Gorgon Gas Development and Jansz Feed Gas Pipeline

Coastal and Marine Baseline State and Environmental Impact Report: Offshore Feed Gas Pipeline System and the Marine Component of the Shore Crossing

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Executive Summary

This Coastal and Marine Baseline State and Environmental Impact Report ('Marine Baseline Report') has been prepared to meet the requirements of Condition 12 of Ministerial Statement No. 769 (MS 769), Condition 14 of Ministerial Statement No. 800 (MS 800), and Condition 11 of EPBC Reference: 2003/1294 and 2008/4178. This version of the Marine Baseline Report is being submitted for approval specifically in respect to the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The development of the Jansz–Io deepwater gas field and associated works and activities, located in Commonwealth Waters, is managed under EPBC Reference: 2005/2184; and the Offshore Feed Gas Pipeline System in Commonwealth Waters is managed under Condition 16A and 16B of EPBC Reference: 2003/1294 and 2008/4178. These matters are not addressed further in this Marine Baseline Report.

Information in this Marine Baseline Report relevant to other Marine Facilities is provided for information only, as it is already approved (for the Marine Upgrade of the existing WAPET Landing, the Materials Offloading Facility [MOF], the Liquefied Natural Gas [LNG] Jetty, and the Dredge Spoil Disposal Ground [DSDG]).

The purpose of this Report is to:

- define and map the hard and soft corals, non-coral benthic macroinvertebrates, macroalgae, seagrass, demersal fish, surficial sediment characteristics, water quality (turbidity and light), and deposited surficial sediment characteristics within the Marine Disturbance Footprint
- define, describe, and map the hard and soft corals, non-coral benthic macroinvertebrates, macroalgae, seagrass, and surficial sediments that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing
- define, describe, and map the hard and soft corals, non-coral benthic macroinvertebrates, macroalgae, seagrass, and surficial sediments of Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing
- define and describe the demersal fish and water quality (including turbidity and light attenuation) that are at risk of Material or Serious Environmental Harm due to construction of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing
- define and describe the demersal fish and water quality (including turbidity and light attenuation) of Reference Sites not at risk of Material or Serious Environmental Harm due to due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing.

Note that the purpose of this Report is not to describe and map the extent and distribution of Coral Assemblages within the Zones of High Impact and the Zones of Moderate Impact, which relate specifically to construction, dredging, and dredge spoil disposal activities for the MOF, LNG Jetty, and the marine component of the WAPET Landing upgrade.

Coral

The benthic habitats near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (the Horizontal Directional Drilling [HDD] exit alignment) were characterised by limestone platform covered with a veneer of unvegetated sand. Corals were present in low abundances and only sparsely scattered colonies of species such as the hard coral *Turbinaria* spp. were recorded. *Turbinaria* is a widespread and common genus, which is well represented in Barrow Island waters where it is found outside coral habitats in benthic macroinvertebrate dominated assemblages. The Marine Disturbance Footprint (MDF) and the areas at risk of Material or Serious Environmental Harm do not contain any significant areas of coral habitat or Coral Assemblages, such that any impacts to corals within these areas would not threaten the survival, viability, or functioning of coral habitat. None of the Regionally Significant Areas on the eastern margin of the Lowendal Shelf to the southern boundary of the Montebello Islands Marine Park, Dugong Reef, Batman Reef, and Southern Barrow Shoals, nor the coral reefs on the southern and central parts of the west coast (e.g. Biggada Reef) are at risk due to the construction or operation of the Offshore Feed Gas Pipeline in State Waters and the marine component of the shore crossing.

Non-coral Benthic Macroinvertebrates, Macroalgae, and Seagrass

The benthic habitats near the marine component of the shore crossing (the HDD exit alignment) were characterised by limestone platform covered with unvegetated sand. Macroalgae were the dominant ecological element, with an average cover of 10 ± 2% in the wider area and 37 ± 3% in the immediate vicinity of the HDD exit alignment. Non-coral benthic macroinvertebrates were rarely the dominant ecological element with a cover of <3%. Seagrass was present at low levels of cover (≈1%).

Macroalgae, seagrass, and benthic macroinvertebrates were surveyed in spring 2008, late winter/early spring 2009, summer 2010, and winter/spring 2010 at eight sites near the HDD exit alignment. Sites at risk of Material or Serious Environmental Harm were located within the MDF, and Reference Sites were located north and south of the MDF.

Macroalgal assemblages represent the dominant ecological element in the shallow waters on the west coast of Barrow Island near the HDD exit alignment. The dominant macroalgae in terms of percentage cover recorded in west coast Barrow Island waters were the brown algae (*Sargassum* spp. and *Dictyopteris* spp.) and the green alga (*Halimeda* spp.). The three most common species recorded at the HDD exit alignment survey sites were *Halimeda discoidea*, *Lobophora variegata*, and *Sargassum* sp. Less common species recorded at these sites included *Caulerpa cactoides* and *Dictyopteris serrata*.

Percentage cover, biomass, and species diversity and composition of the macroalgal assemblages were spatially and temporally variable. There was no indication of differences in the taxonomic composition of macroalgae at sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to the Reference Sites not at risk of Material or Serious Environmental Harm. Estimates of percentage cover, biomass, and taxonomic diversity were generally slightly lower at sites in the MDF and in areas at risk of Material or

Serious Environmental Harm compared to the Reference Sites. All the macroalgal taxa recorded at sites in the MDF and in areas at risk of Material or Serious Environmental Harm were also recorded at Reference Sites and/or were common within the local area and region.

The dominant seagrass recorded in west coast Barrow Island waters was *Syringodium isoetifolium*. Seagrass were only recorded at a few locations and at low levels of percentage cover, growing in mixed assemblages with macroalgae and occasionally benthic macroinvertebrates. The seagrass species recorded at sites in the MDF and in areas at risk of Material or Serious Environmental Harm were well represented elsewhere in Barrow Island waters.

Sessile benthic macroinvertebrates (sea whips, sponges, *Turbinaria* spp., hydroids, and ascidians) were present in relatively low abundances in west coast Barrow Island waters close to the HDD exit alignment. The abundances and taxonomic diversity of the sessile benthic macroinvertebrate assemblages were spatially and temporally variable, both between and within sites. However, there was no indication of differences in the taxonomic composition of benthic macroinvertebrates at sites in the MDF and in areas at risk of Material or Serious Environmental Harm and at Reference Sites not at risk of Material or Serious Environmental Harm. Estimates of total abundances were generally lower at sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to the Reference Site HDDRN. All the sessile benthic macroinvertebrates taxa recorded at sites in the MDF and in areas at risk of Material or Serious Environmental Harm were also recorded at Reference Sites and were well represented elsewhere in Barrow Island waters.

The benthic habitats near the Offshore Feed Gas Pipeline System in State Waters were characterised by unvegetated or bare sand. Macroalgae were the dominant ecological element, although average cover of macroalgae, as well as of non-coral benthic macroinvertebrates, was <0.5%.

Mangroves

There are no mangrove stands on the west coast of Barrow Island. *Avicennia marina* grows in sparse stands only on the east coast of Barrow Island, where it is distributed in a narrow band along soft sediment and rock substrates in the upper littoral and supra-littoral zones of the intertidal area.

Demersal Fish

Demersal fish surveys in macroalgal, soft sediments with sessile non-coral benthic macroinvertebrate and unvegetated sand communities were undertaken in March 2009 and February/March 2010, near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. During the first survey in March 2009 at the Offshore Feed Gas Pipeline System sites, 696 individuals from 56 species and 28 families were recorded at the six sites (25 stereo Baited Remote Underwater Video systems [BRUV] deployments). In February/March 2010, 1262 individuals from 70 species and 31 families were recorded from seven sites (35 stereo-BRUV deployments). The highest number of species observed on a single deployment in 2009 was 25 compared to 32 in 2010, both at soft sediment with sessile benthic macroinvertebrates sites.

In 2009, there were no significant differences in the species richness of fish assemblages between Reference Sites (FGFR1, FGFR2, FGFR3, FGN1) and those at risk of Material or Serious Environmental Harm (FGI1, FGI2), or across sites. However, there was a significant effect of habitat driven by greater species richness at sessile invertebrate sites compared to bare sand sites. In 2010, species richness was significantly higher at the soft sediment with sessile benthic macroinvertebrate site than at the sand sites. The relative abundance and composition of fish assemblages were not significantly different between sites at risk of Material or Serious Environmental Harm and Reference sites, although a trend was indicated for 2009 data. However, in both 2009 and 2010 the relative abundance and composition of fish assemblages differed significantly between habitats and sites. In 2009 five species contributed to differences between sand and sessile invertebrate habitats—Northwest Threadfin Bream (*Pentapodus porosus*), Starry Triggerfish (*Abalistes stellatus*), *Nemipterus* spp. (threadfin bream), Threadfin Emperor (*Lethrinus genivittatus*), and Scombridae spp. (mackerel). All except Scombridae spp. were more abundant in sessile invertebrate habitats. In 2009 and 2010, the size structure of the fish assemblages differed significantly between the soft sediment with sessile benthic macroinvertebrates sites and the sand sites.

In 2009 and 2010, there were no significant differences in the species richness of fish assemblages between Reference Sites and sites in the MDF or in areas at risk of Material or Serious Environmental Harm associated with the Offshore Feed Gas Pipeline System in State Waters. Similarly, in both 2009 and 2010, the relative abundance and composition of fish assemblages were not significantly different between sites in the MDF or in areas at risk of Material or Serious Environmental Harm and Reference Sites. However, there was a significant difference in the relative abundance and composition of fish assemblages in both 2009 and 2010 between habitats and sites.

A total of 1015 individuals from 70 species and 31 families were recorded at the four HDD survey sites (20 stereo-BRUV deployments) surveyed in February/March 2010. The highest number of species observed on a single deployment was 21 at a macroalgae site. Of the 70 species recorded, 49 (70%) were also recorded at Offshore Feed Gas Pipeline System sites located further offshore. Species richness did not differ significantly between community-types (macroalgae vs. sand) or across sites. The relative abundance and composition of fish assemblages were not significantly different between the two community-types surveyed or among sites. The size structure of the fish assemblages differed significantly between the sand site and the macroalgae sites.

Species richness did not differ significantly between Reference Sites and sites in the MDF or in areas at risk of Material or Serious Environmental Harm in the HDD exit alignment. The relative abundance and composition of fish assemblages were not significantly different between the sites in the MDF or in areas at risk of Material or Serious Environmental Harm and Reference Sites. However, there was a difference in the size structure of fish assemblages between Reference Sites (HDDN1, HDDN2, HDDN3) and site HDD1 in the MDF and in areas at risk of Material or Serious Environmental Harm reflecting a large number of small-bodied fish at site HDDN3 and a school of trevally (*Carangoides fulvoguttatus*) at site HDD1.

There were no observable differences in the relative abundance or composition of the demersal fish assemblages between Reference Sites and sites in the MDF and areas at risk of Material or Serious Environmental Harm for the Offshore Feed Gas Pipeline System in State Waters or the HDD exit alignment associated with the marine component of the shore crossing. In 2009, the size structure of demersal fish assemblages differed between the Reference Sites and sites in the

MDF and in areas at risk of Material or Serious Environmental Harm. In 2010, there were no significant differences in the size structure of the fish assemblages at sites in the MDF and in areas at risk of Material or Serious Environmental Harm and Reference Sites; however, a significant difference was detected for the HDD sites due to a large number of small-bodied fish at site HDDN3.

Surficial Sediments

The surficial sediments on the west coast of Barrow Island were predominantly 'Sand' and were generally less variable than on the east coast, with lower proportions of mud and gravel. There was no indication of marked differences in the characteristics of surficial sediments at sites in the MDF and at risk of Material or Serious Environmental Harm and at Reference Sites not at risk of Material or Serious Environmental Harm. Particle-size distribution and percentage wet weight of Total Organic Carbon and Total Inorganic Carbon were similar at survey sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to the Reference Sites.

Water Quality (Turbidity and Light Attenuation)

In the west coast waters of Barrow Island, turbidity and concentrations of suspended sediments were generally low (<5 mg/L) and indicative of clear water environments. There were low levels of sediment deposition (below the limits of instrument detection) and any deposition that did occur was temporary and rapidly resuspended by waves and tidal flow. Wave conditions at the HDD Light-Turbidity-Deposition (LTD) logger site, located in an unprotected area off the west coast, are predominantly influenced by a combination of swell and tidal stage (height and flow rate), rather than the localised wind-generated waves that are common on the east coast. The median daily Wave Height Index recorded by the HDD LTD logger was higher in both summer and winter than the median daily Wave Height Index recorded at the sites on the east coast of Barrow Island monitored as part of the Marine Baseline Program. Median daily light ($\mu E/m^2/s$) and Light Attenuation Coefficient (LAC) (m^{-1}) were generally lower at the HDD LTD logger site than at the deeper sites on the east coast of Barrow Island in both summer and winter. Median daily turbidity (Nephelometric Turbidity Unit [NTU]) was also generally higher at the HDD LTD logger site in both summer and winter, while median daily suspended sediment concentration (SSC) (mg/L) was only higher at site LNG1 than at the HDD LTD logger site in both summer and winter.

Wave activity was important in contributing to local resuspension of sediments, resulting in elevated turbidity and SSCs. Extreme weather events, such as tropical cyclones, also had a strong influence on water quality. Short periods of elevated SSCs, reduced light levels, and elevated light attenuation as a consequence of increased turbidity in the water column, generally coincided with the passage of tropical cyclones. Seabed light levels were primarily influenced by depth and there were seasonal patterns in the daily average light levels.

Water column profiles consistently demonstrated that the water column on the west coast was well mixed with little evidence of stratification, indicative of an offshore environment with limited influence from surface water run-off and groundwater inflow, combined with good flushing and mixing by tidal and atmospheric forcing.

1 Introduction

1.1 Proponent

Chevron Australia Pty Ltd (CAPL) is the proponent and the person taking the action for the Gorgon Gas Development on behalf of these companies (collectively known as the Gorgon Joint Venturers):

- Chevron Australia Pty Ltd
- Shell Development (Australia) Proprietary Limited
- Mobil Australia Resources Company Pty Limited
- Osaka Gas Gorgon Pty Ltd
- Tokyo Gas Gorgon Pty Ltd
- JERA Gorgon Pty Ltd

1.2 Project

CAPL is developing the gas reserves of the Greater Gorgon Area. The gas will be processed in a Gas Treatment Plant (GTP) on Barrow Island, which is located off the Pilbara coast 85 km north-north-east of Onslow in Western Australia (WA) (Figure 1-1).

Subsea gathering systems and subsea pipelines deliver feed gas from the Gorgon and Jansz–Io gas fields to the west coast of Barrow Island. The underground feed gas pipeline system then traverses Barrow Island to the east coast of the Island where the GTP is located. The GTP includes natural gas trains that produce liquefied natural gas (LNG) as well as condensate and domestic gas. Carbon dioxide (CO_2), which occurs naturally in the feed gas, is separated during the production process and injected into deep rock formations below Barrow Island. The LNG and condensate is loaded onto tankers from a jetty and then transported to international markets. Gas for domestic use is exported by pipeline from Barrow Island to the domestic gas collection and distribution network on the WA mainland.

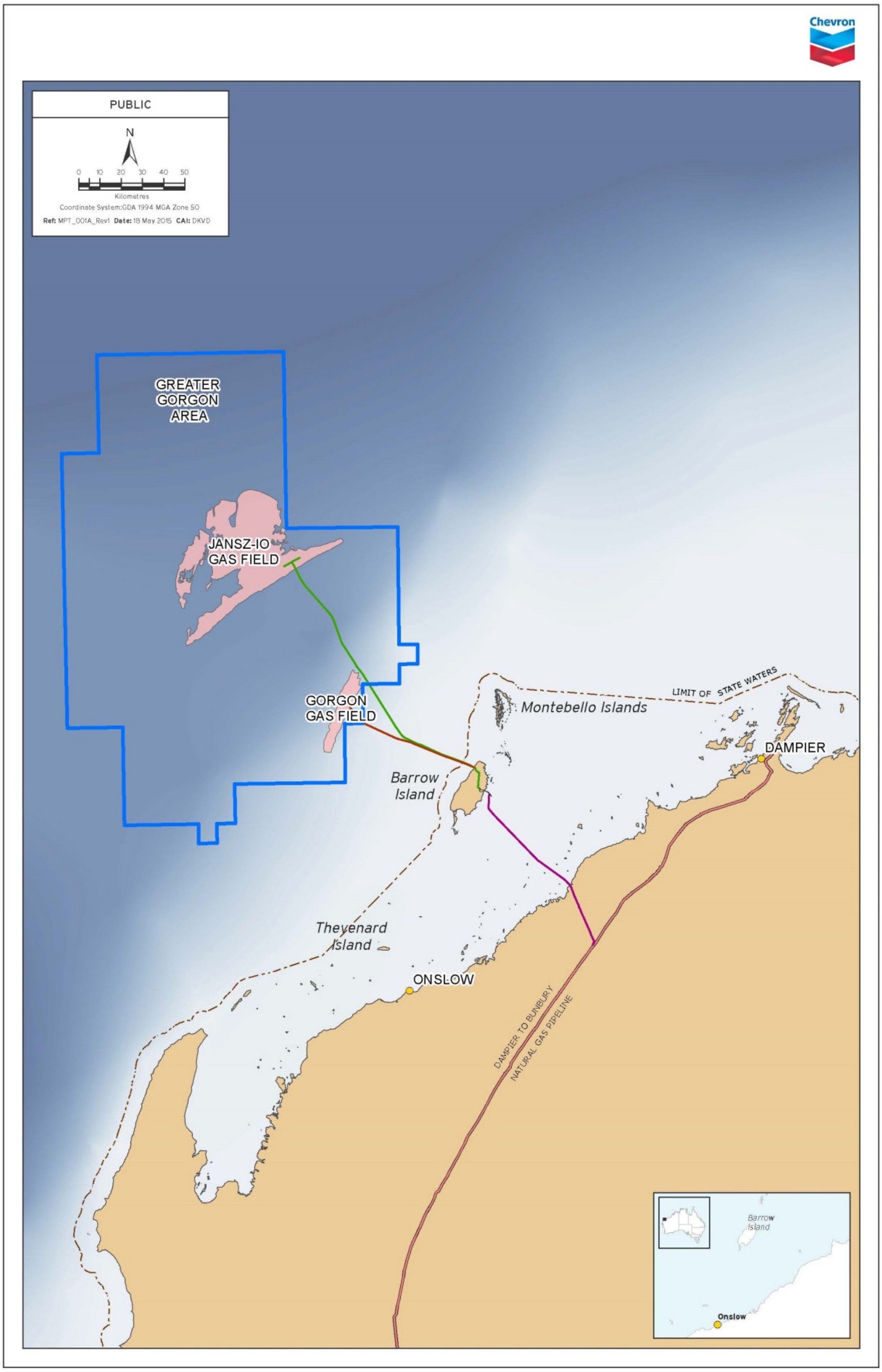


Figure 1-1: Location of Barrow Island and the Greater Gorgon Area

1.3 Environmental Approvals

Table 1-1 summarises the State (WA) and Commonwealth (Cth) environmental approvals for the components of the Gorgon Gas Development.

These approvals, and projects approved under these approvals, have been and may continue to be amended (or replaced) from time to time.

Table 1-1: State and Commonwealth Approvals

Project Approval Stage	State	Commonwealth
Jansz Feed Gas Pipeline	Ministerial Statement (MS) 769 (Ref. 1) 28 May 2008	EPBC Reference: 2005/2184 (Ref. 2). 22 March 2006
Initial Gorgon Gas Development (2 LNG trains)	Initial Gorgon Gas Development comprising two LNG trains – MS 748 (Ref. 3). This was superseded by MS 800. 6 September 2007	Initial Gorgon Gas Development comprising two LNG trains – EPBC Reference: 2003/1294 (Ref. 6). 3 October 2007
Revised and Expanded Gorgon Gas Development (3 LNG trains)	MS 800 (Ref. 4) provides approval for both the initial Gorgon Gas Development and the Revised and Expanded Gorgon Gas Development (compromising three LNG trains). This statement supersedes MS 748. 10 August 2009	The Revised and Expanded Gorgon Gas Development (EPBC Reference: 2008/4178 [Ref. 5]) was approved, and the conditions for the initial Gorgon Gas Development (EPBC Reference: 2003/1294 [Ref. 6]) were varied. 26 August 2009
Dredging Amendment	MS 865 (Ref. 7) provides approval to establish a restart mechanism in the event of a Project-attributable coral health management trigger. This statement is an amendment to Conditions 18, 20, and 21 of MS 800. 8 June 2011	Not applicable
Additional Support Area	MS 965 (Ref. 8) applies the conditions of MS 800 to an Additional Support Area. 2 April 2014	The conditions for the initial Gorgon Gas Development (EPBC Reference: 2003/1294 [Ref. 6]).and for the Revised and Expanded Gorgon Gas Development (EPBC Reference: 2008/4178 [Ref. 5]) were varied. 15 April 2014
Gorgon Gas Development Fourth Train Expansion[1]	MS 1002 (Ref. 9) applies the conditions of MS 800 to the Fourth Train Expansion, and has additional conditions. 30 April 2015	EPBC Reference: 2011/5942 (Ref. 10). 12 May 2016

[1] This Plan will apply to the Fourth Train Expansion once this scope commences.

1.4 Purpose of this Report

1.4.1 Requirement for this Report

1.4.1.1 State Environmental Approval Conditions

This Report is required under Condition 14.2 of MS 800, which is quoted below:

> *Prior to commencement of construction of marine facilities as listed in Condition 14.3, the Proponent shall submit a Coastal and Marine Baseline State and Environmental Impact Report (the Report) that meets the purposes set out in Condition 14.6, as determined by the Minister, unless otherwise allowed in Condition 14.4.*

The Marine Facilities referred to are defined in Condition 14.3 of MS 800 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System
- Domestic Gas Pipeline
- Marine Upgrade of the existing WAPET landing.

Condition 14.3 of MS 800 relates only to components of the Marine Facilities within State Waters (i.e. specifically the Offshore Feed Gas Pipeline System).

This Report is also required under Condition 12.2 of MS 769, which is quoted below:

> *Prior to commencement of construction of marine facilities, as defined in Condition 12.3, the Proponent shall submit a Coastal and Marine Baseline State and Environmental Impact Report (the Report) that meets the purposes set out in Condition 12.5, as determined by the Minister, unless otherwise allowed in Condition 12.4.*

The Jansz Marine Facilities referred to are defined in Condition 12.3 of MS 769 as the Offshore Feed Gas Pipeline System and the marine component of the shore crossing.

1.4.1.2 Commonwealth Environmental Approval Conditions

This Report satisfies the requirements of Condition 11.2 of EPBC Reference: 2003/1294 and 2008/4178, which is quoted below:

> *Prior to commencement of construction of marine facilities as listed in Condition 11.3, the person taking the action must submit a Coastal and Marine Baseline State and Environmental Impact Report (the Report) that meets the purposes set out in Condition 11.6, and the requirements set out in Conditions 11.7 and 11.8 as determined by the Minister, unless otherwise allowed in Condition 11.4.*

The Marine Facilities referred to are defined in Condition 11.3 of EPBC Reference: 2003/1294 and 2008/4178 as the:

- Materials Offloading Facility (MOF)

- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System in State Waters
- Offshore Domestic Gas Pipeline.

Note that these conditions only apply to facilities in State Waters.

1.4.2 Scope

Condition 14.4 of MS 800, Condition 12.4 of MS 769 and Condition 11.4 of EPBC Reference: 2003/1294 and 2008/4178 provide for this Marine Baseline Report to be submitted in a staged approach for different elements. Table 1-2 describes the three separate documents that have been submitted to cover different elements of the marine facilities.

This version of the Marine Baseline Report covers the Offshore Feed Gas Pipeline System within State Waters and the marine component of the shore crossing (Condition 14.3.iv, MS 800; Condition 12.3.i, MS 769; Condition 11.3.IV, EPBC Reference: 2003/1294 and 2008/4178). Information in this Marine Baseline Report relevant to other Marine Facilities is provided for information only.

The survey data referenced in this document were collected prior to installation of the initial Gorgon and Jansz Offshore Feed Gas Pipeline Systems within State Waters (and associated marine component of the shore crossing), which was completed in 2013 and comprised two (30” and 34” diameter) production pipelines, four other pipelines and two umbilical systems. Further surveys were conducted post-installation and showed there had been no significant changes to the monitored ecological elements outside of the direct installation footprint (Ref. 22). Consequently, the information from these surveys is considered to provide an appropriate pre-development environmental baseline for the two umbilicals proposed to be added to the Offshore Feed Gas Pipeline Systems within State Waters (and associated marine component of the shore crossing) in 2024/25.

Table 1-2: Marine Facilities Listed in Ministerial Statements and Corresponding Coastal and Marine Baseline State and Environmental Impact Reports

Applicable Marine Baseline Report Title	Marine Facility	Ministerial Statement	Ministerial Condition	CAPL Doc. Number
Coastal and Marine Baseline State and Environmental Impact Report (MOF, Jetty, DSDG)	Marine Upgrade of the existing WAPET Landing	MS 800	Condition 14.3	G1-NT-REPX0001838
	Materials Offloading Facility (MOF) LNG Jetty Dredge Spoil Disposal Ground (DSDG)	MS 800	Condition 14.3	
		EPBC Reference: 2003/1294 and 2008/4178	Condition 11.3	
Coastal and Marine Baseline State and Environmental Impact Report (Feed Gas and shore crossing) –- *this Report*	Offshore Feed Gas Pipeline System and the Marine Component of the Shore Crossing	MS 769	Condition 12.3	G1-NT-REPX0002749
	Offshore Feed Gas Pipeline System	MS 800	Condition 14.3	
	Offshore Feed Gas Pipeline System in State Waters	EPBC Reference: 2003/1294 and 2008/4178	Condition 11.3	
Coastal and Marine Baseline State and Environmental Impact Report (DomGas Pipeline)	Domestic Gas Pipeline	MS 800	Condition 14.3	G1-NT-REPX0002750
	Offshore Domestic Gas Pipeline	EPBC Reference: 2003/1294 and 2008/4178	Condition 11.3	

1.4.3 Purpose

The purposes of this Marine Baseline Report, as stated in Condition 12.6 of MS 769, are to:

- define and map the ecological elements within the Marine Disturbance Footprint
- define and map the ecological elements that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System and the marine component of the shore crossing
- define and map the ecological elements of Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System and the marine component of the shore crossing, including water quality (turbidity and light).

The purposes of this Marine Baseline Report as stated in Condition 14.6 of MS 800 are to:

- describe and map the benthic ecological elements referred to in Condition 14.2(i–vi) that are at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System
- describe and map the benthic ecological elements referred to in Condition 14.2(i–vi) at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System
- describe the ecological elements referred to in Condition 14.2(vii and viii) that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System
- describe the ecological elements referred to in Condition 14.2(vii and viii) of Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System.

The purposes of this Marine Baseline Report as stated in Condition 11.6 of EPBC Reference: 2003/1294 and 2008/4178 are to:

- describe and map the benthic ecological elements referred to in Condition 11.2(I–VI) that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters
- describe and map the benthic ecological elements referred to in Condition 11.2(I–VI) at Reference Sites that are not at risk or Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters
- describe the ecological elements referred to in Condition 11.2(VII and VIII) that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters
- describe the ecological elements referred to in Condition 11.2(VII and VIII) of Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters.

The methodologies used in this Marine Baseline Report are detailed in the Coastal and Marine Baseline State and Environmental Impact Report Scope of Works (Ref. 19), which was approved under Condition 12.1 of MS 769 and Condition 14.1 of MS 800 on 11 September 2009, and Condition 11.1 of EPBC Reference: 2003/1294 and 2008/4178 on 23 September 2009. The results presented in this Marine Baseline Report are the result of surveys conducted in accordance with the approved Coastal and Marine Baseline State and Environmental Impact Report Scope of Works (Ref. 19).

1.4.4 Requirements

Table 1-3 lists the Approval Condition requirements for this Marine Baseline Report, as stated in Condition 12 of MS 769, Condition 14 of MS 800, and Condition 11 of EPBC Reference: 2003/1294 and 2008/4178 in relation to the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, and the sections in this Marine Baseline Report that fulfil them.

Table 1-3: Condition Requirements Addressed in this Marine Baseline Report

Ministerial Document	Condition No.	Requirement	Section in this Report
MS 769	12.7	The geographic extent of the Report shall be: i. the Offshore Feed Gas Pipeline System and marine component of the shore crossing ii. benthic habitats within 200 m of the Offshore Feed Gas Pipeline System and marine component of the shore crossing in State Waters.	Section 2 provides detail of the geographic extent of the Report required by this condition, including relevant figures. Section 5.3 describes the benthic habitats near the Offshore Feed Gas Pipeline System and the marine component of the shore crossing.
MS 769	12.8.i	The Report shall: • contain spatially accurate (e.g. rectified and geographically referenced) maps showing the locations and spatial extent of the marine facilities in Condition 12.3.	Figure 2-2
MS 769	12.8.ii	The Report shall: • present the results of the surveys described in Condition 12.1.	Sections 5.3.5, 6.4, 7.4, 8.4, 9.4, 11.4 and Appendix C and Appendix D, Sections 12.4 and 13.4
MS 769	12.8.iii	The Report shall record the: • existing dominant and subdominant hard and soft coral species	Section 6.4
		• dominant species of macroalgae	Section 8.4.2
		• dominant species of non-coral benthic macroinvertebrates	Section 7.4.1
		• dominant species of seagrass	Section 9.4.2
		• demersal fish assemblages that characterise these communities.	Section 11.4 and Appendix C and Appendix D

Ministerial Document	Condition No.	Requirement	Section in this Report
MS 769	12.8.iv	The Report shall: • record the population structure, as size class frequency distributions, and other population statistics of recruitment, survival and growth, of dominant hard coral species and selected other key indicator species that characterises these communities.	Hard corals (solitary colonies of *Turbinaria* spp.) are present in low abundance and percentage cover at sites that are at risk of Material or Serious Environmental Harm, in the MDF or at Reference Sites that are not at risk of Material or Serious Environmental Harm and are unlikely to offer the ecological function of a coral community, thus no field surveys have been undertaken to assess these population parameters: Section 6.2
MS 769	12.8.v	The Report shall: • contain a description and map of the ecological elements within the Marine Disturbance Footprint i. Hard and soft corals	There are no Coral Assemblages in the MDF: Section 6.4, Figure 5-4
		ii. Macroalgae	Section 8.4.4 and Figure 8-3
		iii. Non-coral benthic macroinvertebrates	Section 7.4.3 and Figure 7-3
		iv. Seagrass	Section 9.4.4 and Figure 9-3
		v. Demersal fish	Sections 11.4.2 and 11.4.6, Appendix C, and Appendix D
		vi. Surficial sediment characteristics	Section 12.4.1, Figure 12-3, and Figure 12-4
		vii. Water quality (turbidity and light) and deposited surficial sediment characteristics will be required where the construction of Marine Facilities will adversely affect the environment.	Sections 13.4.2.1, 13.4.3.1, 13.4.4.1
MS 769	12.8.vi	The Report shall: • contain a description and map of the ecological elements which are at risk of Material or Serious Environmental Harm due to construction and operation of the Offshore Feed Gas Pipeline System and marine component of the shore crossing i. Hard and soft corals	There are no Coral Assemblages at risk of Material or Serious Environmental Harm: Section 6.4, Figure 5-4
		ii. Macroalgae	Section 8.4.5 and Figure 8-3
		iii. Non-coral benthic macroinvertebrates	Section 7.4.3and Figure 7-3

Ministerial Document	Condition No.	Requirement	Section in this Report
		iv. Seagrass	Section 9.4.5 and Figure 9-3
		v. Demersal fish	Sections 11.4.3, 11.4.7, Appendix C, and Appendix D
		vi. Surficial sediment characteristics	Section 12.4.2, Figure 12-3, and Figure 12-4
		vii. Water Quality (turbidity and light) and deposited surficial sediment characteristics will be required where the construction of Marine Facilities will adversely affect the environment.	Section 13.4.4.2 and Figure 13-2
MS 769	12.8.vii	The Report shall: • present data in an appropriate Geographic Information System (GIS) format.	Existing figures represent GIS data that is up-to-date and complete for the Offshore Feed Gas Pipeline System and the marine component of the shore crossing. All relevant GIS data were provided in digital format with Revision 0 of this Marine Baseline Report.
MS 769	12.8.viii	The Report shall: • establish background water quality (turbidity and light) where the consequences of sea bed disturbance may affect the environment.	Sections 13.4.2.1, 13.4.3.1, 13.4.4.1, and 13.4.4.2
MS 769	12.8.ix	The Report shall: • report on the distribution and characteristics of surficial sediments where the consequences of sea bed disturbance may affect the environment.	Sections 12.4.1 and 12.4.2, Figure 12-3, and Figure 12-4
MS 769	12.8.x	The Report shall: • report on the natural rates and spatial patterns of sediment deposition, and the physical characteristics of the deposited sediment where the consequences of sea bed disturbance may affect the environment.	Section 13.3.4.1.2
MS 769	12.9	To meet the requirements of Condition 12.8, the Proponent shall collect water quality data, data on metocean conditions if considered useful by the proponent and data on natural rates, and spatial patterns of sediment deposition for at least one full annual cycle prior to the construction of the Offshore Feed Gas Pipeline System and marine component of the shore crossing.	Section 13.3.1.1 and Table 13-3, Sections 13.4.2, 13.4.3, 13.4.4 and 13.4.5

Ministerial Document	Condition No.	Requirement	Section in this Report
MS 800	14.7	The geographic extent of the Report shall be: • the Marine Facilities listed in Condition 14.3 • Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence including those that contain significant benthic communities including coral assemblages • the Marine Disturbance Footprint associated with the facilities listed in Condition 14.3 in State Waters • Reference Sites outside the Zone of Influence.	Section 2 provides detail of the geographic extent of this Report required by this Condition, including relevant figures.
MS 800	14.8.i	The Report shall: • contain spatially accurate (i.e. rectified and geographically referenced) maps showing the locations and spatial extent of the marine coastal facilities listed in Condition 14.3.	Figure 2-2
MS 800	14.8.ii	The Report shall: • present the results of the surveys described in Condition 14.1.	Sections 5.3.5, 6.4, 7.4, 8.4, 9.4, 10, 11.4, 12.4 and 13.4, Appendix C, and Appendix D
MS 800	14.8.iii	The Report shall record the: • existing dominant and subdominant hard and soft coral species/taxa	Section 6.4
		• dominant species of macroalgae	Section 8.4.2
		• dominant species of non-coral benthic macroinvertebrates	Section 7.4.1
		• dominant species of seagrass	Section 9.4.2
		• dominant species of mangroves	There are no mangroves at or near the Offshore Feed Gas Pipeline System: Section 10
		• demersal fish assemblages that characterise these communities.	Section 11.4, Appendix C, and Appendix D
MS 800	14.8.iv	The Report shall record the: • population structure of coral communities as colony size-class frequency distributions of dominant hard coral taxa • population statistics of survival and growth of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise these communities • recruitment of hard coral taxa within these communities.	Hard corals (solitary colonies of *Turbinaria* spp.) are present in low abundance and percentage cover at sites that are at risk of Material or Serious Environmental Harm, in the MDF or at Reference Sites that are not at risk of Material or Serious Environmental Harm and are unlikely to offer the ecological function of a coral community, thus no field surveys have been undertaken to assess these population parameters: Section 6.2

Ministerial Document	Condition No.	Requirement	Section in this Report
MS 800	14.8.v	The Report shall: • contain descriptions and spatially accurate (i.e. rectified and geographically referenced) maps in accordance with the purposes set out in Condition 14.6.	Figure 5-4 and descriptions and maps in Sections 7, 8, 9, 10, 11, 12, and 13
MS 800	14.8.vi	The Report shall: • present data in an appropriate Geographic Information System (GIS) format.	Existing figures represent GIS data that is up-to-date and complete for the Offshore Feed Gas Pipeline System. All relevant GIS data were provided in digital format with Revision 0 of this Marine Baseline Report.
MS 800	14.8.vii	The Report shall: • establish and report on background water quality (including measures of turbidity and light attenuation), the natural rates and spatial patterns of sediment deposition, and the physical characteristics of the deposited sediment and characteristics of surficial sediments where dredging and dredge spoil disposal may affect the environment and at Reference Sites where the environment will not be affected.	Approval in relation to the MOF, LNG Jetty, and DSDG was received on 7 April 2010. Dredging and dredge spoil disposal will not be undertaken as part of the Offshore Feed Gas Pipeline System.
MS 800	14.9	To meet the requirements of Condition 14.8, the Proponent shall collect water quality data and data on natural rates and spatial patterns of sediment deposition for at least one full annual cycle prior to the construction of the Marine Facilities listed in Condition 14.3.	Section 13.3.1.1 and Table 13-3, Sections 13.4.2, 13.4.3, 13.4.4, and 13.4.5
EPBC Reference: 2003/1294 and 2008/4178	3.2.1	A description of the EPBC listed species and their habitat likely to be impacted by the components of the action which are the subject of the Marine Baseline Report.	Appendix A
EPBC Reference: 2003/1294 and 2008/4178	3.2.2	An assessment of the risk to these species from the components of the action the subject of that plan, relevant to the Marine Baseline Report.	Appendix A
EPBC Reference: 2003/1294 and 2008/4178	11.7	The geographic extent of the Report must be: • the Marine Facilities listed in Condition 11.3 • Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence including those that contain significant benthic communities including coral assemblages • the Marine Disturbance Footprint associated with the facilities listed in Condition 11.3 in State Waters • Reference Sites outside the Zone of Influence.	Section 2 provides detail of the geographic extent of the Report required by this condition, including relevant figures.

