Surface Water Characteristics - Discharge using a Typical Spring Tide

URS

Drawn: JB | Approved: BW | Date 06/05/2010 | Figure: 7-2 | Rev.A

Job No: 42907100 | A3

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Chevron has prepared a Coastal Processes Management Plan (CPMP) to identify potential changes to coastal processes associated with Project activities, define the potential environmental impact of these changes and develop a framework for managing these impacts within acceptable limits. The most important element addressed by the CPMP is the management of alongshore littoral drift, which will be interrupted by the MOF breakwaters (as discussed above). The CPMP provides a design for a Sand Management System to achieve performance measures related to the management of sand volumes and other factors. Environmental management objectives for coastal process preservation that are relevant to the Delta are:

- no loss of regionally significant mangrove habitat in the Ashburton River Delta through sensitive Project design, appropriate construction management and coastal processes management
- prevent the development of a Project-related erosion trend in the mean sea level shoreline position and dune vegetation line between the Project site and Beadon Creek
- maintain the recreational value of beaches between the Project and Beadon Creek.

In summary, the impact assessment undertaken for the Project has identified that the above effects on coastal sediment processes are expected to occur and management actions will be required to mitigate impacts from the predicted changes to coastal processes.

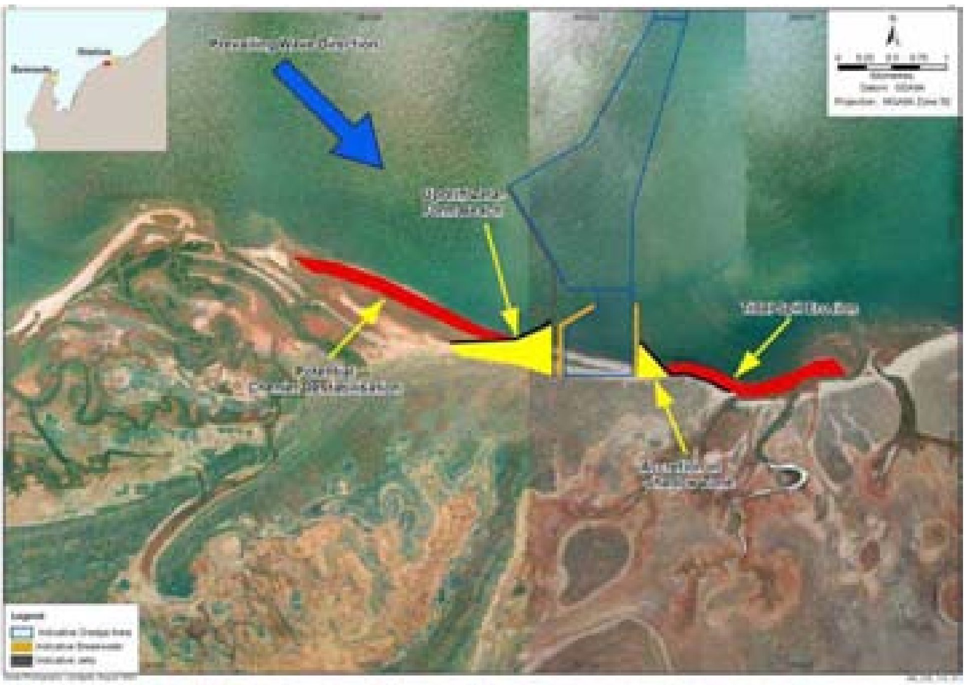


Figure 7-3 Shoreline effects caused by breakwaters. Source: Damara 2010

7.2 Potential Direct Impacts

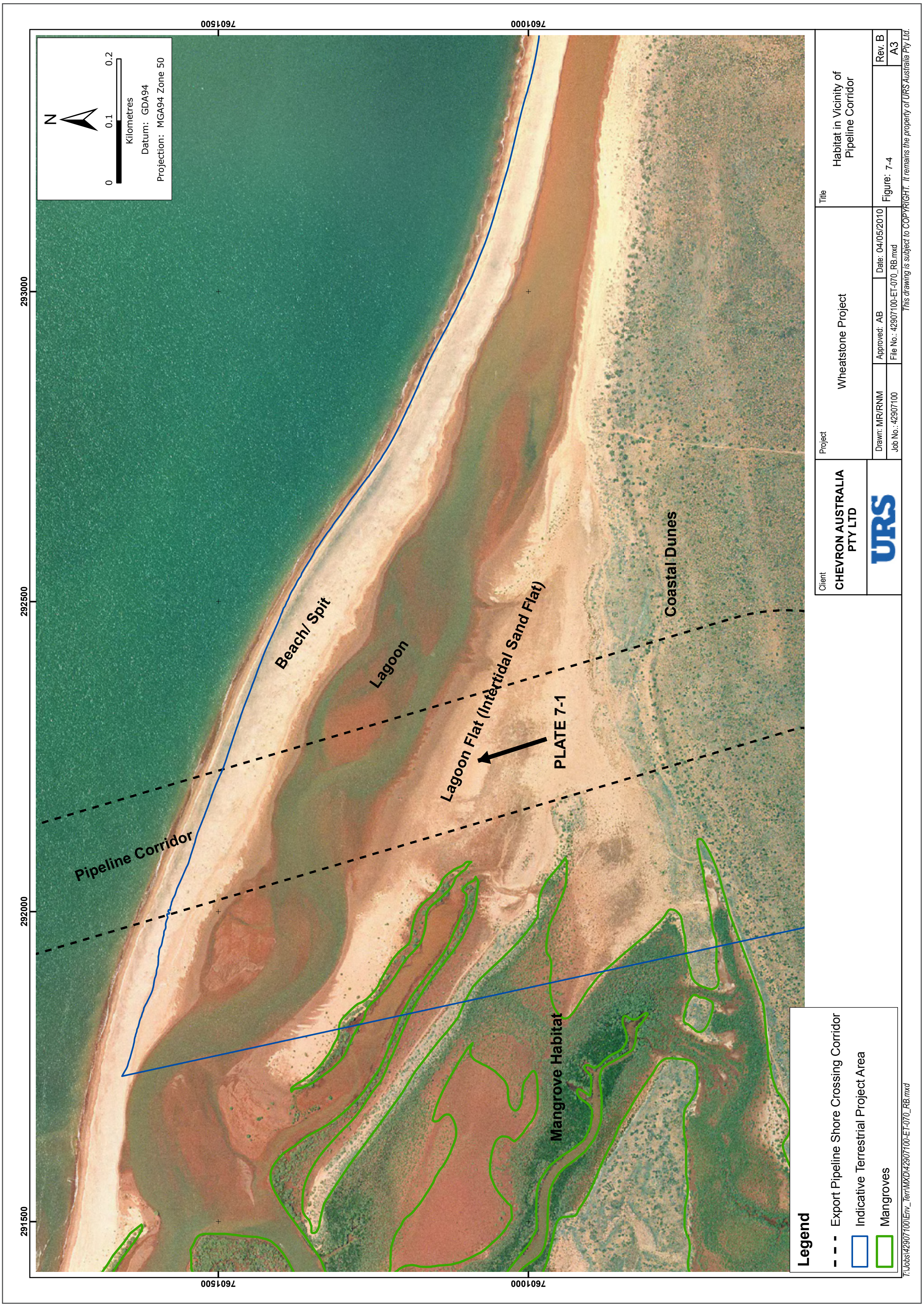
Recognition of the ecological importance and conservation significance of the Ashburton Delta mangrove system has resulted in the design of a project footprint that avoids any direct impact to intertidal BPPH within the Delta (e.g. mangroves, bioturbated mud flat with samphires).

7.2.1 Pipeline shore crossing

The potential for direct impacts to the mangroves of the Ashburton Delta is confined to the pipeline shore crossing area in the eastern most part of the delta where a shallow lagoon occurs within the protection of a barrier sand spit (beach). The location of the proposed pipeline corridor and the habitats present in this area are shown in Figure 7-4.

The pipeline corridor crosses a tidal shallow muddy lagoon and barrier sand spit which widens to the west and becomes increasingly colonised by mangrove seedlings and associated mangrove invertebrate fauna (mainly crabs and molluscs). This lagoon has only recently developed (since 1999) and consists of a subtidal portion and a fringing intertidal sand flat (mapped as "lagoon flat" in Figure 3-2) that is relatively barren of biota but the western end is being colonised by mangrove seedlings. Intertidal surveys and habitat mapping undertaken for the project (URS 2010a,f) indicate that the eastern edge of the Ashburton Delta mangrove habitat (i.e. mature mangrove stands) occurs approximately 200 m west of the corridor (see Figure 7-4). Currently the area of intertidal sand flat located within the pipeline corridor supports a very low density of mangrove seedlings (mean density of seven seedlings per 100 m^2 and 2% cover) as shown in Plate 7-1.

Plate 7-1 Intertidal sand flat habitat within the pipeline corridor



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Datum: GDA94
Projection: MGA94 Zone 50
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291500
Beach/ Spit
Lagoon
Lagoon Flat (Intertidal Sand Flat)
PLATE 7-1
Coastal Dunes
Pipeline Corridor
Mangrove Habitat
Legend
Export Pipeline Shore Crossing Corridor
Indicative Terrestrial Project Area
Mangroves
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Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Habitat in Vicinity of Pipeline Corridor
Drawn: MR/RNM
Approved: AB
Date: 04/05/2010
Job No.: 42907100
File No.: 42907100-ET-070_RB.mxd
Figure: 7-4
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7 Assessment of Potential Impacts of the Project on the Delta

The lagoon/beach spit landform is this area represents the most recent easterly progression of the Delta and, assuming that this landform remains stable, then it is expected that more of the intertidal sand flat fringing the lagoon will become colonised by mangroves and potentially develop into "mangrove habitat". The beach spit that protects the lagoon is considered to be of an ephemeral nature as it is dynamic and has been subject to considerable change over the last 10-20 years (Damara 2010). The spit is mobile and a "conveyor" for alongshore sediment movement to the east during summer. Note, however, that it could potentially be redistributed westward under cyclone-induced wave conditions. Hence the barrier sand spit is highly mobile and the temporal stability and presence of the lagoon and fringing intertidal sand flat needs to be viewed in this context.

The potential for direct impacts is dependent on the method of pipeline installation across the lagoon/sand spit area. Four options for bringing the pipelines to shore at this location were considered:

1. Horizontal Directional Drilling (HDD) from onshore out beneath the lagoon and barrier spit to a location seaward of the spit where minor excavation would be required to link the pipeline to the well.
2. Micro tunnelling beneath the lagoon from a site onshore (i.e. landward of the intertidal zone) to a location on the seaward side of the barrier spit (in the nearshore zone), also requiring minor offshore excavation to link the tunnel to the pipeline.
3. Constructing a coffer dam and then excavating a trench through the lagoon and barrier spit, subsequently pulling the pipeline through the trench and backfilling the trench after the pipeline has been buried, and reinstating the lagoon and spit bathymetry.
4. Bringing the pipeline to the Product Loading Facility (PLF) and then across the beach via the PLF Jetty.

Options 1 and 4 were rejected. Option 1 is not considered feasible because the size of pipeline that needs to be brought ashore is beyond technical capability. Option 4 is also not considered feasible for safety/risk reasons. Options 2 and 3 for the pipeline shore crossing are both considered feasible and have been investigated further.

Option 2 (Micro-tunnelling) is the preferred engineering and environmental solution because it is logistically much easier than trenching and avoids disturbance of the lagoon altogether. However, Chevron wishes to retain access to the trenching option as a fall back position in the event that micro-tunnelling proves technically unfeasible due to adverse geotechnical conditions (currently undefined), and the length of tunnelling required (1.2 to 1.4 km), which is close to the current technological limit for a tunnel of the diameter proposed (3 m). No direct or indirect impacts to the Ashburton Delta system are anticipated from the micro-tunnelling option.

Potential impacts of the trenching option

The trenching option (Option 3) is the only option that risks potential direct impacts to the Ashburton River Delta. This option will involve constructing two parallel rock berms (groynes) across the lagoon and barrier split to a location 200 m seaward of the spit to provide support for excavating, earthmoving and pile driving plant and equipment. These berms may be 40 – 100 m apart (depending on whether provision is required for future pipelines). This rock "coffer dam" will allow excavation of seabed material to create the pull-in trench without risk of backfill due to coastal processes. Excavated material from this area will be stored onshore and may possibly be used to backfill the trench later after the trunkline is installed.

7 Assessment of Potential Impacts of the Project on the Delta

Once the pipelay trench is constructed, the pipeline can be pulled through the trench from onshore. Once the pull is completed the trench will be backfilled with appropriately engineered materials, excavated material, or rock to as close the original bathymetry as can be achieved and the two rock groynes will be removed by excavators working from seaward back to shore. It is anticipated this work will take up to 24 months to complete. Note that this activity would need to be repeated another 2-3 times over the next 25 years, as additional pipelines are bought ashore; unless it is possible to install the required pipeline crossings during the first construction program. Chevron is investigating this possibility, however, the ability to pre-install engineered culverts that will remain operational for future use carries significant technical uncertainty.

The potential physical environmental effects of the trenching options are as follows:

Construction and removal of the berms will create localised and temporary turbidity in adjacent waters but is unlikely to create substantial turbidity within the lagoon given the large size of rock material that will be required to protect the trench over two cyclone seasons and given that all excavated material from within the coffer dam trench could be stored onshore in holding ponds. Some of this material is likely to contain acid sulphate soils which may need to be neutralised whilst in storage. Much of the stored material will be returned to the trench once the pipeline has been installed providing it is considered technically acceptable from an engineering standpoint.

Water flows east of the rock berms and coffer dam will be interrupted while the trench is in place thereby restricting tidal flushing, although this can be ameliorated by constructing a channel through the sand spit/beach to allow water to flow into and out of the lagoon to the east of berms.

Emplacement of the rock berms over 24 months will disrupt coastal processes. Damara (2010) has shown that the sand spit is an ephemeral feature having been substantially removed by Cyclone Vance in 1999 and re-built since by prevailing easterly littoral drift. It is therefore likely that some sediment accretion will occur on the western side of the berms and erosion to the eastern side. Once the berms have been removed, the sand spit is considered likely to reform and the lagoon to recover to its previous character. Hence installation of the first pipeline is likely to result in a temporary impact from which the lagoon will soon recover.

The first such trenching event will probably occur in two to three years time, by which time the lagoon may be further colonised by two year old mangrove seedlings. Trenching the first pipeline is likely to result in a temporary impact from which the lagoon will recover within five years of disturbance. However, subsequent trenching events will damage older and more advanced mangrove seedlings which may take longer than five years to recover to their previous state, particularly if the mangroves removed are 10-15 years old at the time of removal. Repeated trenching also risks modification of sand bar and lagoon stability and associated coastal processes, resulting in potential loss/damage to BPP habitat.

Given the guidance provided in Section 2.1 and assuming that the lagoon reforms and becomes colonised by mangrove seedlings, it is considered unlikely that subsequent trenching works for future pipelines can be undertaken in a way that meets the EPA's objectives for protection of this developing mangrove habitat (however, this would not represent a net loss of the current area of mangrove habitat in the delta). Considering the known ephemeral nature of the sand spit, it is equally possible that a future cyclone may substantially modify it during the next 10-20 years, and the subsequent natural impacts to the lagoon and potential mangrove habitat could be far more significant than those predicted from trenching activities.

7 Assessment of Potential Impacts of the Project on the Delta

As indicated earlier, trenching the pipeline through the eastern lagoon is not Chevron's preferred option. However, Chevron wishes to test the acceptability of the trenching option in case it needs to revert to it in the event of encountering technical difficulties with the preferred micro-tunnelling option.

Micro-tunnelling option

Micro-tunnelling is preferred because it results in very little disturbance to the surface environment and no disturbance to the lagoon and adjacent intertidal sand flats. It basically involves the construction of a 3 m diameter tunnel beneath the dune system and lagoon. All drill cuttings (approx 200,000 m^3) will be disposed of onshore. The only disturbance to nearshore marine waters will occur for a short period of time by the backhoe excavation of a small pit into which the drill head can exit prior to recovery. All excavated material will be placed into a hopper barge and subsequently taken to an approved placement site. Turbidity impacts will be very localised and short term, and barely measurable against the existing high background turbidity in these nearshore waters.

7.2.2 Onshore placement of dredged material

The Project has considered the construction of an onshore placement area to contain dredge material. This would be located within the south-west corner of the processing facility pad footprint (see Figure 7-5). It should be noted, however, that onshore placement of dredged material is no longer the preferred option due to the high fines content of the nearshore sediments. Onshore placement is being retained as an assessable option only in case further geotechnical work indicates that useful fill material can be economically won from the dredging works program.

Should it be required, the construction of the placement area would impound 103 ha of salt flats located in the south-west corner of the allocated project site. Due to extremely irregular tidal inundation, high evaporation rates and hypersaline soil conditions, salt flats are largely devoid of vegetation and do not provide habitat for marine invertebrate fauna.

While the area of salt flats within the placement area footprint can be considered to be a small part of the overall drainage catchment of the Ashburton Delta mangrove ecosystem, the loss of this area of salt flats is not expected to compromise the ecological integrity of the delta for the following reasons:

- Surface water modelling studies show that there will be no significant impact to tidal inundation patterns or freshwater flows (from Ashburton River floods) to the mangrove system from the construction of the placement area - see Section 7.1.1.
- Studies on the biological activity associated with salt flats indicate that in the arid zone coastal areas they do not play a significant role in large-scale nutrient cycles (Biota 2005).
- Extensive areas of salt flat (i.e. several thousand hectares) have been removed by solar salt projects and other developments in the Pilbara (e.g. at Onslow and Port Hedland) and there appear to be no adverse effects on adjacent mangroves or the integrity of the system in which they occur. In the Onslow area, long-term pre- and post-monitoring of mangroves associated with the operation of the Onslow solar salt field have shown no observable impact on mangroves, either around the crystallisers or the evaporative ponds east of the Onslow town site (Biota 2003).

7.3 Potential Indirect Impacts

Potential indirect impacts to the Ashburton Delta mangrove system includes the following issues:

- dredging related sediment deposition
- localised seepage from the onshore dredge material placement area
- stormwater management and disposal
- hydrocarbon spills
- atmospheric emissions
- increased noise emissions
- increased light emissions
- human disturbance (e.g. increased recreational fishing in Delta).

7.3.1 Dredging related sediment deposition

Mangroves have adapted to inundated intertidal mudflats via use of aerial root systems above the mud, which provide oxygen to the plant through small pores. Burial of these aerial root systems by fine marine sediments has the potential to reduce mangrove tree health, or even cause tree deaths. Proposed dredging operations will generate turbid plumes that have the potential to increase sedimentation in some adjacent subtidal habitats.

An assessment of the potential for indirect impacts to mangroves in the Delta from dredging related sediment deposition indicates that such impacts are unlikely given consideration of the following factors:

- Background turbidity concentrations along the Onslow coastline are high under existing conditions and the relative increase in concentrations due to dredging is limited (see Plate 7-2). Mangroves in the area already cope with periods of very high turbidity during Ashburton River flood events.
- The dredge plumes are not expected to give rise to additional sedimentation at a scale that could threaten mangrove communities. A review of sediment burial effects on mangroves in Australia (Ellison 1998) describes the mortality of *Avicennia marina* (the dominant mangrove in the project area) being caused by sedimentation depths of 12–50 cm.
- Dredging activities will occur in nearshore/offshore areas and not within the mangrove fringed tidal creek systems and hence the majority of dredging related sediment mobilisation and deposition will occur in nearshore/offshore areas and not within the intertidal zone where mangroves occur. In areas of the Pilbara coast where dredging has actually occurred within mangrove fringed tidal creek systems (e.g. Port Hedland harbour) there has not been any evidence of significant impacts to mangroves from dredging related sediment deposition.

7 Assessment of Potential Impacts of the Project on the Delta

Plate 7-2 Highly turbid water at the mouth of the Ashburton River (Note: This photo was taken on 7 May 2010 when the river was not in flood)

7.3.2 Seepage from onshore dredge material placement area

The Project has considered onshore placement of up to 10 Mm^3 of dredged material into a purpose-built placement area within the south-west corner of the allocated project site (see Figure 7-5). Typically, the dredging operations will produce seawater slurry with solids to water ratio of about 1:5. The dredge material placement area would be contained by perimeter embankments, except where the dune terrain provides a natural embankment. Internally, the dredge material placement area would be sub-divided into three cells. Two of these cells are intended to contain dredge material; the third forms a sediment trap and sump (Figure 7-5). The perimeter embankments would be constructed using suitable fill and compacted materials.

Consolidation and dewatering of the disposed dredge material will occur within the placement area. The processes of consolidation and dewatering will occur through the decanting of supernatant seawater, seepage of seawater into the groundwater environment and evaporation. Within the sump, there would be storage and retention of decanted seawater, which allows settlement of sediment fines prior to disposal. Seawater disposal to an ocean outfall in front of the Plant Pad is proposed during the dredging campaign.

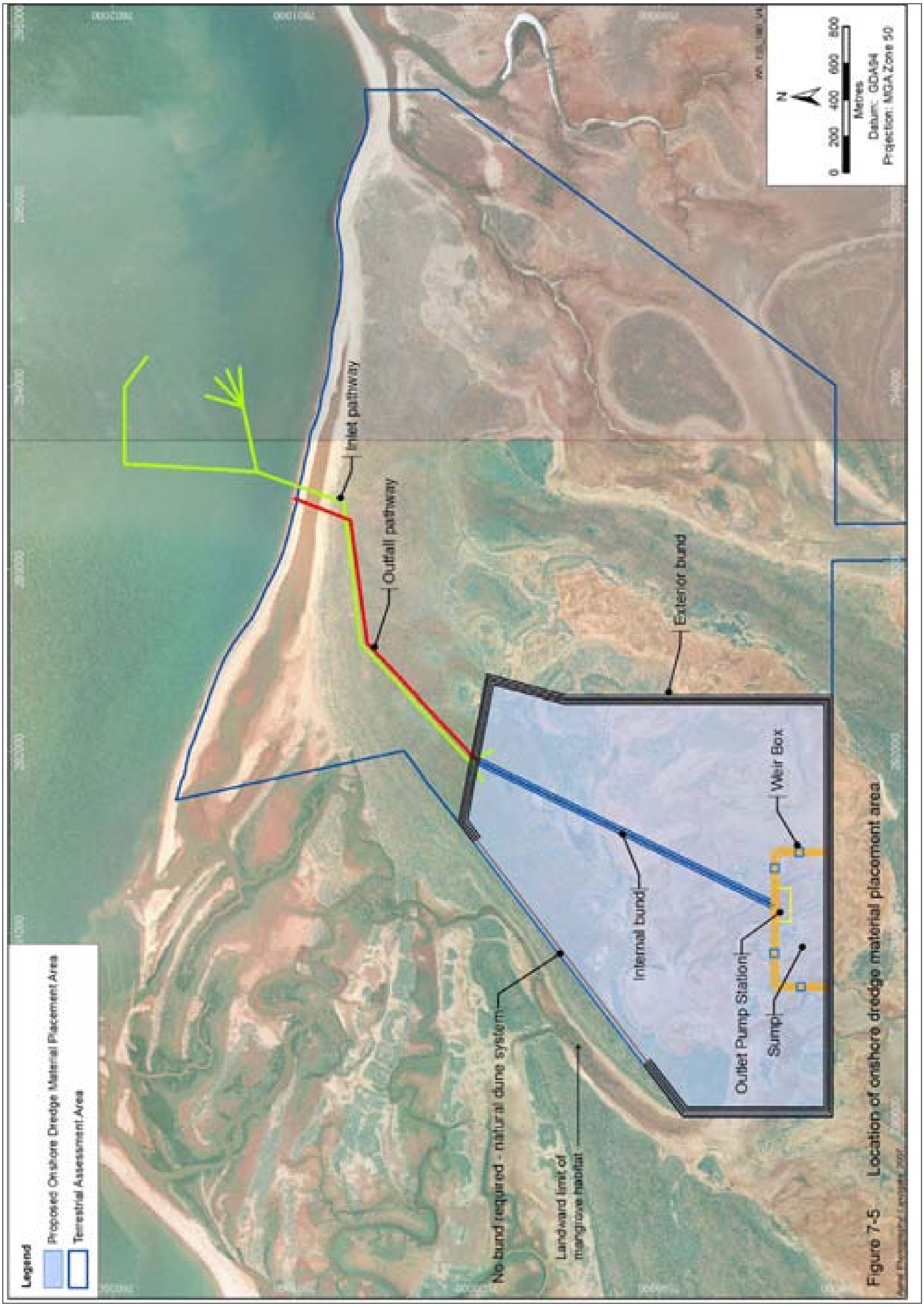

Figure 7-5 Location of onshore dredge material placement area

There have been some cases in Western Australia where the containment of large volumes of water in settling ponds or salt ponds constructed within a tidal flat setting has caused waterlogging and groundwater/soilwater salinity increases resulting in localised mangrove mortality for a distance of up to 100 m from the perimeter of the salt pond bund (i.e. seepage effects superimpose a waterlogging effect over the natural water table fluctuation which impedes the normal physiological function of the mangroves) (Gordon et al. 1995; LDM 1998). In these situations the pond levees are often very close to, if not adjoining the mangroves. The proposed design of the dredge material placement area results in the distance between the closest mangroves and the western perimeter of the placement area being at least 200 m. The dune system which forms the northwest bund for the onshore placement area acts as a buffer area between the placement area and the upper most reaches of a tidal creek that supports a narrow band of mangroves (see Figure 7-5).

Groundwater flow modelling studies have been undertaken to predict the impacts of the dredge material placement area on the local groundwater environment (URS 2010g). The initial groundwater levels at the commencement of dredge material placement are those obtained from the steady-state groundwater flow model. Predictive simulations for a dredging campaign of approximately 16 months were produced to assess the mounding of the water table, increased salt loadings to the water table and seepage of seawater. The main findings of the groundwater modelling studies that are relevant to the Ashburton Delta mangrove system are:

- Mounding of the water table is predicted to occur under the footprint of the dredge material placement area due to the infiltration of seawater. Some water table mounding and seepage of seawater is predicted to occur in areas immediately adjacent to (but outside of) the placement area footprint with the majority of seepage occurring into the salt flat habitat next to the southern perimeter and southwest corner of the placement area and well away from mangrove areas. The seepage fronts are closely linked with the areas of mounded water tables and are predicted to vary over time as the mounded water tables decay.
- A low rate of seepage may occur at the dune/tidal flat margin near the northwest perimeter of the placement area. This is adjacent to the landward most occurence of mangroves that are fringing the upper reaches of a small tidal creek (Fig 7-5). When considering the low rates of seepage in combination with high evaporation rates it is unlikely that the seepage will result in any impacts to mangroves fringing the small creek and any changes will be very localised to the dune/tidal flat margin.

7.3.3 Stormwater management and disposal

Areas of the plant will be segregated to provide separate drainage systems for each category of surface run-off. These consist of contact (potentially contaminated) stormwater and non-contact (uncontaminated) stormwater.

Potentially contaminated stormwater will primarily come from stormwater in the process areas and will be routed to a series of process area catchment sumps. These sumps will hold a first-flush of stormwater, which is expected to be equivalent to 25 mm for approximately 10,000 m^2 of the paved area. These sumps will contain equipment to remove floating oil. The first flush water from the contact stormwater system will be routed to the process water treatment plant for treatment prior to discharge to nearshore waters via the marine outfall at the PLF.

Non-contact surface runoff that is considered uncontaminated will be routed to sediment pond(s) for removal of suspended solids. The sediment ponds will be sized to accommodate a 10 year, six hour rainfall event, which has an hourly rainfall of 18 mm per hour. Emergency spillways will be provided to convey large floods safely past the sediment basins. The water from these ponds will be discharged via drains to Hooley Creek.

Australian water quality standards will be met in the stormwater outfalls.

7.3.4 Hydrocarbon spills

Potential accidental oil spill impacts may occur from both onshore and marine construction works (e.g. construction vehicles/plant, vessels and dredging spread). This is a potential high risk to the delta ecosystem, particularly if hydrocarbon spills occur and find their way into the delta. The likelihood of spills and leaks occurring will be reduced through implementation of a program of inspection, monitoring and maintenance. This management program will be in place throughout the Project. Management controls have been developed to reduce risks associated with various potential sources of leaks or spills and will be undertaken in accordance with the Construction EMP. An Oil Spill Contingency Plan approved by the WA Department of Mines and Petroleum will be in place.

Condensate spills at the PLF during shiploading and diesel spills at the MOF during vessel refuelling are a rare occurrence but are known to have occurred in the past and are considered to be the most credible “worst case” spill scenarios. The risk of a condensate spill actually occurring at the PLF is considered to be low, given the safety implications of such an event. However, it is acknowledged that the potential impact of such a spill on the mangroves of the Ashburton River Delta could be very damaging if condensate was able to get into the delta soon after its release and prior to the more toxic components having evaporated off.

DHI (2010) has simulated the spread and advection of various credible spill scenarios applicable to the Wheatstone Project. One of these scenarios was for a spill of 100 m^3 of condensate over a full minute at the PLF.

The spill scenarios were simulated using a probabilistic modelling approach via the DHI MIKE 21/3 SA oil spill simulation model (DHI 2010). Spills from each scenario were modelled for winter, summer and transition seasons. Each simulation presents not only the direction of spill advection in response to prevailing winds and currents, but also the degradation of the spill as it undergoes a range of weathering processes such as evaporation and entrainment into the water column. These processes are described in the DHI report (DHI 2010). It is important to note that the results of a probabilistic modelling approach show envelopes of possible impact arising from multiple spills occurring under a wide range of conditions. By comparison, the region exposed to one spill will be far less extensive.

Figure 7-6 presents envelopes of the maximum oil thickness from multiple condensate spills at the PLF during winter (top) when the delta is most at risk, and the minimum time to exposure (bottom). This figure indicates that, should such a spill occur at the PLF, the condensate would rapidly (<6 hrs) gain access to the mangrove habitat of the Ashburton River Delta and could result in large-scale mortality of mangroves in this highly sensitive area. Similar maps for a diesel spill at the MOF indicate a potentially similar outcome for the mangroves of the Ashburton River delta (DHI 2010). Therefore, management actions are necessary to ensure such events do not occur. Such management actions are documented in the Chevron Marine Oil Pollution Plan. Chevron will be undertaking an oil spill sensitivity mapping activity to help plan responses to oil spills and to design mitigation approaches.

7 Assessment of Potential Impacts of the Project on the Delta

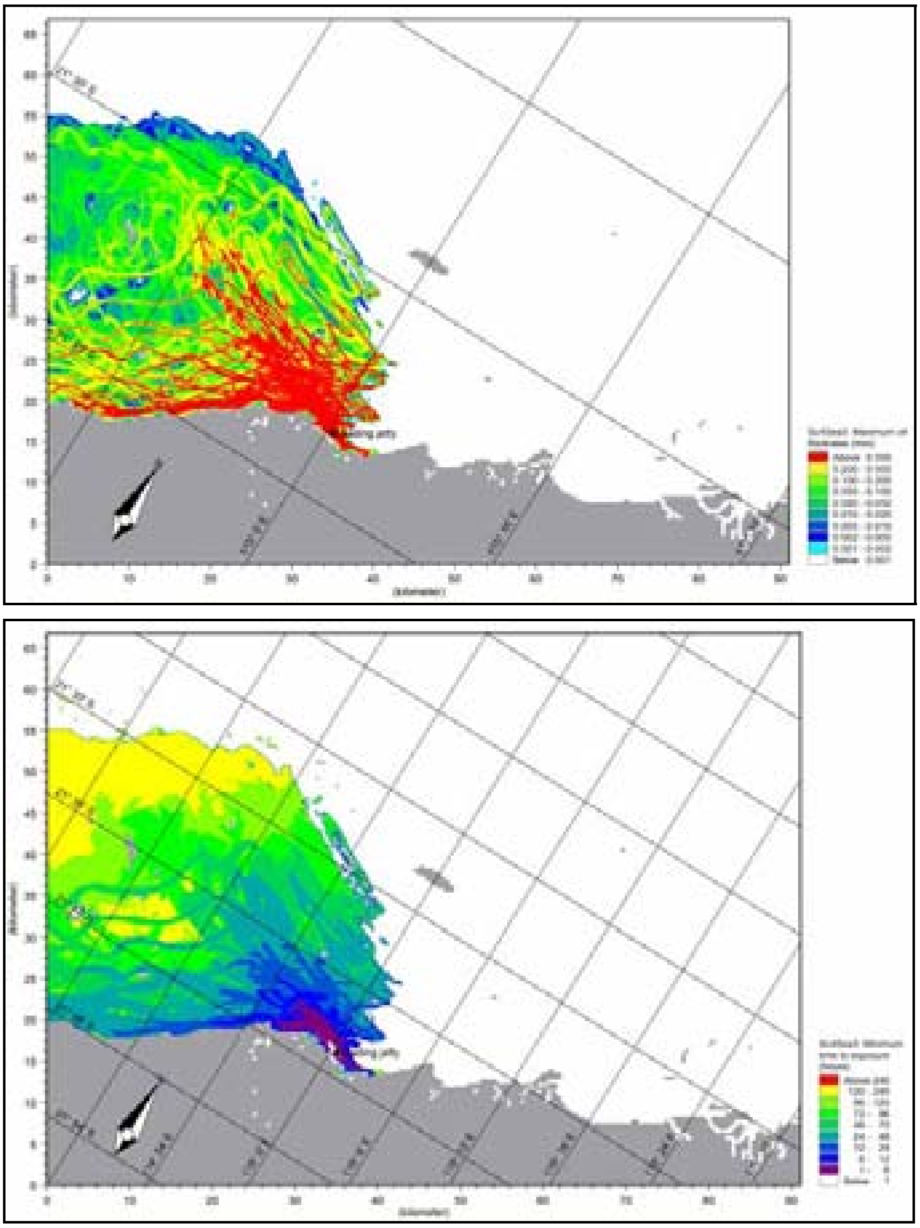

Figure 7-6 Multiple condensate spills at the PLF jetty showing maximum slick thickness during winter (top) and minimum time to exposure during winter (bottom). Source: DHI 2010

7.3.5 Atmospheric emissions

The introduction of an LNG processing plant will increase atmospheric emissions at the site compared to existing concentrations. Each of the phases of construction, commissioning and operation of the onshore development area will contribute differently to the local and regional airshed. This section addresses the types of emissions which are likely as a result of construction and operations during the Project, the existing sources of those emissions and the receptors that are sensitive to changes in air quality. There is limited information available regarding the impacts of atmospheric deposition on Australian flora and vegetation, and very little is known regarding air pollution impacts on mangroves.

Dust emissions

Due to the absence of major anthropogenic dust–generating sources at the Ashburton North site, the existing sources of dust are primarily due to wind–blown dust. Minor anthropogenic sources of dust include tourist and local vehicles visiting areas near the Ashburton River and the Old Onslow heritage area.

Dust from these minor sources exhibits a marked seasonal trend, tied predominantly to the influence of the Pilbara’s wet and dry seasons. This is not only due to the moisture content of the unsealed roads in the area but, during the wet season, the roads are often impassable and closed by the shire. During the dry season visitors are more frequent to the Onslow area and, with the lowered moisture content of the air, the soils and the unsealed roads, dust is readily generated. The characteristically low height of the local vegetation means that dust suspension and re-suspension is often visible from several kilometres. During the summer months, bushfires can also emit a large amount of particulate matter to the atmosphere and remove vegetation that stabilises the soils, leading to further dust generation.

The Ashburton North site is recognised for its relatively soft, silty/sandy soils due to dune and claypan landforms characterised by fine to medium sand resting on clay or mud. When vegetation is removed, or the surface disturbed by vehicles or by sufficiently strong winds, dusty conditions may result.

Dust emissions from the project have the potential to adversely impact the condition of the mangroves. Like other vegetation types, dust deposition can adversely affect the photosynthetic processes by causing blockages of the leaf stomata, thereby preventing adequate uptake of oxygen, carbon dioxide and sunlight, causing an overall decline in vegetation health. It is unlikely that there will be any adverse effects from dust arising from construction and operation of the proposed development. Detailed work by Paling et al. (2001) in Port Hedland has indicated that few declines in mangrove health have occurred adjacent to iron ore stockpiles which act as continual dust emitters.

Dust emissions are likely to be confined largely to onshore construction-related activities within development areas. Source activities will include: construction traffic transporting materials and workforce to site, drill and blast activities, land clearing, earthworks, temporary stockpiling and backfilling the operation of a mobile crushing plant. Dust emissions often vary substantially from day-to-day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. Significant airborne dust can be expected to arise at wind speeds above 8 m/s. This happens when vegetation is removed from loose soil and stockpiles of dry material are established. Traffic movements over bare surfaces and the transport and deposition of dust generating material, including fill, can exacerbate this problem unless properly controlled.

Deposition processes in the study region are expected to be dominated by dry deposition during the dry season and a combination of wet and dry deposition during the wet season. Previous deposition studies undertaken by SKM on the Burrup Peninsula, which is located in the Pilbara region of Western Australia, have indicated that there are large uncertainties associated with the deposition modelling results (SKM 2003). The uncertainties in the modelled depositions are due to uncertainties in the water, soil and vegetation surface resistances employed in the calculations (Hurley 2005). Further monitoring and modelling studies would be required to reduce these uncertainties, including deposition measurements and model validations. As such, the deposition quantities provided in this assessment are considered indicative of what may occur.

Dust emissions are not expected to be a significant issue (Chapter 9 of the ERMP) and are expected to be limited to dry season conditions. The vast majority of the initial material handling activity consists largely of coarse fractions and has a high moisture content which is therefore not prone to wind erosion or dust generation. As the material dries out there may be the need during specific weather conditions (i.e. such as prevailing winds in the direction of the sensitive receptor) to apply a dust suppressant.

A Dust Management Plan will be developed as part of the Construction Environmental Management Plan with the key objective to minimise the generation of dust. A range of dust management controls and monitoring procedures (outlined in Chapter 9 of the ERMP) will be applied during key construction activities at the onshore development area to minimise the potential for dust related impacts to the Ashburton Delta mangroves.

Air emissions

There are no major anthropogenic gaseous emissions in the near vicinity of the Ashburton North site. Minor emission sources include motor vehicles in the surrounding area of Onslow and some small-scale power generation facilities at Onslow and Onslow Salt. Volatile Organic Carbons (VOCs) and oxides of Nitrogen (NOx - the collective term for nitric oxide [NO], nitrogen dioxide [NO_2] and nitrous oxide [N_2O]) are known to be emitted from natural sources.

Native vegetation can be adversely affected by exposure to a number of atmospheric pollutants or combinations of pollutants. However, no Australian ecosystem specific criteria have been established. Chapter 9 of the ERMP prepared for the Wheatstone Project outlines the World Health Organisation (WHO) critical levels and loads which are pertinent to the European environment (WHO 2000).

With respect to the WHO criteria:

- SO_2 is not expected to be a significant pollutant from this gas plant.
- Maximum annual NO_2 concentrations were identified as being 6 ug/m^3 representing 90% of NOx.
- The maximum hourly concentration of ozone was predicted to be 44 ppb, just 4 ppb over the cut-off.
- Maximum nitrogen loads were predicted to be 3.7 kg NO_2/ha/annum.

In view of this, air emissions from the Project are not expected to adversely impact the abundance, diversity, geographic distribution, and productivity and conservation status of the mangroves surrounding the Project and are therefore considered to be a very low risk.

The most significant air pollution emissions from the processing facility will be from the combustion of fuel gas in the gas turbines and from flaring. The main products of combustion of fuel gas are CO and NOx. However, the key air pollutants in terms of risk are NO_2, PM^{10} and subsequent formation of

Ozone (O_3). Atmospheric dispersion modelling of key air emissions under different operating conditions was performed to determine the predicted ground level concentrations at Onslow. As a result of the modelling, it was anticipated that the highest risk National Environmental Protection Measure (NEPM) 'criteria air pollutants' identified for detailed examination in this assessment were NO_2, O_3, and PM^{10}, with the others being not significant to the area.

NOx primarily comes from soil, the oxidation of ammonia and lightning (Yiener & Levy 1995). A major anthropogenic source (the main source) of NOx is from the combustion of fossil fuels. In urban areas, this occurs from automobiles and electricity production. Combustion of fuel gas will be the dominant source for the Project.

An EPA review of the cumulative impacts of nitrogen oxides on the Burrup Peninsula concluded that, whilst modelling of nitrogen oxide emissions from existing and proposed industry indicated a potential risk in terms of short-term impacts to vegetation, the modelling was not conclusive (EPA 2004b). The review also highlighted the lack of information regarding susceptibility of vegetation on the Burrup Peninsula to air emissions and a lack of knowledge of the interaction and synergistic effect of nitrogen oxides with other air emissions (EPA 2004b). While this lack of information makes it difficult to reliably assess the potential impact of air emissions on the Ashburton Delta mangrove system, evidence from long term monitoring programmes in mangrove areas next to existing LNG plants on the Burrup Peninsula and Darwin suggest that there has been no adverse impacts to mangroves attributed to air emissions.

Management of emissions and discharges expected during commissioning and operation will be further assessed and detailed through the Part V (EP Act) regulatory process in the form of a works approval and operating licence which will require government approval prior to commissioning/operation commencing.

7.3.6 Increased noise emissions

Predicted changes to noise levels within and adjacent to the Wheatstone Project area were modelled by SVT Engineering (2009). This study examined a range of scenarios, including construction pile driving and emergency flaring noise emissions. As these are generally short term in nature, the primary scenario considered here in respect to potential mangrove fauna impacts is the normal plant operation case of SVT Engineering (2009). The modelled noise contours predicted for this scenario relative to mangrove habitats are shown in Figure 7-7.

The primary mangrove fauna receptor in regards to predicted noise increases are the mangrove dependent bird species utilising the habitats adjacent to the Wheatstone Project area. There are no quantitative noise levels that can be reliably used to determine changes in avifauna behaviour across the range of mangrove species recorded from the Wheatstone Project area. SVT Engineering (2009) did, however, measure existing ambient noise at 4 Mile Creek and Old Onslow (in coastal settings to the immediate east and west of the Wheatsone Project; Figure 7-7). The average day time ambient L_A10 values for these two sites were 44.6 dB(A) and 45.7 db(A), respectively [SVT Engineering (2009)]. These values provide some guidance as to typical noise levels normally experienced by mangrove avifauna in coastal habitats in the locality. On this basis then, the 50 dB contour in Figure 7-7 is considered to be a nominal threshold above which some level of behavioural change might occur.

7 Assessment of Potential Impacts of the Project on the Delta

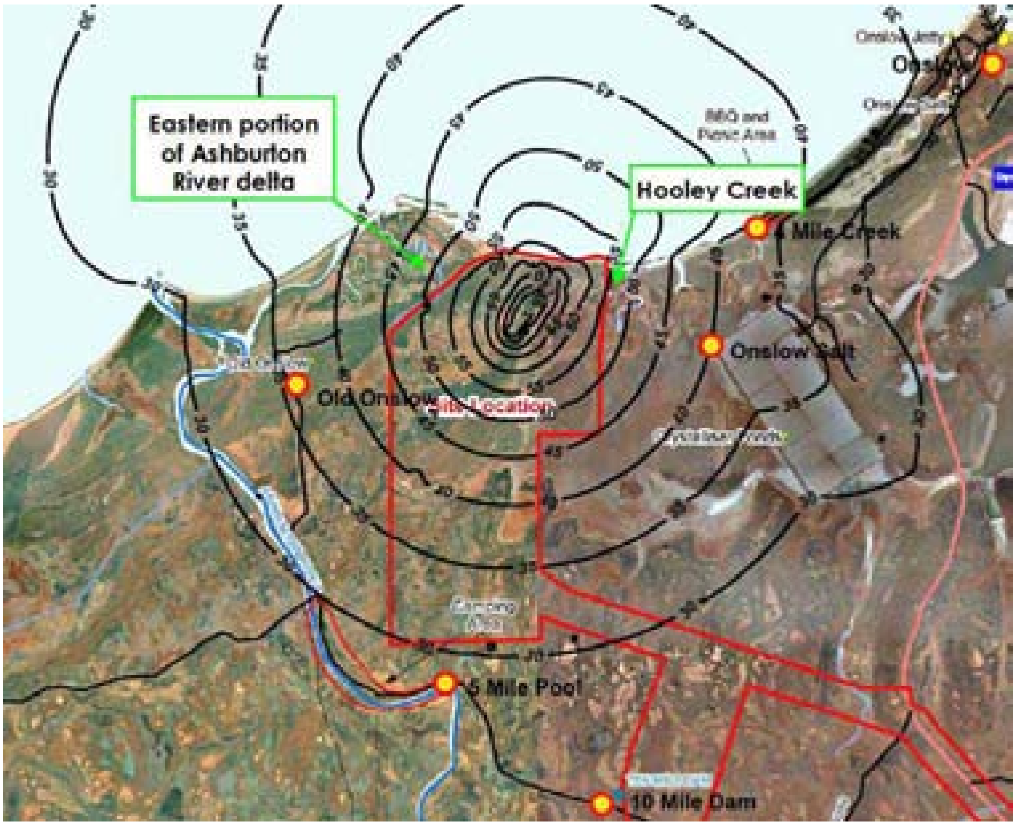

Figure 7-7 Predicted normal plant operational noise levels [modified from SVT Engineering (2009); local areas of mangrove habitat highlighted in green].

Increased noise levels may lead to reduced usage of mangrove habitats immediately adjacent to the new plant within this 50 dB contour. This equates to only the easternmost portion of the Ashburton River Delta mangroves and the mangroves of Hooley Creek (Figure 7-7). However, observational evidence from other Pilbara locations suggests that many mangrove birds can become habituated to increased noise levels over time and this may not lead to reduced habitat use [e.g. at port and conveyor operations in similar mangrove habitats at Finucane Island at Port Hedland (G Humphreys, Biota, pers. obs.) and in mangroves at North East Creek, immediately next to the Woodside LNG plant on the Burrup Peninsula (A Bougher, URS, pers. obs.)]. It is therefore likely that while some small-scale changes in behaviour could occur, the majority of mangrove avifauna species will probably continue to utilise these habitats (Biota 2010b). With the lack of published empirical studies that have examined these questions in natural settings, it is difficult to provide a more quantified assessment at this time.

7.3.7 Increased light emissions

Predicted changes to light levels within and adjacent to the Wheatstone Project area were modelled by URS (2009). Figure 7-8 shows the predicted light intensity levels in Lux for the operation facility in the context of local mangrove habitats. This modelling indicates that the mangrove habitats of Hooley Creek, and of the small coastal area to the north-east of the site, will experience light levels in the range of 1-20 Lux in the immediate vicinity of linear infrastructure crossing points (Figure 7-8; URS 2009).

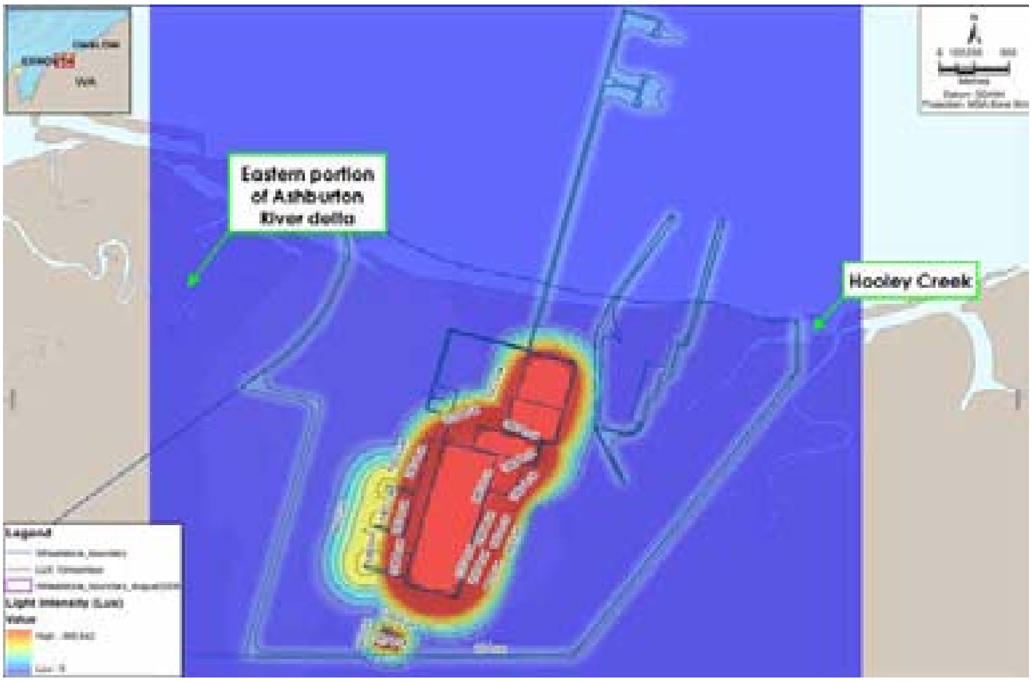

Figure 7-8 Predicted operation light levels (modified from URS Australia (2009); local areas of mangrove habitat highlighted by green arrows).

This exercise demonstrated that the majority of the mangrove habitat associated with Hooley Creek and the Ashburton River Delta will not experience any increase in light levels as a result of the Wheatstone Project (Figure 7-8). As with noise impacts, there are no properly quantified threshold levels at which increased light levels have been empirically demonstrated to affect the behaviour of nocturnal fauna (URS 2009; Biota 2009). However, it is likely that some level of behavioural and ecological response could be expected in the immediate vicinity of the linear infrastructure crossing points shown in Figure 7-8 (where levels of 20 Lux, approximately equivalent to typical street lighting, are predicted).

The primary receptor in this respect is the Priority 1 mangrove specialist, the Little Northern Free-tail Bat *Mormopterus loriae coburgensis*. This species has been demonstrated to occur in the Wheatstone Project area (Biota 2010a) and forages over mangrove habitat in the locality. Increased light levels typically lead to increased activity and concentrations of nocturnal insects, which form the primary dietary items of *M. loriae coburgensis* (Churchill 2009). It is probable, therefore, that there may be a localised increase in bat activity adjacent to these infrastructure corridors. While this may represent a modification to normal behavioural patterns, it is unlikely to lead to any detrimental impact, particularly considering the localised nature of the additional illumination compared to location of mangrove habitats in the area (Figure 7-8). In addition, it is possible that any increased density of bats around development areas could increase the risk of individual bat strikes. This is likely to be mostly limited to the construction phase of the Project and would likely represent the localised loss of individuals from local populations rather than a broader scale impact.

It is also relevant that the distribution of *M. loriae coburgensis* extends up the entire Pilbara coast, through the Kimberley and into the Northern Territory (Churchill 2009), meaning that any positive or negative impacts stemming from light-induced behavioural changes are negligible when considering the species' full distribution. Lighting management measures have also been recommended by URS (2009) for the Wheatstone Project. Considering these factors, and the localised extent of the increased lighting, there would appear to be a low risk of any taxon level conservation status change for *M. loriae coburgensis*.

Note that while marine turtles, particularly the Flatback Turtle *Natator depressus*, may periodically utilise mangrove creeks, the impact of light on this component of the coastal fauna has not been considered as part of this review because as shown in Figure 7-8, the mangroves of the delta which are adjacent to the LNG plant site are unlikely to experience increased light levels. An assessment of light emissions in relation to turtle nesting beaches in the area indicates that known turtle nesting beaches will not experience direct illumination from routine lighting at levels above that of natural phenomena (URS 2010h).

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Conclusions

8.1 Main Findings

This report identifies key processes maintaining the Ashburton Delta mangrove system, assesses the impacts of the project on those processes and undertakes an assessment of potential direct and indirect impacts. A summary of these assessments are:

- Recognition of the ecological importance and conservation significance of the Ashburton Delta mangrove system has resulted in the design of a project footprint that aims to avoids any direct impact to intertidal Benthic Primary Producer Habitat within the Delta (e.g. mangroves, bioturbated mud flat with samphires).
- The only potential for direct impact on the Ashburton Delta mangroves arises from trenching the pipeline shore crossing. Whilst this is not Chevron's preferred option, were it to eventuate, it would temporarily disturb an area of relatively barren intertidal sand flat which currently supports a very low density of mangrove seedlings. The first such trenching activity is therefore unlikely to result in the loss of mature mangroves. However, future trenching activities may well do so (as seedlings would have grown) and therefore, may not satisfy the EPA's guidance to this area.
- None of the key processes identified for maintaining the Delta will be modified to the extent that indirect impacts are expected to occur and no adverse impacts to the Delta mangrove ecosystem are anticipated.
- No direct impacts or longer term indirect impacts to mangrove habitats are expected to occur under the normal operating conditions of the project.
- Should it be required, the onshore placement of dredge material into a bunded area in the south-west section of the project site has the potential to cause localised water table mounding and seepage of seawater in areas immediately adjacent to (but outside of) the placement area footprint. Modelling studies show that the majority of seepage is predicted to occur into the salt flat habitat next to the southern perimeter and southwest corner of the placement area and away from mangrove areas. A low rate of seepage may occur at the dune/tidal flat margin near the northwest perimeter of the placement area. This is adjacent to the landward most occurrence of mangroves that are fringing the upper reaches of a small tidal creek. When considering the low rates of seepage in combination with high evaporation rates it is unlikely that the seepage will result in any impacts to mangroves fringing the small creek and any changes will be very localised to the dune/tidal flat margin.
- The assessment has identified the potential for condensate spills from the Product Loading Facility and, to a lesser extent, diesel spills from the Materials Offloading Facility to adversely affect the mangroves of the Ashburton Delta. It is recognised that spills are rare events but, should they occur in particular conditions, the potential for substantial mangrove mortality is high. Therefore management actions are necessary to ensure such events do not occur. Such management actions are documented in the Chevron Marine Oil Pollution Plan.

Based on the above assessments and historical experience indicating minimal impacts occurring from existing LNG plants and associated port infrastructure in Australia which occur either adjacent to, or amongst, mangrove habitats (e.g. Burrup Peninsula, Darwin Harbour), it is expected that the potential indirect impacts from the operation of the Wheatstone Project would constitute a low risk of adversely impacting the ecological integrity of the Ashburton Delta mangrove system.

In terms of the resilience or capacity of the Ashburton Delta mangrove system to withstand, recover or adapt to the potential human related impacts it should be noted that there is evidence at both the global and more local contexts that mangrove systems are highly resilient. In a discussion examining in part, the fate of mangroves with global warming, Alongi (2008) reiterates that mangroves naturally exhibit a high degree of ecological persistence (i.e. constancy over time regardless of environmental perturbation) and resilience (the ability to recover from disturbance to some more or less persistent state). Over the last few thousand years for example, mangroves have undergone almost continual disturbance as a result of fluctuations in sea-level. In a more local context, on the eastern side of Exmouth Gulf a high degree of recovery is documented as occurring following the destruction of 5,700 hectares of mangroves by Cyclone Vance in 1999 (Paling et al. 2007). In view of the resilience displayed by mangrove systems to natural environmental variation of the magnitude described above, it can be concluded that any long term changes to the Ashburton Delta mangrove system resulting from the proposed LNG plant will be minor, particularly given consideration of the above assessments and proposed management actions.

8.2 Mangrove Monitoring

The proposed Outcome Based Condition (OBC) related to mangrove protection commits Chevron to manage its construction and operation activities to reduce, as far as practicable, Project-attributable impacts to mangroves within the Ashburton Delta and Hooley Creek system. With respect to the Ashburton Delta, the OBC objective is to manage “construction and operational activities to enable no long-term net detectable loss of mangrove habitat”. With this objective in mind, Chevron will design and implement a comprehensive mangrove monitoring programme on the basis of the potential changes to mangrove health and mangrove habitat condition that may occur from the project.

The objective of the programme will be to detect impacts to mangroves and/or the onset of changes to the processes and conditions required for mangrove survival, so mitigation of such changes can be made as effectively as possible (i.e. provide for mangrove protection). To achieve this, focus will be placed on parameters that are readily detectable and these are linked to the main processes responsible for maintenance of mangrove systems and survival of mangroves. Parameters related to mangrove health and mangrove habitat condition and distribution may include:

- mangrove tree species composition and tree density
- mangrove tree health (canopy density and/or tree condition data)
- groundwater/soilwater salinity and water table depths
- sediment heights and ground levels
- hydrocarbon and heavy metals concentrations in mangrove sediments and selected mangrove fauna
- mangrove fauna – diversity and abundance
- mapping of mangrove habitat distribution and coastline movements.

Baseline monitoring will be undertaken prior to the commencement of any construction activities that may impact on intertidal areas. The programme will establish monitoring sites immediately adjacent to the project site (e.g. Hooley Creek and the easternmost section of the Ashburton Delta) and also at more distant locations considered to be outside the likely zone of influence from construction and operation activities (i.e. control or reference sites).

Glossary

	Definition
Barrier islands/limestone barriers	Narrow, shore-parallel limestone or sand ridges which bar and protect tidal embayments. Barrier islands may be mantled by dunes, beach ridges, soils and tidal deposits; surrounded by water at high tides.
Benthic Primary Producers (BPP)	Predominantly photosynthetic marine autotrophs, mainly plants and algae (some examples include seagrasses, mangroves, attached macroalgae), but also include scleractinian corals and some other filter feeding invertebrates such as some sponges and soft corals, which obtain a proportion of their energy requirements from photosynthetic symbiotic microalgae that live in animal tissues. All BPP organisms grow on the seabed either subtidally or intertidally, or as epiphytes.
Benthic Primary Producer communities	Biological communities, including the plants and animals, within which benthic primary producers are the more prominent components.
Benthic Primary Producer Habitats (BPPH)	Both the BPP communities described above as well as the areas of substratum that can and/or does support these communities.
Bioturbation	Turnover of substrate by fauna from burrowing, excavation and other activities.
Channel avulsion	Rapid abandonment of a river channel and the formation of a new river channel. Avulsion usually occurs during flood conditions where river or channel banks are breached, and the hydraulic resistance of the new channel is less than the previous channel.
Chenier	A discrete, elongated, vegetated marine beach ridge, comprised of sand or shell, which is stranded on a coastal mudflat or marsh, roughly parallel to a prograding shoreline
Chenier Spit	A chenier that is joined to the mainland on one end but not the other, thus forming a spit.
Cuspate Foreland (or cuspate spit)	The coastal convexity (in plan form) developed in the lee of a shoal or offshore feature by waves that are diffracted and/or refracted around both sides of the offshore feature. Elongated features may be referred to as cuspate spits. If the foreland links the feature to the mainland reaches, it is a tombolo.
Delta	A landform comprised of branched or interleaved channels and alluvial deposits occurring at the mouth of a river, due to high riverine sediment supply.
Genome	The genetic material characteristic of a particular species.
Halophytic shrubs	Plants that are adapted to living in saline conditions. Some of these plants survive by excreting salt through the leaves; others rely on storage capacity and high salt content (e.g. samphires).
Holocene	Refers to the younger subdivision of the Quaternary in which we are living, the previous subdivision being the Pleistocene. The Holocene, or Recent, is approximately the time since the last glaciation, or about the last 10 000 years.
Intertidal	Environment between the high and low levels of spring tides.
Local Assessment Unit	A specific geographical area which provides the most effective boundaries for management of cumulative environmental impacts on marine habitats.
Lithified Chenier	A chenier that has become cemented through a combination of induration and compaction.
Littoral	The intertidal zone of the sea.

9 Glossary

	Definition
Littoral drift (Littoral transport)	Movement of beach sediments in the littoral zone by waves and currents. It is generally dominated by movement parallel to the shore (longshore drift) although it may sometimes have a cross-shore component.
Mangrove	A plant that grows in sediments regularly inundated by seawater.
Mangal	A mangrove plant community.
Mesotidal	Coastal ocean or waterway with a moderate mean tidal range, between 2 and 4 m.
Nitrogen fixation	The conversion of atmospheric nitrogen into organic nitrogen compounds. This enriches the soil and is carried out by certain bacteria and blue-green algae.
Pelagic	Applied to organisms of the plankton or nekton which inhabit the open water of a sea or lake.
Pleistocene	Refers to the older subdivision of the Quaternary. The Pleistocene, usually ranking as a epoch, was the time of the most recent glaciation, and is generally thought to have lasted from about 2 million years ago to about 10 000 years ago.
Pneumatophore	Breathing roots of some mangrove species. A respiratory root which rises above the soil surface.
Salient	A bulge in the coastline projecting towards an offshore island, breakwater, reef or shoal, but not connected to it as in the case of a tombolo. Developed by a local slowing of longshore drift caused by wave diffraction and refraction.
Sediment Cell	A sediment cell is a section of coast within which the movement of sediment is readily identifiable, if not largely self-contained.
Semi-diurnal	Having a period of, occurring in, or related to approximately half a day.
Supratidal	Areas located above the influence of tides.
Terriginous	Refers to sediments derived from the land.

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The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

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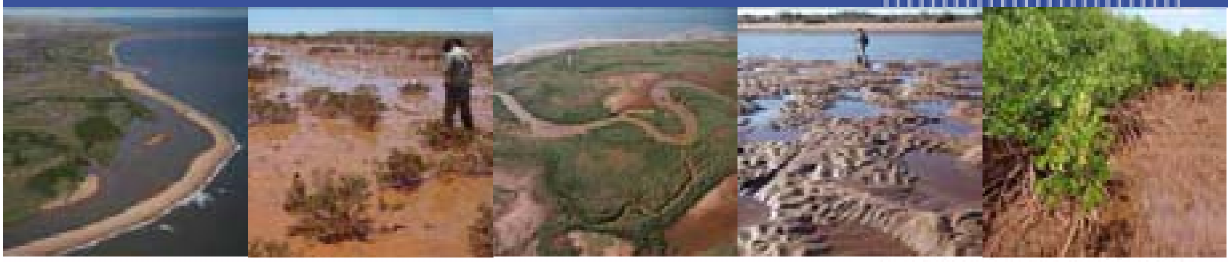

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Appendix N5

Justification of Benthic Primary Producer Habitat Loss Assessment Unit Boundaries

Tables

Figures

Appendices

Abbreviations

Abbreviation	Description
BPP	Benthic Primary Producer
BPPH	Benthic Primary Producer Habitat
BSPH	Benthic Secondary Producer Habitat
CALM	Department of Conservation and Land Management
CD	Chart Datum
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CLG	Cumulative Loss Guideline
DEC	Department of Environment and Conservation
DEWHA	Department of the Environment, Water, Heritage and the Arts (Commonwealth)
DoF	Department of Fisheries
Domgas	Domestic gas
ECU	Ecosystem Unit
EPA	Environment Protection Authority
EPASU	Environment Protection Authority Service Unit
GS	(EPA) Guidance Statement
HAT	Highest Astronomical Tide
IMCRA	Integrated Marine and Coastal Regionalisation of Australia
LAT	Lowest Astronomical Tide
LAU	Local Assessment Unit
LNG	Liquefied Natural Gas
MOF	Materials Offloading Facility
MPB	Microphytobenthos
NWSJEMS	North West Shelf Joint Environmental Management Study
ROV	Remotely Operated Vehicle

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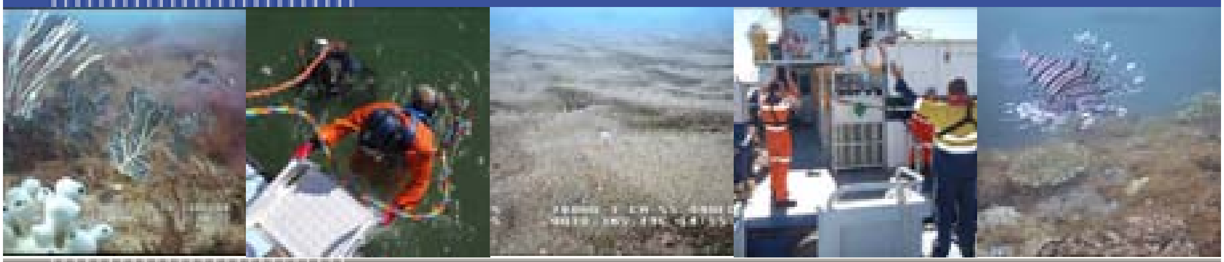

Report

Wheatstone Project: Justification of Benthic Primary Producer Habitat Loss Assessment Unit Boundaries

14 MAY 2010

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Executive Summary

Chevron Australia Pty Ltd proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) and domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara Coast. The LNG and Domgas plant will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and other yet-to-be determined gas fields. The project is referred to as the Wheatstone Project and "Ashburton North" is the proposed site for the LNG and Domgas plant. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State Waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this report have been conducted to support the environmental impact assessment process.