Ministerial Document	Condition No.	Requirement	Section in this Report
EPBC Reference: 2003/1294 and 2008/4178	11.8.I	The Report must: • contain spatially accurate (i.e. rectified and geographically referenced) maps showing the locations and spatial extent of the marine facilities listed in Condition 11.3.	Figure 2-2
EPBC Reference: 2003/1294 and 2008/4178	11.8.II	The Report must: • present the results of the surveys described in Condition 11.1.	Sections 5.3.5, 6.4, 7.4, 8.4, 9.4, 10, 11.4, 12.4, 13.4, Appendix C, and Appendix D
EPBC Reference: 2003/1294 and 2008/4178	11.8.III	The Report must record the: • existing dominant and subdominant hard and soft coral species/taxa	Section 6.4
		• dominant species of macroalgae	Section 8.4.2
		• dominant species of non-coral benthic macroinvertebrates	Section 7.4.1
		• dominant species of seagrass	Section 9.4.2
		• dominant species of mangroves	There are no mangroves at or near the Offshore Feed Gas Pipeline System in State Waters: Section 10
		• demersal fish assemblages that characterise these communities.	Section 11.4, Appendix C, and Appendix D
EPBC Reference: 2003/1294 and 2008/4178	11.8.IV	The Report must record the: • population structure of coral communities as colony size-class frequency distributions of dominant hard coral taxa • population statistics of survival and growth of dominant hard coral taxa and, if appropriate, selected other indicator coral taxa that characterise these communities • recruitment of hard coral taxa within these communities.	Hard corals (solitary colonies of *Turbinaria* spp.) are present in low abundance at sites that are at risk of Material or Serious Environmental Harm, in the MDF or at Reference Sites that are not at risk of Material or Serious Environmental Harm and are unlikely to offer the ecological function of a coral community, thus no field surveys have been undertaken to assess these population parameters: Section 6.2
EPBC Reference: 2003/1294 and 2008/4178	11.8.V	The Report must: • contain descriptions and spatially accurate (i.e. rectified and geographically referenced) maps in accordance with the purposes set out in Condition 11.6.	Figure 5-4 and descriptions and maps in Sections 7, 8, 9, 10, 11, 12, and 13

Ministerial Document	Condition No.	Requirement	Section in this Report
EPBC Reference: 2003/1294 and 2008/4178	11.8.VI	The Report must: • present data in an appropriate Geographic Information System (GIS) format.	Existing figures represent GIS data that is up-to-date and complete for the Offshore Feed Gas Pipeline System in State Waters. All relevant GIS data were provided in digital format with Revision 0 of this Marine Baseline Report.
EPBC Reference: 2003/1294 and 2008/4178	11.8.VII	The Report must: • establish and report on background water quality (including measures of turbidity and light attenuation), the natural rates and spatial patterns of sediment deposition, and the physical characteristics of the deposited sediment and characteristics of surficial sediments where dredging and dredge spoil disposal may affect the environment and at Reference Sites where the environment will not be affected.	Approval in relation to the MOF, LNG Jetty, and DSDG was received on 14 April 2010. Dredging and dredge spoil disposal will not be undertaken as part of the Offshore Feed Gas Pipeline System in State Waters.
EPBC Reference: 2003/1294 and 2008/4178	11.9	To meet the requirements of Condition 11.8, the person taking the action must collect water quality data and data on natural rates and spatial patterns of sediment deposition for at least one full annual cycle prior to the construction of the Marine Facilities listed in Condition 11.3.	Section 13.3.1.1 and Table 13-3, Sections 13.4.2, 13.4.3, 13.4.4, and 13.4.5

Any matter specified in this Report is relevant to the Gorgon Gas Development or Jansz Feed Gas Pipeline only if that matter relates to the specific activities or facilities associated with that particular development.

2 Relevant Facilities and Areas

2.1 Marine Facilities

The Marine Facilities for the Gorgon Gas Development are defined in Condition 14.3 of MS 800 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System
- Domestic Gas Pipeline
- Marine Upgrade of the existing WAPET Landing.

Condition 14.3 of MS 800 relates only to components of the Marine Facilities within State Waters (i.e. specifically the Offshore Feed Gas Pipeline System).

The Marine Facilities for the Jansz Feed Gas Pipeline are defined in Condition 12.3 of MS 769 as the:

- Offshore Feed Gas Pipeline System and the marine component of the shore crossing.

The Marine Facilities for the Gorgon Gas Development are defined in Condition 11.3 of EPBC Reference: 2003/1294 and 2008/4178 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System in State Waters
- Offshore Domestic Gas Pipeline.

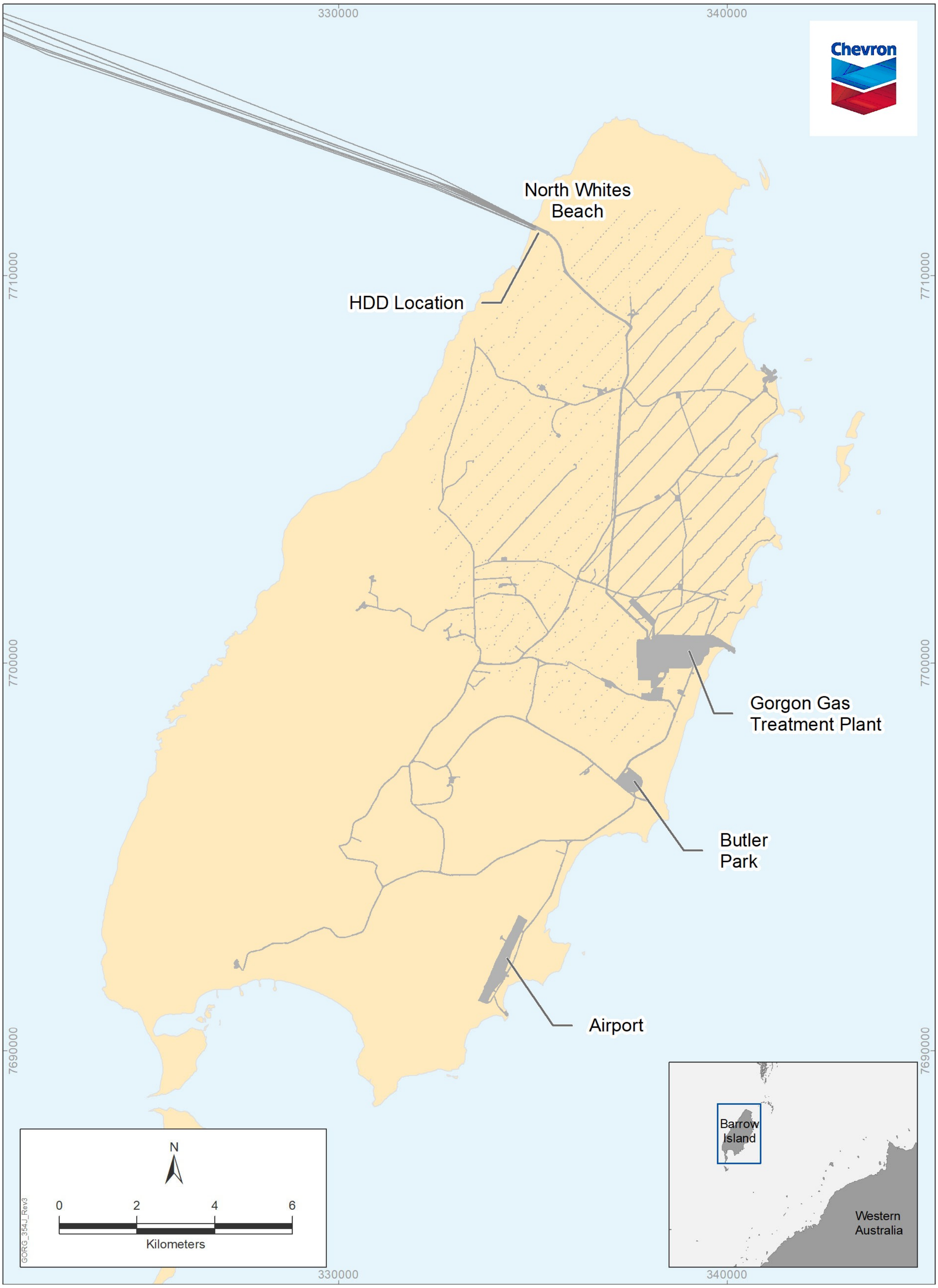


Figure 2-1: Gorgon Gas Development West Coast Marine Facilities

2.2 Activities

This Marine Baseline Report covers activities associated with construction and operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The MOF, LNG Jetty, DSDG, (Offshore) Domestic Gas Pipeline, and Marine Upgrade of the existing WAPET Landing are not covered in this version of the Marine Baseline Report.

Main marine construction activities comprise:

- Pipelines installation on the seabed
- Umbilicals installation on the seabed
- Stabilisation of installed pipelines and umbilicals
- Support to HDD activities
- Seabed surveys

2.3 Marine Areas

2.3.1 Geographic Extent

The geographic extent for reports that cover the Gorgon Gas Development Marine Facilities is defined in Condition 14.7 of MS 800 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty
- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System
- Domestic Gas Pipeline
- Marine Upgrade of the existing WAPET Landing
- Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence, including those that contain significant benthic communities including coral assemblages
- the Marine Disturbance Footprint associated with the Marine Facilities in State Waters
- Reference Sites outside the Zone of Influence.

The geographic extent for reports that cover the Jansz Marine Facilities is defined in Condition 12.7 of MS 769 as the:

- Jansz Offshore Feed Gas Pipeline System and the marine component of the shore crossing
- benthic habitats within 200 m of the Jansz Offshore Feed Gas Pipeline System and the marine component of the shore crossing in State Waters.

The geographic extent for reports that cover the Gorgon Gas Development Marine Facilities is defined in Condition 11.7 of EPBC Reference: 2003/1294 and 2008/4178 as the:

- Materials Offloading Facility (MOF)
- LNG Jetty

- Dredge Spoil Disposal Ground
- Offshore Feed Gas Pipeline System in State Waters
- Offshore Domestic Gas Pipeline
- Dredge Management Areas including the Zones of High Impact, the Zones of Moderate Impact and areas in the Zones of Influence, including those that contain significant benthic communities including coral assemblages
- the Marine Disturbance Footprint associated with the Marine Facilities in State Waters
- Reference Sites outside the Zone of Influence.

2.3.2 Marine Disturbance Footprint

The Gorgon Gas Development MDF is defined in MS 800 as:

> *The area of the seabed to be disturbed by construction or operations activities associated with the marine facilities listed in Condition 14.3 (excepting that area of the seabed to be disturbed by the generation of turbidity and sedimentation from dredging and spoil disposal).*

The Jansz Feed Gas Pipeline MDF is defined in MS 769 as:

> *The area of the seabed to be disturbed by construction or operations activities associated with the Marine Facilities listed in Condition 12.3.*

The Gorgon Gas Development MDF is defined in EPBC Reference: 2003/1294 and 2008/4178 as:

> *The area of the seabed to be disturbed by construction or operations activities associated with the marine facilities listed in Condition 11.3 (excepting that area of the seabed to be disturbed by the generation of turbidity and sedimentation from dredging and spoil disposal).*

Therefore, the MDF includes the Marine Facilities Footprint (the areas of the seabed associated with the physical footprint of the Marine Facilities [the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing]) and the extent of the surrounding seabed in which the planned construction and operation activities could be expected to disturb the seabed. The boundary of the MDF for the west coast Marine Facilities is shown in Figure 2-2 and encompasses an area extending 100 m either side of the outermost design Feed Gas Pipeline System route.

Direct physical disturbance to the seabed within the MDF may include laying and stabilising the Feed Gas Pipeline System directly on the seabed; vessel anchoring and propeller wash; operating drilling equipment, including drilling through subsea geological formations and break out at the HDD exit alignment; installing guidewires and water winning spread, including placing pumps on the seabed and discharge from self-cleaning filters; placing clump weights; span correction; and possible frac-outs. The MDF for the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing also includes areas that will not be disturbed (e.g. areas between anchor positions and between anchor positions and the vessel where no anchors or chains contact the seabed). Thus, the levels of potential disturbance within the MDF of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing may vary from negligible to Material Environmental Harm to Serious Environmental Harm (see Section 2.3.3 for further details).

The MDF of the marine component of the shore crossing includes those areas of the seabed and the associated benthic ecological elements (hard and soft corals, non-coral benthic macroinvertebrates, macroalgae, seagrass, and surficial sediment characteristics) that may be directly affected by the planned construction and operation activities. The MDF includes the impacts of suspended sediment plumes from non-dredging marine HDD activities on water quality (turbidity and light attenuation) and sediment deposition (Section 2.3.2.1). The MDF associated with the Offshore Feed Gas Pipeline System in State Waters includes those areas of the seabed and associated benthic ecological elements that may be directly affected by the Feed Gas Pipeline System installation activities.

2.3.2.1 Determination of Areas of Seabed that may be Affected by Elevated Turbidity and Sedimentation from HDD Marine Activities within the MDF

The MDF for the west coast Marine Facilities includes the areas of the seabed that may be affected by elevated turbidity and sedimentation associated with HDD marine activities. Some drilling fluids and cuttings will be discharged into the marine environment at the seabed exit points. There is also potential for drilling fluids to be lost either to the marine environment or into geological formations via frac-outs through cracks or fissures if fractured formations are encountered during drilling. Numerical modelling was undertaken to predict above background suspended sediment concentrations (SSCs) and sedimentation generated by HDD marine activities on the west coast of Barrow Island (Ref. 27). Of the total amount of cuttings material to be discharged, nearly 90% is expected to range from coarse gravel to coarse sand. Modelling results indicated that these coarse particles would settle close to the HDD exit alignment (<50 m), while fine materials would be effectively dispersed by the ambient currents and wave action to low concentrations (≈1 mg/L) over large distances (<4 km) from the HDD exit alignment. Concentrations >1 mg/L above background SSC were limited to <1000 m from the HDD exit alignment. The highest short-term (<1 hour) SSC predicted 50 m from the discharge point was 12 mg/L and SSC estimates reached 1–12 mg/L for multiple hours at a time over the simulation period. However, the median elevation was estimated to be 1 mg/L and the 80th percentile elevation was predicted to be 2 mg/L, thus elevations would be substantially lower than the extremes for most of the time. Concentrations were predicted to decrease exponentially and to be increasingly more intermittent with distance. At distances beyond 100 m, elevations of SSC were not predicted to remain continuous, thus influences on turbidity and light penetration would be intermittent and minimal at distances >100 m from the HDD exit alignment. This is due to the dynamic movement of the plume as a result of tidal variations and wind forcing. Beyond 400 m from the HDD exit alignment, elevations of SSC >1 mg/L were unusual during simulations and tended to be very short-lived such that the sediment plume would not be discernible above background levels.

Simulations indicated that sand and larger particles would settle around the discharge point, with the final footprint of the cuttings pile predicted to be ≈40 m × 85 m and ≈15 cm high at the peak (Ref. 27). Sedimentation rates were <1 mg/cm^2/day except for the area within the 25 m radius of the HDD exit alignment where the drilling cuttings pile up. In the immediate vicinity of the HDD exit alignment, maximum sediment deposition loads were predicted to peak at 560 mg/cm^2. These particles would be reworked by more energetic combinations of wave and currents, such that the accumulations would progressively spread onto adjacent areas. At distances beyond 100 m, the deposits were predicted to have low concentrations (<10 mg/cm^2) and thicknesses (<0.1 mm). The wider sedimentation rate is considered too low to be significant as the fine material is dispersed over such a wide area.

The modelling also investigated the effects of using a small proportion (10% by volume) of bentonite (added for drilling control) (Ref. 27). The median SSC was predicted to be ≈5 mg/L and the 80th percentile ≈7 mg/L within 25 m of the HDD exit alignment, reflecting the amount of bentonite in the drilling fluid that does not settle rapidly. Nevertheless, the spatial extent of elevated SSC rapidly declined such that 100 m from the HDD exit alignment the median SSC was predicted to be ≈1 mg/L and the 80th percentile ≈2 mg/L, with both values decreasing to 1 mg/L at 400 m from the HDD exit alignment. The sedimentation rates were not affected by the addition of bentonite in the drilling fluid.

From the modelling results, none of the Coral Health Criteria used in predicting the ZoHI and ZoMI in the dredge plume modelling (Ref. 28) were exceeded at a radius >25 m from the HDD exit alignment, under the proposed drilling program for any of the modelling scenarios (Ref. 27).

2.3.2.2 Indicative Anchoring Areas adjacent to the (MDF)

Adjacent to the MDF for the west coast Marine Facilities are the indicative anchoring areas around the HDD exit alignment (hatched areas in Figure 2-2). Anchoring activities will be restricted to within this area and, as far as practicable, within the MDF for the west coast Marine Facilities. It is not proposed that the entire area identified as indicative anchoring areas will be disturbed; each anchor will create localised and minor disturbance at the points of contact with the seabed only, and there will be areas between anchor positions and between the anchor positions and the vessel where no anchors or chains contact the seabed. Any disturbance from anchoring will be temporary and only for the duration of the marine works. Refer to the Horizontal Directional Drilling Management and Monitoring Plan (Ref. 20) and the Offshore Feed Gas Pipeline Installation Management Plan [Ref. 17] for details on the management of anchoring.

Figure 2-2 includes an indicative anchoring area on the west coast of Barrow Island that could be used by Gorgon construction and support vessels requiring anchoring on the west coast for safety/emergency reasons. The west coast indicative anchoring area is located south of the HDD exit alignment and north of the Barrow Island Marine Park. Based on current construction activities, it is envisaged that the west coast indicative anchoring area will be used at any one time by up to approximately ten vessels of up to approximately 30 m in length. The type of anchors deployed, the length of anchor chains on the sea floor, and similar vessel management matters will be at the discretion of each Vessel Master. Where practicable, Vessel Masters will manage vessel anchoring to minimise impacts to the marine environment.

2.3.2.3 Dredging and Dredge Spoil Disposal Activities on the East Coast of Barrow Island

Hydrodynamic modelling was undertaken to predict how fine sediments released during dredging and dredge spoil disposal activities associated with the construction of the MOF and the LNG Jetty at Town Point on the east coast of Barrow Island will disperse through the marine environment under the influence of oceanographic processes (for further information see Section 2.3.3 in the Coastal and Marine Baseline State and Environmental Impact Report [Ref. 29]). Three zones (the ZoHI, ZoMI, and the Zones of Influence [ZoI]) were established to reflect the different levels of predicted impact to corals. As shown in Figure 2-2, the ZoI extends around the northern end of Barrow Island and southwards along the west coast. The ZoI is that area predicted to be influenced indirectly by dredging and dredge spoil disposal activities such that marginal increases in sedimentation and turbidity may occur, but at levels that are not predicted to have measurable impact on corals.

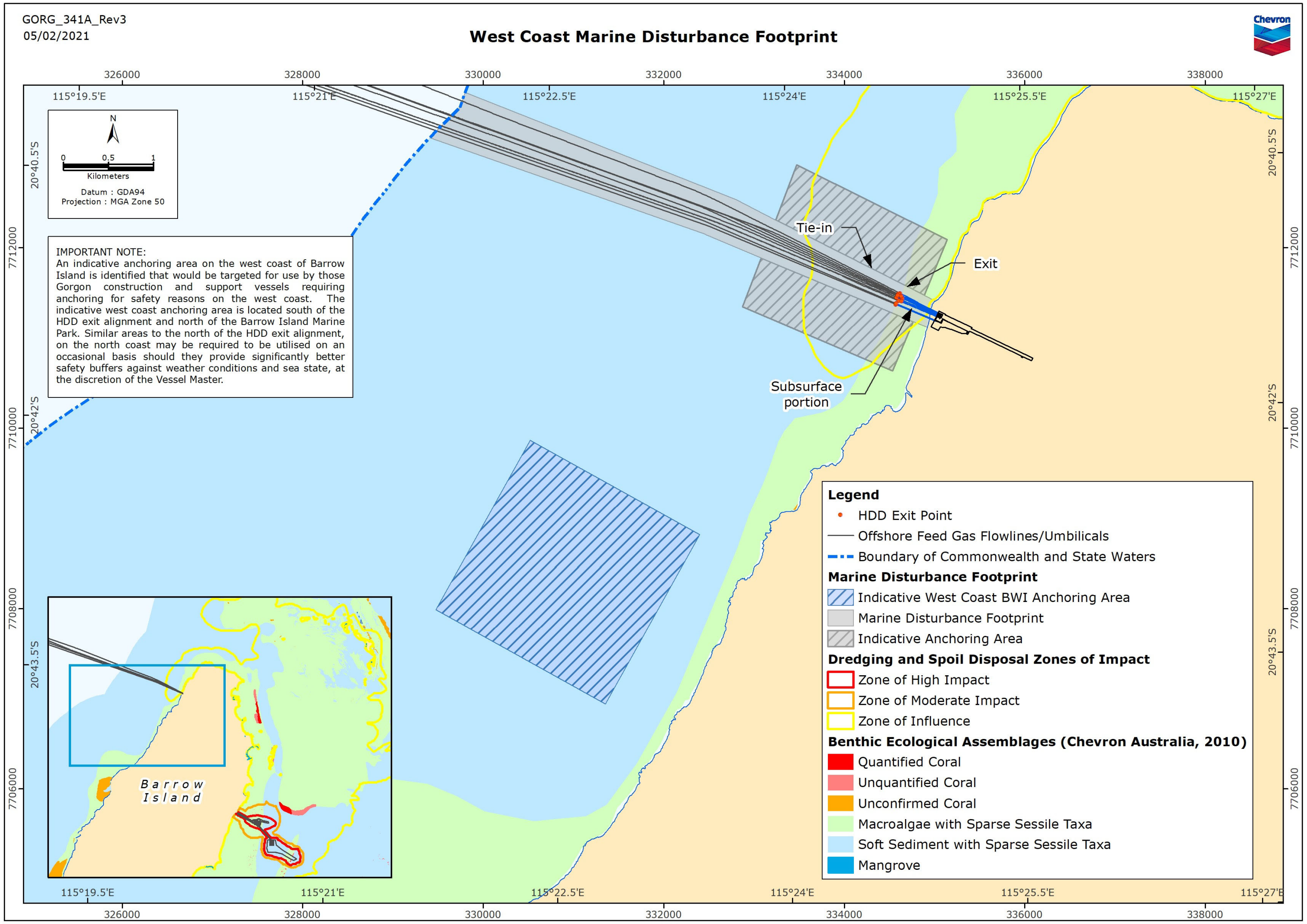


Figure 2-2: MDF for the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

2.3.3 Areas at Risk of Material or Serious Environmental Harm

Material Environmental Harm is defined as:

> *'Environmental harm that is neither trivial nor negligible'.*

Serious Environmental Harm is defined as:

> *'Environmental harm that:*
>
> *a. is irreversible, of a high impact or on a wide scale; or*
>
> *b. is significant or in an area of high conservation value or special significance and is neither trivial nor negligible''.*

Material or Serious Environmental Harm due to the construction or operation of the west coast Marine Facilities may occur within the MDF for the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (described in Section 2.3.2). The level of environmental harm predicted at a particular location within the MDF depends on the types of stressors, the sensitivity of the ecological elements at any location, the likelihood of complete or partial recovery from the disturbance, and the management or mitigation measures taken to reduce impacts.

Serious Environmental Harm, caused by direct placement of the Marine Facilities on the seabed and the physical removal of the substrate, is predicted to affect all benthic ecological elements within the Marine Facilities Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. Recovery to the original state will not be possible, although there will be some colonisation of the new hard substrates created by the Marine Facilities. Examples of seabed disturbances that are predicted to cause Serious Environmental Harm to benthic ecological elements include permanent or irreversible loss or removal of existing substrates and associated ecological elements (e.g. through the direct placement of the Offshore Feed Gas Pipeline System on the seabed and breakout at the HDD exit alignment) and, in shallower waters, potential shading by infrastructure.

Within the surrounding areas in the MDF, beyond the Marine Facilities Footprint, there are likely to be temporary or sublethal impacts that may remove or reduce the existing ecological elements. This is considered to represent Material Environmental Harm. Nevertheless, the substrate is likely to retain its ecological function as benthic habitat and the benthic ecological elements are predicted to recover in the short term (within one to five years) following cessation of the disturbance. Macroalgae and seagrass are well adapted to cycles of disturbance and recovery, thus macroalgal-dominated limestone reefs, subtidal limestone reef platforms with macroalgae, and reef platform/sand with scattered seagrass are predicted to only be temporarily affected (Ref. 12). Hard corals, such as *Turbinaria* spp. and *Acropora* spp., are also predicted to recover or recolonise in the short term. Examples of seabed disturbances that are predicted to cause Material Environmental Harm to benthic ecological elements include: localised or short term (less than five years) impacts such as anchor scouring in a macroalgal bed, seagrass bed, or benthic macroinvertebrate assemblage; disturbance or resuspension of unconsolidated sediments by vessel propeller wash; discharge of drilling cuttings and fluids from HDD activities.

Outside the MDF, the ecological elements are not considered to be at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. Thus, sites located in these areas are considered to be Reference Sites that are suitable for comparison with impacted areas. Where there is an indication that Reference Sites may have been impacted by the construction of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, these sites will be assessed for their suitability as Reference Sites prior to their inclusion in any subsequent analysis undertaken.

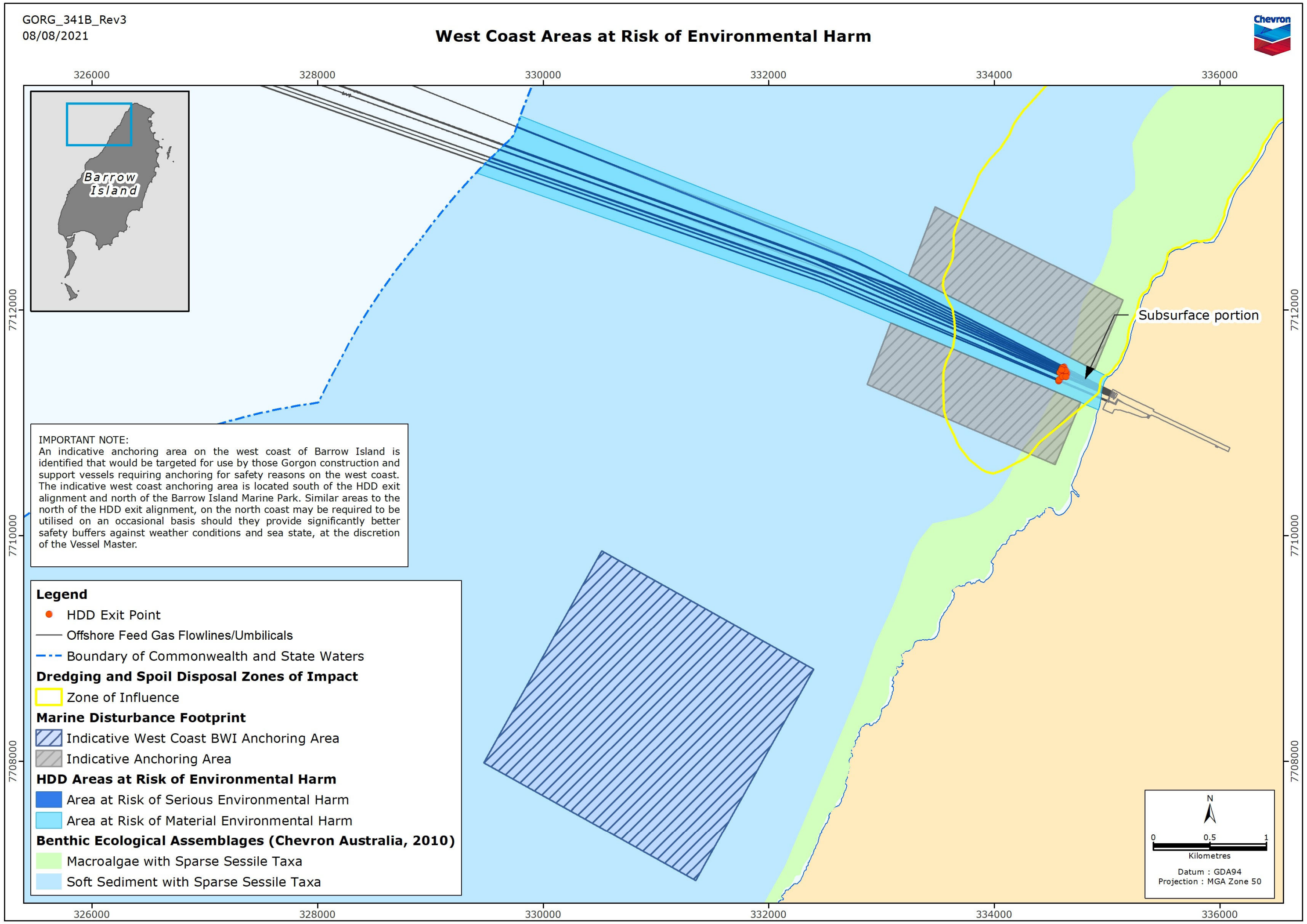


Figure 2-3: Area of Material or Serious Environmental Harm for Benthic Ecological Elements within the West Coast Marine Facilities MDF

3 Marine Environment

3.1 Regional Overview

Barrow Island is approximately 1200 km north of Perth and approximately 130 km west of Dampier and the Burrup Peninsula, within the Pilbara Offshore (PIO) Marine Bioregion (Ref. 30) (Figure 3-1). This Bioregion covers an area of 41 491 km^2 west of the 10 m depth contour between North West Cape and Cape Keraudren (Ref. 31), and is characterised by a series of limestone islands on a wide continental shelf (Ref. 30). Barrow Island is the largest of this group of islands, which include the Montebello and Lowendal Islands to the north-east. The area around the Montebello Islands/Barrow Island contains reef ecosystems with Indonesian and Pacific affinities and is considered unique to this bioregion due to the complexity of substrate types, oceanographic conditions and habitat diversity (Ref. 32; Ref. 31). The area is considered to be relatively undisturbed due to low human use and successful management of industrial activities, including oil and gas developments (Ref. 31).