The purpose of this document is to present and justify the boundaries of the Loss Assessment Units (LAUs) proposed for the Project as a first step toward seeking EPA agreement on the appropriateness of the scales and boundaries proposed for potential impact area. These LAUs will form the basis for Chevron's calculation of cumulative habitat loss assessments as required by the EPA under Guidance Statement 29 (revised) for the Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment (GS 29).

The aspects of the Project with the greatest potential for causing loss or structural change of Benthic Primary Producer Habitats (BPPH) (restricted in distribution to the photic zone which in this region is mostly nearshore waters <30 m Chart Datum [CD]) are capital dredging and activities associated with placement of dredge material. Dredging will be required for construction of the navigation channel and Materials Offloading Facility (MOF), including onshore reclamations and associated dredge material placement activities, and trenching of the trunkline. A number of dredge material placement sites are being investigated. Two occur in deep waters of the inner shelf break (50-70 m CD) some 20 km to the north west of Thevenard Island; another three occur to the east of the proposed navigation channel alignment in waters 5-15 m deep; and an onshore site is also proposed.

Preliminary conservative modelling of potential dredging impact zones (DHI 2009) indicates that visible plumes are likely to extend some 25–30 km in both directions along the coast depending on season (west in winter and east in summer). Hence the potential impact area for the project in the shallow shelf waters which support most of the BPPH is large and covers an area of approximately 3,500 km^2 which extends some 70 km along the coast and about 50 km offshore.

A substantial amount of field survey work has been undertaken by Chevron, URS and others to define the types of BPPH which occur within this area and map their approximate distribution. Subsequently the CSIRO's hierarchical ecosystem classification framework as used by IMCRA (2006) and further developed by Lyne et al. (2006) for the North West Shelf, has been applied to the project area, in an effort to subdivide it into a number of distinct large Ecosystem Units (ECUs) which share common characteristics. Smaller Local Assessment Units (LAUs) based on definable bio-geomorphic attributes and the distribution of various types of BPPH were then been defined for each of the larger ECUs. Finally an estimate is presented of the historical cumulative losses of BPPH that have already occurred within the Project area.

Professor Charles Sheppard of Warwick University in the UK has provided an independent third party review of the methodology and framework used in the development of the justification of BPPH LAUs. His review is attached as Appendix A .

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Introduction

1.1 Project description

Chevron Australia Pty Ltd proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) and domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara Coast. The LNG and Domgas plant will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and other yet-to-be determined gas fields. The project is referred to as the Wheatstone Project and "Ashburton North" is the proposed site for the LNG and Domgas plant. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State Waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this report have been conducted to support the environmental impact assessment process.

1.2 Background (existing guidance)

The key guidance documents for assessing the acceptability of impacts on marine environments in the Wheatstone Project area are the EPA's:

- Guidance Statement No. 1 (GS1) Guidance statement for protection of tropical arid zone mangroves along the Pilbara coastline (EPA 2001);
- Guidance Statement No. 29 (GS29) Benthic Primary Producer Habitat (BPPH) protection for Western Australia's marine environment (EPA 2004); and
- Pilbara Coastal Water Quality Consultation Outcomes (EPA 2006) which provides a marine water quality objectives framework for the region. This guidance is not directly relevant to the protection of benthic habitats and as such is not discussed further in this document.

GS1 identifies areas that support arid zone mangroves that have special conservation significance (EPA 2001). It also sets out the EPA's expectations for the protection of mangroves, while recognising current and potential future development areas. It establishes four categories of protection ranging from no impact acceptable in areas of high conservation value, to restricted and minimised loss of habitat in areas zoned for development.

GS 29 has recently been revised (EPA 2009) by the EPA Service Unit (EPASU) and released for comment by the marine policy settings review stakeholder working group; it is still a draft. However it does substantially clarify the EPA's expectations of proponents and their consultants when assessing the direct and indirect loss of Benthic Primary Producers (BPP) as a result of development proposed for the marine environment.

GS 29 sets out a framework for the assessment of proposals that may impact on BPP and the habitats that can or do support such communities, termed Benthic Primary Producer Habitats (BPPH). The Guidance considers that BPP are 'predominantly marine plants e.g. mangroves, salt marsh, algal mats, seagrasses, and seaweeds (macroalgae and turf algae). BPP can also include invertebrates such as scleractinian corals and some other filter feeding invertebrates such as some sponges and soft corals, which obtain a proportion of their energy requirements from photosynthetic symbiotic microalgae that live in animal tissues. The EPA uses the term BPPH throughout GS29 to mean the ecological units that are BPPH including the dominant BPP communities they support. GS 29 includes mangroves as BPP and to avoid confusion between the application of GS 1 and GS 29, the four

1 Introduction

categories of mangrove protection from GS 1 have now been allocated a protection category under GS 29 (refer Table 1-1 below).

In GS 29, the EPA has provided a set of principles to be applied by proponents and the EPA when considering development proposals that may result in removal or destruction of, or damage to, marine BPP communities or the habitats which support them (EPA 2004). Note that "loss" is now defined in the revised GS 29 (EPA 2009) as being "Considered irreversible if the habitat is removed or if the timeframe for full recovery of that habitat or communities it supports is predicted to be longer than five years." Similarly, "damage" is defined as "Significant alteration to the structure or function of a community or habitat. Damage is considered serious if the timeframe for full recovery is expected to be longer than five years."

The quantitative elements of the risk-based assessment framework in GS 29 consider cumulative loss of BPPH. The EPA has defined six categories of marine ecosystem protection and provided guidance on the amount of BPPH that may be lost due to development as a percentage of BPPH within a defined management area for each category. These percentages are now termed Cumulative Loss Guidelines (CLGs), rather than thresholds. The EPA considers that if CLGs are exceeded, it will be seen as indicative of potential non-acceptability. These six categories of marine ecosystem protection and their corresponding CLGs are summarised in Table 1-1:

Table 1-1 Cumulative loss thresholds for BPPH within defined management areas for six categories of marine ecosystem protection

GS 29 category	Description	Cumulative loss guideline *(percentage of original BPPH within a defined management area)*
A	Extremely special areas (GS 1 guideline 1)	0 %
B	High protection areas other than above (GS1 guideline 2)	1 %
C	Other designated areas (GS 1 guideline 3)	2 %
D	Non-designated areas	5 %
E	Development areas (GS 1 guideline 4)	10 %
F	Areas where cumulative loss thresholds have already been significantly exceeded	0 net damage/loss (+Offsets)

However, given the difficulty of reliably measuring the area of some BPPH, and considering the difficulty of quantifying the ecological significance of their loss, these thresholds will not be used as rigid limits. The acceptability of BPPH damage or loss will, in all cases, be a judgement of the EPA. The EPA will base its decision primarily on its assessment of the overall risk to the ecosystem integrity within a defined management area if a proposal were allowed to be implemented. This will be a key focus of any assessment by the EPA where there is potential for direct or indirect loss of BPPH.

The EPA has identified the following principles of assessment that will apply to proposals which, if implemented would cause damage or loss of BPPH, in order of priority (EPA 2004):

Principle 1. All proponents should demonstrate consideration of options to avoid damage or loss of BPPH, by providing the rationale for selection of the preferred site and broad project design.

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Principle 2. Where avoidance of BPPH is not possible, then the design should aim to minimise damage or loss of BPPH and proponents will be required to justify that design (e.g. through iterative design and demonstrable application of Principle 3 below) in terms of operational needs and environmental constraints at the site and the consequent need for damage or loss of that area of BPPH.

Principle 3. Proponents will need to demonstrate 'best practicable' design, construction methods and environmental management aimed at minimising further damage or loss of BPPH through indirect impacts.

Principle 4. The EPA's judgement on environmental acceptability with respect to damage or loss of BPPH and the risk to ecosystem integrity will be based primarily on its consideration of the proponent's calculations of cumulative loss of each BPPH type within a defined "local assessment unit" (the most "realistic" scenario) together with supporting ecological information, and expert advice, as required.

Principle 5. Where substantial cumulative losses of BPPH have already occurred or would occur if the proposal was implemented, proponents should consider some form of environmental offset (e.g. replacement of impacted reef habitat, seagrass transplants) for the additional damage or loss of BPPH and/or their associated BPP communities within the local assessment unit.

Principle 6. Proposals which, in the judgement of the EPA, pose an unacceptable risk to ecological integrity within a local assessment unit will be presumed to be unable to meet the EPA's objective(s) for this factor and therefore be judged environmentally unacceptable.

The risk-based framework of GS 29 sets out several steps for assessing any implication for BPPH ecosystem integrity (EPA 2004). The first is the definition of a 'Local Assessment Unit (LAU)' for the purposes of applying the EPA guidance. GS 29 considers that an LAU would normally be approximately 50 km² (e.g. a rectangular area defined by a 10 km stretch of coastline extending 5 km offshore"). The purpose of this guidance is to focus the mind of proponents on the need to ensure that a proposed LAU is reasonable and defensible when considering the impact of a proposal on the ecological value and function (integrity) of the habitat of a specified benthic primary producer. However, the EPA will consider larger or smaller LAUs if well justified.

As set out by the EPA, the LAU needs to be a geographical area which provides the most effective boundaries for the management of cumulative environmental impacts on ecological values and functions. In all cases, LAUs should be configured to take into account aspects of marine ecosystems such as biophysical and geomorphic features including bathymetry and position of offshore reefs/islands, substrate type, water circulation patterns, exposure to waves and current and biological attributes such as habitat types. It is recommended that wherever possible, other variables at finer levels of detail, such as the dispersal ranges of BPP, or of their dependent fauna, and, where known, the extent of connectivity among and between BPPHs, are considered in this determination.

Where relevant, the definition of LAUs should also consider administrative boundaries such as zoning schemes within marine conservation reserves and state coastal waters boundaries. With this guidance in mind, for some large proposals or proposals predicted to result in extensive impacts or areas of impact that are discontinuous with infrastructure footprints, it may be necessary to define more than one LAU. In all cases, it is expected that proponents will determine the cumulative loss of, and/or serious damage to, each different BPPH type within each of the LAUs. Evaluating the loss of each of the different BPPH within LAUs provides proponents and the EPA with a basis for considering whether proposals maintain or alter the general proportionality of the different BPPH.

The revised GS 29 defines the following types of BPPH and Benthic Secondary Producers (BSP) (EPA 2009):

- upper intertidal saltmarsh communities;
- mud flats supporting cyanobacterial mats;
- mixed species low density mangrove communities;
- mixed-species dense mangal;
- mixed species macroalgal communities on lower intertidal and shallow subtidal rocks;
- subtidal coral communities on biogenic reefs;
- subtidal coral communities on rocks fringing islands;
- subtidal seagrass communities;
- sessile benthic filter feeder communities (BSP); and
- microphytobenthos communities (MPB).

1.3 Purpose of this document

The purpose of this document is to present and justify the boundaries of the LAUs proposed for the Project as a first step toward seeking EPA agreement on the appropriateness of the scales and boundaries proposed for potential impact area. These LAUs will form the basis for Chevron's calculation of cumulative habitat loss assessments as required by the EPA under GS 29.

However, prior to establishing these units, it is useful to place them and the Project into a regional ecosystem perspective. Therefore the following sections present a summary description of:

- relevant aspects of the proposed Project including spatial scale of potential impact area;
- benthic surveys undertaken in Project area;
- distribution of BPPH and Benthic Secondary Producers Habitat (BSPH) within Project area;
- key physical characteristics of the region surrounding the proposed Project;
- sensitive habitats and species in the Project area;
- historical disturbances or loss of BPPH in the region;
- bio-regional characterisations and ecosystem boundaries; and
- proposed LAU boundaries and area of associated BPP.

Much of the summary is based on the findings of a review of previous mapping and a number of field investigations undertaken by Chevron, URS and others to determine the distribution of intertidal and subtidal marine habitats in the Project area. A review of available regional reports and literature on bio-regional ecosystem characterisation was also used (Lyne et al. 2006).

1.4 Acknowledgements

Much of this document relies on habitat mapping work undertaken by others. The key documents that describe the benthic habitats of the study area are:

- URS (2010) Survey of Benthic Habitats (on Shelf Break) near Onslow.
- URS (2010a) Survey of Subtidal Habitats off Onslow.
- URS (2010b) Intertidal Habitats of the Onslow Coastline.

1 Introduction

The assistance of the authors of the above reports is gratefully acknowledged, as is Dr Barry Wilson who provided valuable internal review of early drafts of this document. Dr Kellie Pendoley provided advice regarding the distribution of turtles in the region.

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Relevant Aspects of the Project

The Project is a large and complex gas development proposal for the construction and operation of a multi-train LNG plant and a Domgas plant 12 km south west of Onslow on the Pilbara Coast (Figure 2-1 and Figure 2-2). The implementation of this Project requires installation of the following infrastructure to allow for the projected maximum capacity of 25 MTPA of LNG:

- Construction of an offshore processing platform, Wheatstone Platform (WP) and drilling of development wells to abstract the gas from the reserve situated in 70 – 200 m depth of water located some 60 km NNW of the Montebello Islands (Figure 2-3).
- Construction of a submarine trunkline for transportation of treated gas from the WP to an onshore LNG plant located at a site known as Ashburton North Strategic Industrial Area (Ashburton North SIA) on the mainland 12 km south of Onslow (Figure 2-1).
- Construction of an onshore LNG plant on sand dunes and some reclaimed tidal mud flat habitat at Hooley Creek located near the significant mangrove habitat of the Ashburton River Delta.
- Construction of shore protection works and breakwaters for an inland dredged Materials Offloading Facility (MOF), plus a 2.5 km long Product Loading Facility (PLF) (Figure 2-4).
- Construction of a 16 km long navigation channel to enable LNG vessels to access the PLF and load LNG. This channel will involve the dredging of up to 45 million cubic metres (Mm^3) of sediment. The sediment will be placed in dredge material placement sites at up to six locations (see Figure 2-2). Three are nearshore, located to the immediate east of the channel (sites A, B and C). Two are offshore, located in 50-70 m depth of water some 40km offshore (sites D and E). The final site is onshore to the south of the MOF and may involve up to 10 Mm^3 of material (site F).

The aspects of the Project with the greatest potential for causing loss of BPPH and BSP (which is mostly restricted in distribution to nearshore waters <30 m Chart Datum [CD]) are capital dredging and activities associated with nearshore onshore dredge material placement. Trenching the trunkline will modify a smaller area of benthic habitat. Preliminary conservative modelling of potential dredging impact zones (DHI 2009) indicates that visible plumes are likely to extend some 25-30 km in both directions along the coast depending on season. Impact assessment of similar developments elsewhere on the Western Australian coast indicates that substantial modification of habitats and associated biotic communities by sediment smothering is not anticipated beyond 0.5 km either side of the navigation channel and dredge material placement area footprints. This is because the heavier sediments with potential to smother habitats tend to settle rapidly after disturbance (Stoddart & Stoddart 2004).

As indicated earlier, the LAU needs to be a geographical area which provides the most effective boundaries for the management of cumulative environmental impacts on ecological values and functions. Given the wide distribution of project components from onshore to deep waters offshore and the potential scale of sediment plumes from dredging operations, a Project study area of some 70 km alongshore x 50 km offshore and centred on the plant site has been defined (Figure 2-2).

2 Relevant Aspects of the Project

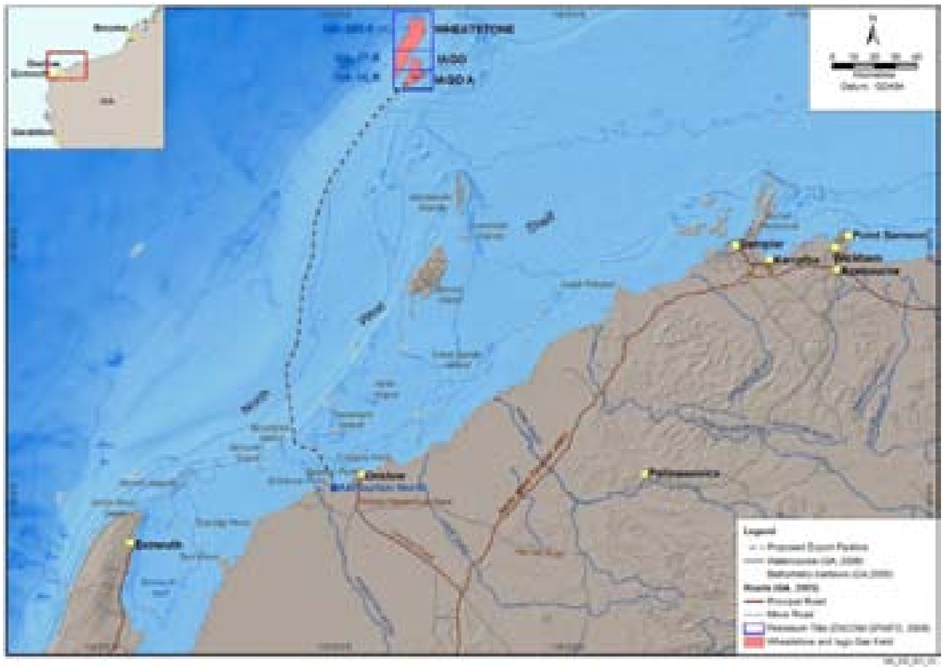

Figure 2-1 Regional bathymetry showing total Project area

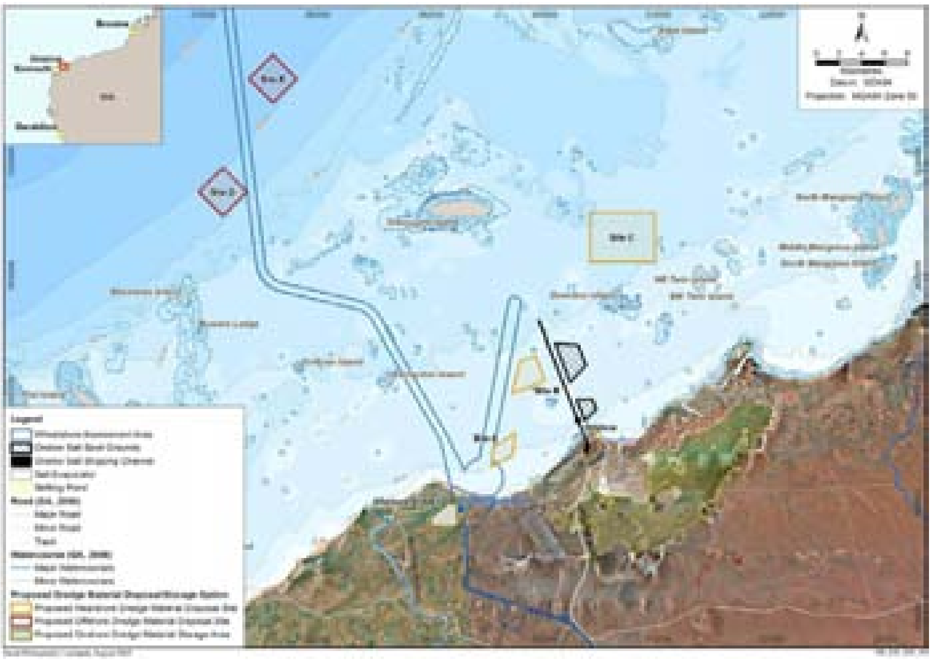

Figure 2-2 Map showing location of Project nearshore components overlying bathymetry

2 Relevant Aspects of the Project

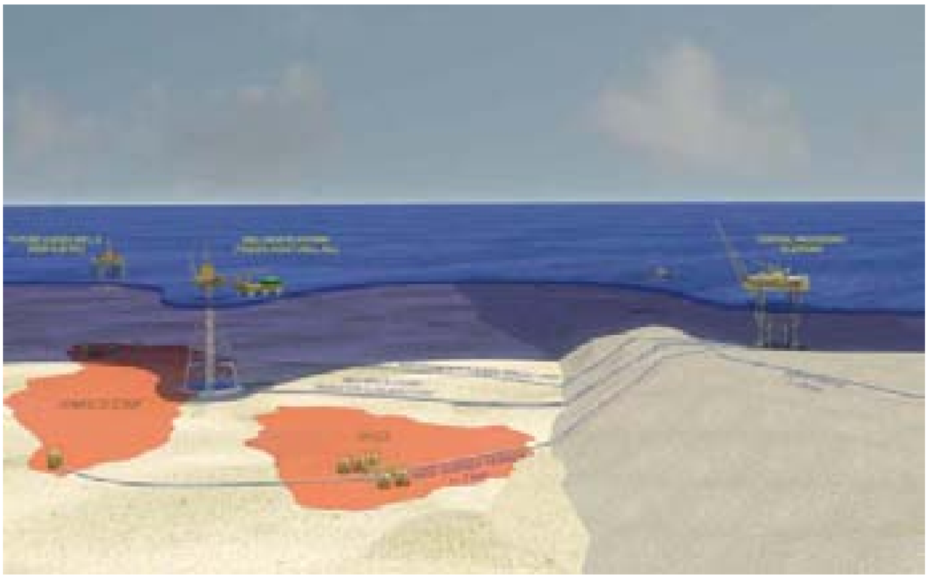

Figure 2-3 Schematic of Project offshore development

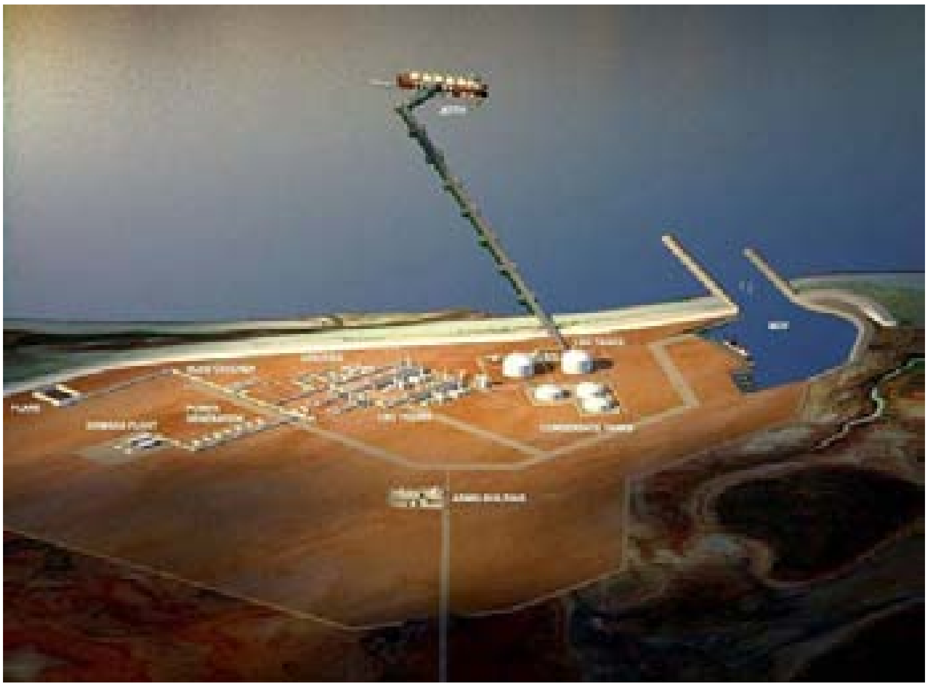

Figure 2-4 Schematic of Project nearshore and onshore development

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3 Summary Description of the Environment

3.1 Benthic surveys conducted in the Project area

A wide range of surveys were undertaken by Chevron, URS and others to describe the range of marine habitats which occur within the study area and map their distribution. Surveys conducted to date include:

- Three Remote Operated Vehicle (ROV) surveys of the subtidal habitats on the seafloor in the Project study area undertaken in December 2008, May 2009 and September 2009 (URS 2010a). The summer survey - conducted in December 2008 inspected 150 sites and focussed on the navigation channel, trunkline and dredge material placement area options and contiguous potential impact areas. The ROV survey conducted in May 2009 inspected 46 sites and was focussed on hard substrate areas in the vicinity of the navigation channel (reef, bommies, shoals, and islands) with the aim of identifying suitable areas to establish coral dive transects for future impact monitoring. The winter survey conducted in August 2009 inspected 155 sites and was focussed on:
  - "ground-truthing" gaps in potential hard substratum areas (reef, bommies, shoals, and islands) derived from Admiralty chart and URS interpolated nearshore bathymetry surface maps;
  - revisiting high coverage soft sediment BPPH areas identified in the summer ROV survey to look for seasonal trends;
  - far-field areas and proposed offshore dredge material placement sites were also surveyed.
- Surveys of intertidal habitats in the vicinity of the Ashburton North SIA site and along the adjacent coastline between Ashburton River and Coolgra Point were undertaken between November 2008 and May 2009. The surveys focussed on: beach, sand flat and rocky shore habitats; and mangroves and adjoining high tidal mud flats in the Ashburton Delta, Hooleys Creek area, and a selection of regional sites. The surveys used a combination of land access, vessel and aerial survey techniques (URS 2009b).
- A survey of representative inter-tidal habitats on eight islands within the project area was conducted in February 2009 with a focus on rocky shore communities (URS 2009c).
- A Coastal geomorphology survey was conducted in May 2009. The focus was on developing an understanding of the evolution of coastal landforms and coastal process in the area. Dating analysis and historic examination of coastal stability showed evidence of previous coastal shorelines and marine/estuarine habitats (Damara 2010).
- A tow and drop camera survey of the continental shelf break was conducted in August 2009. The continental shelf break is defined in this region as the area between 20-70 m isobath. Towed video footage covering five transects on the shelf break were analysed according to substrate and biotic composition of benthic assemblages (UWA 2009).

3.2 Benthic habitat mapping

Information obtained from the surveys has been collated and the distribution of the various benthic habitats has been mapped. Figure 3-1 presents the composite benthic habitat map for the study area. Habitat classification was derived from several sources, following the systematic methodology outlined in Bancroft (2003) and Lyne et al. (2006). At the highest level, the habitat is categorised as intertidal or subtidal. Both areas are then further divided into hard or soft substrate, and subtidal habitats are further separated to show location of sand veneered pavement.

3 Summary Description of the Environment

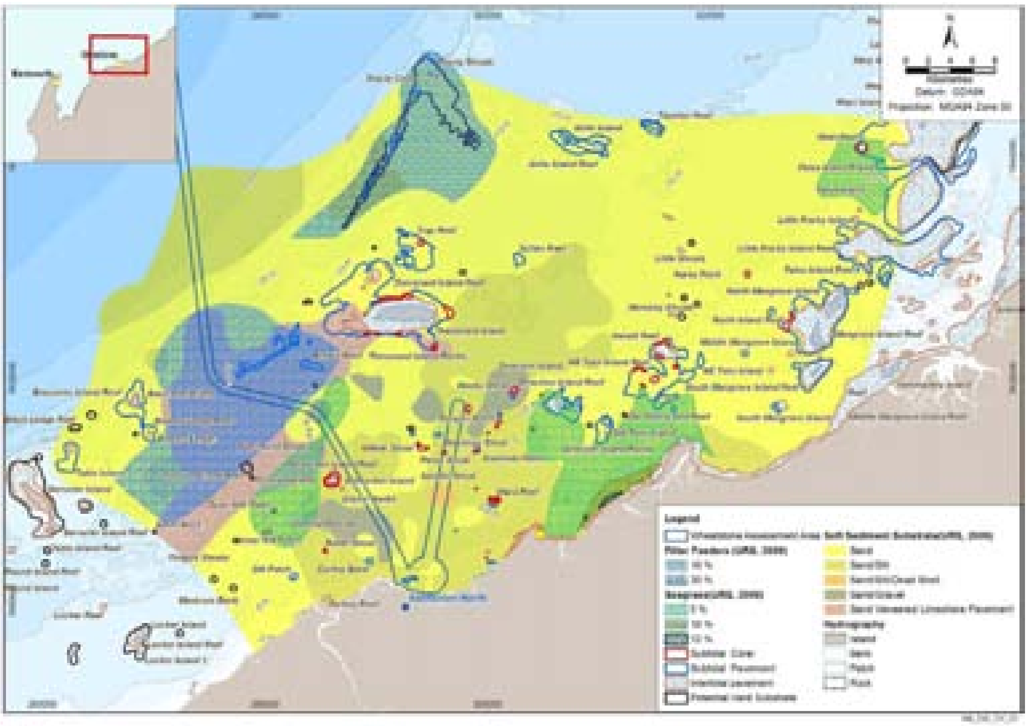

Figure 3-1 Indicative distribution of marine habitats in the Project area

Bottom sediments in the Project area show evidence of zonation with nearshore sediments having predominantly high silt content due to terrigenous sediment loading from the Ashburton River. Elsewhere, sand and pavement dominates the inner shelf although finer sediments are found in patches due to oceanographic conditions around islands and shoals. Finer sands and silts dominate the less energetic parts of the outer shelf. Considerable areas of pavement are found on the upper section (10-40 m isobath) of the shelf break (UWA 2009).

The detailed methodology used in the development of the habitat maps is described in the Method Statement for Benthic Habitat Mapping for Wheatstone (URS 2010d).

The following BPPH types have been recognised in this study area and are distributed from Mean High Water Springs (MHWS) level down to ~70 m depth:

- upper intertidal mud flats supporting cyanobacterial algal mats;
- upper intertidal saltmarsh/burrowing crab communities;
- mixed species low density mangrove communities;
- mixed-species dense mangal;
- mixed species macroalgal communities on lower intertidal and shallow subtidal pavements;
- subtidal coral communities on rocks fringing islands or on shoals;
- scattered ephemeral seagrass (*Halodule* spp) patches generally at low cover on most of the soft substrates of the study area, but with some more protected areas exhibiting denser cover (~10%);

- scattered foliose brown algae occurring on most of the soft substrates of the region, but in greater density on areas of sand veneered pavement;
- sessile benthic filter feeder communities (sponge/whip gardens) primarily located in deeper offshore waters (10-40 m CD) on sand veneered limestone pavement. Such communities also found generally in low abundance on some of the nearshore shoals where corals are dominant; and
- red microalgal mat (MPB) occurring on sandy substrate in deeper waters of the shelf break (40-70 m CD).

The BPPH types which are most widespread in the region and which cover the greatest area are the ephemeral low cover foliose algae and seagrasses which occur on soft substrates and sandy pavement in the region. The next largest single BPPH unit is the sessile filter feeders that occur on sand veneered pavement. All other BPPH types are restricted in distribution to either intertidal flats, or hard bottom reefs and shoals, both intertidal and subtidal. They also occupy relatively small areas in comparison to that occupied by the soft substrates. Coral communities are not abundant in the immediate vicinity of the Project area. They are restricted to a small number of individual shoals that occur along the 10 m isobath and along the edges of the intertidal pavements which fringe many of the islands in the region. Mangroves, samphires and algal mat communities are relatively widespread onshore, but occur within discrete creek or river systems. Most of the shoreline in the study area is comprised of sandy beach.

3.3 Key physical characteristics

The key physical characteristics of the marine environment of the Project area are:

- The coastline between Tubridgi Point and Coolgra Point is primarily a series of sandy barrier islands that protect tidal flats behind them. Tidal creeks drain these flats at intervals along the coast and discreet mangrove assemblages are located in these creeks (Figure 2-2).
- The Ashburton River Delta occurs in the middle of this coastline and supports a large and significant mangrove estuary.
- Chains of islands and shoals form lines approximately parallel to the shore between the mouth of Exmouth Gulf and Barrow Island. One line occurs in shallow waters, close to the 5 m isobath. The other is located closer to the 20 m isobath and includes more substantial islands such as the Muiron, Serrurier, Bessieres and Thevenard islands. Their presence also has ramifications for wave refraction water current patterns and sediment movement in the nearshore environment.
- Nearshore waters are shallow (<10 m) and generally turbid; offshore waters are slightly deeper (<20 m) and generally less turbid. In general, waters are more turbid in summer than in winter as a result of wind-wave generated sediment resuspension and rainfall runoff after cyclones.
- Nearshore currents flow parallel to shore and are dominated by the tidal component whereas offshore currents are mainly wind driven. Larger scale ocean currents are found to have little effect on the Project area as their influence is predominantly found beyond the 200 m isobath (DHI 2009).
- At a regional scale nearshore currents are generally higher than offshore currents due to increases in velocities around islands and shoals. However, the nearshore tidal driven currents of the Project's local area and the proposed navigation channel are generally mild (DHI 2009).
- The nearshore waters of the Project area experience a semi-diurnal tide with a Highest Astronomical Tide (HAT) of 2.9 m.
- Cyclones and storm surges are a relatively frequent occurrence (once every two to three years).

- There is a high level of biological connectivity throughout the Project area, as well as the wider the region. Studies undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the North West Shelf Joint Environmental Management Study (NWSJEMS) study (Condie et al. 2006) modelled coral spawn dispersal and showed that after seven days there was significant transport of coral larvae from the Montebello Islands to Ningaloo Reef.
- The coastline extending over 80 km from approximately Tubridgi Point to Coolgra Point can be considered as one single sediment cell (Damara 2010). The major sediment supply to the cell comes from the large catchment of the Ashburton River which covers approximately 78,000 km^2. The river only flows sporadically in response to major rainfall events usually associated with cyclones. When the river flows it discharges a substantial sediment load which turns nearshore waters turbid for some months after flooding. The annual sediment load is estimated by URS (2009) to be an average of 1.3 MTPA.
- The Ashburton sediment cell can be divided into two sectors; the shore between Tubridgi Point and Entrance Point at the mouth of the Ashburton River, and the eastern shore from the river mouth to Coolgra Point. The cell comprises a net alongshore sediment transport system with a generally easterly direction, though it is reversible with onshore winds that prevail from time to time.

3.4 Sensitive habitats and species in Project area

Although the Project area is within a development zone and occurs within the Onslow port limits it does contain habitats of conservation value that need protection. These include the following:

- The mangroves of the Ashburton River Delta which have been identified in GS 1 as being “regionally significant” (EPA 2001). As such Guideline 1 applies and they will be treated as “Extremely special areas” under the revised GS 29. This means that the EPA will afford these mangroves the highest level of protection, and that adverse effects from development are prohibited.
- Thevenard Island and Serrurier Island are both nature reserves and are important turtle nesting and seabird nesting and roosting areas (DEWHA 2009). Serrurier Island is a major nesting and possibly foraging area for green turtles. Caspian terns, little terns, wedge-tailed shearwaters and ospreys also breed on Serrurier Island (DEWHA 2009). Thevenard Island supports a significant flatback turtle rookery and is also a foraging area for green turtles. Thevenard Island also supports a recreational fishing and diving holiday camp and as such the reefs surrounding the island are an important recreational resource. Direction Island is also an important recreational resource which is readily accessible from Onslow.
- The shallow waters of the Mangrove Islands and Mary Anne Group of Islands are known to support a high abundance of turtles (Pendoley 2009), and are known to be a feeding ground for hawksbill turtles (DEWHA 2009, CWR 2009). These waters also support large areas of macroalgal beds and both biogenic coral reef and coral communities on pavement.
- Exmouth Gulf is an important resting area during winter months for humpback whales, particularly for females and calves on their southern migration. Six aerial surveys conducted between May and July 2009 (centred on the project location and running offshore) sighted a total of 228 humpback whales on their northern migration through the Project region (CWR 2009).
- The eastern shore of Exmouth Gulf is known to support a large number of dugongs (~1,000) which feed on seagrass beds in the area (DEWHA 2006). Eighty-six dugongs were sighted during

the above mentioned aerial surveys (CWR 2009), predominantly in the south western portion of the study area and in water depths less than 10 m.

- Ward Reef is a relatively large reef close to Beadon Point. It is unusual in that it supports a high diversity and cover of corals which survive in an area that regularly experiences a turbid water environment.

3.5 Historical loss of BPPH in the Project area

The study area has a long development history and the following marine habitat impacts are known to have occurred to date.

- Onslow was originally located at the Ashburton River mouth, the site of the historic buildings of 'Old Onslow'. This site was proclaimed a town in 1883 and a riverside wharf augmented a small lighter landing, along the Ashburton River, in 1885. These original port facilities for Onslow were four miles upstream of the entrance bar to the Ashburton River in a deep pool of water. A small but undefined area of mangroves is believed to have been removed beneath the jetty. The hazardous entry to the Ashburton River and the vulnerability of the landing to river floods resulted in the construction of a new sea jetty structure on the coast in north easterly direction from the coastline east of the estuary. The jetty was 960 ft long and 14 ft wide with a 124 ft long and 30 ft wide berthing head. The jetty was completed in 1900 with a low water depth of only eight feet (LePage 1986). This jetty was destroyed in a subsequent cyclone.
- Development of a small fishing boat harbour in Beadon Creek has resulted in minor loss (~1 ha) of mangroves on the southern shore.
- Development of the Onslow Salt Field has resulted in loss of upper tidal flats from Coolgra Point to Four Mile Creek, plus minor loss of mangroves (1 ha) near the pump station on Beadon Creek (Figure 3-2).
- Modification of seafloor benthos distribution on the nearshore (5-15 m CD) soft substrates which occur along this shoreline (Figure 3-3) by the local prawn trawling industry (Sporer et al. 2007).
- Seafloor habitat modification in the vicinity of the Onslow Salt shipping channel and spoil grounds (Figure 3-3).
- Seafloor habitat modification in the immediate vicinity of oil and gas submarine pipelines and platforms and the vessel load out terminal related to the Thevenard Island oilfield, and the offshore Griffin oil and gas field (Figure 3-3).

3 Summary Description of the Environment

Figure 3-2 Onslow salt ponds and onshore Project area

Cutting of a pipeline trench through the limestone pavement on the east side of Thevenard Island resulted in the loss of a few corals fringing the outer edge of the platform. Review of the Thevenard Island annual environmental monitoring reports (Chevron 2001, Chevron 2002, Chevron 2002a, Chevron 2008, RPS 2006) indicated that since the commencement of the monitoring program in 1995, Project operations on the island have not significantly disturbed the health of the coral reef habitats within the area. The most significant deterioration of reef health was in the 2005/2006 cyclone season. The five cyclones that hit the Onslow area were responsible for damage to the coral reefs around Thevenard Island, Ashburton and Boa Reef, with the loss of colonies at some reefs ranging up to 10-15%. However coral recovery following the cyclone impacts was evident at some sites via attachment and development of damaged/broken coral fragments (Chevron 2007).

Therefore, the only loss of coral habitat arising from human activity that is known to have occurred in the Project area is on the platform edge fringing the eastern side of Thevenard Island where a pipeline trench was cut through the limestone platform to access the processing and storage facilities on the island. The area lost at the time is estimated to be no more than 0.1 ha (10 x 100 m).

Estimating the potential BPPH impacts of past trawling activity is difficult given that it is not known what the condition of the original habitat was like previous to trawling. However some information is available from the Western Australian Department of Fisheries (DoF) which suggests that little habitat modification has resulted from this activity (DoF 2003). The DoF applied to the then Commonwealth Department of Environment and Heritage for the Onslow Prawn Managed Fishery to be certified as being managed in an environmentally sustainable manner. The detailed application assessed the impact of the fishery on seagrasses as negligible based on three factors:

1. Most areas of seagrass are in areas that are closed to trawling.
2. Most trawlers actively avoid trawling near seagrass areas as rolls of broken-off seagrass get caught in the mouth of the codend, causing the net to stop fishing and for the prawns already caught in the net to become entangled and difficult to release.
3. The introduction of Bycatch Reduction Devices and Fish Exclusion Devices will further encourage trawlers to avoid seagrass areas since the grid component for both of the devices is highly susceptible to clogging by balls of seagrass.

Based on the above assessment, and given the ephemeral nature of the seagrasses which occur in this region, no attempt has been made to assess historical seagrass loss.

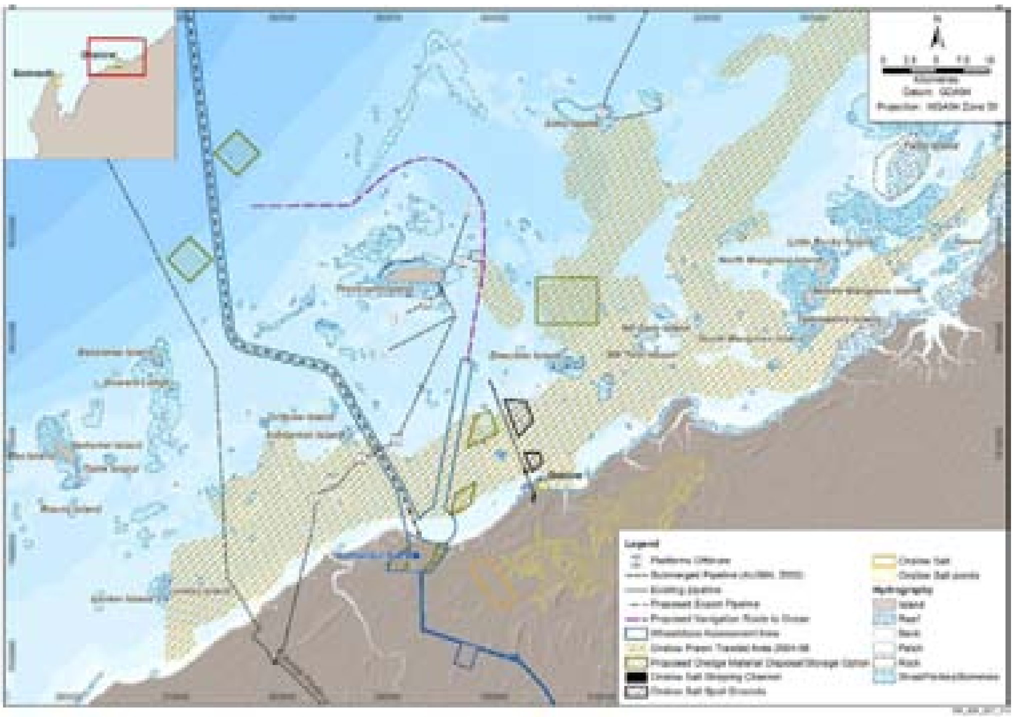

Figure 3-3 Existing and proposed areas of disturbance

An estimate of historical mangrove loss arising from developments in intertidal areas is presented in Table 3-1 based largely on information available within reports prepared for the Onslow Salt Project (Gulf Holdings 1990, HGM 1998, EPA 1997, URS 2010e). Tables 3-2 and 3-3 present estimates of bioturbated samphire flats and algal mat habitat loss respectively as a result of development of the Onslow Salt Project.

3 Summary Description of the Environment

Table 3-1 BPPH assessment Onslow area: mangroves

Location	Original mangrove extent (ha)	Historical loss of mangroves (ha & %)	Remaining area (ha)
Ashburton Delta	527 ha [4]	0	527 ha
Hooleys Creek to Four Mile Creek	84 ha [4]	1 ha or 1% [1]	83 ha
Beadon Creek to Coolgra Point	839 ha [1]	2 ha or 0.2% [1]	837 ha
Totals	1,450 ha	2 ha or 0.1%	1,448 ha

Table 3-2 BPPH assessment Onslow area: high tidal mud flat – bioturbated mud flat and samphire zone

Location	Original mangrove extent (ha)	Historical loss of mangroves (ha & %)	Remaining area (ha)
Ashburton Delta	683 ha [4]	0 ha or 0%	683 ha
Hooleys Creek to Four Mile Creek	639 ha [1,4]	2 ha or 0.3 % [1,4]	637 ha [4]
Beadon Creek to Coolgra Point	1,160 ha	40 ha or 3%	1,120 ha
Totals	**1,322 ha**	**2 ha or 0.2 %**	**1,320 ha**

Table 3-3 BPPH assessment Onslow area: algal mats

Location	Original mangrove extent (ha)	Historical loss of mangroves (ha & %)	Remaining area (ha)
Ashburton Delta	0 ha	0 ha or 0%	0 ha
Hooley's Creek to Four Mile Creek	1,004 ha [1,4]	189 ha or 19% [1,2,3]	815 ha
Beadon Creek to Coolgra Point	1,008 ha [1]	191 ha or 19% [1,3]	817 ha
Totals	**2,012 ha**	**380 ha or 19%** [1,3]	**1,632 ha**

* 1 Gulf Holdings (1990)
* 2 HGM (1998) Note: this mangrove area estimate is likely to be an underestimate due to the remote sensing technique only mapping dense cover mangroves
* 3 EPA (1997)
* 4 URS (2010e)

Table 3-1 shows that there has been very little loss of mangrove habitat within the region. Losses that have occurred are restricted to Beadon Creek and include the loss of approximately 1 ha in the vicinity of the solar ponds intake and another 1-2 ha on the south side of Beadon Creek where the wharf and boat ramp have been developed.

Table 3-3 shows that there has been substantial algal mat habitat loss in the tidal flat system which now supports the Onslow solar salt ponds. Both the Coolgra Point/Beadon Creek tidal flats and the Four Mile and Hooley Creek tidal flats have lost in the vicinity of ~ 200 ha which represents a nearly 20% loss of algal mat BPPH within each system.

3 Summary Description of the Environment

In summary it would appear that, whilst a substantial level of disturbance to nearshore subtidal sediments has occurred, this has not in fact resulted in an identifiable loss of subtidal BPPH. BPPH loss in the region to date is restricted to the high intertidal zone which primarily supports algal mats.

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Ecosystem Characterisation

4.1 Introduction

As indicated in Section 2, the Project area encompasses a relatively large area of nearshore shelf which varies in depth from HAT to ~70 m CD and extends alongshore for some 70 km. Available information on ecosystem characterisation in this region was reviewed in an attempt to divide the study area into recognisable ecosystem units which share common characteristics prior to defining LAUs for BPPH loss assessment.

There have been a number of attempts to classify ecosystems and habitat distribution along the north western coast of Western Australia. The early attempts (Semeniuk 1986, Semeniuk 1993) developed a classification of the coastline based on distribution of recognisable geomorphic units. This approach was used for nearshore waters by the Western Australia Department of Conservation and Land Management (CALM) for developing a representative marine reserve system for Western Australia (CALM 1994).

The distribution of areas considered to merit reservation along the Pilbara coast in the CALM report is shown in Figure 4-1 (CALM 1994). This figure shows that recognisably distinct habitat or ecosystem groupings occur at the large scale (or megascale as defined by Semeniuk 1986) along this coastline. It also shows that the coastline and nearshore waters of the Project area, located some 12 km south west of Onslow, is one of the very few stretches of coast which was considered at that time not to have merit for reservation.

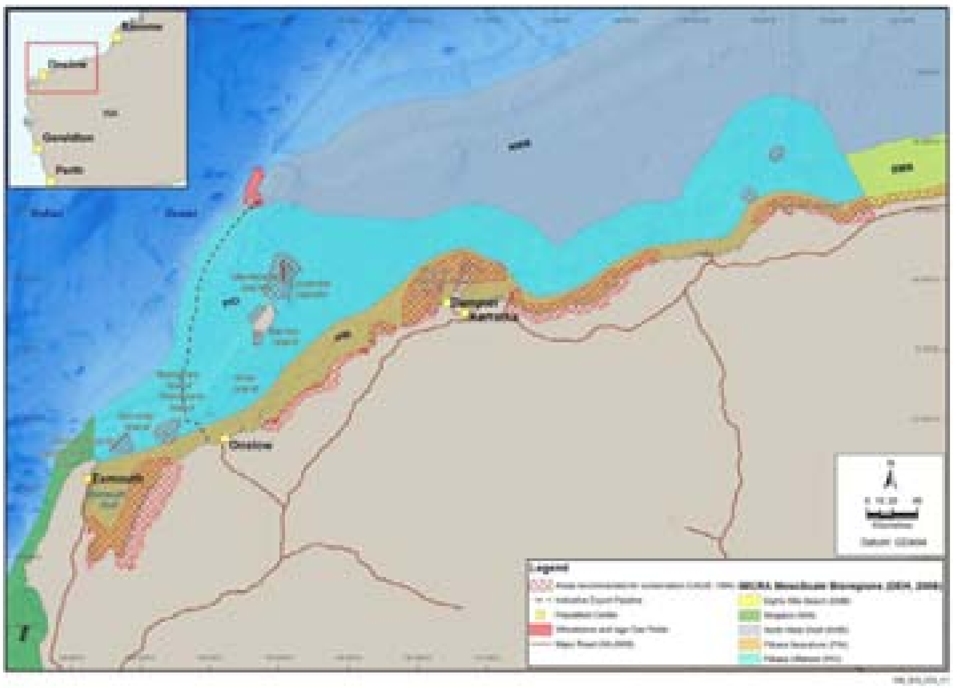

Figure 4-1 The Pilbara coast between North West Cape and Cape Keraudren depicting areas recommended for reservation (CALM 1994) overlain on the IMCRA bioregions – Pilbara nearshore (PIN) and Pilbara offshore (PIO)

4.2 North West Shelf Province - IMCRA

In 1998, an interim ecosystem-based classification for marine and coastal environments was released by the Commonwealth Department of Environment (DEC) known as the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 1998). In coastal areas it is based on a benthic bioregionalisation, based on the biogeography of fish. An amended version was released in 2006 (IMCRA 2006). IMCRA establishes a spatial framework for classifying Australia's marine environment into bioregions that make sense ecologically and are at a scale useful for regional planning. Its purpose is to provide a spatially hierarchical framework for regional levels of planning and management. It is based on the CSIRO Hierarchical Habitat Classification framework which starts at a large regional scale (provinces) reflecting paleo-historic evolutionary processes and gradually devolves into smaller units (meso-scale bioregions).

The Pilbara coast is contained within the largest IMCRA unit, a province, which in this case is the North West Shelf Province. The Pilbara coast is subdivided into two smaller meso-scale units. The scale and boundary of these two systems is shown above on Figure 4-1 and described as follows:

4.2.1 Pilbara nearshore (PIN)

The Pilbara nearshore is located nearshore (HAT to 10 m depth) from Cape Keraurdren to North West Cape. It supports a high diversity of infauna from intertidal mudflats and sandflats associated with fringing mangals in bays and lagoons. Highly turbid water is associated with large tidal range. Fringing coral reefs are found around some of the islands.

4.2.2 Pilbara offshore (PIO)

The Pilbara offshore is located seaward of the 10 m isobath to 200 m isobath between North West Cape and the Monte Bello Islands where the ocean water is less turbid than that of the inshore area and there are significant differences in marine ecosystems. It includes many coral reef ecosystems.

4.3 Ecosystem characterisation of Australia's North West Shelf

The CSIRO hierarchical habitat classification scheme has been recently expanded to delineate even smaller units for the Pilbara region by Lyne et al. (2006). This work was conducted as part of the NWSJEMS undertaken by CSIRO and DEC, and resulted in the production of a technical report (No: 12) entitled "Ecosystem Characterization of Australia's North West Shelf". The study extended the IMCRA ecosystem mapping to a further two hierarchical levels, referred to as Level 2 – Biomes and Level 3 – Biogeomorphic Units. It also provided an example for extending the classification to a fourth hierarchical level based on identification of localised biotopes. This approach has been used in this report to develop scientifically justifiable LAU boundaries.

The Level 2 and Level 3 units that apply to the Project area are as follows.

4.3.1 Level 2 biomes

Level 2 Biomes represent habitat structures responding to the largest environmental gradient, in this case bathymetry. The Level 2 biomic structure of the region contains three sub-units:

1. Level 2A units consist of demersal shelf and coastal zone.
2. Level 2B units identified (refer Figure 4-2) are:

4 Ecosystem Characterisation

- Coastal biome (HAT to 20 m CD); which can be further divided into two categories:
  - the estuaries, lagoons and embayments (HAT to 10 m CD) corresponding to the PIN unit above
  - the subtidal nearshore biome (10 to 20 m CD);
- Inner shelf biome (20 to 70 m CD);
- Mid shelf biome (70 to 120 m CD); and
- Outer shelf biome (120 to 200 m CD).

3. Level 2C units along the coast consist of broad alongshore categorisation based on distinct basement structural features and their corresponding collection of biological attributes.

The proposed Project is therefore located in the North West Shelf Province and occurs across all four Level 2B biomes units as shown in Figure 4-2.

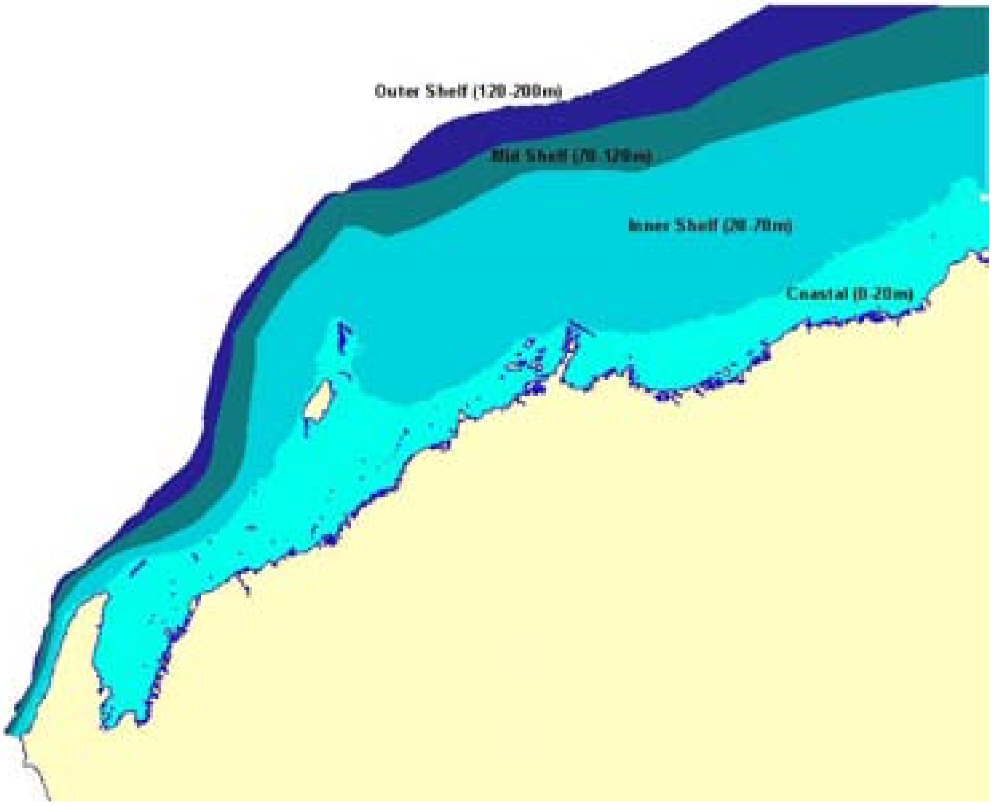

Figure 4-2 The Pilbara coast between North West Cape and Cape Keraudren showing the scale and location of the four Level 2B biome units identified on the North West Shelf Province (Lyne et al. 2006)

4.3.2 Level 3 biogeomorphic units

These are major structural sub-components of Level 2 biomes. They are based on biogeomorphic and landform characteristics, largely on the approach pioneered by Semeniuk (1986, 1993) and CALM (1994). Conceptually, biogeomorphic units are divided into three sub-units, A, B and C but these subdivisions are poorly defined in the offshore areas because of limited data on seabed features. Biogeomorphic units do not differentiate facies and so are independent of substrate type.

Figure 4-3 presents the level 3A coastal (0-20 m CD) biogeomorphic units mapped for the Pilbara coast by Lyne et al. (2006). The unmapped area seaward to the blue boundary line contains the inner, middle and outer shelf biome units described in the Level 2B classification above.

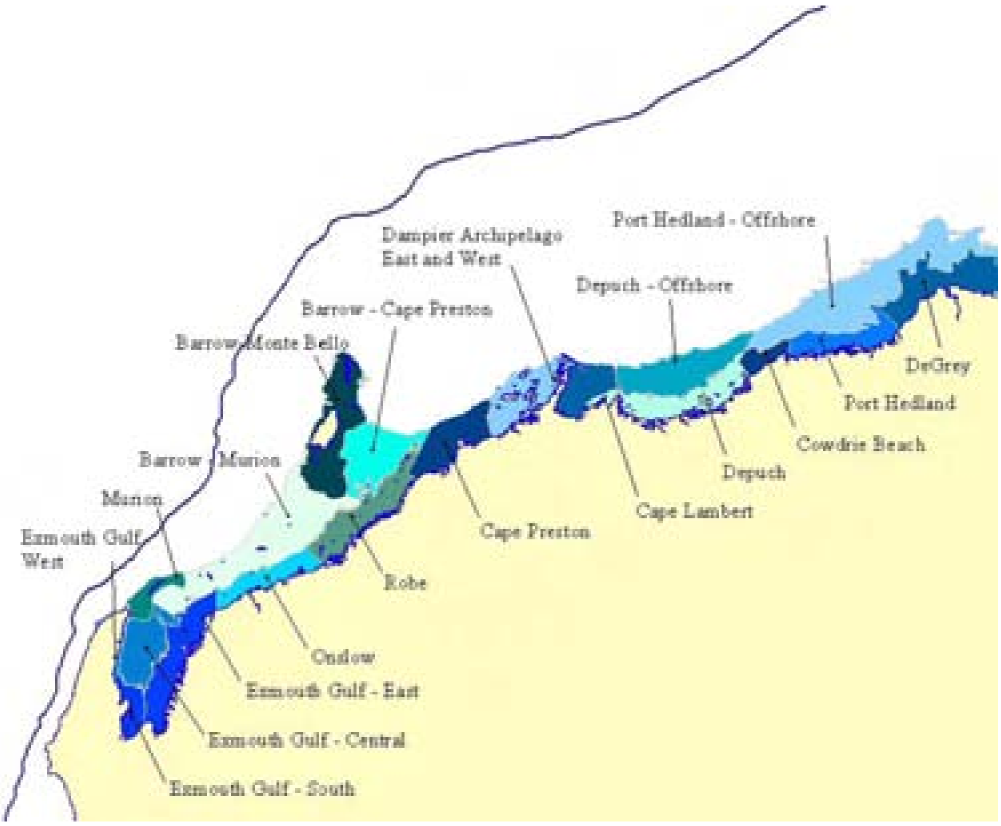

Figure 4-3 Coastal biogeomorphic units at Level 3A for the Pilbara coast

The proposed Project is contained within the following three corresponding Level 2B and Level 3A biogeomorphic units (from offshore to coast):

- **Level 2B Shelf Biome Unit** (20- 200 m CD). The offshore platforms and most of the trunkline will be installed in this unit and the offshore dredge material placement sites may occur within this unit.

- **Barrow – Murion Biogeomorphic Unit.** The unit is described as the waters between the Barrow Island shoals and Murion Islands/Exmouth Gulf that are bounded by the 20 m contour offshore and the 10 m contour nearshore, and which represent a transition zone between coastal and marine waters. Major islands within this unit include Serrurier, Bessieres, Thevenard and Airlie Islands. Dredging will extend into the southern part of this unit below Thevenard Island. Nearshore dredge material placement sites may occur also within this unit to the east of Thevenard Island.
- **Onslow Biogeomorphic Unit** This unit is described as the waters between the 10 m isobath and the sandy coastline between Tubridgi Point and Coolgra Point. It contains an active delta, beaches and distinct mangroves, an exposed coast subject to occasional terrestrial outflows, and numerous small low limestone islands supporting corals. This is the unit in which most of the Project construction work, including dredging and the onshore dredge material placement area, will occur.

4.4 Project area Level 4 biotopes

These units reflect more specific habitat types which occur within each of the above Level 3 biogeomorphic units and generally defines the level at which habitat mapping occurs to describe the distribution of habitats/biotopes. The biotope consists of a physical habitat with its biological community; i.e. it is a term which refers to the combination of the physical environment (habitat) and its distinctive assemblage of conspicuous species. So, a biotope combines the concepts of habitat and community for defining geographical units. Habitat mapping combines habitat information from sample data (e.g. ROV point surveys) with full coverage of physical proxy habitat factors (e.g. substratum type and bathymetry) that are known to discriminate between habitats. Biotopes identified within the biogeomorphic units of this Project area are listed below.

4.4.1 Onslow biogeomorphic unit

The Onslow biogeomorphic unit is subdivided into an intertidal (HAT to LAT) and a subtidal component containing a range of local-scale biotopes comprised as follows:

Intertidal biotopes (HAT to LAT)

- Sandy beaches;
- Sand bars and shoals at the mouth of tidal creeks;
- Mangroves;
- Bioturbated high tidal mud flats with samphire communities;
- Cyanobacteria algal mats;
- Supratidal salt flats;
- Nearshore limestone platforms at Coolgra Point and Beadon Point; and
- Offshore intertidal limestone platforms around the smaller islands.

Subtidal biotopes (0-10 m CD)

- Nearshore soft substrates (silt/sand/gravel beds) supporting low abundance ephemeral seagrasses and algae and burrowing infauna);
- Scattered patch reefs and shoals where limestone pavement is exposed and colonised by algae, corals, sponges and other invertebrates; and

- Emergent reefs and small islands supporting fringing coral bommies (Ward Reef, Ashburton, Tortoise and Direction Islands) and macroalgae.

4.4.2 Barrow – Murion biogeomorphic unit

Subdivided into an intertidal (HAT to LAT) and a subtidal component containing a range of local-scale biotopes as follows:

- Sandy beaches;
- Intertidal limestone platforms;
- Shallow subtidal limestone pavement supporting dense macroalgae;
- Biogenic coral reef fringing islands;
- Coral communities on hard shoals or rock;
- Sponge/ascidian filter feeders on sand veneered pavement; and
- Sand/gravel plains and shoals supporting sparse foliose macroalgae.

4.4.3 Inner shelf biome

This unit comprises the shelf slope between 20-70 m depth (refer Figure 4-2).

ROV Surveys by UWA (2009) indicate that the upper part of this unit (20-40 m CD) is comprised largely of hard pavement or sand veneered pavement which supports a highly variable, filter feeding community of sponges, whips and fans. Below 40 m the substrate is soft and comprised of burrowing infauna, with little epibiota other than a thin red microalgal mat. Hence this unit contains just two biotopes as follows:

- Filter feeders on sand veneered pavement; and
- Sand plain supporting burrowing infauna and microalgal mat.

4.5 Ecosystem units (ECUs)

As stated in the discussion above, the Project is located within three large (mesoscale) ecosystem/biogeomorphic units. The main area of disturbance will be the region immediately surrounding the Ashburton North SIA, trunkline, navigation channel, PLF and dredge material placement areas. Hence any calculation of BPPH loss will need to recognise that these local ecosystem units occur and calculate losses pertinent to each system.

It also needs to be recognised that, for some widespread BPPH, there is a need for large management areas to accommodate both the potential scale of impacts from the Project and the analysis of previous cumulative impacts. Therefore, four major ECUs are proposed (Figure 4-4). They are:

- **ECU0 – Onslow onshore** encompassing intertidal habitats between HAT and LAT.
- **ECU1 – Onslow nearshore** encompassing waters between LAT and up to 10 m depth in relatively complex bathymetry covering mainly soft substrates but including a ridge of scattered patch shoals which support corals and sponges.
- **ECU2 – Onslow offshore** encompassing waters between 10-20 m and including most offshore islands and coral reefs and algal dominated shoals.
- **ECU3 – Onslow inner shelf** incorporating the relatively steep gradient shelf break from 20 m to 70 m.