3.2 Montebello/Barrow Island Marine Conservation Reserves

Barrow Island is a Class A nature reserve for the purposes of 'Conservation of Flora and Fauna' under the Western Australian *Conservation and Land Management Act 1984* (CALM Act) (WA). The *Barrow Island Act 2003* (WA) allows for the implementation of the Gorgon Gas Development and makes provision for areas on Barrow Island to be used for gas processing. CAPL and predecessor companies have operated an oil field on Barrow Island since the 1960s and this operation is expected to continue for another 15 to 20 years.

The State Waters around Barrow Island are part of the Montebello Islands/Barrow Island Marine Conservation Reserves, except for the Barrow Island Port Area on the east coast of Barrow Island, which contains most of the Gorgon Gas Development Marine Facilities (Figure 3-1). The Port of Varanus Island, located north-east of Barrow Island, is also excluded from the Conservation Reserves. These Conservation Reserves are reserved under the CALM Act and their management is guided by the Management Plan for the Montebello/Barrow Islands Marine Conservation Reserves 2007–2017 (Ref. 31). There are two categories of marine reserve in the waters around Barrow Island. The largest of these is the Barrow Island Marine Management Area, which includes one conservation area—the Bandicoot Bay Conservation Area located on the south coast of Barrow Island. The Bandicoot Bay Conservation Area includes the largest intertidal sand/mudflat community in the reserves and was established for the protection of benthic fauna and seabirds (Ref. 31). The remainder of the Barrow Island Marine Management Area is not zoned. The Barrow Island Marine Park is off the west coast of Barrow Island, also within the Barrow Island Marine Management Area. The zoning of the Barrow Island Marine Park comprises one sanctuary zone, representing the entire marine park. The Western Barrow Island Sanctuary Zone includes Biggada Reef, an example of significant fringing reef that occurs in the reserves; and Turtle Bay, a significant aggregation/breeding area for Green Turtles (*Chelonia mydas*) and occasionally Hawksbill (*Eretmochelys imbricata*) and Flatback (*Natator depressus*) Turtles (Ref. 31).

The waters around Barrow Island support a diverse assemblage of tropical and subtropical marine fauna. Two major currents—the Leeuwin Current and the Indonesian Throughflow—have a strong influence on species distribution, recruitment and biological productivity in these waters (Ref. 33). The Leeuwin Current and the Indonesian Throughflow create a biological connection between marine flora and fauna of the Montebello Islands/Barrow Island region and the more tropical environments to the north and east (Ref. 31). Consequently, most marine species in this region are widely distributed.

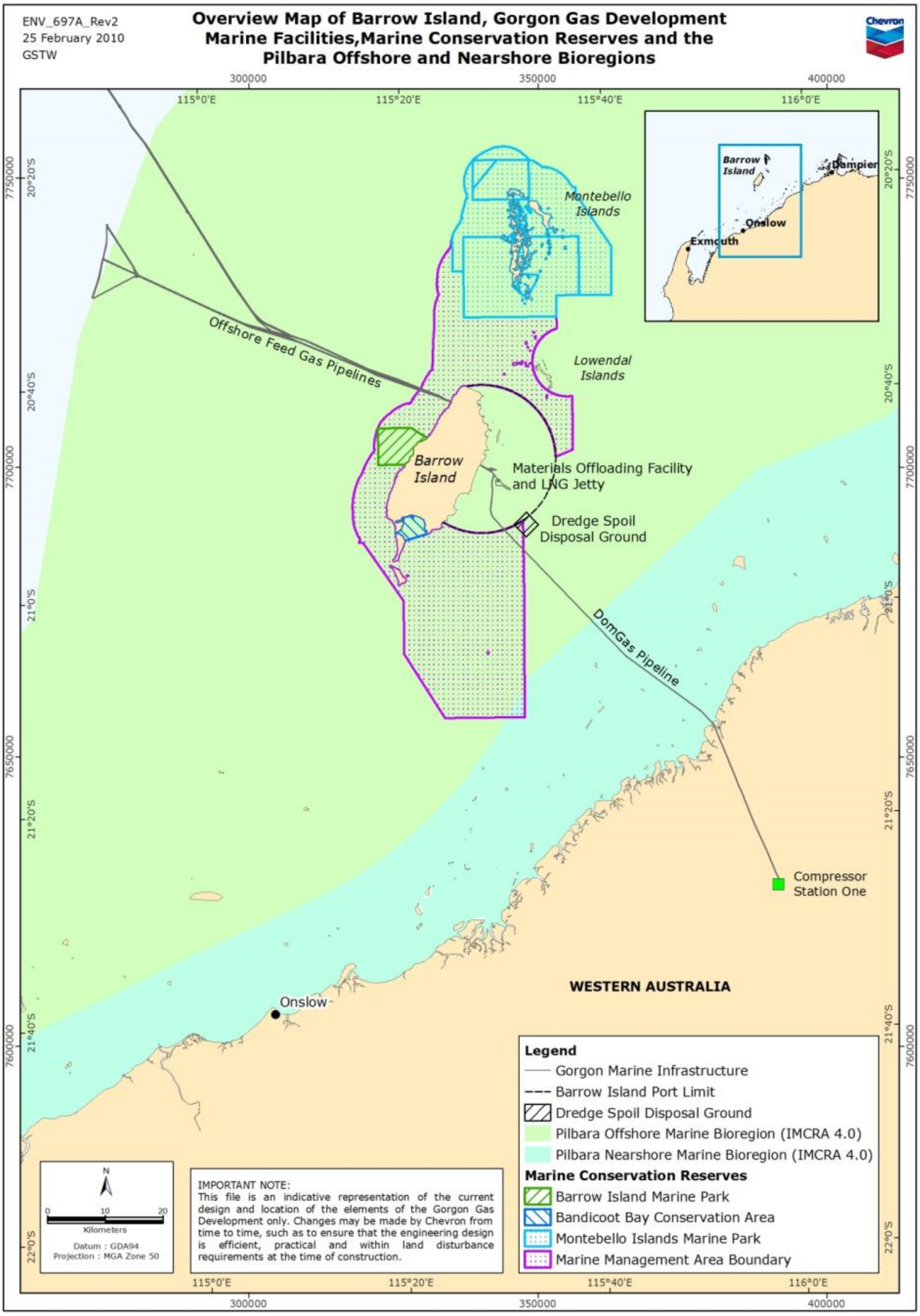


Figure 3-1: Overview Map of Barrow Island, Gorgon Gas Development Marine Facilities, Marine Conservation Reserves, and the Pilbara Offshore and Nearshore Bioregions

3.3 Meteorology

The mean ambient wind speed around Barrow Island during summer (October–March) is 6.6 m/s and the maximum summer wind speed is 16.2 m/s (Ref. 33). The dominant wind directions during summer are from the south-west and west. During winter (April–September), winds approach from the east, south, and south-west, with a mean speed of 5.8 m/s and a maximum speed of 19.4 m/s. The wind prevails from the south-west for more than 50% of the time (Ref. 27). In general, wind speeds are <10 m/s for more than 90% of the time, but rarely fall below 1 m/s (2.2% of the time). Peak winds on Barrow Island range between 32 and 44 m/s and are associated either with very strong breezes or storms (Ref. 27).

Barrow Island is in a region of high tropical cyclone frequency, with an average of four cyclones passing within 400 nautical miles of it each year (Ref. 34). Tropical cyclones usually form in the Timor and Arafura seas between November and April. They initially travel generally in a south-westerly direction, but as they travel further south their tracks become more variable (Ref. 34). Under extreme cyclonic conditions, winds can reach more than 250 km/h (Ref. 27).

3.4 Oceanography

3.4.1 Bathymetry

Barrow Island lays on the shallow (generally <5 m deep) limestone shelf that supports the whole Montebello Islands/Barrow Island group. A broad intertidal platform adjacent to Barrow Island grades slowly to the subtidal limestone shelf (Ref. 11). Water depths between the islands and the mainland generally do not exceed 20 m, whereas water depths on the west coast of Barrow Island increase rapidly from the shore down to the 20 m isobath. Water depths along the Offshore Feed Gas Pipeline System on the west coast of Barrow Island reach approximately 25 m at the limit of State Waters.

3.4.2 Tides

Astronomic tides in the Barrow Island region are semidiurnal, comprising two high tides and two low tides per day. The tidal range varies significantly around Barrow Island with a maximum spring tide range on the east coast of just over 4 m, whereas on the west coast the tidal range is <2.5 m (Ref. 35; Ref. 36; Ref. 33). The significant tidal ranges and shallow bathymetry result in large areas of exposed seabed at low tide (Ref. 37).

The direction of tidal currents is a flood flow towards the south-west and an ebb flow towards the north-east (Ref. 38). As a result of the shallow bathymetry, the flood tide cannot fully propagate to the coast across the Barrow Island Shoals to the south-east, or through the channels between Barrow Island and the Montebello Islands. A large water flux is forced northward along the western side of Barrow Island and then flows to the coast around the northern end of the Montebello Islands. This produces a southward-flowing flood tide on the east coast of the Montebello Islands and Barrow Island. There is a region near the south-eastern end of Barrow Island where this flow meets the flow coming across the Barrow Island Shoals and these flow towards the coast. The ebb tide behaves approximately in reverse to the flood tide, with most of the water flux flowing up the eastern side of the Lowendal Shelf and around the northern end of the Montebello Islands. This tidal flow is the major flushing mechanism for waters from the eastern side of Barrow Island into the open sea.

Wind events also drive episodic non-tidal flow events in the nearshore and in deeper waters off the Montebello Islands/Barrow Island, when tide influences are weaker or during neap tides (Ref. 27).

3.4.3 Currents

The current patterns on the eastern side of Barrow Island are strongly dominated by the tide and its spring–neap cycle. However, longer-term transport over the inner- and mid-shelf is mainly controlled by wind-driven flow, which follows the seasonal switch from summer monsoon winds to south-easterly trade winds in winter. Because of the tidal mechanisms, the currents on the eastern side of Barrow Island can be quite strong.

On the western side of Barrow Island, the driving forces for ocean currents are more complex (Ref. 39). The tidal currents are weaker, particularly in the deeper waters, but satellite imagery indicates that phenomena associated with large-scale ocean circulations in the Indian Ocean, such as eddies and other geostrophic flows, can impinge on the region. The wave-driven longshore currents on the west coast of Barrow Island are mostly northward, with a peak magnitude of around 0.3 to 0.4 m/s (Ref. 27). Episodic reversals of the longshore current direction occur during winter, as waves driven by north-west storm winds generate southward currents (Ref. 27). Wave-driven longshore currents are likely to be an important contributor to sediment dispersion along the west coast of Barrow Island (Ref. 27).

3.4.4 Waves

Local wind-generated seas have variable wave heights, typically ranging from 0 to 4 m outside tropical cyclone conditions (Ref. 27). Typically wave heights at Barrow Island are within the 0.2–0.5 m range, with peak periods of 2–4 s (Ref. 40). Maximum wave heights are mostly a result of tropical cyclones, which can generate waves in a radial direction out from the storm centre and therefore may generate swell from any direction, with wave heights ranging from 0.5 to 9.0 m (Ref. 27).

The eastern side of Barrow Island is largely sheltered from ocean swells by Barrow Island, the Lowendal Shelf, and the shallow bathymetry between Barrow Island and the mainland (Ref. 38; Ref. 33). The ambient nearshore wave climate is dominated by locally generated sea states derived from easterly sea breezes between the mainland and Barrow Island, which mostly occur during winter. These breezes direct waves against the east coast of Barrow Island and are most effective in directing wave energy onto the nearshore zone.

The south-western to north-western sides of Barrow Island are exposed to the open ocean and a relatively vigorous wave climate, bringing long-period Southern Ocean swells and shorter-period local wind waves, particularly during times of sustained southerly winds. The Southern Ocean swell (also known as the Indian Ocean swell) typically arrives at the outer edge of the continental shelf from the south and south-west, before refracting over shallower parts of the shelf and approaching Barrow Island from the west, north-west, or north (Ref. 27). At times, the Southern Ocean swell can refract around the northern and southern ends of Barrow Island, but the shallow bathymetry prevents significant propagation (Ref. 38). The surf zone near the shore crossing on the west coast of Barrow Island is generally 100 to 150 m wide, sometimes extending more than 200 m offshore (Ref. 27).

3.5 Seabed Topography and Sediment Characteristics

On the east coast of Barrow Island, the intertidal limestone reef flats and shallow pavement reef are covered by sand, gravel, and coral, with scattered pinnacles. Bare sands overlay limestone pavements in many parts of the area, with exposed pavement and more rubble in areas where water currents are stronger (Ref. 11). The thickness of the unconsolidated sediments overlaying the limestone pavements ranges between 0.5 m and 3 m (Ref. 11). The thicker sediment layers are in deeper water off the nearshore platform (Ref. 11).

Off the west coast of Barrow Island, the seabed topography in water depths <30 m is relatively level with some areas of relief between 25 and 20 m water depth (Ref. 41). Closer to shore, the seabed becomes undulating and slopes gently up from 20 m water depth (800 m offshore) to 5 m water depth (240 m offshore), with average seabed gradient ranging from approximately 0.1 ° in 20 m to 17 m water depth to 0.9 ° in shallower waters. In water depths less than 5 m, the seabed rises sharply, with a maximum gradient of 3 ° at a water depth of <2 m.

Geological formations offshore from North Whites Beach have been affected by the influence of fluctuating sea levels, resulting in sequences of erosion of the upper layers, weathering, and submersion of the formations that are currently offshore (Ref. 42). Fresh water seeping through solution holes, weathered zones, and cracks in the rock mass have further eroded and corroded these formations. The main seabed features are outcropping cemented sediments and prominent sand ripples/ribbon features, orientated north-east to south-west, and small-scale sand waves orientated west-south-west to east-north-east in an area south-east of the HDD marine activities (Ref. 41). Closer to shore, the main seabed feature is a limestone reef, which extends into the intertidal zone. The presence of sand ripples and the patchiness of the exposed sediment are indicative of a high-energy environment.

The seabed off the west coast of Barrow Island consists of a patchy thin (<1 m) veneer of unconsolidated carbonate sand/fine gravel overlaying cemented calcarenite/caprock in waters between 20 m and 40 m (Ref. 43). Further offshore (to depths of 55 m) are local depressions within which thicker (up to 5 m thick) layers of carbonate sand/gravelly sand accumulate.

4 General Approach to Methods

4.1 Introduction

Coastal and marine baseline surveys for the Gorgon Gas Development have been conducted in Barrow Island waters since 2003. The Marine Baseline Program required under Condition 12 of MS 769, Condition 14 of MS 800, and Condition 11 of EPBC Reference: 2003/1294 and 2008/4178, was initiated in November 2007 and may continue until the construction activities for each of the Marine Facilities commence. The surveys conducted as part of the Gorgon Gas Development Marine Baseline Program have contributed to improving the knowledge of the Barrow Island marine environment.

The Marine Baseline Program has been designed to provide baseline data for the:

- Marine Facilities Construction Environmental Management Plan required under Condition 17 of MS 800 and Condition 13 of EPBC Reference: 2003/1294 and 2008/4178 (Ref. 44)
- Protection of Coral and Coral Assemblages required under Condition 18 of MS 800 (Ref. 45)
- Dredging and Spoil Disposal Management and Monitoring Plan required under Condition 20 of MS 800 and Condition 14 of EPBC Reference: 2003/1294 and 2008/4178 (Ref. 46)
- Initial Water Quality Criteria for Dredging and Spoil Disposal Activities required under Condition 21 of MS 800 (Ref. 47)
- Horizontal Directional Drilling Management and Monitoring Plan required under Condition 22 of MS 800, Condition 13 of MS 769 and Condition 15 of EPBC Reference: 2003/1294 and 2008/4178 (Ref. 20)
- Offshore Feed Gas Pipeline Installation Management Plan required under Condition 23 of MS 800, Condition 14 of MS 769 and Condition 16 of EPBC Reference: 2003/1294 and 2008/4178 (Ref. 17)
- Marine Environmental Quality Management Plan (required by Condition 23A of MS 800) (Ref. 21)
- Post-development Coastal and Marine State and Environmental Impact Reports (required by Condition 24 of MS 800, Condition 15 of MS 769 and Condition 17 of EPBC Reference: 2003/1294 and 2008/4178) (Ref. 22).

4.2 Sampling Sites

The Marine Baseline Program was designed to include sites on the west coast of Barrow Island that are potentially at risk of Material or Serious Environmental Harm (Section 2.3.3) as a result of the construction and operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, as well as Reference Sites that are not at risk of Material or Serious Environmental Harm as a result of the construction and operation of these Marine Facilities (Section 2.3.3). A suite of these sites may be monitored during the Post-development Coastal and Marine State Surveys following completion of the offshore pipe-laying (Condition 15, MS 769).

Sampling Sites BR, NEBWI1, and NEBWI2 are shared between the Marine Baseline Program reported in the Coastal and Marine Baseline State and

Environmental Impact Report (MOF, LNG Jetty, DSDG) (Ref. 29) and the Coastal and Marine Baseline State and Environmental Impact Report (Offshore Feed Gas Pipeline System and the Marine Component of the Shore Crossing) – this Report. Survey results to July 2009 are reported in the Marine Baseline Program for the MOF, LNG Jetty, and DSDG. This could result in discrepancies for macroalgae and seagrass species lists and abundance for Sites NEBWI1 and BR, and for non-coral benthic macroinvertebrates for Site NEBWI2 between the two reports. This Report includes the most complete set of data with survey results to October 2010 for non-coral benthic macroinvertebrates, macroalgae, and seagrass.

4.3 Sampling Frequency and Temporal Scope

Table 4-1 summarises the sampling frequency and temporal scope for each ecological element surveyed during the Marine Baseline Program for the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. Where practicable, sampling frequency was designed to account for predicted seasonal differences. For example, the seagrass and macroalgae surveys were conducted over late winter/early spring and summer to capture seasonal differences, while water quality was measured over a full annual cycle to capture tidal, daily, and/or seasonal variations. Other ecological elements without predicted seasonal influences, such as surficial sediments, were sampled on different occasions during the baseline period.

The broadscale camera tow surveys and dive surveys that commenced in 2003 for the Gorgon Gas Development EIS/ERMP (Ref. 11; Ref. 12) were extended between May and August 2009 to provide more detailed information in relation to the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Section 5.3).

Table 4-1: Summary of the Marine Baseline Program for the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

<table>
<tr><th>Ecological Element</th><th>Survey Type/Method</th><th>Sampling Program</th><th>Temporal Scope</th></tr>
<tr><td>Hard and soft corals (Section 6)</td><td>Diver transects and photoquadrats with Coral Point Count with Excel extensions (CPCe) analysis</td><td rowspan="4">4 HDD Survey Sites
3 or 4 Reference Sites</td><td rowspan="4">November 2008
July 2009
September 2009
March 2010
August/October 2010 (not hard and soft corals)</td></tr>
<tr><td>Non-coral benthic macroinvertebrates (Section 7)</td><td>Video transect
Video footage analysis</td></tr>
<tr><td>Macroalgae (Section 8)</td><td rowspan="2">Diver transects and photoquadrats with CPCe analysis</td></tr>
<tr><td>Seagrass (Section 9)</td></tr>
<tr><td>Demersal fish (Section 11)</td><td>Baited Remote Underwater Stereo-Video (stereo-BRUV) systems</td><td>6 Offshore Feed Gas Survey Sites
7 Offshore Feed Gas Survey Sites + 4 HDD Survey Sites</td><td>March 2009
March 2010</td></tr>
</table>

Ecological Element	Survey Type/Method	Sampling Program	Temporal Scope
Surficial sediments (Section 12)	Grab samples	29 sites	October 2009
Water quality (Section 13)	Light-Turbidity-Deposition (LTD) loggers	Biggada Reef (BR) HDD	Dec 2007–Oct 2009 May 2009–May 2010
	Water quality profiles	14 sites 24 sites 56 sites	May 2009 Oct 2009 June 2010

4.4 Basis of Program Design

The Marine Baseline Program was designed to provide a dataset against which to compare the data from post-development monitoring. The general basis of the design has been to provide the potential for pre- and post-development data to be analysed using the Multiple Before-After, Control-Impact (MBACI) approach of Keough and Mapstone (Ref. 48). This approach involves statistical analyses that test for an interaction between predicted impact and (multiple) reference areas across periods of time before and after predicted impacts occur. More generally, the main hypothesis being tested for each measure of an ecological element is that there is a change at impact site(s) between before-and-after the Marine Facilities construction activities that is greater than the changes occurring over the same time period at Reference Sites. It is expected that the main focus of monitoring will be for 'press' type impacts, where the Marine Facilities construction activities cause sustained changes in an ecological element (Figure 4-1). However, in some cases, transient changes such as 'pulse' type impacts may also be tested for (Ref. 49).

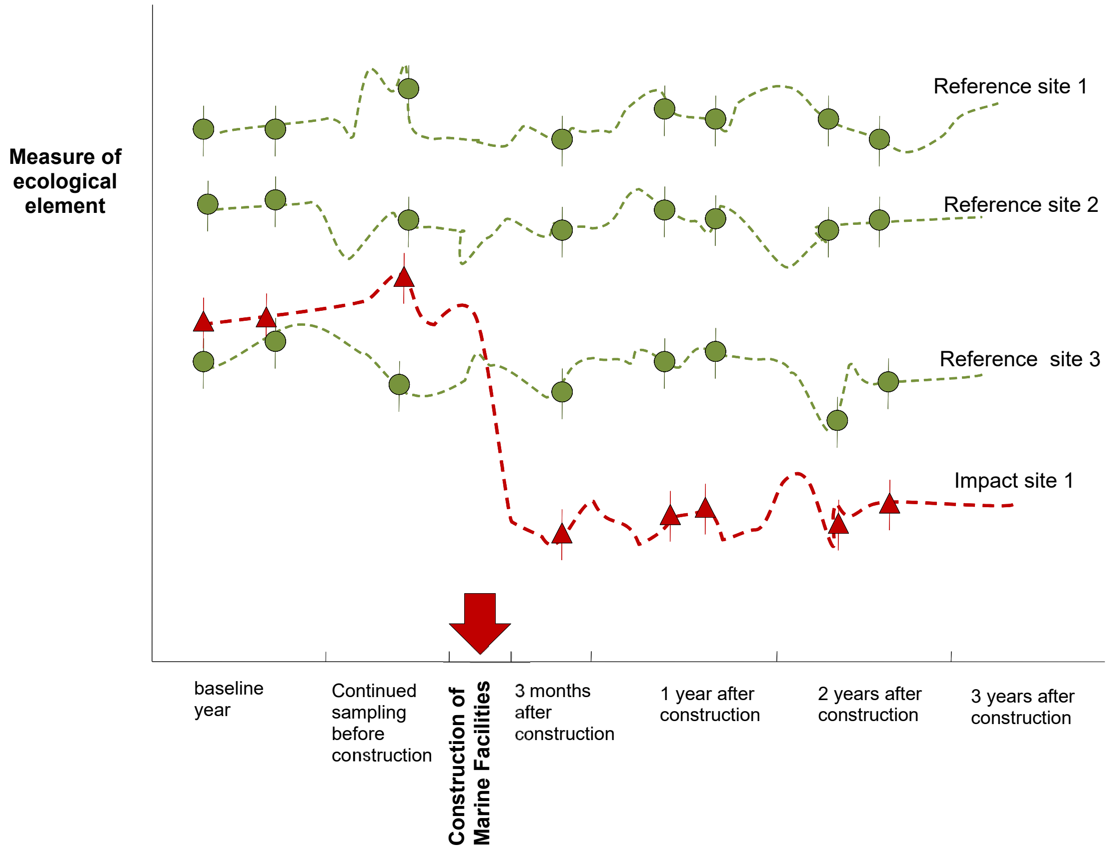


Figure 4-1: Overview of MBACI Sampling Designs – 'Press' Impact shows how Changes will be Detected Before–After Construction of Marine Facilities

It is proposed that the design approach shown in Figure 4-1 will be used to detect whether changes (before–after Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing construction activities) at one or more impact sites are greater than changes (before–after Marine Facilities construction activities) across multiple Reference Sites. For illustrative purposes, three reference sites and one impact site are shown in Figure 4-1, although for all ecological elements more sites may be monitored where practicable, with the final number of sites monitored determined by the practicalities of undertaking field sampling (Ref. 19). Where practicable, more Reference Sites were sampled than impact sites, which is best practice in impact assessment monitoring programs (Ref. 50; Ref. 51).

Impact monitoring sites were located at varying distances away from the Marine Facilities construction activities. Therefore, statistical tests may be undertaken for impacts at different spatial scales away from the main areas of disturbance; these tests assess the changes at impact sites in areas at risk of Material or Serious Environmental Harm against natural changes at Reference Sites not at risk of Material or Serious Environmental Harm. Reference Site locations should always be independent of the Marine Facilities construction activities.

Multiple impact and Reference Sites were sampled during the Marine Baseline Program for each ecological element and before the commencement of Marine Facilities construction activities. These sites were sampled again after the completion of the Foundation Project Marine Facilities construction activities.

Wherever practicable, sampling was repeated multiple times within the Marine Baseline Program (Ref. 19); each sampling time (at least several weeks apart) will be treated as a replicate measure at a site within the 'before' period. The test for a 'press' impact in the main Before–After/Control–Impact interaction in a MBACI design is equivalent to a two-sample *t*-test comparing the changes between before-and-after periods for the impact sites with the changes between before-and-after periods for the Reference Sites. Thus for each site, the average of sampling occasions before Marine Facilities construction activities is calculated, as is the average of sampling occasions in the after period. The difference between these two averages is calculated for each site and the *t*-test undertaken on these differences (impact vs. reference). The replicate times nested within the before (and after) periods are not independent of other similar measurements within that level (i.e. they are all 'pseudo-replicates' within a period). However, the average of these nested measurements at a site over a period is treated as an independent estimate in the analysis.

Sampling before the commencement of construction of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing was undertaken over a single (baseline) year, although sampling was, where practicable, repeated over different periods within the year (Ref. 19). Therefore, the designs and Analysis of Variance (ANOVA)-based statistical analyses that may be used to detect impacts from Marine Facilities construction activities are likely to be asymmetrical, with different numbers of sampling years (and times) within before–after periods and different numbers of sites within reference–impact areas. Time will be treated as a fixed factor because the sampling years are fixed (i.e. non-random) within the before-and-after impact periods. Because the precision of Marine Facilities construction activities estimates at each site depends on the number of replicate times each site was sampled within the before–after periods, the power of the monitoring program to detect impacts also depends on how many times each site was sampled in each period.

Power analyses and determination of likely effect sizes are not presented in this Marine Baseline Report because these depend on the:

- sampling achieved before the commencement of Marine Facilities construction activities
- number of sites sampled post-development
- length of time (and the number of replicate sampling events conducted) post-development.

4.5 Scientific Expertise

The Marine Baseline Program was undertaken by RPS Australia/SE Asia, supported by Oceanic Offshore Commercial Diving Services and Gun Marine Services Pty Ltd. These surveys also drew extensively on the expertise of several technical specialists, as listed in Table 4-2.

Table 4-2: Technical Specialists Involved in the Marine Baseline Program for the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Ecological Element	Technical Specialists	Affiliation	Contribution to the Marine Baseline Program
Non-coral benthic macroinvertebrates	Dr Barry Wilson	Independent marine consultant	Specialist taxonomic identification of molluscs and intertidal benthic invertebrates
Macroalgae and Seagrass	Dr John Huisman	School of Biological Sciences and Biotechnology, Murdoch University	Specialist taxonomic identification of macroalgae and seagrass
Demersal Fish	Professor Jessica Meeuwig Dr Dianne Watson Dr Kris Waddington Associate Professor Euan Harvey	Centre for Marine Futures, University of Western Australia	Input into demersal fish survey design and implementation Analysis of stereo-BRUVs footage Statistical analysis, interpretation of results, and reporting
Surficial Water Sediments and Water Quality	Professor Peter Ridd Dr James Whinney	School of Mathematics, Physics and Information Technology, James Cook University, Queensland	Analysis and interpretation of raw data downloaded from the LTD loggers Calibration of LTD loggers and maintenance in event of equipment failure

5 Benthic Habitat Classification and Mapping

5.1 Mapping of Benthic Assemblages in the Marine Baseline Program

5.1.1 Background

The assessment of potential impacts on marine benthic habitats in the EIS/ERMP (Ref. 11; Ref. 12) required surveying and mapping the area potentially affected by marine infrastructure, dredging, and dredge spoil disposal. The survey area covered the extent of the predicted Dredge Management Areas and the Management Units set up to assess the impacts, which covered thousands of hectares. This necessitated broadscale qualitative assessment and mapping of marine benthic habitats. The objective of the mapping was to refine and confirm the distribution of major reef systems and other benthic habitats in the area likely to be affected by the proposed Marine Facilities. These maps were used to guide marine infrastructure design, environmental impact assessment, and to calculate benthic primary producer habitat (BPPH) losses in accordance with EPA Guidance Statement No. 29 (Ref. 24 [now superseded by Environmental Assessment Guideline No. 3, Ref. 25]).

The broadscale, qualitative maps of major benthic features and benthic habitats included in the EIS/ERMP (Ref. 11; Ref. 12) were based on a Geographic Information System (GIS) version of an existing broadscale benthic habitat map of the Montebello Islands/Barrow Island area (Ref. 52; Ref. 31). Areas of potentially significant coral and other habitats near the east and west coast Marine Facilities and along the Offshore Feed Gas Pipeline in State Waters and Domestic Gas Pipeline routes, which required ground-truthing to confirm their classification, were identified from the broadscale map (Ref. 52) and geo-rectified aerial photographs.

Ground-truthing involved hundreds of kilometres of towed video camera transects and in-water surveys to confirm that significant benthic communities within the areas covered by the Management Units for the BPPH assessment were identified. The benthic habitat classifications were consistent with the scheme used in the existing broadscale map (Ref. 52), which was updated for the areas where new qualitative ground-truth data were collected. Only areas where coral cover was estimated to be representative of a coral community (nominally >10%, although this could not be directly measured at this scale) and the supporting and surrounding benthic substrate where corals were likely to be able to grow were mapped as ‘Coral Habitats’. Areas that were classified as ‘Unconfirmed Coral’ in the existing broadscale map (Ref. 52) and that had not been surveyed further for the EIS/ERMP (Ref. 11; Ref. 12) remained as ‘Unconfirmed Coral’ in the EIS/ERMP. Consistent with the existing mapping of the large limestone shelf areas around Barrow Island and the Montebello and Lowendal Islands, isolated bombora were not classified as ‘Coral Habitat’.

The benthic habitat maps in the Gorgon Gas Development Revised and Expanded Proposal PER (Ref. 14) were used primarily to guide the design of the marine infrastructure for the Revised and Expanded Proposal environmental impact assessment and for the associated revised BPPH loss calculations. The maps in the Revised and Expanded Proposal PER (Ref. 14) were developed by updating the existing EIS/ERMP maps (Ref. 11; Ref. 12, incorporating improved or more recent imagery and by using additional ground-truthed data collected since mid-2005. More recent aerial photography and Laser Airborne Depth Sounder (LADS) imagery for some areas were used to identify additional benthic features requiring ground-truthing. The imagery was also used to map the areas where it was proposed to establish Reference Sites (e.g. for the dredging and dredge spoil disposal monitoring program) and to improve the definition of boundaries in the existing benthic habitat map. These features were ground-truthed using towed video camera transects and in-water surveys between 2007 and mid-2008. Benthic habitats were classified and BPPH impacts were assessed using the same methods in the EIS/ERMP (Ref. 11) to enable comparison of the extent impacts predicted for the Approved and the Revised and Expanded Proposals.

MS 748 included the requirement to define and map the ecological elements (including ‘hard and soft corals’) within areas likely to be affected by the Gorgon Gas Development and at reference areas outside the areas predicted to be impacted. Thus, the survey area was extended to improve the definition of benthic habitats at potential Reference Sites and the accuracy of maps was improved in these areas. The requirement to ‘define and map’ ecological elements was addressed through further refinement of the EIS/ERMP (Ref. 11; Ref. 12) and Revised and Expanded Proposal PER (Ref. 14) maps, with a shift in emphasis from coral habitats to ‘hard and soft corals’ as the ecological element. This required refinement of the distribution of corals rather than the substrates they are likely to grow on (as required for the BPPH assessment). These maps show the distribution of coral assemblages in the appropriate areas without providing quantitative estimates of the percentage cover of corals within the assemblages.