4 Ecosystem Characterisation

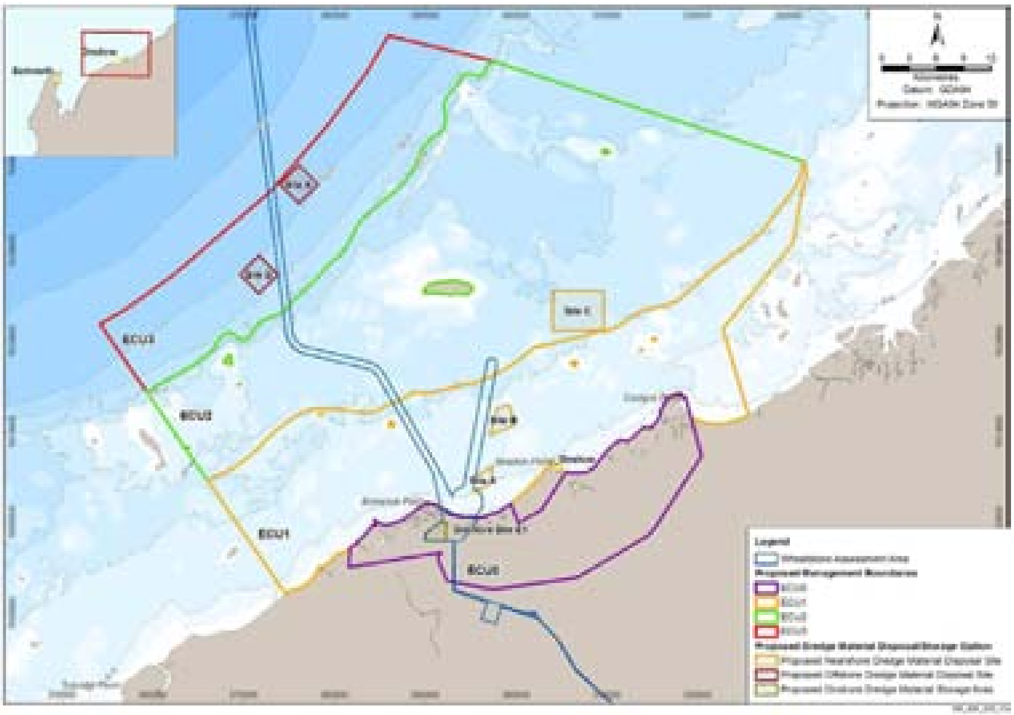

Figure 4-4 Proposed ecosystem units for the Project area

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Proposed Local Assessment Units (LAUs)

5.1 Proposed local assessment units

A range of smaller scale LAUs, based on local scale biotopes and BPPH occur within each ECU. Figure 5-1 presents the distribution and boundaries for proposed LAUs within which to assess the cumulative loss of BPPH arising from both direct and indirect impacts arising from the Project. Table 5-1 presents the area (in ha) of the principal BPPH and BSP that have been estimated to occur (via measurement by ARCVIEW GIS) within each of the designated LAUs.

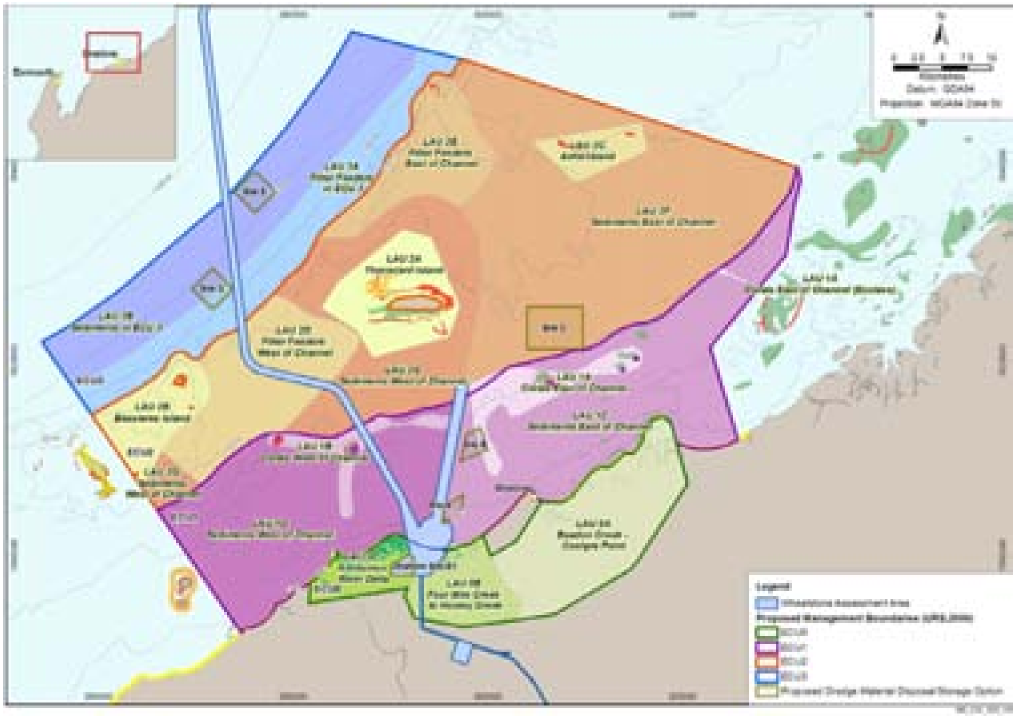

Figure 5-1 Proposed local assessment units for BPPH loss assessment

The proposed LAUs are described below for each of the major Ecosystem Units (ECUs) defined in the previous section.

5.1.1 Onslow onshore (ECU0)

LAU 0A Onslow Salt: The mangroves and associated samphire flats and algal mats which occur between Coolgra Point and Beadon Creek (the intertidal region modified by the Onslow solar salt field).

LAU 0B Hooley Creek: The mangroves and associated samphire flats and algal mats which occur between Four mile Creek and Hooley Creek (the intertidal area immediately to the east of the Project area and containing some of the plant footprint).

LAU 0C Ashburton River: The mangroves and associated samphire flats of the Ashburton River Delta (adjacent the Project area to the west).

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5 Proposed Local Assessment Units (LAUs)

The BPPH loss assessment for the intertidal units (LAU 0A, 0B, and 0C) will address loss of mangroves, samphires and burrowing crabs, and algal mats as three separate subunits.

5.1.2 Onslow nearshore (ECU1)

LAU 1A Corals east of channel: All coral communities occurring within ECU1 to the east of the channel.

LAU 1B Corals west of channel: All coral communities occurring within ECU1 to the west of the channel.

LAU 1C Sediments east of channel: All soft sandy substrates supporting low abundance ephemeral seagrasses and/or ephemeral foliose brown algae which occur east of the channel within the ECU1 boundary.

LAU 1D Sediments west of channel: All soft sandy substrates supporting low abundance ephemeral seagrasses and/or ephemeral foliose brown algae which occur west of the channel within the ECU1 boundary.

The navigation channel has been used as an arbitrary boundary to separate the study area into an east and west component in recognition that seasonal impacts are likely on both sides of the channel and that the LAUs need to be of a manageable size. However this division is purely arbitrary because the units are the same biotope on both sides of the channel.

The revised GS 29 (EPA 2009, p. 4) recognises that ephemeral seagrasses, foliose algae and microphytobenthos (MPB) rapidly recover from disturbance and as such, while the EPA still expects proponents to understand the extent of impacts of their proposals on sandy ephemeral communities, it does not expect impacts to be a significant consideration for most assessments.

5.1.3 Onslow offshore (ECU2)

LAU 2A Thevenard Island: The hard substrate shoals surrounding Thevenard Island and the coral, sponge and macroalgal communities that they support.

LAU 2B Bessieres Island: The hard substrate shoals surrounding Bessieres Island and the coral, sponge and macroalgal communities that they support.

LAU 2C Airlie Island: The hard substrate shoals surrounding Airlie Island and the coral, sponge and macroalgal communities that they support.

LAU 2D Filter feeders west of channel: The sand veneered limestone pavement that supports sponge/ascidian filter feeders and occurs to the west of Thevenard Island.

LAU 2E Filter feeders east of channel: The sand veneered limestone pavement that supports sponge/ascidian filter feeders and occurs to the east of the navigation channel in the vicinity of the Rosily shoals.

LAU 2F Sediments east of channel: All sand/gravel substrates supporting low abundance ephemeral seagrasses and/or ephemeral foliose brown algae which occur east of the channel within the ECU2 boundary.

LAU 2G Sediments west of channel: All sand/gravel substrates supporting low abundance ephemeral seagrasses and/or ephemeral foliose brown algae which occur west of the channel within the ECU2 boundary.

5.1.4 Inner shelf (ECU3)

LAU 3A Filter feeders in ECU3: The variable filter feeding communities (sponge, whips, hydroids and fans) that inhabit the pavement and sand veneered pavement which occur between 20 and 40 m CD.

LAU 3B Sediments in ECU3: The soft substrates that occur below 40 m CD and support burrowing infauna and a red microalgal mat.

5.2 Area of BPPH within each Local Assessment Unit

Table 5-1 presents the area (in ha) of each BPPH and BSPH calculated to occur within each of the designated LAUs using the “calculate geometry” function of ARC GIS.9.3 software. It also presents the EPA CLG category that is believed to apply to each LAU. The mapping used to calculate the BPPH unit areas in ECU0 (Onslow onshore) is presented in Appendix N of the ERMP (Intertidal habitats of the Onslow Coastline) and is based on detailed interpretation of high quality aerial photographs. The mapping used to calculate the remaining BPPH units in Appendix N of the ERMP (Survey of Subtidal Habitats off Onslow, Western Australia). Two units (corals at Bessieres Island and corals at Airlie Island) were estimated for the available DEC/CSIRO (DEC 2006) base map because these areas were not intensively surveyed by URS. The DEC/CSIRO base map is the coral layer beneath Figure 5-1.

5 Proposed Local Assessment Units (LAUs)

Table 5-1 Area (ha) of principal BPPH/BSPH found within designated LAUs for the nearshore Project area and applicable EPA CLG category

No.	Local Assessment Unit Code	BPPH/BSPH type	Area (ha)	EPA CLG Category
1	LAU 0A Beadon Ck-Coolgra Pt	Mangrove	837	C
2		Samphire/burrowing crab mudflat	1,120	C
3		Algal mats	817	C
4	LAU 0B Four Mile – Hooley Ck	Mangrove	83	E
5		Samphire/burrowing crab mudflat	637	E
6		Algal mats	815	F
7	LAU 0C Ashburton River Delta	Mangrove	527	A
8		Samphire/burrowing crab mudflat	683	A
9		Algal mats	Not Present	
10	LAU 1A Corals east of channel	Coral communities on rock	444	E
11	LAU 1B Corals west of channel	Coral communities on rock	224	E
12	LAU 1C Sediments east of channel	Ephemeral seagrass and algae	43,973	E
13	LAU 1DSediments west of channel	Ephemeral seagrass and algae	39,056	E
14	LAU 2A Thevenard Island	Coral reef	196	E
15		Macroalgal communities	10,694	E
16	LAU 2B Bessieres Island	Coral on rocky substrate (est)*	9	D
17		Macroalgal communities	7,770	D
18	LAU 2C Airlie island	Coral on rocky substrate (est)*	39	E
19		Macroalgal communities	4,039	E
20	LAU 2D Filter feeders west of channel	Sponge/ascidian filter feeders	18,472	E
21	LAU 2E Filter feeders east of channel	Sponge/ascidian filter feeders	12,124	E
22	LAU 2F Sediments east of channel	Ephemeral seagrass and algae	62,757	E
23	LAU 2G Sediments west of channel	Ephemeral seagrass and algae	23,852	E
24	LAU 3A Filter feeders in ECU3	Sponge/ascidian filter feeders	19,920	D
25	LAU 3B Sediments in ECU3	Sediments & burrowing infauna	29,143	D

(est)* = estimated for the DEC/CSIRO Database

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between September 2009 and March 2010, and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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Appendix A Prof Charles Sheppard Review

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Chief Editor: *Marine Pollution Bulletin*

A.1 Final comments: Revised LAUs

Received 03 May 2010

1. The Loss Assessment Units proposed here are both logical and appropriate. In the first instance, three large major divisions run parallel to the shoreline, which approximates the bathymetric distribution of habitats. Most of these are larger than the target recommended but in this case, given the topography and biological structure of this area, they are appropriate. Within each, several sub units are identified. Between them all they cover a range of important habitats.

2. It is important to note that earlier comments made about the importance of deeper, non-photosynthetic benthic life on the rock have been carefully addressed, so that the units now identified include not only areas of important primary production but also areas of benthic, filter feeding animal life (secondary production). The latter can be equally important both in terms of ecological connectivity and in terms of providing food for pelagic, demersal and even for commercially important species. This important, usually deeper habitat now appears to be catered for satisfactorily.

3. The arguments made for defining what in some cases are very large units are biologically sound. They are a useful scheme for framing ways for estimating and for reducing damage to this very large development area. The GIS mapping software used also, of course, will facilitate area estimations.

4. It is recognized that some of the important habitats overlap, and this also is accounted for in this revised document.

5. The issue of biological connectivity is currently viewed as being an important concept along the North West Australian region, and one which is also being addressed in connection with other developments in northwest Western Australia. Connectivity is the key to many processes involving dispersion of marine life and, in this context, may be very important in terms of natural regeneration of areas which are disturbed during construction. With reference to this, the several LAUs in the three main sublittoral units appear to be well spaced so that individual assessments of each, when assessed separately, will aid in understanding of whether or not any impedance to species dispersion becomes a potential issue. For example, zone 2 would not be treated as one major unit but will be viewed more in terms of the several subunits contained within it. This will aid biological understanding with respect to possible barriers to species dispersal at the scale involved during construction.

6. In conclusion, the monitoring units are appropriately sized for this particular sublittoral region. They encompass the relevant biological habitats including benthic non-photosynthetic habitats, and are

Appendix A

spaced in such a way that maximum information can be obtained on consequences during the course of the development.

A.2 Interim Comments: Summary of comments made on BPPH and Management Units

Received: 14 Sept 2009.

EPA statement 29

EPA guidance note 29 was revised in mid-year, which cleared up some important issues. Even so, it appears to contain two points in particular, applicable to a project such as this, which, if followed rigorously, could miss important issues: firstly the reversibility assumptions of habitat damage, and secondly the fact that emphasis is made on photosynthetic units, almost to the exclusion of highly diverse habitats such as secondary production habitats.

- EPA sensibly say that damaged habitats should be accorded similar value to undamaged ones. This has excellent intent, and caters for the possibility that damage can be reversed. But for reefs, almost all empirical evidence shows that reversibly does not take place, at least in human lifetimes, once they become damaged beyond fairly modest thresholds. Change on reefs is analogous to that of a clockwork ratchet - rotation is not freely reversible as in a wheel, but is more like a ratchet which permits one-way movement only. (This principle applies much less to seagrasses and mangroves.)
- The focus on primary production is not always applicable. Soft coral reefs and sponge dominated reefs are only moderately primarily productive, and reefs deeper than the photic zone may have no primary productivity whatsoever, yet all are highly biodiverse. Note that "biodiversity" is the focus of most of the world's environmental law, more so than the EPA's primary productivity focus. I sensed in the mid-year revision that some adjustment in emphasis was made, but high biodiversity should receive equal attention to primary production. Secondary productivity on soft substrates is key to many fisheries, for example. High diversity deep habitats, which apparently certainly exist in some abundance in Western Australia, should be considered to be as important as BPPH in mitigation measures (because they are as important biologically).

In the present proposal, dredging is overwhelmingly likely to cause the most damage on sublittoral habitats, whether BPPH, high diversity, or both. The sedimentation released, not the physical excavation itself, is what may cause the most problem - it may be the cause of most of the 'collateral damage'. The solution to this is to eliminate as much as possible any sediment plumes from dredging.

- One crucial damage avoidance method will be to avoid any temporary relocations of sediment to and from temporary dumping grounds, which are then removed for a second time. Avoidance of this in principle will result in substantially less sediment than if each volume is moved twice.
- Disposal of material onto land is not considered here. Disposal of the large planned volume into deep water must be conducted only into areas where survey has shown them to contain no high diversity reefs such as sponge reefs, (even though these have no primary productivity). Furthermore disposal should not be made at the surface but via pipes which descend much closer to the soft seabed. In this way, disposal can be done close to the seabed in areas where there are known to be no reefs, thus avoiding environmental damage.

Appendix A

The management units

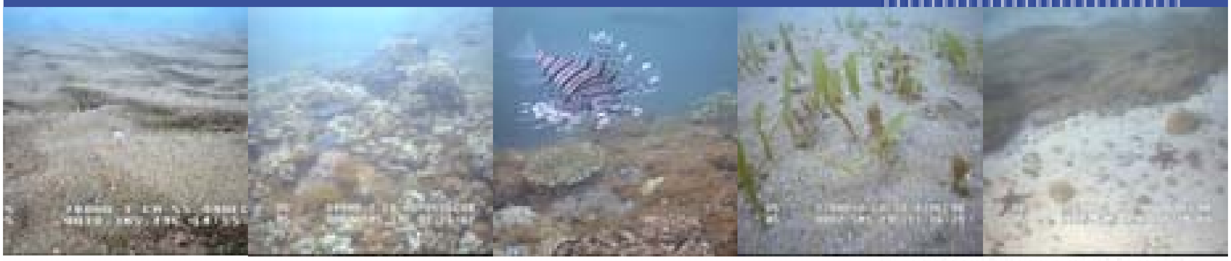
A guideline management unit size of 50 km² is proposed by EPA but the justification for this size is difficult in the present case which covers very large areas. The mid-year revision of EPA document 29 contains an example of three MUs either side of an area of work, which is justified well. The present project proposes three main, large MUs also, but arranged approximately parallel to the shore. This is equally valid for the reasons stated in that proposal. (It also proposes several smaller, important units which embrace nearshore habitats such as mangroves.) Overall the three main units proposed in this project are biologically sensible.

- Accepting for convenience (for 'accountancy' purposes) the percentage impact or threshold concept, an important condition is to be able to actually compute, within the defined area, the percentage of any unit which may be impacted. This requires unrealistically detailed survey in conditions where several hundred square kilometres contain dozens of small patch reefs (which existing information suggests is the case here).
- A problem with the management unit approach occurs when there are, for example, many small patch reefs spread across a large, soft substrate plain, which appears to be the case for one of these main units. The obliteration of all those reefs might still fall under an EPA 5% limit for the whole MU, for example, yet might permit obliteration of the > 5% of it which is reefs, which would be counter to EPA's intent. On the other hand, it would be absurd, indeed impossible, to have each of the numerous patch reefs described as one unit each. This proposed MU is a mosaic, and because it cannot ecologically be described as being "coral reef BPPH" there is no simple solution.
- One complication might be that the difference between cumulative loss of 4.9 and 5.1% is biologically meaningless but possibly legally meaningful. The need by the contractor to arrive at a figure below the magic threshold could generate more work than useful biological work. While I am sure everybody understands this, it is again not clear what can be done about it.
- An additional complication where this situation exists is that blanketing of even all of the seabed by fines settling out from dredging, might cause effectively permanent destruction of its small proportion of reefs but only temporary damage to the soft substrate habitats between them.
- Assuming a simple case whereby damage is greatest next to the excavation and reduces progressively from the worked area, the larger the MU, the lower will be the overall percentage area damaged. Presumably, this is one reason why the guideline of 50 km^2 was arrived at. However, in the present case, the large areas are well justified because they encompass the gross area covered by the project as a whole. Given that adoption of very many small MUs (in this case each of the scattered patch reefs, for example) is an impossible or impracticable approach, the case made for the three large ones made here is sensible. It is difficult to think of other workable and meaningful schemes, other than the one given as an example in the July revision of EPA 29; the latter is equally justifiable but, if adopted in the present case, would struggle with exactly the same issue.

Summary

The July 2009 revision of EPA guidance note 29 shows some welcome differences in both a biological sense and in the practical sense of the contractor being able to follow the guidelines. The guidelines need to be assessed in a biologically meaningful way, with emphasis placed primarily on reducing damage to biologically important systems. High diversity <u>secondary</u> production areas should be accorded as great an emphasis as, for example, a low diversity <u>primary</u> producing area.

- I believe the management units proposed are a useful scheme of framing ways to reduce damage to each part of this very large area. The small MUs along the shore and shallow water are also sound. In the deepest, large unit, one very important issue is to ensure that disposal of dredged material does not smother or lie close to areas of hard substrate with high diversity.
- It should be recognized that damage to reefs, whether photosynthetic in shallow water or non-photosynthetic in deep water, will be essentially permanent in any reasonable time frame. In contrast, recovery of seagrass beds or algae beds for example, can indeed be treated as being recoverable.
- The scheme proposed here of three principal units lying roughly parallel to the shoreline, is valid, and will be convenient and suitable for the present task. Each of the three could be further subdivided but, from information available, no greater improvements would likely result. Important coastal habitats are already separated into sub units.
- It will be recognized that the area affected by dredging fall-out could be 10 to 100 times greater than the area actually excavated or used as a dump site. In both cases this is caused by suspended and dispersing fine particles. Loss of light caused by sediment plumes are short lived and usually survivable; smothering from settling out sediment is commonly not. However, moderate sedimentation on existing muddy habitats is like to be trivial in its effects (natural sedimentation is high anyway in this area).
- If planning of the route dredged and of the sites of material disposal avoids all areas of greatest importance as best possible (following the ongoing and detailed survey work) then the MUs proposed will be suitable. It is assumed that both can be adapted, if necessary, following the full benthic survey results.



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Appendix N6

Wheatstone Project 20-70m Contour Habitat Survey Field Report

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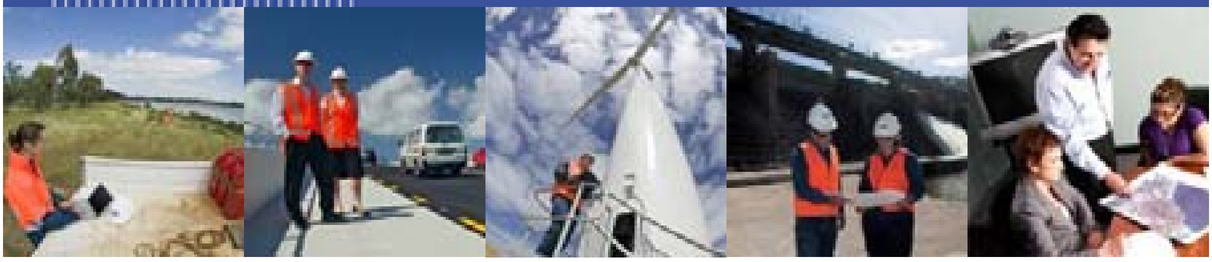

Report

Project Wheatstone: 20-70 m Contour Habitat Survey Field Report

4 MAY 2010

Prepared for

Chevron Australia Pty Ltd

250 St Georges Terrace
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42907466

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1 Introduction

To support the environmental approvals for the Wheatstone project, on behalf of Chevron Australia Pty Ltd , URS is undertaking investigations of the benthic communities offshore from Onslow in the north west of WA. To aid the mapping of benthic habitats located in and adjacent to the proposed development area, URS Australia Pty Ltd (URS) and the Centre for Marine Futures (CMF) at The University of Western Australia (UWA) undertook a combined tow video and drop camera survey along five transects between the 20-70 m contours during 26-31 August 2009. It has been suggested that filter feeder habitats located within this depth range may be important for foraging turtles.

1.1 Objectives

- To collect video footage of benthic assemblages along five transects between the depths 20-70 m in a region off Onslow, Western Australia. Approximately 45 linear kilometres of video footage was collected from an area of approximately 360 km^2 using a towed camera system developed by CMF.
- To remotely collect still images of benthic communities of interest (high coverage and complexity) along the above towed video transects using a drop camera system developed by CMF. Images were also collected from along a proposed pipeline route. Collected images provided a baseline for these communities.
- To analyse collected video footage, providing a description of benthic assemblages along these transects in this region.
- To analyse collected images, providing estimates of the percent cover of different benthic groups in these areas, as a benchmark for future potential impact studies and as a quantitative measure of benthic communities.

2 Methodology

2.1 Broad-scale classification of benthic habitats

The towed video system was towed over the sea-bed at speeds between one and three knots. The towed video system had a forward facing camera that was used for the broad scale classification of benthic assemblages. Precise geographic positioning of the footage was provided using the software package StarFix coupled with an Ultra-Short Base-Line (USBL) positioning system.

Towed video footage was analysed according to substrate and biotic composition of benthic assemblages.

2.2 Fine-scale quantification of benthic habitats

Following the broad-scale classification of benthic habitats, patches of epibenthic coverage of above average density and/or diversity that may be important as turtle foraging areas were surveyed using a drop camera system. This system was used to provide percent cover estimates of different benthic groups.

The drop photo system consisted of two remotely triggered cameras mounted on a steel frame. The first camera was situated at an angle and provided a video feed to the winch operator aboard the boat, allowing the camera frame to be positioned upright on the substrate. The second camera was positioned over a fixed quadrat and captured a high resolution image of the sea floor. When capturing images, the boat was positioned over a site and the drop photo system lowered using a winch. As the boat drifted over the site, the drop photo system was raised, then lowered. Each time the frame was lowered to the bottom, an image of the seafloor was captured, providing a series of benthic images for each site. The geographic position of each captured image was determined using a differential Geographic Positioning System (GPS) coupled with an USBL positioning system. Drop photo images were analysed using point intercept methodology whereby 50 points were randomly overlaid on each image with the taxa occurring at each point classified, providing a quantitative measure of benthic assemblages at each site.

Sites were selected according to the following criteria and in consultation with Tye Pope from URS:

- Sites with high complexity, density and diversity of epibenthic coverage were selected as these were thought to be important turtle foraging areas.
- Sites that covered a range of biotic habitats (e.g. sites dominated by sponges vs. sites dominated by primary producers) were selected.
- Where possible, sites were chosen that were spatially distributed across the study area to be representative of the five transects.
- Sites were at least 100 m apart.

3 Survey Activities

3.1 Tuesday 25 August

URS and UWA personnel caught the 07:50 Qantas flight from Perth to Karratha, took separate taxis to Mermaid Marine Supply Base. Mike Dean and the Chevron IIF Facilitator also took the same flight.

Boarded the *MV Calypso Star* (Calypso) at 10:20. Vessel Induction conducted by Ian Kuhnell (Skipper) from 10:30 to 11:30 for all URS, UWA and Chevron personnel.

Broadsword marine crew undertook IIF induction from 11:45 to 14:45.

Pre-mobilisation induction conducted by Zoe Heath from 14:15 to 16:00 with all personnel involved.

Mike Dean from Chevron conducted the final vessel audit close-out with Ian Kuhnell and Carey Wood. All actions were closed out.

UWA personnel set up their systems when not participating in inductions.

Plan to steam from Dampier to offshore Onslow from 18:30 to approximately 09:30 (15 hours as a worst case scenario) with a head wind.

At 19:30 on 25 Aug, all personnel were involved in a fire drill and evacuation drill. The Man Overboard Procedure was also discussed again with all personnel present.

3.2 Wednesday 26 August

All UWA survey equipment was set-up from 07:00 to 09:30

Toolbox held at 09:30 to 10:30 with all personnel involved. UWA Party Chief explained the tow camera system and deployment, survey and retrieval method. The potential hazards and associated controls of the survey were discussed again.

UWA tracking system was calibrated from 10:30 to 12:15

Final setup for attempt one was complete by 13:30. Camera was deployed at transect C-CC (approximately 12.0 km west of Thevenard Island) but a stop work was issued by Kris Waddington from UWA before the camera reached the water as the cable was catching under itself on the drum of the winch. This was deemed unsafe as it put extra tension on the cable and would prevent paying out in the event of a substrate hookup. A capstan winch was suggested and a Job Hazard Analysis (JHA) was conducted for this deployment/retrieval method from 14:00 to 14:15. It was deemed that the two hazards identified with the previous winch were eliminated through the new method.

The camera was deployed using the new configuration at 15:00. Approximately 12.0 km of the 16.0 km transect was surveyed (from 13-50 m depth). The camera was retrieved at 17:30 due to poor light at survey depth.

3.3 Thursday 27 August

Toolbox held from 07:00 to 07:15 with all personnel involved. The following was discussed:

- Discussion to determine if any new potential hazards, that have not been previously identified and assessed, had arisen from the previous days work. None were found but effective communications were reiterated and the back-deck viewing screen was replaced to assist in this area
- Manual handling
- 4sight cards from previous day
- Tow speed and engine utilisation to determine most efficient and effective data collection methodology.

Chevron operations at Thevenard Island were called and a message was left detailing the survey plan/location for the day and the Calypso's contact details.

Set-up for the day occurred from 07:15 to 09:00 which included rigging up the viewing screen on the back deck to improve communications to the winch driver and cable operators.

Onsite at 09:00 approximately 10.0 km along Transect C-CC (17.0 km NW of Thevenard Island)

Tow camera deployment 1: 09:00 to 10:15, this tow camera run overlapped with approximately 1.3 km of Transect C-CC (from 45-63 m depth) from yesterday to ensure a proper link was established. 3.8 km of video data was collected during this deployment (a total of 14.2 km for the C-CC transect) prior to a transmittal problem forcing retrieval of the camera to the surface for testing. The beacon was found to be working and a software malfunction was the problem. The software was re-installed which mitigated the problem.

Tow camera deployment 2: 11:00 to 12:30, the camera overlapped the previous run on Transect C-CC by approximately 0.5 km and was towed 3.0 km through to the end of the transect. The total length of the C-CC transect was 16.7 km.

12:30 to 13:00, the vessel steamed to Transect A-AA which extended 8.9 km north from the lee of Serrurier Island (the western most transect), approximately 28 km SW of Transect C-CC.

Tow camera deployment 3: 14:15 to 17:20, Transect A-AA was surveyed with the tow camera. Depth range was 15-70 m and the full distance (8.9 km) was captured in the single deployment.

3.4 Friday 28 August

Toolbox held from 06:30 to 06:45 with all personnel present. The following was discussed:

- If any new potential hazards, that had not been previously identified and assessed, had arisen from the previous days work or may potentially arise during the drop camera operations. None were identified but manual handling technique, man overboard procedure and effective communications were reiterated

- 4sight cards from previous day
- It was suggested that the top row of safety chains be removed to make lifting the drop camera frame over them easier, this was dismissed as the increase in man overboard risk would be unacceptable. It was noted that the winch actually lifts the frame and the deploying person only has to guide the frame and does not bear the full weight.

Chevron operations at Thevenard Island were called at 06:45 and a message was left detailing the survey plan/location for the day and the Calypso's contact details.

Skipper Ian Kuhnell initiated radio contact with MV Lobo at 07:20 to inform them of the proposed location and schedule of the Calypso for the day. No sim-ops issues were identified. Scheduled radio contact between the Calypso and Lobo will be undertaken daily at 08:00.

Onsite at 07:00 at the shallow end of C-CC transect (approximately 12 km W of Thevenard Island). 20 sites were sampled with the drop camera which consisted of 10 replicates (photos) per site. Areas of high and representative substrate and epibenthic cover were identified during the tow camera work which dictated the location of the drop camera sites. Drop camera work for this transect was completed at 12:15.

12:15 to 13:30, the vessel steamed to Transect E-EE starting on the lee of the NE tip of the Rosily Shoals.

Tow camera deployment 1: 13:30 to 15:40, the full 6.0 km of Transect E-EE, which had a depth range of 15-70 m, was surveyed during this deployment.

15:40 to 16:10, the vessel steamed SSW to the shallow end of Transect D DD to initiate tow camera work.

Tow camera deployment 2: 16:15 to 17:30, 5.5 km of the 11.0 km transect was surveyed until poor light warranted retrieval. The depth range was 15 to 38 m.

End of survey activities for Day 3 of the 20-70 m Contour Habitat Survey. 17:50 to 19:10, steamed to shallow end of transect B-BB to anchor for the night (approximately 1.0 km north of Bessieres Island).

3.5 Saturday 29 August

Toolbox held from 06:30 to 06:45 with all personnel present. The following was discussed:

- Proposed schedule for the day
- If any new potential hazards, that had not been previously identified and assessed, had arisen from the previous days work. One was identified and was subject to a JHA
- 4sight cards from previous day
- Weather forecast and the stop work authority was reiterated.

Chevron operations at Thevenard Island were called at 06:45 and a message was left detailing the survey plan/location for the day and the Calypso's contact details.

Skipper Ian Kuhnell attempted radio contact with MV Lobo at 06:25 but there was no response. The Lobo was known to be docked at Onslow.

Onsite at 07:00 at the shallow end of Transect B-BB, starting approximately 1.0 km N of Bessieres Island. 07:15 to 10:40, the full length of the transect (9.6 km) was surveyed with the tow camera, depth range was 15 to 20 m

10:40 to 12:05, the vessel steamed to Transect D-DD to complete tow camera work for the deeper half. 12:05 to 14:45, latter half of the transect was surveyed to a total length of 11.0 km.

Selected drop camera sites along Transect D-DD were then sampled from 15:10 to 17:05 as winds had calmed enough.

End of activities for Day 4 of the 20-70 m Contour Habitat Survey.

17:15 to 18:00, steamed to shallow end of transect E-EE to anchor for the night.

3.6 Sunday 30 August

Toolbox held from 06:30 to 06:45 with all personnel present. The following was discussed:

- Proposed schedule for the day
- If any new potential hazards, that had not been previously identified and assessed, had arisen from the previous days work. Ian Kuhnell (Skipper) mentioned that he had noticed a number of box jellyfish in the water, the need for full Personal Protective Equipment (PPE) was reiterated.
- 4sight cards from previous day
- Fatigue management, the weather overnight was notably rough and not everyone had a comfortable sleep
- Weather forecast and the stop work authority was reiterated, especially given that some people might be feeling fatigued.

Chevron operations at Thevenard Island were called at 07:45 and a message was left detailing the survey plan/location for the day and the Calypso's contact details.

Skipper Ian Kuhnell attempted radio contact with MV Lobo at 09:00 but there was no response. The Lobo was known to be docked at Onslow at present.

Onsite at 07:00 at the shallow end of Transect E-EE (the NE tip of the Rosily Shoals). Eight pre-selected sites were surveyed with the drop camera configuration, each site consisted of 10 replicate photos. Drop camera work at transect complete at 08:35.

08:40 to 09:25, Calypso steamed to Transect D-DD to complete drop camera work for this transect. One site was sampled from 09:30 to 09:40.

09:40 to 12:00, Calypso steamed Transect A-AA to undertake drop camera work commencing at the shallow end of the transect (1 km N of Serrurier Island). 11 pre-selected sites were surveyed with the drop camera configuration and each site consisted of 10 replicate photos. Drop camera work at transect complete at 13:50.

13:55 to 14:20, Calypso steamed Transect B-BB to undertake drop camera work commencing at the deep end of Transect B-BB (10 km N of Bessieres Island). Five pre-selected sites were surveyed with the drop camera configuration, each site consisted of 10 replicate photos. Drop camera work at transect complete at 15:45.

End of survey activities for Day 5 of the 20-70 m Contour Habitat Survey.

16:00 to 17:30, begin to pack drop camera equipment away and steam to anchor point for the night.

3.7 Monday 31 August

Toolbox held from 06:30 to 06:45 with all personnel present. The following was discussed:

- Proposed schedule for the day
- If any new potential hazards, that had not been previously identified and assessed, had arisen from the previous days work or that could potentially pose a risk during today's activities
- 4sight cards from previous day

- Manual handling technique during de-mobilisation

Chevron operations at Thevenard Island were called at 06:40 and a message was left detailing the survey plan/location for the day and the Calypso's contact details.

Skipper Ian Kuhnell attempted radio contact with MV Lobo at 06:20 but there was no response. The Lobo was known to be docked at Onslow at present.

Onsite at 07:00 at the shallow end of Transect C-CC (approximately 12 km W of Thevenard Island) to re-run the tow camera line covered during the first survey day, i.e. 12 km length. This was undertaken due to a tracking system transmission error experienced during that first day. The tow camera was deployed at 07:15 and retrieved at 10:00. End of survey activities for Day 6 of the 20-70 m Contour Habitat Survey.

10:00 to 16:30, pack-up UWA equipment.

11:30, Commence steam to Mermaid Marine Supply Base in Dampier.

3.8 Tuesday 1 September

Docked vessel at Mermaid Marine Supply Base at 07:00.

Toolbox held from 07:00 to 07:15 with all personnel present. The following was discussed:

- Proposed schedule for the day and personnel movements
- If any new potential hazards, that had not been previously identified and assessed, had arisen from the previous days work or that could potentially pose a risk during today's activities
- 4sight cards from previous day
- Manual handling technique during de-mobilisation (loading and unloading)
- Requirement for full PPE if outside when the vessels is alongside the wharf
- UWA crew thanked the BroadSword crew for a job very well done

07:30 to 08:00, Mermaid Marine Stevedores unloaded UWA equipment.

10:15, UWA crew departed in taxi bound for Karratha Airport. Flight departed at 11:30. Safe passage was confirmed via a phone call at 16:30.

4 Preliminary Findings

The following preliminary findings were derived from the viewer's initial observations recorded during the time of the survey and are not derived from any formal or statistical analyses. More definitive conclusions will be defined through statistical analyses and subsequent reporting to be undertaken by UWA.

4.1 Transect A

20-30 m (depth): Medium density algal patches interspersed with patchy sessile invertebrates over low relief pavement.

30-40 m: Patchy sessile invertebrates with some bare sand patches over low relief pavement.

40-50 m: Sand with sparse patches of sponges.

50-70 m: Sand with trace sessile invertebrates.

4.2 Transect B

20-35 m: Low relief platform dominated by sponges and other sessile invertebrates, sparse red algae also present.

35-55 m: Sand with trace sponges, hydroids and crinoids.

55-70 m: Sand with trace sponges and crinoids, a red benthic microalgae mat seen in some areas.

4.3 Transect C

4.3.1 Run 1

20-30 m: Patchy sessile invertebrates over low relief pavement

30-40 m: Sand with trace sessile invertebrates

40-65 m: Sand with very sparse sessile invertebrates

65-70 m: Patchy to medium density sponge garden over low relief pavement (as indicated by the hydro-acoustic data).

4.3.2 Run 2

20-35 m: Low relief platform with medium dense sponges and sea whips, *Caulerpa* beds were observed in the shallower section.

35-40 m: Sand with very sparse crinoids and occasional rocky outcrop with sparse sessile invertebrates.

4.4 Transect D

20-35 m: Predominantly sand with occasional rock platforms dominated by medium dense sponges and sea whips and trace filamentous red algae.

35-65 m: Sand with very sparse sponge gardens.

65-70 m: Sand with trace hydroids and sponges.

4.5 Transect E

20-30 m: Thin sand veneer over low relief pavement with medium density sessile invertebrates and patchy algae.

30-40 m: Sand with trace sessile invertebrates.

40-70 m: Sand with very sparse sessile invertebrates (hydroids, anemones, sea pens and sponges).

4.6 Broadscale Classification

Generally, the highest coverages of epibenthic biota were found at depths between 20-40 m at a medium density over low relief pavement dominated by red algae and sessile invertebrates (such as sponges, sea whips and soft corals) and red algae. Substrates below the 40 m contour were sand dominated with trace to very sparse sessile invertebrates such as crinoids, hydroids, ascidians and sea whips.

Superficially, Transects A and E appeared to host larger areas of low relief pavement and higher densities of epibenthic biota compared to Transects B, C and D.

5 Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 17 August 2009.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 31 August – 11 September 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

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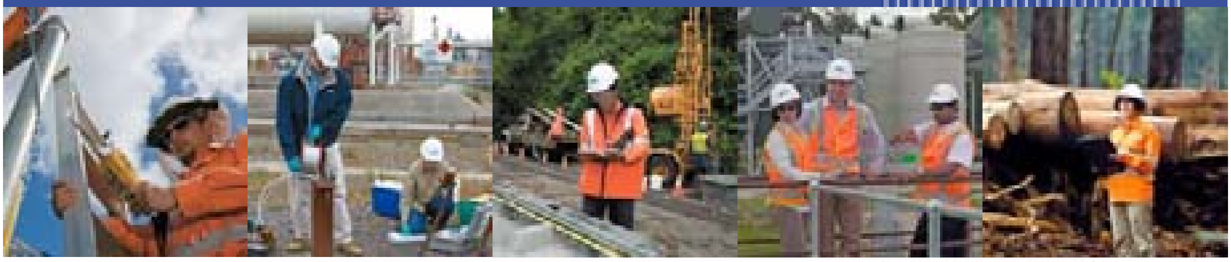

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Appendix N7

Baseline Coral Community Description

Tables

Figures

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MScience

WHEATSTONE LNG DEVELOPMENT

BASELINE CORAL COMMUNITY DESCRIPTION

Report: MSA134R2

Report to:
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Document Information

REPORT NO.	MSA134R2
TITLE	WHEATSTONE LNG DEVELOPMENT : BASELINE CORAL COMMUNITY DESCRIPTION
DATE	22 July 2009
JOB	MSA134
CLIENT	URS Australia
USAGE	This document presents data describing baseline environmental conditions for the Wheatstone LNG Development.
PRECIS	A survey of coral communities identified as significant coral communities for the Wheatstone LNG marine works was conducted in June 2009. This document presents a quantitative assessment of the composition and density of 16 of those communities.
KEYWORDS	Coral, Monitoring, Onslow, dredging

Version-Date	**Released by**	**Purpose**
V.1 22 July 09	JAS	Draft: Client review
V.2 21 Oct 09	JAS	Final
V.3 1 Dec 09	JAS	Include Chevron comments
V.4 2 Mar 10	JAS	Revise site names to align with URS
V.5 10 May 10	JAS	Final

SUMMARY

Chevron Australia Pty Ltd (Chevron) is undertaking an environmental impact assessment of their proposed Wheatstone LNG Development (the Project). The Project involves a substantial marine construction program including approximately 2 years of capital dredging off the Onslow area of Western Australia.

The dredging program and its associated sediment plume contain the potential to impact adversely on benthic communities close to those operations. A preliminary model of sediment suspension and dispersion has been used to develop a working estimate of the area which may be influenced indirectly by dredging. Of the benthic communities identified by field surveys to date within that area, the most sensitive are likely to be coral communities.

The results of broadscale surveys of benthic habitats, including more detailed evaluation using a remotely operated underwater vehicle, were used to allow a subsequent diving survey to establish permanent fixed transects across the most significant coral communities. The corals within these belt transects were then recorded photographically at 16 sites and scored for spatial cover of corals divided into ten morpho-taxonomic groupings.

Analyses presented here provide a quantitative snapshot of the coral communities present within the potential impact area prior to any development works. The overall picture is of a set of healthy coral communities with low levels of current impacts. Coral density varied between 30% and 70% cover, with the higher cover areas dominated by low relief corals such as *Montipora* or tabulate *Acropora*.

There is a general cline in community type from inshore, dominated by species of *Montipora*, to offshore, dominated by *Acropora* species with a zone of mixed community types in between. An inverse relationship between the level of coral cover and the community diversity was evident, with many sites being entirely dominated by cover of plate *Montipora* corals. The high cover – low diversity nature of many sites may be indicative of low levels of environmental disturbance.

1.0 INTRODUCTION

Chevron Australia Pty Ltd (Chevron) is undertaking an environmental impact assessment of their proposed Wheatstone LNG Development (the Project). The Project involves a substantial marine construction program including approximately 2 years of capital dredging off the Onslow area of Western Australia (Figure 1).

Large dredging programs pose a risk to adjacent benthic communities via their physical impacts and the effects of sediment which is suspended in the water column during dredging or disposal operations. Within north-western Australia there has been a focus on the risks of dredging for coral communities (Blakeway 2005; Gilmour, Cooper et al. 2006).

As part of the assessment of the potential for the Project to impact on coral communities and in preparation for establishing a baseline against which to evaluate or manage impacts during dredging, a snapshot of the current status of coral communities is presented here.

URS Australia (URS) has undertaken the fieldwork to locate and survey corals based on methodologies described in Section 2 of this report. The MScience Pty Ltd (MScience) role in this work has been to:

- Provide divers with considerable experience in establishing field monitoring of corals within the Pilbara nearshore to assist in establishing fixed coral transects;
- Score the images resulting from field surveys using techniques established and tested in previous coral survey s for dredging projects;
- Analyse and interpret the data from images and report here to provide a snapshot of the current status of corals in the project area.

At this stage only the coral communities within the potential impact areas (see below) have been surveyed. Later surveys are planned to identify potential comparative sites outside of impact zones within the development of a monitoring program.

1.1 PURPOSE OF THIS REPORT

This report presents a quantitative evaluation of the highest value coral communities throughout the area potentially impacted by dredging or sediment plumes generated by the Wheatstone Project, including:

- Estimates of coral cover and the presence of stress indicators such as coral bleaching; and

- An evaluation of the community diversity and taxonomic structure.

The former provides an indication of the location of the high density (high value) coral communities of the area for future impact assessment as well as one point in a pre-dredging coral health baseline. The latter provides an indicator of whether coral community types are distributed spatially within zones which may structure community composition based on environmental factors and could be used in evaluating the ecological value of different areas of coral and their potential sensitivity to dredging impacts.

In this first assessment, 'high value' coral is equated with high density (benthic cover) as a practical method to focus the detailed surveys on key sites within the broader survey area. It does not imply that there is a necessary correlation between measures of ecological importance (such as biodiversity or rarity) and cover. It recognises that the survey area will have benthic habitats with sparse corals (often at less than 5% cover over large areas) which are unlikely to offer the ecological function of 'coral habitat' due to their low density and other areas which have a 'coral habitat' function. It provides a mechanism to concentrate on the latter.

The report does not provide:

- identification of corals to species level;
- an evaluation of the spatial extent of coral distributions;
- estimates of the abundance of corals outside of areas of high density coral;
- a finalised monitoring design;
- an evaluation of the potential for any impacts of the project on corals;
- an evaluation of the local, regional or national significance of these communities.

1.2 Impact Predictions Used Here

A basis for the spatial distribution of survey sites was developed using a preliminary model of sediment plume dispersion modified by water quality thresholds.

Figures from a preliminary modelling report[1] were examined to approximate sediment distributions in the water column. The figures present a range of increments of suspended sediment concentration (SSC) derived from dredging and spoil disposal and the percentage of time within a 14d period of dredging that this SSC is exceeded for an area.

Based on MScience experience with other projects, zones of impact were established as follows:

- HIGH IMPACT – an area 500m either side of the dredged area;

[1] DHI Water & Environment: *Preliminary Dredge Sediment Plume and Sedimentation Modelling – Worst Case Summer and Winter Scenarios.* Per D.Ogburn email 0920, 27 March 2009.

- MODERATE IMPACT – where SSC from dredging is elevated by >10 mg/L for > 10-15% of the period;
- INFLUENCE – where SSC is elevated by >2mg/L for >20-30% of the period.

Levels of impact implied by these categories are:

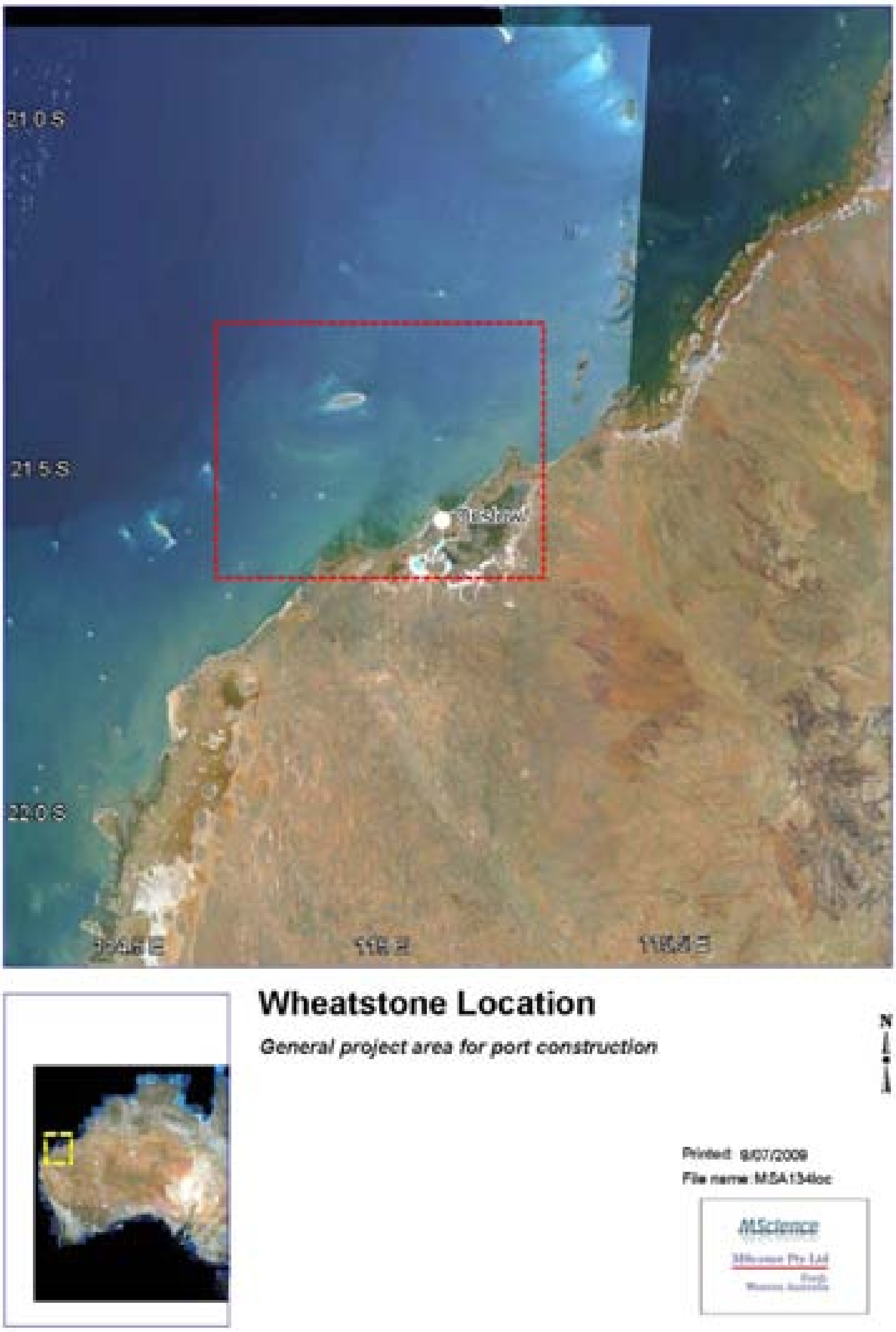
- HIGH IMPACT – majority of coral community lost;
- MODERATE IMPACT – some mortality of the coral community;
- INFLUENCE – physiological change but no mortality.

The current scheme should be viewed as no more than a 'likely guess' at this stage and is not underpinned by any detailed analytical process. As water quality modelling at present is also rudimentary, it would not be appropriate to develop precise and detailed threshold values with which to interrogate it. The criteria have been set to be quite conservative and we do not suggest that this level of water quality experienced over a 14 day period would produce any environmental impacts.

We assume that the 14 day models are indicative of much longer dredging periods. Over those periods, resuspension of deposited sediment might also occur. That has not been factored into these estimates.

Resultant Zones of Impact are shown in Figure 2 along with the sites sampled in this survey.

Figure 1. General project area.



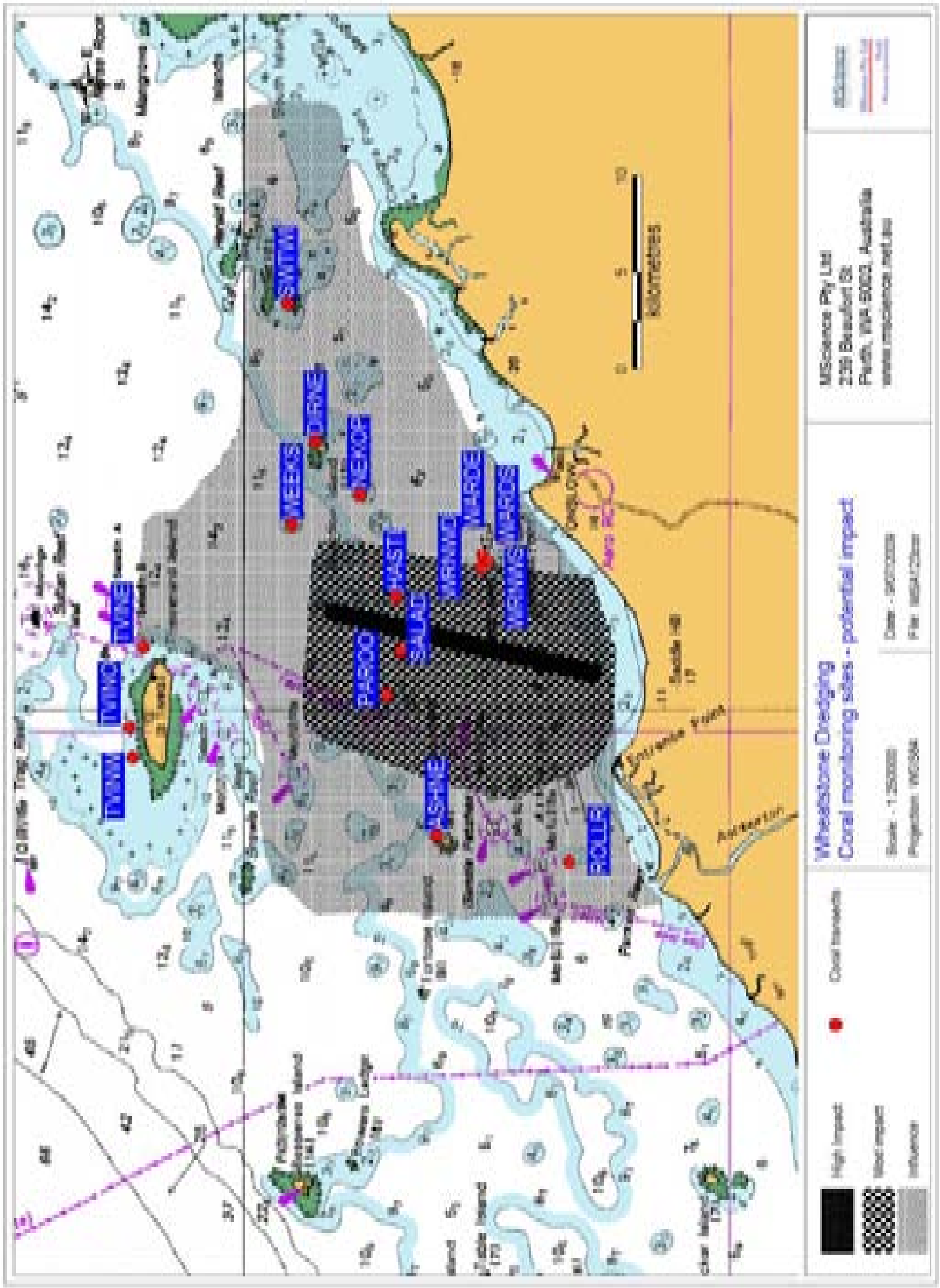


Figure 2. Working impact zonation scheme and sites sampled in this survey.

2.0 METHODS

2.1 PROGRAM OBJECTIVES

The objectives of this survey were to establish fixed belt transects within coral communities and record images of the entire transects for later analysis. Analysis of images was to allow quantitative assessment of the cover of corals, and other general benthic cover categories (flora, non-coral fauna, abiotics), within these transects.

Categorisation of corals within images into general, but meaningful, categories was planned to provide information on coral community diversity and structure. While clear and repeatable identification of corals to species or genus would be preferable to generalised groups, this is not practical using images alone.

2.2 SURVEY DESIGN

2.2.1 PARAMETERS

For this survey the basic unit of measurement is the percentage of substrate within belt transects covered by living coral assigned to gross taxonomic classes.

Coral classes were established here on the observations of divers, who had undertaken the field program, as to the dominant genera distinguishing differences at sites. Those divers were qualified marine scientists with many years experience in field evaluation of the identification of Pilbara corals.

These classes were modified against practical issues such as the colony morphology (as it relates to susceptibility to sedimentation) and the capacity to reliably identify the taxonomic unit from transect photographs. Noting that the latter may also be required in periods of poor visibility.

The coral classes used were those of Table 1.

2.2.2 SITES

Sixteen sampling sites were selected to represent examples of the higher density coral communities at various levels of risk from the indirect impacts of dredging.

Site selection was conducted by URS. Initial mapping was done using bathymetric maps and video from a remotely operated vehicle (ROV) to identify areas of coral habitat (WS0-0000-HES-RPT-URS-000-00010-00 Draft Report Wheatstone LNG Project : Subtidal Marine Habitat Survey 42907061-2163 : R1386). Following that, areas defined as coral habitat were further examined using the ROV to select the highest cover in areas accessible by a diving support vessel. Transects were then placed by divers along the most abundant coral areas found.

Sites to the north of Thevenard Island are placed to detect any potential impacts from an offshore spoil ground Figure 2.

Table 1. Coral classes used in scoring.

Group	Description
Acropora	All members of the genus *Acropora*
Agaricids	Members of the family Agariciidae
Favids	Members of the family Faviidae plus the mussid genus *Acanthastrea*
Montipora	All members of the genera *Montipora& Oxypora*
Mussids	Members of the family Mussiidae excluding *Acanthastrea*
Pectinids	Members of the family Pectiniidae
Pocilloporids	All members of the genera *Pocillopora & Stylophora*
Porites	All members of the genus *Porites*
Turbinaria	All members of the genus *Turbinaria*
Other	Scleractinian corals not listed above and *Millepora*

Table 2. Coral survey sites.

Site Number	Site Code	Location	Depth	Reef Type
1	ASHNE	Ashburton Island - NE	5-7m	Reef slope
2	DIRNE	Direction Island - NE	4-6m	Reef slope
3	HASTI	Hastings Shoal	4-6m	Patch reef
4	NEKOP	Northeast Koolinda Shoal	3-5m	Patch reef
5	PAROO	Paroo Shoal	4-8m	Patch reef
6	ROLLR	Roller Shoals	5-6m	Patch reef
7	SALAD	Saladin Shoal	3-5m	Patch reef
8	SWTWI	Southwest Twin Island	1-3m	Reef edge (flat/slope)
9	TVINE	Thevenard Island - Northeast	3-5m	Patch reef
10	TVINO	Thevenard Island - North	3-5m	Reef slope
11	TVINW	Thevenard Island - Northwest	3-5m	Reef slope
12	WARDE	Ward Reef	4-6m	Reef slope
13	WARDS	Ward Reef	3-4m	Reef flat
14	WRNWD	Ward Reef	4-6m	Reef slope
15	WRNWS	Ward Reef	2-4m	Reef flat
16	WEEKS	Weeks Shoal	4-6m	Patch reef

2.2.3 Methods

Transects to evaluate density of live coral

Belt transects examine a relatively small proportion of the coral community at any site, but are capable of providing robust and repeatable information on coral densities and community composition (Ryan and Heyward 2003; Jokiel, Rodgers et al. 2005; Nadon and Stirling 2006).

Coral cover may be estimated to better than 10% precision and accuracy by the use of fixed belt transects. For coral communities with live cover in excess of 30%, 5 fixed transects of 10 metres length each may be used to provide a set of images which can be scored for coral density. This has been shown to provide a better than 80% power of detecting a 10% change in coral communities elsewhere in the Pilbara nearshore (Stoddart, Grey et al. 2005; Stoddart 2008).

In the present case, 5 x 10 m transects were placed along in a set linear design through representative sections of the highest local cover in coral communities. Transects locations were fixed by permanent markers at either end and the mid-point of transects.

Each transect was recorded with 30 overlapping images (each approximately 50 x 70 cm). Each image was scored for the proportion of live coral (using the categories of Table 1), fauna (non-coral, e.g. soft corals, urchins, zoanthids), flora (macroalgae only) using 25 points per image overlaid using Photogrid software (courtesy of C.Bird, U. Hawaii). Algae other than macroalgae (e.g. turfs and algal films) were placed in the 'abiotic' category as these lifeforms can be difficult to discern repeatedly through images.

Corals scored as live are also divided into bleached or unbleached categories. Bleaching assessment using transect images is a good indicator of bleaching but can be prone to overestimating bleaching due to misidentification of corals in images where contrast between a dark background and a light coral cause exposure differences. Estimates of live coral cover include bleached coral.

Further discussion of the methodology can be found in Stoddart et al. (2005).

3.0 RESULTS

3.1 ASHBURTON ISLAND NORTHEAST (ASHNE)

Coral cover varied from 20 to 47% cover and was composed principally of the genera *Montipora* (33%) and *Acropora* (24%) (Table 3, Figure 3, Figure 4). Bleaching was apparent within one transect where several bleached corals (principally *Pocillopora*) were recorded.

Table 3. Coral cover (%) at ASHNE.

Transect		Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
	1	30.9%	0.3%	0.3%	0.0%	68.6%	1.6%	0.0%
	2	47.4%	0.1%	0.3%	0.0%	52.2%	0.9%	0.0%
	3	30.9%	0.0%	0.1%	0.0%	68.9%	1.8%	0.0%
	4	29.7%	0.0%	0.0%	0.0%	70.3%	0.8%	0.0%
	5	20.5%	0.0%	0.0%	0.0%	79.5%	2.6%	18.7%
Mean		**31.9%**	**0.1%**	**0.1%**	**0.0%**	**67.9%**	**1.5%**	**3.7%**
Std Dev		9.69%	0.12%	0.14%	0.00%	9.84%	0.72%	

Figure 3. Coral cover across the ASHNE transects.

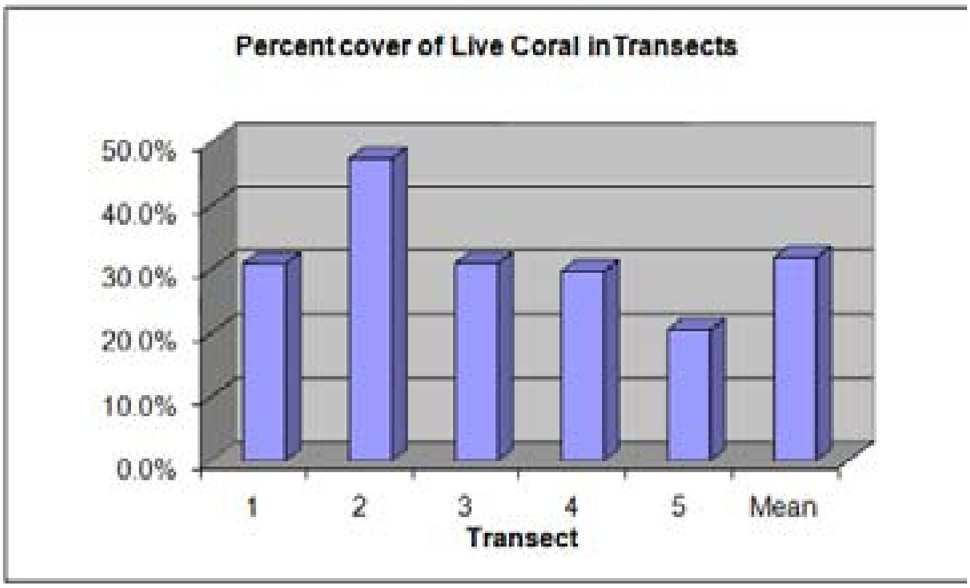


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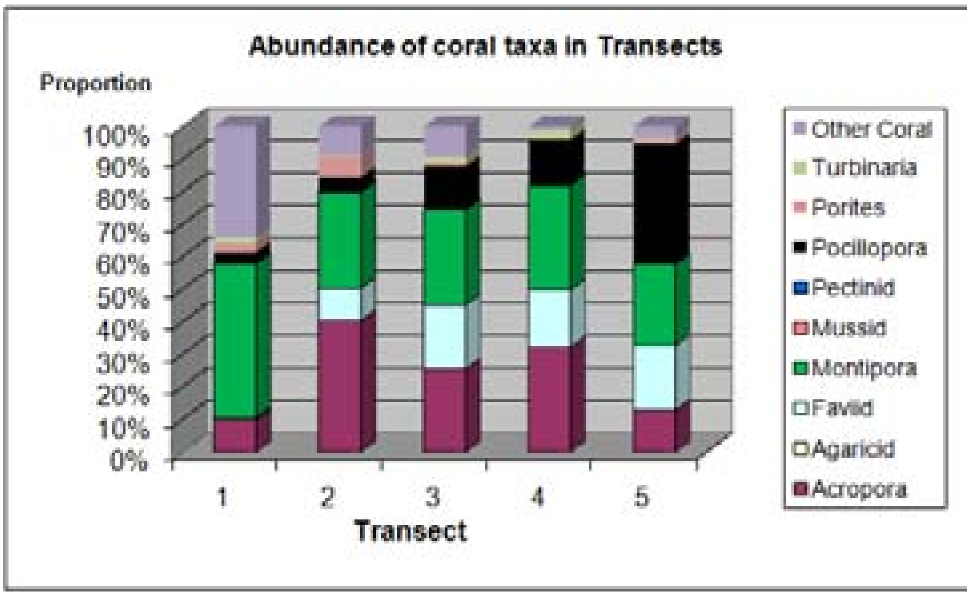
Figure 4. Community composition of ASHNE transects.



3.2 DIRECTION ISLAND NORTHEAST (DIRNE)

Live coral cover was ~35% for all transects except for 19% in transect five (Table 4, Figure 5). The dominant genus is *Porites* (32%) with the Other Coral group composed mainly of *Goniopora* and *Merulina* (Figure 6). A small amount of bleaching was present in transect one.