Therefore, the focus of the mapping for the Marine Baseline Program was an improved qualitative description (‘map’) of benthic ecological assemblages and a refinement in the survey methods to enable coral assemblages to be quantified. The quantitative maps in the Marine Baseline Report are based on the qualitative maps provided in the Revised and Expanded Proposal PER (Ref. 14), with the polygon boundaries refined on the basis of additional imagery, LADS data for Reference Sites, and Multi-Beam Sonar data for the Marine Facilities, and then redefined according to the level of quantification undertaken for each polygon. Benthic features identified from the imagery were ground-truthed using a combination of transects and photoquadrats analysed using Coral Point Count with Excel extensions (CPCe) (Ref. 53) for percentage cover and diver visual estimates. The boundaries of polygons were then redrawn to correspond with information from ground-truthing observations and remote sensing.

The definition of ‘Coral Assemblages’ was quantified (diver visual estimate of percentage cover or measured photo-quadrat estimate) as ‘a cover of live coral of greater than 10%’. This is consistent with other large-scale coral mapping studies (Ref. 54; Ref. 55; Ref. 56). Under this definition of ‘Coral Assemblage’ (>10% measured live coral cover), many of the polygons resulting from data collected during earlier surveys for the EIS/ERMP (Ref. 11; Ref. 12) and the Revised and Expanded Proposal PER (Ref. 14), could not be confirmed to comply with this criterion and thus could not be classified as ‘Coral Assemblages’. Consequently, polygons for which there were no quantitative data to support their classification as ‘Coral Assemblages’ were relabelled as ‘Unconfirmed Coral’. Although many were known to be dominated by coral from earlier qualitative ground-truthing surveys, insufficient quantitative data were available to classify them as ‘Coral Assemblage’ (>10% measured coral cover). Therefore, some polygons presented as ‘Confirmed Coral’ in the EIS/ERMP (Ref. 11; Ref. 12) and the Revised and Expanded Proposal PER (Ref. 14) are now identified as ‘Unconfirmed Coral’ in maps in the Marine Baseline Report.

In the maps in the Marine Baseline Report these terms are used:

- 'Quantified Coral': Classifies all polygons that were either confirmed as Coral Assemblages in a quantitative manner (i.e. point census of photoquadrats taken along transects at monitoring sites) or confirmed as Coral Assemblages in a qualitative manner (i.e. visual estimation during ground-truthing surveys), as having cover >10%.
- 'Unquantified Coral': Classifies those polygons that are, or may be, potential Coral Assemblages, which were identified or refined as benthic features using survey data (e.g. remote imagery, in situ surveys). However, these areas have not been ground-truthed and classified in accordance with the Barrow Island habitat classification scheme described in Section 5.2 and Appendix B, thus there are insufficient data for them to be classified as 'Quantified Coral'. These may be classified as 'Quantified Coral' in the future if ground-truthing confirms that live coral cover is >10% and the boundaries are refined such that only Coral Assemblages are present within the mapped polygon.
- 'Unconfirmed Coral': Unchanged from the CALM map (Ref. 52). These may be classified as 'Quantified Coral' in the future if ground-truthing confirms that live coral cover is >10% and the boundaries are refined such that only Coral Assemblages are present within the mapped polygon.

5.1.2 Methods

To map the ecological elements as required under Condition 14.6 of MS 800, Condition 12.6 of MS 769 and Condition 11.6 of EPBC Reference: 2003/1294 and 2008/4178, seabed features were identified using existing broadscale habitat maps from around Barrow Island (Ref. 52; Ref. 31) and a variety of remote sensing data, including high resolution aerial imagery, LADS data, Multi-Beam Sonar and Side-Scan Sonar data from across the study area and entered into a GIS (Figure 5-1). Not all data sources were available for all the areas mapped.

The seabed features identified from the remote imagery were then ground-truthed using towed video camera and in-water surveys (Figure 5-1). Bathymetric irregularities were more intensively ground-truthed than areas of bathymetric similarity (i.e. flat, featureless areas) as previous surveys around Barrow Island have found areas of bathymetric similarity to be more homogenous than areas of bathymetric dissimilarity. Underwater video footage was captured using a MAKO-towed video unit fitted with a 3CCD image sensor in a custom-built housing with a protective frame and with top and tail planes fitted for stability. Images were transmitted through an umbilical to a control box on the vessel. Positional information from a Garmin Global Positioning System (GPS) unit was overlaid on the video footage before it was recorded to DVD. The extensive ground-truthing observations across the study area were plotted over the broadscale benthic habitat map (Ref. 52) and remote sensing data in the GIS. Areas beyond the survey sites that were not adequately ground-truthed to enable classification are presented as the underlying habitat category from the existing broadscale benthic habitat map of the Montebello Islands/Barrow Island area (Ref. 52; Ref. 31).

The benthic habitats were classified in accordance with the Barrow Island habitat classification scheme described in Section 5.2 and Appendix B. Benthic habitats were classified from the video imagery in real-time using a custom interface in the Environmental Systems Research Institute (ESRI) ArcPad software, also connected to a Garmin GPS unit. Observations were recorded using drop-down menus containing the hierarchical table of biophysical characteristics that make up the habitat classification scheme. In areas of high seabed complexity, observations were recorded approximately every 30 seconds, or when a feature of interest or a change in habitat type was observed. At a towing speed of ≈2 knots, observations made every 30 seconds were separated by ≈30 m.

The boundaries of polygons were then redrawn to correspond with information from the remote sensing and the ground-truthing observations. The ground-truthing observations were plotted over a map of the polygons representing the identified seabed features, and the georeferenced observations were used to assign an ecological element classification (assemblage category) to each polygon. A decision tree was used to define and classify the polygons drawn around seabed features (Figure 5-2). Benthic features with >10% estimated live coral cover were mapped as ‘Coral Assemblage’ irrespective of the other assemblages present. For example, if a seabed feature had 20% live coral cover and 80% macroalgal cover, it was mapped as a ‘Coral Assemblage’. Where coral cover was <10%, but other ecological elements were present at >10% cover, then the ecological element that covered the greatest percentage of the substrate was recorded as the dominant ecological element. For example, if a seabed feature had 5% live coral cover and 95% macroalgal cover, it was mapped as a ‘Macroalgal Assemblage’. Where no ecological element covered >10% of the area being described, the polygon was classified as ‘Unvegetated’.

High profile reefs, extensive rocky shelves, the surrounding expanses of unconsolidated soft sediments, and mangroves have boundaries that can be distinguished from bathymetric data or aerial imagery and thus can be mapped as discrete polygons. Non-coral benthic macroinvertebrates and seagrass that were present in spatially and temporally varying (generally sparse) densities, with no distinct boundaries that can be reliably delineated using remote imagery, cannot readily be mapped as discrete polygons on maps of ecological elements. Because of the difficulties in drawing accurate polygon boundaries, a simplified mapping scheme was used; this scheme has six mapping classes:

- Quantified Coral
- Unquantified Coral
- Unconfirmed Coral
- Macroalgae with Sparse Sessile Taxa
- Soft Sediment with Sparse Sessile Taxa
- Mangroves.

Features mapped using the ‘Macroalgae with Sparse Sessile Taxa’ class contained assemblages dominated by macroalgae. Seagrass and non-coral benthic macroinvertebrates often co-existed in areas where macroalgae were the most common ecological element. This mapping class is used to indicate that the mapped area is dominated by macroalgae, but does contain some other sessile taxa at subdominant levels of cover. This is consistent with the existing broadscale habitat maps from around Barrow Island (Ref. 52; Ref. 31), which do not include a seagrass or benthic macroinvertebrate category.

Features mapped using the ‘Soft Sediment with Sparse Sessile Taxa’ class mostly comprised unvegetated sand, with no associated sessile biota. Patches of seagrass and non-coral benthic macroinvertebrates were present within this broader landscape of bare sand, but the boundaries of these patches could not be mapped accurately. This mapping class is used to indicate that the mapped area is dominated by unvegetated sand, but does contain some other sessile taxa at subdominant levels of cover.

As required under Condition 14.6 of MS 800, Condition 12.6 of MS 769, and Condition 11.6 of EPBC Reference: 2003/1294 and 2008/4178, maps of each of the ecological elements are presented in this Marine Baseline Report. Generally, the boundaries of coral, macroalgal, and soft sediment habitats could be clearly identified and were mapped as discrete polygons. Because of the difficulties in drawing polygon boundaries, point observations of non-coral benthic macroinvertebrates and seagrass are presented on maps as presence/absence data. It is also difficult to delineate distinct boundaries between different surficial sediment types without losing much of the potentially important information on small-scale spatial variability and gradients between sediment types on larger scales. Therefore, surficial sediments are presented graphically in terms of the sediment type recorded at each sampling location.

Although they may often exhibit distinct habitat associations, demersal fish assemblages are difficult to map because they are not always spatially restricted to the sampling sites and individual species within the assemblage may exhibit varying levels of site attachment. The relative abundance and diversity of demersal fish characteristic of macroalgae, soft sediments with sessile benthic macroinvertebrates, and sand communities in Barrow Island waters are presented in interactive Excel charts (Appendix D).

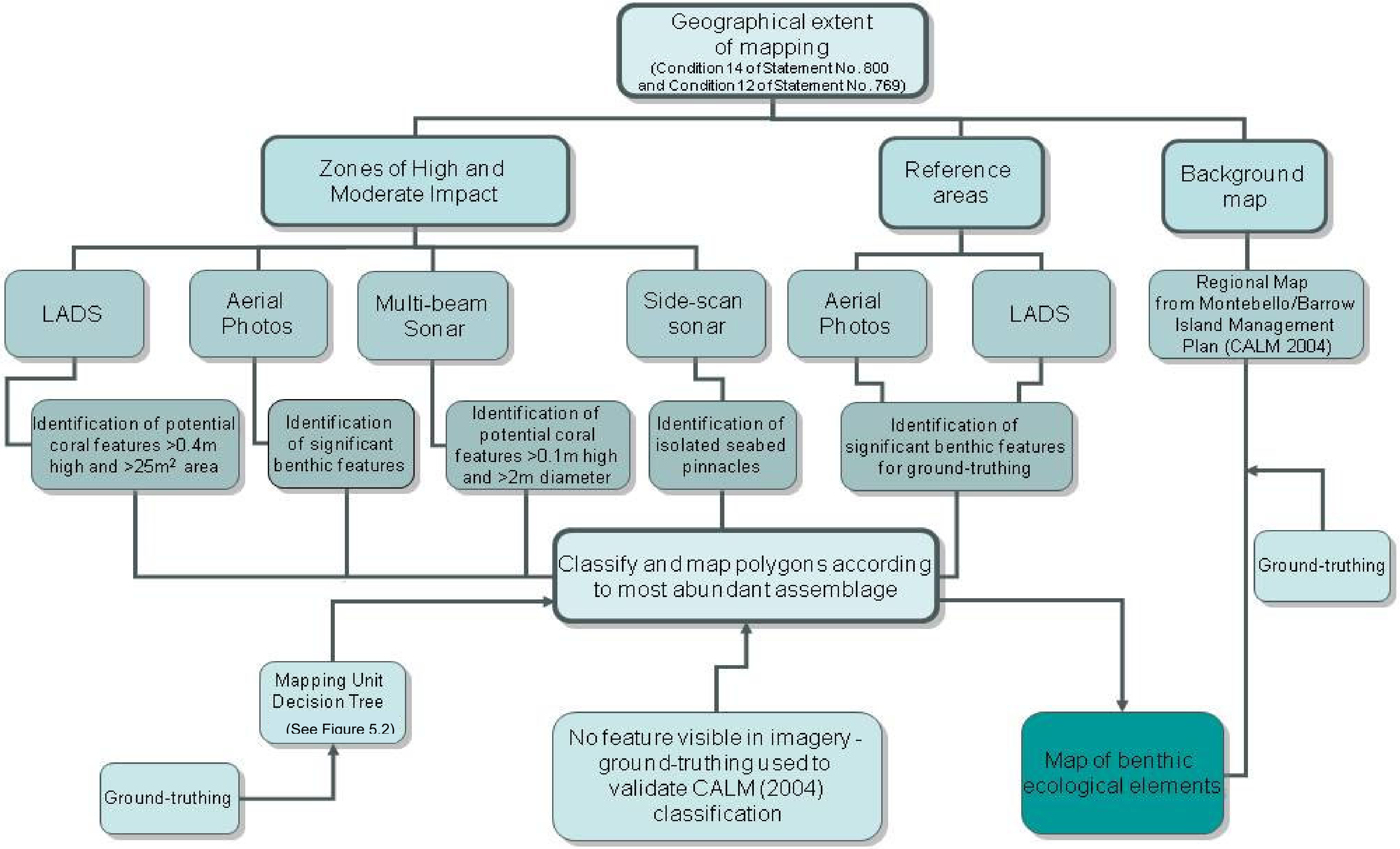


Figure 5-1: Process for Identifying and Mapping Seabed Features

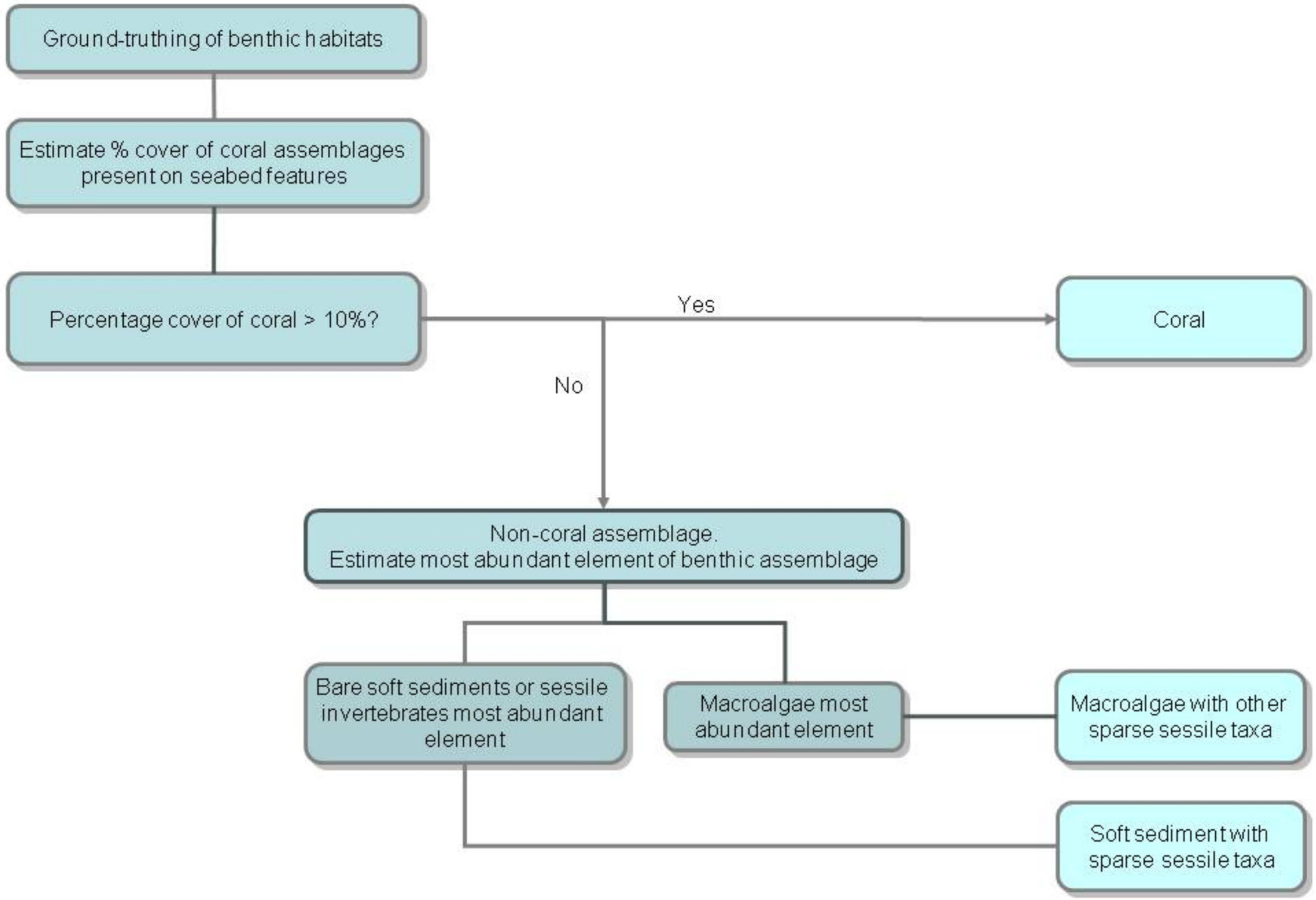


Figure 5-2: Habitat Classification Unit Decision Tree

5.2 Benthic Habitat Classification Scheme

Ground-truthed data were classified according to a hierarchical system of biophysical characteristics designed to facilitate consistent definition of benthic habitats in Barrow Island waters (Appendix B).

The classification system uses attributes in five categories to describe the habitats:

- most common relief of the underlying substrate (e.g. flat, gently sloping, steeply sloping, vertical wall)
- most common substrate type (e.g. silt, rubble, boulders, limestone pavement, low profile reef, high profile reef)
- most common or dominant ecological element found on the substrate (e.g. seagrass, coral, macroalgae)
- biological density or percentage cover of the most common taxa (e.g. sparse, medium, dense)
- most common or dominant taxa (family, genera, or species where possible) within that assemblage (e.g. *Halophila* spp.), or physical descriptor where no biota were present.

Table 5-1 details the classification scheme categories and attributes.

Table 5-1: Benthic Habitat Classification Categories and Attributes

Category	Attribute	Definition
Relief	Flat or microripples	Slope 0–5° with ripples 0–0.5 m high
	Gently sloping	5–35°
	Steeply sloping	35–70°
	Vertical wall	70–90°
	Macroripples	Slope 0–5° and ripples >0.5 m high
Substrate Type	Sand	Unconsolidated sediment 0.63–2 mm in diameter
	Silt	Unconsolidated sediment <0.63 mm in diameter
	Mud	Dense consolidated mixture of silt to sand sized particles
	Gravel	Unconsolidated sediment 2–10 mm in diameter
	Rubble	Unconsolidated sediment 10–250 mm in diameter
	Consolidated rubble	Sediment >10 mm in diameter with a covering of biotic or abiotic material that keeps the rubble in place
	Limestone pavement	Horizontal surface of exposed limestone rock
	Limestone pavement with sand veneer	Limestone rock patchily covered with sand; the sand may range in depth from centimetres to metres
	Boulders	Unconsolidated sediment >250 mm in diameter
	Reef – low profile	Reef of biotic or abiotic origin, ranging from flat to vertical; low profile: <1 m vertical change per 1 m horizontal
	Reef – high profile	Reef of biotic or abiotic origin, ranging from flat to vertical; high profile: >1 m vertical change per 1 m horizontal

Category	Attribute	Definition
	Sand with shell fragment	Unconsolidated sediment 0.63–2 mm in diameter, containing large, easily visible pieces of shell
	Silt with shell fragment	Unconsolidated sediment <0.63 mm in diameter, containing large, easily visible pieces of shell
Dominant Ecological Element	Macroalgae	Macroalgae greatest % cover, coral <10%
	Seagrass	Seagrass greatest % cover, coral <10%
	Non-coral benthic macroinvertebrates	Non-coral benthic macroinvertebrates greatest % cover, coral <10%
	Coral – hard and soft	Coral >10% cover
	Mangroves	Mangrove forests and isolated mangrove trees
	Unvegetated	Benthic assemblages collectively <10% cover
% Cover	Sparse – macroalgae	5–25% estimated cover
	Medium – macroalgae	25–75% estimated cover
	Dense – macroalgae	>75% estimated cover
	Sparse – seagrass	5–25% estimated cover
	Medium – seagrass	25–75% estimated cover
	Dense – seagrass	>75% estimated cover
	Present – Non-coral benthic macroinvertebrates	Presence/absence recorded
	Sparse – coral	0–10% estimated cover
	Medium – coral	10–50% estimated cover
	Dense – coral	50–75% estimated cover
	Very dense – coral	>75% estimated cover
	Present – mangrove	Presence/absence recorded for mangroves
	Unknown density	% cover not recorded

Dominant and subdominant taxa were classified to the greatest practicable taxonomic resolution. For towed video camera surveys, the resolution of the video footage varied according to weather conditions and water clarity. In clear water, it was possible to classify the dominant and subdominant taxon descriptor of the habitat classification to the species level (e.g. flat, limestone pavement with macroalgae, dominated by sparse *Sargassopsis decurrens*). In turbid water, or with poor quality video footage, it was often only possible to identify the dominant/subdominant taxon to phylum or class (e.g. flat limestone pavement with macroalgae, dominated by medium unidentified Phaeophyceae). Less-common taxa and associated species were also recorded where possible. While this information increased the level of knowledge of the ecology of the study area, it did not inform habitat classification for mapping purposes.

The scheme is consistent with other habitat classification schemes used in Australia (see Ref. 57; Ref. 58; Ref. 59; Ref. 60; Ref. 61; Ref. 62; Ref. 63; Ref. 64; Ref. 65; Ref. 66; Ref. 67). While the hierarchy used is similar to that of other schemes (e.g. classifying by relief, then substrate, then biological modifiers such as dominant ecological elements and dominant taxa), the habitat classification scheme developed for Barrow Island waters is tailored around the ecological elements defined in Condition 14.2 of MS 800, Condition 12.2 of MS 769, and Condition 11.2 of EPBC Reference: 2003/1294 and 2008/4178.

5.3 Detailed Mapping of Ecological Elements Associated with the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

5.3.1 Survey Area

The area near the proposed route of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing was surveyed using remotely operated drop camera and diver transects to provide qualitative descriptions of the benthic habitats and assemblages, which were supplemented by quantitative descriptions of the habitat types at selected locations. Remotely operated drop camera surveys and diver transects covered an area of ≈2 km^2 around the HDD exit alignment, while drop camera surveys covered ≈25 km of seabed transects within State Waters. The area surveyed and mapped included the benthic habitats and assemblages within 200 m of the proposed route of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. Note: This information was collected to supplement mapping undertaken previously during the Marine Baseline Program (Section 5.1) to provide more detailed information on the benthic assemblages near the proposed route of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing.

5.3.2 Methods

5.3.2.1 Remotely Operated Drop Camera Surveys

Eleven drop camera transects, in a grid pattern orientated parallel and perpendicular to the coast, were surveyed in the immediate vicinity of the HDD exit alignment (Figure 5-3). An additional five transects, orientated perpendicular to the coast, were surveyed in areas outside the MDF and outside the areas at risk of Material or Serious Environmental Harm and in similar water depths to the areas surveyed around the HDD exit alignment. The transects were located approximately 500 m apart and up to 1.8 km north and south of the HDD exit alignment.

Five drop camera transects were also surveyed along the proposed route of the Offshore Feed Gas Pipeline System from the shallow waters near Barrow Island to beyond the limits of State Waters in ≈25 m water depth (Figure 5-3).

The benthic habitats and assemblages at all locations were photographed using a remotely operated Canon Powershot G9 camera. The camera housing was fixed to a frame such that photographs were taken 0.6 m above the seabed, providing a 0.1725 m^2 field of view. Near the HDD exit alignment, photographs were taken at ≈10 m intervals along each transect, while along the proposed route of the Offshore Feed Gas Pipeline System, photographs were taken at ≈30 m to 70 m intervals, depending on the seabed and weather conditions.

The camera operator viewed the live video feed and captured still photographs at locations determined by the GIS operator. The location of each photograph was recorded by the GIS operator using the ESRI ArcPad software package running on a laptop connected to a Garmin GPS76 unit. The live video feed was recorded to DVD and hard drive in a Panasonic DMR-EX78 recorder. To remove the potential for observer bias, the GIS operator was not able to see the video feed from the camera. Benthic habitats surveyed using the remotely operated drop camera were classified by the camera operator who noted the substrate relief and type and estimated the cover of the dominant ecological elements at each location (Section 5.2; Appendix B).

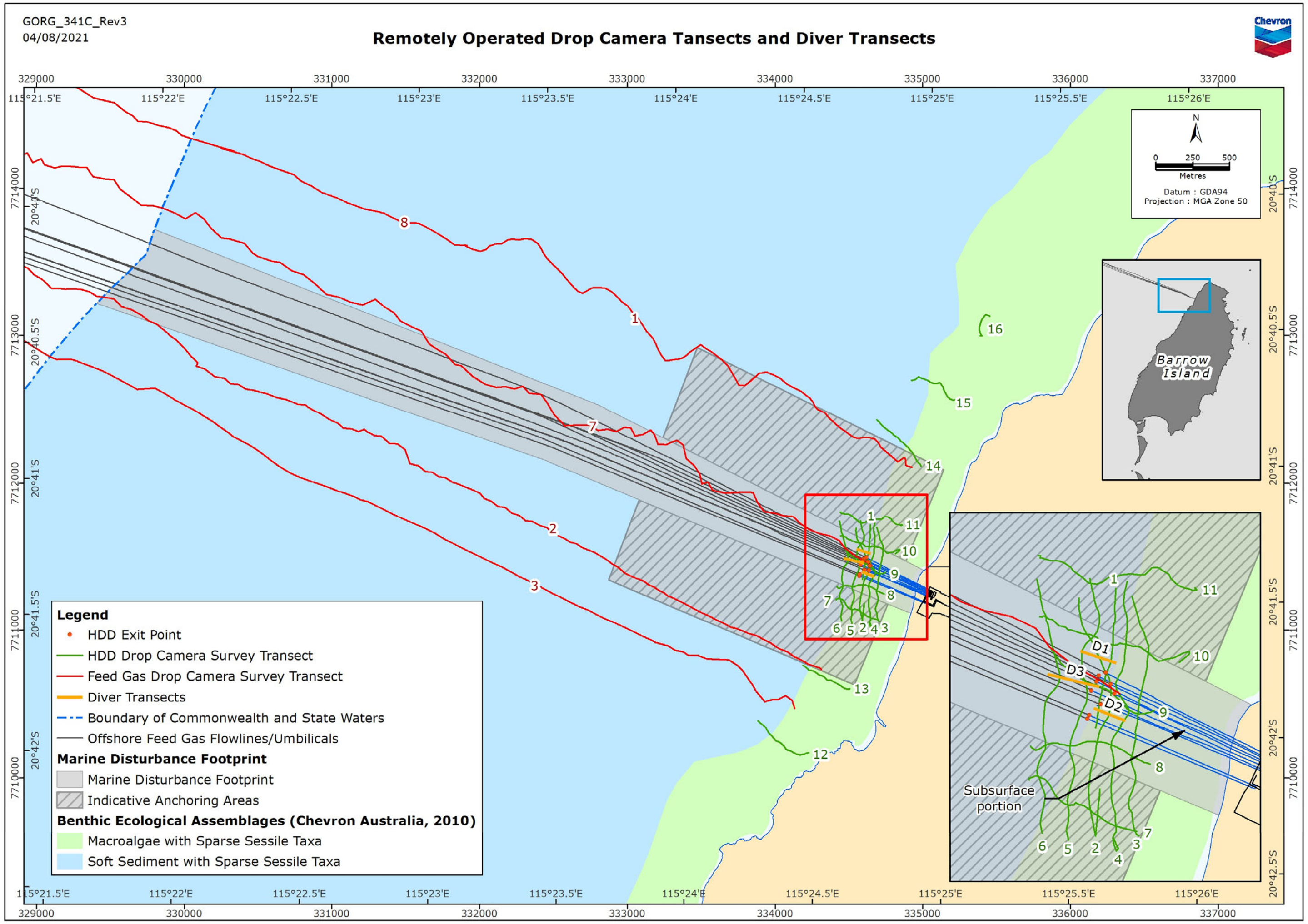


Figure 5-3: Location of Remotely Operated Drop Camera Transects and Diver Photograph Transects near the HDD Exit Alignment

5.3.2.2 Diver Transect Surveys

At three locations near the HDD exit alignment, nine 20 m long transects, with two to four transects at each location, were surveyed (Figure 5-3). The starting point for each transect and the distance separating transects (0–20 m) at each location, were determined before commencing the survey to avoid any bias in selecting the transect position. The coordinates for the start and end point of each transect were recorded using a handheld GPS.

At 2 m intervals along each transect, four adjacent 0.25 m^2 subquadrats, forming a square covering 1 m^2, were photographed using a Canon Ixus 860IS digital camera in an underwater housing.

5.3.3 Timing and Frequency of Sampling

Surveying and mapping the ecological elements associated with the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing was undertaken between May and August 2009.

5.3.4 Treatment of Survey Data

Field observations indicated that the type of benthic habitats and cover of benthic assemblages was consistent spatially, thus detailed analysis of a subset of photographs (from the drop camera and diver transect surveys) using CPCe (Ref. 53) was considered appropriate to provide quantitative descriptions of the benthic habitats and assemblages. Fifty photographs for CPCe analysis were randomly selected from the complete set of photographed quadrats from the diver transects near the HDD exit alignment, 50 from the drop camera transects surveyed near the HDD exit alignment and along the coast, as well as 100 from the drop camera transects surveyed near the proposed route of the Offshore Feed Gas Pipeline System. Of the 50 photographs selected from the diver transects, only 48 were of a suitable quality for analysis. On the basis of the mean and variance of percentage cover in this subset of photographs, estimates of the gain in precision from analysing more than 48 quadrats indicated that only minor increases would have been achieved by analysing more quadrats. Therefore, photographs that were of insufficient quality for analysis using CPCe were not re-assigned; instead, they were excluded from further analysis.

Digital images were analysed using CPCe. Thirty random points were overlaid over the image and each point visually classified into the broad categories of benthic cover (macroalgae, seagrass, coral, non-coral benthic macroinvertebrates, sand, pavement, rubble, and unidentified). The percentage of all points scored as each benthic ecological element per photograph was calculated and the average (± standard error [SE]) cover of dominant ecological elements was determined for the diver transects, the drop camera surveys near the HDD exit alignment and along the coast, and the drop camera surveys near the proposed route of the Offshore Feed Gas Pipeline System. Benthic habitats in the photographs analysed using CPCe were classified using a combination of the information provided by the drop camera operators (i.e. substrate relief and type) and CPCe outputs (i.e. identification and percentage cover of dominant and subdominant ecological elements). The use of CPCe analysis increased the level of taxonomic detail by providing quantitative measure of the cover of dominant and subdominant ecological elements. The cover of dominant and subdominant ecological elements was categorised as ‘sparse’ (5–25%), ‘medium’ (25–75%), or ‘dense’ (>75%) cover; except for non-coral benthic macroinvertebrates, which were classified as ‘present’ (Section 5.2; Appendix B). Unvegetated substrate was classified as ‘bare’ or ‘unknown’ density.

5.3.5 Results

5.3.5.1 Drop Camera Surveys near the HDD Exit Alignment

5.3.5.1.1 Broad Descriptions of Overall Survey Area from Drop Camera Observations

Field observations from the drop camera surveys indicate that the benthic habitat was predominantly unvegetated or bare sand, or sand covering a gently sloping limestone pavement (Figure 5-4). Sand was the dominant substrate type at 54% of the drop camera locations; limestone pavement with a sand veneer was the dominant substrate type at 43% of the locations; limestone pavement with no sand veneer was the dominant substrate type at <2% of locations; while low profile reef was identified at two (<0.5%) locations.

In terms of dominant ecological elements, 56% of the drop camera locations were classified as unvegetated. Macroalgae were the dominant ecological element at 41% of the locations. Macroalgal cover was sparse at 55%, medium at 44%, and dense at <2% of these locations.

Corals were present at two of the drop camera locations near the HDD exit alignment. A sparse cover of soft corals was recorded at one location and a single colony on sand (representing a medium cover) of the hard coral *Turbinaria* sp. was recorded at a second location (Figure 5-4). Non-coral benthic macroinvertebrates (ascidians, molluscs, sponges, gorgonians, and sea whips) were the dominant ecological elements at 20 (3%) of the locations.

5.3.5.1.2 Detailed Description from CPCe Analysis

Based on the results from the CPCe analysis of 50 drop camera photographs, most of the benthic habitat near the HDD exit alignment was unvegetated substrate, predominantly sand (mean percentage cover 83 ± 3%), with unvegetated substrate the only habitat recorded in 50% of the photographs analysed. Macroalgae on sand or limestone pavement with a shallow sand veneer were the dominant ecological element in 15 of the photographs analysed, with an average cover of 28 ± 5% and an overall average percentage cover of 10 ± 2%. The macroalgal assemblages were dominated by *Sargassum* spp., *Halimeda* spp., and unidentified turfing algae.

Non-coral benthic macroinvertebrates (sponges, ascidians, sea whips, gorgonians, and hydroids) represented on average <3% of the overall percentage cover of the benthic habitat and assemblages near the HDD exit alignment and were the dominant ecological element (average percentage cover 18 ± 3%) in three of the photographs analysed. Corals and seagrass were not recorded in any of the 50 drop camera photographs analysed with CPCe.

5.3.5.2 Diver Transect Surveys near the HDD Exit Alignment

5.3.5.2.1 Detailed Description from CPCe Analysis

Based on the results from the CPCe analysis of the 48 diver transect photographs, the benthic habitat near the HDD exit alignment was characterised by a gently sloping, sand-covered limestone pavement with some macroalgae. Mean percentage cover of unvegetated substrate, predominantly sand or limestone pavement with a shallow sand veneer, was 53 ± 3%. Unvegetated substrate had the highest percentage cover in 29 of the photographs analysed.

Macroalgae on sand or limestone pavement with a shallow sand veneer were the dominant ecological element in 43 of the photographs analysed, with an average cover of 40 ± 3% and an overall average percentage cover of 37 ± 3%. The macroalgal assemblages were dominated by an unidentified green alga, *Sargassum* sp., unidentified turfing algae, *Dictyopteris* sp., and *Halimeda* cf. *cuneata*.

The coral cover was low, accounting for <1% (average) of the overall percentage cover of the benthic habitat and assemblages in the 48 photographs analysed. The hard coral *Turbinaria* spp. was the only coral species recorded (in six of the 48 photographs analysed). However, the cover of *Turbinaria* sp. was >10% in only one of the photographs where it was the dominant ecological element, comprising a single colony covering 15% of the 0.25 m^2 photo-quadrat; no corals were recorded in the three adjacent subquadrats. Seagrass was not recorded in any of the 48 diver transect photographs analysed with CPCe. Non-coral benthic macroinvertebrates (sponges, gorgonians, and hydroids) were present in 15 of the photographs analysed and accounted for <3% (average) of the overall percentage cover of the benthic habitat and assemblages near the HDD exit alignment.

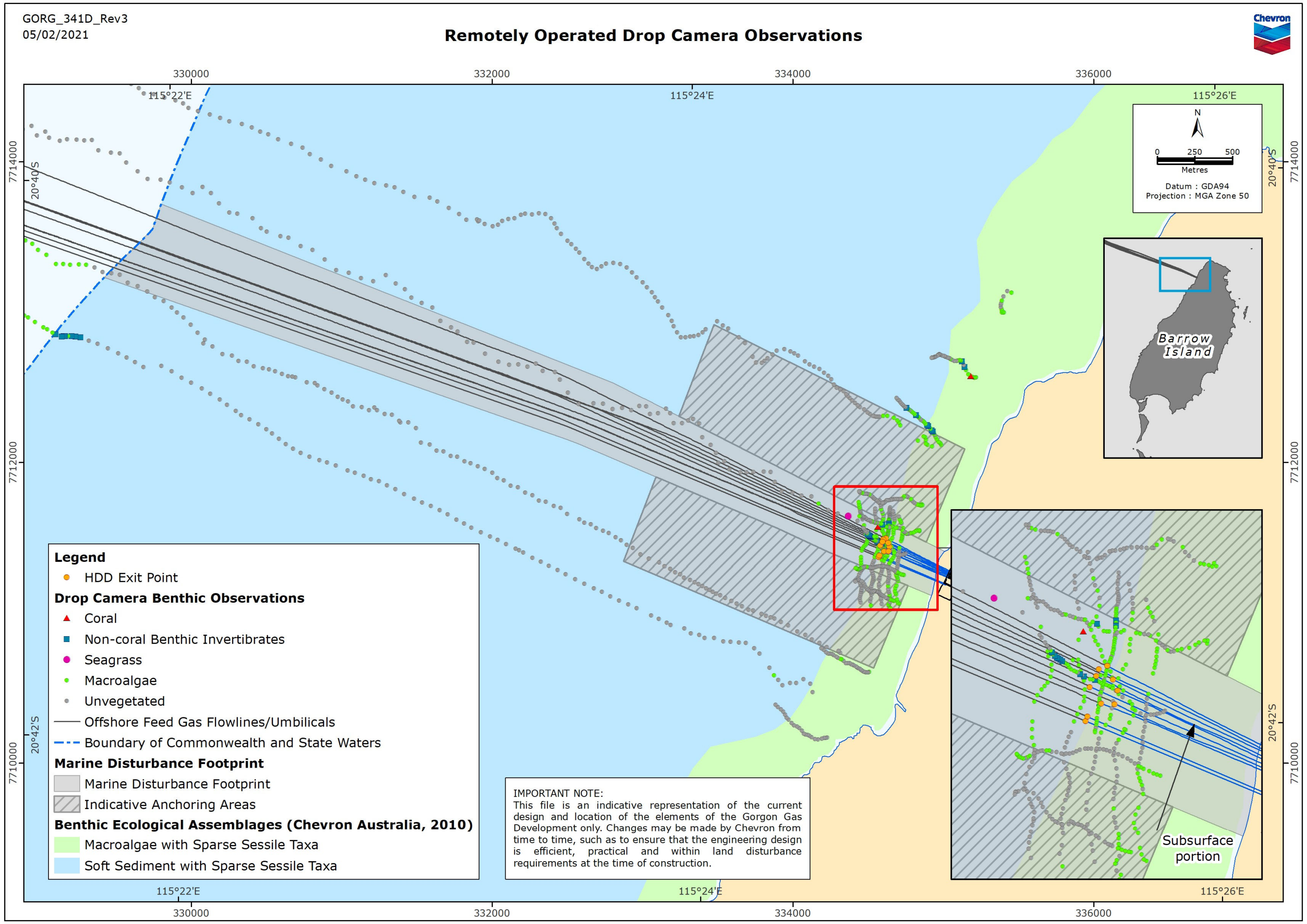


Figure 5-4: Dominant Ecological Elements near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing, as Determined from Field Observations made from Drop Camera Imagery

5.3.5.3 Drop Camera Surveys along the Feed Gas Pipeline System

5.3.5.3.1 Broad Descriptions of Overall Survey Area from Drop Camera Observations

Field observations from the drop camera surveys indicate that the benthic habitat along the Offshore Feed Gas Pipeline route was predominantly unvegetated or bare sand (Figure 5-4). Sand was the dominant substrate type at 91% of the drop camera locations; limestone pavement with a shallow sand veneer was the dominant substrate type at 8% of the locations; limestone pavement with no sand veneer was the dominant substrate type at <1% of locations; and rubble was the dominant substrate at <0.5% of locations.

In terms of dominant ecological elements, 86% of the drop camera locations were classified as unvegetated. Macroalgae were the dominant ecological element at 10% of the locations; macroalgal cover was sparse in 96% of these locations and medium in the remainder. The seagrass *Halophila spinulosa* was dominant at one location, where sparse cover was recorded.

Non-coral benthic macroinvertebrates were the dominant ecological element at <4% of the drop camera locations. Coral was the dominant ecological element at one location and cover comprised a single *Turbinaria* sp. colony on sand, recorded as medium cover.

5.3.5.3.2 Detailed Description from CPCe Analysis

Based on the results from the CPCe analysis of 100 drop camera photographs, unvegetated substrate, predominantly sand, comprised 99 ± 0.4% (average) of the benthic habitat. Macroalgae comprised <0.5% (average) cover of the benthic habitat and assemblages. Macroalgae on sand or limestone pavement with a shallow sand veneer were the dominant ecological element in five of the photographs analysed, with 3% to 13% cover. The macroalgal assemblages were dominated by *Sargassum* sp. Seagrass (*Halophila spinulosa*) was recorded in one of the 100 drop camera photographs analysed with CPCe (3% cover).

Non-coral benthic macroinvertebrates represented <0.5% (average) of the overall percentage cover of the benthic habitat and assemblages and were the dominant ecological element (an anemone and sea whips) in three of the photographs analysed (3% cover). Hard corals (*Turbinaria* spp.) represented <0.5% of the overall cover, and were recorded in only one of the 100 drop camera photographs. At this location, just outside State Waters, a single *Turbinaria* sp. colony represented 28% cover of the benthic habitat and assemblages.

5.3.6 Conclusions

The benthic habitats near the proposed route of the Offshore Feed Gas Pipeline System in State Waters were characterised by unvegetated or bare sand. Macroalgae were the dominant ecological element, although average cover of macroalgae, as well as of non-coral benthic macroinvertebrates, was <0.5%. Seagrass (*Halophila spinulosa*) was recorded at one location near the Offshore Feed Gas Pipeline System route. A single colony of the hard coral *Turbinaria* sp. was recorded at one location near the Offshore Feed Gas Pipeline System route and no Coral Assemblages were recorded.

The benthic habitats near the marine component of the shore crossing (the HDD exit alignment) were characterised by limestone platform covered with unvegetated sand. Macroalgae were the dominant ecological element, with an average cover of 10 ± 2% in the wider area and 37 ± 3% in the immediate vicinity of the HDD exit alignment. Non-coral benthic macroinvertebrates were rarely the dominant ecological element with <3% cover. Seagrass was present at low levels of cover (≈1%). The hard coral *Turbinaria* spp. and soft corals were the only corals recorded near the HDD exit alignment; however, field observations and more detailed analysis of photographs indicated that *Turbinaria* spp. colonies were only occasionally recorded.

Turbinaria is a widespread and common genus of hard coral that is well represented in Barrow Island waters (Ref. 29). Near the proposed route of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, *Turbinaria* spp. were present in low abundances and only isolated colonies were observed that were not part of reef-building coral assemblages.

6 Hard and Soft Corals

6.1 Introduction

The marine habitats in the Pilbara Region support a variety of coral species that vary spatially, with clearer waters in offshore areas having higher coral density and diversity than that of high turbid nearshore areas (Ref. 68). Coral surveys in north-western Australia have generally been concentrated in areas associated with industrial development. Approximately 318 hermatypic coral species from 70 genera are known to occur in Western Australia (Ref. 68). Surveys conducted at the Dampier Archipelago in 2004 found that four coral genera dominated the coral assemblages: *Acropora* (especially plate *Acropora*), *Porites*, *Pavona*, and *Turbinaria* (Ref. 69). The fifth most abundant type of coral assemblage was a 'mixed' assemblage, consisting of *Turbinaria*, faviids, and other scleractinian corals. A total of 229 species of coral from 57 hermatypic coral genera have been recorded in the Dampier Archipelago (Ref. 70).

At least 150 species of hard corals from 54 genera were recorded in the Montebello Islands/Barrow Island region during a survey conducted by the Western Australian Museum (Ref. 71). The fringing reefs in the relatively clear and high-energy conditions west and south-west of the Montebello Islands, as well bomboras and patch reefs in the more turbid and lower-energy waters along the eastern edge of the Montebello Islands, are believed to support the best-developed coral communities in the Montebello Islands/Barrow Island region (Ref. 31). For Barrow Island specifically, the most significant coral reefs are located at Biggada Reef on the west coast, Dugong Reef and Batman Reef off the south-east coast, and along the edge of the Lowendal Shelf on the eastern side of Barrow Island (Ref. 31). Surveys undertaken in the waters around Barrow Island have identified 196 species of hard corals in 48 genera, and seven soft coral genera from the suborder Alcyoniina (Ref. 29). These included six new records for Australia (although unpublished information indicates *Platygyra acuta* was previously recorded in Western Australia), nine new records for Western Australia, and three new records for the North West Shelf.

On the west coast of Barrow Island, coral reefs are limited to the southern and central parts of the west coast. Biggada Reef on the central west coast of Barrow Island (Table 13-1, Figure 13-1) is an extensive, largely intertidal coral reef that extends to the subtidal zone (Ref. 31). The reef crest and lagoon areas support extensive expanses of corals that are exposed on very low tides. Surveys of the intertidal component of Biggada Reef in 1995 revealed a diverse fauna that included at least 64 species of hard coral (Ref. 72).

Corals in the west coast Management Unit[2] are limited to small scattered corals, such as *Turbinaria* spp., which are considered part of the macroalgae dominated BPPH unit (Ref. 11). The limestone pavement reef off North Whites Beach, near the marine component of the shore crossing, supports a variable cover of macroalgae and small, sparsely scattered corals (*Acropora* spp. and *Turbinaria* spp.) (Ref. 73).

In Commonwealth Waters further offshore from North Whites Beach, there are two high profile reefs in water depths of approximately 40 to 45 m (Ref. 11). These

[2] Fourteen Management Units were defined to assess impacts to BPPHs associated with the Gorgon Gas Development—11 around Barrow Island and three adjacent to the mainland (Section 11.4, Chevron Australia 2005; Section 8.8, Chevron Australia 2006).

rocky reefs support scattered black (soft) corals such as *Cirrhipathes* sp. and *Antipathes* sp., and the hard coral *Pachyseris* sp. (Ref. 11).

6.2 Scope

This Section records the existing dominant and subdominant hard and soft coral species/taxa (Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes/defines and maps the hard and soft coral species/taxa:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.iii, MS 800; Condition 11.6.III, EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.iv, MS 800; Condition 11.6.iv, EPBC Reference: 2003/1294 and 2008/4178).

For the purposes of the Marine Baseline Program, ‘hard corals’ are considered to be the reef-building corals within the order Scleractinia. Corals were classified according to the online Integrated Taxonomic Information System (ITIS) (http://www.itis.gov); as taxonomic regrouping of some species and genera into new clades and families based on genetic analyses (Ref. 74; Ref. 75) are only just being developed and are not yet commonly recognised.

The hard coral *Turbinaria* is a widespread and common genus of hard coral that occurs outside coral habitats in benthic macroinvertebrate dominated assemblages in Barrow Island waters (Ref. 29). Because *Turbinaria* are more like other benthic macroinvertebrates (i.e. solitary with a low profile and low benthic cover) than the reef-building corals within the order Scleractinia, they are included in Section 7 (non-coral benthic macroinvertebrates) rather than in this Section.

‘Soft corals’ have no skeleton and are not considered reef-building organisms. For the purposes of the Marine Baseline Program, ‘soft corals’ are those within the order Alcyonacea (soft corals) and suborder Alcyoniina (‘true soft corals’) (http://www.itis.gov). Generally, identifying soft corals is difficult, except for the suborder Alcyoniina and even these species are difficult to distinguish (Ref. 76). The other organisms within the order Alcyonacea include sea whips (suborder Calcaxonia) and sea fans (suborders Holaxonia and Scleraxonia) (http://www.itis.gov). These are also included in Section 7 (non-coral benthic macroinvertebrates) because they are commonly observed in benthic macroinvertebrate dominated assemblages in Barrow Island waters (outside coral reef habitats). Therefore, they are considered to be an important part of the sessile benthic macroinvertebrate assemblages.

Non-scleractinian corals (e.g. *Millepora* sp.; class Hydrozoa) were recorded only if they were dominant or subdominant and were identified only to genus level.

Given the recorded absence of Coral Assemblages and the correspondingly low abundance and percentage cover of hard and soft corals (Section 5.3), which are unlikely to offer the ecological function of a coral community near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, no field surveys have been undertaken to assess:

- the population structure of coral communities, colony size-class frequency distributions of dominant hard coral species/taxa and selected other key indicator species that characterise these communities (Condition 12.8.iv. MS 769; Condition 14.8.iv.a, MS 800; Condition 11.8.IV.a, EPBC Reference: 2003/1294 and 2008/4178)
- the population statistics of survival of dominant hard coral species/taxa and, if appropriate, selected other indicator coral taxa/key indicator species that characterise these communities (Condition 12.8.iv. MS 769; Condition 14.8.iv.b, MS 800; Condition 11.8.IV.b, EPBC Reference: 2003/1294 and 2008/4178)
- the population statistics of growth of dominant hard coral species/taxa and, if appropriate, selected other indicator coral taxa/key indicator species that characterise these communities (Condition 12.8.iv. MS 769; Condition 14.8.iv.b, MS 800; Condition 11.8.IV.b, EPBC Reference: 2003/1294 and 2008/4178)
- the recruitment of hard coral taxa/species within these communities (Condition 12.8.iv. MS 769; Condition 14.8.iv.c, MS 800; Condition 11.8.IV.c, EPBC Reference: 2003/1294 and 2008/4178).

This is consistent with the approach set out in the approved Coastal and Marine Baseline State and Environmental Impact Report Scope of Works (Ref. 19), which identified that, wherever possible, baseline coral survey sites would be established in areas of high coral cover to maximise the number of replicate colonies of each species that could be selected to monitor coral population parameters at each site, and to enable robust comparisons between potential impact sites and Reference Sites. Twelve baseline coral survey sites were included in the Marine Baseline Program, including one at Biggada Reef on the west coast of Barrow Island (Ref. 29). These sites were selected to include most large Coral Assemblages within the ZoHI and ZoMI associated with dredging and dredge spoil disposal activities, significant coral reefs (Ant Point Reef, Southern Lowendal Shelf, Dugong Reef, Batman Reef and Southern Barrow Shoals) that were identified in the EIS/ERMP (Ref. 11; Ref. 12), and more distant Reference Sites identified from the broadscale benthic habitat map of the Montebello Islands/Barrow Island area (Ref. 52; Ref. 31).

6.3 Methods

Section 5.3 describes how the ecological elements associated with the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing were mapped. Section 7 (non-coral benthic macroinvertebrates) reports on the quantitative surveys of the hard coral *Turbinaria* spp. .

6.4 Results

Field observations from drop camera and diver surveys indicate that corals were present in low abundances near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, and only isolated colonies were observed, which were not part of reef-building coral assemblages (Figure 5-4). A single colony of the hard coral *Turbinaria* sp. was recorded on sand at one location near the Offshore Feed Gas Pipeline System (Section 5.3.5.3.1). The hard coral *Turbinaria* spp. and soft corals were the only corals recorded near the HDD exit alignment, with a sparse cover of soft corals recorded at one location and a single colony of *Turbinaria* sp. on sand recorded at a second location (Section 5.3.5.1.1).

There were no Coral Assemblages recorded near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing.

6.5 Discussion

The benthic habitats near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing were characterised by limestone platform covered with a veneer of unvegetated sand. Macroalgae were the dominant ecological element (Section 8). None of the Regionally Significant Areas on the eastern margin of the Lowendal Shelf to the southern boundary of the Montebello Islands Marine Park, Dugong Reef, Batman Reef, and Southern Barrow Shoals, nor the coral reefs on the southern and central parts of the west coast (e.g. Biggada Reef) of Barrow Island, are at risk due to the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The MDF and the areas at risk of Material or Serious Environmental Harm do not contain any significant areas of coral habitat or Coral Assemblages, such that any impacts to corals within these areas would not threaten the survival, viability, or functioning of coral habitat.

The EIS/ERMP (Ref. 11) presented calculations for the BPPH loss associated with the HDD marine activities. These calculations were based on preliminary modelling, which indicated that elevated SSCs and sedimentation resulting from the use of bentonite would extend around the northern end of Barrow Island. Based on the results from the updated modelling (Ref. 27), the Detectable Net Mortality of Coral Assemblages for HDD marine activities associated with the construction of the shoreline crossing on the west coast of Barrow Island is not expected to exceed 1.2 ha (Condition 13.5, MS 769; Condition 22.6, MS 800; and Condition 15.6, EPBC Reference: 2003/1294 and 2008/4178).

7 Non-Coral Benthic Macroinvertebrates

7.1 Introduction

Although the knowledge of the non-coral benthic macroinvertebrate assemblages in the Montebello Islands/Barrow Island region is generally limited to species lists and distributions of taxa, the available information suggests that the assemblages are species-rich (Ref. 71; Ref. 77; Ref. 11; Ref. 47; Ref. 31; Ref. 73). Invertebrate species richness is considered high in the Montebello Islands region in particular, with 633 species of molluscs and 170 species of echinoderms recorded (Ref. 77; Marsh *et al.* [1993] cited in Ref. 31). Deeper limestone reef areas in the region may support benthic macroinvertebrate communities that contain diverse assemblages of tubular, digitate, laminar, branching, globose, and encrusting sponges; hydroids; gorgonians (sea fans); soft corals (sea whips); colonial and solitary ascidians; bryozoans and small scleractinian corals (such as *Turbinaria* spp.) (Ref. 11; Ref. 47).

The habitats on the east and west coasts of Barrow Island support different non-coral benthic macroinvertebrate assemblages (Ref. 11). Of the 316 species of molluscs recorded from Barrow Island, less than one third occur on both coasts. The muddier habitats on the east coast support a greater proportion of bivalve species, while the west coast supports a greater proportion of coral reef gastropod species (Ref. 11). The gastropod *Amoria macandrewi* is endemic to sandbars within the Montebello Islands/Barrow Island region (Ref. 11). The macroinvertebrate fauna of the rocky shores and intertidal mudflats on the leeward sides of the offshore islands in the Montebello Islands/Barrow Island region also have strong affinities with the fauna of the nearshore intertidal areas on the mainland (Ref. 11).

Non-coral benthic macroinvertebrate assemblages characteristic of the western shores of Barrow Island are typical of the Pilbara Offshore (PIO) Marine Bioregion and have affinities with assemblages of the west coast of the Montebello Islands (Ref. 11). Previous surveys have recorded 32 species of echinoderm and 75 species of mollusc on the intertidal reef at Biggada Reef (Ref. 72; Ref. 11).

The infauna community in the shallow subtidal areas off North Whites Beach on the west coast of Barrow Island was surveyed between 2002 and 2004 and again in 2006 (Ref. 11; Ref. 73). The benthic habitats along the Offshore Feed Gas Pipeline System route comprise soft sediments of varying grain-size, with isolated rocky reefs and patches of exposed pavement reef supporting sparse filter-feeding assemblages dominated by sea whips, gorgonians, and sponges (Ref. 11). A total of 406 individuals from 15 sample sites were recorded during the 2006 survey (Ref. 73). Along the Offshore Feed Gas Pipeline System route, in water depths of ≈11 m (near the HDD exit alignment), benthic fauna were sparse and included branching and tubular sponges, tube worms, and soft corals such as sea whips and *Sarcophyton* spp. (Ref. 11; Ref. 73). These habitats are widespread in the Pilbara Region (Ref. 11).

Further offshore, outside State Waters in water depths of approximately 40 to 45 m, rocky reefs provide structural diversity to an otherwise planar seabed (Ref. 11). Areas of platform reef are known to support benthic invertebrates including scattered black corals (*Cirrhipathes* spp., *Antipathes* spp.), sponges, sea whips (*Junceella*), and branching gorgonians (Ref. 11). Areas of upstanding reef in similar water depths support encrusting or lithophagic sponges and abundant fish (Ref. 11).

7.2 Scope

This Section records the existing dominant species of non-coral benthic macroinvertebrates (Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes/defines and maps the non-coral benthic macroinvertebrates:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.iii, MS 800; Condition 11.6.III EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.iv, MS 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

Non-coral benthic macroinvertebrates (hereafter referred to as ‘benthic macroinvertebrates’) are a broad category of fauna that include sessile, filter-feeding taxa such as sponges, gorgonians, and ascidians, as well as motile taxa such as asteroids (starfish), echinoids (sea urchins), and holothurians (sea cucumbers). The Marine Baseline Program has focused on the dominant (most common) benthic macroinvertebrate species among the sessile, habitat-forming groups, which characterise the benthic macroinvertebrate assemblages around Barrow Island (Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178).

The soft corals (order Alcyonacea) are commonly observed in benthic macroinvertebrate dominated assemblages in Barrow Island waters (outside coral reef habitats) and represent an important part of the sessile benthic macroinvertebrate assemblages; they are included in this Section. The hard coral *Turbinaria* spp. is also common in these assemblages and has been included as a benthic macroinvertebrate as, from a habitat perspective, it is more like other benthic macroinvertebrates (i.e. solitary with a low profile and low benthic cover) than the hard corals discussed in Section 6.

7.3 Methods

7.3.1 Site Locations

As part of the Marine Baseline Program for the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, eight benthic macroinvertebrate survey sites were selected within areas where benthic macroinvertebrates were identified as potentially being present through broadscale habitat mapping on the west coast of Barrow Island (Section 5.3). The sites were all located on limestone pavement. Four of the sites were selected based on their proximity to the HDD exit alignment (Table 7-1; Figure 7-1)—one site (HDD1) was within the Marine Facilities Footprint, one was north (HDD2) and one south (HDD3) of the Marine Facilities Footprint within the MDF in the area at

Risk of Material or Serious Environmental Harm, and a fourth site (HDD4) was at the edge of the MDF, north of the HDD exit alignment. Four Reference Sites, which are not expected to be impacted by the HDD marine activities and therefore are not at Risk of Material or Serious Environmental Harm, were located south (BR and HDDRS2) and north (HDDRN and NEBWI2) of the HDD exit alignment. Site HDDRS2 was added in the August to October 2010 survey, as site HDDRN was inaccessible. Note: It is anticipated that anchoring within the indicative anchoring area will be managed such that there will be no impact at the Reference Site HDDRN.

Table 7-1: West Coast Barrow Island Benthic Macroinvertebrate Survey Sites and Dates

Site Code		Easting	Northing	Latitude	Longitude	Survey Date			
		(GDA94, MGA Zone 50)		(GDA94)		Nov 2008	Sep/Oct 2009	Mar 2010	Aug/Oct 2010
At risk of Material or Serious Environ-mental Harm	HDD1	334666	7711398	20° 41.374' S	115° 24.755' E		X	X	X
	HDD2	334677	7711541	20° 41.297' S	115° 24.762' E		X	X	X
	HDD3	334548	7711351	20° 41.399' S	115° 24.686' E		X	X	X
	HDD4	334738	7711539	20° 41.298' S	115° 24.797' E		X	X	X
Reference Sites	HDDRN	334965	7712144	20° 40.972' S	115° 24.931' E		X	X	
	BR	329877	7704929	20° 44.855' S	115° 21.959' E			X	X
	NEBWI2	343137	7713599	20° 40.225' S	115° 29.645' E	X			X
	HDDRS2	329675	7705354	20° 44.623' S	115° 21.845' E				X

Note: Non-coral benthic macroinvertebrate survey sites were also macroalgae and seagrass survey sites where these ecological elements co-occurred in the same area.

Qualitative intertidal surveys were undertaken at the HDD shore crossing at North Whites Beach, at three sites (Max's Point, Max's Beach North, Max's Beach South) north and one site (South Whites Beach) south of the HDD shore crossing (Table 7-2) (Ref. 78).

Table 7-2: Qualitative Intertidal Survey Sites near the HDD Shore Crossing

Site Name		Easting	Northing	Latitude	Longitude
		(GDA94, MGA Zone 50)		(GDA94)	
At risk of Material or Serious Environmental Harm	North Whites Beach (HDD)	334938	7711298	20° 41.430' S	115° 24.910' E
Reference Sites	Max's Point	335453	7712513	20° 40.774' S	115° 25.214' E
	Max's Beach North	335333	7712248	20° 40.917' S	115° 25.144' E
	Max's Beach South	335087	7711579	20° 41.279' S	115° 24.998' E
	South Whites Beach	334675	7710438	20° 41.895' S	115° 24.754' E

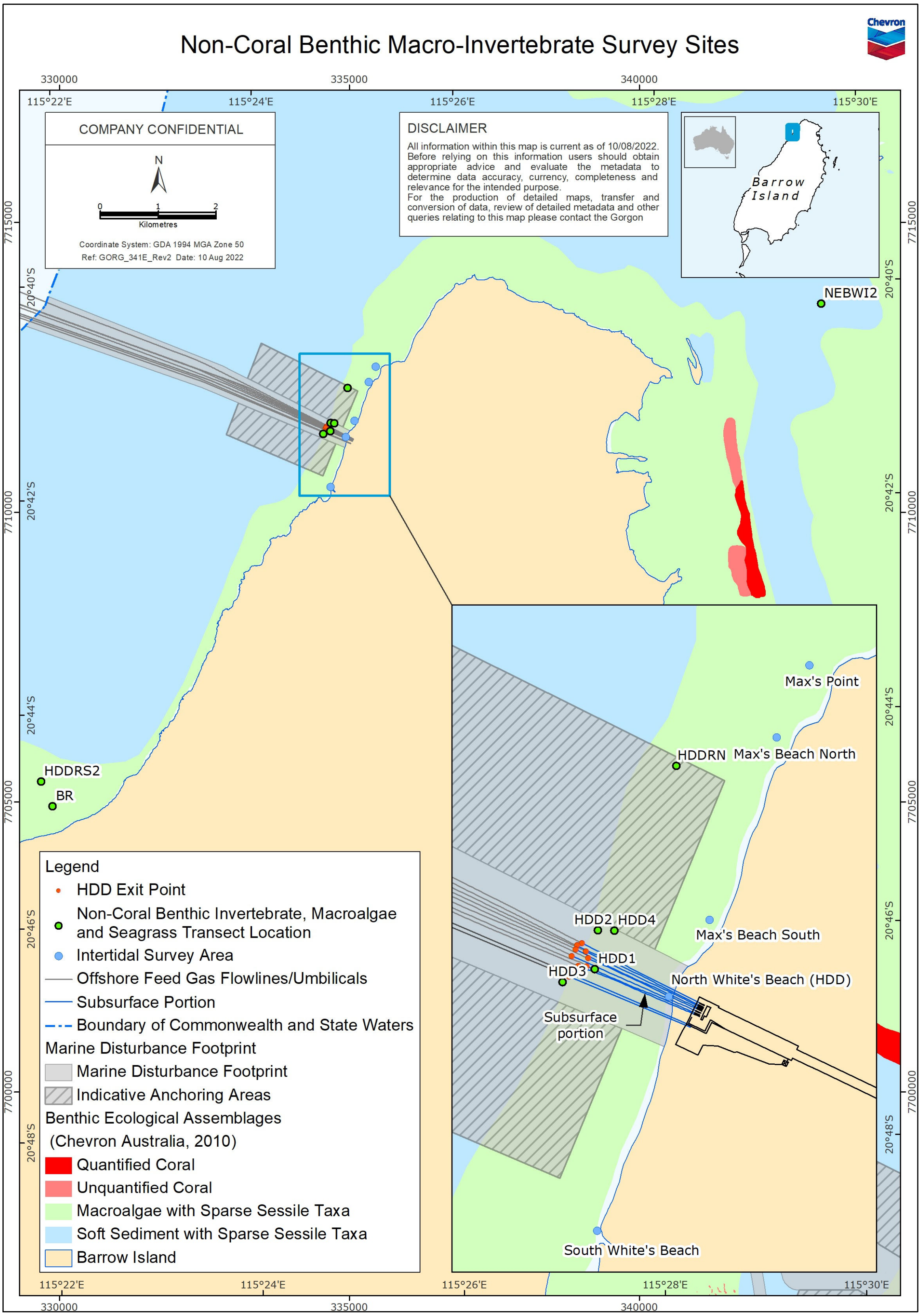

Non-Coral Benthic Macro-Invertebrate Survey Sites
COMPANY CONFIDENTIAL
N
Kilometres
Coordinate System: GDA 1994 MGA Zone 50
Ref: GORG_341E_Rev2 Date: 10 Aug 2022
DISCLAIMER
All information within this map is current as of 10/08/2022. Before relying on this information users should obtain appropriate advice and evaluate the metadata to determine data accuracy, currency, completeness and relevance for the intended purpose.
For the production of detailed maps, transfer and conversion of data, review of detailed metadata and other queries relating to this map please contact the Gorgon
Barrow Island
NEBWI2
HDDRS2
BR
Max's Point
HDDRN
Max's Beach North
HDD2
HDD4
Max's Beach South
HDD1
HDD3
North White's Beach (HDD)
Subsurface portion
South White's Beach
Legend
HDD Exit Point
Non-Coral Benthic Invertebrate, Macroalgae and Seagrass Transect Location
Intertidal Survey Area
Offshore Feed Gas Flowlines/Umbilicals
Subsurface Portion
Boundary of Commonwealth and State Waters
Marine Disturbance Footprint
Marine Disturbance Footprint
Indicative Anchoring Areas
Benthic Ecological Assemblages
(Chevron Australia, 2010)
Quantified Coral
Unquantified Coral
Macroalgae with Sparse Sessile Taxa
Soft Sediment with Sparse Sessile Taxa
Barrow Island
330000
335000
340000
115°22'E
115°24'E
115°26'E
115°28'E
115°30'E
7715000
7710000
7705000
7700000
20°40'S
20°42'S
20°44'S
20°46'S
20°48'S

Figure 7-1: Non-Coral Benthic Macroinvertebrate Survey Sites near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

7.3.2 Methods

Section 5.3 describes how the ecological elements associated with the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing were mapped.

At each pre-selected randomly chosen survey site, three 30 m long and 0.5 m wide belt transects were filmed using a diver-operated high definition video camera in a waterproof housing, with the lens maintained at a fixed distance of 50 cm from the substratum (Ref. 19). Each transect covered an area of approximately 15 m^2. The three transects were laid out at approximately 90° from a central clump weight deployed at each site. The coordinates of the start point of each transect were recorded using GPS. The variability within and among transects was estimated based on the preliminary field data collected in November 2008, to confirm that the proposed sampling design would adequately account for natural variability at these spatial scales.

Because the identification of soft corals and sponges to species level is often problematic, video footage was used to help describe the benthic macroinvertebrate assemblages at a broad taxonomic level (Ref. 79; P. Alderslade, pers. comm. RPS November 2008). However, as changes to assemblages may still be detected at this level (Ref. 80; Ref. 81), this broad level of information is considered appropriate as a baseline to determine the impacts of the disturbance associated with the HDD marine activities and installation of pipelines.

The qualitative intertidal survey involved identifying and recording the non-coral benthic macroinvertebrate species present, including visual identification and collecting or photographing samples for subsequent species-level identification (Ref. 78).