Table 4. Coral cover (%) at DIRNE.

Transect		Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
	1	33.7%	0.3%	0.0%	0.0%	66.0%	2.7%	0.8%
	2	35.5%	0.0%	0.0%	0.0%	64.5%	2.5%	0.0%
	3	32.7%	0.0%	0.0%	0.0%	67.3%	0.9%	0.0%
	4	36.3%	0.0%	0.0%	0.0%	63.7%	1.1%	0.0%
	5	19.1%	0.0%	0.0%	0.0%	80.9%	0.9%	0.0%
Mean		**31.5%**	**0.1%**	**0.0%**	**0.0%**	**68.5%**	**1.6%**	**0.2%**
Std Dev		7.04%	0.12%	0.00%	0.00%	7.07%	0.89%	

Figure 5. Coral cover across the DIRNE transects.

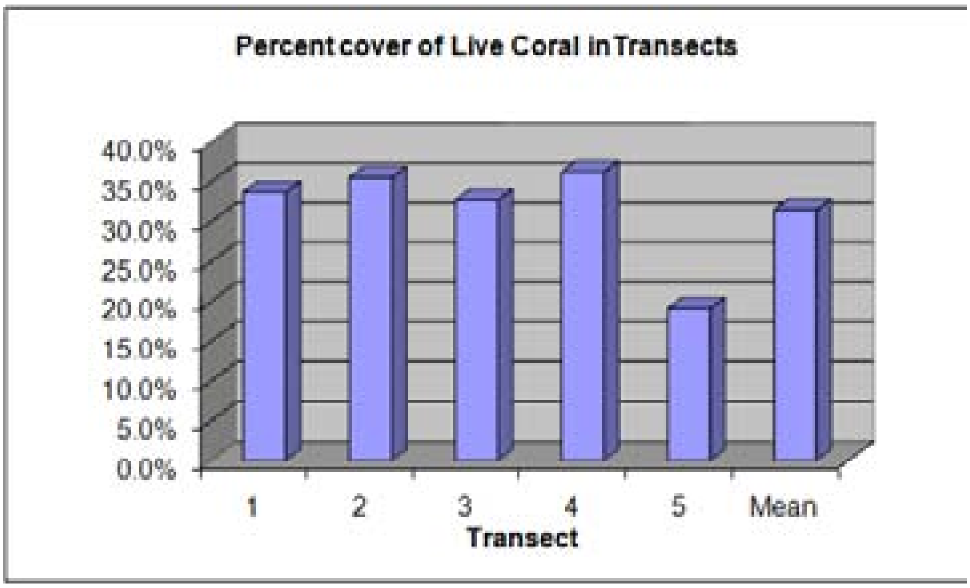
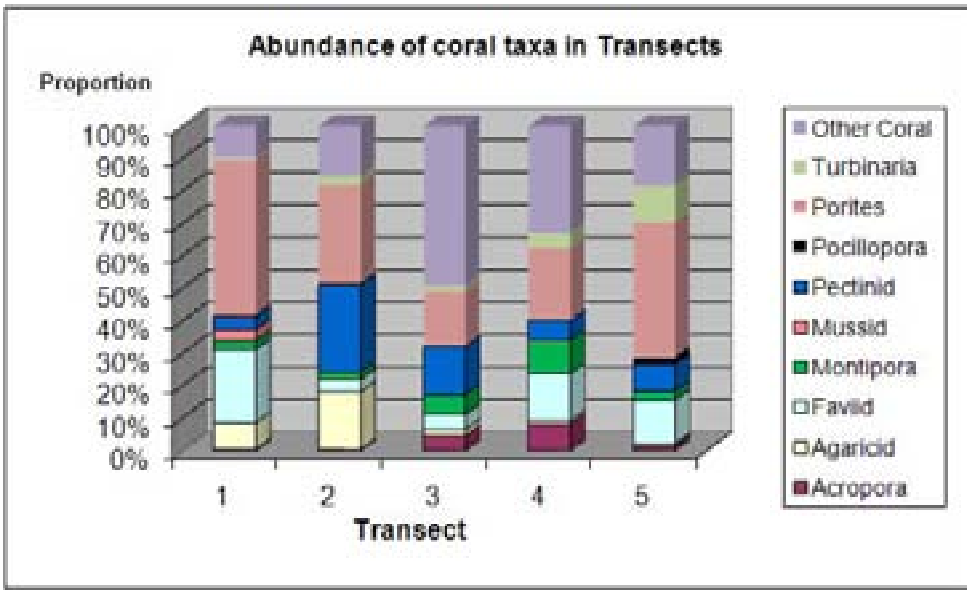


Figure 6. Community composition of DIRNE transects.



3.3 HASTINGS SHOAL (HASTI)

Coral cover at the HASTI transects was either moderate (33%) or high (>60%) with no bleaching evident (Table 5, Figure 7). Both moderate and high cover transects had similar communities dominated by *Montipora* with *Acropora* as a subdominant (Figure 8).

Table 5. Coral cover (%) at HASTI.

Transect		Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
	1	61.2%	0.0%	0.1%	0.0%	38.6%	2.0%	0.0%
	2	69.1%	0.0%	2.3%	0.0%	28.6%	3.2%	0.0%
	3	64.9%	1.1%	0.8%	0.0%	33.1%	4.5%	0.0%
	4	33.9%	0.0%	0.7%	0.1%	65.3%	1.2%	0.0%
	5	32.0%	6.4%	4.0%	0.0%	57.6%	3.6%	0.0%
Mean		**52.2%**	**1.5%**	**1.6%**	**0.0%**	**44.7%**	**2.9%**	**0.0%**
Std Dev		17.81%	2.76%	1.57%	0.06%	15.97%	1.28%	

Figure 7. Coral cover across the HASTI transects.

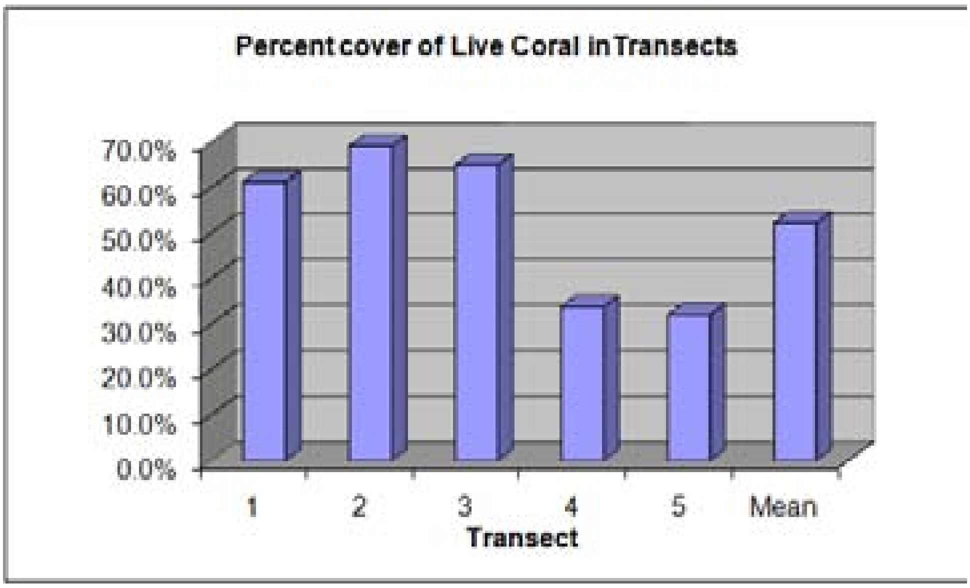
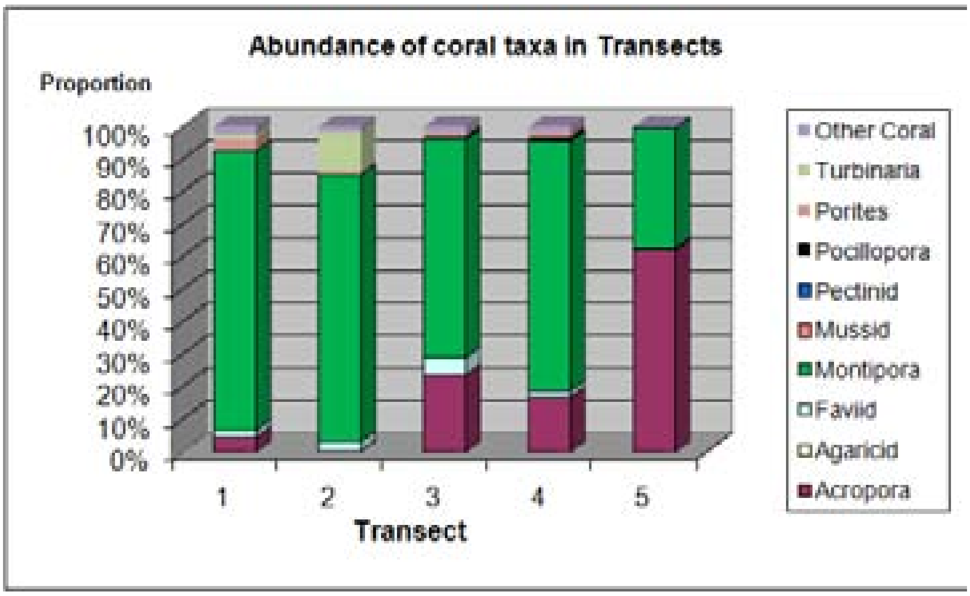


Figure 8. Community composition of HASTI transects.



3.4 Northeast Koolinda (NEKOP)

Coral cover at NEKOP was generally high (>60%) and composed predominantly of *Acropora* with *Montipora* subdominant (Table 6, Figure 9, Figure 10). There was no bleaching evident.

Table 6. Coral cover (%) at NEKOPI.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	62.8%	0.0%	1.2%	0.0%	36.0%	2.3%	0.0%
2	66.2%	0.0%	1.1%	0.0%	32.7%	2.2%	0.0%
3	73.5%	0.0%	2.0%	0.5%	23.9%	1.4%	0.0%
4	67.0%	0.0%	1.4%	0.1%	31.5%	3.0%	0.0%
5	68.6%	0.0%	1.4%	0.0%	30.1%	2.0%	0.0%
Mean	**67.6%**	**0.0%**	**1.4%**	**0.1%**	**30.8%**	**2.2%**	**0.0%**
Std Dev	3.93%	0.00%	0.36%	0.23%	4.45%	0.60%	

Figure 9. Coral cover across the NEKOP transects.

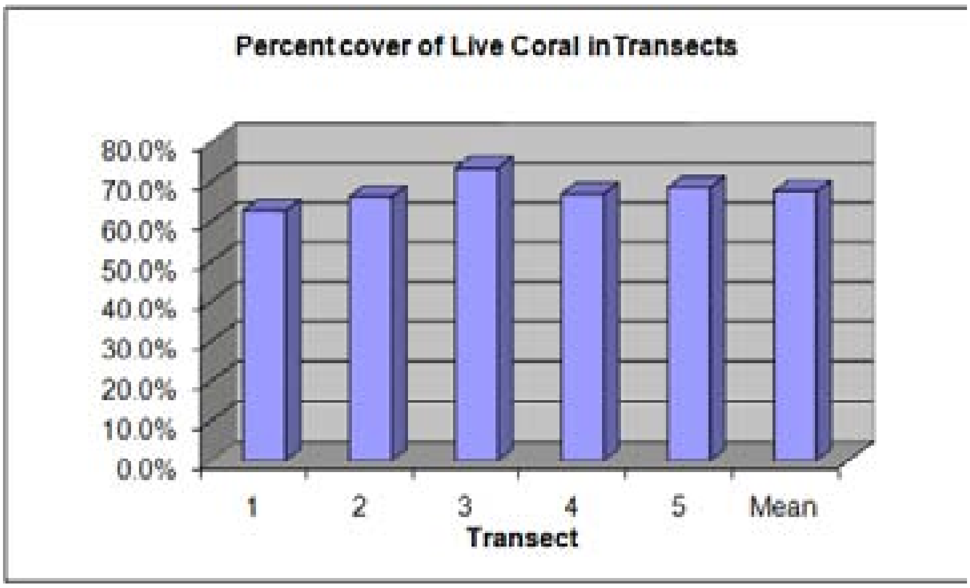
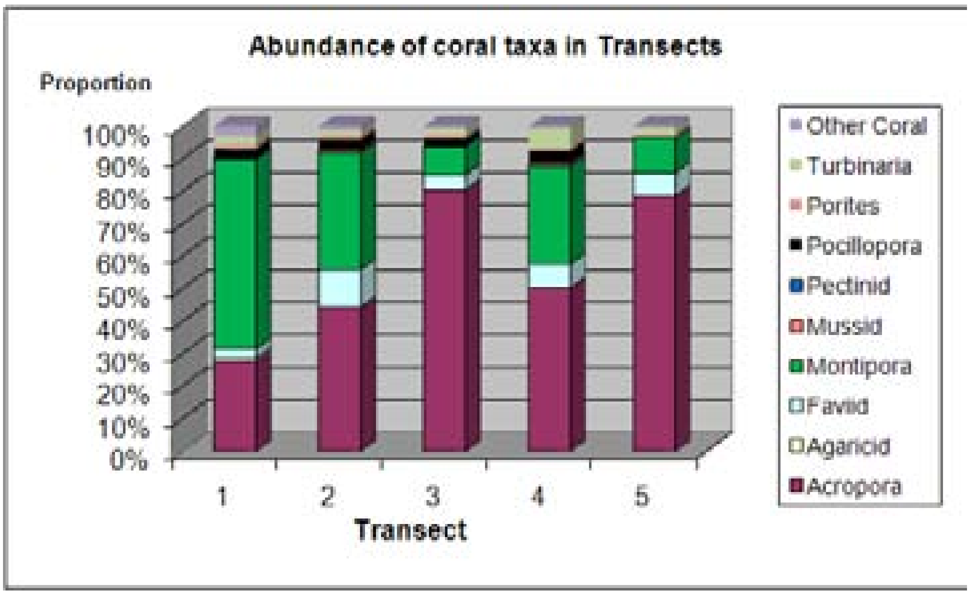


Figure 10. Community composition of NEKOP transects.



3.5 Paroo Shoals (PAROO)

Coral cover varied from 16% in transect one to 68% in transect three (Table 7, Figure 11). The community was dominated by *Montipora* with *Acropora* subdominant (Figure 12). No bleaching was observed.

Table 7. Coral cover (%) at PAROO.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	16.4%	0.0%	2.6%	0.0%	81.0%	0.9%	0.0%
2	22.3%	0.0%	2.2%	0.0%	75.5%	1.5%	0.0%
3	67.9%	0.0%	2.7%	0.0%	29.4%	7.4%	0.0%
4	27.0%	0.0%	9.5%	0.0%	63.5%	3.2%	0.0%
5	61.4%	0.0%	1.0%	0.0%	37.7%	5.8%	0.0%
Mean	**39.0%**	**0.0%**	**3.6%**	**0.0%**	**57.4%**	**3.8%**	**0.0%**
Std Dev	23.81%	0.00%	3.37%	0.00%	22.91%	2.79%	

Figure 11. Coral cover across the PAROO transects.

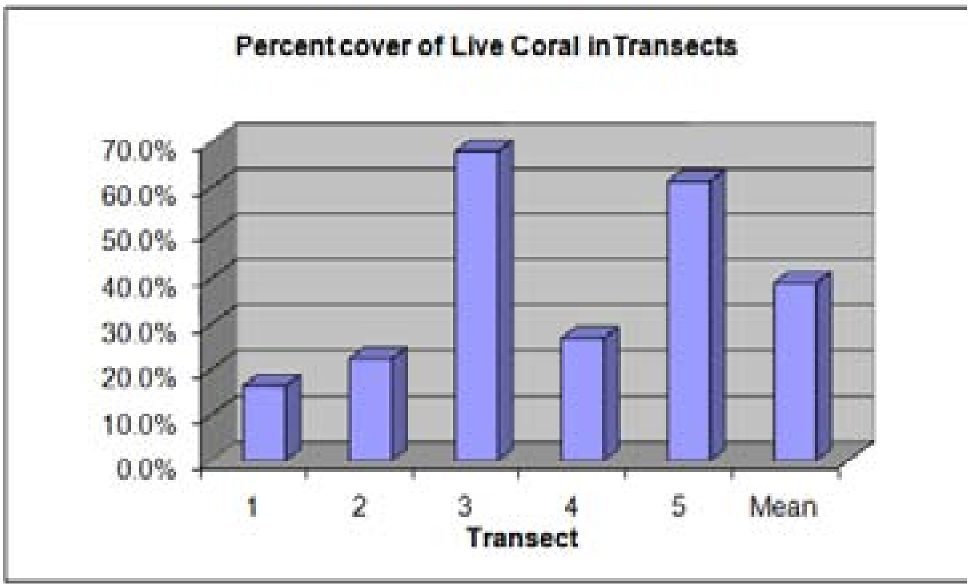
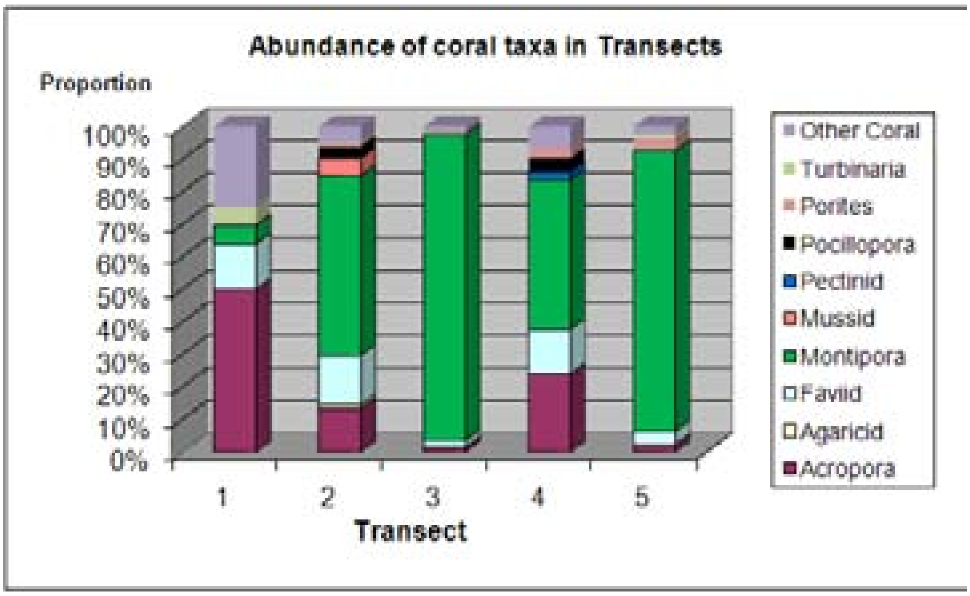


Figure 12. Community composition of PAROO transects.



3.6 ROLLER SHOALS (ROLLR)

Coral cover at ROLLR ranged from 47% to 86% (Table 8, Figure 13). The site was dominated almost completely by *Montipora* (78%) with a small amount of *Acropora* (8%) also present (Figure 14). A small amount of bleaching was observed on some *Montipora* corals.

Table 8. Coral cover (%) at ROLLR.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	68.7%	0.3%	0.9%	0.0%	30.1%	1.1%	0.8%
2	56.1%	0.0%	0.7%	0.0%	43.3%	1.1%	0.5%
3	85.9%	0.0%	0.7%	0.0%	13.4%	2.5%	0.3%
4	47.6%	1.1%	3.1%	0.0%	48.2%	0.9%	0.0%
5	67.7%	0.1%	1.2%	0.0%	30.9%	1.2%	0.0%
Mean	**65.2%**	**0.3%**	**1.3%**	**0.0%**	**33.2%**	**1.4%**	**0.3%**
Std Dev	14.49%	0.45%	1.02%	0.00%	13.54%	0.62%	

Figure 13. Coral cover across the ROLLR transects.

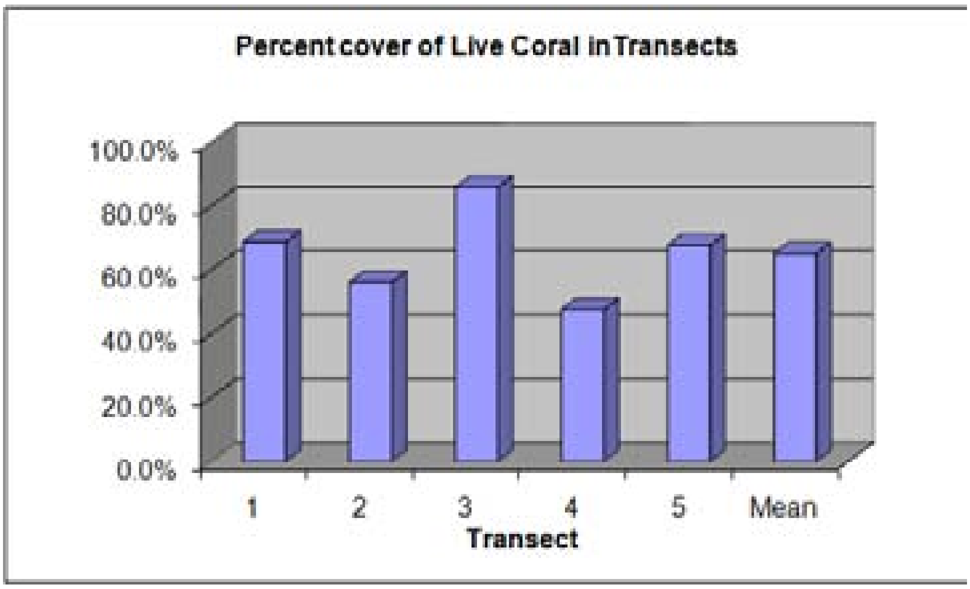
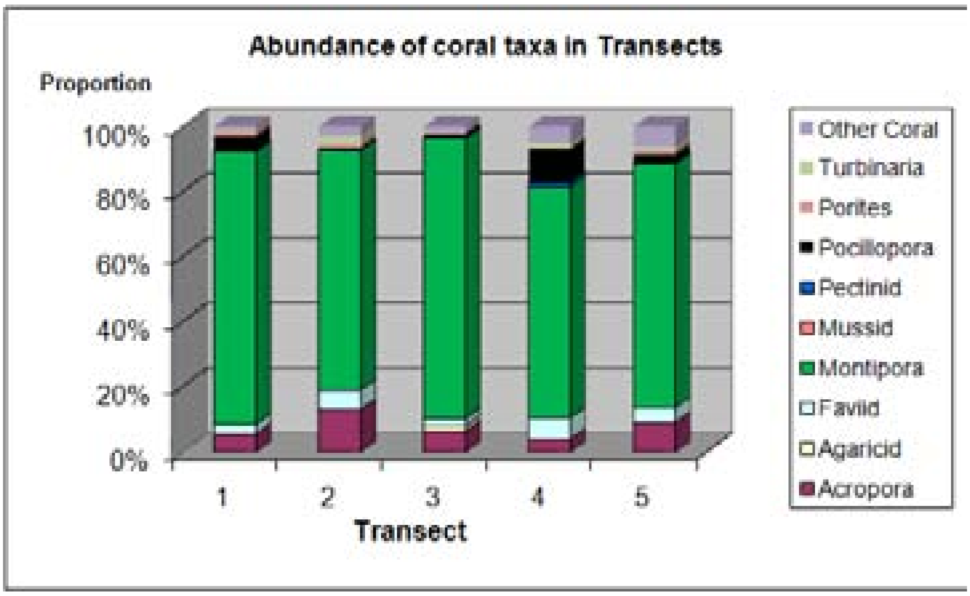


Figure 14. Community composition of ROLLR transects.



3.7 SALADIN SHOAL (SALAD)

Coral cover at SALAD varied from 47% to 76% (Table 9, Figure 15). The dominant genera was *Montipora* (35%) followed by *Acropora* (29%) and *Pocillopora* (28%) (Figure 16). A small amount of bleaching was detected on the branching corals *Acropora* and *Pocillopora*.

Table 9. Coral cover (%) at SALAD.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	68.3%	0.0%	0.3%	0.0%	31.5%	4.9%	0.4%
2	56.1%	0.0%	2.0%	0.0%	41.9%	6.2%	0.3%
3	46.5%	0.0%	1.3%	0.0%	52.3%	5.9%	0.0%
4	76.4%	0.0%	1.0%	0.0%	22.6%	5.2%	0.0%
5	51.6%	0.0%	1.1%	0.0%	47.2%	6.1%	0.0%
Mean	**59.8%**	**0.0%**	**1.1%**	**0.0%**	**39.1%**	**5.7%**	**0.1%**
Std Dev	12.31%	0.00%	0.61%	0.00%	12.03%	0.59%	

Figure 15. Coral cover across the SALAD transects.

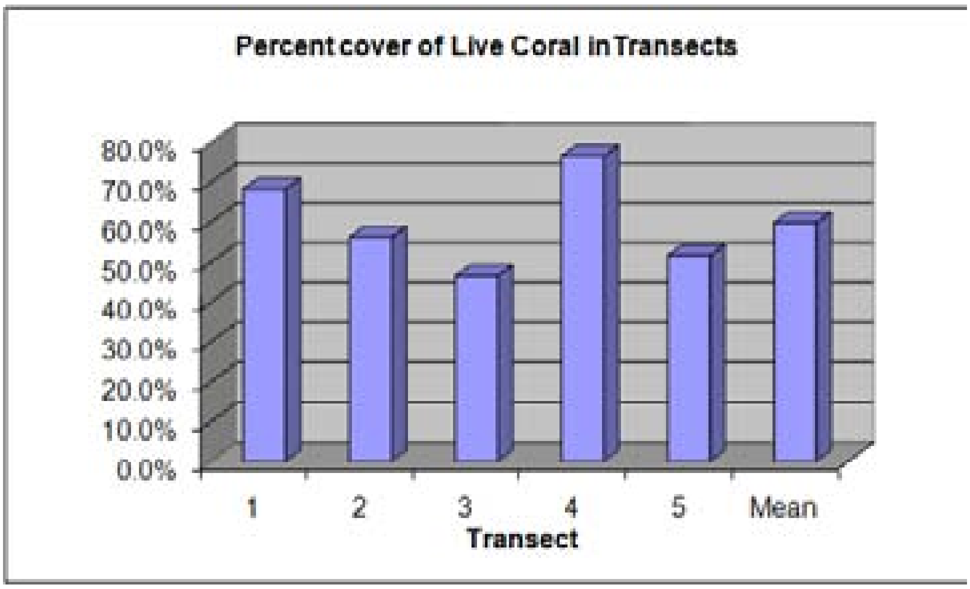
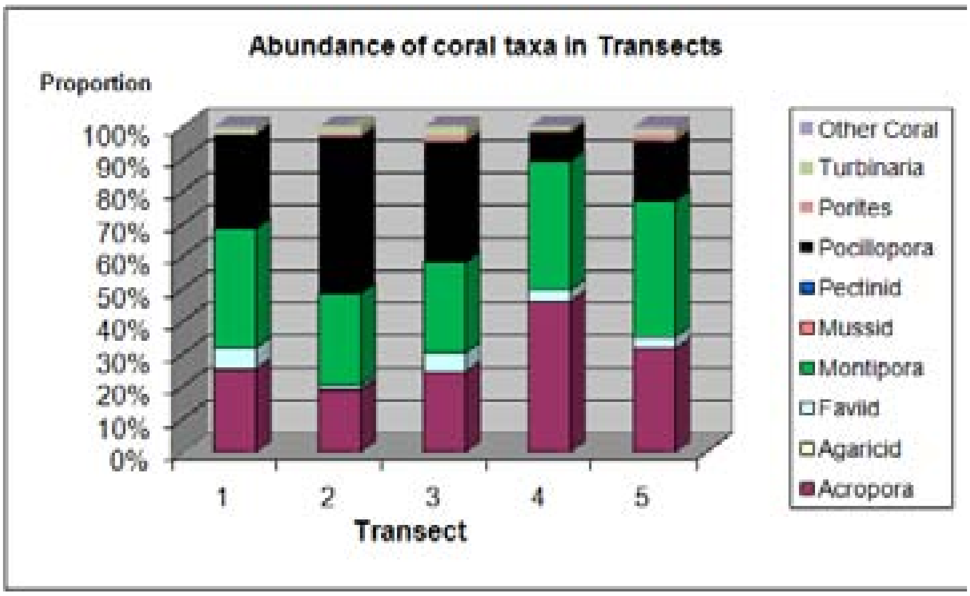


Figure 16. Community composition of SALAD transects.



3.8 SOUTHWEST TWIN ISLAND (SWTWI)

Cover at SWTWI was generally around 30% (Table 10, Figure 17). The community was dominated by *Porites* (39%) including massive and branching types. The subdominant group was Faviid (20%) (Figure 18). No bleaching was observed.

Table 10.Coral cover (%) at SWTWI.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	30.2%	0.0%	0.0%	0.0%	69.8%	3.0%	0.0%
2	21.5%	0.0%	0.0%	0.0%	78.5%	2.2%	0.0%
3	37.7%	0.0%	0.0%	0.0%	62.3%	2.5%	0.0%
4	24.4%	0.0%	0.0%	0.0%	75.6%	1.8%	0.0%
5	35.2%	0.1%	0.0%	0.0%	64.7%	3.0%	0.0%
Mean	**29.8%**	**0.0%**	**0.0%**	**0.0%**	**70.2%**	**2.5%**	**0.0%**
Std Dev	6.87%	0.06%	0.00%	0.00%	6.90%	0.55%	

Figure 17. Coral cover across the SWTWI transects.

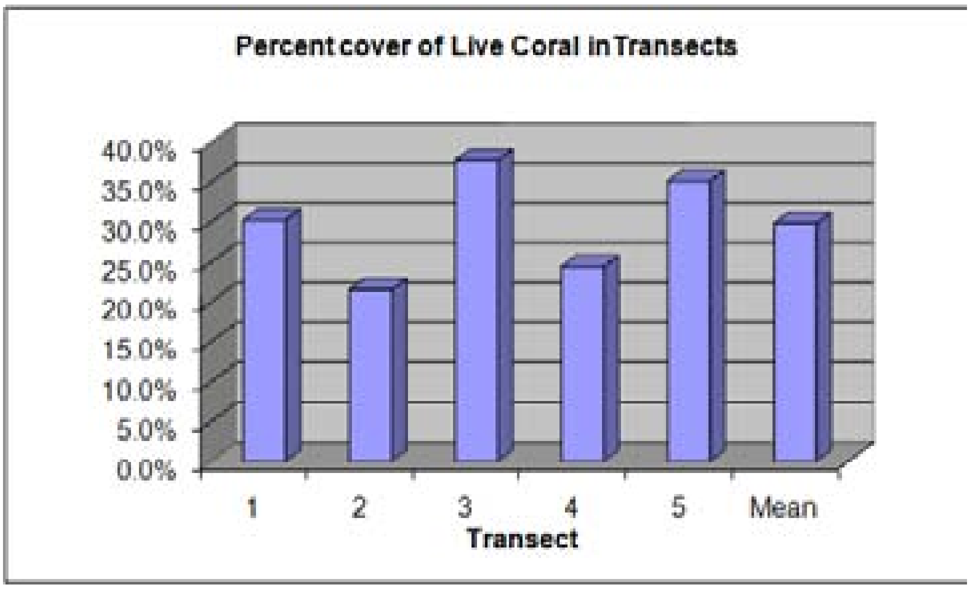
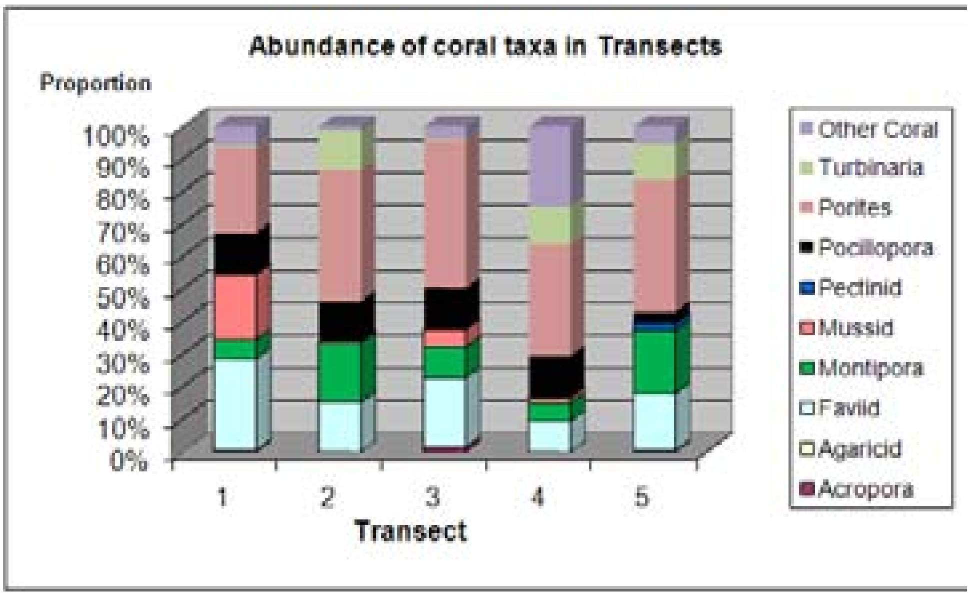


Figure 18. Community composition of SWTWI transects.



3.9 Thevenard Island Northeast (TVINE)

Cover at TVINE was generally around 30% (Table 11, Figure 19). The community was dominated equally by *Acropora* (35%) and Faviid (35%) groups (Figure 20). No bleaching was observed.

Table 11. Coral cover (%) at TVINE.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	37.6%	0.0%	3.0%	0.0%	59.5%	0.7%	0.0%
2	34.5%	0.0%	2.7%	0.0%	62.8%	1.8%	0.0%
3	30.0%	0.0%	0.1%	0.0%	69.9%	1.4%	0.0%
4	28.7%	0.0%	1.4%	0.0%	70.0%	1.9%	0.0%
5	27.1%	0.0%	3.0%	0.0%	70.0%	0.9%	0.0%
Mean	**31.6%**	**0.0%**	**2.0%**	**0.0%**	**66.4%**	**1.3%**	**0.0%**
Std Dev	4.35%	0.00%	1.25%	0.00%	4.96%	0.52%	

Figure 19. Coral cover across the TVINE transects.

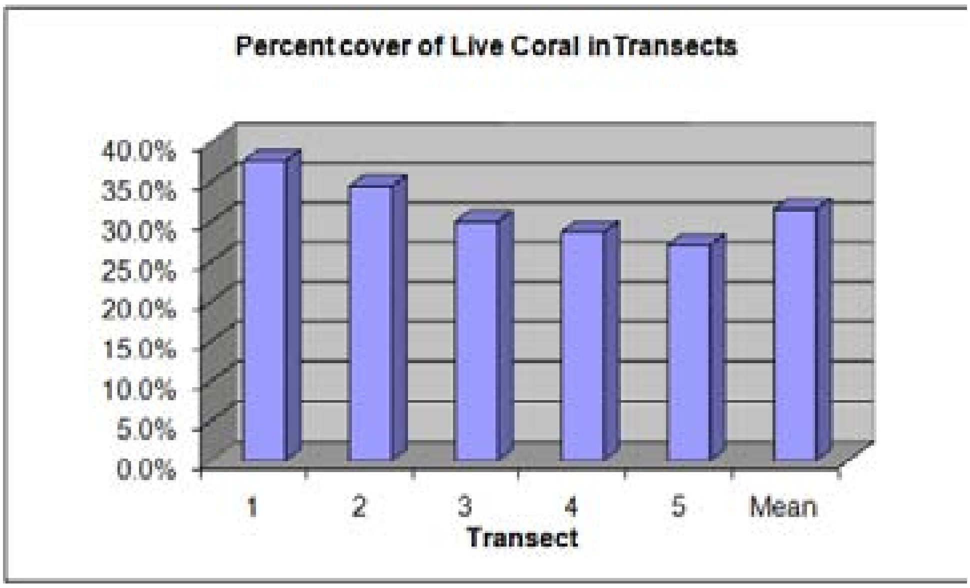
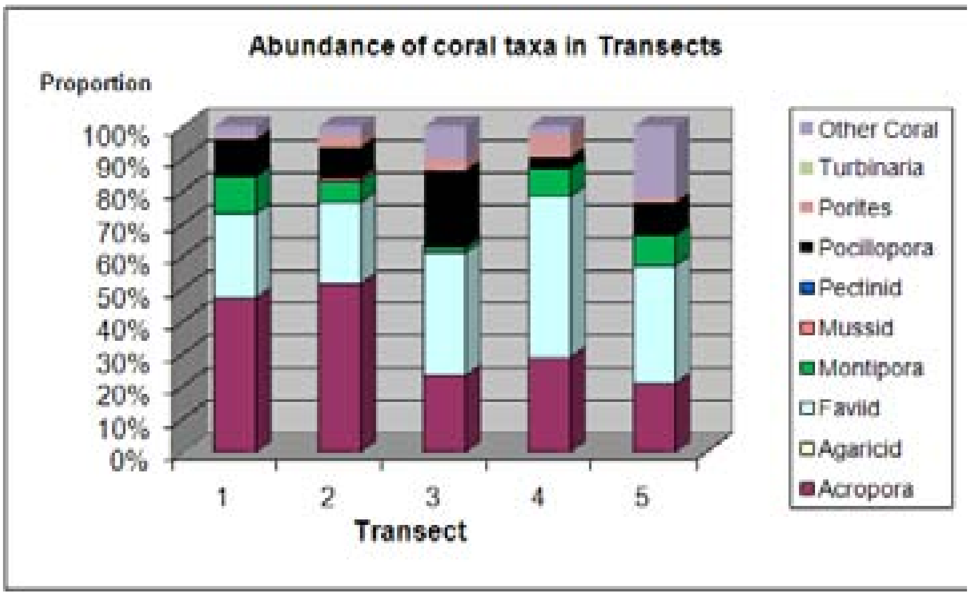


Figure 20. Community composition of TVINE transects.



3.10 THEVENARD ISLAND NORTHWEST (TVINW)

Cover at TVINW varied from 38% to 56% (Table 12, Figure 21). The community was composed of equally dominant genera *Montipora* (30%) and *Acropora* (30%) (Figure 22). A small amount of bleaching was observed.

Table 12. Coral cover (%) at TVINW.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	43.4%	0.0%	0.3%	0.0%	56.3%	0.8%	0.0%
2	56.2%	0.1%	0.4%	0.0%	43.2%	3.9%	0.0%
3	41.0%	0.0%	0.1%	0.0%	58.8%	1.9%	0.0%
4	38.5%	0.0%	0.4%	0.0%	61.1%	1.6%	0.4%
5	52.9%	0.8%	0.3%	0.0%	46.0%	2.9%	0.3%
Mean	**46.4%**	**0.2%**	**0.3%**	**0.0%**	**53.1%**	**2.2%**	**0.1%**
Std Dev	7.75%	0.36%	0.12%	0.00%	8.00%	1.19%	

Figure 21. Coral cover across the TVINW transects.

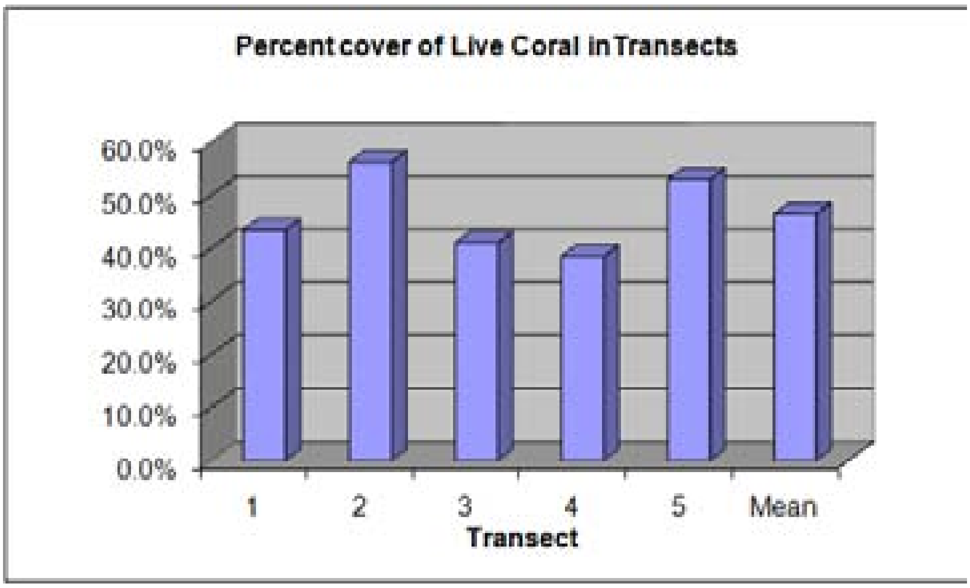
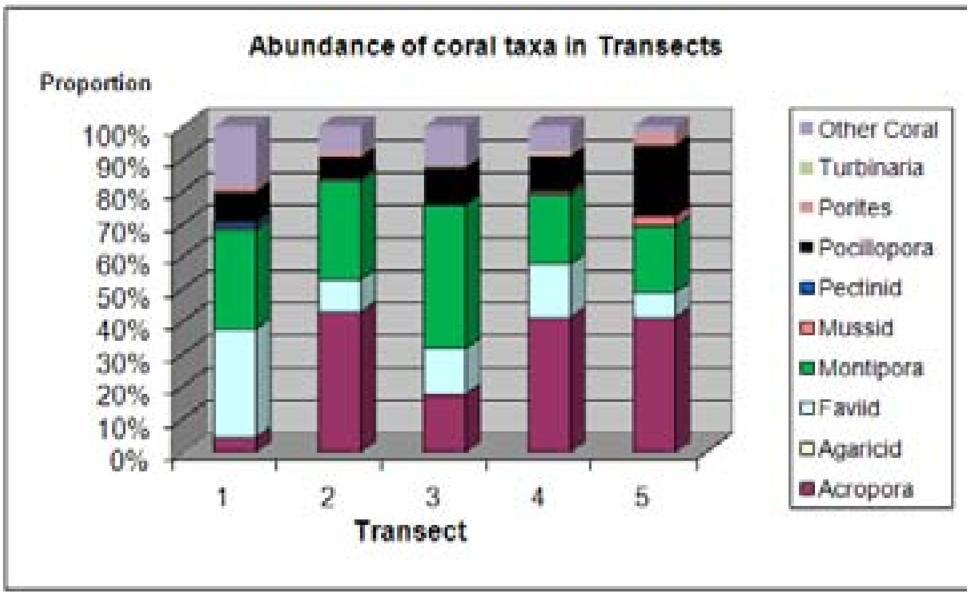


Figure 22. Community composition of TVINW transects.



3.11 Thevenard Island North (TVINO)

Live coral cover at TVINO ranged from 42% to 51% (Table 13, Figure 23). Community composition was more diverse than other sites, with Other being the largest group (35%), composed mainly of *Merulina*. Faviids (22%) and *Acropora* (21%) were also present in smaller numbers (Figure 24). A single bleached Pectinid was observed in the second transect.

Table 13.Coral cover (%) at TVINO.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	50.8%	0.0%	0.3%	0.0%	48.9%	1.1%	0.0%
2	45.6%	0.0%	0.1%	0.0%	54.3%	2.3%	0.3%
3	51.0%	0.0%	0.0%	0.0%	49.0%	2.2%	0.0%
4	41.7%	0.0%	0.1%	0.0%	58.1%	0.9%	0.0%
5	44.3%	0.0%	0.0%	0.0%	55.7%	2.9%	0.0%
Mean	**46.7%**	**0.0%**	**0.1%**	**0.0%**	**53.2%**	**1.9%**	**0.1%**
Std Dev	4.09%	0.00%	0.11%	0.00%	4.10%	0.84%	

Figure 23. Coral cover across the TVINO transects.

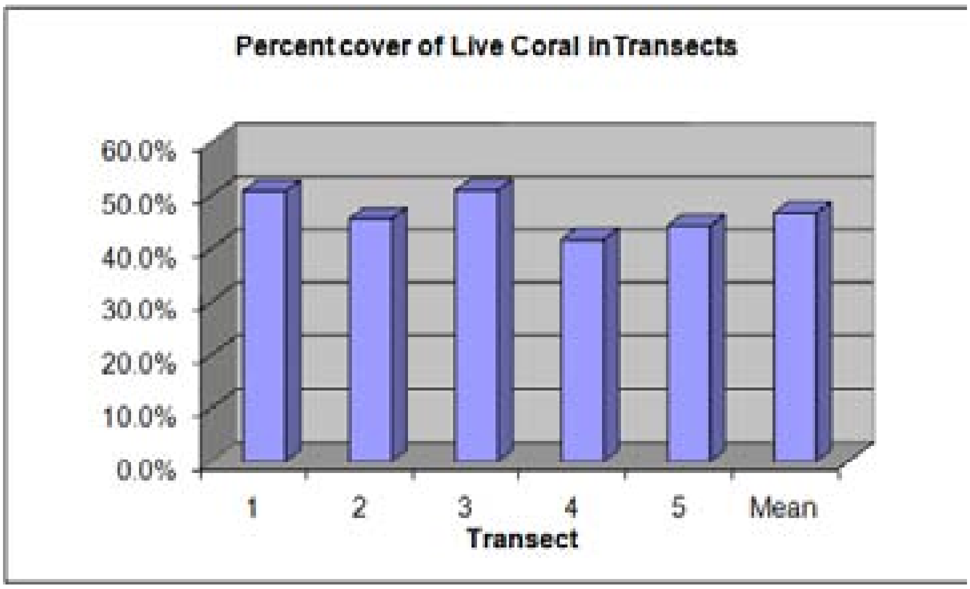
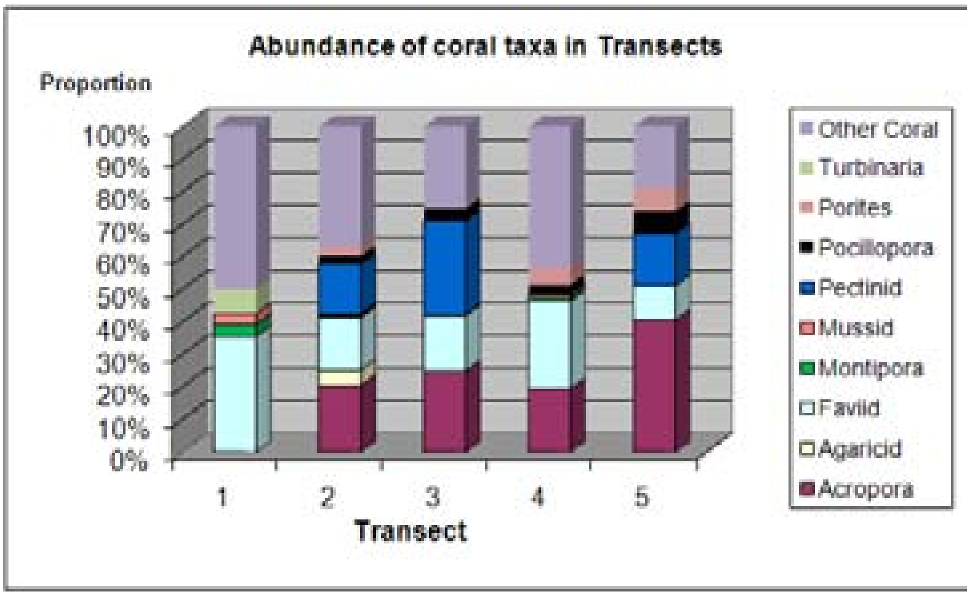


Figure 24. Community composition of TVINO transects.



3.12 Ward Reef East (WARDE)

WARDE was generally a high cover site, with transects ranging from 48% to 79% live coral cover (Table 14, Figure 25). The community was dominated by *Montipora* (45%) with subdominant Agaricids (40%) composed mainly of *Pachyseris* (Figure 26). No bleaching was detected.

Table 14.Coral cover (%) at WARDE.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	63.2%	0.0%	0.4%	0.0%	36.4%	3.3%	0.0%
2	60.4%	0.1%	0.8%	0.0%	38.6%	3.4%	0.0%
3	78.8%	0.0%	0.0%	0.0%	21.2%	3.3%	0.0%
4	56.8%	0.0%	0.0%	0.0%	43.2%	3.9%	0.0%
5	48.0%	0.0%	0.0%	0.0%	52.0%	5.0%	0.0%
Mean	**61.5%**	**0.0%**	**0.2%**	**0.0%**	**38.3%**	**3.8%**	**0.0%**
Std Dev	11.25%	0.06%	0.37%	0.00%	11.25%	0.73%	

Figure 25. Coral cover across the WARDE transects.

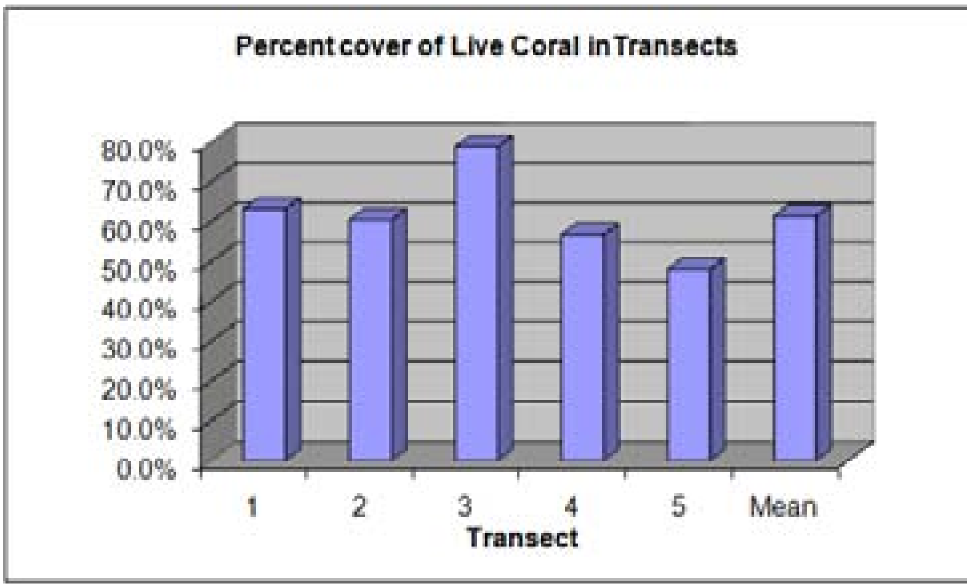
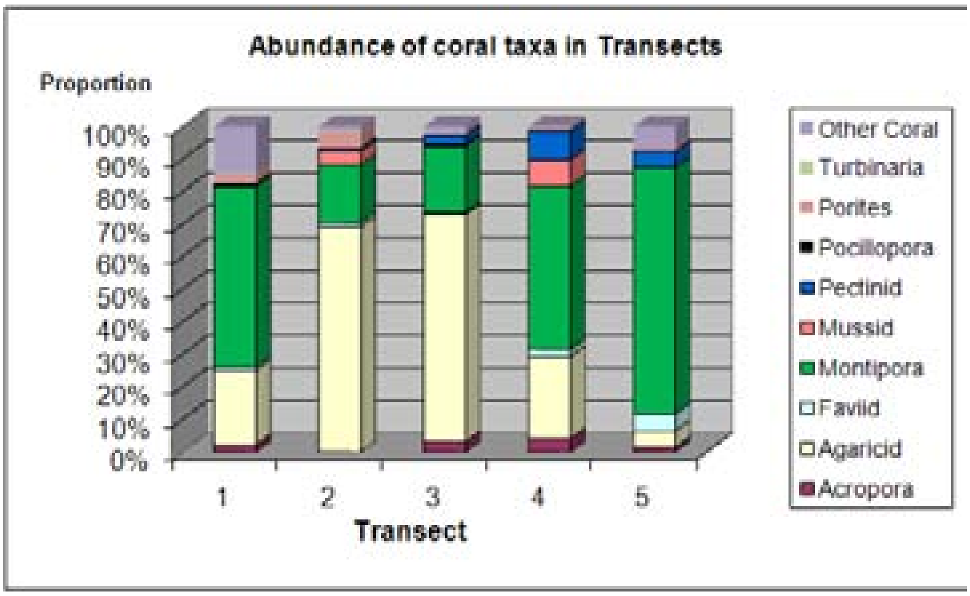


Figure 26. Community composition of WARDE transects.



3.13 Ward Reef South (WARDS)

Live cover is mostly around 40%, with 70% cover in the second transect (, Figure 27). The coral community at the site is almost completely composed of *Montipora* (91%) (Figure 28). A small amount of bleached and broken *Montipora* was observed in the third transect.

Table 15. Coral cover (%) at WARDS.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	48.5%	2.0%	0.0%	0.0%	49.5%	6.1%	0.0%
2	70.2%	0.0%	0.0%	0.0%	29.8%	6.5%	0.2%
3	42.8%	0.0%	0.1%	0.0%	57.0%	6.4%	0.7%
4	45.4%	0.3%	0.0%	0.3%	54.1%	5.0%	0.0%
5	35.6%	0.6%	0.0%	0.0%	63.9%	7.1%	0.0%
Mean	**48.5%**	**0.6%**	**0.0%**	**0.1%**	**50.9%**	**6.2%**	**0.2%**
Std Dev	13.02%	0.82%	0.06%	0.13%	12.86%	0.77%	

Figure 27. Coral cover across the WARDS transects.

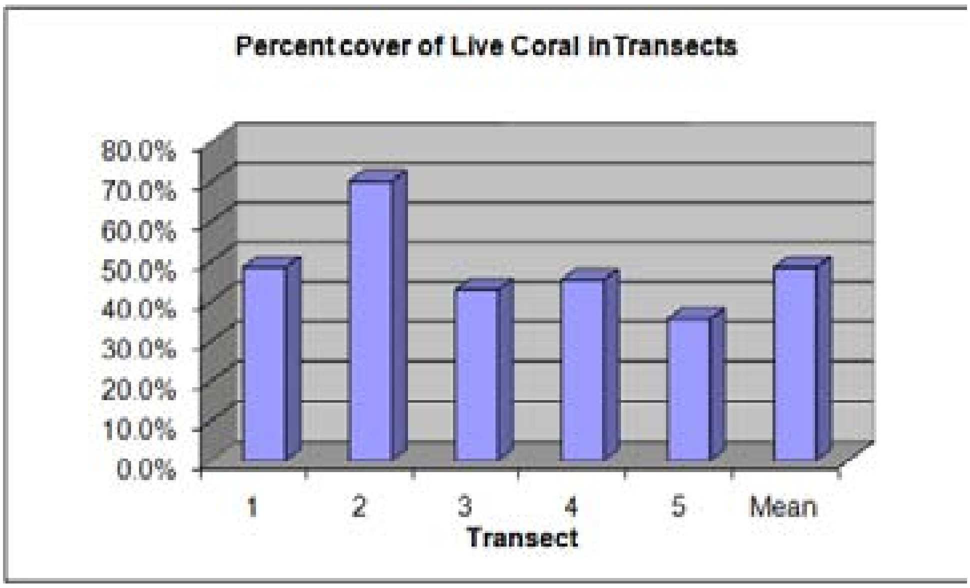
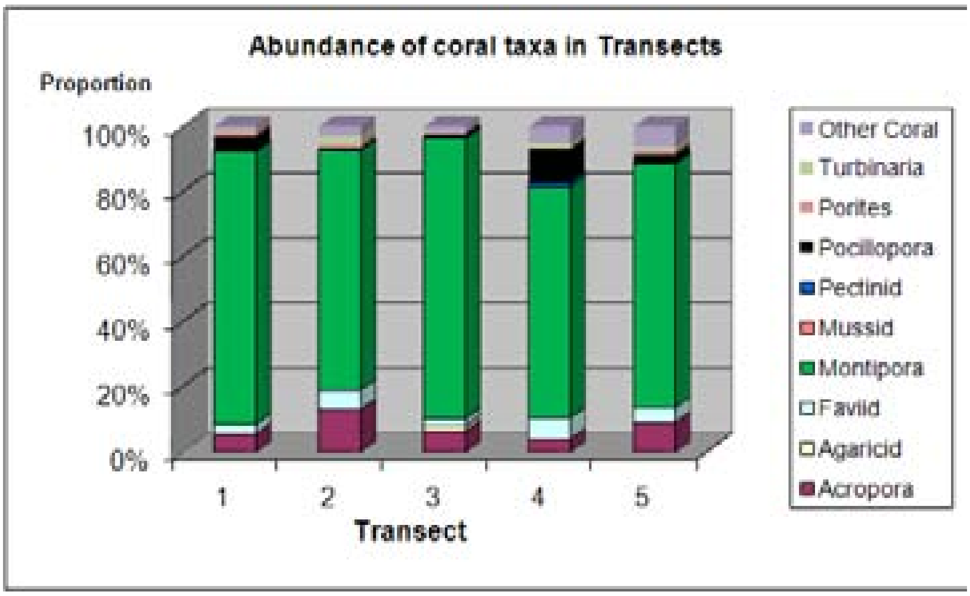


Figure 28. Community composition of WARDS transects.



3.14 WEEKS SHOAL (WEEKS)

Coral cover at WEEKS varied from 20% up to 32% (Table 16, Figure 29). The community was composed mainly of *Montipora* (55%) with Faviids (20%) subdominant (Figure 30). No bleaching was observed.

Table 16. Coral cover (%) at WEEKS.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	31.1%	2.5%	4.1%	0.0%	62.4%	2.6%	0.0%
2	19.9%	0.7%	18.1%	0.0%	61.2%	4.6%	0.0%
3	28.9%	0.4%	1.2%	0.0%	69.5%	1.8%	0.0%
4	32.5%	0.0%	4.9%	0.0%	62.6%	5.0%	0.0%
5	32.0%	0.1%	2.4%	0.0%	65.4%	1.6%	0.0%
Mean	**28.9%**	**0.7%**	**6.2%**	**0.0%**	**64.2%**	**3.1%**	**0.0%**
Std Dev	5.18%	1.00%	6.84%	0.00%	3.32%	1.60%	

Figure 29. Coral cover across the WEEKS transects.

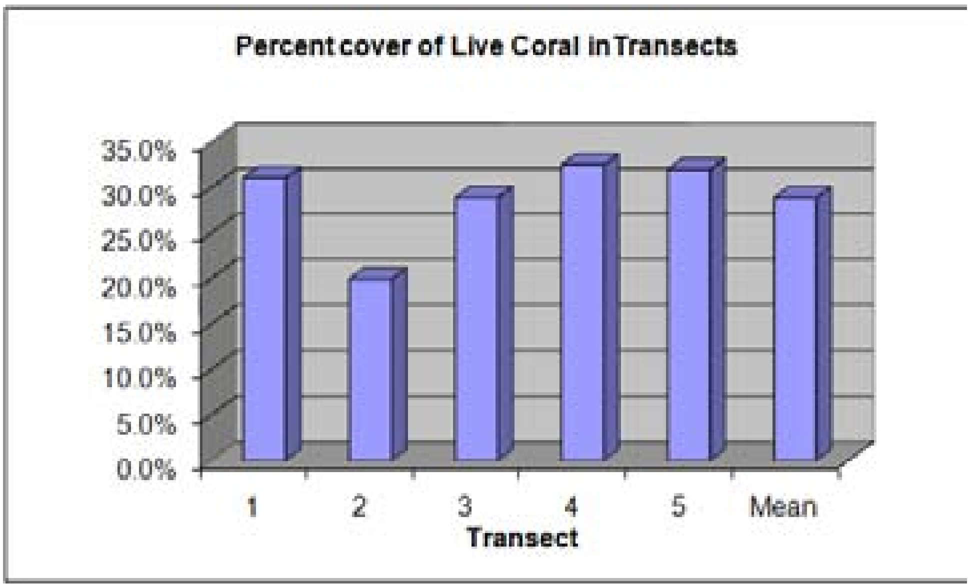
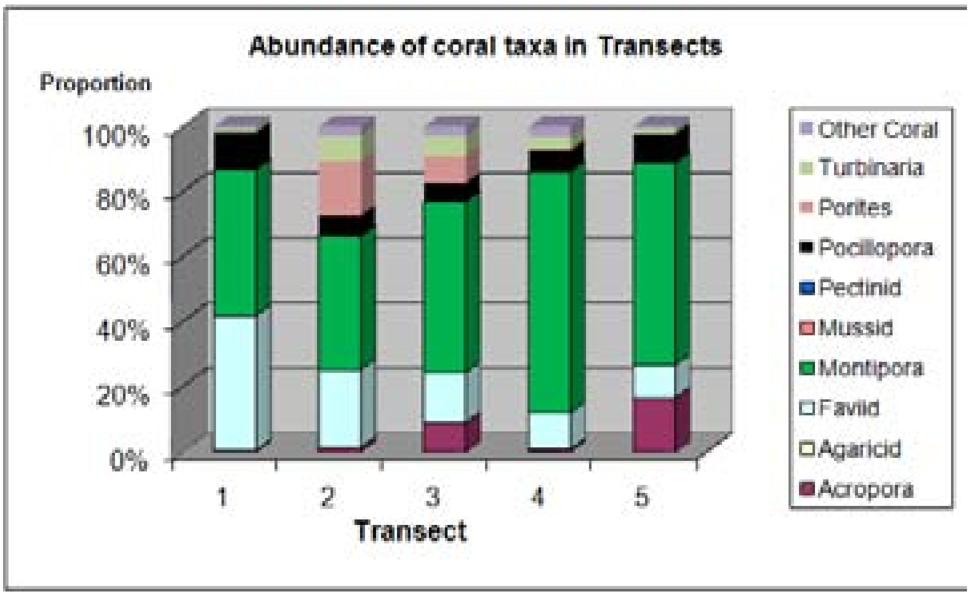


Figure 30. Community composition of WEEKS transects.



3.15 Ward Reef Northwest Shallow (WRNWS)

Live coral cover at WRNWS ranged from 43% to 64% (Table 17, Figure 31). It was almost completely composed of the genus *Montipora* (93%) (Figure 32). A small number of bleached *Montipora* were observed across all transects.

Table 17. Coral cover (%) at WRNWS.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	61.1%	14.8%	0.1%	0.0%	24.0%	2.5%	0.9%
2	43.0%	8.7%	0.0%	0.0%	48.4%	3.0%	0.3%
3	59.3%	9.0%	0.1%	0.0%	31.6%	3.9%	0.7%
4	64.4%	9.1%	0.0%	0.0%	26.5%	3.2%	0.2%
5	48.3%	12.9%	0.3%	0.0%	38.5%	1.8%	0.3%
Mean	**55.2%**	**10.9%**	**0.1%**	**0.0%**	**33.8%**	**2.9%**	**0.5%**
Std Dev	9.11%	2.77%	0.11%	0.00%	9.83%	0.79%	

Figure 31. Coral cover across the WRNWS transects.