7.3.3 Timing and Frequency of Sampling

Sampling was undertaken in spring 2008 (November), late winter/early spring 2009 (September/ October), summer 2010 (March), and winter/early spring (August/ September/ October) 2010 (Table 7-1).

The qualitative intertidal survey at the HDD shore crossing was undertaken in February 2008 (Ref. 78).

7.3.4 Treatment of Survey Data

Video footage of transects was reviewed to:

- identify growth form of the sessile benthic macroinvertebrates (specifically sponges)
- identify family (where possible) of the sessile benthic macroinvertebrates
- estimate the abundance of the sessile benthic macroinvertebrates (i.e. numbers of individuals of each of the major benthic macroinvertebrates groups in each transect).

7.4 Results

7.4.1 Dominant Benthic Macroinvertebrates in West Coast Barrow Island Waters

The most commonly recorded (dominant) benthic macroinvertebrate taxa recorded in west coast Barrow Island waters from all baseline surveys combined included (Figure 7-2): sea whips, sponges (of varying morphology), hard corals (*Turbinaria* spp.), ascidians (colonial and solitary), hydroids, 'other' hard corals, and 'other' soft corals.

Dominant benthic macroinvertebrates per area (either at risk of Material or Serious Environmental Harm, or Reference Sites) are presented per survey for all baseline surveys in Table 7-3.

Table 7-3: Dominant Non-Coral Benthic Macroinvertebrate Taxonomic Groups per Area and per Survey during Baseline

Area	Nov 2008	Sept/Oct 2009	March 2010	Aug/Oct 2010
At risk of Material or Serious Environmental Harm	NS	Sea whips	Sponge (variable)	Sea whips
		Sponge (variable)	Ascidian (colonial)	Hydroids Sponge (variable)
		Turbinaria spp.	Hydroids 'Other' soft corals Sea whips	'Other' soft corals
		Ascidian (solitary)	Ascidian (solitary) 'Other' hard corals Sponge (cup) *Turbinaria* spp. Unidentified	Ascidian (colonial)
		Sponge (barrel) Sponge (fan)		'Other' hard corals Sponge (fan)
		Hydroids 'Other' hard corals 'Other' soft corals Unidentified		*Turbinaria* spp. Unidentified
				Anemones Ascidian (solitary) Gastropods Sponge (barrel)
Reference	Sponge (variable) *Turbinaria* spp.	Sea whips	Sea whips	Hydroids
	Sponge (fan)	'Other' soft corals	Sponge (variable)	Ascidian (colonial)
	'Other' hard corals	'Other' hard corals Sponge (fan) *Turbinaria* spp.	'Other' soft corals	*Turbinaria* spp.
	Crinoids	Sponge (cup) Sponge (variable)	*Turbinaria* spp.	Sea whips
	Sea whips	Crinoids Hydroids	'Other' hard corals	'Other' hard corals
	Ascidian (solitary) Gorgonians	Ascidian (colonial) Gorgonians	Sponge (fan) Hydroids	Sponge (variable)

<table>
<tr><th>Area</th><th>Nov 2008</th><th>Sept/Oct 2009</th><th>March 2010</th><th>Aug/Oct 2010</th></tr>
<tr><td rowspan="4"></td><td rowspan="4">Sea stars
Sponge (branching)
Sponge (cup)
Sponge (globular)
Sponge (Tubular)</td><td rowspan="4">Sponge (digitate)
Unidentified</td><td>Crinoids</td><td>‘Other’ soft corals</td></tr>
<tr><td>Ascidian (colonial)
Sponge (cup)</td><td>Sponge (fan)</td></tr>
<tr><td rowspan="2">Sponge (barrel)
Sea stars</td><td>Gorgonians</td></tr>
<tr><td>Sponge (branching)
Sponge (cup)</td></tr>
</table>

Notes:

Taxonomic group listed in order of abundance from highest to lowest

Multiple categories within a cell = categories with the same relative abundance

NS = Not Surveyed

Sponges were classified according to a morphological classification scheme (barrel-shaped sponges [*Xestospongia*], branching sponges, cup-shaped sponges, digitate sponges, fan/flabellate sponges, globular sponges, tubular sponges, or sponges with variable [irregular] morphologies) adapted from Bell and Barnes (Ref. 82).

The term ‘gorgonian’ is used in this Report to describe the densely reticulate sea fans growing in a single plane and with a rigid exoskeleton. The term ‘sea whip’ is used to describe the fleshy branching and unbranching soft corals (e.g. *Junceella* spp., *Rumphella* spp.).

Figure 7-2: Flat Limestone Pavement on Shallow Sand Veneer with Sparse Corals and Occasional Macroalgae

Note: 15% Turbinaria sp., 4% macroalgae.

Benthic macroinvertebrates were present in relatively low abundances on the limestone platforms at the HDD exit alignment survey sites, growing in mixed assemblages with macroalgae and occasionally seagrass. The most abundant taxa were sea whips (0.0 ± 0.0 to 27.0 ± 10.2 per 15 m^2 transect, or 0.0–1.8/m^2), hydroids (0.0 ± 0.0 to 18.0 ± 6.0 per 15 m^2 transect, or 0.0–1.2/m^2), ascidians (colonial) (0.0 ± 0.0 to 17.3 ± 5.5 per 15 m^2 transect, or 0.0–1.2/m^2), *Turbinaria* spp. (0.0 ± 0.0 to 11.7 ± 2.0 per 15 m^2 transect, or 0.0–0.8/m^2) and sponge (variable) 0.0 ± 0.0 to 5.7 ± 2.3 per 15 m^2 transect, or 0.0-0.4/m^2) with all remaining taxa recording fewer than 5.0 individuals per 15 m^2 transect or 0.3 individuals per 1 m^2 (Table 7-4 and Table 7-5). The most common taxa, in terms of numbers of sites at which they were recorded, were ‘other hard corals’ (eight sites), sea whips (seven sites), with sponges (variable) and ascidian (colonial) both recorded at six sites.

The intertidal areas on the north-west of Barrow Island are predominantly wave-cut algal-dominated rock flats fronting either steeply sloping beaches, or are remnants of older, higher wave-cut Late Pleistocene benches (Ref. 78). These habitats are typical of intertidal areas along the west coast of Barrow Island (Ref. 11). Surveys of the intertidal areas at five sites along the north-west of Barrow Island (South Whites Beach, North Whites Beach, Max’s Beach South, Max’s Beach North and Max’s Point) recorded 138 species of intertidal molluscs (Ref. 78). These included two species of polyplacophorans (*Acanthopleura gemmata*, *Acanthopleura spinosa*), 19 species of bivalve molluscs (e.g. *Barbatia* cf. *velata*, *Brachidontes ustulatus*, *Cardita variegata*, *Chama* sp., *Lithophaga nasuta*, *Nassarius sufflatus*, *Saccostrea cucullata*, *Septifer bilocularis*, *Thais aculeata*, *Tridacna maxima*), 109 species of prosobranch gastropods (e.g. *Angaria delphinus*, *Cellana radiata*, *Conus coronatus*, *Conus doreensis*, *Cronia avellana*, *Cypraea caputserpentis*, *Cypraea helvola*, *Cypraea moneta*, *Dendropoma* sp., *Drupa ricinus*, *Hipponix conicus*, *Mitrella albina*, *Stilifer* sp., *Strombus mutabilis*, *Tectus pyramis*, *Turbo haynesi*), three species of opisthobranchs (*Haminoea* sp., *Aplysia dactylomela*, *Aplysia* sp.), three species of heterobranchs (*Heliacus* sp., *Torinia* sp., *Pyramidellid* sp.) and two pulmonates (*Siphonaria* sp., *Onchidium* sp.). The intertidal macroinvertebrate fauna was moderately diverse and typical of exposed limestone shores of the West Pilbara, with most species widespread in the tropical Indo-West Pacific and Northern Australian regions (Ref. 78).

7.4.2 Distribution of Benthic Macroinvertebrates near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Figure 7-3 shows the spatial distribution of benthic macroinvertebrates near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing as point (presence/absence) observations derived from broadscale mapping (drop camera surveys and diver transect surveys). ‘Null observations’ were recorded where benthic macroinvertebrates were not observed. Maps showing the spatial distribution of benthic macroinvertebrates in Barrow Island waters, including the west coast, are presented in Ref. 47.

The substrate at all HDD exit alignment survey sites was a relatively flat limestone pavement with a sand veneer of varying, but generally shallow, depth. Non-coral benthic macroinvertebrates were the dominant ecological element at 3% of locations in the wider area surrounding the HDD exit alignment surveyed with a drop camera (Section 5.3.5.1.1), and represented on average <3% of the overall percentage cover near the HDD exit alignment (Sections 5.3.5.1.2 and 5.3.5.2.1).

Corals were recorded at two locations during the drop camera surveys (Section 5.3.5.1.1). There was sparse cover of soft corals at one location and medium cover of the hard coral *Turbinaria* sp. at a second location, represented by a single colony on sand. Near the Offshore Feed Gas Pipeline System in State Waters surveyed with a drop camera, non-coral benthic macroinvertebrates were the dominant ecological element at <4% of the locations (Section 5.3.5.3.1) and represented <0.5% of the overall percentage cover (Section 5.3.5.3.2).

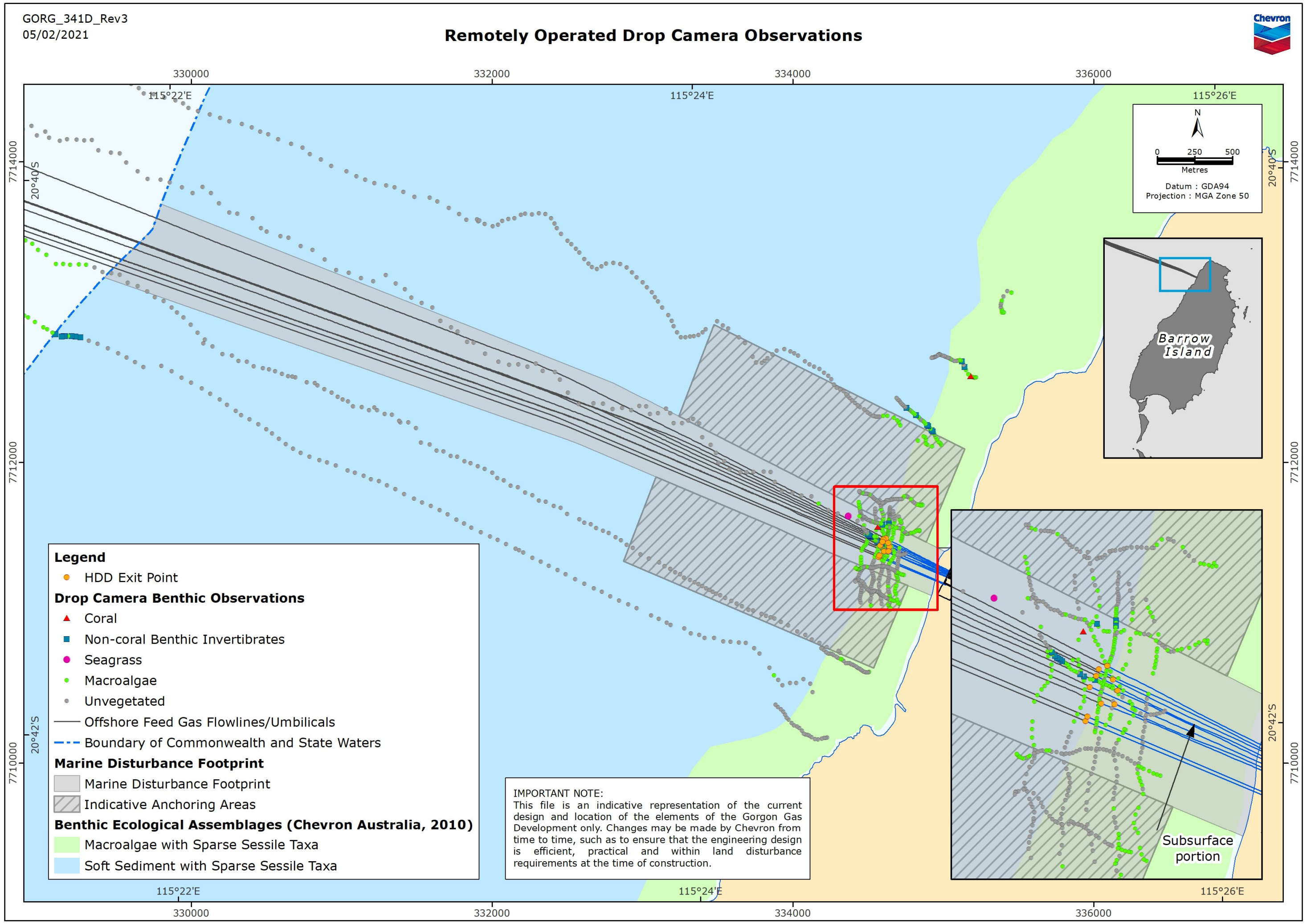


Figure 7-3: Observations of Benthic Macroinvertebrates in the MDF for the West Coast Marine Facilities, in Areas at Risk of Material or Serious Environmental Harm and in Areas not at Risk of Material or Serious Environmental Harm

7.4.3 Definition and Description of Benthic Macroinvertebrate Assemblages in the MDF associated with the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The benthic macroinvertebrates in the MDF associated with the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included anemones, ascidians, crinoids, gastropods, hydroids, other hard corals, other soft corals, sea stars, sea whips, sponges of various morphologies, and *Turbinaria* spp. (Table 7-4).

The highest total mean abundances of benthic macroinvertebrates were recorded in late winter/early spring 2009 at HDD2 (29.3 ± 14.9/15 m^2 transect or 2.0/m^2) and winter/early spring 2010 at HDD2 (15.7 ± 14.2/15 m^2 transect or 1/m^2) and HDD3 (15.7 ± 11.7/15 m^2 transect or 1/m^2) (Table 7-4; Figure 7-4). The lowest total mean abundances were recorded at HDD4 (0.3 ± 0.3/15 m^2 transect or 0.02/m^2) and HDD3 (0.7 ± 0.3/15 m^2 transect or 0.05/m^2) in late winter/early spring 2009, and at HDD4 (no recorded macroinvertebrates) and HDD2 (1.0 ± 1.0/15 m^2 transect or 0.07/m^2) in summer 2010. The sites with low abundances of benthic macroinvertebrates generally had a deeper sediment veneer (≥10 cm depth) overlaying the limestone pavement.

Sea whips were the most abundant taxa recorded in the late winter/early spring surveys of 2009 and 2010, with highest abundances recorded at HDD2 in 2009 (23.3 ± 12.2/15 m^2 transect or 1.6/m^2) and in 2010 (11.3 ± 10.8/15 m^2 transect or 0.8/m^2). Variable sponges were the most abundant taxa recorded in summer 2010 at HDD1 and HDD3 (1.7 ± 1.7/15 m^2 transect or 0.1/m^2 for both sites) (Table 7-4).

The hard coral *Turbinaria* spp. was recorded in low abundance (between 0.3 ± 0.3/15 m^2 transect or 0.02/m^2 and 1.0 ± 0.6/15 m^2 transect or 0.1/m^2) only at HDD1 and HDD2. There were five taxa recorded in abundances ≥2.0/15 m^2 transect (>0.1/m^2)—sea whips at HDD2 in late winter/early spring 2009 and 2010, and the other four (colonial ascidians, hydroids, other soft corals, and variable sponges) at HDD3 in winter/spring 2010.

The highest diversity of taxa (ten taxa) was recorded at HDD2 in late winter/early spring 2009 and at HDD3 in winter/spring 2010 (Table 7-4; Figure 7-4). The lowest diversities of taxa (two taxa or fewer) were recorded in summer 2010 (zero taxon) and in late winter/early spring 2009 (one taxon) at HDD4; all other sites each had two taxa recorded on one survey (late winter/early spring 2009: HDD3; winter/spring 2010: HDD1; and summer 2010: HDD2).

Table 7-4: Mean Benthic Macroinvertebrate Abundance ± SE per 30 m Transect (approximately 15 m^2) at Sites within the MDF and at Risk of Material or Serious Environmental Harm for each Sampling Occasion

Benthic Macroinvertebrate	Mean Abundance (± SE)											
	HDD1			HDD2			HDD3			HDD4		
	Sep 09	Mar 10	Aug/Oct 10	Sep 09	Mar 10	Aug/Oct 10	Sep 09	Mar 10	Aug/Oct 10	Sep 09	Mar 10	Aug/Oct 10
Anemone	—	—	—	—	—	0.7 ± 0.7	—	—	—	—	—	—
Ascidian (colonial)	—	0.7 ± 0.3	—	—	0.7 ± 0.7	—	—	0.3 ± 0.3	2.3 ± 2.3	—	—	—
Ascidian (solitary)	0.7 ± 0.7	—	—	0.3 ± 0.3	—	—	0.3 ± 0.3	0.3 ± 0.3	0.7 ± 0.3	0.3 ± 0.3	—	—
Bivalve	—	—	—	—	—	—	—	—	—	—	—	—
Crinoid	—	—	—	—	—	—	—	—	—	—	—	0.3 ± 0.3
Gastropod	—	—	—	—	—	0.7 ± 0.7	—	—	—	—	—	—
Gorgonian	—	—	—	—	—	—	—	—	—	—	—	—
Hydroid	—	—	—	0.3 ± 0.3	—	—	—	0.7 ± 0.7	3.7 ± 3.7	—	—	—
Nudibranch	—	—	—	—	—	—	—	—	—	—	—	—
Other hard coral	—	0.3 ± 0.3	—	0.3 ± 0.3	—	—	—	—	1.3 ± 0.9	—	—	0.3 ± 0.3
Other soft coral (e.g. Alcyoniidae)	—	—	—	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	—	0.3 ± 0.3	2.3 ± 2.3	—	—	—
Sea cucumber	—	—	—	—	—	—	—	—	—	—	—	—
Sea pen	—	—	—	—	—	—	—	—	—	—	—	—
Sea star	—	—	—	—	—	0.3 ± 0.3	—	—	—	—	—	—
Sea urchin	—	—	—	—	—	—	—	—	—	—	—	—
Sea whip	0.3 ± 0.3	0.7 ± 0.7	—	23.3 ± 12.2	—	11.3 ± 10.8	0.3 ± 0.3	—	1.7 ± 1.7	—	—	1.0 ± 1.0
Sponge (barrel)	—	—	—	0.7 ± 0.3	—	0.3 ± 0.3	—	—	0.3 ± 0.3	—	—	—
Sponge (branching)	—	—	—	—	—	—	—	—	—	—	—	—

Benthic Macroinvertebrate	Mean Abundance (± SE)											
	HDD1			HDD2			HDD3			HDD4		
	Sep 09	Mar 10	Aug/Oct 10	Sep 09	Mar 10	Aug/Oct 10	Sep 09	Mar 10	Aug/Oct 10	Sep 09	Mar 10	Aug/Oct 10
Sponge (cup)	—	—	—	—	—	—	—	0.3 ± 0.3	0.3 ± 0.3	—	—	—
Sponge (digitate)	—	—	—	—	—	—	—	—	—	—	—	—
Sponge (fan)	—	—	—	0.7 ± 0.7	—	1.0 ± 1.0	—	—	0.7 ± 0.7	—	—	—
Sponge (globular)	—	—	—	—	—	—	—	—	—	—	—	0.3 ± 0.3
Sponge (tubular)	—	—	—	—	—	—	—	—	—	—	—	—
Sponge (variable)	0.7 ± 0.7	1.7 ± 1.7	0.7 ± 0.7	2.0 ± 1.5	—	0.7 ± 0.7	—	1.7 ± 1.7	2.3 ± 0.3	—	—	—
Turbinaria spp.	0.7 ± 0.7	0.3 ± 0.3	—	1.0 ± 0.6	—	1.0 ± 0.6	—	—	—	—	—	—
Zoanthid	—	—	—	—	—	—	—	—	—	—	—	—
unidentified	—	—	0.7 ± 0.3	0.3 ± 0.3	—	—	—	0.3 ± 0.3	—	—	—	0.3 ± 0.3
Total	**2.3 ± 2.3**	**3.7 ± 1.7**	**1.3 ± 0.3**	**29.3 ± 14.9**	**1.0 ± 1.0**	**15.7 ± 14.2**	**0.7 ± 0.3**	**4.0 ± 2.5**	**15.7 ± 11.7**	**0.3 ± 0.3**	**0.0 ± 0.0**	**2.3 ± 2.3**
Total number of taxonomic groups	**4**	**5**	**2**	**10**	**2**	**9**	**2**	**7**	**10**	**1**	**0**	**5**

7.4.4 Definition and Description of Benthic Macroinvertebrate Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The benthic macroinvertebrates not at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included ascidians, crinoids, gorgonians, hydroids, other hard corals, other soft corals, sea stars, sea whips, sponges of various morphologies, and *Turbinaria* spp. (Table 7-5).

Low taxonomic diversity and abundances of benthic macroinvertebrates were recorded at HDDRS2 in winter/spring 2010 with only other hard corals (0.3 ± 0.3/15 m^2 transect or 0.02/m^2) (Table 7-5) recorded. The highest total mean abundances of benthic macroinvertebrates were recorded at NEBWI2 in winter/spring (62.0 ± 6.1/15 m^2 transect or 4.1/m^2) (Figure 7-4). Sea whips were the most abundant taxa recorded in both late winter/early spring 2009 (27.0 ± 10.2/15 m^2 transect or 1.8/m^2) and summer 2010 (20.7 ± 3.3/15 m^2 transect or 1.38/m^2). Three additional taxa were recorded in abundances >10/15 m^2 transect (0.7/m^2) in winter/spring 2010 at NEBWI2 (colonial ascidians, hydroids) and BR (*Turbinaria* spp.). Highest taxonomic diversity was recorded at NEBWI2 in winter/spring 2010 (15 taxa) and in spring 2008 (13 taxa); Site HDDRN also had 13 taxa in late winter/early spring 2009. NEBWI2 and HDDRN both had 12 to 15 taxa while BR and HDDRS2 had five or fewer taxa recorded.

Table 7-5: Mean Benthic Macroinvertebrate Abundance ± SE per 30 m Transect (approximately 15 m^2) at Reference Sites not at Risk of Material or Serious Environmental Harm for each Sampling Occasion

Benthic Macro-invertebrate	Mean Abundance (± SE)						
	NEBWI2		HDDRN		BR		HDDRS2
	Nov 08	Aug/ Oct 10	Sep/Oct 09	March 10	March 10	Aug/Oct 10	Aug/Oct 10
Anemone	—	—	—	—	—	—	—
Ascidian (colonial)	—	17.3 ± 5.5	0.3 ± 0.3	1.3 ± 0.3	—	0.3 ± 0.3	—
Ascidian (solitary)	0.3 ± 0.3	—	—	—	—	—	—
Bivalve	—	—	—	—	—	—	—
Crinoid	1.0 ± 1.0	0.7 ± 0.3	1.0 ± 0.6	1.7 ± 0.9	—	—	—
Gastropod	—	—	—	—	—	—	—
Gorgonian	0.3 ± 0.3	2.0 ± 0.6	0.3 ± 0.3	—	—	—	—
Hydroid	—	18.0 ± 6.0	1.0 ± 0.6	2.0 ± 1.5	—	—	—
Nudibranch	—	—	—	—	—	—	—
Other hard coral	1.7 ± 1.7	2.7 ± 0.3	2.0 ± 1.5	2.0 ± 0.6	0.3 ± 0.3	3.6 ± 0.7	0.3 ± 0.3
Other soft coral (e.g. Alcyoniidae)	—	1.7 ± 0.3	3.0 ± 1.0	4.7 ± 2.0	0.3 ± 0.3	1.3 ± 0.7	—
Sea cucumber	—	—	—	—	—	—	—

Benthic Macro-invertebrate	Mean Abundance (± SE)						
	NEBWI2		HDDRN		BR		HDDRS2
	Nov 08	Aug/ Oct 10	Sep/Oct 09	March 10	March 10	Aug/Oct 10	Aug/Oct 10
Sea pen	—	—	—	—	—	—	—
Sea star	0.3 ± 0.3	0.7 ± 0.3	—	0.7 ± 0.3	—	—	—
Sea urchin	—	—	—	—	—	—	—
Sea whip	0.7 ± 0.3	4.3 ± 0.9	27.0 ± 10.2	20.7 ± 3.3	—	2.7 ± 1.3	—
Sponge (barrel)	—	0.7 ± 0.3	—	0.7 ± 0.7	—	—	—
Sponge (branching)	0.3 ± 0.3	1.0 ± 0.6	—	—	—	—	—
Sponge (cup)	0.3 ± 0.3	1.0 ± 0.6	1.3 ± 0.7	1.3 ±0.9	—	—	—
Sponge (digitate)	—	0.3 ± 0.3	0.3 ± 0.3	—	—	—	—
Sponge (fan)	2.0 ± 0.6	2.3 ± 0.7	2.0 ± 0.6	2.0 ± 0.6	—	—	—
Sponge (globular)	0.3 ± 0.3	—	—	—	—	—	—
Sponge (tubular)	0.3 ± 0.3	—	—	—	—	—	—
Sponge (variable)	3.3 ± 1.2	5.7 ± 2.3	1.3 ± 0.3	5.7 ± 0.7	0.3 ± 0.3	—	—
Turbinaria spp.	3.3 ± 2.3	3.7 ± 3.7	2.0 ± 0.6	2.3 ± 1.2	0.7 ± 0.7	11.7 ± 2.0	—
Zoanthid	—	—	—	—	—	—	—
Unidentified	—	—	0.3 ± 0.3	—	—	—	—
Total	**14.3 ± 4.7**	**62.0 ± 6.1**	**42.0 ± 14.4**	**45.0 ± 7.6**	**1.7 ± 1.2**	**19.7 ± 2.4**	**0.3 ± 0.3**
Total number of taxonomic groups	**13**	**15**	**13**	**12**	**4**	**5**	**1**

Note: — indicates zero value recorded.

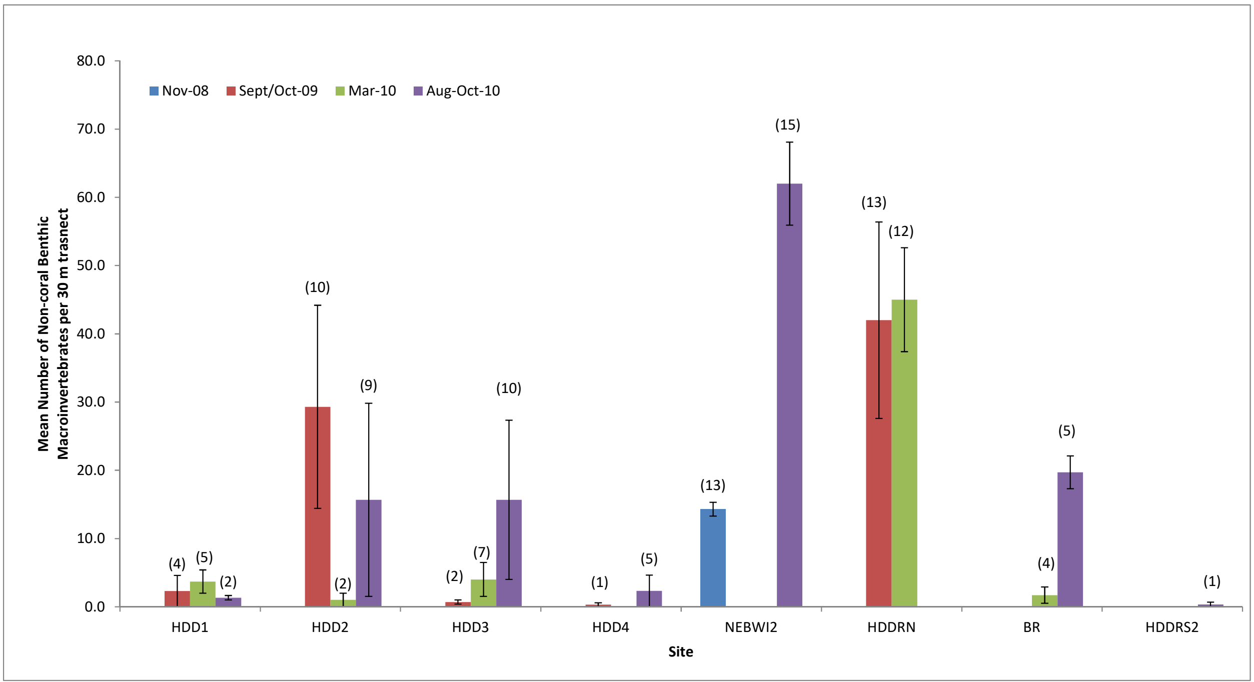


Figure 7-4: Mean Abundance (± SE) of Sessile Benthic Macroinvertebrates per 30 m Transect (15 m^2) at Survey Sites near the HDD Exit Alignment and Reference Sites for each Sampling Occasion

Note: Numbers in parentheses = the number of taxonomic groups recorded at each site and time (unidentified taxa included as a taxonomic group).

7.4.5 Definition and Description of Benthic Macroinvertebrate Assemblages at North Whites Beach

Few macroinvertebrates, including the littorinids (*Nodilittorina pyramidalis* and *Nodilittorina australis*) and the neritid gastropod *Nerita plicata*, were recorded on the rocky escarpment in the upper shore area of North Whites Beach (Ref. 78). Occasional siphonarian limpets (*Siphonaria* sp.) were recorded on the bare limestone pavement in the upper shore area, while mytilid bivalves (e.g. *Brachidontes ustulatus*) and balanid barnacles were recorded on the higher rock surfaces of the mid-shore area. The mid-shore area was also characterised by naticid gastropods (*Natica pseustes*, *Natica gualteriana*, and *Natica euzona*). Further seaward, on the mid-shore platform, there were a few crustaceans and the gastropods *Anachus miser*, *Mitrella albina*, *Pyrene* cf. *varians*, and *Turbo haynesi* were the most common species. The tubiculous gastropod *Dendropoma* sp. was common on bare pavement surfaces, and the bivalve *Brachidontes ustulatus* and the barnacle *Megabalanus* sp. were reported on high, bare pavement. The oyster *Saccostrea cucullata* was recorded on the tops of stones on the platform surface, along with the thaid *Thais aculeata*. There was a moderately diverse assemblage of cryptic macroinvertebrates, predominantly molluscs (e.g. several species of the cowry *Cypraea* spp.), but also species such as anemones, which were recorded on the undersides of boulders in this area, while holothurians were also common in the mid-shore. Several species of gastropods (e.g. *Angaria delphinus*, *Tectus pyramis*, *Strombus mutabilis*, *Cypraea moneta*, *Cypraea caputserpentis*, *Cronia avellana*, and *Conus doreensis*) were recorded in crevices on the pavement surface. The clam *Tridacna maxima* was present in shallow pools, but was not common. On the seaward side of the mid-shore platform, occasional *Echinometra mathaei* were recorded, while the echinoids *Diadema* *setosum*, *Echinothrix diadema*, and *Tripneustes gratilla*, were present in larger pools and areas of water around large rocks on the platform.

7.5 Discussion and Conclusions

Sessile benthic macroinvertebrates were present in relatively low abundances in west coast Barrow Island waters near the HDD exit alignment. Serious Environmental Harm, caused by the direct placement of the Marine Facilities on the seabed and physical removal of the substrate, is predicted to affect sessile benthic macroinvertebrates within the Marine Facilities Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The areas at risk of Material Environmental Harm include those areas within the MDF that are not within the Marine Facilities Footprint. The patchy distribution of benthic macroinvertebrates makes it difficult to estimate the total area of benthic macroinvertebrates that may be impacted as a consequence of the construction of the Marine Facilities on the west coast of Barrow Island. The Marine Facilities Footprint may potentially impact ~0.1 ha (~0.015%) of the total area of 'Macroalgae with Sparse Sessile Taxa' (≈665 ha) and ≈19 ha (≈1%) of 'Soft Sediments with Sparse Sessile Taxa' (≈3085 ha) in Management Unit 1 on the west coast of Barrow Island.[3] The MDF associated with the construction of the Marine Facilities may potentially impact up to ≈11.5 ha (~2%) of the total area of 'Macroalgae with Sparse Sessile Taxa' and ≈83.6 ha (~3%) of 'Soft Sediments with Sparse Sessile Taxa' in Management Unit 1.

There were no significant benthic macroinvertebrate assemblages observed near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The quantitative surveys on the west coast of Barrow Island indicated that the benthic macroinvertebrates assemblages differed to a degree between surveys, as well as between sites. Estimates of total abundances of benthic macroinvertebrates at Reference Sites NEBWI2 and HDDRN on the west coast were higher than those recorded at sites on the east coast of Barrow Island, while taxonomic diversity was slightly lower at west coast sites than at east coast sites (Ref. 29). However, there was no indication of differences in the taxonomic composition of benthic macroinvertebrates at sites in the MDF or at risk of Material or Serious Environmental Harm and at Reference Sites not at risk of Material or Serious Environmental Harm. All benthic macroinvertebrate taxa recorded at sites in the MDF and in areas at Risk of Material or Serious Environmental Harm were also recorded at Reference Sites and were well represented elsewhere in Barrow Island waters (Ref. 29).