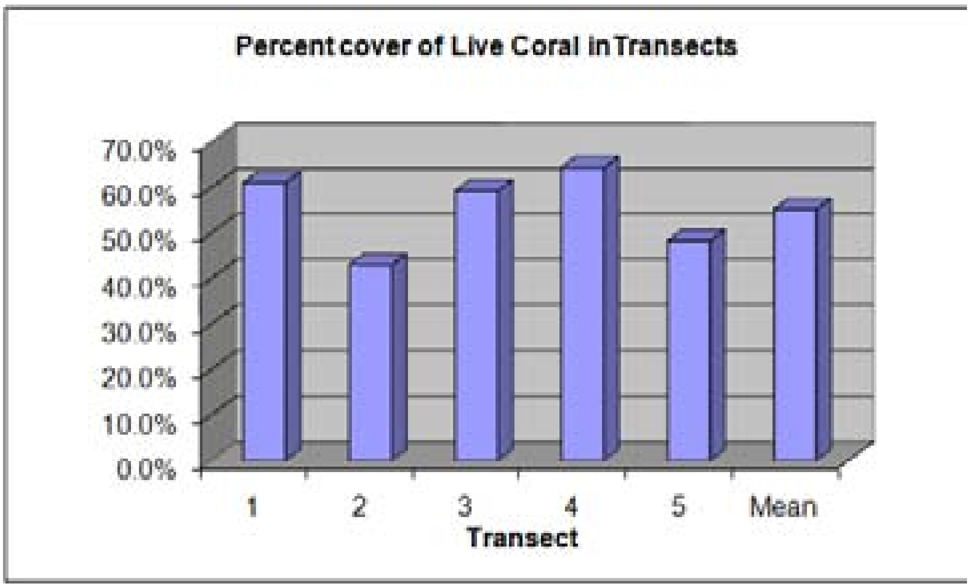
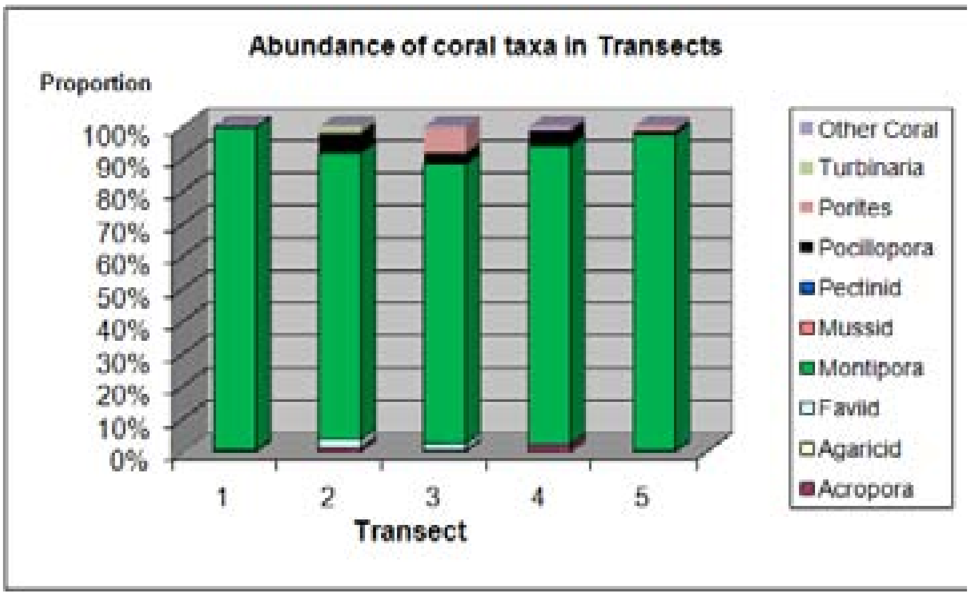


Figure 32. Community composition of WRNWS transects.



3.16 Ward Reef Northwest Deep (WRNWD)

Coral cover at WRNWD varied from 28% up to 53% (Table 18, Figure 33Figure 34). The community was composed almost completely of *Montipora* (91%) (Figure 34). A small amount of bleaching was observed on the *Montipora* corals.

Table 18. Coral cover (%) at WRNWD.

Transect	Live Coral	Flora	Fauna	Dead	Abiotic	Unknown	Bleached
1	44.1%	0.0%	0.1%	0.0%	55.8%	3.3%	0.0%
2	33.8%	0.1%	0.3%	0.0%	65.8%	1.7%	0.4%
3	53.6%	0.3%	0.3%	0.0%	45.8%	2.3%	0.0%
4	49.3%	2.5%	0.0%	0.0%	48.1%	2.2%	0.3%
5	28.7%	0.8%	0.0%	0.0%	70.4%	2.2%	0.0%
Mean	**41.9%**	**0.7%**	**0.1%**	**0.0%**	**57.2%**	**2.3%**	**0.1%**
Std Dev	10.43%	1.01%	0.14%	0.00%	10.76%	0.60%	

Figure 33. Coral cover across the WRNWD transects.

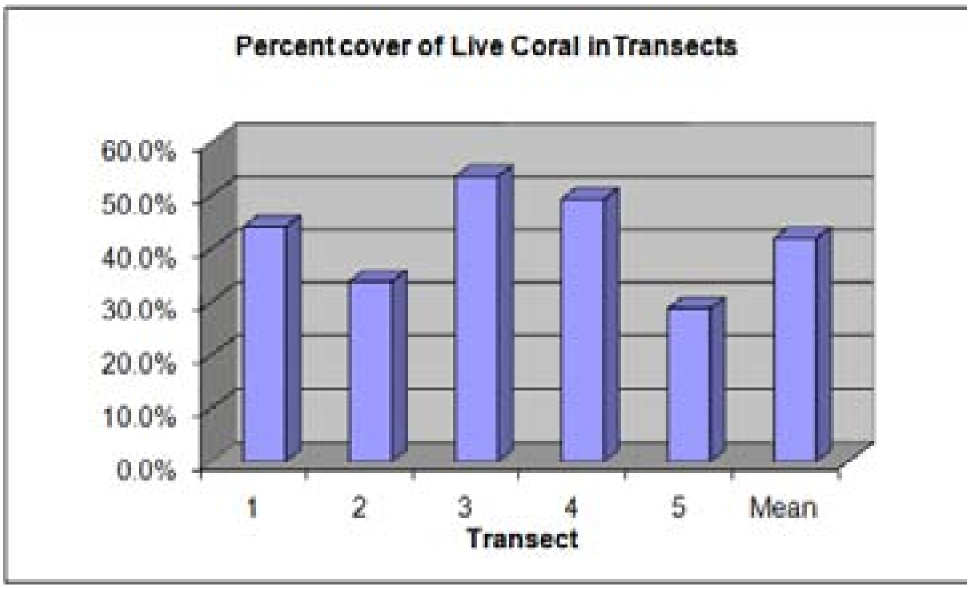
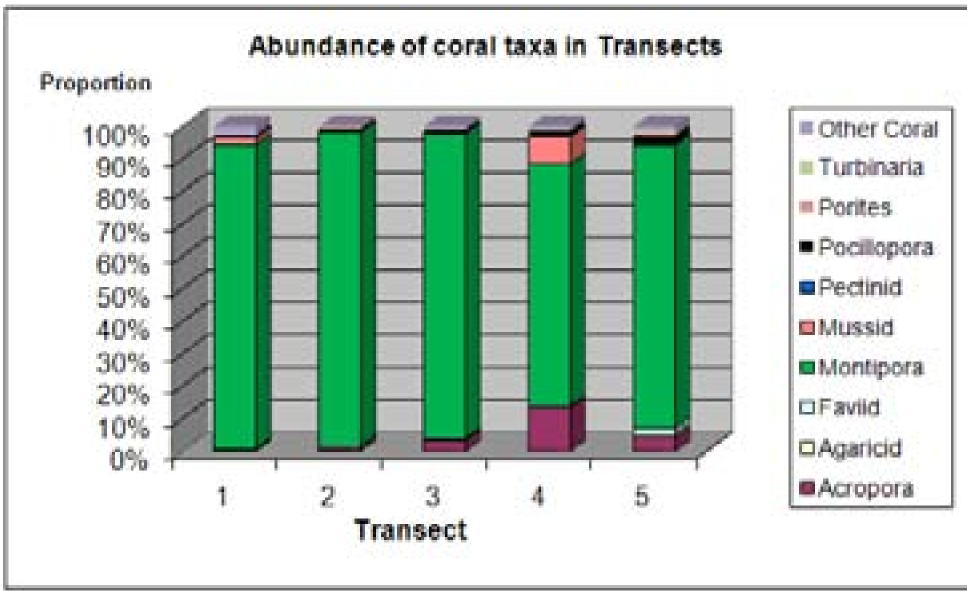


Figure 34. Community composition of WRNWD transects.

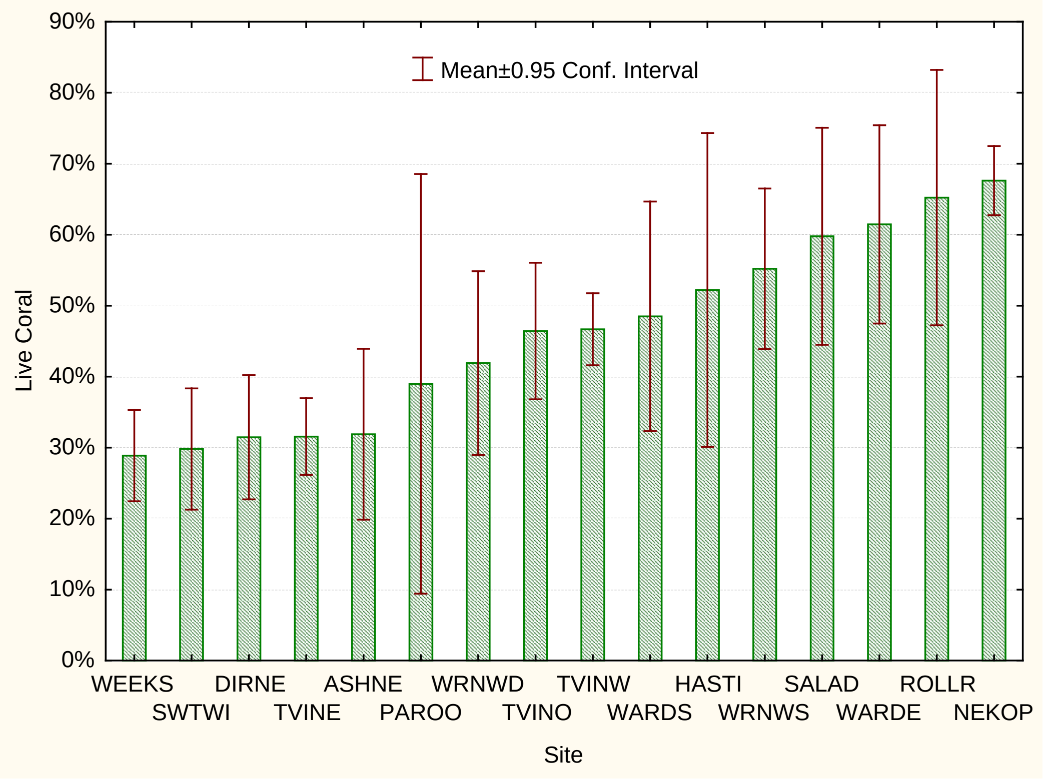


3.17 Comparison of Sites

Overall, the picture is of healthy coral communities with little bleaching, virtually no areas of freshly dead coral and generally low levels of macroalgal growth. This is a typical picture for coastal coral communities of the Pilbara Region during the dry winter period when thermal stress is low and macroalgal communities are in decline (MScience unpublished data). Only ASHNE at 4% shows a noticeable amount of bleaching – due largely to two colonies of *Pocillopora damicornis*, suffering from what may be a disease. Macroalgal cover was less than 2% at all sites except at WRNWS where a common alga (possibly *Hypnea pannosa* – pers comm. J. Huisman) covers an average of 11% of the substrate.

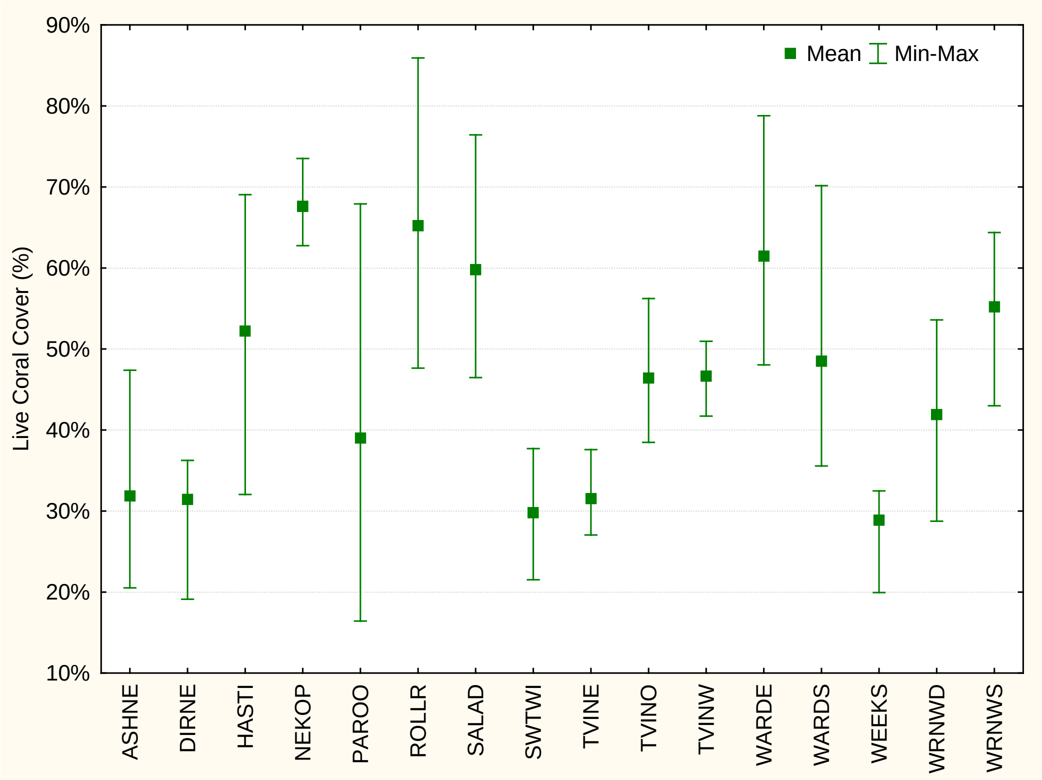
The sixteen sites surveyed here may be compared in terms of the cover of living coral or the taxonomic composition of communities. For coral cover, sites returned a continuous gradient from 29% at Weeks Shoal to 67% at NE Koolinda (Figure 35).

Figure 35. Mean cover of live coral at all sites.



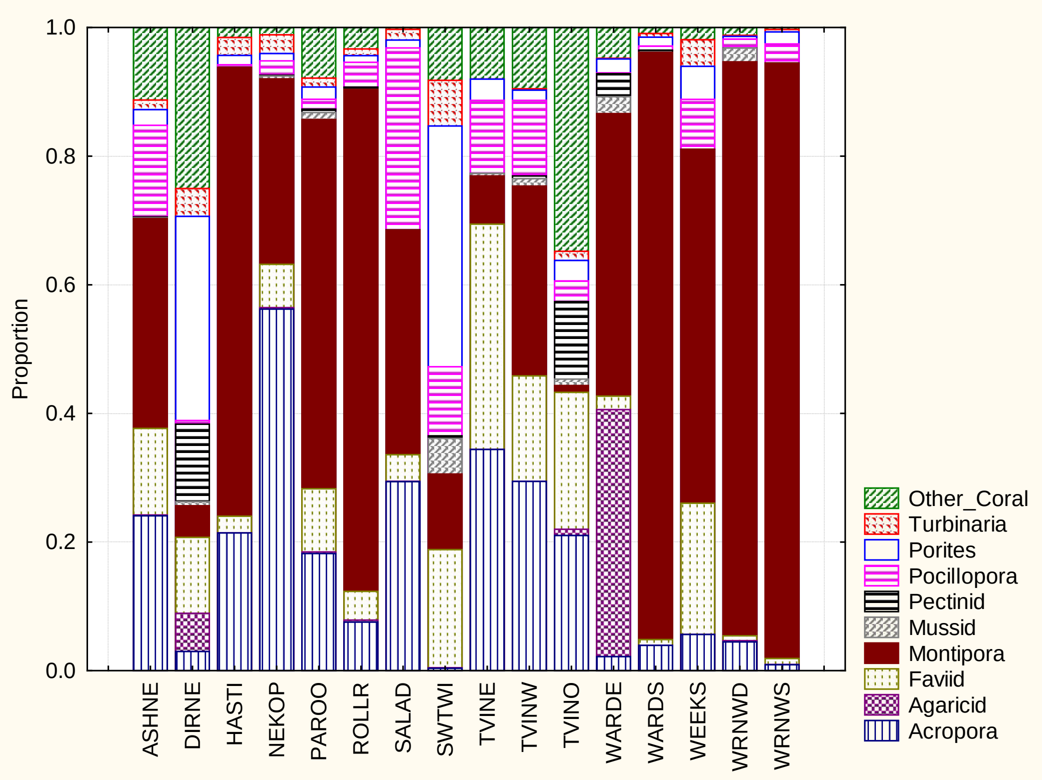
There is little capacity to group sites on the basis of coral density or to detect any spatial trend in cover. In examining the potential significance of coral cover at sites it should be remembered that the belt transects were selected to cover the highest densities of corals at a site rather than be representative of the cover density over large areas of the site. At some sites coral cover can be highly variable with transects varying by up to 5-fold from minimum to maximum (Figure 36).

Figure 36. Mean, maximum and minimum cover in coral transects at each site.



Much of the higher coral cover in this area is associated with spreading corals such as tabulate *Acropora* or plate *Montipora*, and those species dominate in assessments of community structure based on the abundance of coral cover (Figure 37).

Figure 37. Community composition at each site (alphabetic).



Community diversity at these sites varies from virtual monospecific stands of Montipora at WRNS, WARDS and WRNWD to highly diverse sites like DIRNE and SWTWI (Figure 38). In general, there is a negative relationship between coral cover and diversity, within which the Montipora-dominated sites stand out as of particularly low diversity (Figure 39). "High cover – low diversity" coral communities are usually considered to represent examples of stable (low levels of perturbation) environments (Connell 1978).

The above should be qualified with the provisos that diversity categories are our 10 morpho-taxonomic groupings (and not species) and that the assessment is based on cover rather than numbers of individuals.

Figure 38. Community diversity levels using the Shannon Wiener index (SWI).

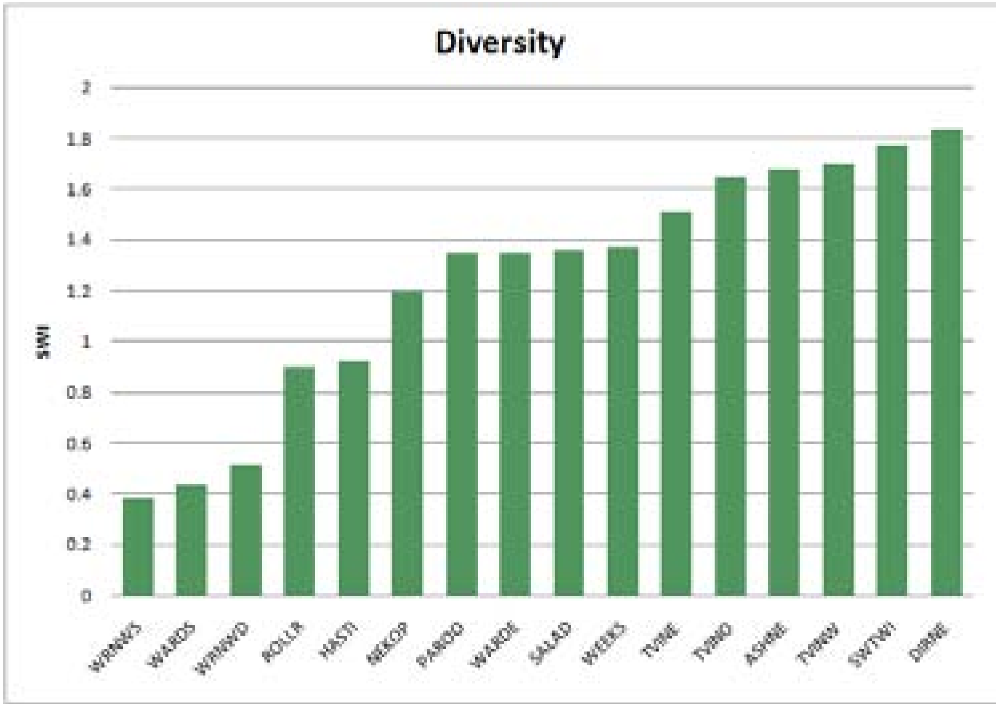
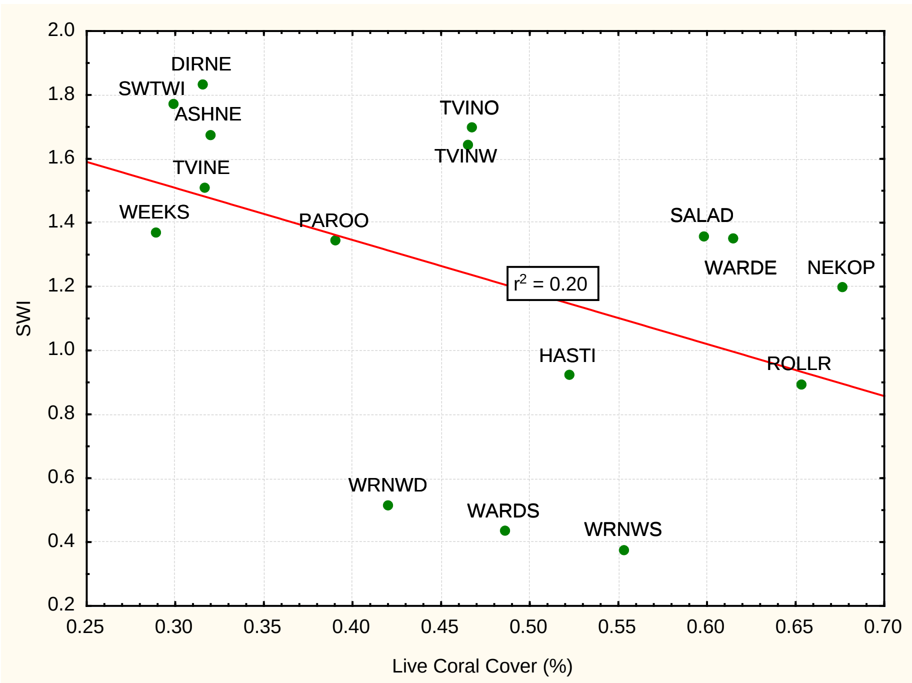


Figure 39. Relationship of community diversity to coral cover.



In evaluating whether distinct community types are present, it is possible to further reduce the complexity of the 10-group description of communities in Figure 37 through the use of Principal Components Analysis. PCA expresses the variation common to the various groups across sites within new components. A PCA based on the current data suggests that up to 60% of the total variance in the abundance of coral community groups can be explained by two components (Table 19).

Table 19. PCA matrix for the first two principal components of community structure.

	Component	
	1	2
Acropora	-.066	*.822*
Agaricid	.051	*-.518*
Faviid	*.606*	*.546*
Montipora	*-.852*	-.421
Mussid	*.501*	-.453
Pectinid	*.688*	-.171
Pocillopora	.066	*.624*
Porites	*.796*	-.337
Turbinaria	*.629*	-.161
Other Coral	*.778*	.084

Table 19 shows the degree to which the morpho-taxonomic groups are correlated with the composite components using PCA. As an arbitrary cutoff, factor loadings above 0.5 are highlighted to illustrate what the component represents. In this case, component 1 contrasts the dominance of Montipora with more diverse mixed coral communities. Component 2 contrasts the Acropora-Pocillopora (with Faviids) against abundant Agaricids. This second component appears to be an inshore-offshore indicator.

There are several methods of evaluating whether the coral communities seen at sites fall into distinct groupings. Community types at each site can be plotted on the first 2 principal components (Figure 40). Visual assessment of groupings emerging from that plot are characterised in Table 20.

A second method of producing groups is to retain the full 10 categories and produce an index of similarity (or dissimilarity) to produce hierarchical clusters (in this case using the average similarity of each cluster to compare with the next potential member). The classification so produced (Figure 41) is quite similar to the one based on PCA. The primary split in the groupings is based on whether communities are dominated by *Montipora*.

Figure 40. Coral communities at sites plotted on principal component axes.

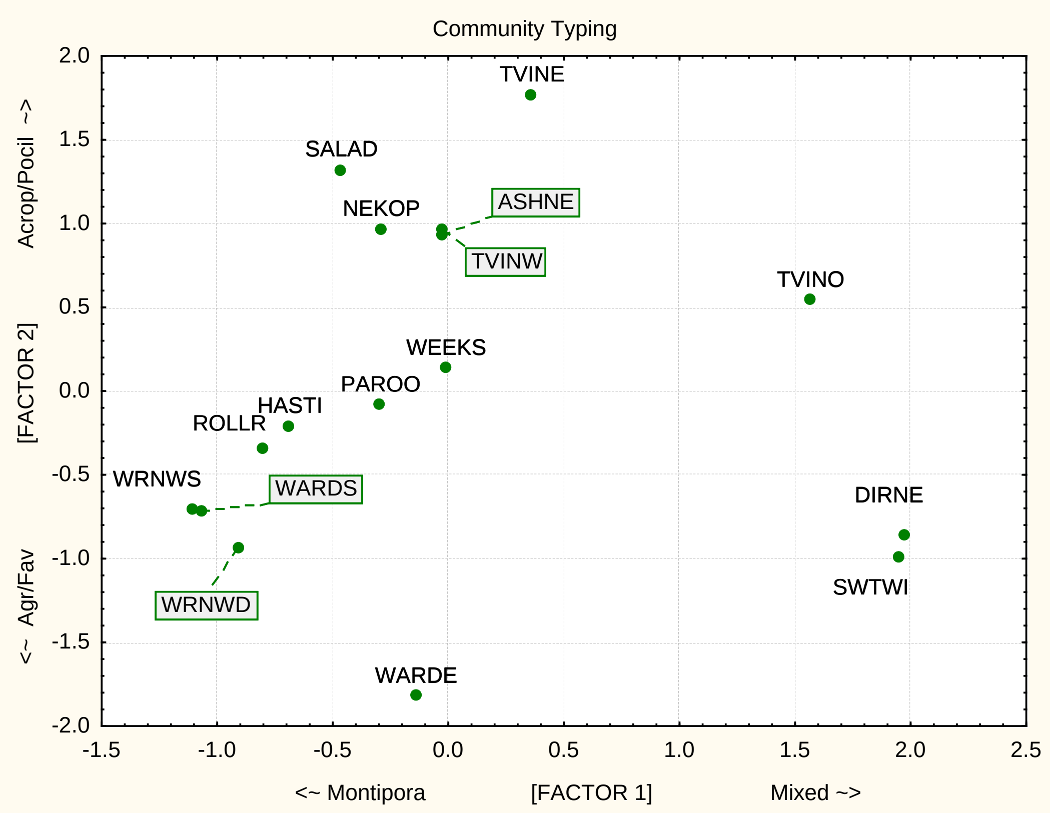
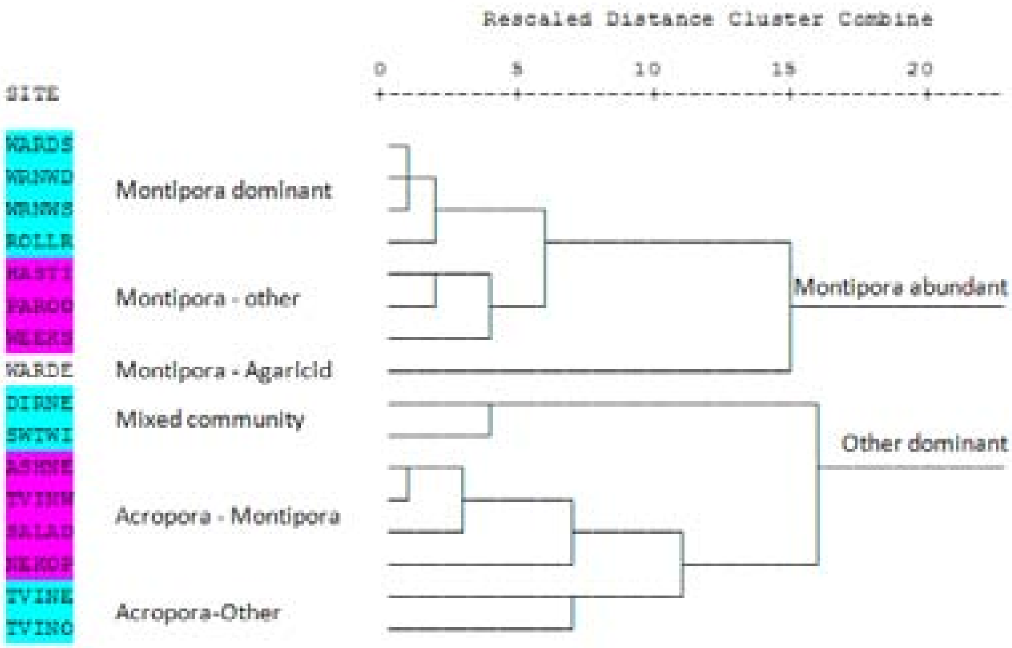


Table 20. Coral community groupings based on PCA.

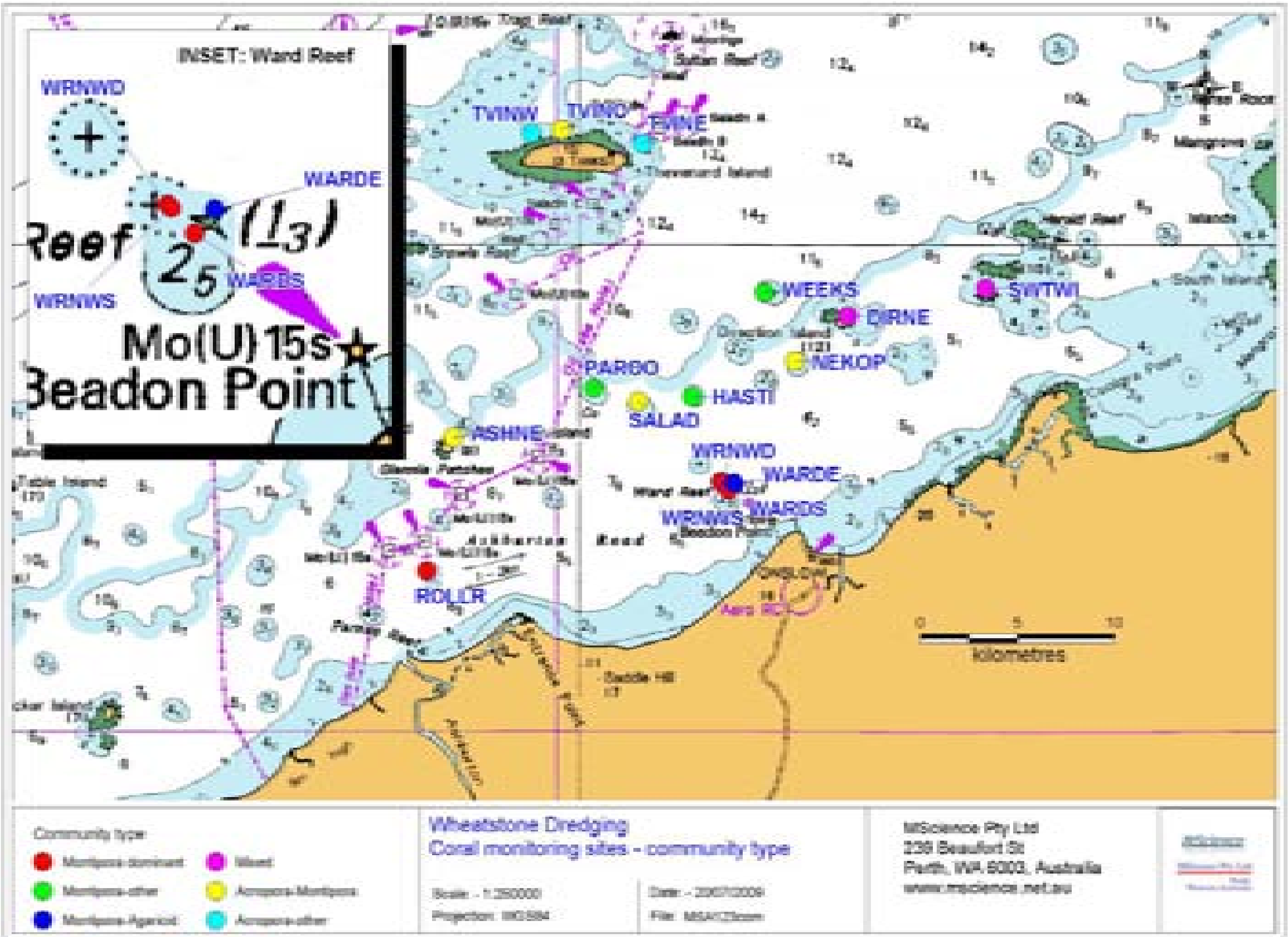
Group		Members
1.	Mixed – Low Acropora	DIRNE, SWTWI
2.	Mixed – Some Acropora	TVINO
3.	Acropora - Pocillopora	ASHNE, NEKOP, SALAD, TVINE, TVINW
4.	Montipora - dominated	HASTI, PAROO, ROLLR, WEEKS, WRNWD, WRNWS
5.	Montipora with Agaricid/Faviid	WARDE

Figure 41. Coral community groupings based on similarity clustering.



Applying the classification of Figure 41 to sites and mapping the result (Figure 42), suggests that there may be three zones of coral communities. An inshore zone where Montipora are highly dominant, a transition zone where *Montipora* are abundant but where other corals (including *Acropora*) may become dominant, and an offshore zone where *Acropora* becomes the dominant coral. Such a zonation could also be viewed as a simple gradient from inshore to offshore. Within the above, small-scale habitat variation might be responsible for community structuring, as evident in the variety of habitat types within the transition zone.

Figure 42. Map showing location of community types.



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3.18 Morphology of the Dominant Corals

Both Stafford-Smith (1993) and Gilmour et al. (2006) relate sediment tolerance in species of corals in part to the morphology of the colony growth form. The broad taxonomic groupings used here to characterise the coral communities surveyed contain a variety of species with differing morphology.

Table 21 provides an indication of the morphology of the most common representatives of these groups found in the sites surveyed here and lists their sensitivity to sediment impacts as provided by Gilmour et al.(2006).

Table 21. Colony morphology and sensitivity to sediment of the common representatives of taxonomic groups found at surveys sites.

Group	Morphology	Sensitivity*
Acropora	Mixed: tabulate or branching	High/Medium
Agaricids	Foliose	High
Favids	Massive	Medium
Montipora	Foliose/Encrusting	High
Mussids	Massive-submassive	n/a
Pectinids	Foliose	High
Pocilloporids	Branching	Medium
Porites	Massive	Medium
Turbinaria	Foliose-vase	Low
Other	Various	n/a

* after Gilmour et al. (2006)

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Appendix N8

Survey of Benthic Habitats near Onslow, Western Australia

Tables

Figures

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WHEATSTONE – SURVEY OF BENTHIC HABITATS NEAR ONSLOW, WESTERN AUSTRALIA

(15-70 metres)

Kris Waddington

Gary Kendrick

REPORT CMF 2009-010

PRODUCED FOR URS AUSTRALIA PTY LTD

CENTRE FOR MARINE FUTURES

THE UNIVERSITY OF WESTERN AUSTRALIA

Perth

November 2009

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EXECUTIVE SUMMARY

The current study used two remote survey methods – towed video and drop camera, to survey benthic assemblages between the depths of 15 and 70 metres in the vicinity of Onslow Western Australia. The objectives of the proposed study were to (i) characterise the benthic assemblages along the route of a proposed pipeline and place these assemblages into a regional context, and (ii) identify areas that may be important for turtle foraging in the region. Five towed video transects, ranging in length from 6 to 17 kilometres were surveyed. A further 53 sites identified from towed video footage as being above average complexity were surveyed using the drop camera system to gather quantitative estimates of cover of biotic groups. It should be noted that the towed video provides a characterisation of the area with some assessment of variability at a broad scale. The photoquadrats captured by the drop camera system provide a baseline for testing future impacts, assuming adequate temporal and spatial sampling in subsequent surveys.

Sand was the dominant substratum observed in the current study – comprising 75% of the substrata observed in the region, and over 90% of observed substrata in deep water (>40 metres). Sand typically formed large patches greater than 200 metres in length. Biotic communities associated with sand habitats were typically sparse and dominated by mats of red microalgae. Low profile reef and sand inundated reef were the other substrata observed in the study area. Areas of reef were most commonly observed in shallow waters (<20 m) on the shallow inshore shelf and on the offshore slope to 40 m depth. These substrata were also more commonly observed on transects A and B. Biotic communities associated with low profile reef were more dense than the biotic communities on sand inundated reef. These areas were typically "sponge gardens" with biotic composition dominated by sponges, red algae and brown algae. Biotic communities associated with sand inundated reef were dominated by sponges and red algae, with hydroids, sea whips and soft corals also common.

Benthic assemblages were also found to differ with depth. In general, biotic communities in deep water were observed to be sparser than those in shallower areas (<40 m). This is likely due to the greater occurrence of low profile reef and sand inundated reef in areas less than 40 m depth. Differences in the composition of biotic communities were also observed with depth, thought these likely reflect the lower coverage of biota in deep water areas (>40 metres).

Benthic assemblages differed among transects, with depth and between areas of potential impacts, indicating large natural spatial variability across the study area. Biotic communities along the route of the proposed pipeline also showed significant (albeit weak) differences to biotic communities on the other transects, with less red algae and sponges and more red algal mat, brown algae and sea whips. Finally, a number of areas that may be important for turtle foraging were identified in the current study. These areas contained above average abundance of sessile invertebrates. Such areas were most commonly encountered on the shallow nearshore shelf (<20 m depth), and on the offshore shelf to 40 m depth and were typically associated with low profile reefs.

INTRODUCTION

As part of the Wheatstone LNG project, towed video and drop camera surveys were undertaken between the depths 15 and 70 metres in the region of Onslow, Western Australia. Surveys were undertaken by the Centre for Marine Futures (CMF), The University of Western Australia (UWA). The study had the following objectives:

- To establish a baseline of benthic communities present along a proposed pipeline route and determine if these communities are comparable in density and composition to other benthic communities occurring in the study area.
- To identify general patterns in benthic composition across the study area and identify factors that may explain any observed variation in benthic composition.
- To identify areas of sessile invertebrates that may be important areas for foraging turtles.

Benthic communities in the north-west shelf region of Western Australia are influenced by both the Indonesian through-flow and Leeuwin Current – the major currents affecting this region (Batteen et al. 1992; Meyers et al. 1995). These major currents link coastal areas in the region with offshore areas. Cyclones, semi-diurnal tides and outflow from the Ashburton River (primarily during the wet season) are also important for the structuring of benthic communities in this region (Holloway 1983). Coastal development and trawling are the main human activities that may also affect benthic communities of this region (Fulton et al. 2006).

Populations of flatback (*Natator depressus*) and green turtles (*Chelonia mydas*) are also known to occur in this region. Evidence suggests turtles are present in the region year round and nest on nearby Islands (Pendoley 2005). Flatback turtles are thought to forage over soft bottom habitats supporting sea pens and sessile invertebrates while green turtles are thought to forage in the vicinity of seagrass and algal beds (Pendoley 2005). These habitats occur across the region in coastal waters less than 100 m in depth. While work to determine turtle habitat utilisation in the region is ongoing, an understanding of benthic assemblages in the study area will contribute to understanding the importance of the area for turtle populations.

The current study used two techniques to survey benthic communities – towed video and drop camera. Towed video was used for the classification of benthic assemblages on broad spatial scales (kilometres), while drop camera was used for quantitative estimation of the cover of benthic groups on a fine spatial scale (metres). Both of these systems were combined with the software package StarFix, an Ultra Short BaseLine (USBL) system and differential Geographical Positioning System (GPS), allowing the captured footage and images to be precisely geo-referenced. It should be noted that the towed video provides a characterisation of the benthic assemblages within the study area. The photoquadrats provide a baseline for testing future impacts, assuming adequate temporal and spatial sampling in future surveys.

METHODS

Study Area

The study area was offshore of Onslow (21° 41' S; 115° 08' E), Western Australia (Figure 1a, 1b). Benthic assemblages between the depths of approximately 15 and 70 metres were surveyed in this study. This region is characterised by a shallow nearshore shelf area that extends seawards from the beach slope. These nearshore shelves are marked at the outer edge by a shelf break at approximately 20 m deep. Beyond the shelf break, the offshore slope extends below 70 metres depth. For a more detailed description of the terms used here, please see Pickrill (1983). The study area surveyed encompassed shallow nearshore areas (<20 m; herein described as shallow water), the shelf break at approximately 20 m depth (including shallow water areas <20 m and mid depth areas between 20 m and <40 m), and areas of the offshore slope (including mid depth areas between 20 m and 40 m, and deep water areas between 40 and 70 metres). With the exception of previous hydroacoustic surveys along the proposed pipeline route, very little is known about the seabed in this region. Benthic communities were surveyed using two techniques, towed video and drop camera. These methods are described in detail below.

Towed Video

The towed video system was used for the broad-scale classification of benthic assemblages. Towing speed ranged between one and three knots over predetermined transects on the seafloor. Precise geographical positioning was provided using the software package Starfix coupled with an Ultra-Short Base-Line (USBL) positioning system.

Video footage from towed video surveys was analysed according to substrata and biotic composition. Footage was analysed using a "continuous method" where segments of similar substrata and biota were identified and classified separately. The list of categories used to classify video footage is provided in Table 1. When classifying assemblages, the percent cover of substrata and biotic group in the habitat segment was visually estimated. Where trace amounts of biotic coverage were observed, these were recorded as "Trace". When analysing these data, trace amounts of biota were estimated as 0.1% coverage. Estimates of percent coverage were provided to separate frequently observed groups from those rarely seen. Given the variation in the field of view of the footage and visibility, results should be interpreted in this context. As opposed to the qualitative information provided by towed video surveys, drop camera surveys were used to provide quantitative information on benthic assemblages.

Drop Camera

The drop camera system provided still photographs (photo-quadrats) of benthic assemblages and was used to quantify percent cover of different benthic groups on a finer scale (metres). The drop photo method of sampling used a remotely triggered camera system mounted on a steel frame. The system consisted of two cameras – the first camera was situated at an angle and provided a video feed to the winch operator aboard the boat, allowing the camera frame to be positioned upright on the substrata. The second camera was positioned over a fixed quadrat and captured a high resolution photo-quadrat (573 x 376 mm) of the sea floor. When capturing images, the boat was positioned over a site and the drop photo system lowered using a winch. As the boat drifted over the site, the drop photo system was raised, then lowered. Each time the frame was lowered to the bottom, an image of the seafloor was captured, providing a series of ten benthic images for each site. The geographic position of each captured image was determined using a differential GPS coupled with an USBL positioning system. Composition of benthic habitat classes was assessed using the in-house image analysis program, "JEHP". This program used a point intercept method whereby 50 points were overlaid on each image using a random approach. The benthos at each of these points was then classified according to the benthic groups in Table 2. The benthic categories included four abiotic and 31 biotic groups (Table 2). When image quality was insufficient for identification of biotic groups, or taxa were unable to be identified, points were classified as "Unknown – Image Quality" or "Unknown –

Identification" respectively. In instances where taxa were recorded as "Unknown – Identification", efforts were made to later identify taxa in consultation with senior scientists.

All surveys were undertaken from the Calypso Star, a Broadsword Marine Contractors vessel based in Darwin. The sampling team consisted of five members; two to operate the winch and deploy/retrieve the camera systems, one to coil the umbilical, one to communicate the position of the camera system above the sea-floor and one to operate the spatial positioning software and capture the footage/ images. UWA and URS Australia Pty Ltd personnel were mobilised from Perth to Karratha where they boarded the boat and travelled to the study area. Sampling occurred over six consecutive days from 26th to 31st August 2009.

Sampling Plan

The location of the towed video survey transects were selected following discussion with URS. One transect was situated along the proposed pipeline route (transect C), with a further four transects (two to the south-west – transects A and B; two to the north-east – transects D & E) selected to cover the area of interest and provide regional context for habitats observed along the proposed pipeline route (Figure 1a). All transects were selected to cross the shelf break in the region, running from approximately 15 metres depth to 70 metres depth (though the transect along the pipeline route began at 13 metres depth) (Figure 1a). Results from towed video surveys along the pipeline route also can be used to ground-truth results from hydroacoustic surveys previously conducted.

Following towed video surveys, drop camera surveys were undertaken to provide quantitative information on benthic communities of interest along the towed video transects (Figure 1b). Sites for drop camera surveys were selected by UWA and URS following towed video surveys. The following criteria were used to select sites for drop camera surveys:

- Sites with high complexity, density and diversity of benthic communities.
- If present, sites covering a range of biotic habitats.
- Sites were selected from each of the five towed video transects so as to be spatially distributed across the entire study area.
- Where possible, sites that were separated by at least 100 metres.

- Where possible, sites covered the surveyed depth gradient – though the greater complexity of benthic communities in shallow water meant that sampling effort was skewed towards shallow water communities.

To provide a greater understanding of the range of habitats present along the route of the proposed pipeline, additional drop camera sites were surveyed along transect C. A summary of sampling effort by transect is provided in Table 3.

Statistical Analysis

A list of key statistical terms used to analyse data are included in Appendix 1.

Towed Video

Percentage cover of substrata and biota for each habitat segment was estimated from video analysis. The lengths of these habitat segments along a transect were calculated from eastings (m) and northings (m) using Pythagoras' theorem. A standardised measure for substrata and biotic cover was then calculated by multiplying the percent cover of each group by the patch length (see example below). Standardising estimates of percent coverage against patch length removes the bias of estimating percent coverage of different sized patches, providing a more accurate representation of benthic assemblages.

Example of standardising procedure.

Patch Length (m)	Cover Biotic Group A (%)	Cover Biotic Group B (%)	Standardised Cover Group A	Standardised Cover Group B
70	1	90	70	6300
33	65	30	2145 (i.e. 33 x 65)	990
12	80	15	960	180
150	25	60	3750	9000

Towed video data were also used to estimate the area likely to be impacted by the pipe-lay trial. This analysis was undertaken using the percent cover estimates for each biotic group on each transect, assuming biotic groups on transect C are disturbed, and assuming the width of the area disturbed by the pipe-lay trial is 50 metres.

A four way Permutational Analysis of Variance (PERMANOVA) (Anderson 2001) was used to compare patch length among the factors Impact (fixed; 2 levels), Transect (random; nested in Impact), Depth (fixed, 3 levels) and Substrata (fixed; 3 levels). Patch length was chosen as a metric to describe benthic assemblages as it gives a measure of the spatial extent of different habitats. The factor "Impact" was included to examine differences in benthic community between the pipeline likely to be impacted by the proposed pipeline (transect C) and those unlikely to be impacted by the proposed pipeline (transects A, B, D, and E). The PERMANOVA test was undertaken on square root transformed data and based on Euclidean distance. Where significant variation was detected, pairwise tests were used to identify differences between pairs of groups.

The composition of benthic assemblages was also investigated using multivariate techniques. Standardised data were used for multivariate analysis with analysis undertaken on the standardised coverage of biota observed on each habitat patch. Patterns in community structure were illustrated using non-metric Multidimensional Scaling (nMDS) based on a Bray-Curtis similarity matrix (Clarke and Warwick 2001). All biotic data were square root transformed to reduce the influence of dominant habitat categories. Patterns in biotic community structure were illustrated separately for each of the factors Transect (random factor; nested in Impact), Depth (fixed factor; 3 levels) and Impact (fixed factor; 2 levels). Separate analysis of similarity (ANOSIM) tests (Clarke and Warwick 2001) were also undertaken to determine the extent to which each of the factors could explain observed variation in biotic community composition. Where differences were detected using ANOSIM, pairwise tests were performed to find groups that significantly differed ($p<0.05$) and the percentage contribution of benthic groups to observed differences were assessed using the SIMPER routine in the PRIMER package (Clarke and Warwick 2001).

Drop Camera

Sites were chosen that represented areas of maximum biotic complexity (using a stratified haphazard approach), thus comparisons apply only to these communities. The percent cover of total biota was first determined for each site. Abiotic groups (sand, gravel, sand inundated reef, and bare rock) were then removed and a three way PERMANOVA (Anderson 2001) was used to compare biotic cover among the factors Impact (fixed factor; 2 levels), Transect (random factor; nested in Impact) and Depth (fixed factor, 3 levels). The PERMANOVA was undertaken using square root transformed data and was based on Euclidean distance.

Where significant variation was detected, pairwise tests were used to test for differences among pairs of groups ($p<0.05$).

Variation in the composition of benthic assemblages was investigated using multivariate approaches. So that patterns in assemblage structure were not masked by the dominance of abiotic groups, analysis was undertaken using only the biotic groups, with analysis restricted to sites with coverage of greater than 2% biotic coverage. Prior to analysis, data were square root transformed to reduce the influence of dominant habitat classes and maintain the influence of sparser habitat classes. Patterns in assemblage structure were illustrated using non-metric Multidimensional Scaling (nMDS) based on a Bray-Curtis similarity matrix (Clarke and Warwick 2001). Separate ANOSIM tests were used to determine the extent to which variation in biotic community structure could be explained by the factors Transect (random; nested in Impact), Depth (fixed, 3 levels) and Impact (fixed; 2 levels). The percentage contribution of each benthic group to any differences observed between transects', depths and with impact were then assessed using the SIMPER routine.

RESULTS

Overview

A total of 53.1 kilometres of towed video and 53 drop photo sites were surveyed across the study area (Figures 1a, 1b; Table 3). Transect C (along the proposed pipeline route) was the longest transect surveyed (17 kilometres) and also had the greatest number of sites surveyed using the drop photo system (n=18). Representative photos of observed substrata and biotic groups are included in Appendix 3.

Towed Video

In total, 260 habitat patches were observed in the current study. These patches had a mean length of 210 ± 26 metres (s.e.) (Table 4). Sand patches were most frequently observed and largest compared to the reef categories (Table 4). Only one patch of medium profile reef was observed in the current study (82 metres long on transect A in the 20-40 depth class) (Table 4). Due to the low occurrence of medium profile reef, this category was excluded from formal statistical analysis. A summary of habitat patches by substrata and transect is included (Table 4), while the percent cover of biotic groups has been determined by transect for mid-depth systems and for all depths (Table 5).

Area Likely to be Impacted by the Pipe-Lay Trial

The mean algal cover in the 48,000 ha area of the UWA study was 4.99%, the mean filter feeder cover was 3.36%, while the mean soft coral cover was 1.27%. *Halophila* sp. coverage was estimated to be 0.02%. The pipe-lay trial will disrupt an estimated 10.4 ha of transect C. At an average 3.82% algal coverage observed for transect C, approximately 1.58 Ha of algae is expected to be disturbed from transect C. This represents 0.064% of the estimated coverage of macroalgae within the study area. At an average 2.55% filter feeder coverage observed for transect C, approximately 1.02 Ha of filter feeders is expected to be disturbed from transect C. This represents 0.063% of the estimated coverage of filter feeders in the study area. At an average 1.47% soft coral coverage observed for transect C, approximately 0.59 Ha of soft coral is expected to be disturbed from transect C. This represents 0.096% of the estimated coverage of soft corals in the study area. As no seagrass was observed on transect C during the UWA study, no seagrass is expected to be disturbed during the pipe-lay trial.

Results of the four way PERMANOVA identified a significant interaction between patch length and the factors Impact, Depth, and Substrata, indicating patch length varied according to an interaction of these factors (Table 6), suggesting patch length was not consistent among factors. Pairwise tests were undertaken to identify the sources of variation in patch length (Tables 7-9). When examining pairs of levels for the factor Impact, no differences in patch length were observed between the transect likely to be impacted, transect C, and the other transects (Table 9).

Figure 2 shows the occurrence of substrata and biota for all transects surveyed in the current study. Sand was the dominant substratum observed on all transects and was particularly common on transects C, D, and E (Table 10; Figure 2). Transect A was observed to have the most sand inundated reef and low profile reef, with low profile reef also common on transect B (Table 10; Figure 2). The density of biota on sand areas was generally low and dominated by red algal mat, with crinoids, red algae (foliose and filamentous forms) and hydroids also present. Of the three substrata observed in the current study, low profile reef had the greatest density of biota (Figure 2). Sponges, red algae and brown algae dominated low profile reefs on transects A, B and C, while sponges and red algae were the dominant biota observed on the reefs of transect D (Table 11; Figure 2). In contrast, low profile reef on transect E was dominated by hydroids, though sponges and red algae were also common (Figure 2). The density of biota on sand inundated reefs was generally higher than that on sand but lower than that on low profile reefs (Figure 2). Biotic assemblages on sand inundated reef were dominated by sponges and red algae on transects A and B, with sponges, sea whips, red algae and red algal mat frequently observed on transect C (Figure 2). Sponges, soft corals and red algae were the dominant biota on transect D (Table 11; Figure 2). As for low profile reefs on transect E, sand inundated reefs on this transect were dominated by hydroids, sponges and red algae (Figure 2).

The occurrences of substrata and biota were also summarised among three depth classes; shallow (<20 m), mid-depth (20-40m), and deep (>40 m) (Table 12, 13; Figure 3). Shallow areas correspond to areas of the shallow nearshore shelf, while mid-depth and deep areas are both situated on the offshore slope (Pickrill 1983). Sand was observed to be the dominant substratum at all depths, and was particularly abundant on deeper areas of the offshore slope (Table 12; Figure 3). Sand inundated reef and low profile reef were most commonly observed in shallow areas and at mid depths (Table 12; Figure 3). The highest density of biota was observed on low profile reef, with lower densities observed on sand inundated reef, and the lowest density of biota occurring on sand (Figure 3). Sponge and red algae were observed on all three substrata in shallow water (Figure 3). In addition to sponge and red algae, green algae were common on shallow water sand areas, brown algae and sea whips were common on low profile reef, while sea whips were also common on sand inundated reef (Figure 3). Crinoids, hydroids, red and green algae and red algal mat all occurred on sand at mid-depths. Brown algae, sponges and red algae were commonly observed on low profile reefs at these depths, while sponges and red algae were the biota most common on sand inundated reef. In deep water, red algal mat was the most commonly observed biotic group on sand (Figure 3), while sponges and red algae were the most commonly observed biotic groups on sand inundated reef and low profile reef (Figure 3).

Differences in the composition of biotic communities were observed between transects based on multivariate analysis of towed video data. While these differences were not clearly apparent from the nMDS plot (Figure 4), an ANOSIM test indicated significant differences in biotic communities exist among transects (Clarke's R = 0.159, p = 0.001, permutations =

999). While significantly different, the low value for Clarke's R indicated the magnitude of differences between transects was relatively small and that other factors also likely contributed to patterns in biotic community structure between transects. Pairwise tests indicated transect A had significantly different biotic compositions to all other transects and transects B & E; and D & C also differed significantly ($p<0.05$) (Table 14). SIMPER analyses indicated it was the lower abundance of red algal mat and higher abundance of sponges on transect A relative to the other transects that drove observed differences between transect A and the other transects (Appendix 2; Tables 1-4). Higher abundance of red algae on transect A relative to transects C, D and E also contributed to observed differences (Appendix 2; Tables 2-4), though the reverse patterns are true when comparing transects A and B (Appendix 2; Table 1). Higher occurrence of red algae and red algal mat on transect B compared to transect E was found to drive differences between these transects (Appendix 2; Table 5). These biotic groups were also important for explaining observed differences between transects D and C (Appendix 2; Table 6).

Significant differences in the composition of biotic communities among depth classes were also observed (Figure 5). An ANOSIM test identified significant differences in biotic community composition among depth classes (Clarke's R = 0.235, p = 0.001, permutations = 999), with pairwise tests indicating the biotic composition of all depth classes significantly differs ($p<0.05$) (Table 15). SIMPER analysis indicated it was low abundance of red algae, sponge and brown algae at depths <20 m compared to the 20-40 m range that was primarily responsible for driving observed differences in biotic community composition (Appendix 2; Table 7). It was the very high occurrence of the red algal mat and low occurrence of red algae in deep water (>40 m) that was responsible for driving differences between these communities and communities occurring in shallow water (<20 m), and at "mid-depths" (20-40 m) (Appendix 2; Tables 8, 9).

Finally, significant variation in biotic communities was observed based on the factor Impact (Clarke's R = 0.088, p = 0.002, permutations = 999). The low value for Clarke's R indicated that despite statistical differences existing, the magnitude of the differences between biotic communities of transects likely and unlikely to be impacted was small. This was further demonstrated by the overlap of points on the nMDS for the factor Impact (Figure 6). This distribution suggested that despite statistically significant variation in the structure of biotic communities as a function of Impact, the ecological meaningfulness of these differences is unclear. Further investigation using SIMPER analysis indicated it was primarily lower abundances of red algae and sponge on the transect likely to be impacted (transect C) that were responsible for observed differences (Appendix 2; Table 10).

Drop Camera

Figure 7 shows the occurrence of biotic groups by both depth and transect. Sites located along transects A, B, and C differed in composition to sites on transects D and E (Figure 7). Accordingly, results will be presented separately here. Biotic coverage of sites on transects A and C in shallow water (<20 m) (no sites were sampled at this depth on transect B) were dominated by foliose algae, with some sponge and soft corals also observed (Figure 7). At mid-depths (20-40 m), foliose algae along with algal mat were observed to be important contributors to biotic coverage for sites on transects A, B, and C. At deeper depths (>40 m), biotic coverage was again dominated by algal mat – particularly for sites on transects A and C, with sessile invertebrates such as ascidians, sponges and bryozoans frequently observed on transect B sites. These sessile invertebrate groups were also present at deep-water sites located along transects A and C.

In terms of sites surveyed along transect D and E (Figure 7), shallow water sites (<20 m) on transect D were dominated by algal mat and encrusting coralline algae, with sponge also abundant (Figure 7). At mid-depths (20-40 m), sites along transects D and E were dominated by sessile invertebrate such as non-encrusting bryozoans, soft corals/gorgonians, and sponges. Deep water (>40 m) sites located on transect E were dominated by hydroids, crinoids, and non-encrusting bryozoans (Figure 7).

A three way PERMANOVA was used to investigate variability in biotic cover among the factors Impact, Transect and Depth. A significant interaction was identified between the factors transect (impact) and depth (Table 16), indicating that the way total biotic cover varied with depth also depended upon the transect. Pairwise tests determined that differences in total biotic coverage existed between the shallow and deep sites on transect C and between the depths mid-depths and deep sites on transect E (Table 17).

Significant differences in benthic assemblages were observed between transects based on multivariate analysis of the drop camera data. An nMDS plot of benthic assemblage data demonstrated separation in sites based on the factor "transect" (Figure 8). Subsequent analysis using ANOSIM verified benthic assemblages of sites along different transects were statistically significant (Clarke's R = 0.39, p = 0.001, permutations = 999). Pairwise tests indicated significant differences in benthic assemblage structure were present between all transects except transects D & E; and D & B (Table 18).

Similarity Percentages (SIMPER) analyses were undertaken to determine which benthic groupings contributed most to the observed dissimilarity between transects and depths. Algal mat was consistently a major contributor to observed variation between sites on transect C and those on the other transects (Appendix 2; Tables 11-14). Transect C had consistently higher coverage of algal mat compared to transects D and E (Appendix 2; Table 11, 12), but lower coverage than both transects A and B (Appendix 2; Table 13, 14). A full list of benthic groups contributing to differences in assemblage structure is included in Appendix 2.

Significant differences in benthic assemblage structure with depth were also identified (Figure 9; Clarke's R = 0.21, p = 0.001, permutations = 999). Pairwise tests indicate benthic assemblages occurring in deep water differed significantly to benthic assemblages in shallow water and mid-depths (Table 19). Differences between shallow water assemblages and deep water assemblages were primarily driven by higher abundance of red algae, brown algae and algal mat in shallow water (Appendix 2; Table 19), while observed differences between mid-depths and deep water were driven by higher abundances of algal mat, non-encrusting bryozoans, sponges, unknown algae (foliose), brown algae and red algae at mid-depths compared to deep water (Appendix 2; Table 20). Observed differences in biota with depth may also have been due to lower coverage of biota in deep water compared to shallow water (Figure 10).

Differences in benthic assemblages were also investigated according to factor "Impact". Benthic assemblages were found to be significantly different based on the factor Impact (Figure 11; Clarke's R = 0.141, p = 0.011, permutations = 999). SIMPER analyses indicated differences in benthic assemblages between sites likely and unlikely to be impacted were driven by lower abundance of algal mat, red algae, sponge, unknown foliose algae and non-encrusting bryozoans at sites on the transect likely to be impacted relative to sites unlikely to be impacted (Appendix 2; Table 21). Of the species driving 60% of the differences between sites likely and unlikely to be impacted, brown algae and sea whips were the only biotic groups more abundant at the potentially impacted sites (Appendix 2; Table 21).

Assessment of Unknown Groups

The use of a high quality camera and external light source provided image quality that was sufficient to identify all taxa within photo-quadrats to the level of taxonomic resolution employed in this study. In rare cases where a part of the captured image was obscured, the program JEHP allowed for such points to be classified as 'unknown - image quality'. Of the 53 sites surveyed in the current study, only two sites had any points classified as 'Unknown – Image Quality'. In total, only three of the classified points (0.01%) were classified as unknown due to image quality in the current study, indicating image quality had a negligible effect on identification of biotic groups. Further, no points observed during the current study were unable to be identified to the level of taxonomic resolution specified.

DISCUSSION

The current study set out to characterise the benthic assemblages occurring along the route of the proposed pipeline (transect C in this study) and place these benthic assemblages in a regional context. The combination of towed video and drop camera systems was effective at characterising the benthic assemblages occurring in the study area. Benthic assemblages in the study area were determined to be highly variable according to an interaction of the factors depth, transect, potential impact and substrata. This indicates benthic assemblages occurring in the study area had high natural variability. Sand was found to be the dominant substrata in the study area, comprising over 75% of all surveyed substrata in the region. In deeper areas of the offshore slope (>40 m), sand was even more dominant – representing over 90% of surveyed substrata. Sand habitats at these depths were typically large – forming habitat segments hundreds of metres long, explaining why habitat patches in deep water were larger than those observed at shallower depths. The biota occurring on sand habitats was sparse with the composition dominated by red algal mat (particularly in deep water), though hydroids and crinoids were also present. Low profile reef was also commonly observed in the study area, particularly at shallow (<20 m) and mid-depths (20-40 m), and on transects A and B. Of all substrata observed, low profile reefs were observed to have the highest density of biota, with biota characterised by sponges, red algae and brown algae.

These biota commonly formed areas of "sponge garden" on low profile reef. Similar sponge garden communities have been observed on reef habitats in the nearby Dampier Archipelago (Fromont et al. 2006), while many species of marine algae have also been recorded in the region (Huisman and Borowitzka 2003). The third major substratum observed in the current study was sand inundated reef. This substratum refers to areas of low profile reef covered with an established layer of sand, and with biota characteristic of a reef ecosystem (Appendix 3). Sand inundated reef was most common at shallow and mid-depths and on transect D and E. The biotic composition of this substratum was characterised by sponge and red algae, with hydroids, sea whips and soft corals also common. The biotic composition of low profile reef and sand inundated reef on transect E was also observed to differ to the biotic composition of these substrata on the other transects. In contrast to the other transects, hydroids were frequently observed associated with these substrata on transect E.

The drop camera system was used to examine in more detail areas of complexity observed during the towed video survey, and provided a quantitative description of benthic biota on a finer scale (metres). The biotic composition of communities observed on a fine scale was largely consistent with the composition of biota determined from the towed video footage. For example, the red algal mat observed during the towed video surveys was again observed to be dominant at deeper depths from the drop photo surveys, with foliose algal groups and sponges also common at shallow depths. Further, differences in biotic composition between transect C and the other transects were largely consistent with both methods recording high abundances of brown algae and sea whips and low abundances of sponge and red algae on transect C compared to the other transects. Both methods also determined transect E to be dissimilar to the other transects, with hydroids more common on transect E.

The red algal mat observed in the current study was found to be particularly widespread on sand substratum in deep-water and drove differences in benthic assemblages between transects and depth classes. This algal mat is a combination of red microalgae and cyanobacteria and forms a thin layer on the surface of the substratum. While it is likely that this algal mat is a significant contributor to benthic primary productivity in this region, such algal mats are also frequently disturbed and are likely to be removed by scour when waves penetrate to these depths (Gary Kendrick, personal communication 2009). As a result, it is likely that the contribution of the algal mat to primary productivity is seasonal in nature.

The current study has been successful in characterising benthic assemblages benthic assemblages within the study area. Low profile reef and sand inundated reefs were more commonly encountered in shallow nearshore shelf areas and mid-depths), while deep areas were characterised by large sand areas. The benthic assemblages of the study area were found to differ in density and composition based on a combination of the factors depth, transect, potential impact, and substratum. This indicates that there is high natural variability in benthic assemblages in the study area and a number of processes may be acting in concert to structure benthic assemblages in the study area.

Observed patterns in benthic assemblages may be driven by a number of factors. Benthic assemblages in marine ecosystems have been demonstrated to vary according to factors including latitude (Bellwood and Hughes 2001), temperature (Schils and Wilson 2006), light limitation (Carpenter 1985), turbidity (Airoldi and Virgilio 1998; Irving and Connell 2002), and sedimentation (Airoldi and Cinelli 1997; Irving and Connell 2002). Any one or combination of these physical factors may be important for structuring benthic assemblages in the current study. The mouth of the Ashburton River is also present in the study area. With peak outflow during the cyclone season from December to April, an increase in sedimentation and turbidity in coastal areas associated with river flow may also play a role in structuring benthic assemblages. However, to determine the processes structuring benthic assemblages in this region, further sampling across gradients in these physical factors would need to be undertaken.