[3] Fourteen Management Units were defined to assess impacts to benthic primary producer habitats associated with the Gorgon Gas Development—11 on Barrow Island and three on the mainland (Section 11.4, Ref. 11; Section 8.8, Ref. 12).

8 Macroalgae

8.1 Introduction

The macroalgal flora of tropical northern Australia are relatively poorly known compared to temperate regions and there have been few systematic collections undertaken to date (Ref. 83). A marine flora checklist for the Dampier Archipelago lists some 210 species, including 114 species of red algae (Rhodophyta), 50 species of green algae (Chlorophyta), 32 species of brown algae (Heterokontophyta, Phaeophyceae), and five species of blue-green algae (Cyanophyta) (Ref. 83). Fifty-seven were new records for Western Australia and five were new records for Australia. Ninety-one species of macroalgae were identified in Barrow Island waters during the Marine Baseline Program, including 35 species of red algae, 28 species of green algae, 27 species of brown algae, and one blue-green species (Cyanophyta) (Ref. 29).

The macroalgal assemblages are typically dominated by species of brown algae, particularly of the genera *Sargassum*, *Turbinaria*, and *Padina* (Ref. 11; Ref. 31). Other common taxa include *Halimeda*, *Dictyopteris*, *Dictyota*, *Cystoseira*, *Codium,* and *Laurencia*. Green algae from the genera *Caulerpa* and *Cladophora*, and red algae from the genera *Centroceras*, *Ceramium*, *Champia*, *Chondria*, *Gelidiopsis*, and *Hypnea* are dominant or widespread off the east coast of Barrow Island (Ref. 11; Ref. 31; Ref. 73). Some species, such as *Avrainvillea* sp. and *Halimeda macroloba*, appear to be restricted to the east coast of Barrow Island (Ref. 11). One species, *Gracilaria urvillei*, is known only from Barrow Island (Ref. 11).

Macroalgal-dominated limestone reef and subtidal reef platform/sand mosaic are the most extensive habitat types in the Montebello Islands/Barrow Island region (Ref. 31), including in the waters around Barrow Island (Ref. 29). During the Marine Baseline Program, macroalgal assemblages were commonly recorded on limestone pavement in depths of 5 to 10 m and were the most common ecological element along the shallow shelf off the east coast of Barrow Island and on the East Barrow Ridge (Ref. 29). Macroalgal assemblages were also common across the shallow limestone pavement of the Southern Lowendal Shelf that extends north towards the Montebello Islands. Macroalgae often co-occurred in lower abundance with seagrass and non-coral benthic macroinvertebrates. Macroalgae were not common on soft sediments and sparse percentage covers were recorded on substrate comprising thick sand veneer over limestone pavement and on sand, on the east coast of Barrow Island, with little-to-no macroalgae recorded in the deeper sand areas; e.g. between the broad, shallow limestone platform adjacent to the east coast of Barrow Island and the East Barrow Ridge (Ref. 29).

At North Whites Beach on the west coast of Barrow Island, macroalgae species grow on the shallow subtidal pavement reef at varying densities (Ref. 11). Macroalgae species are particularly dense in reef fissures and holes. Macroalgal beds are also found on the high profile reefs that stand up to three metres above the seabed in nearshore waters of approximately 5 to 10 m water depth (Ref. 11). The macroalgal assemblages found on the limestone reef off North Whites Beach include *Sargassum* spp., *Dictyopteris* spp., and *Halimeda* spp. (Ref. 11).

The extensive subtidal macroalgae communities are major benthic primary producers, significantly contributing to the productivity of the region, as well as providing refuge areas for fish and invertebrates (Ref. 31). Macroalgal habitats in the Montebello Islands/Barrow Island region vary seasonally in response to water temperature, day length, reproductive cycles, physical disturbance, and regrowth (Ref. 31; Ref. 29).

8.2 Scope

This Section records the existing dominant species of macroalgae (Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes/defines and maps the macroalgae:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.iii, MS 800; Condition 11.6.III EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.iv, MS 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

8.3 Methods

8.3.1 Site Locations

As part of the Marine Baseline Program for the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, eight macroalgal survey sites were selected within those areas where macroalgae were identified as being present through broadscale habitat mapping on the west coast of Barrow Island (Section 5.3). The sites were all located on relatively flat limestone pavement with a sand veneer of varying, but generally shallow, depth. Four of the sites were selected based on their proximity to the HDD exit alignment (Table 8-1; Figure 8-1)—one site (HDD1) was located within the Marine Facilities Footprint, one was located north (HDD2) and one south (HDD3) of the Marine Facilities Footprint within the MDF in the area at Risk of Material or Serious Environmental Harm, and the fourth site (HDD4) was located at the edge of the MDF, north of the HDD exit alignment. Two Reference Sites, which are not expected to be impacted by the HDD marine activities and therefore are not at Risk of Material or Serious Environmental Harm, were located south of the HDD exit alignment (Biggada Reef [BR] and HDDRS2) and two Reference Sites were located north of the HDD exit alignment (NEBWI1 and HDDRN). The Site BR was surveyed at an alternative location in July 2009; subsequent surveys returned to the initial location Site HDDRS2 was added in the August/October 2010 survey, as site HDDRN was inaccessible. Note: It is anticipated that anchoring within the indicative anchoring area will be managed such that there will be no impact at the Reference Site HDDRN.

Table 8-1: West Coast Macroalgal Survey Sites and Survey Dates

Site Code		Easting	Northing	Latitude	Longitude	Survey Date				
		(GDA94, MGA Zone 50)		(GDA94)		Nov 08	Jul 09~	Sep 09	Mar 10	Aug-Oct 10
At risk of Material or Serious Environmental Harm	HDD1	334666	7711398	20° 41.374' S	115° 24.755' E			X	X	X
	HDD2	334677	7711541	20° 41.297' S	115° 24.762' E			X	X	X
	HDD3	334548	7711351	20° 41.399' S	115° 24.686' E			X	X	X
	HDD4	334738	7711539	20° 41.298' S	115° 24.797' E			X	X	X
Reference Sites	HDDRN	334965	7712144	20° 40.972' S	115° 24.931' E			X	X	
	BR	329877	7704929	20° 44.855' S	115° 21.959' E	X	X~		X	X
	NEBWI1	343959	7716235	20° 38.801' S	115° 30.132' E	X				X
	HDDRS2	329675	7705354	20° 44.623' S	115° 21.845' E					X

Note

~ Site BR data from July 2009 was collected approximately 650 m from the initial site at the following coordinates: 20° 44.774' S (7705071)/ 115° 21.589' E (329234)

Macroalgal survey sites were also seagrass and benthic macroinvertebrate survey sites where these ecological elements co-occurred in the same area.

Qualitative intertidal surveys were undertaken at the HDD shore crossing at North Whites Beach, at three sites located to the north (Max's Point, Max's Beach North, Max's Beach South) and one to the south of the HDD shore crossing (South Whites Beach) (Table 8-2) (Ref. 78).

Table 8-2: Qualitative Intertidal Survey Sites near the HDD Shore Crossing

Site Name		Easting	Northing	Latitude	Longitude
		(GDA94, MGA Zone 50)		(GDA94)	
At risk of Material or Serious Environmental Harm	North Whites Beach (HDD)	334938	7711298	20° 41.430' S	115° 24.910' E
Reference Sites	Max's Point	335453	7712513	20° 40.774' S	115° 25.214' E
	Max's Beach North	335333	7712248	20° 40.917' S	115° 25.144' E
	Max's Beach South	335087	7711579	20° 41.279' S	115° 24.998' E
	South Whites Beach	334675	7710438	20° 41.895' S	115° 24.754' E

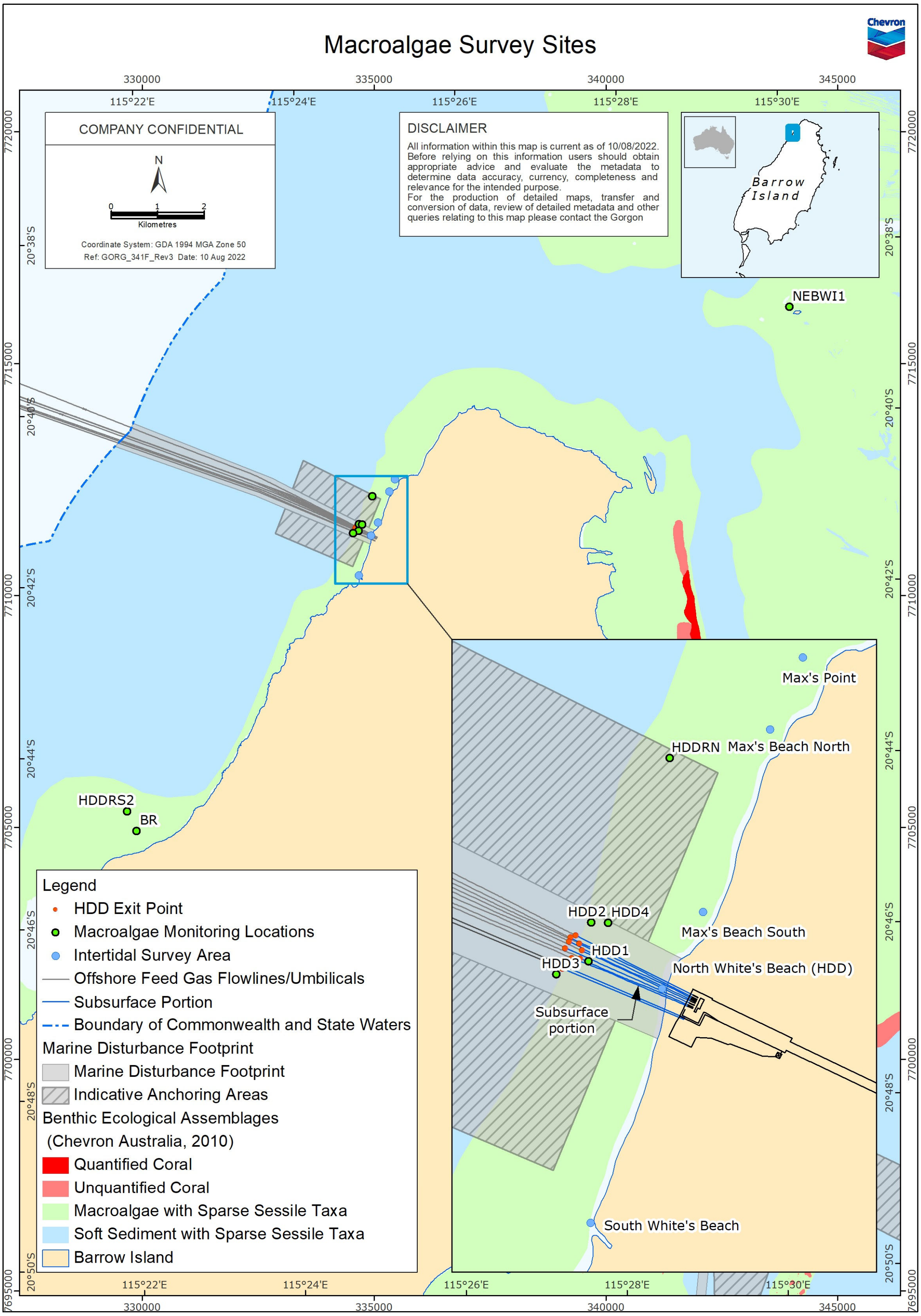

Macroalgae Survey Sites
COMPANY CONFIDENTIAL
N
0 1 2
Kilometres
Coordinate System: GDA 1994 MGA Zone 50
Ref: GORG_341F_Rev3 Date: 10 Aug 2022
DISCLAIMER
All information within this map is current as of 10/08/2022. Before relying on this information users should obtain appropriate advice and evaluate the metadata to determine data accuracy, currency, completeness and relevance for the intended purpose.
For the production of detailed maps, transfer and conversion of data, review of detailed metadata and other queries relating to this map please contact the Gorgon
Barrow Island
NEBWI1
HDDRS2
BR
Max's Point
HDDRN
Max's Beach North
HDD2
HDD4
Max's Beach South
HDD1
HDD3
North White's Beach (HDD)
Subsurface portion
South White's Beach
Legend
HDD Exit Point
Macroalgae Monitoring Locations
Intertidal Survey Area
Offshore Feed Gas Flowlines/Umbilicals
Subsurface Portion
Boundary of Commonwealth and State Waters
Marine Disturbance Footprint
Marine Disturbance Footprint
Indicative Anchoring Areas
Benthic Ecological Assemblages
(Chevron Australia, 2010)
Quantified Coral
Unquantified Coral
Macroalgae with Sparse Sessile Taxa
Soft Sediment with Sparse Sessile Taxa
Barrow Island
330000
335000
340000
345000
115°22'E
115°24'E
115°26'E
115°28'E
115°30'E
7720000
7715000
7710000
7705000
7700000
7695000
20°38'S
20°40'S
20°42'S
20°44'S
20°46'S
20°48'S
20°50'S

Figure 8-1: Macroalgal Survey Sites near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

8.3.2 Methods

Mapping of the ecological elements associated with the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing is described in Section 5.3.

At each pre-selected randomly chosen survey site, three 30 m length transects were laid out from a central clump weight (Ref. 19). The three transects were laid out at approximately 90° from the central clump weight. The coordinates of the start point of each transect were recorded using GPS.

A total area of 1 m^2 (either a single 1 m^2 quadrat or four 0.25 m^2 quadrats forming a square covering a total of 1 m^2) was photographed at 5 m intervals along the right side of each transect (i.e. a total of seven locations along each transect). The species of macroalgae present in each quadrat were also recorded. The macroalgae species present in each quadrat were identified to the lowest reliable taxonomic level (to genus and species level where possible). Voucher samples of those species that could not be reliably identified in the field were collected, preserved and catalogued for identification by Dr John Huisman (Murdoch University, Western Australia).

The macroalgae in replicate 0.25 m^2 quadrats were collected for measurement of total biomass. In November 2008 and September 2009, one 0.25 m^2 quadrat was sampled at 10 m and at 20 m intervals on the left side of each transect (i.e. a total of six biomass samples per site). Note: Macroalgal biomass was not recorded at the Biggada Reef site in November 2008 due to restrictions on field times. In July 2009, March 2010, and August/October 2010, two 0.25 m^2 quadrats were sampled at 10 m and 20 m intervals along each transect (i.e. a total of 12 biomass samples per site). If a quadrat was located on bare sand, no biomass sample was collected. Samples were blot-dried and total wet weight was recorded.

The qualitative intertidal survey involved the identification and recording of the macroalgae species present, including visual identification and collection or photography of samples for subsequent species-level identification (Ref. 78).

8.3.3 Timing and Frequency of Sampling

Sampling was undertaken in spring 2008 (November), winter 2009 (July), late winter/early spring 2009 (September/October), late summer 2010 (March), and winter/spring (August/September/October) 2010 (Table 8-1).

The qualitative intertidal survey at the HDD shore crossing was undertaken in February 2008 (Ref. 78).

8.3.4 Treatment of Survey Data

Digital images were analysed using Coral Point Count with Excel extensions (CPCe) (Ref. 53). Either 30 (for a single 1 m^2 quadrat) or 32 (for four 0.25 m^2 quadrats) random points were overlain over the image and each point visually classified into the broad categories of benthic cover (macroalgae, seagrass, turf algae, coral, non-coral benthic macroinvertebrates, sand, pavement, rubble, and unidentified). The percentage of all points scored as each benthic ecological element per photograph was calculated and the average (± SE) percentage cover of dominant ecological elements was determined.

Any quadrats with zero biomass values from the Marine Baseline Program were removed and the mean ± SE for each site was calculated. The biomass is used as a measure of macroalgae health, rather than a secondary measure of cover.

8.4 Results

8.4.1 Macroalgae in West Coast Barrow Island Waters

Different survey techniques were used for the various components of the Marine Baseline Program, including broadscale mapping (Section 5.1) and small-scale quantitative sampling. These all contributed to the systematic compilation of the macroalgae reported in west coast Barrow Island waters. The macroalgal taxa recorded during surveys near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing are listed in Table 8-3 (refer also to Figure 8-2).

Table 8-3: Macroalgae Species Identified in Surveys near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Division		
Rhodophyta	**Phaeophyta**	**Chlorophyta**
Champia stipitata	*Dictyopteris serrata*	*Caulerpa brachypus*
Chondria sp.	*Dictyopteris* sp.	*Caulerpa cactoides*
Cliftonaea pectinata	*Lobophora variegata*	*Caulerpa cupressoides*
Coelarthrum cliftonii	*Padina* spp.	*Caulerpa mexicana*
Coelarthrum opuntia	*Sargassopsis decurrens*	*Caulerpa taxifolia*
Corynomorpha prismatica	*Sargassum peronii*	*Caulerpa* sp.
Crustose coralline algae	*Sargassum spinuligerum*	*Cladophora vagabunda*
Dasya sp. 1	*Sargassum* spp.	*Cladophora* sp.
Dasya sp. 2	*Spatoglossum macrodontum*	*Halimeda cuneata*
Desikacharyella indica	*Sphacelaria rigidula*	*Halimeda discoidea*
Dichotomaria obtusata	Unidentified Phaeophyceae	*Halimeda* sp.
Dichotomaria sp.		*Siphonocladus tropicus*
Erythroclonium elongatum		
Erythroclonium sonderi		
Galaxaura sp.		
Gracilaria sp.		
Griffithsia sp.		
Haliptilon roseum		
Heterosiphonia crassipes		
Herposiphonia sp.		
Jania adhaerens		
Laurencia sp.		
Lophosiphonia prostrata		
Martensia sp.		

Division		
Rhodophyta	**Phaeophyta**	**Chlorophyta**
Micropeuce sp.		
Solieria robusta		
Polysiphonia sp.		
Scinaia tsinglanensis		
Spyridia hypnoides		
Tricleocarpa cylindrica		

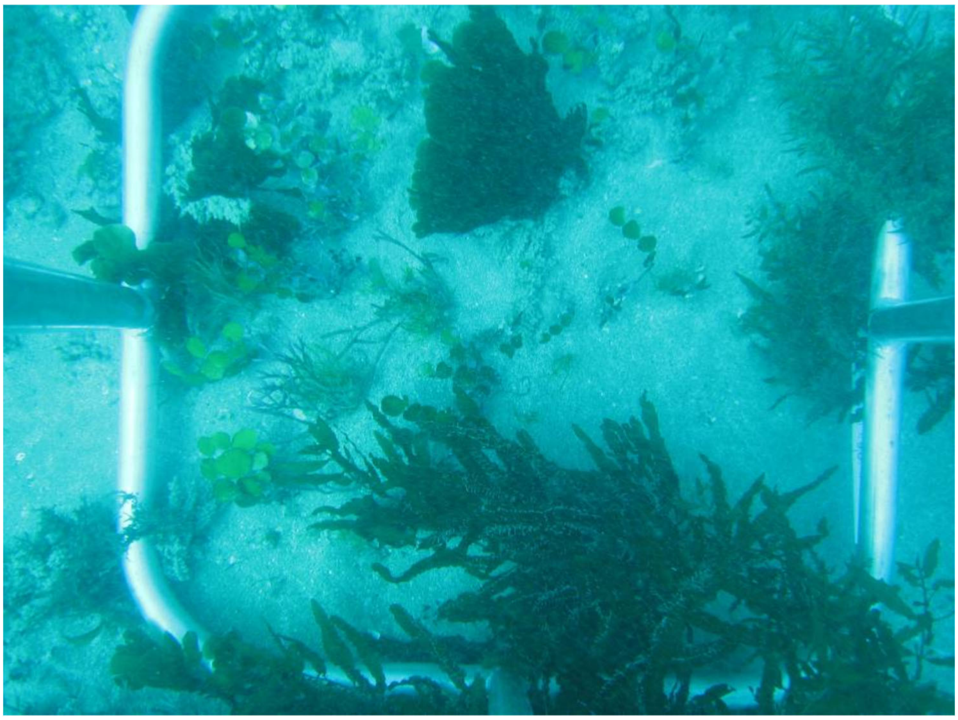


Figure 8-2: Flat Limestone Pavement with Shallow Sand Veneer, with Medium Cover of Macroalgae, in the Immediate Vicinity of HDD Exit Alignment

Note: 30% Sargassum sp., 23% Halimeda cuneata and 20% Unidentified Phaeophyceae.

Species recorded during surveys at Biggada Reef (BR) included: Rhodophyta: *Acrochaetium* sp., *Anotrichium tenue*, *Champia parvula*, *Champia* sp., *Chondria* sp., *Chondrophycus* sp., Corallinaceae, *Cottoniella filamentosa*, *Dasya* sp., *Desikacharyella indica*, *Dichotomaria* sp., *Galaxaura* sp., *Gayliella flaccida*, *Griffithsia* sp., *Haliptilon roseum*, *Herposiphonia secunda*, *Heterosiphonia callithamnion*, *Jania rosea*, *Jania* sp., *Laurencia* sp., *Polysiphonia* sp., *Spyridia filamentosa*, *Tolypiocladia glomerulata*; Phaeophyta: *Dictyopteris australis*, *Dictyopteris woodwardia*, *Dictyota* sp., *Encyothalia cliftonii*, *Feldmannia* sp., *Hincksia mitchelliae*, *Hormophysa cuneiformis*, *Lobophora variegata*, *Padina sanctae-crucis*, *Padina* sp., turfing Phaeophyceae sp., *Sirophysalis trinodis*, *Sargassopsis decurrens*, *Sargassum* sp. 1, *Sphacelaria rigidula, Spatoglossum macrodontum*; Chlorophyta: *Caulerpa corynephora*, *Caulerpa cupressoides*, *Cladophora vagabunda, Halimeda cf. cuneata, Calothrix* sp.*, Halimeda discoidea*, and *Udotea flabellum.*

Species recorded during surveys at NEBWI1 included: Rhodophyta: *Aglaothamnion cordatum*, *Amphiroa* sp.*, Asparagopsis taxiformis*, *Champia parvula*, *Champia* sp., *Chondria* sp., *Cladurus alternifera, Coelarthrum cliftonii*, *Coelarthrum opuntia, Corynomorpha prismatica, Dasya* sp.*, Desikacharyella* sp.*, Dudresnaya* sp.*, Galaxaura rugosa*, *Gracilaria* sp., *Heterosiphonia callithamnion*, *Hypnea pannosa, Jania rosea*, *Leveillea jungermannioides*, *Lophocladia* sp., *Placophora binderi*, *Platysiphonia delicata*, *Polysiphonia* sp., *Scinaia tsinglanensis,* and *Sebdenia flabellata;* Phaeophyta*: Dictyopteris serrata*, *Dictyopteris woodwardia*, *Hincksia mitchelliae*, *Hydroclathrus clathratus*, *Lobophora variegata, Padina* sp., *Sargassopsis decurrens*, *Sargassum oligocystum, Sargassum spinuligerum, Sargassum* sp. 1, *Spatoglossum macrodontum*, *Sirophysalis trinodis*, *Sphacelaria rigidula*, *Sporochnus comosus*, *Sporochnus* sp.*; Chlorophyta: Caulerpa corynephora*, *Caulerpa cupressoides*, *Caulerpa lentillifera, Caulerpa mexicana, Caulerpa racemosa f. laetevirens, Halimeda* cf. *discoidea*, and *Ulva paradoxa.*

Note: Macroalgae species lists for Sites BR and NEBWI1 are also reported in the Coastal and Marine Baseline State and Environmental Impact Report (MOF, Jetty, DSDG) but only include survey results up to July 2009 (Ref. 29).

Species recorded during one survey at HDDRS2 included: Phaeophyta: *Hormophysa cuneiformis, Lobophora variegata, Padina* sp.*, Sargassopsis decurrens, Sargassum* sp., and *Sporochnus* sp.; Chlorophyta: *Avrainvillea nigricans* and *Halimeda discoidea.*

The intertidal areas on the north-west of Barrow Island are predominantly wave-cut algal-dominated rock flats fronting either steeply sloping beaches or remnants of older, higher wave-cut Late Pleistocene benches (Ref. 78). These habitats are typical of intertidal areas along the west coast of Barrow Island (Ref. 11). Surveys of the intertidal areas at five sites along the north-west of Barrow Island (South Whites Beach, North Whites Beach, Max's Beach South, Max's Beach North, and Max's Point) recorded 78 species of macroalgae, including 42 red algae (e.g. *Acanthophora spicifera*, *Centroceras clavulatum*, *Chondrophycus papillosus*, *Eucheuma denticulatum*, *Gracilaria salicornia*, *Hypnea cervicornis*, *Jania adhaerens*, *Laurencia* sp., *Leveillea jungermannioides*, *Yamadaella caenomyce*), 19 green algae (e.g. *Anadyomene plicata*, *Boergesenia forbesii*, *Boodlea composita*, *Caulerpa racemosa*, *Caulerpa sertularioides*, *Halimeda discoidea*), 17 brown algae (e.g. *Cystoseira* sp., *Sirophysalis trinodis*, *Dictyota ciliolata*, *Padina australis*, *Padina boryana*, *Sargassum myriocystum*) and one cyanobacterium (Ref. 78). Generally the composition of the macroalgal assemblages was similar at all sites, although the densities of some species was variable, e.g. southern sites had a lower diversity of *Sargassum* species, primarily *S. myriocystum*, while *S. myriocystum*, *S. oligocystum*, *S.* cf. *thunbergii* and *Sargassum* sp. were recorded at northern sites. Common species at all sites were *Sirophysalis trinodis* and *Cystoseira* sp. Virtually all other species were recorded in low densities.

The intertidal survey at North Whites Beach identified 46 species of macroalgae, including 19 red algae (e.g. *Actinotrichia fragilis*, *Amphiroa anceps*, *Ceramium isogonum*, *Digenea simplex*, *Hydropuntia urvillea*, *Sarconema filiforme*), 16 green algae (e.g. *Bryopsis indica*, *Cladophora herpestica*, *Cladophora vagabunda*, *Chaetomorpha gracilis*, *Neomeris vanbosseae*, *Struvea plumosa*, *Valoniopsis* *pachynema*) and 11 brown algae (e.g. *Sargassopsis decurrens*, *Sargassum oligocystum*, *Sargassum* cf. *thunbergii*, *Sphacelaria rigidula*) (Ref. 78).

8.4.2 Dominant Macroalgae in West Coast Barrow Island Waters

The dominant (or most common) macroalgae in terms of percentage cover recorded in west coast Barrow Island waters were the brown algae (*Sargassum* and *Dictyopteris* spp.) and the green alga (*Halimeda* spp.). The three most common species recorded at the HDD exit alignment survey sites were *Halimeda discoidea*, *Lobophora variegata*, and *Sargassum* sp. Less common species recorded at these sites included *Caulerpa cactoides* and *Dictyopteris serrata*.

Table 8-4: Macroalgae Dominant and Subdominant per Survey and per Site

Area	Site	Species	Nov 2008	2009*	March 2010	Aug/Oct 2010
At risk of Material or Serious Environmental Harm	HDD1	Dominant	NS	*Lobophora variegata*	*Sargassum* spp.	*Lobophora variegata*
		Subdominant	NS	*Sargassum* sp. *Dictyopteris* sp. *Dichotomaria obtusata* *Halimeda discoidea*	*Dictyopteris* spp. *Lobophora variegata* *Sporochnus comosus*[1] *Halimeda discoidea*	*Sargassum* spp. *Dictyopteris* spp.[1]
	HDD2	Dominant	NS	*Sargassum* spp.	*Sargassum* spp.	*Lobophora variegata*[1]
		Subdominant	NS	*Dictyopteris serrata* *Lobophora variegata* *Halimeda discoidea*	*Lobophora variegata*	*Dictyopteris serrata* *Halimeda discoidea* *Haliptilon roseum*
	HDD3	Dominant	NS	*Sargassum* spp.	*Sargassum* spp.	*Sargassum spinuligerum*
		Subdominant	NS	*Lobophora variegata* Dictyopteris sp.[1]	*Lobophora variegata* *Halimeda discoidea* *Sporochnus comosus*[1] *Dictyopteris serrata*	*Lobophora variegata* *Dictyopteris serrata*
	HDD4	Dominant	NS	*Sargassum* spp.	*Sargassum* spp.	*Dictyopteris serrata*
		Subdominant	NS	*Lobophora variegata* *Dictyopteris* spp.[1] *Dichotomaria obtusata*	*Dictyopteris serrata* *Lobophora variegata* *Halimeda discoidea* *Dichotomaria obtusata* *Sporochnus comosus*[1]	*Lobophora variegata* *Sargassum* spp. *Dichotomaria* sp.
Reference Sites	HDDRN	Dominant	NS	*Dictyopteris serrata* *Dictyopteris* sp.	*Sargassum* spp.	NS
		Subdominant	NS	*Lobophora variegata* *Halimeda discoidea* *Encyothalia cliftonii*[1]	*Halimeda discoidea* Sporochnus comosus[1] Dictyopteris spp. Lobophora variegata	NS

Area	Site	Species	Nov 2008	2009*	March 2010	Aug/Oct 2010
	BR	Dominant	*Sargassum* spp.	*Sargassum* spp. *Dictyopteris woodwardii*	*Sargassum* spp.	*Halimeda discoidea*
		Subdominant	*Halimeda* cf. *cuneata* *Caulerpa corynephora* *Caulerpa cupressoides*	*Halimeda* cf. *cuneata* *Caulerpa corynephora* *Caulerpa cupressoides*	*Sirophysalis trinodis*[1,2] *Dictyopteris* spp. *Halimeda discoidea*	*Sirophysalis trinodis*[2] *Sargassum* spp. *Lobophora variegata*
	NEBWI1	Dominant	*Sargassum* spp.	NS	NS	*Sargassum* spp.
		Subdominant	*Halimeda* cf. *discoidea* *Dictyopteris serrata* *Dictyopteris woodwardii*	NS	NS	*Halimeda discoidea*[1] *Sporochnus* sp. *Chondria* sp.
	HDDRS2	Dominant	NS	NS	NS	*Sargassum* spp.
		Subdominant	NS	NS	NS	*Sporochnus* sp. *Lobophora variegata* *Padina* sp.

Notes

NS *Site not surveyed*

1 *Species/taxa were visually identified from photoquadrats by BMT Oceanica's nominated taxonomic expert; samples of these species were not collected and therefore identities have not been confirmed by Dr John Huisman*

2 *Previously known as Cystoseira trinodis*

*** *Site BR surveyed in July 2009; Sites HDD1 to HDD4 and HDDRN surveyed in September 2009*

~ *Site BR data from July 2009 was collected approximately 650 m from the initial site at these coordinates: 20° 44.774' S (7705071)/ 115° 21.589' E (329234)*

8.4.3 Distribution of Macroalgae near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Figure 8-3 shows the spatial distribution of macroalgae near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing as point (presence/absence) observations derived from broadscale mapping (dropped camera surveys and diver transect surveys). 'Null observations' were recorded where macroalgae were not observed. Maps showing the spatial distribution of macroalgae in Barrow Island waters, including the west coast, are presented in Ref. 47.

The substrate at all HDD exit alignment survey sites was a relatively flat limestone pavement with a sand veneer of varying, but generally shallow, depth. Macroalgae were the dominant ecological element at 41% of the locations in the wider area surrounding the HDD exit alignment surveyed with a drop camera (Section 5.3.5.1.1). Where macroalgae were the dominant ecological element, the average percentage cover was 28 ± 5%, with the overall average across all analyses 10 ± 2% (Section 5.3.5.1.2). Near the Offshore Feed Gas Pipeline System in State Waters surveyed with a drop camera, macroalgae were the dominant ecological element at 10% of the locations, but macroalgae cover was generally sparse where macroalgae occurred (Section 5.3.5.3.1).