Turtle Foraging Areas

The current study also set out to identify benthic communities that may be important foraging areas for turtle populations. Populations of flatback and green turtles are known to occur in the region. These species are thought to forage over habitats including seagrass, algal beds and sessile invertebrates (Pendoley 2005). While studies of turtle habitat utilisation in the region are ongoing, identifying areas with high coverage of these groups will complement these studies. As such, given the presence of algae and sessile invertebrates in this area, it is possible that turtles may forage here. Areas of greatest biotic density were most commonly observed on low profile reef substratum at shallow and mid-depths (to 40 m depth) suggesting that these areas would be relatively more important to turtles than deeper areas with lower biotic cover.

Impact of the Proposed Pipeline in a Regional Context

A number of comparisons were made in the current study to determine if benthic assemblages along the pipeline route were similar to other benthic assemblages occurring in the region. The area likely to be impacted by the pipe-lay trial is considered small relative to the rest of the study area. For all biotic groups, less than 0.03% of the biotic coverage present in the study area is likely to be disturbed by the pipe-lay trial. From the multivariate analysis, no differences in the size of habitat patches were observed based on the factor "Impact". However, differences in the composition of habitats were identified according to the factor "Impact". These differences were driven by lower abundance of red algae and sponge and higher abundance of red algal mat, brown algae and sea whips on the transect likely to be impacted (transect C).

Drop photo sampling indicated that the coverage of biota along the likely impacted transect (transect C) was significantly lower than the biotic coverage of transect A and B. The composition of habitats was also observed to differ depending on impact, though these differences were primarily driven by lower abundance of biotic groups along the pipeline route. In fact, of the species driving 60% of the dissimilarity between the factors, only brown algae and sea whips were observed to be more abundant on the pipeline route.

Conclusions

The current study determined that benthic assemblages in the study area were highly variable. Biotic community composition was found to vary according to transect and depth, while a general decline in biotic coverage was observed with depth. Low profile reef and sand inundated reef were more commonly observed in shallow nearshore areas and mid-depth areas of the offshore slope, while deep areas of the offshore slope were characterised by large sand plains. Further, some differences in community composition were detected between the location of the proposed pipeline (transect C) and the other transects. Transect C was determined to have similar amounts of low profile reef and sand inundated reef as transects D and E, but lower amounts of these habitats than transect A and B. Further, the biotic coverage of transect C was determined to be lower than transects A and B.

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APPENDIX 1

List of key statistical terms used for data analysis.

Analysis of Similarity (ANOSIM) – Distance-based statistical test based on permutations. ANOSIM provides a means of testing for significant differences between two or more groups of sampling units. ANOSIM is analogous to Analysis of Variance (ANOVA) in that it compares within group variability to among group variability but is not constrained by the assumptions underlying ANOVA. It can be paired with SIMPER analyses to identify variables (e.g. species, taxa) that drive the differences between groups.

Bray-Curtis Similarity – An index of similarity between paired samples of multivariate data. The most commonly used similarity index for abundance and biomass data that are not continuous and where joint-absences (e.g. two samples both do not include a given variable) should not influence measures of sample similarity.

Non-metric Multidimensional Scaling (nMDS) – A data visualising technique used to explore the relative similarity and dissimilarity of samples as a function of their proximity in 2 or 3 dimensional space. Stress indicates how well the high dimensional relationships between samples are represented in 2 or 3 dimensional space; stress values greater than 0.15 indicate that little structure can be observed.

p-value – The probability of observing a value for the test statistic that is at least as extreme as the value that was actually observed, given the null hypothesis is true. For tests such as ANOSIM, the p-value is generated by permutation.

R Statistic – Statistic used to discriminate between two or more groups of sampling units. Values for R range between −1 and 1 with $R = 0$ indicating completely random grouping while $R = 1$ and $R = -1$ indicates positive and negative associations among samples.

SIMPER Routine – A test for determining which variables are the most important in differentiating groups. SIMPER cannot be used in complex ANOVA designs where more than two factors are considered and interactions are present. To this end, SIMPER was here paired with ANOSIM; see ANOSIM above.

APPENDIX 2

Table 1: Biotic groups driving differences in biotic community structure between transects A and B determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund A	Av. Abund B	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	29.13	33.14	14.64	1.37	22.75	22.75
Red Algal Mat	4.32	12.80	9.32	0.63	14.47	37.22
Sponge	21.60	20.51	9.14	1.15	14.19	51.41
Brown Algae	5.92	21.26	8.79	0.98	13.65	65.06
Sea Whips	2.60	10.54	4.62	0.95	7.17	72.23
Other Soft Corals	5.52	8.23	4.40	1.14	6.83	79.06
Crinoids	1.75	4.72	3.33	0.41	5.18	84.24
Green Algae	1.19	6.13	2.38	0.54	3.69	87.93
Bryozoans	1.07	2.98	1.61	0.57	2.51	90.44

Table 2: Biotic groups driving differences in biotic community structure between transects A and C determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund A	Av. Abund C	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	29.13	13.57	17.55	1.26	25.47	25.47
Sponge	21.60	14.58	12.76	1.25	18.52	43.99
Red Algal Mat	4.32	9.46	6.62	0.48	9.61	53.60
Brown Algae	5.92	7.64	6.44	0.81	9.36	62.96
Green Algae	1.19	5.99	5.81	0.49	8.44	71.39
Sea Whips	2.60	9.23	5.68	0.97	8.24	79.64
Other Soft Corals	5.52	5.78	4.84	1.02	7.02	86.66
Ascidians	2.54	4.38	3.00	0.88	4.36	91.02

Table 3: Biotic groups driving differences in biotic community structure between transects A and D determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund A	Av. Abund D	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	29.13	7.44	20.45	1.52	27.31	27.31
Sponge	21.60	9.99	13.21	1.31	17.65	44.96
Red Algal Mat	4.32	11.03	10.70	0.72	14.29	59.24
Other Soft Corals	5.52	5.88	5.62	1.03	7.51	66.76
Brown Algae	5.92	1.90	4.77	0.61	6.37	73.13
Crinoids	1.75	5.32	4.50	0.45	6.01	79.13
Sea Whips	2.60	4.12	3.58	0.76	4.78	83.92
Hydroids	1.30	4.89	3.03	0.42	4.05	87.97
Ascidians	2.54	2.11	2.54	0.71	3.39	91.36

Table 4: Biotic groups driving differences in biotic community structure between transects A and E determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund A	Av. Abund E	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	29.13	12.06	14.51	1.45	21.97	21.97
Sponge	21.60	15.44	11.08	1.30	16.79	38.76
Hydroids	1.30	15.44	8.69	1.12	13.16	51.92

Other Soft Corals	5.52	9.08	5.87	1.12	8.88	60.80
Red Algal Mat	4.32	8.54	5.77	0.46	8.75	69.55
Crinoids	1.75	7.74	5.04	0.54	7.64	77.18
Brown Algae	5.92	0.00	3.49	0.52	5.28	82.47
Ascidians	2.54	4.71	3.21	0.90	4.86	87.33
Sea Whips	2.60	2.22	2.60	0.61	3.94	91.27

Table 5: Biotic groups driving differences in biotic community structure between transects B and E determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund B	Av. Abund E	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	33.14	12.06	13.84	1.70	18.96	18.96
Red Algal Mat	12.80	8.54	10.41	0.68	14.27	33.23
Brown Algae	21.26	0.00	7.48	0.81	10.25	43.48
Sponge	20.51	15.44	7.39	1.27	10.13	53.61
Hydroids	0.46	15.44	7.20	1.03	9.86	63.47
Crinoids	4.72	7.74	5.70	0.59	7.81	71.28
Other Soft Corals	8.23	9.08	5.10	1.14	6.99	78.27
Sea Whips	10.54	2.22	4.79	0.94	6.57	84.84
Ascidians	0.79	4.71	2.36	0.74	3.24	88.07
Green Algae	6.13	0.67	2.04	0.49	2.79	90.87

Table 6: Biotic groups driving differences in biotic community structure between transects D and C determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund D	Av. Abund C	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algal Mat	11.03	9.46	13.49	0.77	17.48	17.48
Red Algae	7.44	13.57	10.87	1.23	14.09	31.57
Sponge	9.99	14.58	10.74	1.29	13.91	45.48
Sea Whips	4.12	9.23	6.96	1.05	9.02	54.50
Green Algae	0.00	5.99	6.43	0.46	8.34	62.83
Other Soft Corals	5.88	5.78	6.10	1.01	7.91	70.74
Brown Algae	1.90	7.64	5.46	0.71	7.07	77.81
Crinoids	5.32	1.96	4.99	0.45	6.46	84.27
Ascidians	2.11	4.38	3.48	0.83	4.51	88.78
Hydroids	4.89	1.87	3.39	0.44	4.40	93.18

Table 7: Biotic groups driving differences in biotic community structure between the depth classes for shallow (<20 m) and mid-depth (20-40 m) areas as determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund <20	Av. Abund 20-40	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	14.09	26.68	16.14	1.24	24.44	24.44
Sponge	13.62	19.05	10.96	1.32	16.59	41.03
Brown Algae	7.78	8.90	7.54	0.89	11.42	52.45
Sea Whips	8.48	4.60	6.32	0.99	9.56	62.01
Green Algae	4.82	3.01	5.86	0.48	8.87	70.88
Other Soft Corals	5.50	6.91	5.68	1.05	8.60	79.48
Ascidians	3.70	3.35	3.49	0.92	5.29	84.77
Hydroids	0.52	3.33	2.32	0.36	3.51	88.28

Crinoids	0.12	2.50	2.21	0.28	3.35	91.62

Table 8: Biotic groups driving differences in biotic community structure between the depth classes <20 m and >40 m determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund <20	Av. Abund >40	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algal Mat	0.54	32.56	20.80	1.12	25.95	25.95
Red Algae	14.09	8.48	11.25	1.13	14.04	409
Sponge	13.62	14.52	11.22	1.14	14.00	53.99
Sea Whips	8.48	4.27	6.09	1.01	7.59	61.58
Other Soft Corals	5.50	5.66	5.17	1.00	6.45	68.03
Crinoids	0.12	8.85	4.95	0.53	6.18	74.21
Brown Algae	7.78	0.00	4.62	0.66	5.76	79.97
Green Algae	4.82	0.00	4.40	0.37	5.49	85.46
Hydroids	0.52	6.74	3.67	0.63	4.58	90.04

Table 9: Biotic groups driving differences in biotic community structure between the depth classes 20-40 m and >40 m determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund 20-40	Av. Abund >40	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algal Mat	1.12	32.56	18.75	1.09	23.81	23.81
Red Algae	26.68	8.48	15.48	1.38	19.66	43.46
Sponge	19.05	14.52	11.81	1.25	15.00	58.46
Crinoids	2.50	8.85	5.76	0.57	7.32	65.78
Other Soft Corals	6.91	5.66	5.06	1.01	6.43	72.21
Hydroids	3.33	6.74	4.49	0.63	5.70	77.91
Brown Algae	8.90	0.00	4.01	0.56	5.10	83.01
Sea Whips	4.60	4.27	3.67	0.80	4.66	87.67
Ascidians	3.35	1.63	2.13	0.66	2.71	90.38

Table 10: Biotic groups driving differences in biotic community structure between transect likely and unlikely to be impacted determined from towed video surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund (Unl.)	Av. Abund (Likely)	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	21.13	13.57	14.25	1.20	19.73	19.73
Sponge	17.27	14.58	11.29	1.25	15.62	35.35
Red Algal Mat	7.92	9.46	9.44	0.59	13.07	48.41
Brown Algae	5.97	7.64	6.22	0.78	8.60	57.01
Sea Whips	4.02	9.23	6.15	1.00	8.51	65.52
Green Algae	1.41	5.99	5.94	0.48	8.22	73.74
Other Soft Corals	6.41	5.78	5.35	1.02	7.41	81.15
Crinoids	3.93	1.96	3.42	0.40	4.73	85.89
Ascidians	2.45	4.38	3.14	0.85	4.34	90.23

Table 11: Biotic groups driving differences in benthic assemblage structure between sites on transects C and D determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund C	Av. Abund D	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	0.97	0.93	8.10	1.39	12.10	12.10
Brown Algae	0.75	0.14	7.18	0.98	10.73	22.84
Unkn. Alg. (Foliose)	0.56	0.17	6.19	1.22	9.25	32.09

Sponge	0.55	0.56	5.78	1.36	8.64	40.73
Non-Encrusting Bry.	0.26	0.35	4.74	1.03	7.08	47.81
Red Algae	0.44	0.15	4.52	0.73	6.76	54.56
Sea Whips	0.36	0.05	4.33	1.05	6.48	61.04
Encrusting Cor. Alg.	0.07	0.35	3.77	0.87	5.63	66.67
Dead Shell	0.28	0.05	3.37	0.84	5.04	71.71
Colonial Ascidian	0.04	0.24	2.77	0.96	4.14	75.85
Soft Coral Gorgonians	0.12	0.11	2.43	0.52	3.64	79.49
Encrusting Coral	0.09	0.13	2.04	0.68	3.05	82.54
Green Algae	0.17	0.11	1.99	0.95	2.97	85.52
Seagrass *Halophila* sp.	0.05	0.11	1.93	0.48	2.88	88.40
Solitary Ascidian	0.08	0.11	1.66	0.79	2.48	90.88

Table 12: Biotic groups driving differences in benthic assemblage structure between sites on transects C and E determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund C	Av. Abund E	Av. Diss	Diss/SD	Contrib. %	Cum.%
Hydroids	0.03	1.10	12.40	1.41	16.41	16.41
Non-Encrusting Bry.	0.26	1.21	10.86	1.37	14.38	30.79
Sponge	0.55	0.52	6.51	1.29	8.62	39.41
Algal Mat	0.97	0.62	6.27	1.39	8.30	47.71
Brown Algae	0.75	0.00	6.07	0.88	8.03	55.74
Unkn. Alg. (Foliose)	0.56	0.25	5.18	1.35	6.85	62.60
Red Algae	0.44	0.15	3.94	0.86	5.21	67.81
Sea Whips	0.36	0.00	3.86	1.11	5.11	72.92
Colonial Ascidian	0.04	0.33	3.28	1.44	4.35	77.27
Dead Shell	0.28	0.14	3.23	0.92	4.28	81.54
Encrusting Cor. Alg.	0.07	0.27	2.58	0.80	3.42	84.96
Encrusting Coral	0.09	0.17	2.30	0.78	3.05	88.01
Green Algae	0.17	0.00	1.27	0.65	1.68	89.68
Massive Coral	0.03	0.09	1.22	0.53	1.61	91.29

Table 13: Biotic groups driving differences in benthic assemblage structure between sites on transects C and A determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund C	Av. Abund A	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	0.97	2.74	13.17	1.33	20.08	20.08
Red Algae	0.44	1.80	10.37	1.08	15.81	35.89
Brown Algae	0.75	1.01	6.38	1.24	9.72	45.60
Sponge	0.55	1.36	5.99	1.36	9.13	54.74
Encrusting Coral	0.09	0.59	4.34	0.75	6.62	61.36
Unkn. Alg. (Foliose)	0.56	0.87	4.15	1.31	6.33	67.69
Non-Encrusting Bry.	0.26	0.43	2.67	1.17	4.07	71.76
Dead Shell	0.28	0.42	2.44	1.16	3.71	75.48
Sea Whips	0.36	0.00	2.38	1.12	3.63	79.10
Plate Coral	0.06	0.35	2.25	0.87	3.43	82.54
Encrusting Cor. Alg.	0.07	0.29	1.70	0.70	2.59	85.13
Colonial Ascidian	0.04	0.22	1.42	0.60	2.17	87.30
Solitary Ascidian	0.08	0.14	1.18	0.71	1.79	89.09

Green Algae	0.17	0.07	1.14	0.80	1.74	90.83

Table 14: Biotic groups driving differences in benthic assemblage structure between sites on transects C and B determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund C	Av. Abund B	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	0.97	1.33	8.93	1.19	13.09	13.09
Unkn. Alg. (Foliose)	0.56	1.43	8.29	1.71	12.15	25.24
Brown Algae	0.75	0.73	6.39	1.16	9.37	34.61
Red Algae	0.44	0.88	5.74	1.04	8.42	43.03
Sponge	0.55	0.70	4.57	1.11	6.70	49.73
Encrusting Cor. Alg.	0.07	0.75	4.01	0.98	5.88	55.61
Solitary Ascidian	0.08	0.29	3.56	0.82	5.21	60.82
Sea Whips	0.36	0.25	3.52	0.90	5.15	65.98
Green Algae	0.17	0.56	3.36	1.12	4.93	70.91
Non-Encrusting Bry.	0.26	0.28	2.90	0.90	4.25	75.16
Dead Shell	0.28	0.09	2.63	0.70	3.85	79.01
Plate Coral	0.06	0.41	2.34	1.21	3.43	82.44
Colonial Ascidian	0.04	0.17	2.22	0.60	3.25	85.70
Encrusting Coral	0.09	0.28	1.94	0.87	2.84	88.54
Fungiid Coral	0.00	0.33	1.66	0.49	2.43	90.97

Table 15: Biotic groups driving differences in benthic assemblage structure between sites on transects D and A determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund D	Av. Abund A	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	0.93	2.74	14.31	1.45	20.96	20.96
Red Algae	0.15	1.80	10.97	1.09	16.06	37.02
Sponge	0.56	1.36	6.29	1.46	9.21	46.23
Brown Algae	0.14	1.01	6.03	1.11	8.82	55.05
Unkn. Alg. (Foliose)	0.17	0.87	5.05	1.30	7.39	62.44
Encrusting Coral	0.13	0.59	4.46	0.77	6.52	68.96
Encrusting Cor. Alg.	0.35	0.29	2.84	1.00	4.16	73.13
Dead Shell	0.05	0.42	2.56	1.27	3.74	76.87
Non-Encrusting Bry.	0.35	0.43	2.46	1.18	3.60	80.47
Plate Coral	0.07	0.35	2.44	0.90	3.58	84.05
Colonial Ascidian	0.24	0.22	2.19	0.96	3.21	87.26
Solitary Ascidian	0.11	0.14	1.25	0.77	1.83	89.09
Massive Coral	0.07	0.12	1.13	0.66	1.66	90.75

Table 16: Biotic groups driving differences in benthic assemblage structure between sites on transects E and A determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund E	Av. Abund A	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	0.62	2.74	14.46	1.56	19.45	19.45
Red Algae	0.15	1.80	10.06	1.08	13.54	32.99
Hydroids	1.10	0.03	7.29	1.53	9.81	42.80
Sponge	0.52	1.36	6.70	1.44	9.01	51.81
Brown Algae	0.00	1.01	5.72	1.10	7.69	59.50
Non-Encrusting Bry.	1.21	0.43	5.57	1.36	7.50	67.00

Unkn. Alg. (Foliose)	0.25	0.87	4.59	1.29	6.17	73.18
Encrusting Coral	0.17	0.59	4.03	0.80	5.42	78.59
Dead Shell	0.14	0.42	2.48	1.27	3.33	81.93
Encrusting Cor. Alg.	0.27	0.29	2.31	0.93	3.11	85.04
Colonial Ascidian	0.33	0.22	2.20	1.22	2.96	88.01
Plate Coral	0.00	0.35	2.14	0.80	2.88	90.88

Table 17: Biotic groups driving differences in benthic assemblage structure between sites on transects E and B determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund E	Av. Abund B	Av. Diss	Diss/SD	Contrib. %	Cum.%
Hydroids	1.10	0.00	10.61	1.11	13.82	13.82
Non-Encrusting Bry.	1.21	0.28	8.56	1.13	11.16	24.98
Unkn. Alg. (Foliose)	0.25	1.43	8.50	1.63	11.07	36.05
Algal Mat	0.62	1.33	6.87	1.52	8.95	45.00
Sponge	0.52	0.70	5.71	1.15	7.44	52.44
Red Algae	0.15	0.88	5.18	1.28	6.75	59.19
Encrusting Cor. Alg.	0.27	0.75	4.53	1.15	5.90	65.09
Brown Algae	0.00	0.73	4.37	1.52	5.70	70.78
Solitary Ascidian	0.06	0.29	3.32	0.89	4.32	75.11
Green Algae	0.00	0.56	3.11	1.02	4.05	79.16
Colonial Ascidian	0.33	0.17	2.54	1.02	3.31	82.47
Plate Coral	0.00	0.41	2.17	1.11	2.83	85.30
Encrusting Coral	0.17	0.28	2.07	0.92	2.69	87.99
Massive Coral	0.09	0.28	1.88	0.88	2.45	90.44

Table 18: Biotic groups driving differences in benthic assemblage structure between sites on transects A and B determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund A	Av. Abund B	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	2.74	1.33	11.93	1.03	19.10	19.10
Red Algae	1.80	0.88	8.63	1.01	13.82	32.92
Unkn. Alg. (Foliose)	0.87	1.43	5.77	1.44	9.24	42.15
Sponge	1.36	0.70	5.06	1.13	8.10	50.25
Brown Algae	1.01	0.73	4.83	1.15	7.74	57.99
Encrusting Coral	0.59	0.28	3.53	0.70	5.65	63.64
Encrusting Cor. Alg.	0.29	0.75	3.31	1.07	5.30	68.93
Green Algae	0.07	0.56	2.43	1.15	3.89	72.82
Plate Coral	0.35	0.41	2.24	0.94	3.58	76.41
Dead Shell	0.42	0.09	2.09	1.11	3.35	79.76
Non-Encrusting Bry.	0.43	0.28	1.99	1.01	3.18	82.95
Solitary Ascidian	0.14	0.29	1.70	1.00	2.73	85.67
Colonial Ascidian	0.22	0.17	1.70	0.77	2.73	88.40
Massive Coral	0.12	0.28	1.35	0.97	2.17	90.57

Table 19: Biotic groups driving differences in benthic assemblage structure between sites at depth classes < 20 m and >40 metres determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund <20	Av. Abund >40	Av. Diss	Diss/SD	Contrib. %	Cum.%
Red Algae	1.71	0.00	12.42	1.13	17.65	17.65
Brown Algae	1.21	0.16	9.01	1.28	12.81	30.46
Algal Mat	1.08	1.00	7.71	1.23	10.96	41.42
Sponge	0.96	0.38	6.86	1.55	9.75	51.17
Unkn. Alg. (Foliose)	0.72	0.41	5.13	1.15	7.30	58.47
Non-Encrusting Bry.	0.34	0.10	3.33	1.01	4.73	63.20
Encrusting Cor. Alg.	0.29	0.00	3.20	0.73	4.55	67.75
Sea Whips	0.23	0.21	3.15	0.90	4.47	72.22
Dead Shell	0.32	0.11	2.64	1.03	3.75	75.97
Green Algae	0.26	0.00	2.28	1.04	3.24	79.21
Colonial Ascidian	0.16	0.14	2.27	0.81	3.23	82.44
Seagrass *Halophila* sp.	0.20	0.00	2.23	0.57	3.17	85.61
Solitary Ascidian	0.19	0.17	2.22	0.96	3.16	88.76
Soft Coral Gorgonians	0.19	0.00	1.81	0.37	2.57	91.33

Table 20: Biotic groups driving differences in benthic assemblage structure between sites at depth classes 20-40 m and >40 metres determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund 20-40	Av. Abund >40	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	1.82	1.00	12.62	1.34	17.53	17.53
Non-Encrusting Bry.	0.65	0.10	6.82	1.02	9.48	27.01
Sponge	0.88	0.38	6.74	1.40	9.36	36.38
Unkn. Alg. (Foliose)	0.74	0.41	6.06	1.29	8.43	44.80
Brown Algae	0.60	0.16	5.11	0.94	7.10	51.90
Red Algae	0.67	0.00	4.73	0.81	6.57	58.47
Hydroids	0.26	0.05	4.02	0.50	5.59	64.06
Encrusting Coral	0.43	0.00	3.78	0.72	5.25	69.31
Dead Shell	0.28	0.11	2.98	0.80	4.15	73.45
Sea Whips	0.12	0.21	2.62	0.82	3.64	77.09
Encrusting Cor. Alg.	0.39	0.00	2.61	0.73	3.63	80.72
Colonial Ascidian	0.18	0.14	2.30	0.79	3.19	83.91
Plate Coral	0.28	0.00	2.16	0.77	3.00	86.91
Solitary Ascidian	0.06	0.17	1.94	0.70	2.70	89.61
Massive Coral	0.17	0.00	1.54	0.63	2.14	91.75

Table 21: Biotic groups driving differences in benthic assemblage structure between sites on transects likely to be impacted by proposed pipeline and those unlikely to be impacted by the proposed pipeline determined from drop camera surveys. Cut off for contributions 90% (Cumulative).

Biotic Group	Av. Abund (Likely)	Av. Abund (Unl.)	Av. Diss	Diss/SD	Contrib. %	Cum.%
Algal Mat	0.97	1.68	9.98	1.2	14.63	14.63
Red Algae	0.44	0.96	7.02	0.88	10.29	24.92
Brown Algae	0.75	0.58	6.5	1.07	9.53	34.45
Sponge	0.55	0.9	5.78	1.29	8.47	42.92
Unkn. Alg. (Foliose)	0.56	0.71	5.56	1.27	8.15	51.08
Non-Encrusting Bry.	0.26	0.53	4.69	0.86	6.87	57.95

Sea Whips	0.36	0.06	3.3	0.98	4.84	62.79
Encrusting Coral	0.09	0.35	3.01	0.68	4.41	67.2
Dead Shell	0.28	0.23	2.83	0.88	4.14	71.34
Encrusting Cor. Alg.	0.07	0.38	2.75	0.78	4.03	75.37
Hydroids	0.03	0.22	2.67	0.43	3.91	79.28
Colonial Ascidian	0.04	0.24	2.22	0.78	3.25	82.53
Plate Coral	0.06	0.23	1.81	0.74	2.65	85.18
Green Algae	0.17	0.16	1.77	0.8	2.59	87.77
Solitary Ascidian	0.08	0.14	1.7	0.65	2.49	90.25

APPENDIX 3

Representative images of substrata and biotic groups observed in the current study.

Nb. As some groups occur in trace amounts (<1% of assemblage), representative images of these groups could not be included.

Substratum Groups

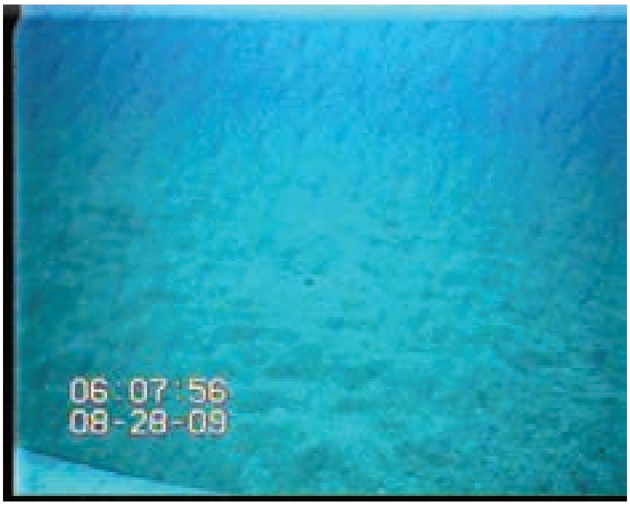

Image 1: Sand

Image 2: Sand inundated reef

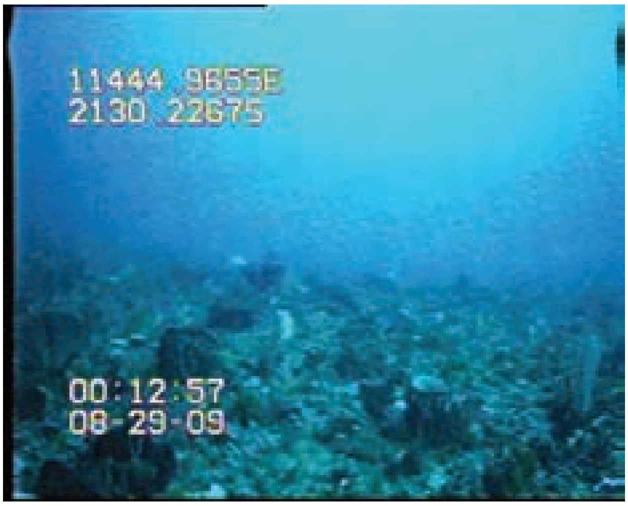

Image 3: Low profile reef

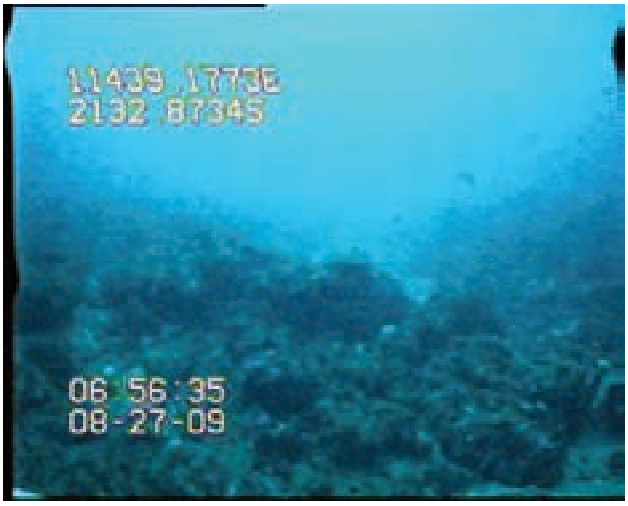

Image 4: Medium profile reef

Biotic Groups

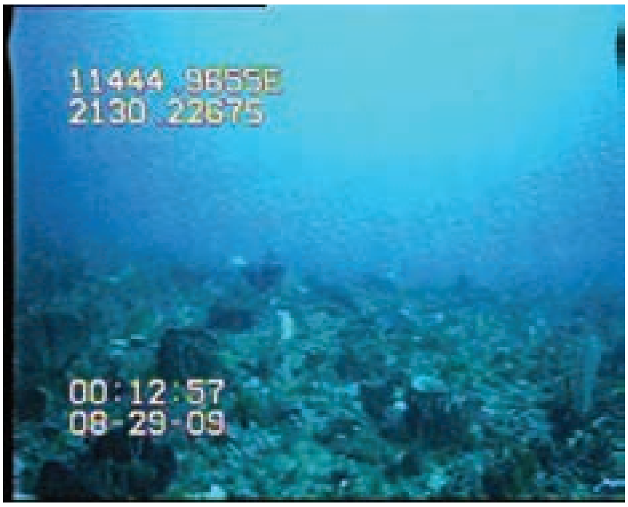

Image 5: Sponges

Image 6: Hydroids

Image 7: Bryozoans

Image 8: Ascidian

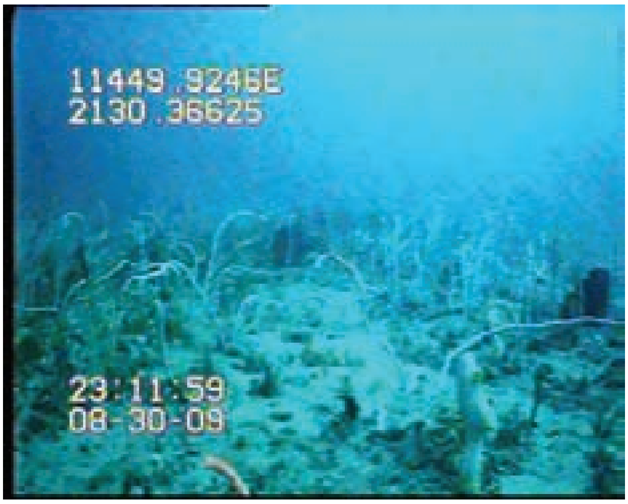

Image 9: Sea whips

Image 10: Sea pen

Image 11: Soft coral (Family Nephtheidae).

Image 12: Black coral

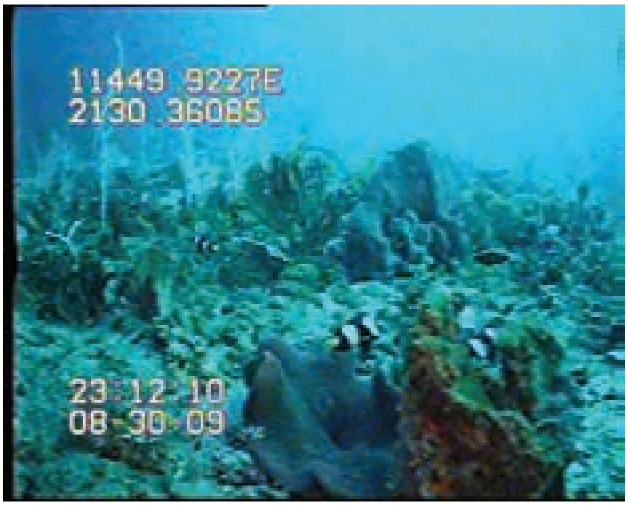

Image 13: Anemone

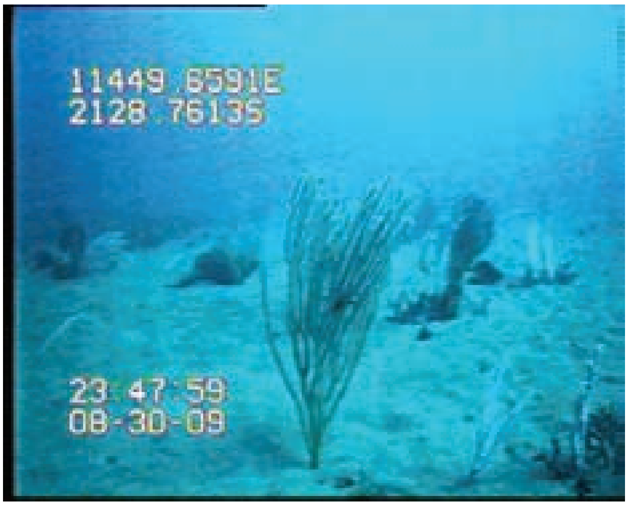

Image 14: Other soft coral

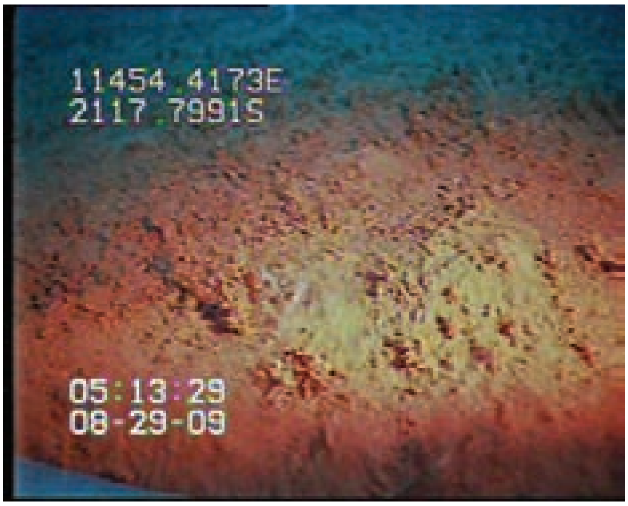

Image 15: Red algal mat

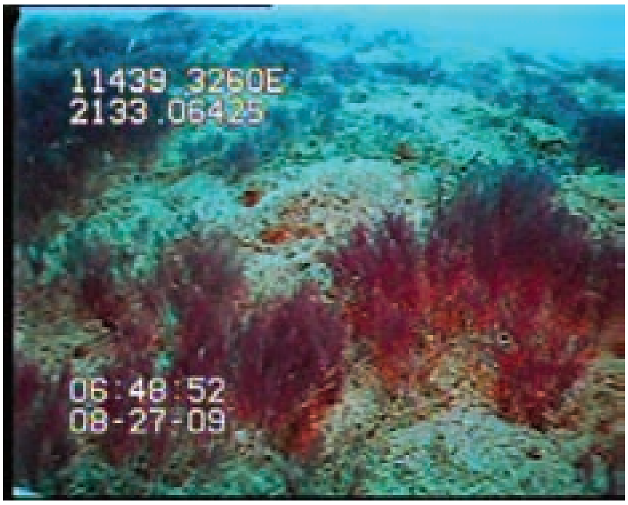

Image 16: Red algae

Image 17: Brown algae

Image 18: Green algae

Image 19: Crinoids

Image 20: Holothurian

Image 21: Seagrass (*Halophila* sp.)

Image 22: Hard coral (encrusting)

Image 23: Hard coral (massive)

Image 24: Hard coral (plate)

TABLES

Table 1: List of substrate and biotic categories used to classify towed video footage.

Substrata	Red Algal Mat
Sand*	Red Algae
Low Profile Reef**	Brown Algae
Medium Profile Reef†	Green Algae
Sand Inundated Reef††	Crinoids
	Holothurians
Biotic	Other Motile Invertebrates
Sponge	Seagrass *Halophila* sp.
Hydroids	Hard Coral (Branching)
Bryozoans	Hard Coral (Encrusting)
Ascidians	Hard Coral (Foliose)
Gorgonians	Hard Coral (Massive)
Sea Whips	Hard Coral (Sub-Massive)
Sea Pens	Hard Coral (Plate)
Soft Coral (Family Nephtheidae)	Hard Coral (Unknown)
Black Corals	
Anemones	
Other Soft Corals	

* Sand describes grains of sediment less than 2mm in diameter.
** Low profile reef describes hard substrata with slopes less than 30 degrees.
† Medium profile reef describes hard substrata with slopes between 30 and 70 metres.
†† Sand inundated reef describes areas where no hard substrata was visible due to the presence of sand, but biotic classes such as sessile invertebrates and macroalgae (which require a solid substrata for attachment), were present.

Table 2: List of benthic groups used to classify drop photo images.

Biotic	
Sponge	Unknown Algae (Foliose)
Sea Whips	Unknown Algae (Filamentous)
Hydroids	Algal Mat
Anemones	Encrusting Coralline Algae
Solitary Ascidian	Encrusting Algae (Other)
Colonial Ascidian	Seagrass *Halophila* sp.
Soft Coral Gorgonians	Sea Urchin
Massive Coral	Sea Star
Encrusting Coral	Crinoid
Branched Coral	Dead Shell
Plate Coral	Unknown (Identification)
Foliose Coral	Unknown (Image Quality)
Fungiid Coral	
Coral (Other)	**Abiotic**
Encrusting Bryozoan	Sand
Non-Encrusting Bryozoan	Gravel (>2cm)
Brown Algae	Bare Rock
Red Algae	Sand Inundated Reef
Green Algae	

Table 3: Summary of sampling effort in the current study.

Transect	Length Towed Video (km)	Number of Drop Photo Sites	Impact from Proposed Pipeline
A	8.96	11	Unlikely
B	9.81	5	Unlikely
C	17.00	18	Likely
D	11.18	11	Unlikely
E	6.14	8	Unlikely
Total:	53.10	53	

Table 4: Summary of habitat patches by transect and substratum observed from towed video surveys in the current study. Values represent mean length of habitat patches (± SE).

	Substratum				
Transect	**Low Profile Reef**	**Medium Profile Reef**	**Sand**	**Sand Inundated Reef**	**All Substrata**
A	90 (±17)	82	204 (±80)	64 (±12)	110 (±22)
B	224 (±34)	-	876 (±300)	89 (±32)	456 (±135)
C	77 (±13)	-	345 (±103)	87 (±31)	221 (±57)
D	169 (±137)	-	260 (± 55)	44 (±11)	211 (±43)
E	47 (±15)	-	434 (±159)	117 (±62)	280 (±95)
All Transects:	106 (±13)	82	341 (± 51)	72 (±11)	210 (±26)
No. Patches:	70	1	124	65	260

Table 5: Showing percent coverage of benthic groups by transect and depth.

Depth (m)	Transect	Macroalgae	Filter Feeders	Soft Corals	Seagrass (*Halophila* sp.)
20-40	A	29.47	12.01	1.97	0.1
20-40	B	32.48	5.65	3.82	0.27
20-40	C	5.66	4.25	1.76	0
20-40	D	1.44	4.74	1.66	0
20-40	E	2.68	9.52	1.98	0
All	A	12.32	8	1.33	0.06
All	B	7.31	1.41	1.03	0.06
All	C	3.82	2.55	1.47	0
All	D	1.08	2.54	1.25	0.02
All	E	0.95	3.7	1.04	0

Table 6: Results of four way PERMANOVA to test for differences in the size of habitat patches determined from towed video sampling among impact, depth, substrata and transect.

Patch Length	df	SS	MS	Pseudo-F	P(perm)	No. of perms
Impact	1	1.19	1.19	0.36	0.414	119
Depth	2	577.9	288.9	1.52	0.313	999
Substrata	2	929.9	464.9	5.12	0.052	999
Tr. (Im.)	3	206.4	68.8	1.30	0.287	999
Im. x De.	2	16.8	8.41	0.22	0.788	999
Im. x Sub.	2	25.1	12.5	0.54	0.609	998
De. x Sub.	4	442	110.6	13.0	0.019	998
Tr. (Im.) x De.	6	780	130	2.45	0.045	997
Tr. (Im.) x Sub.	6	358	59.6	1.12	0.32	999
ImxDexSub.	3	109	36.4	6.39	0.044	999
Tr(Im)xDexSub.	5	33.591	6.71	0.12	0.975	999
Res	222	11763	52.9			
Total	258	21096				

Table 7: Pairwise tests examining variation in habitat patch length for the interaction Impact x Depth x Substrata. Pairs of levels of the factor substrata

		Depth Class		
		<20 m	20-40 m	>40 m
Impact	Unlikely	LPR=SIR LPR≠S SIR=S	LPR=SIR LPR=S SIR=S	LPR=SIR LPR=S SIR≠S (p=0.06)
	Likely	LPR=SIR LPR=S SIR=S	LPR=SIR LPR=S SIR=S	SIR=S

LPR = Low Profile Reef; SIR = Sand Inundated Reef; S = Sand

Table 8: Pairwise tests examining variation in habitat patch length for the interaction Impact x Depth x Substrata. Pairs of levels of the factor depth

		Substrata		
		LPR	SIR	Sand
Impact	Unlikely	<20=20-40 20=>40 20-40≠>40	<20=20-40 <20=>40 20-40=>40	<20=20-40 <20=>40 20-40=>40
	Likely	<20≠20-40	<20=20-40 <20=>40 20-40=>40	<20≠20-40 <20≠>40 20-40=>40

LPR = Low Profile Reef; SIR = Sand Inundated Reef; S = Sand

Table 9: Pairwise tests examining variation in habitat patch length for the interaction Impact x Depth x Substrata. Pairs of levels of the factor impact

		Substrata		
		LPR	SIR	Sand
Depth Class	<20 m	Unlik.=Lik	Unlik.=Lik	Unlik.=Lik
	20-40 m	Unlik.=Lik	Unlik.=Lik	Unlik.=Lik
	>40 m	-	Unlik.=Lik	Unlik.=Lik

Table 10: Percentage cover of different substrata determined from towed video analysis summarised by transect.

Transect	Substrata	Substrata (%)
A	Low Profile Reef	30.19
	Medium Profile Reef	0.91
	Sand	47.66
	Sand Inundated Reef	21.24
B	Low Profile Reef	21.42
	Sand	75.19
	Sand Inundated Reef	3.39
C	Low Profile Reef	10.57
	Sand	82.97
	Sand Inundated Reef	6.47
D	Low Profile Reef	4.46
	Sand	91.34
	Sand Inundated Reef	4.20
E	Low Profile Reef	2.27
	Sand	84.44
	Sand Inundated Reef	13.29

Table 11: Percentage cover of different biotic groups summarised by transect determined from towed video analysis. The 12 most common biotic groups are included.

	Transect				
Biotic Group	**A**	**B**	**C**	**D**	**E**
Red Algae	55.54	43.05	24.61	19.77	21.08
Sponges	25.63	13.13	22.90	20.61	27.50
Brown Algae	9.98	23.37	15.38	8.99	0.00
Sea Whips	0.82	7.03	12.97	5.83	2.87
Soft Corals (Other)	3.14	2.38	5.90	9.40	8.71
Red Algal Mat	1.41	3.70	5.32	15.97	4.15
Green Algae	1.12	3.90	8.20	0.00	0.64
Hydroids	0.29	0.02	0.58	5.03	24.34
Ascidians	0.84	0.39	3.01	2.60	4.78
Crinoids	0.25	0.43	0.29	6.49	2.30
Bryazoans	0.28	0.97	0.58	0.40	1.63
Seagrass - *Halophila* sp	0.42	0.39	0.00	0.40	0.00
Other Biota	0.27	1.25	0.26	4.51	2.01

Table 12: Percentage cover of different substrata determined from towed video analysis summarised by depth class.

Depth Class (metres)	Substrata	Substrata (%)
<20	Low Profile Reef	21.66
	Sand	61.11
	Sand Inundated Reef	17.23
20-40	Low Profile Reef	33.42
	Medium Profile Reef	0.51
	Sand	50.22
	Sand Inundated Reef	15.84
>40	Low Profile Reef	2.87
	Sand	93.40
	Sand Inundated Reef	3.73

Table 13: Percentage cover of different biotic groups summarised by transect determined from towed video analysis. The 12 most common biotic groups are included.

Biotic Group	Depth Class (metres)		
	<20	20-40	>40
Red Algae	27.16	50.11	19.53
Sponges	21.91	22.39	32.64
Brown Algae	18.15	11.79	0.00
Sea Whips	13.97	2.34	2.58
Soft Corals (Other)	5.39	4.47	4.24
Red Algal Mat	0.50	0.41	32.76
Green Algae	8.37	1.74	0.00
Hydroids	0.36	2.59	2.86
Ascidians	2.77	1.58	0.62
Crinoids	0.07	0.99	2.49
Bryazoans	0.21	0.57	0.78
Seagrass - *Halophila* sp.	0.28	0.33	0.00
Other Biota	0.85	0.69	1.49

Table 14: Pairwise comparisons showing differences in biotic communities among transects determined from towed video surveys. Results considered significant at p<0.05

Comparison	Clarke's R	No. Permutations	p-value
A, B	0.253	999	0.001
A, D	0.356	999	0.001
A, E	0.324	999	0.001
A, C	0.142	999	0.001
B, D	0.026	999	0.250
B, E	0.215	999	0.001
B, C	0.00	999	0.543
D, E	0.00	999	0.588
D, C	0.094	999	0.001
E, C	0.00	999	0.511

Table 15: Pairwise comparisons showing differences in biotic communities among depth classes determined from towed video surveys. Results considered significant at p<0.05

Comparison	Clarke's R	No. Permutations	p-value
<20 m, 20-40 m	0.076	999	0.003
<20 m, >40 m	0.325	999	0.001
20-40 m, >40 m	0.372	999	0.001

Table 16: Results of PERMANOVA to test for differences in biota determined from drop photo sampling among impact, depth and transect.

Biotic Cover	df	SS	MS	Pseudo-F	P(perm)	No. of perms
Impact	1	1.87	1.87	0.04	0.801	120
Depth	2	44.3	22.1	5.05	0.091	999
Tr.(Im.)	3	92.9	30.9	32.8	0.001	999
ImxDe	2	7.59	3.79	0.96	0.469	999
Tr(Im)xDe	4	11.5	2.88	3.05	0.027	999
Res	40	37.7	0.94			
Total	52	292				

Table 17: Pairwise tests examining variation in habitat patch length for the interaction Transect(Impact) x Depth. Pairs of levels of the factor depth.

Transect	Impact	Comparison
A		<20=20-40
		<20=>40
	Unlikely	20-40=>40
B	Unlikely	20-40=>40
C		<20m=20-40
		<20≠>40
	Likely	20-40=>40
D		<20=20-40
		<20=>40
	Unlikely	20-40=>40
E	Unlikely	20-40≠>40

Table 18: Pairwise comparisons showing differences in benthic assemblage structure among transects determined from drop camera surveys. Results considered significant at p<0.05

Comparison	Clarke's R	No. Permutations	p-value
C, D	0.21	999	0.03
C, E	0.60	999	0.001
C, A	0.34	999	0.004
C, B	0.27	999	0.02
D, E	0.25	462	0.056
D, A	0.58	999	0.001
D, B	0.04	462	0.32
E, A	0.82	999	0.001
E, B	0.47	126	0.024
A, B	0.33	999	0.03

Table 19: Pairwise comparisons showing differences in benthic assemblage structure among depth classes determined from drop camera surveys. Results considered significant at p<0.05

Comparison	Clarke's R	No. Permutations	p-value
<20 m, 20-40 m	0.013	999	0.37
<20 m, >40 m	0.397	999	0.001
20-40 m, >40 m	0.326	999	0.002

FIGURES

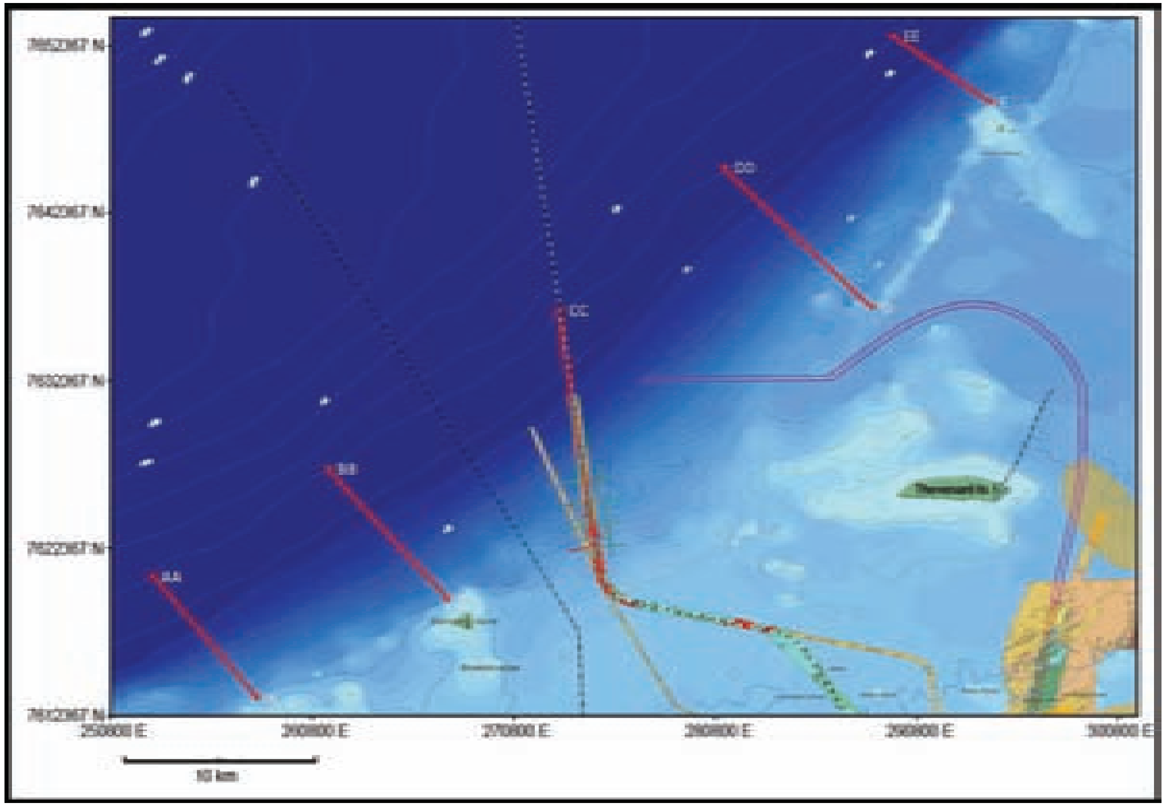

Figure 1a: Map showing the location of the five towed video transects surveyed in this study.

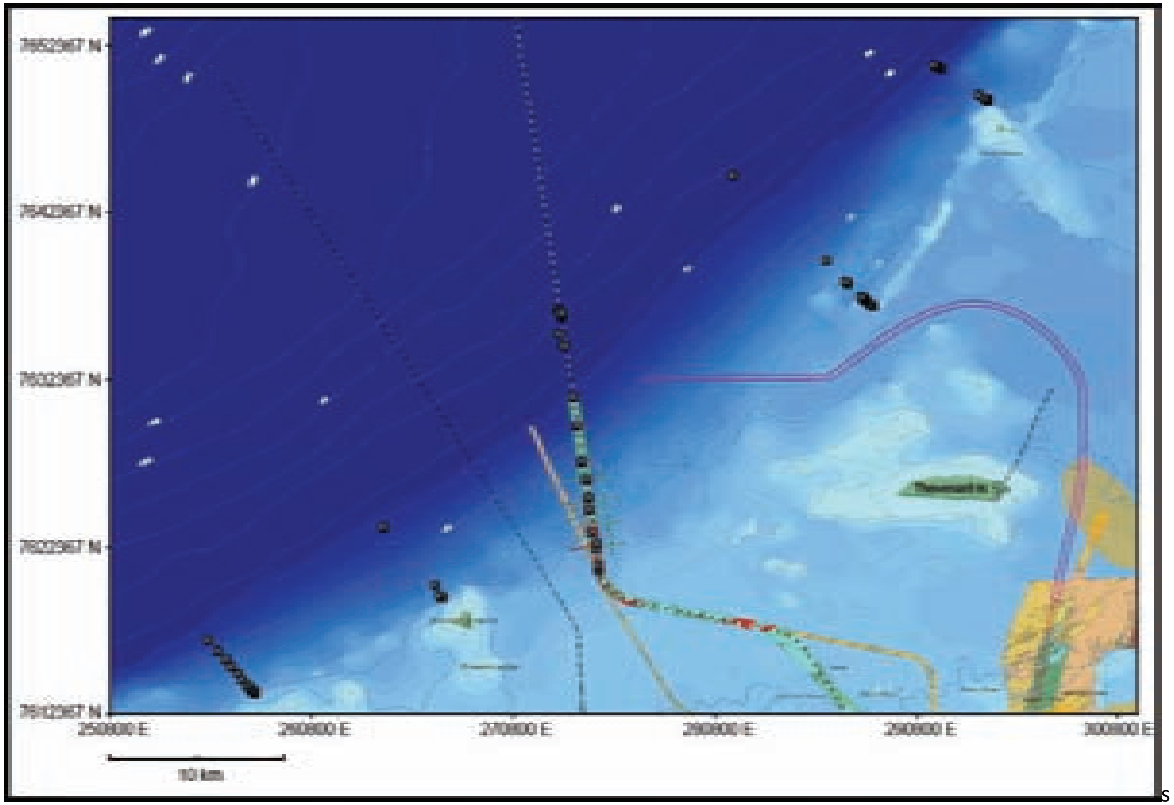

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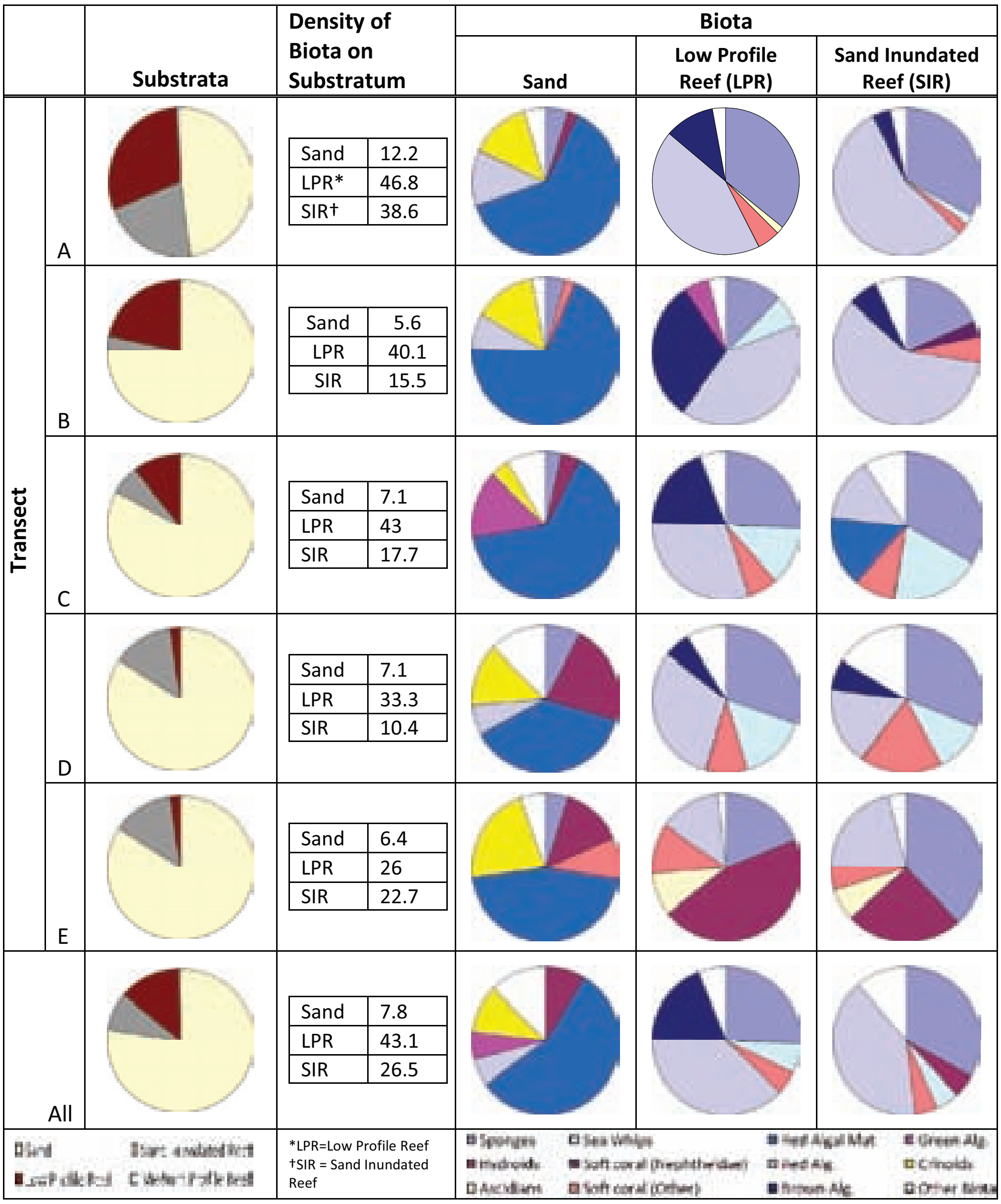
Figure 1b: Map showing the location of the 53 drop camera sites surveyed in this study.



Transect	Sand	LPR	SIR
A	12.2	46.8	38.6
B	5.6	40.1	15.5
C	7.1	43	17.7
D	7.1	33.3	10.4
E	6.4	26	22.7
All	7.8	43.1	26.5

Figure 2: Summary of substrata and biota by transect. Substrata column shows the proportion of each substratum occurring on each transect. Density of biota on substratum shows the density of substrate coverage to coverage of biota, while biotic columns shows the five most important biotic groups occurring on each substratum.

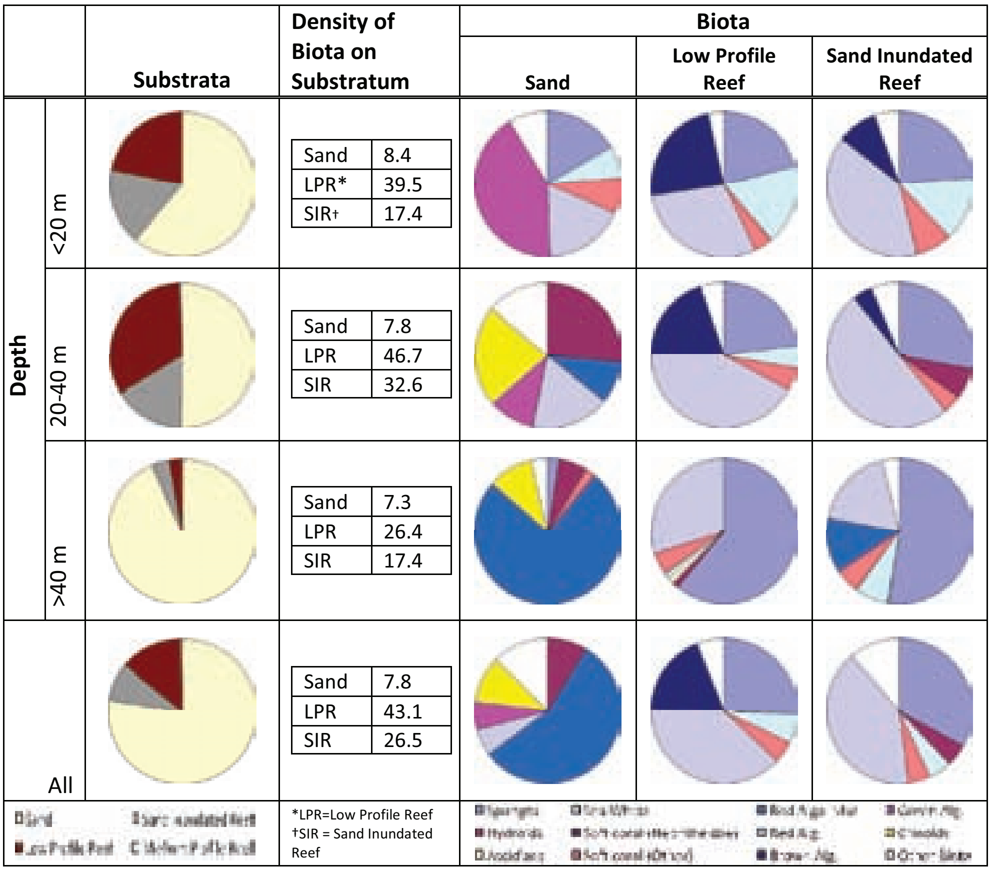


Figure 3: Summary of substrata and biota by depth class. Substrata column shows the proportion of each substratum occurring at each depth. Density of biota on substratum shows the density of substrate coverage to coverage of biota, while biotic columns show the five most important biotic groups on each substratum.

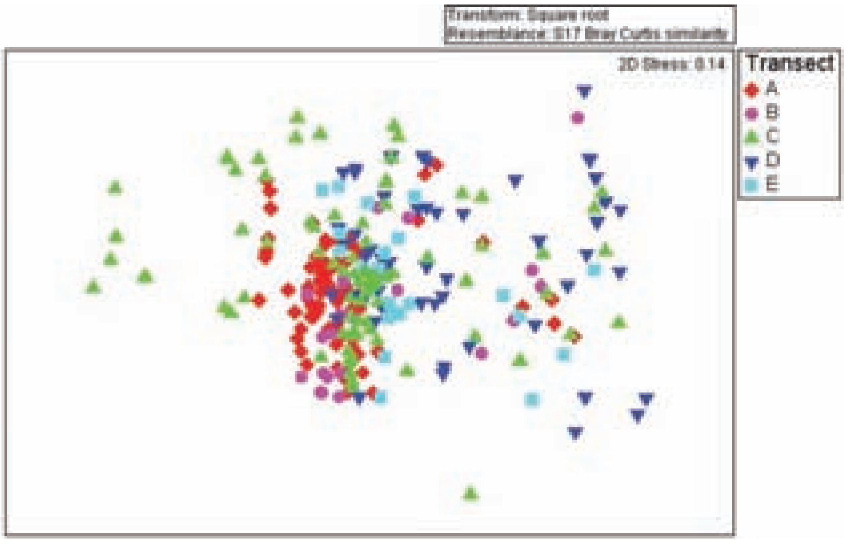


Figure 4: nMDS ordination illustrating differences of all towed video biotic data among "Transects". Ordination was based on Bray-Curtis similarity matrix of square-root transformed data.

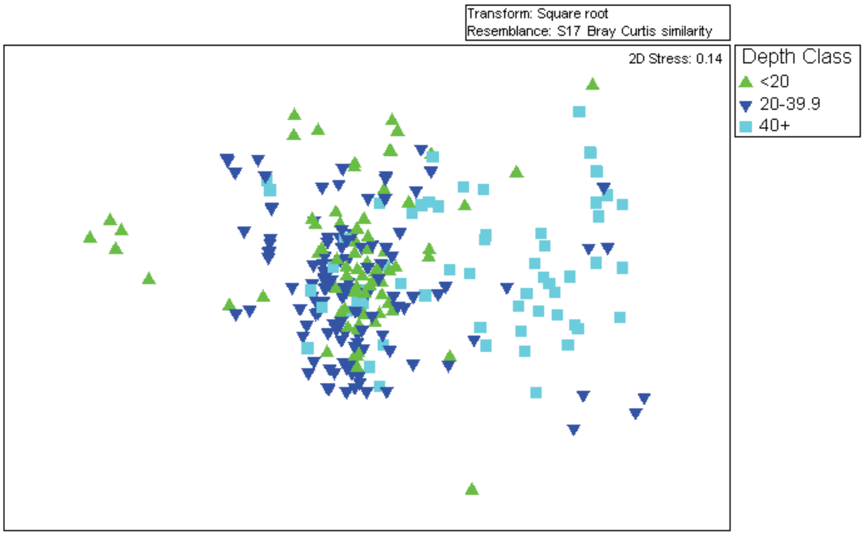


Figure 5: nMDS ordination illustrating differences of all towed video biotic data among "Depth classes". Ordination was based on Bray-Curtis similarity matrix of square-root transformed data.

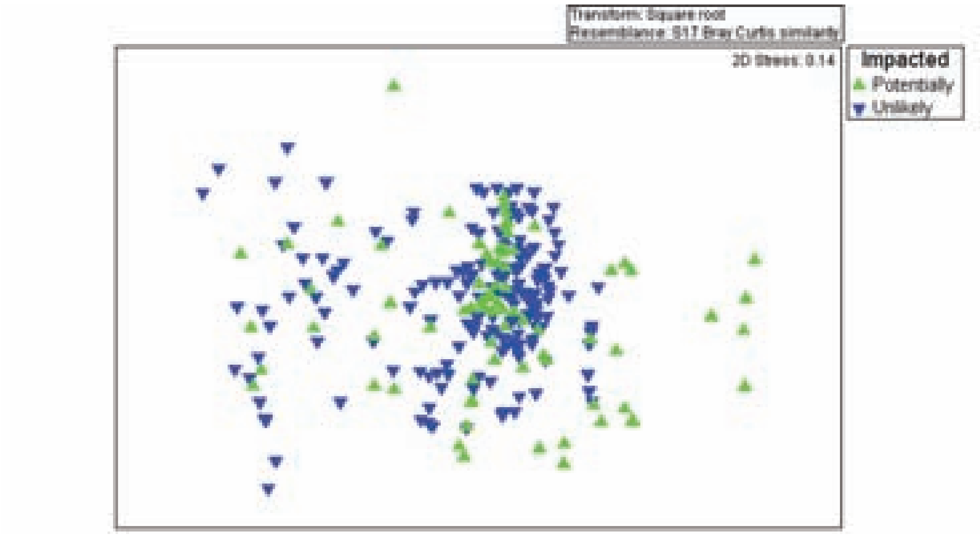


Figure 6: nMDS ordination illustrating differences of all towed video biotic data among levels of the factor “Impact”. Ordination was based on Bray-Curtis similarity matrix of square-root transformed data.

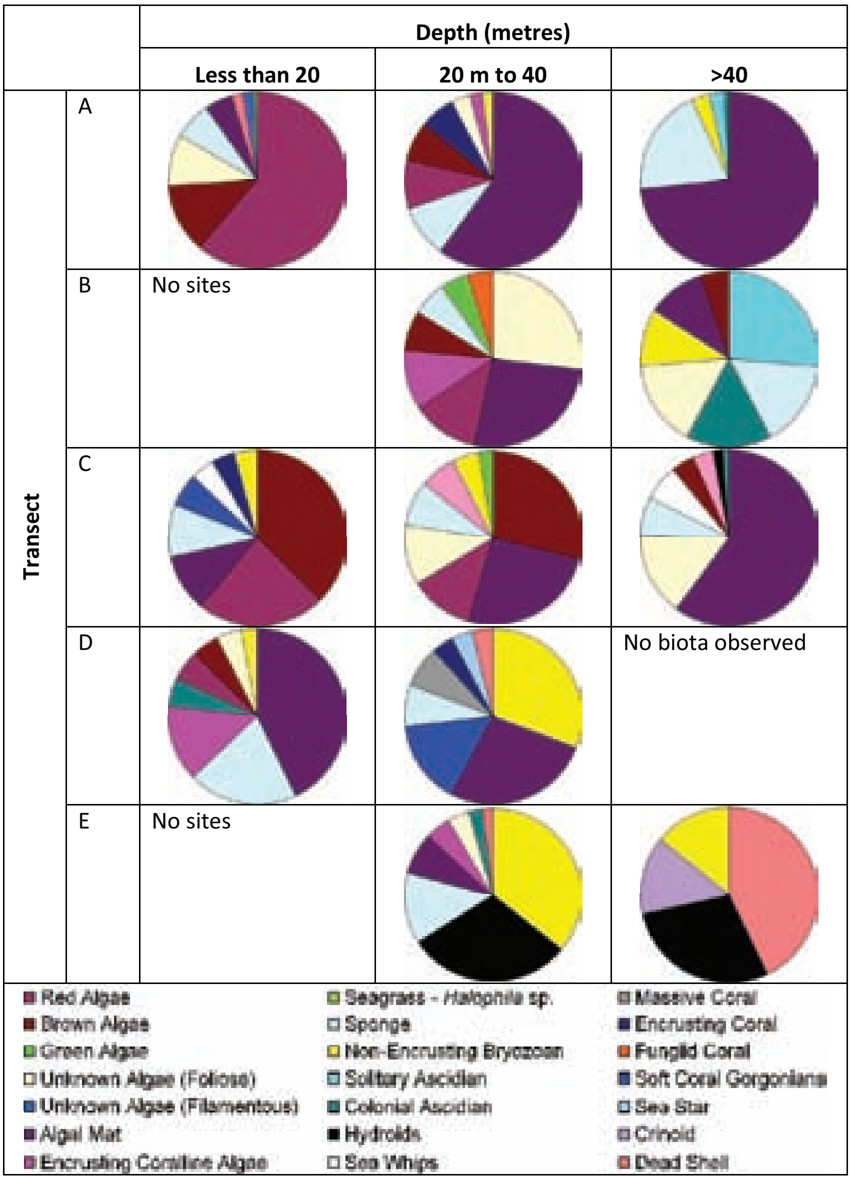


Figure 7: Occurrence of biotic groups by depth and transect. The eight main biotic groups are presented for each transect x depth combination.

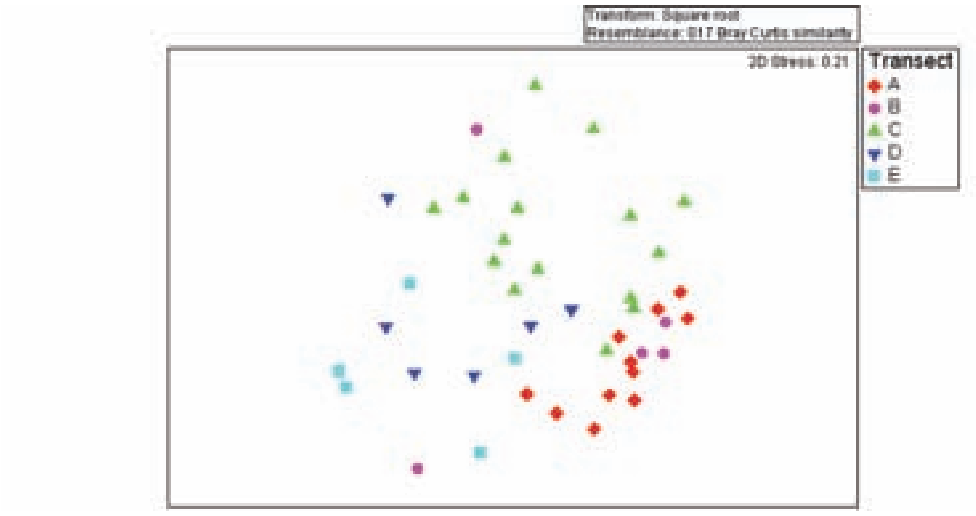


Figure 8: nMDS ordination illustrating differences of all drop photo data among “transects”. Ordination was based on Bray-Curtis similarity matrix of square-root transformed data.

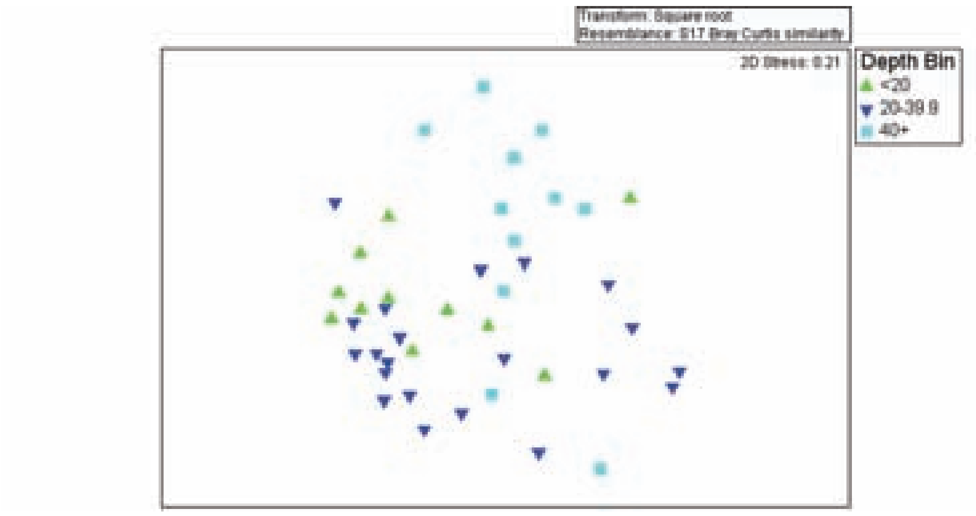


Figure 9: nMDS ordination illustrating differences of all drop photo data among “depth classes”. Ordination was based on Bray-Curtis similarity matrix of square-root transformed data.

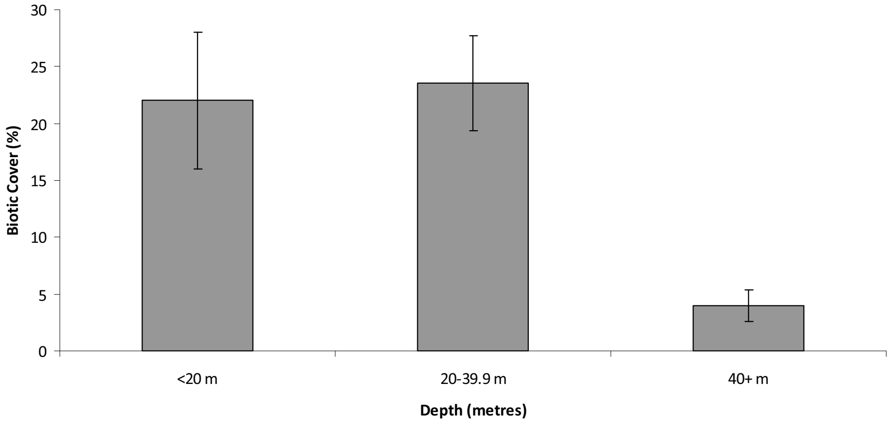


Figure 10: Relationship between depth and percent cover of biota determined from drop photo sampling. Error bars refer to standard error.

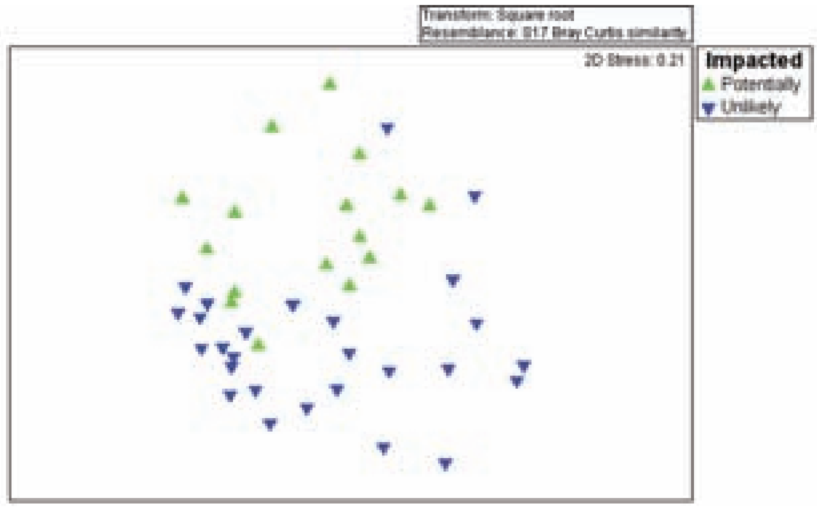


Figure 11: nMDS ordination illustrating differences of all drop photo data among levels of the factor "Impact". Ordination was based on Bray-Curtis similarity matrix of square-root transformed data.

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Deepwater Habitat Survey

Tables

Figures

Appendices

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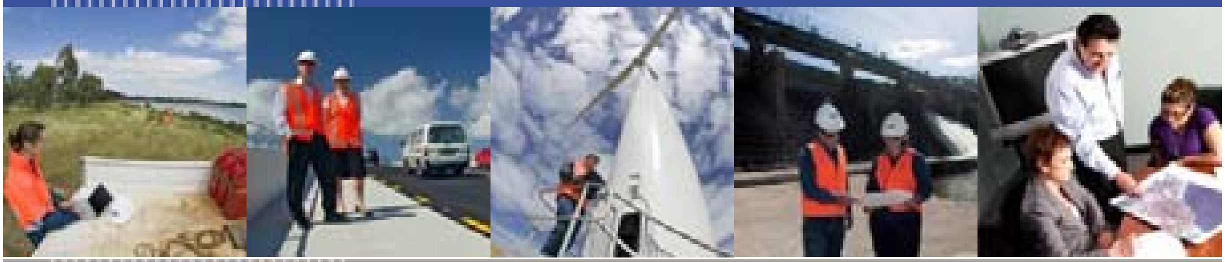

Report

Wheatstone Project: Deepwater Habitat Survey

5 MAY 2010

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Executive Summary

Chevron Australia Pty Ltd proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) and domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara Coast. The LNG and Domgas plant will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and other yet-to-be determined gas fields. The project is referred to as the Wheatstone Project and "Ashburton North" is the proposed site for the LNG and Domgas plant. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State Waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this report have been conducted to support the environmental impact assessment process.

This report details the results of a survey of deepwater benthic habitats along the proposed trunkline route. The trunkline will be approximately 225km long and extend from the Wheatstone Platform to the Ashburton North Strategic Industrial Area (Ashburton North SIA). The trunkline will pass through three marine bioregions:

- Pilbara inshore region, which extends from the shoreline to the 10 m depth contour;
- Pilbara offshore region, extending from the 10 m depth contour to the edge of the continental shelf; and
- North West Shelf, including the area of the gas fields.

The present report addresses sites surveyed in 75 - 270 m water depths. It complements habitat mapping studies previously conducted by URS in <70 m of water. A companion study (URS 2009) examines the trunkline route and four transects parallel to the route on the outer continental shelf. The objectives of the present study were to:

- collect video footage of the range of benthic assemblages within the deepwater sections of the proposed development area;
- ground truth data obtained from previous hydroacoustic surveys;
- analyse recorded video footage, providing a description of substrate and benthic assemblages that is consistent and comparable to the shallow water studies; and
- produce a broad-scale habitat classification map of the surveyed area.

Forty-two transects were surveyed by Remotely Operated Vehicle (ROV) within and adjacent to gas field WA-17-R, WA-253-P and WA-356-P and along the proposed trunkline route between 3-8 September 2009 in depths of 70-250 m. Transects were chosen to provide information on representative habitats in the gas fields, and along the proposed trunkline route.

Habitats were strongly correlated with the hydroacoustic data used to initially determine the transect locations. As expected, lower levels of reflectivity correlated to softer substrates and low coverage of benthic sessile invertebrates. This constituted the majority of the survey area. Higher levels of reflectivity corresponded to harder substrate and sparse (1-2%) to occasional (2-10%) epibenthic coverage. The majority of the sites surveyed were comparable and based within the following habitat classification:

- flat to micro rippled (<0.5 m) relief;
- silt/sand substrate;

Executive Summary

- sparse (1-10 /m^2) to abundant (50-100 /m^2) bioturbation (evidence of infauna such as burrows and mounds); and
- trace to very sparse (<1%) benthic sessile and motile invertebrates including soft corals, sea pens, sponges, sea whips, ascidians, urchins and hydroids.

Areas surveyed that consisted of hard substrate (limestone/sandstone) and isolated bombies found along the proposed trunkline route generally hosted sparse (1-2%) to occasional (2-10%) coverage of a diverse array of benthic sessile invertebrates, dominated by gorgonians (sea fans and whips), sponges and soft corals. These areas also had fish aggregations, with species such as gold-band snapper, batfish, red emperor, spangled emperor and Rankin cod present.

The proposed location of the Wheatstone Platform (WP) is on a large ridgeline (approximately 11 km long) over an area of hard substrate with occasional (2-10%) coverage of benthic sessile invertebrates, which was the highest abundance observed in the study area. This level of occasional coverage is likely to be found along the length of the ridgeline and on most hard substrates at this depth in the region.

Transect DT2-12 revealed a unique geological formation that was not observed elsewhere in the study area. The 30 m high cliff is possibly an ancient coastline relic from when the sea had receded to this level some 18,000-20,000 years ago. Previously buried structures such as deceased coral reefs and polychaete tubes appeared to be eroding out of the formation and accumulating in the sink environment presented at the foot of the drop-off. It is noted that the northern most Mobile Offshore Drilling Unit (MODU) anchor pattern encroaches upon the southern edge of this habitat cell.

Overall, no ecologically isolated, sensitive, unique or significant habitats were found in the study area. Construction of the WP in an area of occasional (2-10%) sessile invertebrate coverage may have an adverse localised effect on the benthic biota, but rapid re-colonisation is expected to occur.

Introduction

1.1 Background

Chevron Australia Pty Ltd proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) and domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara Coast. The LNG and Domgas plant will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and other yet-to-be determined gas fields (Figure 1-1). The project is referred to as the Wheatstone Project and "Ashburton North" is the proposed site for the LNG and Domgas plant. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State Waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this report have been conducted to support the environmental impact assessment process.

The present report details the results of a survey of deepwater benthic habitats along the proposed trunkline route.

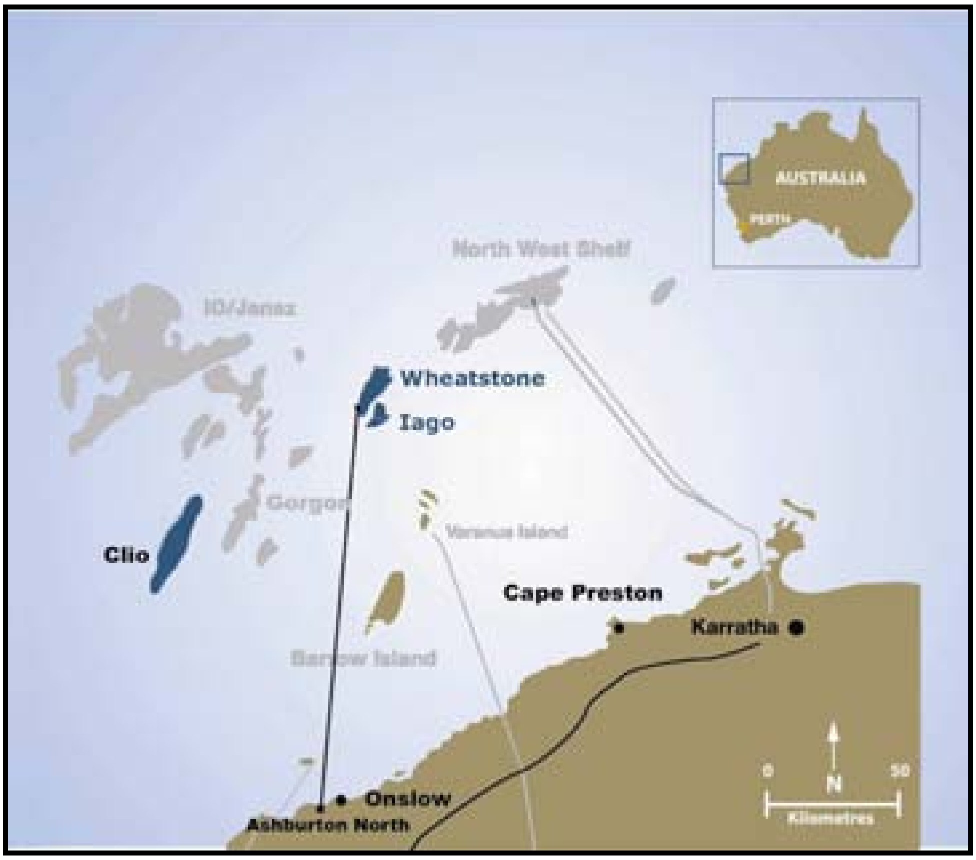

Figure 1-1 Location of the Wheatstone Project

1 Introduction

The trunkline route to shore will probably cross the shallow nearshore shelf between Thevenard and Bessieres Island, and skirt Ashburton Island before coming ashore at the Ashburton North Strategic Industrial Area (Ashburton North SIA). The trunkline design, including stabilisation, burial, etc has not yet been defined; however combinations of the following options have been considered:

- ploughing and backfilling;
- trenching and backfilling; or
- rock dumping.

In the case of ploughing and trenching the estimated depth to bottom of trench is 2 m. Trenching would be undertaken by a mechanical trenching machine.

Offshore facilities will consist of wells, jumper lines, manifolds, infield flowlines, umbilicals, the Wheatstone Platform (WP) and export flowline. The proposed wells are predominantly located in clusters around the manifold centres, although satellite wells are proposed for later production to recover trapped reserves. The wells will be connected to the manifolds by jumper lines and the manifolds will be connected to the WP by infield flowlines and risers.

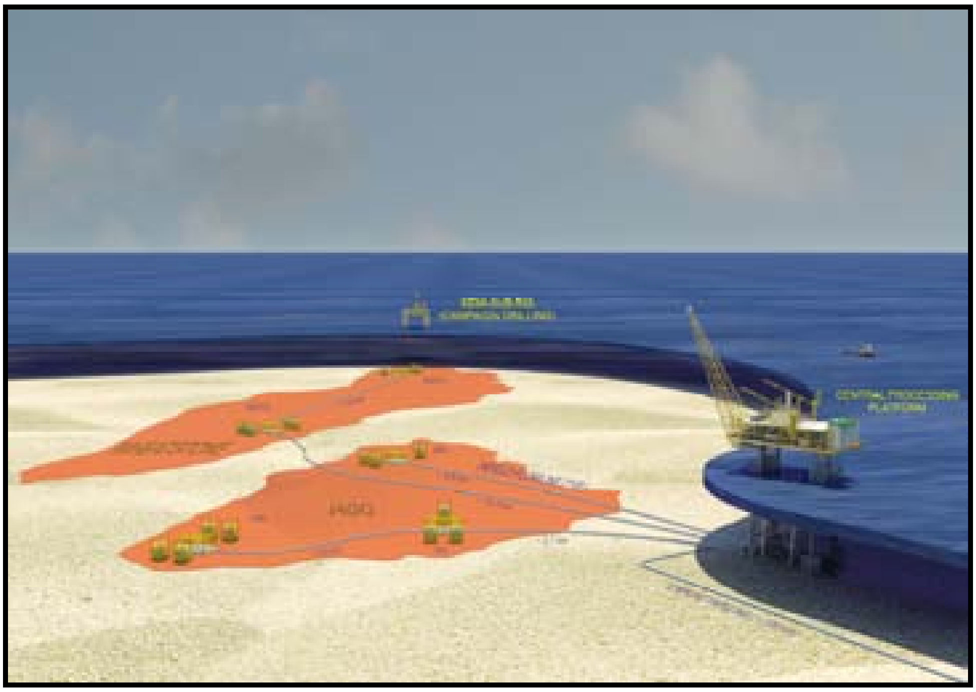

Figure 1-2 Proposed offshore infrastructure layout

1.2 Purpose of this document

The marine environment in which the proposed Project is situated extends from the upper intertidal zone through to depths in excess of 250 m, encompassing the full width of the continental shelf.

1 Introduction

The federal Department of the Environment and Heritage (2006) defines mesoscale regions (IMCRA) as extending in area between 3,000 km^2 and 240,000 km^2 in its marine and coastal regionalisation for Australia. The trunkline route traverses three of the IMCRA regions:

- Pilbara inshore region, which extends from the shoreline to the 10 m depth contour;
- Pilbara offshore region, extending from the 10 m depth contour to the edge of the continental shelf; and
- North West Shelf (NWS), including the area of the gas fields.

The present report addresses sites surveyed in 70-270 m water depths to complement habitat mapping studies previously conducted by URS in <70 m of water (URS 2009). A companion study (UWA 2009) examines the trunkline route and four transects parallel to the route on the outer continental shelf.

1.2.1 Existing knowledge of habitats and associated fauna in deepwater environment

Little is known of the habitats and associated biota in the area. However, deep pavement substrates have been known to support diverse communities of sessile filter feeding invertebrates such as sponges, colonial and solitary ascidians, hydroids, soft corals and gorgonians, including sea fans and sea whips. These assemblages are attached to the pavement reef and provide a habitat for fish and motile invertebrates. It is likely that light limited areas of hard substrate too deep to facilitate macroalgae and coral growth will support these benthic sessile invertebrate communities.

Soft sediment such as silt and sand are generally too unstable to support diverse assemblages of benthic sessile invertebrates but are more likely to support diverse infaunal communities, which are evident by burrows and mounds constructed by the animals. These habitats offer minimal structural diversity and offer a detritus based food-web. Finer sediments and detritus generally accumulate in deep, low energy areas and support diverse infaunal assemblages (Kinhill 1999).

Similar studies undertaken within the NWS region of deepwater benthic habitats have been conducted by Woodside Energy Limited (Woodside) for their Pluto LNG development. The Pluto field is located on the NWS approximately 180 km north west of Dampier in approximately 400 – 1000 m of water. The project’s offshore marine baseline surveys were conducted within the offshore development areas; permit WA-350-P and at the proposed location for the offshore platform nearby permits WA-350-P (Woodside 2006).

The surveys investigated the benthic habitats and communities down the continental slope inside and outside one of a number of canyon systems which traverse the Pluto field and generally observed sparse but highly diverse infauna. The surveys identified a number of epifaunal species that previously had not been recorded in Australia, Western Australia or the NWS region; however it has been noted that this may well be a result of the general lack of previous studies within this region rather than the rarity of the fauna. On the continental shelf (150 - 200 m depth) epifauna was most abundant and an inverse relation was observed between the abundance of fauna and depth (Woodside 2006).

The surveys found that the majority of the Pluto field seabed comprised soft sediments with presence of a rock pinnacle field in about 300 m depth. Remotely Operated Vehicle (ROV) surveys indicated these pinnacles were constructed by a deepwater coral, providing habitat for other epifaunal demersal species. These records of deepwater coral were the first recorded in the vicinity of the NWS (Woodside 2006).

1 Introduction

Other projects providing data for deepwater offshore marine benthic habitats of the NWS region include those conducted by Apache Energy Limited (Apache) for Petroleum Lease WA 209-P which contains the Reindeer Gas Field. The project includes an associated pipeline corridor for a 90 km subsea pipeline stretching from the proposed offshore platform within the Reindeer Gas Field to the mainland south of Karratha (Apache 2008).

The Apache (2008) surveys found that the deepwater marine benthic habitat of the pipeline corridor ranged from isolated coral bombora and coral patch reef dominated by macroalgae closer to shore, to bare coarse sandy substrate at the seaward end of the corridor. Patches of seagrass and limestone pavement, with macroalgae and minor filter feeding communities were identified at several locations along the pipeline route. Habitats leading offshore from Gnoorea Point, along the pipeline corridor, were dominated by large areas of sandy substrate. The benthic substrates at the proposed platform were dominated by medium coarse sand; epibenthic filter feeding communities were generally depauperate or absent.

Additionally, ChevronTexaco Australia Pty Ltd conducted similar studies for the Gorgon gas field project situated at Barrow Island in the NWS region. The deepwater studies undertaken found an offshore benthic habitat dominance of soft substrate with scattered soft corals and seagrass on sand in deeper waters off the east coast of Barrow Island (ChevronTexaco 2005). ROV transects conducted along the proposed trunkline route indicate dominance of heavily bioturbated soft sediment to a depth of approximately 180 m. Some isolated rocky reefs and patches of exposed pavement reef were identified supporting sparse filter-feeding assemblages, dominated by sea whips, gorgonians and sponges (ChevronTexaco 2005).

1.3 Study objectives

The objectives of this study were to:

- collect video footage of the range of benthic assemblages within the deepwater sections of the proposed development area;
- ground truth data obtained from previous hydroacoustic surveys;
- analyse recorded video footage, providing a description of substrate and benthic assemblages that is consistent and comparable to similar studies undertaken in shallower water; and
- produce a broad-scale habitat classification map of the surveyed area using the methodology developed for the Project by URS.

Survey Equipment and Methodology

2.1 Survey

URS undertook a Remotely Operated Vehicle (ROV) video survey along 42 transects within and adjacent to the petroleum titles (WA-253-P & WA-17-R, WA-356-P) and along the proposed trunkline route between 3-8 September 2009 in depths of 70-270 m.

2.2 Remote operated vehicle equipment

Transects were surveyed using an ROV (Figure 2-1) with an installed video camera with a remote feed to a surface mounted display and digital recorder. The ROV used for the video survey, operated by DiveWorks, was a Falcon Seaeye manufactured by SAAB Technologies. It has the following specifications:

- single phase power requirement;
- 300 m depth rating;
- 400 m umbilical length;
- dimensions 1.0 x 0.5 x 0.6 m (length x height x width);
- 55 kg launch weight;
- maximum forward speed >3 knots;
- 8.5 kg payload;
- distributed intelligence control system;
- high resolution colour camera on 180º tilt platform;
- horizontal field of view 91º;
- variable intensity 150 watts of lighting; and
- auto heading and depth.

Figure 2-1 Falcon Seaeye Remote Operated Vehicle

The real-time video overlay system updates at a rate of 98 ms and provides the following display information:

- site identification;
- compass heading (±0.5°);
- depth;
- easting/northing (geographic position [GDA94]);
- camera tilt position;
- the number of twists in the umbilical;
- degree of vehicle pitch and roll; and
- date and time.

2.3 Survey equipment

The ROV positioning and tracking systems were provided and operated by Neptune who undertook the following scope:

- real-time positioning and monitoring of the *Calypso* and ROV during survey activities
- display of proposed Project subsea structure information on the tracking screens; and
- logging of ROV point data and transmitted to DiveWorks' video screen via the video overlay system.

Equipment utilised for the survey were installed and configured as per Neptune Geomatics' and manufacturer/industry standards. The following primary survey systems were installed onboard the *Calypso*:

- QINSy Survey primary navigation system and QINSy remote navigation displays;
- Veripos Standard Differential Global Positioning System (DGPS) and Verify multiple reference station quality control software;
- TSS Meridian gyrocompass;
- CSI Vector Pro DGPS;
- TSS DMS-05 Roll, Pitch and Heave Sensor; and
- Sonardyne Fusion Ultra Short Baseline (USBL) acoustic positioning system.

Survey systems were tested and calibrated following Neptune Geomatics' and manufacturer/industry standards. Primary testing and calibration activities included:

- Establishment of geodetic survey control at Mermaid Wharf, Dampier to facilitate onshore system calibrations.
- Computation of a QINSy geodetic parameters worked example.
- Heading sensor calibrations of the primary TSS Meridian gyrocompass and secondary CSI Vector Pro heading systems calibrated using a Topcon Total Station and terrestrial survey observations from survey control established on Mermaid Wharf quayside.
- Positioning system checks of the primary Veripos Standard and secondary CSI Vector Pro differential systems using a Topcon Total Station and terrestrial survey observations from survey control established on Mermaid Wharf quayside.
- Installation of the TSS DMS-05 Surface Motion Sensor within close proximity to the vessel's centre of gravity. The heave/pitch/roll sign conventions were checked to ensure correct orientation of the motion reference system.

- Measurement of sensor mounting angles over a 15 minute period using the system's internal firmware. Values were documented and accepted within the motion sensor's internal memory.
- Configuration and deployment of the Valeport Midas Sound Velocity Profiler.

The Sonardyne USBL system was checked quayside prior to the commencement of survey operations. The USBL system checks within QINSy were undertaken as per the static calibration procedure detailed in Neptune's USBL Operations Guideline.

A sound speed profile was obtained at the calibration site quayside and entered into the Sonardyne Fusion software. A directional Super-Sub Mini beacon was deployed over the bow and stern of the *Calypso* and the USBL bearing was compared to the actual bearing. This resultant correction angle was then entered into the Sonardyne Fusion Software.

A vessel Spin Check was undertaken to verify the roll, pitch and heading corrections determined within the QINSy Calibration module.

2.4 Site selection

Sites were chosen to collect information on representative habitats in the petroleum titles, and along the proposed trunkline route. Substrate types were identified through analysis of two previous geophysical surveys of the proposed development (EGS 2006, Fugro 2008). These surveys inferred substrate type by the differing hydroacoustic reflectivity of the seabed by the towed sensor array; in this study reflectivity is defined as the strength of an acoustic echo. High reflectivity indicates hard substrates and lower reflectivity indicates softer substrates. Substrates are confirmed by collecting grab samples of the seabed. For this deepwater survey, transects intersected sites that:

- are proposed for subsea infrastructure (e.g. subsea wells, platform, manifolds and interfiled pipelines, and trunkline);
- represented different substrate densities or unique physical features discernible from data collected during the previous hydroacoustic and bathymetric surveys;
- crossed textural boundaries discernible from previous hydroacoustic survey data;
- potentially covered a range of biotic habitats including major physical features such as ridges, mega-ripples and pavement/reef; and
- were spatially distributed across the study area to be representative of the range of habitats within the proposed development area.

Each transect was initially set as a nominal 500 m straight line running either parallel or perpendicular to the isobath and intersecting the point of interest if one existed. Transect lengths were shortened if no habitat change was observed within the first 200 m of the transect and no substrate change was indicated by the hydroacoustic data within the remaining length of the transect. The transect locations are shown in Appendix A.

2.5 Broad-scale classification of benthic habitats

The ROV was flown along each transect approximately 0.5 m above the seabed at speeds of 0.5-2 knots. The forward facing video camera was angled toward the seabed at approximately 30° and the ROV lights were adjusted to maintain the best visual quality. The ROV was flown along a fixed heading as accurately as possible with minimal peripheral deviation for inspection of features of interest.

2 Survey Equipment and Methodology

For each transect, or habitat boundary within each transect (if a substantial change was noted), written observations were recorded and a video record made to characterise the habitat type using the following characteristics:

- site ID;
- date;
- time;
- transect start (and each habitat change) position (northings/eastings in datum GDA94);
- transect finish position (northings/eastings datum GDA94);
- water depth (m);
- relief;
- substrate type;
- dominant ecological element, taxa and cover/abundance; and
- subdominant ecological element, subdominant taxa, cover/abundance.

Observations on fish and other fauna were made and records made of any species identified. Due to the large extent of the area being surveyed and the limited time available for the survey, fish and other mobile fauna were recorded only on an opportunistic basis. The habitat classification key used for the survey is displayed in Appendix D.

Results and Discussion

3.1 Hydroacoustic data and habitat categories

The hydroacoustic data used to initially determine the transect locations provided a useful proxy for developing habitat classifications. As predicted, lower levels of reflectivity corresponded to softer substrates and sparse coverage of benthic sessile invertebrates, which constituted the majority of the survey area. Higher levels of reflectivity corresponded to harder substrate and sparse (1-2%) to occasional (2-10%) epibenthic coverage. Using the hydroacoustic data it was possible to develop textural boundaries (shaded areas) that broadly differentiate benthic areas with varying substratum.

Habitat classification “cells” were developed by cross-referencing the data from ROV surveys with the pre-existing textural boundaries determined by the hydroacoustic data. This approach was selected based on the strong relationship evident between sites within the same boundaries. Each site has been allocated to a particular habitat cell as shown in Appendix B, with these allocations providing the basis for the habitat mapping. For the purpose of this study, a habitat cell is simply an area characterised by a sequence of benthic substratum, areas of faunal activity (i.e. bioturbation) and/or sessile benthic organisms. While some of these features are not strictly ‘habitat’, they provide information on the associated faunal assemblages that characterise the study site. Habitat cell descriptions are detailed in Table 3-1 and representative photos are shown as plates in Appendix C.

Table 3-1 Habitat cell descriptions

Habitat Cell	Hydroacoustic Reflectivity	Habitat Description	Plate Ref.
Field 1 (F1)	50	Flat to micro-rippled (<0.5 m height) sand/silt, very sparse (<1/m^2) to moderate (10-50 /m^2) bioturbation, trace to very sparse (<1%) benthic sessile and motile invertebrates	1 & 2
F2	160	Ancient coastal reef relic, gently sloping (3-35°) sand/silt to vertical (70-90°) rock wall, seabed covered with deceased invertebrate debris (broken tubes and coral reef), trace to sparse (1-2%) benthic sessile invertebrates mainly comprising polychaetes (tubeworms)	3 & 4
F3	128	Flat to micro-rippled (<0.5 m height) sand/silt, very sparse (<1/m^2) to sparse (1-10 /m^2) bioturbation, trace to very sparse (<1%) benthic sessile and motile invertebrates	5 & 6
F4	50	Flat to micro-rippled (<0.5 m height) sand/silt, very sparse (<1 /m^2) to moderate (10-50 /m^2) bioturbation, trace benthic sessile and motile invertebrates	7 & 8
F5	128	Flat sand/silt, sometimes with shells present, very sparse (<1 /m^2) to moderate (10-50 /m^2) bioturbation, trace benthic sessile and motile invertebrates	9 & 10
F6	192	Flat sand/silt with shell fragments to steeply sloping (35-70°) limestone pavement with a shallow sand veneer, very sparse (<1 /m^2) bioturbation and occasional (2-10%) benthic sessile invertebrates	11 &12
F7	160	Flat sand/silt and rubble with very sparse (<1 /m^2) bioturbation, trace benthic sessile and motile invertebrates	13 & 14
F8	168	Flat sand/silt with sparse (1-2%) benthic sessile invertebrates	15 & 16
F9	228	Gently sloping (3-35°) limestone pavement with shallow sand veneer, occasional (2-10%) benthic sessile invertebrates	17 & 18
Pipeline 1 (P1)	50	Flat to micro-rippled (<0.5 m height) sand/silt with very sparse (<1 /m^2) to frequent (50-100 /m^2) bioturbation and trace benthic sessile invertebrates	19 & 20

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Habitat Cell	Hydroacoustic Reflectivity	Habitat Description	Plate Ref.
P2	NS	Flat sand/silt with sparse (1-10 /m^2) to moderate (10-50 /m^2) bioturbation, trace to sparse (1-2%) benthic sessile invertebrates, small isolated steeply sloping (35-75°) bombies also present with occasional (2-10%) benthic sessile invertebrates	21 & 22
P3	168	Flat to micro-rippled (<0.5 m height) sand/silt with moderate (10-50 /m^2) bioturbation and trace to sparse (1-2%) benthic sessile invertebrates, isolated flat to steeply sloping (35-70°) bombies with sparse (1-2%) to occasional (2-10%) benthic sessile invertebrates	23 & 24
P4	218	Gently sloping (3-35°) low profile reef with occasional (2-10%) benthic sessile invertebrates	25 & 26
P5	128	Flat to varying relief sand/silt with moderate (10-50 /m^2) to frequent (50-100 /m^2) bioturbation, including large infauna mounds, trace benthic sessile invertebrates	27 & 28
P6	148	Gently sloping (3-35°), with varying relief, sand/silt with moderate (10-50 /m^2) bioturbation, including large infauna mounds and trace benthic sessile invertebrates	29 & 30
P7	160	Flat to gently sloping (3-35°), with varying relief, sand/silt with moderate (10-50 /m^2) to frequent (50-100 m^2) bioturbation, including large infauna mounds and trace benthic sessile invertebrates	31 & 32
P8	192	Flat sand/silt with frequent (50-100 /m^2) bioturbation and trace benthic sessile invertebrates	33 & 34

Note: NS = Not hydroacoustic Surveyed

3.2 Key findings

As seen in Appendix B, the majority of the sites surveyed were comparable and based within the following habitat classification:

- flat to micro rippled (<0.5 m) relief;
- silt/sand substrate;
- sparse (1-10 /m^2) to abundant (50-100 /m^2) bioturbation (evidence of infauna such as burrows and mounds); and
- trace to very sparse (<1%) benthic sessile and motile invertebrates including soft corals, sea pens, sponges, sea whips, ascidians, urchins and hydroids.

These soft substrate habitats are not considered ecologically sensitive, unique or significant to the region.

Areas surveyed that consisted of hard substrate (limestone/sandstone), e.g. Transects DT1-15, DT3-10, and DT1-19 and the isolated bombies found along the proposed trunkline route generally hosted sparse (1-2%) to occasional (2-10%) coverage of a diverse array of benthic sessile invertebrates. These were dominated by gorgonians (sea fans and whips), sponges and soft corals. These areas also had fish aggregations, with species such as gold-band snapper, batfish, red emperor, spangled emperor and Rankin cod present.

The proposed location of the WP (Transect DT1-15) is on a large ridgeline (approximately 11 km long) over an area of hard substrate with occasional (2-10%) coverage of a diverse array of benthic sessile invertebrates, which was the highest abundance observed in the study area. This level of occasional

3 Results and Discussion

coverage is likely to be found along the length of the ridgeline and on most hard substrates at this depth in the region.

Transect DT2-12 revealed a unique geological formation that was not observed elsewhere in the study area (Table B-1). The 30 m high cliff is possibly an ancient coastline relic from when the sea had receded to this level some 18,000-20,000 years ago (Wilson 2009). Previously buried structures such as deceased coral reefs and polychaete tubes appeared to be eroding out of the formation and accumulating in the sink environment presented at the foot of the drop-off. It is noted that the northern most Mobile Offshore Drilling Unit (MODU) anchor pattern encroaches upon the southern edge of this habitat cell.

Transects DT2-4 and DT2-6 intersected the previous appraisal drill sites Iago 3 (spudded 24 May 2008) and Iago 2 (spudded 23 March 2008) respectively. Both sites had evidence of drill cuttings that were noticeable within a radius of up to 30 m from the well locations. The cuttings pile was more definitive at Iago 3 and consisted of higher profile semi-consolidated fine material, whereas the cuttings pile surrounding Iago-2 more closely resembled the sediments of the surrounding area, possibly due to more rapid natural assimilation and reworking of the sediments by currents and burrowing invertebrates. Both drill sites had fish aggregations, possibly due to the provision of more diverse habitats relative to homogenous surrounding area.

Overall, no ecologically isolated, sensitive, unique or significant habitats were found in the study area. Construction of the WP in an area of occasional (2-10%) sessile invertebrate coverage may have an adverse localised effect on the benthic biota.

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Acknowledgements

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 18 August 2009.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

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A

Appendix A Transect Locations

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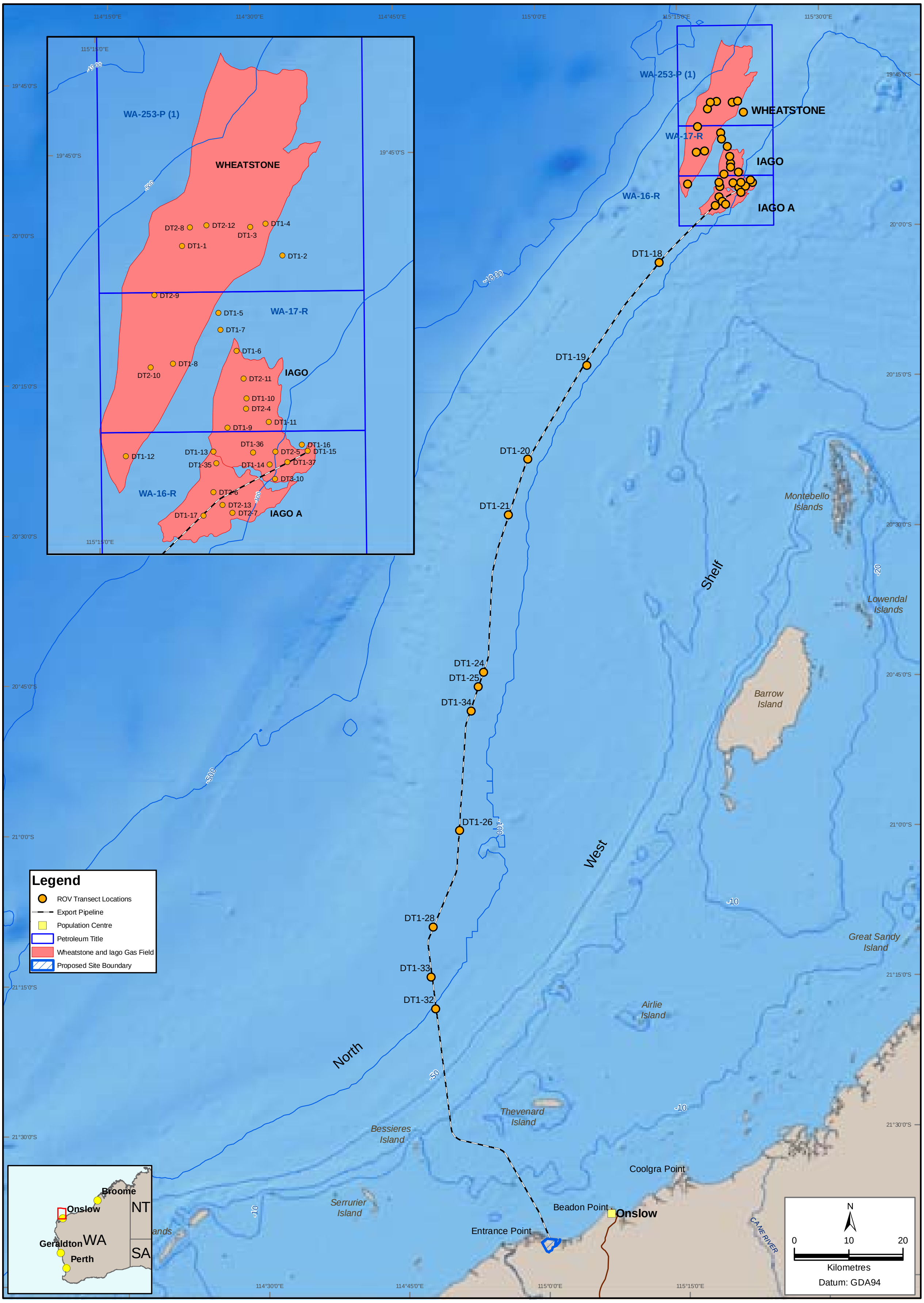
WA-253-P (1)
WHEATSTONE
WA-17-R
IAGO
WA-16-R
IAGO A
DT1-18
DT1-19
DT1-20
DT1-21
DT1-24
DT1-25
DT1-34
DT1-26
DT1-28
DT1-33
DT1-32
Montebello Islands
Lowendal Islands
Barrow Island
Great Sandy Island
Airlie Island
Thevenard Island
Bessieres Island
Serrurier Island
Coolgra Point
Beadon Point
Onslow
Entrance Point
North West Shelf
Legend
ROV Transect Locations
Export Pipeline
Population Centre
Petroleum Title
Wheatstone and Iago Gas Field
Proposed Site Boundary
Broome
Onslow
Geraldton
WA
Perth
NT
SA
Kilometres
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Datum: GDA94
42907100-EM-046.mxd

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B

Appendix B Transect Habitat Classifications

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Table B-1: Transect locations, habitat descriptions and adjacent proposed development

Site ID	Gas Field	Adjacent Proposed Development	Hydroacoustic Reflectivity (Substrate Density)	Hydroacoustic Texture Cell	Transect Start (or new habitat start) GDA94		Transect Finish (or habitat finish) GDA94		Water Depth (m)	Habitat Description	Mega-Fauna	No. Individuals
DT2-8	Wheatstone	Modu Anchor Pattern	50	F1	322918	7810432	322788	7810519	258-270	Micro-rippled (<0.5 m height) sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace urchins, anemones, hydroids and sea pens		
DT1-1	Wheatstone	Manifold	50	F1	322230	7809340	322380	7809223	235-231	Flat sand/silt with moderate (10-50 m/sq) bioturbation (mounds and burrows) and trace anemones, sea pens, hydroids, urchins (three different species including *Loveniidae* sp.) and ascidians	Fish	2-5
DT2-9	Wheatstone	Manifold	50	F1	320497	7806067	320545	7805965	222-220	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and soft corals (possibly Dendronephthya sp. or Umbellulifera) with trace sea whips, ascidians, hydroids and sea pens	Fish	1
DT2-12	Wheatstone	NA	160	F2	323974	7810620	323949	7810623	224-225	Gently sloping (3-35 deg) sand/silt with very sparse (<1%) tubeworm polychaetes (Sabellidae) and trace sponges, sea pens, anemones, ascidians and soft corals. Seabed covered with debris which appeared to consist of broken invertebrate tubes and dead sponges, fish included gold-band snapper	Fish	51-100
	Wheatstone	NA	160	F2	323949	7810623	323945	7810676	225-243	Vertical reef wall (70-90 deg) with a 30 m drop-off with sparse (1-2%) tubeworm polychaetes (Sabellidae) on the edge, fish included gold-band snapper	Fish	21-50
	Wheatstone	NA	160	F2	323945	7810676	323899	7810667	243-255	Steeply sloping (35-70 deg) high profile reef with no epibenthos. Unique habitat with large pieces of deceased reef (coral) detritus and broken tubes (from tubeworms) covering. The area at the foot of the cliff presented a sink environment which may account for the large accumulation of debris, fish included gold-band snapper	Fish	21-50
DT2-10	Wheatstone	Manifold	128	F3	320179	7801312	320343	7801176	200-197	Flat sand/silt with sparse (10-50 m/sq) bioturbation (mounds and burrows) and trace Gorgonians (sea fans and whips), sea pens, soft corals (Dendronephthya sp.) and ascidians		
DT1-3	Wheatstone	W-A & Wheatstone 9 Wells	128	F3	326972	7810493	326686	7810523	190-191	Micro-rippled (<0.5 m height) sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace sea pens, soft corals, hydroids, anemones, sponges and sea whips, hermit crab also noted	Fish	1
DT1-4	Wheatstone	W-A2 & Wheatstone 9 alt Wells	128	F3	327902	7810823	327759	7810616	181-181	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1%) soft corals and bioturbation (<1 m/sq), trace ascidians, urchins and sea pens, one crab also noted	Fish	1
DT1-5	NA	Iago_b_North & Iago 6 Wells	NS (likely 128)	F3	324847	7804966	324626	7804715	177-177	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and trace sea pens, soft corals, ascidians, anemones, urchins, brittle stars, sea whips and anemones	Fish	2-5
DT1-8	Wheatstone	Wellhead Option	128	F3	321659	7801547	321818	7801418	187-183	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and soft corals (<1%) (possibly *Studeroites* sp.), trace sea pens and sea whips	Fish	1
DT1-12	Wheatstone	Wheatstone 6 Well (6ST)	NS (likely 50)	F4	318585	7795434	318704	7795312	168-166	Micro-rippled (<0.5 m height) sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace sea pens, sea whips and anemones, fish was a sole	Fish	1
DT1-7	NA	Iago_b_East Well	NA (likely 50)	F4	324792	7803777	324931	7803668	170-168	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and trace sea pens, soft corals, sea whips and anemones		

Table B-1: Transect locations, habitat descriptions and adjacent proposed development

Site ID	Gas Field	Adjacent Proposed Development	Hydroacoustic Reflectivity (Substrate Density)	Hydroacoustic Texture Cell	Transect Start (or new habitat start) GDA94		Transect Finish (or habitat finish) GDA94		Water Depth (m)	Habitat Description	Mega-Fauna	No. Individuals
DT1-2	NA	Wheatstone 10 & W-Iago-B Wells	NS (likely 50)	F4	329116	7808666	328797	7808602	158-160	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and trace soft corals, sea pens and urchins		
DT1-6	Iago	Iago_a_South & Iago 5 Wells	NS (likely 50)	F4	325828	7802340	326095	7802336	154-154	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and trace anemones		
DT2-11	Iago	Manifold	NS (likely 50)	F4	326257	7800574	326478	7800416	141-139	Micro-rippled (<0.5 m height) sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace anemones, one shark observed	Fish	2-5
DT1-10	Iago	West 3 Well	NS (likely 50)	F4	326487	7799251	326659	7799136	131-129	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and trace sea whips, soft coral, urchins, sea pens and sponges	Fish	6-10
DT1-9	Iago	West 9	50	F4	325439	7797209	325233	7797336	130-132	Flat sand/silt with moderate (10-50 m/sq) bioturbation (mounds and burrows) and trace soft corals (*Dendronephthya* sp.)		
DT1-13	Iago	West 1 Well	50	F4	324349	7795567	324474	7795779	129-129	Flat sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace soft corals, sea pens, ascidians and sponges, crab and several prawns observed	Other	1
DT2-4	Iago	Iago 3 Well (existing)	NS (likely 50)	F4	326394	7798625	326553	7798522	131-127	Flat sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace soft corals, sea pens, ascidians and sponges, fish identified included gold-band snapper, white-tip reef shark and spangled emperor	Fish	51-100
DT2-4	Iago	Iago 3 Well (existing)	NS (likely 50)	F4	326553	7798522	326602	7798494	127-128	Gently sloping (3-35 deg) sand/silt with frequent (50-100 m/sq) bioturbation, drill cuttings pile evident (radius of approximately 30 m), depression in the centre is possibly previous drill site, small horizontal ledge located inside crater, fish identified included batfish, spangled emperor, red emperor and saddle-tail snapper	Fish	101-999
DT2-4	Iago	Iago 3 Well (existing)	NS (likely 50)	F4	326602	7798494	326739	7798407	128-128	Flat sand/silt with moderate (10-50 m/sq) bioturbation (mounds and burrows).		
DT1-35	Iago	Manifold	50	F4	324673	7794869	324509	7794981	124-125	Flat sand/silt with sparse (1-10 m/sq) bioturbation (mounds and burrows) and trace sea pens, sea whips, tube worms, ascidians and sponges		
DT2-6	Iago	Iago 2 Well (existing)	50	F4	324364	7793031	324446	7792972	120-120	Flat sand/silt with moderate (10-50 m/sq) bioturbation (mounds and burrows) and trace sea pens, sea whips, sponges, soft corals, drill cuttings pile evident within 10 m radius of existing drill site as semi consolidated sediment, fish included lionfish and saddle-tail snapper	Fish	101-999
DT1-17	Iago	North 1 Well	50-128	F5	323683	7791489	323831	7791395	119-117	Micro-rippled (<0.5 m height) to flat (end of transect) sand/silt with very sparse (<1 m/sq) bioturbation and trace anemones, sea whips, sea pens, crinoids, soft corals, hydroids and sponges	Fish	1
DT2-13	Iago	South-1 Well	128	F5	325020	7792065	325012	7792264	113-115	Flat sand/silt with very sparse (<1 m/sq) bioturbation and trace sea pens, soft corals, sea whips, sponges, hydroids and urchins, patches of micro-ripples towards the end of the transect, crustaceans (prawns)	Other	2-5
DT1-36	Iago	Manifold	128	F5	327109	7795597	326939	7795682	115-116	Flat sand/silt with moderate (10-50 m/sq) bioturbation and trace crinoids, sea pens, sea whips, sponges and soft corals		
DT1-11	Iago	Wellhead Option	128	F5	327895	7797613	328186	7797646	114-114	Flat sand/silt with shell fragments and moderate (10-50 m/sq) bioturbation, trace sponges, sea pens, ascidians, sea whips, hydroids, urchins, crinoids and soft corals (*Dendronephthya* sp.)		

Table B-1: Transect locations, habitat descriptions and adjacent proposed development

Site ID	Gas Field	Adjacent Proposed Development	Hydroacoustic Reflectivity (Substrate Density)	Hydroacoustic Texture Cell	Transect Start (or new habitat start) GDA94		Transect Finish (or habitat finish) GDA94		Water Depth (m)	Habitat Description	Mega-Fauna	No. Individuals
DT2-7	Iago	NA	128	F5	325766	7791663	325584	7791624	111-109	Flat sand/silt with sparse (1-10 m/sq) bioturbation and trace sponges, urchins, hydroids, sea pens, soft corals , ascidians and tube worms		
DT1-14	Iago	East 1 Well	128	F5	328103	7794962	328120	7794681	108-106	Flat sand/silt with sparse (1-10 m/sq) bioturbation and trace sea pens, soft corals, sponges, tubeworms and crinoids	Fish	1
DT2-5	Iago	Iago 7 Well	128	F5	328567	7795689	328398	7795686	107-107	Flat sand/silt with sparse (1-10 m/sq) bioturbation and trace sponges, sea pens and fan worms	Fish	2-5
DT3-10	Iago	NA	192	F6	328525	7793856	328481	7793881	94-95	Flat sand/silt with shell fragments and occasional (2-10%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), sponges, sea pens and hydroids also present	Fish	21-50
	Iago	NA	192	F6	328481	7793881	328466	7793897	95-98	Steeply sloping (35-70 deg) limestone pavement with shallow sand veneer, occasional (2-10%) soft corals and filter feeders mainly comprising sponges and Gorgonians (sea fans and whips), sea pens and hydroids also present	Fish	21-50
	Iago	NA	192	F6	328466	7793897	328452	7793913	98-100	Flat sand/silt with very sparse (<1 m/sq) bioturbation	Fish	21-50
DT1-37	Iago	Proposed pipeline route	160	F7	329382	7794990	329191	7794996	95-98	Flat sand/silt and rubble with very sparse (<1 m/sq) bioturbation, trace sea pens, crinoids, soft corals, hydroids, sponges, fan worms and urchins		
DT1-16	Iago	NA	168	F8	330226	7796165	330244	7796157	90-90	Flat sand/silt with sparse (1-2%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips) and sponges	Fish	6-10
DT1-15	Iago	Central Processing Platform	228	F9	330525	7795485	330679	7795971	76-75	Gently sloping (3-35 deg) limestone pavement with shallow sand veneer, occasional (2-10%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips). Sponges also present	Fish	51-100
DT1-18	NA	Proposed Pipeline Route	50	P1	313286	7780992	313429	7780870	126-123	Micro-rippled (<0.5 m height) sand/silt with very sparse (<1 m/sq) bioturbation (mounds and burrows) and trace sea pens, fish were trevally	Fish	2-5
DT1-19	NA	400m east of proposed pipeline route	NS	P2	300020	7761989	300049	7761954	118-121	Flat sand/silt with moderate (10-50 m/sq) bioturbation and trace sea pens, hydroids and sea fans	Fish	21-50
	NA	400m east of proposed pipeline route	NS	P2	300049	7761954	300047	7761941	121-120	Flat sand/silt with sparse (1-2%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), sponges and hydroids also present		
	NA	400m east of proposed pipeline route	NS	P2	300047	7761941	300065	7761912	120-119	Steeply sloping (35-70 deg) low profile bombie with occasional (2-10%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), sponges and crinoids also present	Fish	11-20
	NA	400m east of proposed pipeline route	NS	P2	300065	7761912	300067	7761895	119-119	Flat sand/silt with moderate (10-50 m/sq) bioturbation and trace sea pens		
	NA	400m east of proposed pipeline route	NS	P2	300067	7761895	300066	7761883	119-119	Steeply sloping (35-70 deg) low profile bombie with occasional (2-10%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), sponges, crinoids and sea pens also present	Fish	6-10
	NA	400m east of proposed pipeline route	NS	P2	300066	7761883	300080	7761867	119-120	Flat sand/silt with sparse (1-2%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), sponges also present		
	NA	400m east of proposed pipeline route	NS	P2	300080	7761867	300088	7761858	120-121	Flat sand/silt with sparse (1-10 m/sq) bioturbation and trace sea pens		
DT1-20	NA	Proposed Pipeline Route	50	P1	289156	7744595	289207	7744684	115	Flat sand/silt with frequent (50-100 m/sq) bioturbation and trace hydroids, sea whips, sea pens and anemones		

Table B-1: Transect locations, habitat descriptions and adjacent proposed development

Site ID	Gas Field	Adjacent Proposed Development	Hydroacoustic Reflectivity (Substrate Density)	Hydroacoustic Texture Cell	Transect Start (or new habitat start) GDA94		Transect Finish (or habitat finish) GDA94		Water Depth (m)	Habitat Description	Mega-Fauna	No. Individuals
DT1-21	NA	Proposed Pipeline Route	168	P3	285658	7734370	285565	7734382	110-110	Micro-rippled (<0.5 m height) sand/silt with moderate (10-50 m/sq) bioturbation and sparse (1-2%) soft coral and filter feeders mainly comprising Gorgonians (sea fans and whips), trace sea pens		
	NA	Proposed Pipeline Route	218	P4	285565	7734382	285548	7734389	110-110	Gently sloping (3-35 deg) low profile reef with occasional (2-10%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), sponges also present	Fish	21-50
	NA	Proposed Pipeline Route	168	P3	285548	7734389	285501	7734409	110-110	Micro-rippled (<0.5 m height) sand/silt with moderate (10-50 m/sq) bioturbation		
DT1-24	NA	Proposed Pipeline Route	168	P3	280955	7705476	280982	7705403	108-107	Flat sand/silt with moderate (10-50 m/sq) bioturbation and very sparse (<1%) soft corals and filter feeders mainly comprising of Gorgonians (sea fans and whips), trace sea pens		
	NA	Proposed Pipeline Route	168	P3	280982	7705403	280981	7705400	107-108	Steeply sloping (35-70 deg) high profile reef with sparse (1-2%) soft corals and filter feeders mainly comprising sponges, trace hydroids and sea whips	Fish	51-100
	NA	Proposed Pipeline Route	168-128	P3 & P5	280981	7705400	281029	7705226	108-107	Flat sand/silt with moderate (10-50 m/sq) bioturbation and very sparse (<1%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), trace hydroids, soft corals		
DT1-25	NA	Proposed Pipeline Route	168	P3	279966	7702667	280105	7702719	106-107	Flat sand/silt with moderate (10-50 m/sq) bioturbation and sparse (1-2%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips), trace sponges, sea pens, isolated rock patch which generally hosted sparse (1-2%) Gorgonians (sea fans and whips)	Fish	6-10
DT1-34	NA	Proposed Pipeline Route	128-168	P3 & P5	278565	7698115	278769	7698232	106-106	Flat sand/silt with moderate (10-50 m/sq) bioturbation and trace sea pens, sea whips and sponges		
	NA	Proposed Pipeline Route	168	P3	278769	7698232	278769	7698232	106-107	Flat low profile isolated rock patch with occasional (2-10%) soft corals and filter feeders mainly comprising Gorgonians (sea fans and whips)	Fish	6-10
	NA	Proposed Pipeline Route	168	P3	278769	7698232	278809	7698254	107-107	Flat sand/silt with moderate (10-50 m/sq) bioturbation and trace sea pens and sea whips		
DT1-26	NA	Proposed Pipeline Route	128-168	P3 & P5	276431	7676226	276721	7676009	108-108	Gently sloping (3-35 deg) sand/silt with frequent (50-100 m/sq) bioturbation and trace urchins, sea pens and sea whips, varying degrees of relief in some areas, large infauna mounds	Fish	1
DT1-28	NA	Proposed Pipeline Route	148-160	P6 & P7	271635	7658349	271874	7658353	113-113	Gently sloping (3-35 deg) sand/silt with moderate (10-50 m/sq) bioturbation and trace sea pens, varying degrees of relief in some areas, large infauna mounds	Fish	1
DT1-33	NA	Proposed Pipeline Route	128	P5	271297	7649258	271376	7648957	110-110	Flat sand/silt with moderate (10-50 m/sq) bioturbation and trace sponges, soft corals, ascidians and sea pens, large infauna mounds		
DT1-32	NA	Proposed Pipeline Route	160-192	P8, P3 & P7	272180	7643363	272193	7643161	100-99	Flat sand/silt with frequent (50-100 m/sq) bioturbation and trace soft corals, sea whips, sponges, hydroids, sea pens and ascidians		

C

Appendix C Habitat Cell Plates

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Plate 1 Representative photo from Habitat Cell F1, Transect DT1-1
Plate 2 Representative photo from Habitat Cell F1, Transect DT2-8

Plate 3 Representative photo from Habitat Cell F2, Transect DT2-12
Plate 4 Representative photo from Habitat Cell F2, Transect DT2-12

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Report No.:	R1427	**Deepwater Habitat Survey**	

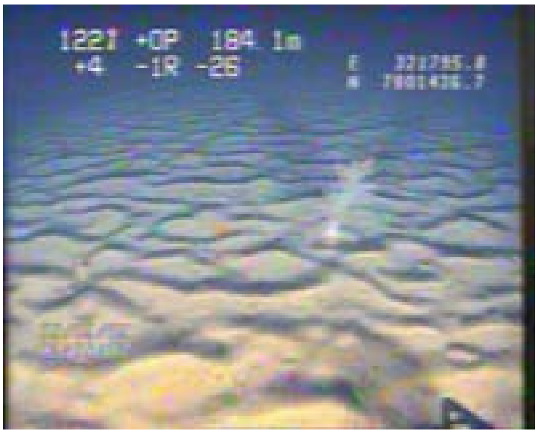


Plate 5 Representative photo from Habitat Cell F3 including a soft coral (possibly *Studeriotes* sp.), Transect DT1-8

Plate 6 Representative photo from Habitat Cell F3, Transect DT2-10

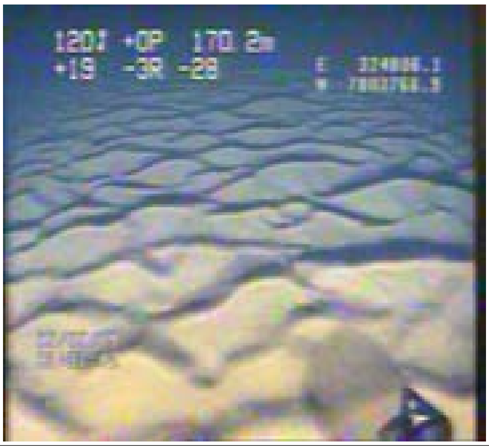
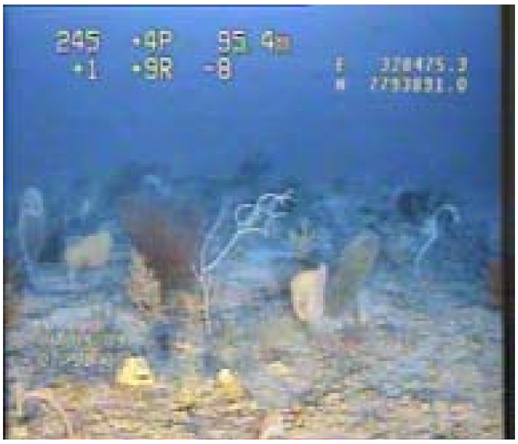


Plate 7 Representative photo from Habitat Cell F4, Transect DT1-7

Plate 8 Representative photo from Habitat Cell F4, Transect DT1-9

Job No.:	42907100-2163	**Chevron Australia Pty Ltd**	**Plates**
Report No.:	R1427	**Deepwater Habitat Survey**	URS

Plate 9 Representative photo from Habitat Cell F5 including a sponge, Transect DT1-36
Plate 10 Representative photo from Habitat Cell F5, Transect DT2-5



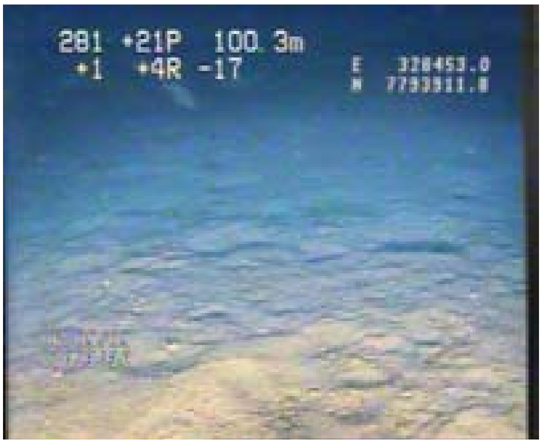


Plate 11 Representative photo from Habitat Cell F6 including various Gorgonians (sea fans and whips) and sponges, Transect DT3-10
Plate 12 Representative photo from Habitat Cell F6, Transect DT3-10

Job No.:	42907100-2163	**Chevron Australia Pty Ltd**	**Plates**
Report No.:	R1427	**Deepwater Habitat Survey**	URS

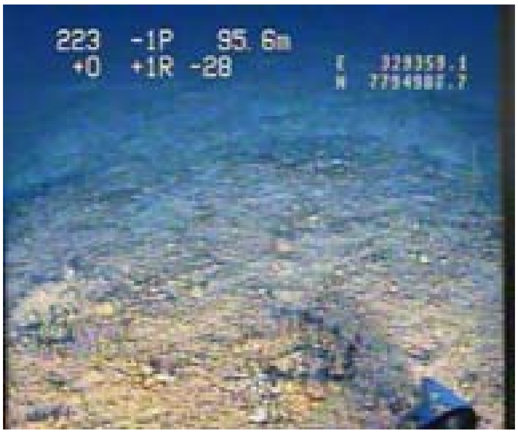


Plate 13 Representative photo from Habitat Cell F7, Transect DT1-37
Plate 14 Representative photo from Habitat Cell F7 including hydriod, Transect DT1-37

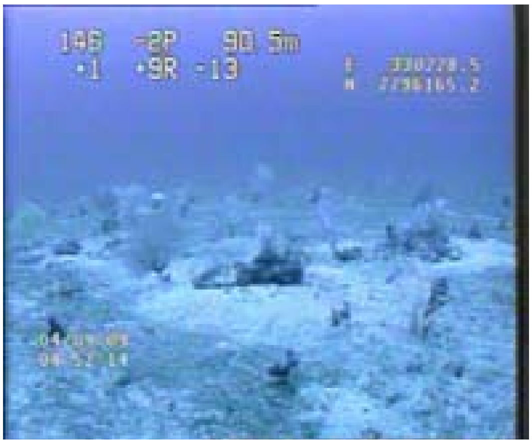


Plate 15 Representative photo from Habitat Cell F8 including various Gorgonians (sea fans), Transect DT1-16
Plate 16 Representative photo from Habitat Cell F8 including a vase sponge, Transect DT1-16

Job No.:	42907100-2163	**Chevron Australia Pty Ltd**	**Plates**
Report No.:	R1427	**Deepwater Habitat Survey**	URS

Plate 17 Representative photo from Habitat Cell F9 including various Gorgonians (sea fans and whips) and sponges, Transect DT1-15

Plate 18 Representative photo from Habitat Cell F9 including various Gorgonians (sea fans) and sponges, Transect DT1-15

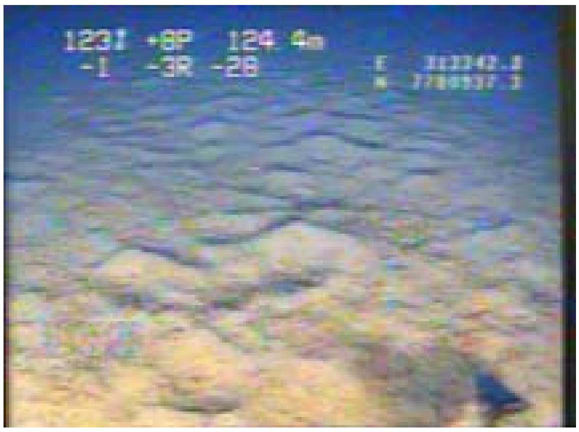


Plate 19 Representative photo from Habitat Cell P1, Transect DT1-18

Plate 20 Representative photo from Habitat Cell P1, Transect DT1-18

Job No.:	42907100-2163	**Chevron Australia Pty Ltd**	**Plates**
Report No.:	R1427	**Deepwater Habitat Survey**	URS

Plate 21 Representative photo from Habitat Cell P2 including infauna burrows, Transect DT1-19

Plate 22 Representative photo from Habitat Cell P2 of bombie with attached Gogonians (sea fans and whips) and vase sponge, Transect DT1-19

Plate 23 Representative photo from Habitat Cell P3 of bombie with attached sponges, Transect DT1-24

Plate 24 Representative photo from Habitat Cell P3, Transect DT1-34

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Plate 25 **Representative photo from Habitat Cell P4 including various Gorgonians (sea fans), Transect DT1-21**

Plate 26 **Representative photo from Habitat Cell P4 including various Gorgonians (sea whips), Transect DT1-21**

Plate 27 **Representative photo from Habitat Cell P5, Transect DT1-33**

Plate 28 **Representative photo from Habitat Cell P5 including large infauna mound, Transect DT1-33**

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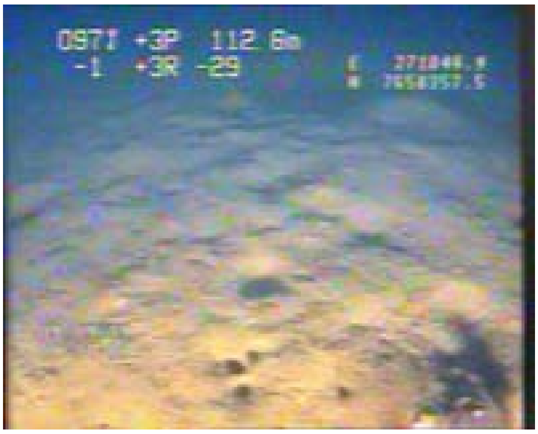

Plate 29 Representative photo from Habitat Cell P6, Transect DT1-28
Plate 30 Representative photo from Habitat Cell P6, Transect DT1-28

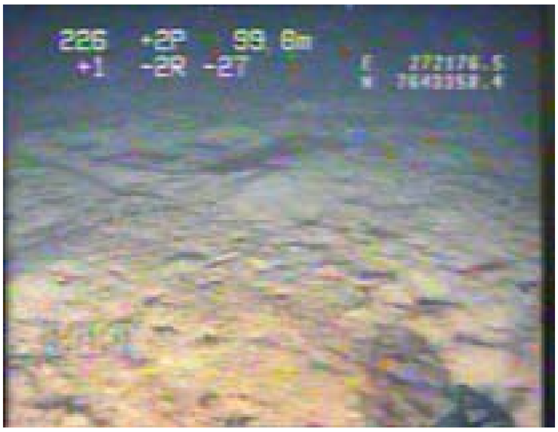

Plate 31 Representative photo from Habitat Cell P7, Transect DT1-32
Plate 32 Representative photo from Habitat Cell P7 including soft coral, Transect DT1-32

Job No.:	42907100-2163	**Chevron Australia Pty Ltd**	**Plates**
Report No.:	R1427	**Deepwater Habitat Survey**	URS

Plate 33 **Representative photo from Habitat Cell P8 including soft coral (Possible *Xenia* sp.), Transect DT1-32**

Plate 34 **Representative photo from Habitat Cell P8 including hydroid, Transect DT1-32**

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D

Appendix D Field Habitat Description Key

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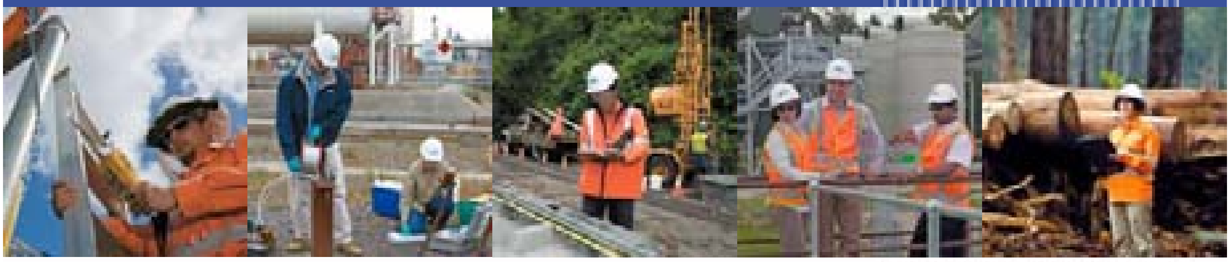
PHYSICAL FACTORS		BIOLOGICAL FACTORS								
Relief	**Substrate Type**	**Dominant Ecological Element**	**Cover/Abundance**	**Dominant Taxa**	**Sub-Dominant Ecological Element**	**Cover/Abundance**	**Sub-Dominant Taxa**	**Comments**	**Mega-Fauna**	**No. Individuals**
Flat	Sand/Silt	Macroalgae	**Biota**	Mixed Rhodophyta (Red)	Macroalgae	**Biota**	Mixed Rhodophyta (Red)		Fish	1
Gently sloping (3-35 deg)	Sand/Silt with shell fragments		Very Sparse (<1%)	Mixed Chlorophyta (Green)		Very Sparse (< 1%)	Mixed Chlorophyta (Green)		Sea snakes	2-5
Steeply sloping (35-70 deg)	Gravel		Sparse (1-2%)	Mixed Phaeophyceae (Brown)		Sparse (1-2%)	Mixed Phaeophyceae (Brown)		Turtles	6-10
Vertical wall (70-90 deg) and caves/overhangs	Cobbles		Occasional (2-10%)	Algal mat/turf		Occasional (2-10%)	Algal mat/turf		Rays	11-20
Micro-ripples <0.5 m height)	Consolidated cobbles		Moderate (10-25%)	Unidentified macroalgae		Moderate (10-25%)	Unidentified macroalgae		Sharks	21-50
Macro-ripples (>0.5 m height)	Boulders	Seagrass	Frequent (25-50%)	*Halophila*	Seagrass	Frequent (25-50%)	*Halophila*		Crocodiles	51-100
	Limestone pavement		Abundant (50-75%)	*Halodule*		Abundant (50-75%)	*Halodule*		Whales/dolphins	101-999
	Limestone pavement with shallow sand veneer		Dense (75-100%)	*Thalassia*		Dense (75-100%)	*Thalassia*		Other	>999
	Reef - low profile/simple		**Bioturbation (m/sq=m^2)**	*Heterozostera*		**Bioturbation (m/sq=m^2)**	*Heterozostera*			
	Reef - high profile/complex		Very Sparse (<1 m/sq)	*Amphibolis*		Very Sparse (<1 m/sq)	*Amphibolis*			
			Sparse (1-10 m/sq)	*Posidonia*		Sparse (1-10 m/sq)	*Posidonia*			
			Moderate (10-50 m/sq)	Unidentified seagrass		Moderate (10-50 m/sq)	Unidentified seagrass			
		Hard Corals	Frequent (50-100 m/sq)	Faviidae	Hard Corals	Frequent (50-100 m/sq)	Faviidae			
			Abundant (>100 m/sq)	Acroporidae		Abundant (>100 m/sq)	Acroporidae			
				Dendrophylliidae			Dendrophylliidae			
				Poritidae			Poritidae			
				Musiidae			Musiidae			
				Unidentified hard coral			Unidentified hard coral			
		Soft Corals and Filter Feeders		Soft Corals	Soft Corals and Filter Feeders		Soft Corals			
				Anemones			Anemones			
				Sea fans and whips (Gorgonians)			Sea fans and whips (Gorgonians)			
				Sea pens			Sea pens			
				Sponges			Sponges			
				Ascidians			Ascidians			
				Bryozoans			Bryozoans			
				Hydroids			Hydroids			
		Motile Invertebrates		Sea stars (Asteroidea)	Motile Invertebrates		Sea stars (Asteroidea)			
				Brittle stars (Ophiuroidea)			Brittle stars (Ophiuroidea)			
				Feather stars (Crinoidea)			Feather stars (Crinoidea)			
				Sea urchins and sand dollars			Sea urchins and sand dollars			
				Holothurians			Holothurians			
				Polychaetes (e.g. tube worms)			Polychaetes (e.g. tube worms)			
				Bivalves			Bivalves			
				Crustaceans			Crustaceans			
				Other			Other			
		No Epibenthos		Undisturbed	No Epibenthos		Undisturbed			
				Bioturbated (mounds and burrows)			Bioturbated (mounds and burrows)			
				Drift macroalgae			Drift macroalgae			
				Drift seagrass			Drift seagrass			



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Appendix N10

Survey of Intertidal Fauna on the Islands off Onslow, Western Australia

Tables

Figures

Appendices

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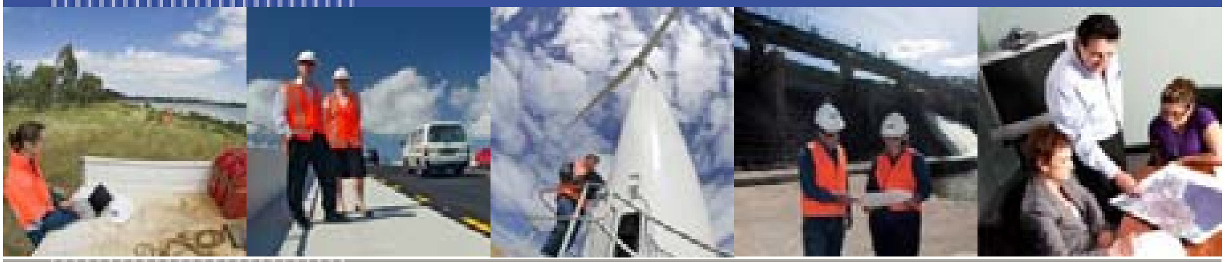

Report

Survey of Intertidal Fauna on the Islands off Onslow, Western Australia

29 APRIL 2010

Prepared for

Chevron Australia Pty Ltd

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Reference: 42907466/R1446/M&C 3194/1
Status: Final

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Executive Summary

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara coast. The LNG and Domgas plants will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and yet-to-be determined gas fields. The Wheatstone Project is referred to as the Project and the Ashburton North Strategic Industrial Area (Ashburton North SIA) is the proposed site for the LNG and Domgas plants. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this survey of the intertidal invertebrate biota on islands in the Project area have been conducted to support the environmental impact assessment process.

The present study surveys the intertidal fauna of eight islands. Molluscs were examined in detail because they are taxonomically diverse, ecologically important and relatively well known taxonomically. Corals were also actively identified. Less detailed records were made of other groups such as echinoderms, crustaceans and fish, and there were incidental records of seagrasses.

Diversity of intertidal invertebrates was moderate. A total of 169 species of molluscs were identified: 4 chitons, 129 gastropods, 33 bivalves and 3 cephalopods. In addition, there were 16 scleractinian corals, 11 holothurians and 20 crustaceans. Exposed sandy and rocky shores were the primary intertidal habitats on the Onslow islands. Very few species were found on sand beaches, primarily the ghost crab *Ocypode* sp. and the small crab *Scopimera* sp. Diversity on rocky shores was higher.

Most of the species recorded were tropical. Of the 117 molluscs identified to species, 112 are tropical Indo-West Pacific species or are widely distributed across northern Australia. However, *Polinices conicus* is a temperate species that extends from Queensland across southern Australia and north to Broome, WA. The four species endemic to Western Australia are all widely distributed within WA. The ranges of non-molluscan taxa identified during the study were similarly large.

Two key points arise from this study. The intertidal habitats of the islands off Onslow have moderate species diversity caused by low intertidal habitat diversity on the islands. Species found in the survey are all widespread, with the great majority having Indo-West Pacific distributions. No species were found that are rare, endangered or in need of special protection.

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1

Introduction

1.1 Background

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara coast. The LNG and Domgas plants will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and yet-to-be determined gas fields. The Wheatstone Project is referred to as the Project and Ashburton North Strategic Industrial Area (Ashburton North SIA) is the proposed site for the LNG and Domgas plants. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The investigations outlined in this survey of the intertidal invertebrate biota on islands in the Project area have been conducted to support the environmental impact assessment process.

The present study is one of a series undertaken by URS to document the marine benthic communities of the Onslow region and place them into regional context. There are eight such studies:

- A survey in November 2008 to describe the major intertidal habitats in the area of the potential LNG site at Onslow between Coolgra Point and the Ashburton River, concentrating on rocky and sandy intertidal communities (URS 2009);
- A companion survey of the same region, concentrating on mangrove communities undertaken in February 2009;
- A subtidal diving survey of coral communities in the nearshore area in June 2009;
- Remotely operated vehicle (ROV) survey – Summer of subtidal habitats in December 2008;
- ROV survey – Winter of subtidal habitats in August 2009;
- ROV survey – Subtidal coral habitats in May 2009;
- ROV survey – Deepwater and shelf break using tow camera in August 2009; and
- The present study, which examines intertidal communities on the offshore islands.

1.2 Scope of Work

The scope of work for the study was to survey the invertebrate biota of intertidal habitats on eight islands in the Project area and to place the results into a regional context.

1.3 Acknowledgements

It is a pleasure to acknowledge the help of the crew of the Adrenalin Sprint. It is also a pleasure to acknowledge the help and encouragement of Ceri Morgan and Daniella Hanf in working on the project.

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2 Methods

2.1 Site Selection

A map of the region illustrating the proposed trunkline route and navigation channel was used to select sites (Figure 2-1). The goal was to survey larger islands in the immediate vicinity of proposed activities and also to provide comparative data from islands away from possible activities. The survey was undertaken from 8-13 February 2009. Islands examined (Figure 2-1) were:

- Direction Island;
- Thevenard Island (western end);
- Table Island;
- Serrurier Island;
- Bessieres Island;
- Ashburton Island;
- Tortoise Island; and
- Northeast Twin Island.

2.2 Survey Methodology

Each island was surveyed on a single low spring tide, with several phyla of fauna being sampled. On morning tides the survey started in the lowest exposed zone and moved up the shore as the tide rose; during the afternoon tide the process was reversed, with the survey starting in the upper intertidal zone and moving down the shore as the tide fell (Table 2-1). Surveying during spring tides meant that the greatest possible range of intertidal area was examined. The search included all intertidal habitats encountered on each island: sandy shores, rocky areas, beachrock platforms, dead coral slabs, tidepools, etc., to develop as broad an indication of diversity as possible. In addition, the fauna was categorised into three habitats on each island: species characteristic of the upper, mid and lower intertidal.

Table 2-1 Stations sampled off Onslow from 9 to 13 February 2009. Tidal data are from the Department of Planning and Infrastructure (DPI) (2009), adjusted to Western Daylight Savings Time.

Island	Day	Date	Low tide (WDT)	Tidal height (m)	Start of transect	
					Eastings	Northings
Direction	Monday	9 Feb	0607	0.61	306669	7617510
Thevenard	Monday	9 Feb	1730	1.20	290057	7625841
Table	Tuesday	10 Feb	0646	0.52	263946	7608380
Serrurier	Tuesday	10 Feb	1838	1.00	258413	7610583
Bessieres	Wednesday	11 Feb	0719	0.48	268619	7617779
Ashburton	Wednesday	11 Feb	1927	0.85	286576	7610869
Tortoise	Thursday	12 Feb	0750	0.50	278708	7612044
NE Twin	Thursday	12 Feb	2010	0.75	315419	7620232

Molluscs were selected for detailed examination because they are taxonomically diverse, ecologically important and relatively well known taxonomically. In addition, dead shells provide a further indication of diversity on the shores; soft bodied organisms often leave no recognisable trace of their existence. Aside from a few species, such as cuttlebones (*Sepia*) that float, the presence of a dead shell indicates the species lives in the area. Corals were also actively identified because of their ecological

2 Methods

importance and their sensitivity among the general public and regulatory agencies, including their role in primary production. Incidental records were made of echinoderms, crustaceans, fish and seagrasses.

Wherever possible, molluscs were identified in the field using readily available sources (Lamprell & Whitehead 1992; Wells & Bryce 2000). Shells of species that could not be identified in the field were returned to Perth where they were identified using Wilson (1994). Gosliner *et al*. (1996) and Allen & Steene (2003) were used for other invertebrates. In addition, there were specific texts for crustaceans (Jones & Morgan 1994), corals (Veron 1986) and echinoderms (Coleman 1994).

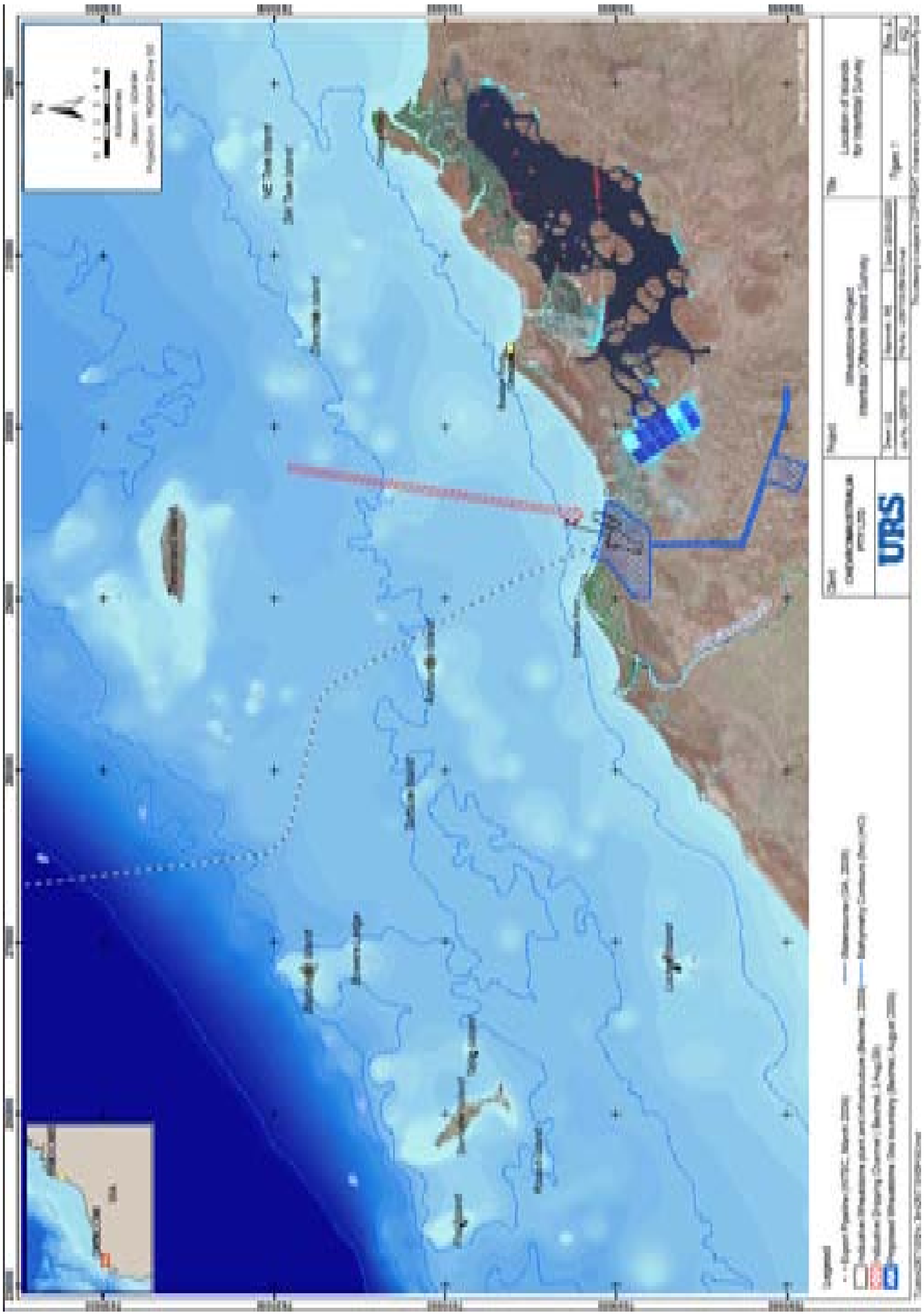

Figure 2-1 Location of islands for intertidal survey.

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Results & Discussion

3.1 Species Diversity

A total of 169 species of molluscs were identified: 4 chitons, 129 gastropods, 33 bivalves and 3 cephalopods. In addition, there were 16 scleractinian corals, 11 holothurians and 20 crustaceans (Appendices A and B). Selected species are depicted in Appendix C. Diversity in the Onslow islands area was moderate, much lower than in the nearby Montebello Islands, where a survey by the Western Australian Museum recorded 633 species (Wells *et al*. 2000). Similarly, an expedition to the Muiron Islands and eastern shore of Exmouth Gulf recorded 655 species (Slack-Smith & Bryce 1996). However, the numbers of species recorded are not directly comparable, as the Montebellos expedition lasted 13 days and had three people collecting molluscs, and the Muiron Islands trip had two people collecting for 12 days. Both of those surveys also included diving. However, the low number of species of molluscs and other groups encountered during the survey of the intertidal areas of Onslow islands was indicative of a real phenomenon of only moderate diversity in the region, which may be attributed to low habitat diversity.

There was low invertebrate diversity even within the habitats present on the Onslow islands. Very few species were found on sand beaches, primarily the ghost crab *Ocypode* sp. and the small crab *Scopimera* sp. While the species list for particular rocky shores was of moderate size, the list includes species recorded as dead shells. Information presented in Jones (2004) suggests there is a greater species diversity on rocky shores of the Burrup Peninsula near Dampier than on the Onslow islands.

Corals were notable in being in very low diversity, with only 16 species being recorded, and very few individuals of each species. Veron & Marsh (1989) recorded 39 species of 23 genera from the Passage Islands, which are an extensive chain of low sandy islands and reefs lying close to the Pilbara coast and approximately 80 km to the northeast of the Project area. The Veron & Marsh (1989) list includes species only found subtidally in addition to the intertidal species, but does indicate that diversity on the intertidal portions of the islands examined in the present study is only a small percentage of the total number of species living in the area.

3.2 Habitat Diversity

Exposed sandy and rocky shores were the primary intertidal habitats on the Onslow islands. There were no mangroves, coral reefs, seagrass beds or protected embayments in the Project area that would have provided habitat for a wider range of species.

The habitat diversity on the islands is lower than on the Onslow coastline, where there are also extensive areas of coastal mangroves, intertidal sand and mudflats, and estuaries. The fauna and flora of the continental shoreline in the Project area has been studied by LeProvost Environmental Consulting (1991) and URS (2009). In particular, the largest known bed of large seagrasses in the Pilbara is a patch of *Cymodocea angustata* at Mary Anne Reef, east of Onslow, which has several hundred hectares of 30 to 50% cover. The bed occurs primarily at a depth of 2 to 3 m (Walker & Prince 1987). The other seagrasses in the area, predominately *Halophila* are transitory species that reach lengths of only 5-10 cm and do not form dense beds. The only seagrass found on the present survey was small (<5 m2) patches of *Thalassia hemprichii* at Ashburton Island.

The low diversity of habitats present on the islands offshore of Onslow is in stark contrast to the variety of habitats available in the nearby Montebello Islands (Berry & Wells 2000) or in the Dampier Archipelago and the adjacent Burrup Peninsula (Wells & Walker 2003; Jones 2004). All of the habitats present on the Onslow islands also occur in the Montebellos and in Dampier. In addition, both the

Montebellos and Dampier also have substantial habitats of shallow water coral reefs that extend into the lower intertidal zone, mangroves, mudflats, sandflats and protected embayments, none of which occur on the islands examined off Onslow.

3.3 Species Distribution Patterns

There are three distribution patterns in the shallow water marine biota of Western Australia. The north coast of Australia, from North West Cape to the southern part of the Great Barrier Reef is part of the vast Indo-West Pacific province that extends from the east coast of Africa to Hawaii. The south coast of WA, east of Cape Leeuwin, is part of the southern Australian warm temperate region that extends to the east coast of the continent. The west coast, between Cape Leeuwin and North West Cape, is a region of marine biogeographic overlap, where the tropical and temperate biotas meet. In addition, about 10% of the shallow water marine biota is endemic to Western Australia. These species are concentrated on the west coast, but some species occur on the north and south coasts (Wells 1980; Wilson & Allen 1987).

Located on the north coast, the marine biota of the Onslow islands is overwhelmingly tropical. Of the 117 molluscs identified to species, 112 are tropical Indo-West Pacific species or are widely distributed across northern Australia. However, *Polinices conicus* is a temperate species that extends from Queensland across southern Australia and north to Broome, WA. Only four species endemic to Western Australia were found during the study. *Cronia avellana* has an extensive range, from Albany to the Kimberley. The cone shell *Conus dorreensis* has a similar range, but only reaches as far north as Dampier. The cardiid bivalve *Acrosterigma dupuchense* and the cone shell *Conus novaehollandiae* both occur on the north coast of WA from Exmouth Gulf to Broome (Wilson & Stevenson 1977; Wilson 1994). The volute *Amoria macandrewi* has a very restricted range, occurring only from the Montebello Islands to Barrow Island (Wilson 1994), but none were encountered during the present study. The distributional ranges of non-molluscan taxa identified during the study were similarly large. The present findings for Onslow are consistent with other studies of marine distribution patterns along the northwest coast of Australia that have shown that there are no major barriers to distribution. If the required habitat is present in an area, the species will be able to colonise it. The first major distributional barrier on the north coast occurs in the region of Ningaloo Reef. Many tropical species reach as far south as Ningaloo, but their ranges do not extend further south (Wells 1980; Blaber *et al*. 1985).

The general widespread distribution of marine invertebrates results from over 95% of species having a planktonic larval dispersal stage. This stage can range in duration from a few days to over a year. The larvae are carried about wherever the currents take them, readily colonising new areas if environmental conditions permit. The ability of long-term larvae to extend their ranges was demonstrated by three South African species of gastropod molluscs that were found at Cape Leeuwin, WA. They are believed to have crossed the Indian Ocean as planktonic larvae and settled in the Cape Leeuwin area, but failed to develop populations in WA (Wells & Kilburn 1986). Similarly, planktonic larvae of some molluscs and other groups have been found to have travelled 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 larval stage 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.

Little is known of ocean currents in the Onslow region, but Pearce *et al*. (2003) published a detailed account of the oceanography in the nearby Dampier Archipelago. Tides, local winds, large scale circulation and continental shelf waves are the driving influences for local currents in the archipelago. The effects of these factors are strongly modified by the topography of the local sea floor. Current speeds reach 50 cm/sec at the entrance to Mermaid Sound. During the summer, the prevailing westerly winds force the ocean water in an easterly direction. This is reversed in winter by the strong easterly winds. The effects of winds can be enhanced by tropical cyclones that are concentrated in summer months. Onslow is well known as a location where cyclones come ashore on the north coast, most recently Cyclone Dominic on 27 January 2009 that was a Category 2 storm when it struck Onslow. The North West Shelf is the origin of the Leeuwin Current that flows down the west coast of Western Australia. However, the current is on the outer continental shelf and does not have much effect in the Dampier Archipelago, or presumably the nearshore Onslow region. While there will be differences between the localised currents of the Dampier Archipelago and the nearshore islands off Onslow examined in this report, there is clearly sufficient water movement inter-regionally to allow the widespread distribution of planktonic larvae. This was demonstrated by McKinnon *et al*. (2003), who showed that Cyclone Tiffany caused pronounced changes in water characteristics and plankton communities of copepods and fish when it arrived in the area in January 1998. The cyclone caused substantial southward transport of oceanic water masses. The authors suggested that such episodic short term events may cause long-shore transport of shelf waters and be important for dispersal of plankton communities in the area.

A major analysis of the worldwide distribution of 3,225 species of coral reef biota (corals, fish, molluscs and rock lobsters) considered species with restricted ranges to be those that occurred in 10 or fewer grids of two degrees of latitude and longitude, equivalent to an area of approximately 500,000 square kilometres (Roberts *et al.* 2002). While such species can be threatened by large-scale impacts, such as global warming and coral bleaching, they are not threatened by activities that have impacts restricted to areas ranging from a few square kilometres to a few tens of square kilometres. The study described 18 hotspots of coral reef biodiversity in the world. A significant hotspot was reported for the west coast of Western Australia that included Ningaloo Reef, the outer islands of Shark Bay, the Houtman Abrolhos Islands and Pocillopora Reef at Rottnest Island. The WA hotspot ranked 7th in total diversity (768 species) and 2nd in restricted range species (56), but only 15th in terms of human threat to the hotspot. It is critical that this hotspot be protected, but it is well away from the Project area.

3.4 Vertical Zonation

There was little evidence of vertical distribution of the biota on the sandy shorelines on the islands. The primary species recorded were the upper intertidal *Ocypode* sp. and the small crab *Scopimera* sp. (Appendix A). Diversity was much greater on the rocky shores, with the zonation pattern being similar to that recorded in Dampier by Wells & Walker (2003) and Jones (2004). The only species found in the upper intertidal was the littorinid snail *Nodilittorina trochoides*. The middle intertidal area was dominated by a variety of molluscs, including oysters (*Saccostrea cuccullata*), chitons (*Acanthopleura gemmata*, *A. spinosa*), and gastropods. Barnacles, particularly *Tetraclita squamosa*, and crabs such as *Leptograpsus* were abundant in this region. As in other areas, the lowest part of the intertidal zone has the greatest frequency and duration of immersion, so the largest number of species is able to survive in this area. While diversity was increased, the number of individuals of most species was still low.

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4

Conclusion

The key points arising from this study are:

- The intertidal habitats of the islands off Onslow have moderate species diversity. Species found in the survey are all widespread, with the great majority having Indo-West Pacific distributions. No species were found that are rare, endangered or in need of special protection.
- The moderate species diversity is caused by the low intertidal habitat diversity on the islands. There are no mangroves, seagrass beds or muddy shores and very few intertidal corals found on the islands surveyed.

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Limitations

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A

Appendix A Survey Data from Intertidal Islands off Onslow.

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Appendix A

Island	Date	Time	Eastings	Northings	Notes
Direction Island	9 Feb 09	0700-0900			Low sandy island with low vegetation. One hut on island. Numerous old turtle nesting depressions. Entire island sandy in upper intertidal. Mid intertidal mixture of sand and limestone beachrock. Some dead coral rubble in lower intertidal. Surveyed entire island starting from southeast corner, moving counter clockwise. Extensive shallows around island, ranging from 75 m wide in southeast to 700 m wide in west. Most not exposed on tide. Lots of macroalgae washed up on shore.
			0306669	7617510	Started in sand
			0306635	7617744	Extensive beachrock platform
			0306231	7617793	End of rock platform, back into sand.
			0306051	7617688	Limestone rubble.
			0306043	7617597	End of platform, back into sand.
			0603273	7617413	Back into beachrock.
			0306521	7617377	Back into sand.
					UPPER INTERTIDAL
					Crustaceans: *Ocypode* sp.
					MID INTERTIDAL
					Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa*.Gastropoda: *Patella flexuosa, Cellana radiata, Planaxis sulcatus, Onchidium* sp., *Siphonaria* sp. Bivalvia: *Saccostrea cuccullata.*
					Crustaceans: *Chthamalus,* hermit crabs.
					LOWER INTERTIDAL
					Molluscs: Gastropoda: *Rhinoclavis bituberculatum, Drupella cornus, Strombus mutabilis, S. vittatus, S. urceus, Lambis lambis, Morula granulata, M. crassulnata, Cronia avellana, Syrinx aruanus, Conus novaehollandiae, Aulicina nivosa, Nassarius dorsatus, Pyramidella acus, Natica gualteriana, Modulus tectum, Haliotis squamata, Astralium rotularia, Turbo cinereus, Trochus hanleyanus, Rhinoclavis brettinghami, Oliva caldania, Tonna* sp., *Bulla* sp., *Cypraea caputserpentis, C.* cf. *eglantina, Nassarius albescens, Polinices conicus, Tectus pyramis, Clypeomorus* sp., *C. zonatus, Nerita undata, Melo amphora* egg mass, *Mitra scutulata, Pyramidella* sp., *Angaria delphinus.* Bivalvia: *Acrosterigma dupuchense, A. reeveanum, Trisidos semitorta, Lithophaga* sp., *Barbatia amygdalototsum, Pteria penguin, Pinna bicolor, Antigona* sp., *Tridacna maxima, Modiolus philippinarum, Tellina*

Appendix A

Island	Date	Time	Eastings	Northings	Notes
					staurella, Venus toreuma, Chama sp. Cephalopoda: *Octopus* sp. (orange), *Sepia* sp. Crustaceans: *Grapsus albolineatus, Ocypode* sp., portunid sp., *Petrolisthes* sp., *Panulirus versicolor, Chthamalus,* spider crab, hermit crabs.
					Scleractinian corals: *Favites* sp., *Platygyra* sp., *Porites* sp. Echinoderms: *Holothuria leucospilota, H. atra*, *Tripneustes* sp. Sponges: Numerous sponges washed up on beach. Fish: Black tipped reef shark, sergeant majors (*Abededuf*), blue spotted rays, shark egg case. Polychaete: Chaetopterid tube.
Thevenard Island (western end)	09 Feb 09	1600-1830	 0290057 0290633 0289783 0290061 0290301 0290662	 7625841 7625589 7635563 7625417 7625404 7625387	Large sandy island, too large to survey on one tide. Starter on northwestern corner in sandy area. Went around western tip to southern coast. Start low beachrock platform. Western point on beachrock platform. Onto sand beach. Shoreline with lots of dead rubble in lower intertidal. End of main rubble zone. Sand beach at end of survey, but sand continues. UPPER INTERTIDAL No species found. MID INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata.* Gastropoda: *Siphonaria* sp. Bivalvia: *Saccostrea cuccullata.* Crustaceans: Hermit crabs. LOWER INTERTIDAL

Appendix A

Island	Date	Time	Eastings	Northings	Notes
					Molluscs: Gastropoda: *Liotina peroni, Phasianella* sp., *Macroschisma munita, Strombus mutabilis, S. urceus, M. crassulnata, Cronia avellana, Syrinx aruanus, Pseudovertagus aluco, Nassarius dorsatus, N. reeveanus, Pyramidella acus, Natica gualteriana, Cheilea equestris, Turbo cinereus, Trochus hanleyanus, Rhinoclavis brettinghami, Bulla* sp., *Bulla ampulla, Cypraea caputserpentis, C. cylindrica, C. moneta, Nassarius albescens, C. zonatus, Nerita albicilla, Cominella* sp., *Pyrene scripta, Melo amphora, Haminoea* sp., *Conus dorreensis, C. spectrum,C. coronatus, Mitra scutulata.* Bivalvia: *Pinna bicolor, Antigona chemnitzii*, *Tridacna maxima, Acrosterigma dupuchense, A. reeveanum, A. alternatum, Paphies* sp., *Modiolus philippinarum, Septifer bilocularis, Fragum hemicardium, Cardita* sp., *Megacardita incrassata, Chlamys sp., Anadara* sp., *Lima lima, Chama* sp. *Pinctada* sp., *Spondylus* sp. Cephalopoda: *Octopus* sp. (orange), *Sepia* sp. Crustaceans: *Grapsus albolineatus,* portunid sp., crab, hermit crabs, *Atergatis floridus.* Echinoderms: *Holothuria leucospilota.* Fish: Black tipped reef shark, blue spotted rays, shark egg case, blennies in tidepool.
Table Island	10 Feb 2009	1700-1800			Small sandy island with sandspit on eastern end. Extensive reef on northern side, but most below low tide mark.
			263946	7608380	Started on sand spit.
			263876	7608404	Spit merges into rocky intertidal shore with flat beachrock platform at low tide. Beachrock extends to western end of island, southern side is rockier.
			263894	7608369	Back near start, base of sand spit. UPPER INTERTIDAL Crustaceans: *Ocypode* sp. MID INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa.* Gastropoda: *Patella flexuosa, Planaxis sulcatus, Siphonaria* sp. Bivalvia: *Saccostrea cuccullata.* Crustaceans: Hermit crabs.

Appendix A

Island	Date	Time	Eastings	Northings	Notes
					LOWER INTERTIDAL Molluscs: Gastropoda: *Rhinoclavis bituberculatum, Drupella cornus, Strombus mutabilis, Morula granulata, M. crassulnata, Cronia avellana, Thais aculeata, Cymatium aquatile, Conus novaehollandiae, Malea pomum, Cypraea caputserpentis, C. cylindrica, C. helvola, C. moneta, C. asellus, Tectus pyramis, T. fenestratus, Nerita undata, Pyrene scripta, Melo amphora, Siphonaria* sp., *Conus dorreensis, Conus capitaneus, Mitra scutulata, Angaria delphinus, Turbo argyrostomus, Bursa granularis, Cerithium columna, Conus geographus, C. textile, Pyrene turturina, Tutufa bufo, Cantharus undosus, Nassarius reeveanus, Septa vespacea, Pisania ignea, C. pulicarius, Xenoturris cingulifera,* Bivalvia: *Arca navicularis, Glycymeris* sp., *Barbatia amygdalototsum, Tridacna maxima, Venus toreuma, Chama* sp., *Tellina* sp. Cephalopoda: *Sepia* sp. Crustaceans: *Grapsus albolineatus, Chthamalus,* hermit crabs, *Atergatis floridus,* mantis shrimp Echinoderms: *Holothuria atra.* Fish: Moray eel.

Appendix A

Island	Date	Time	Eastings	Northings	Notes
Serrurier Island	10 Feb 09	1830-1930			Extensive sandy island. Numerous turtle tracks on beach. One green turtle leaving water. Shoreline on eastern side entirely sand. Map shows reef, but too low to be exposed on tide. Rocky shore at northern end exposed to considerable wave action. Rocky intertidal with small lower intertidal platform.
			258413	7610583	Start of rocks.
			258254	7610286	End of rocks, started back.
			258413	7610583	Return to starting point.
					UPPER INTERTIDAL Molluscs: Gastropoda: *Nodilittorina millegrana.* Crustaceans: *Ocypode* sp. MID INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa.*Gastropoda: *Planaxis sulcatus, Siphonaria* sp. Bivalvia: *Saccostrea cucullata.* Crustaceans: *Chthamalus,* hermit crabs. LOWER INTERTIDAL Molluscs: Molluscs: Gastropoda: *Strombus mutabilis, S. urceus, Thais aculeata, Drupa ricinus, Syrinx aruanus, Cerithiumn novaehollandiae, Pseudovertagus aluco, Aulicina nivosa, Cheilea equestris, Rhinoclavis bituberculatum, Cypraea caputserpentis, C. moneta, C.* cf. *eglantina, Melo amphora*, *Conus dorreensis, Turbo argyrostomus, Bursa granularis, Polinices melanostomus, Peristernia incarnata, Thais aculeata, Serpulorbis sp. Amoria grayi, Bulla, Nerita undata, Mitra scutulata, Oliva, Mitra mitra, P melanostomus, C. sponsalis, Cellana radiate, Hipponix conicus, Nassarius reeveanus, Strombus vomer, Cantharidus sp., Drupa fusconigra, Nassarius sp.* Bivalvia: *Antigona* sp., *Tridacna maxima, Acrosterigma reeveanum, Circe* sp., *Tellina staurella, Fragum hemicardium, Megacardita incrassata, Anadara* sp., *Botula vagina, Tridacna squamosa.* Cephalopoda: *Sepia* sp. Crustaceans: *Grapsus albolineatus, Ocypode*, *Chthamalus,* hermit crabs. Echinoderms: *Tripneustes* sp.

Appendix A

Island	Date	Time	Eastings	Northings	Notes
Bessieres Island	11 Feb 09	0700-0940	268619 268665 268262 268 619	7617779 7618234 7618488 7617779	Small sandy island with rocks around most of coast. Platform largest on west side, up to 100 m wide. Upper intertidal sand. Rocks generally started at mid tide. Started on southern side and circumnavigated the island counterclockwise. UPPER INTERTIDAL Crustaceans: *Ocypode* sp., *Scopimera* sp. MID INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata.* Gastropoda: *Patella flexuosa, Planaxis sulcatus, Siphonaria* sp. Bivalvia: *Saccostrea cuccullata.* Crustaceans: *Chthamalus,* balanid sp., hermit crabs. LOWER INTERTIDAL Molluscs: Gastropoda: *Phasianella* sp., *Tectus pyramis, T. fenestratus, Angaria delphinus, Modulus tectum, Nerita plicata, N. albicilla, N. undata, Hybochelus cancellata, Cerithium novaehollandiae, Clypeomorus zonatus, Serpulorbis sipho, Rhinoclavis bituberculatum, R. brettinghami, Cheilea equestris, Strombus mutabilis, S. vittatus, Polinices melanostomus, Cypraea helvola, C. caputserpentis, C. moneta, C. vitellus, C. eglantina, Bursa granularis, Septa exarata, Morula granulata, Drupella cornus, Drupa ricinus, D. fusconigra, Cronia avellana, Thais aculeata, Coralliophila neritoides, Mancinella mancinella, Pyrene scripta, Cantharus undosus, Peristernia incarnata, Latirus paetelianus, Nassarius gualteriana, N. reeveanus, Syrinx aruanus, Mitra scutulata, Conus geographus, C. lividus, Conus* sp., *Xenoturris cingulifera*. Bivalvia: *Tridacna maxima, Septifer bilocularis, Chama* sp., *Spondylus* sp. 2., *Venus toreuma, Antigona* sp. Cephalopoda: *Octopus* sp., *Sepia* sp. Scleractinian corals: *Acropora* sp., *Favia* sp., *Favites* sp., *Goniastrea* sp., *Goniopora* sp., *Lobophyllia* sp., *Pavona* sp., *Platygyra daedalea*, *Porites cylindrica, Porites* sp. Crustaceans: Hermit crabs, *Atergis floridus,* crab, alpheid shrimp, *Panilirus versicolor, Scylla serrata, Eriphia* sp. Echinoderms: *Holothuria leucospilota, H. atra,* holothurian sp. 2 (reddish), *Tosia* sp. Fish: Blue spotted ray, moray eels.

Appendix A

Island	Date	Time	Eastings	Northings	Notes
Ashburton Island	11 Feb 2009	1715-1930			Sandy island approached from east at gap in reef. Extensive platform on most sides of the island. Up to several hundred metres wide, flat limestone with little relief, low diversity. Rocks at seaward margin of platform but are sealed to bottom. Few that can be turned over, still low diversity. Shallow lagoon with dense cover of brown algae – *Sargassum* ?
			286576	7610869	Start survey on sand beach moving to the west.
			286429	7611253	Begin reef.
			285899	7611337	Westernmost point in survey.
			286576	7610869	Return to starting point.
					UPPER INTERTIDAL
					No species found.
					MID INTERTIDAL
					Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa.* Gastropoda: *Patella flexuosa, Cellana radiata, Nerita undata, Planaxis sulcatus, Onchidium* sp.2, *Siphonaria* sp. Bivalvia: *Saccostrea cuccullata.*
					Crustaceans: *Chthamalus,* hermit crabs.
					LOWER INTERTIDAL
					Molluscs: Molluscs: Gastropoda: *Turbo argyrostoma, Bulla* sp., *Strombus urceus, Cypraea cylindrica, C. caputserpentis, C. moneta, C. carneola, C. asellus, Chelidonura* sp., *C. crassulnata, M. granulata, Astralium, Trochus hanleyanus, Thais aculeata, Rhinoclavis brettinghami, Cerithium columna, Strombus mutabilis, Cronia avellana, Mitra scutulata, Drupa fusconigra, Turbo cinereus, Grapsus albolineatus, Tonna* sp., *Pyrene scripta, Angaria delphinus, Clypeomorus* sp. 2, *Aplysia dactylomela, Conus sponsalis.* Bivalvia: *Acrostrigma reeveanus, Barbatia amygdalototsum, Tridacna maxima, Chama* sp., *Septifer bilocularis, Vulsella* sp., *Spondylus* sp., *Spondylus* sp. 2, *Pinctada maxima, Botula vagina, Tridacna squamosa, Tellina staurella, Pinna deltodes.* Cephalopoda: *Octopus* sp. (orange).
					Scleractinian corals: *Favia* sp., *Favites* sp., *Goniastrea* sp., *Platygyra* sp., *Turbinaria* sp.
					Crustaceans: *Grapsus albolineatus, Atergis floridus, Petrolisthes* sp., hermit crabs, *Thalamita* sp., *Calappa* sp.
					Echinoderms: *Holothuria leucospilota, H. atra*, holothurians sp 2., ophiuroid.
					Fish: Blue spotted rays.

Appendix A

Island	Date	Time	Eastings	Northings	Notes
Tortoise Island	12 Feb 2009	0730-0930			Low flat island largely surrounded by extensive reefs. Rntered on sand spit on eastern side. Sand spit extends to upper intertidal. Other parts of the island have rocky shore, low cliffs, from upper to lower intertidal, then flat limestone platform that extends out for several hundred metres. Rockier at seaward edge of platform, also isolated rocks on platform surface.
			278708	7612044	Start on sand spit.
			278352	7612069	Furthest extent of survey.
			278708	7612044	Return to starting point.
					UPPER INTERTIDAL No species found. MID INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa*. Gastropoda: *Patella flexuosa, Nerita undata, Siphonaria* sp. *Cellana radiata, Onchidium* sp. Bivalvia: *Saccostrea cuccullata.* Crustaceans: *Chthamalus,* hermit crabs. LOWER INTERTIDAL Molluscs: Molluscs: *Onithochiton* sp. Gastropoda: *Peristernia incarnata, Rhinoclavis brettinghami, Clanculus* sp., *Conus textile, Conus sponsalis, C. carneola, Turbo argyrostomus, Strombus mutabilis, Bursa granularis, Cerithium novaehollandiae, Pyrene scripta, Malea pomum, Modulus tectum, Peristernia incarnata, Nerita albicilla, Cerithium nesioticum, C.* cf. *alveolus, Cantharus undosus, C. erythrostomus, Thais aculeata, Drupella cornus, Cronia crassulnata, C. avellana, Coralliophia neritoides, Drupa ricinus, Tectus pyramis, Hipponix conicus, Morula granulata, Pinna dolabrata, Septifer bilocularis, Conus dorreensis, C. chaldeus, C. lividus, C. sponsalis, Cypraea caputserpentis, C. vitellus, C. solida, C. lynx, C. moneta, C. annulus, Thais aculeata, Lithophaga* sp., *Mancinella mancilla, Antigona* sp., *Lambis chiragra, Modiolus philippinarum, Nerita plicata, Siphonaria* sp., *Septifer* sp., *Engina* sp., *Mitra scutulata, Drupa ricinus, Nerita albicilla,* chromodorid sp., gymnodorid sp., *Terebra* sp., *Chicoreus microphyllus, Strombus vomer, Mancinella mancilla.* Bivalvia: *Hyotissa hyotis, Lima lima, Chama* sp., *Chlamys* sp., *Glycymeris* sp., *Pinctada maxima, Hippopus hippopus, Antigona* sp., *Tridacna maxima, Spondylus* sp., *Spondylus* sp. 2, *Venus toreuma.* Cephalopoda: *Sepia* sp. Scleractinian corals: *Acropora* sp., faviid sp., *Goniastrea* sp., *Lobophytum* sp., *Pocillopora eydouxi, Pocillopora*

Appendix A

Island	Date	Time	Eastings	Northings	Notes
					verrucosa, Turbinaria sp. Crustaceans: *Grapsus albolineatus, Atergis floridus, Petrolisthes* sp., hermit crabs, xanthid spp., *?Percnon planissimum, Eriphia sebana* Echinoderms: *Holothuria atra, H. leucospilota*, purple holothurians, ophiuroid. *Echinometra* sp., small cucumber, *Linckia laevigata*. Fish: *Periopthalmus* sp.
NE Twin Island	12 Feb 2009	1730-1830			Started survey near western end of island on sandy beach, moved west on southern side. Rocky intertidal shore with low cliffs up to 2 m high in some areas in upper to mid intertidal. Low intertidal was a series of very flat terraced platforms. Little relief, some small holes and undulations, but basically flat. Largely bare of macroalgae, though there were a few small patches of ?*Sargassum* with an area of a few square metres each.
			315419	7620232	Start of survey.
			315298	7620545	Furthest extent of survey.
			315419	7620232	Return to starting point.
					UPPER INTERTIDAL Molluscs: Gastropoda: *Nodilittorina millegrana.* MID INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa*. Gastropoda:*Planaxis sulcatus, Siphonaria* sp., *Nerita undata.* Bivalvia: *Saccostrea cuccullata,* Crustaceans: *Chthamalus* sp., *Tetraclita* sp., hermit crabs. LOWER INTERTIDAL Molluscs: Polyplacophora: *Acanthopleura gemmata, A. spinosa, Onithochiton* sp. 2. Gastropoda: *Strombus vittatus, Aulicina nivosa, Cypraea caputserpentis, C. cylindrica, C. moneta, Siphonaria* sp., *Morula granulata, Polinices melanostomus, Cronia crassulnata, Tectus pyramis, Turbo cinereus, Syrinx aruanus, Clypeomorus* sp. 3, *Turbo cinereus, Hexaplex stainforhi, Trochus fenestratus, Angari delphinus, Astralium rotularia, Melo amphora, Cerithium novaehollandiae, Mitra scutulata, Cronia avellana, Pyrene punctata, Cypraea asellus.*

Appendix A

Island	Date	Time	Eastings	Northings	Notes
					Bivalvia: *Glycymeris* sp., *Acrosterigma* sp., *Anadara* sp., *Tridacna maxima, Tellina staurella, Septifer bilocularis, Asaphis violaceans.* Cephalopoda: *Octopus* sp. (orange), Crustaceans: Hermit crabs, *Atergis floridus, Grapsus albolineatus.* Echinoderms: *Holothuria leucospilota,* synaptid sp.

B

Appendix B Intertidal Species Identified on Islands off Onslow.

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Scientific name	Scientific name	Scientific name
Polyplacophora		
Acanthopleura gemmata	*Onithochiton* sp.	*Onithochiton* sp. 2
Acanthopleura spinosa		
Class Gastropoda		
Patella flexuosa	*Cypraea annulus*	*Mitrella albina*
Cellana radiata	*Natica gualteriana*	*Latirus paetelianus*
Haliotis squamata	*Polinices conicus*	*Peristernia incarnata*
Liotina peroni	*Polinices melanostomus*	*Pisania ignea*
Trochus hanleyanus	*Cypraea asellus*	*Nassarius albescens*
Tectus fenestratus	*Cypraea caputserpentis*	*Nassarius dorsatus*
Tectus pyramis	*Cypraea carneola*	*Nassarius gualteriana*
Angaria delphinus	*Cypraea cylindrica*	*Nassarius reeveanus*
Astralium rotularia	*Cypraea eglantina*	*Nassarius* sp.
Cantharidus sp.	*Cypraea helvola*	*Syrinx aruanus*
Clanculus sp.	*Cypraea moneta*	*Oliva caldania*
Turbo argyrostomus	*Cypraea solida*	*Mitra mitra*
Phasianella sp.	*Cypraea vitellus*	*Mitra scutulata*
Turbo cinereus	*Tonna* sp.	*Amoria grayi*
Modulus tectum	*Malea pomum*	*Aulicina nivosa*
Nerita albicilla	*Cymatium aquatile*	*Melo amphora*
Nerita plicata	*Septa exarata*	*Xenoturris cingulifera*
Nerita undata	*Septa vespacea*	*Conus capitaneus*
Planaxis sulcatus	*Bursa granularis*	*Conus chaldeus*
Nodilittorina millegrana	*Bursa rosa*	*Conus coronatus*
Cheilea equestris	*Tutufa bufo*	*Conus dorreensis*
Serpulorbis sp.	*Chicoreus microphyllus*	*Conus geographus*
Cerithium cf. *alveolus*	*Coralliophila neritoides*	*Conus lividus*
Cerithium columna	*Cronia avellana*	*Conus novaehollandiae*
Cerithium nesioticum	*Drupa fusconigra*	*Conus pulicarius*
Cerithium novaehollandiae	*Drupa ricinus*	*Conus* sp.
Clypeomorus sp.	*Drupella cornus*	*Conus sponsalis*
Clypeomorus sp. 2	*Hexaplex stainforthi*	*Conus textile*
Clypeomorus sp. 3	*Mancinella mancinella*	*Terebra* sp.
Clypeomorus zonatus	*Morula crassulnata*	*Pyramidella acus*
Pseudovertagus aluco	*Morula granulata*	*Pyramidella* sp.
Rhinoclavis bituberculatum	*Morula uva*	*Bulla ventricosa*
Rhinoclavis brettinghami	*Thais aculeata*	*Chelidonura* sp.
Hipponix conicus	*Cantharus undosus*	*Aplysia dactylomela*
Lambis chiragra	*Pyrene essingtonensis*	Chromodorid sp.
Lambis lambis	*Engina* sp.	Gymnodorid sp.
Strombus mutabilis	*Pyrene flava*	*Siphonaria* sp.
Strombus urceus	*Pyrene punctata*	*Onchidium* sp.
Strombus vittatus	*Pyrene scripta*	*Onchidium* sp. 2 (small)
Srtombus vomer	*Pyrene turturina*	

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Class Bivalvia		
Anadara sp.	*Saccostrea cucullata*	*Spondylus* sp.
Arca navicularis	*Hyotissa hyotis*	*Spondylus* sp. 2
Barbatia amygdalototsum	*Chlamys* sp.	*Pteria pengiun*
Trisidos semitorta	*Vulsella* sp.	*Tellina* sp.
Megacardita incrassata	*Chama* sp.	*Tellina staurella*
Glycymeris sp.	*Acrosterigma alternatum*	*Antigona chemnitzii*
Modiolus philippinarum	*Acrosterigma dupuchense*	*Asaphis violaceans*
Lithophaga sp.	*Acrosterigma reeveanum*	*Circe* sp.
Septifer sp.	*Fragum hemicardium*	*Paphies* sp.
Pinna bicolor	*Hippopus hippopus*	*Venus toreuma*
Pinna deltodes	*Tridacna maxima*	*Antigona chemnitzii*
Cephalopoda		
Octopus sp.	*Octopus* sp. (orange)	*Sepia* sp.
Scleractinian corals:		
Acropora sp.	*Lobophyllia* sp.	*Pocillopora eydouxi*
Favia sp.	*Lobophytum* sp.	*Pocillopora verrucosa*
faviid sp.	*Pavona* sp.	*Porites cylindrica*
Favites sp.	*Platygyra* sp.	*Porites* sp.
Goniastrea sp.	*Platygyra daedalea*	*Turbinaria* sp.
Goniopora sp.		
Crustaceans		
Balanid sp.	*Atergis floridus*	Portunid sp.
Chthamalus sp.	*Calappa* sp.	*Scopimera* sp.
Mantis shrimp	*Eriphia sebana*	*Scylla serrata*
Alpheid shrimp	*Grapsus albolineatus*	Spider crab
Panulirus versicolor	*?Percnon planissimum*	*Thalamita* sp.
Hermit crabs	*Petrolisthes* sp.	Xanthid spp.
Ocypode sp.		
Echinoderms		
Holothuria atra	Holothurian sp. 3 (small)	*Echinometra* sp.
Holothuria leucospilota	Synaptid sp.	*Tripneustes* sp.
Holothurian sp. 1 (purple)	*Linckia laevigata*	Ophiuroid sp.
Holothurian sp. 2 (reddish)	*Tosia* sp.	

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C

Appendix C Photos of Representative Habitats and Species.

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Heavily bioeroded rocks such as this have oysters (*Saccostrea cuccullata*).

The giant clam *Tridacna maxima* is common in lower intertidal areas.

Appendix C

Acanthopleura gemmata **is the most common chiton.**

A moderately diverse biota occurs on rocky platforms such as this.

The sea cucumber *Holothuria atra* is occasionally found in intertidal tidepools.

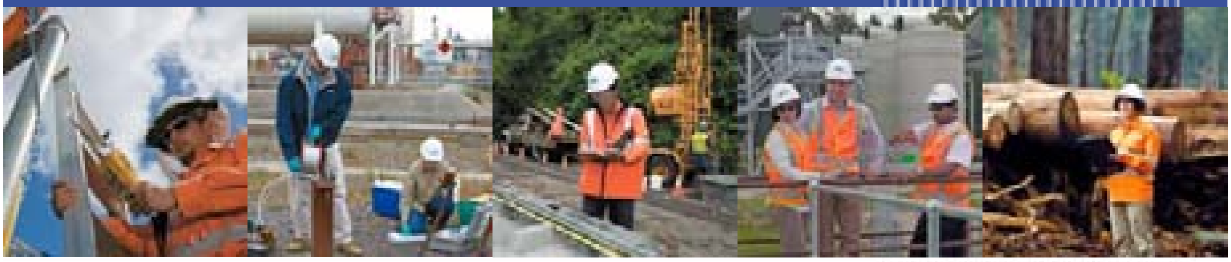
Grapsid crabs are common.

Appendix C

The ghost crab *Ocypode* sp. is common on upper intertidal sandy shores.

There are a variety of habitats on this rocky shore at Bessiers Island

Macroalgal wrack was most abundant on the sandy beach at Direction Island.



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