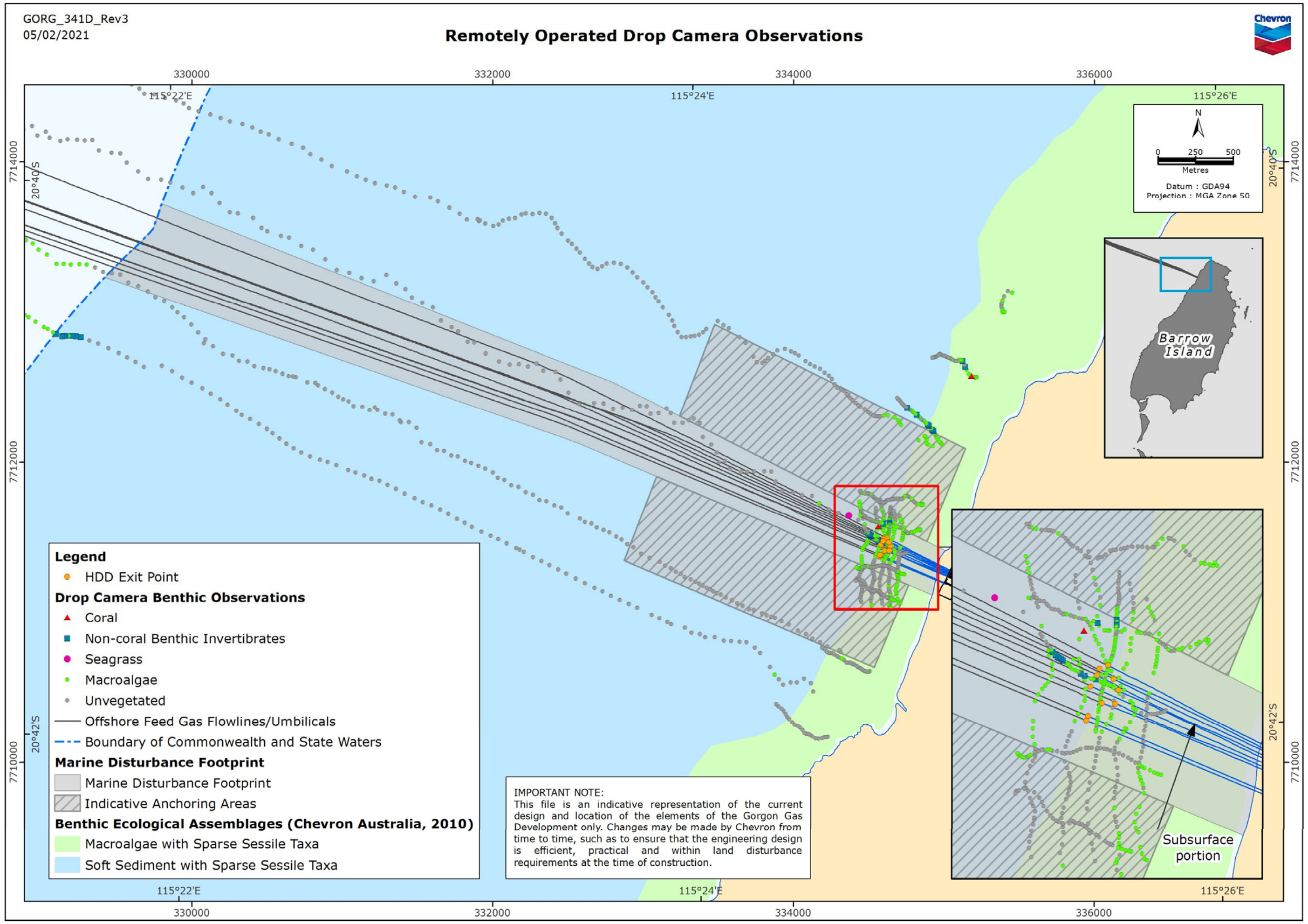


Figure 8-3: Observations of Macroalgae in the MDF for the West Coast Marine Facilities, in Areas at Risk of Material or Serious Environmental Harm and in Areas not at Risk of Material or Serious Environmental Harm

8.4.4 Definition and Description of Macroalgal Assemblages in the MDF Associated with the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The macroalgae in the MDF associated with the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included: Rhodophyta: *Champia stipitata*, *Chondria* sp., *Cliftonaea pectinata*, *Coelarthrum cliftonii, Coelarthrum opuntia*, *Corynomorpha prismatica, Dasya* sp. 1, *Dasya* sp. 2, *Dichotomaria* sp., *Dichotomaria obtusata*, *Erythroclonium elongatum*, *Erythroclonium sonderi*, *Gracilaria* sp., *Griffithsia* sp., *Jania adhaerens*, *Haliptilon roseum, Heterosiphonia crassipes, Laurencia* sp., *Martensia* sp., *Micropeuce* sp., *Polysiphonia* sp., *Scinaia tsinglanensis, Solieria robusta*, *Spyridia hypnoides*, *Tricleocarpa cylindrica; Phaeophyta: Dictyopteris serrata*, *Dictyopteris* sp., *Lobophora variegata, Padina* sp., *Sargassum peronii, Sargassum* sp., *Sargassum spinuligerum, Spatoglossum macrodontum*, *Sphacelaria rigidula*, and *Spyridia hypnoides*; Chlorophyta: *Caulerpa brachypus*, *Caulerpa cactoides*, *Caulerpa cupressoides, Caulerpa mexicana, Caulerpa taxifolia*, *Cladophora vagabunda, Cladophora* sp., *Halimeda discoidea,* and *Siphonocladus tropicus* (Table 8-5).

Estimates of mean macroalgal percentage cover at the HDD exit alignment survey sites in the MDF varied between ≈4% and 18% in winter/spring 2010 and ≈7% to 30% in summer, with the highest percentage cover recorded at HDD1 in late winter/early spring and at HDD4 in summer (Table 8-6). Estimates of mean macroalgae biomass varied between ≈68 and 987 g wet weight/m^2 in late winter/early spring 2010 and ≈600 to 1406 g wet weight/m^2 in summer (Figure 8-4). The highest mean biomass was recorded at HDD3 in summer. Except for HDD2, both mean percentage cover and mean biomass were higher in summer than in late winter/early spring 2009 and winter/spring 2010. Highest species diversity was recorded at HDD3 in winter/spring 2010 (21 species) and HDD2 (19 species), and the lowest (four species) at HDD3 in late winter/early spring 2009.

8.4.5 Definition and Description of Macroalgal Assemblages at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The macroalgae at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included: Rhodophyta: *Champia stipitata*, *Chondria* sp., *Cliftonaea pectinata*, *Coelarthrum cliftonii, Coelarthrum opuntia*, *Corynomorpha prismatica, Dasya* sp. 1, *Dasya* sp. 2, *Dichotomaria* sp., *Dichotomaria obtusata*, *Erythroclonium elongatum*, *Erythroclonium sonderi*, *Gracilaria* sp., *Griffithsia* sp., *Jania adhaerens*, *Haliptilon roseum, Heterosiphonia crassipes, Laurencia* sp., *Martensia* sp., *Micropeuce* sp., *Polysiphonia* sp., *Scinaia tsinglanensis, Solieria robusta*, *Spyridia hypnoides*, *Tricleocarpa cylindrica; Phaeophyta: Dictyopteris serrata*, *Dictyopteris* sp., *Lobophora variegata, Padina* sp., *Sargassum peronii, Sargassum* sp., *Sargassum spinuligerum, Spatoglossum macrodontum*, *Sphacelaria rigidula*, and *Spyridia hypnoides*; Chlorophyta: *Caulerpa brachypus*, *Caulerpa cactoides*, *Caulerpa cupressoides, Caulerpa mexicana, Caulerpa taxifolia*, *Cladophora vagabunda, Cladophora* sp., *Halimeda discoidea,* and *Siphonocladus tropicus* (Table 8-5).

Estimates of mean macroalgal percentage cover at the HDD exit alignment survey sites at risk of Material or Serious Environmental Harm varied between ≈4% and 18% in winter/spring 2010 and ≈7% to 30% in summer, with the highest percentage cover recorded at HDD1 and at HDD4 in summer (2010) (Table 8-6). Estimates of mean macroalgae biomass varied between ≈68 and 987 g wet weight/m^2 in late winter/early spring 2010 and ≈600 to 1406 g wet weight/m^2 in summer (Figure 8-4). The highest mean biomass was recorded at HDD2 in winter/spring 2010 and at HDD3 in summer. HDD2, both mean percentage cover and mean biomass were higher in summer than in late winter/early spring 2009 and winter/spring 2010. Highest species diversity was recorded at HDD3 in winter/spring 2010 (21 species) and HDD2 (19 species), and the lowest (four species) at HDD3 in late winter/early spring 2009.

Table 8-5: List of Macroalgae Species at Sites within the MDF and at Risk of Material or Serious Environmental Harm for each Sampling Occasion

Site	Macroalgae Species Recorded at MDF Sites			
	September 2009	March 2010	August/October 2010	
HDD1	*Caulerpa cactoides*	*Caulerpa cactoides*	*Caulerpa cupressoides*	*Spatoglossum macrodontum*
	Dichotomaria obtusata	*Dictyopteris* sp.	*Cladophora* sp.	*Cliftonaea pectinata*
	Dictyopteris sp.	*Halimeda discoidea*	*Halimeda discoidea*	*Coelarthrum opuntia*
	Halimeda discoidea	*Lobophora variegata*	*Lobophora variegata*	*Dichotomaria obtusata*
	Lobophora variegata	*Sargassum* sp.	*Sargassum peronii*	*Dichotomaria* sp.
	Sargassum sp.		*Sargassum* sp.	*Tricleocarpa cylindrica*
HDD2	*Coelarthrum opuntia*	*Dichotomaria obtusata*	*Cliftonaea pectinata*	*Solieria robusta*
	Dasya sp. 2	*Dictyopteris* sp.	*Coelarthrum opuntia*	*Dictyopteris serrata*
	Dictyopteris serrata	*Halimeda discoidea*	*Corynomorpha prismatica*	*Sargassum* sp.
	Halimeda discoidea	*Lobophora variegata*	*Dichotomaria obtusata*	*Spatoglossum macrodontum*
	Lobophora variegata	*Padina* sp.	*Erythroclonium elongatum*	*Caulerpa* sp.
	Sargassum sp.	*Sargassum* sp.	*Erythroclonium sonderi*	*Cladophora vagabunda*
	Solieria robusta	*Spatoglossum macrodontum*	*Gracilaria* sp.	*Cladophora* sp.
	Spatoglossum macrodontum		*Haliptilon roseum*	*Halimeda discoidea*
			Heterosiphonia crassipes	*Siphonocladus tropicus*
			Micropeuce sp.	
HDD3	*Dichotomaria obtusata*	*Coelarthrum opuntia*	*Caulerpa mexicana*	*Corynomorpha prismatica*
	Halimeda discoidea	*Dictyopteris serrata*	*Cladophora* sp.	*Dichotomaria obtusata*
	Lobophora variegata	*Halimeda discoidea*	*Halimeda discoidea*	*Erythroclonium elongatum*
	Sargassum sp.	*Lobophora variegata*	*Siphonocladus tropicus*	*Erythroclonium sonderi*
		Sargassum sp.	*Dictyopteris serrata*	*Griffithsia* sp.
		Solieria robusta	*Lobophora variegata*	*Laurencia* sp.
			Sargassum spinuligerum	*Martensia* sp.

Site	Macroalgae Species Recorded at MDF Sites			
	September 2009	**March 2010**	**August/October 2010**	
			Champia stipitata	*Scinaia tsinglanensis*
			Cliftonaea pectinata	*Solieria robusta*
			Coelarthrum cliftonii	*Spyridia hypnoides*
			Coelarthrum opuntia	
HDD4	*Caulerpa taxifolia*	*Caulerpa taxifolia*	*Halimeda discoidea*	*Polysiphonia* sp.
	Dasya sp. 1	*Dichotomaria obtusata*	*Dictyopteris serrata*	
	Dichotomaria obtusata	*Halimeda discoidea*	*Lobophora variegata*	
	Halimeda discoidea	*Jania adhaerens*	*Sargassum spinuligerum*	
	Jania adhaerens	*Lobophora variegata*	*Sargassum* sp.	
	Lobophora variegata	*Sargassum* sp.	*Chondria* sp.	
	Sargassum sp.	*Coelarthrum opuntia*	*Coelarthrum opuntia*	
	Solieria robusta	*Caulerpa brachypus*	*Dichotomaria* sp.	
	Sphacelaria rigidula	*Solieria robusta*	*Gracilaria* sp.	
		Dictyopteris serrata	*Micropeuce* sp.	

Table 8-6: Macroalgal Mean Percentage Cover (± SE) and Mean Total Biomass (± SE) at Sites within the MDF and At Risk of Material or Serious Environmental Harm

Site	Mean % Cover ± SE/m^2						Mean Biomass (g) ± SE/m^2						Total Number of Species		
	Sep 2009	n	Mar 2010	n	Aug/Oct 2010	n	Sep 2009	n	Mar 2010	n	Aug/Oct 2010	n	Sep 2009	Mar 2010	Aug/Oct 2010
HDD1	11.4 ± 3.5	20	29.6 ± 5.7	21	17.9± 2.6	21	748.7 ± 86.7	3	1026.0 ± 230.2	10	512.0 ± 118.5^	11	6	5	12
HDD2	16.8 ± 3.3	21	7.0 ± 4.8	21	13.7± 1.9	21	809.7 ± 188.0	6	600.4 ± 33.2	2	987.2 ± 40.8^	10	8	7	19
HDD3	8.8 ± 4.0	18	26.4 ± 5.6	21	11.8± 1.8	21	610.0 ± 517.3	3	1405.7 ± 472.1	4	119.3 ± 42.1	6	4	6	21
HDD4	8.4 ± 3.3	21	30.1 ± 6.6	21	4.1± 1.4	21	568.0 ± 237.5	3	1126.9 ± 221.7	9	68.0 ± 29.7#	4	9	10	11

Notes

n *%cover: number of photoquadrats sampled; Biomass: number of quadrats excluding zero biomass quadrats.*

^ *Estimation of mean macroalgae biomass taken from combined macroalgae and seagrass biomass samples*

One transect excluded from mean macroalgae biomass calculation as the macroalgae and seagrass biomass were combined (36.0 ± 8.0 g/m^2)

8.4.6 Definition and Description of Macroalgal Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The macroalgae not at Risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included, but were not limited to: Rhodophyta: *Amphiroa* sp., *Asparagopsis taxiformis*, *Champia parvula*, *Chondria* sp., Cladurus alternifera, Cliftonaea pectinata, *Coelarthrum cliftonii*, *Coelarthrum opuntia, Corynomorpha prismatica*, *Dasya* sp. 1, Desikacharyella sp., *Dichotomaria* sp., *Dichotomaria obtusata, Dudresnaya* sp., *Galaxaura rugosa*, *Gracilaria* sp., *Hypnea pannosa*, *Jania adhaerens, Jania rosea*, *Laurencia* sp., *Lophocladia* sp., *Scinaia tsinglanensis, Sebdenia flabellata, Solieria robusta*; Phaeophyta: *Cystoseira trinodis*, *Dictyopteris australis*, *Dictyopteris serrata, Dictyopteris woodwardia*, *Dictyopteris* sp., *Dictyota* sp., *Encyothalia cliftonii*, *Hormophysa cuneiformis, Lobophora variegata, Padina* sp., Phaeophyceae sp., *Sargassopsis decurrens, Sargassum oligocystum*, *Sargassum spinuligerum, Sargassum* sp., *Spatoglossum macrodontum, Sporochnus* sp.; Chlorophyta: *Caulerpa brachypus, Caulerpa cactoides, Caulerpa cupressoides, Caulerpa corynephora*, *Spatoglossum macrodontum*, *Sporochnus comosus*, *Caulerpa taxifolia*, *Halimeda* cf. *cuneata,* and *Halimeda discoidea* (Table 8-7).

The highest estimate of mean macroalgal percentage cover was 55% at NEBWI1 in spring 2008 while it was the lowest also at NEBWI1 (≈15%) in winter/spring 2010 (Table 8-8). Mean macroalgal percentage cover at Site BR ranged between ≈22% and ≈42% for the four surveys conducted. Mean biomass ranged between ≈390 g wet weight/m^2 at HDDRS2 in winter/spring 2010 and ≈1827 g wet weight/m^2 in spring 2008 at NEBWI1 (Figure 8-4). The highest species diversities were recorded in winter/spring 2010 at NEBWI1 (27 taxa).

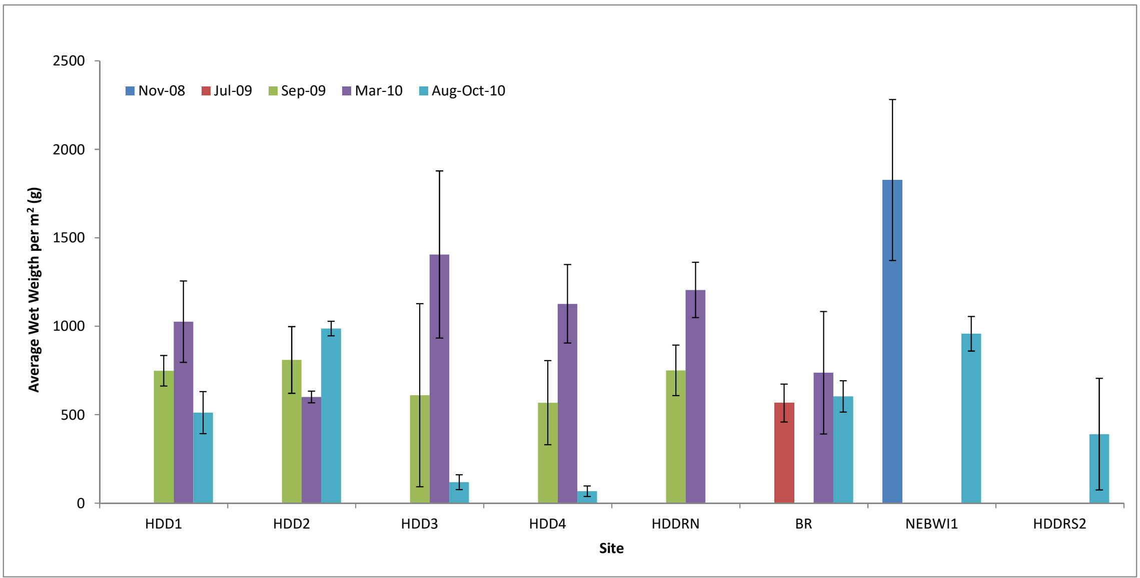


Figure 8-4: Mean Macroalgal Biomass (± SE) per metre^2 at Survey Sites near the HDD Exit Alignment and Reference Sites

Note: Aug/Oct 2010 data: A combined seagrass and macroalgae biomass is presented for Reference Sites HDD1, HDD2 and NEBWI; for Site HDD4: one transect was excluded from mean biomass calculations as the macroalgae and seagrass biomass were combined (36 ± 8 g/m^2).

Table 8-7: Macroalgae Species Recorded at Reference Sites HDDRN, BR, NEBWI1, and HDDRS2 not at Risk of Material or Serious Environmental Harm

Site	Macroalgae Species Recorded at Reference Sites			
	November 2008”	2009” # ~	March 2010	Aug/Oct 2010
HDDRN	Not Surveyed	*Caulerpa cactoides*	*Caulerpa cactoides*	Not Surveyed
		Caulerpa cupressoides	*Caulerpa cupressoides*	
		Caulerpa taxifolia	*Coelarthrum opuntia*	
		Coelarthrum opuntia	*Dasya* sp.	
		Dichotomaria obtusata	*Dichotomaria obtusata*	
		Dictyopteris serrata	*Dictyopteris serrata*	
		Dictyopteris sp.	*Dictyopteris* sp.	
		Halimeda discoidea	*Halimeda discoidea*	
		Jania adhaerens	*Jania adhaerens*	
		Lobophora variegata	*Lobophora variegata*	
			Sargassum sp.	
			Solieria robusta	
BR	*Caulerpa corynephora*	*Caulerpa corynephora*	*Caulerpa brachypus*	*Halimeda discoidea*
	Caulerpa cupressoides	*Dictyopteris woodwardii*	*Dichotomaria obtusata*	*Udotea flabellum*
	Champia parvula	*Champia parvula*	*Dictyopteris* sp.	*Cystoseira trinodis*
	Encyothalia cliftonii	*Encyothalia cliftonii*	*Halimeda discoidea*	*Dictyopteris australis*
	Halimeda cf. *cuneata*	*Halimeda* cf. *cuneata*	*Lobophora variegata*	*Dictyopteris woodwardia*
	Jania rosea	*Jania rosea*	*Padina* sp.	*Dictyota* sp.
	Padina sp.	*Padina* sp.	*Sargassopsis decurrens*	*Hormophysa cuneiformis*
	Sargassopsis decurrens	*Phaeophyceae* sp.	*Sargassum* sp.	*Lobophora variegata*
	Sargassum sp. 1	*Sargassopsis decurrens*		*Padina sanctae-crucis*
				Padina sp.
				Sargassum decurrens
				Sargassum sp.
				Spatoglossum macrodontum
				Dichotomaria sp.
				Laurencia sp.
NEBWI1	*Asparagopsis taxiformis*	Not Surveyed	Not Surveyed	*Caulerpa corynephora*
	Caulerpa corynephora			*Caulerpa lentillifera*
	Caulerpa cupressoides			*Caulerpa mexicana*
	Champia parvula			*Caulerpa racemosa f. laetevirens*
	Encyothalia cliftonii			*Ulva paradoxa*
	Dictyopteris serrata			*Cystoseira trinodis*
	Dictyopteris woodwardii			*Lobophora variegata*

Site	Macroalgae Species Recorded at Reference Sites			
	November 2008“	**2009“ # ~**	**March 2010**	**Aug/Oct 2010**
	Galaxaura rugosa			*Padina* sp.
	Halimeda cf. *discoidea*			*Sargassum decurrens*
	Padina sp.			*Sargassum spinuligerum*
	Sargassopsis decurrens			*Spatoglossum macrodontum*
	Sargassum oligocystum			*Sporochnus* sp.
	Sargassum sp. 1			*Amphiroa* sp.
	Spatoglossum macrodontum			*Asparagopsis taxiformis*
	Sporochnus comosus			*Chondria* sp.
				Cladurus alternifera
				Coelarthrum cliftonii
				Coelarthrum opuntia
				Corynomorpha prismatica
				Dasya sp.
				Desikacharyella sp.
				Dudresnaya sp.[3]
				Gracilaria sp.
				Hypnea pannosa
				Lophocladia sp.
				Scinaia tsinglanensis
				Sebdenia flabellata
HDDRS2	Not Surveyed	Not Surveyed	Not Surveyed	*Avrainvillea nigricans*
				Halimeda discoidea
				Hormophysa cuneiformis
				Lobophora variegata
				Padina sp.
				Sargassum decurrens
				Sargassum sp.
				Sporochnus sp.

Notes

“ *Sites surveyed in November 2008 (BR, NEBWI1) and July 2009 (BR) only recorded the dominant macroalgae species.*

* *Site BR surveyed in July 2009; Site HDDRN surveyed in September 2009*

~ *Site BR data from July 2009 was collected approximately 650 m from the initial site at these coordinates: 20° 44.774' S (7705071)/ 115° 21.589' E (329234)*

Table 8-8: Macroalgal Mean Percentage Cover (± SE) and Mean Total Biomass (± SE) at the Reference Sites HDDRN, BR, NEBWI1, and HDDRS2 not at Risk of Material or Serious Environmental Harm

Site	Mean % Cover ± SE/m²								Mean Biomass (g) ± SE/m²								Number of Species			
	Nov 2008	n	2009*	n	Mar 2010	n	Aug/Oct 2010	n	Nov 2008	n	2009*	n	Mar 2010	n	Aug/Oct 2010	n	Nov 2008	2009*	Mar 2010	Aug\/Oct 2010
HDDRN	NS	-	21.7 ± 2.9	21	32.4 ± 3.8	21	NS	-	NS	-	751.0 ± 142.6	5	1205.3 ± 156.7	12	NS	-	NS	10	12	NS
BR	41.7 ± 4.2	21	27.6 ± 2.8~	21	31.2 ± 7.3	21	22.1± 2.3	21	No samples collected	-	565.9 ± 107.1~	12	737.6 ± 345.9	8	604.0 ±88.4	11	9”	9”~	8	15
NEBWI1	55.1 ± 2.8	21	NS	-	NS	-	14.8 ± 2.2	21	1826.7 ± 454.9	6	NS	-	NS	-	957.7±315.4^	12	15”	NS	NS	27
HDDRS2	NS	-	NS	-	NS	-	17.6 ± 2.3	21	NS	-	NS	-	NS	-	390.0 ±98.0	10	NS	NS	NS	8

Notes

n %cover: number of photoquadrats sampled; Biomass: number of quadrats excluding zero biomass quadrats

NS not surveyed

“ *Sites surveyed in November 2008 (BR, NEBWI1) and July 2009 (BR) only recorded the dominant macroalgae species*

* *Site BR surveyed in July 2009; Site HDDRN surveyed in September 2009*

~ *Site BR data from July 2009 was collected approximately 650 m from the initial site at these coordinates: 20° 44.774' S (7705071)/ 115° 21.589' E (329234)*

^ *Estimation of mean macroalgae biomass taken from combined macroalgae and seagrass biomass samples*

\- *Indicates zero sample size*

8.4.7 Definition and Description of Macroalgal Assemblages at North Whites Beach

Patches of *Ulva* sp. were recorded on the bare limestone pavement at the cliff base in the upper shore area at North Whites Beach (Ref. 78). In the mid-shore area there was ≈90% macroalgal cover of the limestone pavement. The dominant macroalgae in this area were *Sargassum* spp. At the interface of the reef platform and the beach, *Ulva flexuosa*, *Padina* sp., and *Boergesenia forbesii* were recorded. *Sargassum myriocystum* was the dominant macroalga, both on the limestone flats and in pools, with *Sirophysalis trinodis*, *Hormophysa cuneiformis,* and *Cystoseira* sp. also recorded. Other species recorded included *Digenea simplex*, *Boodlea composita*, *Caulerpa racemosa*, *Cladophora herpestica*, *Halimeda* sp. (in pools), *Cystoseira* sp., and *Laurencia* sp. Towards the reef edge, the macroalgal cover was sparser, with *Dictyota ciliolata*, *Laurencia* cf. *obtusa*, *Sargassum oligocystum*, *Halimeda* sp., and *Padina* sp. recorded. Other species present included *Acanthophora spicifera*, *Gelidiella acerosa*, *Sargassopsis decurrens*, *Valoniopsis pachynema,* and *Hydropuntia urvillea*. *Struvea* sp. was recorded on the vertical walls of rock pools.

8.5 Discussion and Conclusions

Macroalgae are the most abundant and extensive ecological element in west coast Barrow Island waters near the HDD exit alignment. Serious Environmental Harm, caused by the direct placement of the Marine Facilities on the seabed and physical removal of the substrate, is predicted to affect macroalgae within the Marine Facilities Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The areas at risk of Material Environmental Harm include those areas within the MDF that are not within the Marine Facilities Footprint. The patchy distribution of macroalgae, as well as the spatial variability in percentage cover, makes it difficult to estimate the total area of macroalgae that may be impacted as a consequence of the construction of the Marine Facilities on the west coast of Barrow Island. The Marine Facilities Footprint may potentially impact ~0.1 ha (~0.015%) of the total area of ‘Macroalgae with Sparse Sessile Taxa’ (≈665 ha) in Management Unit 1 on the west coast of Barrow Island. The MDF associated with the construction of the Marine Facilities may potentially impact up to ≈11.5 ha (~2%) of the total area of ‘Macroalgae with Sparse Sessile Taxa’ in Management Unit 1.

The quantitative surveys on the west coast of Barrow Island indicated that the macroalgal assemblages differed to a degree between surveys, with estimates of percentage cover and biomass generally higher in summer. Taxonomic diversity was generally higher in the winter/spring 2010 survey than during the other surveys. Estimates of percentage cover, biomass, and taxonomic diversity were generally slightly lower at sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to the Reference Sites. However, there was no indication of differences in taxonomic composition of macroalgae at sites in the MDF, at sites at risk of Material or Serious Environmental Harm, and at Reference Sites not at risk of Material or Serious Environmental Harm. All the macroalgal taxa recorded at sites in the MDF and in areas at risk of Material or Serious Environmental Harm were also recorded at Reference Sites and/or were common within the local area and region (Ref. 29).

9 Seagrass

9.1 Introduction

The diversity and distribution of seagrass species on the North West Shelf are not well documented. Huisman and Borowitzka (Ref. 83) identified nine species of seagrass in the Dampier Archipelago, from the families Hydrocharitaceae and Cymodoceaceae. Seven species have been recorded to date from the Montebello Islands/Barrow Island region—*Cymodocea angustata, Halophila ovalis, H. spinulosa, Halodule uninervis*, *Thalassia hemprichii*, *Thalassodendron ciliatum,* and *Syringodium isoetifolium* (Ref. 31). Of these, *Halophila* spp. are the most common on shallow soft substrates and sand veneers throughout the region (Ref. 31). Seagrass do not appear to form extensive beds in the area, but rather are sparsely interspersed between macroalgae, extending from the intertidal zone to approximately 15 m water depth (Ref. 31).

Seagrass distribution in the waters surrounding Barrow Island is even less well known. Six species of seagrass were identified during the Marine Baseline Program—*Cymodocea serrulata*, *Syringodium isoetifolium*, *Halodule* sp., *Halophila decipiens*, *Halophila ovalis*, and *Halophila spinulosa* (Ref. 29). The dominant (or most common) seagrass in terms of percentage cover were *H. ovalis* and *H. spinulosa*. During the Marine Baseline Program, seagrass were observed across a range of benthic substrates, including soft sediments at water depths of 14 to 18 m and on veneers of sand covering limestone pavement at depths of 5 to 10 m. Seagrass were observed as both mono-specific assemblages of *Halophila* spp., or, more rarely, mixed assemblages of *Halophila* spp. and *Syringodium* spp. Non-coral benthic macroinvertebrates and coral were occasionally recorded co-occurring with seagrass in the macroalgal-dominated assemblages on the shallow limestone pavement east of Barrow Island. Seagrass were also occasionally recorded co-occurring with non-coral benthic macroinvertebrates in deeper soft sediment habitats.

Seagrass (*Halodule* sp.) has been reported to occur at low densities in the shallow subtidal zone on sand veneers that cover areas of pavement reef off North Whites Beach on the west coast of Barrow Island (Ref. 73).

Seagrass beds in the Montebello Islands/Barrow Island region make an important contribution to the local productivity, are an important direct food source for some animals (e.g. Dugongs [*Dugong dugon*] and Green Turtles [*Chelonia mydas*]), and provide refuge for fish and invertebrates (Ref. 11; Ref. 31). Seagrass habitats in the Montebello Islands/Barrow Island region vary seasonally in response to water temperature, day length, reproductive cycles, physical disturbance, and regrowth (Ref. 31; Ref. 29).

9.2 Scope

This Section records the existing dominant species of seagrass (Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178) and describes/defines and maps the seagrass:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)

- at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.iii, MS 800; Condition 11.6.III, EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.iv, MS 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

9.3 Methods

9.3.1 Site Locations

As part of the Marine Baseline Program for the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, eight seagrass survey sites were selected within areas where seagrass was identified as potentially being present through broadscale habitat mapping on the west coast of Barrow Island (Section 5.3). The sites were all located on relatively flat limestone pavement with a sand veneer of varying, but generally shallow, depth. Four of the sites were selected based on their proximity to the HDD exit alignment (Table 9-1; Figure 9-1)one sites (HDD1) was located within the Marine Facilities Footprint, one was located north (HDD2) and one south (HDD3) of the Marine Facilities Footprint within the MDF in the area at Risk of Material or Serious Environmental Harm, and a fourth site (HDD4) was located at the edge of the MDF, north of the HDD exit alignment. Two Reference Sites, which are not expected to be impacted by the HDD marine activities and therefore are not at Risk of Material or Serious Environmental Harm, were located south of the HDD exit alignment (Biggada Reef [BR] and HDDRS2) and two Reference Sites were located north of the HDD exit alignment (NEBWI1 and HDDRN). The Site BR was surveyed at an alternative location in July 2009; subsequent surveys returned to the initial location. Site HDDRS2 was added in the August/October 2010 survey, as site HDDRN was inaccessible. Note: It is anticipated that anchoring within the indicative anchoring area will be managed such that there will be no impact at the Reference Site HDDRN.

Table 9-1: West Coast Seagrass Survey Sites and Survey Dates

Site Code		Easting	Northing	Latitude	Longitude	Survey Date				
		(GDA94, MGA Zone 50)		(GDA94)		Nov 08	Jul 09~	Sep 09	Mar 10	Aug–Oct 10
At risk of Material or Serious Environmental Harm	HDD1	334666	7711398	20° 41.374' S	115° 24.755' E			X	X	X
	HDD2	334677	7711541	20° 41.297' S	115° 24.762' E			X	X	X
	HDD3	334548	7711351	20° 41.399' S	115° 24.686' E			X	X	X

Site Code		Easting	Northing	Latitude	Longitude	Survey Date				
		(GDA94, MGA Zone 50)		(GDA94)		Nov 08	Jul 09~	Sep 09	Mar 10	Aug–Oct 10
	HDD4	334738	7711539	20° 41.298' S	115° 24.797' E			X	X	X
Reference Sites	HDDRN	334965	7712144	20° 40.972' S	115° 24.931' E			X	X	
	BR	329877	7704929	20° 44.855' S	115° 21.959' E	X	X~		X	X
	NEBWI1	343959	7716235	20° 38.801' S	115° 30.132' E	X				X
	HDDRS2	329675	7705354	20° 44.623' S	115° 21.845' E					X

Notes:

~ Site BR data from July 2009 was collected approximately 650 m from the initial site at these coordinates: 20° 44.774' S (7705071)/ 115° 21.589' E (329234)

Seagrass survey sites were also macroalgae and benthic macroinvertebrate survey sites where these ecological elements co-occurred in the same area.

Qualitative intertidal surveys were undertaken at the HDD shore crossing at North Whites Beach, at three sites located north (Max's Point, Max's Beach North, Max's Beach South) and one south of the HDD shore crossing (South Whites Beach) (Table 9-2) (Ref. 78).

Table 9-2: Qualitative Intertidal Survey Sites near the HDD Shore Crossing

Site Name		Easting	Northing	Latitude	Longitude
		(GDA94, MGA Zone 50)		(GDA94)	
At risk of Material or Serious Environmental Harm	North Whites Beach (HDD)	334938	7711298	20° 41.430' S	115° 24.910' E
Reference Sites	Max's Point	335453	7712513	20° 40.774' S	115° 25.214' E
	Max's Beach North	335333	7712248	20° 40.917' S	115° 25.144' E
	Max's Beach South	335087	7711579	20° 41.279' S	115° 24.998' E
	South Whites Beach	334675	7710438	20° 41.895' S	115° 24.754' E

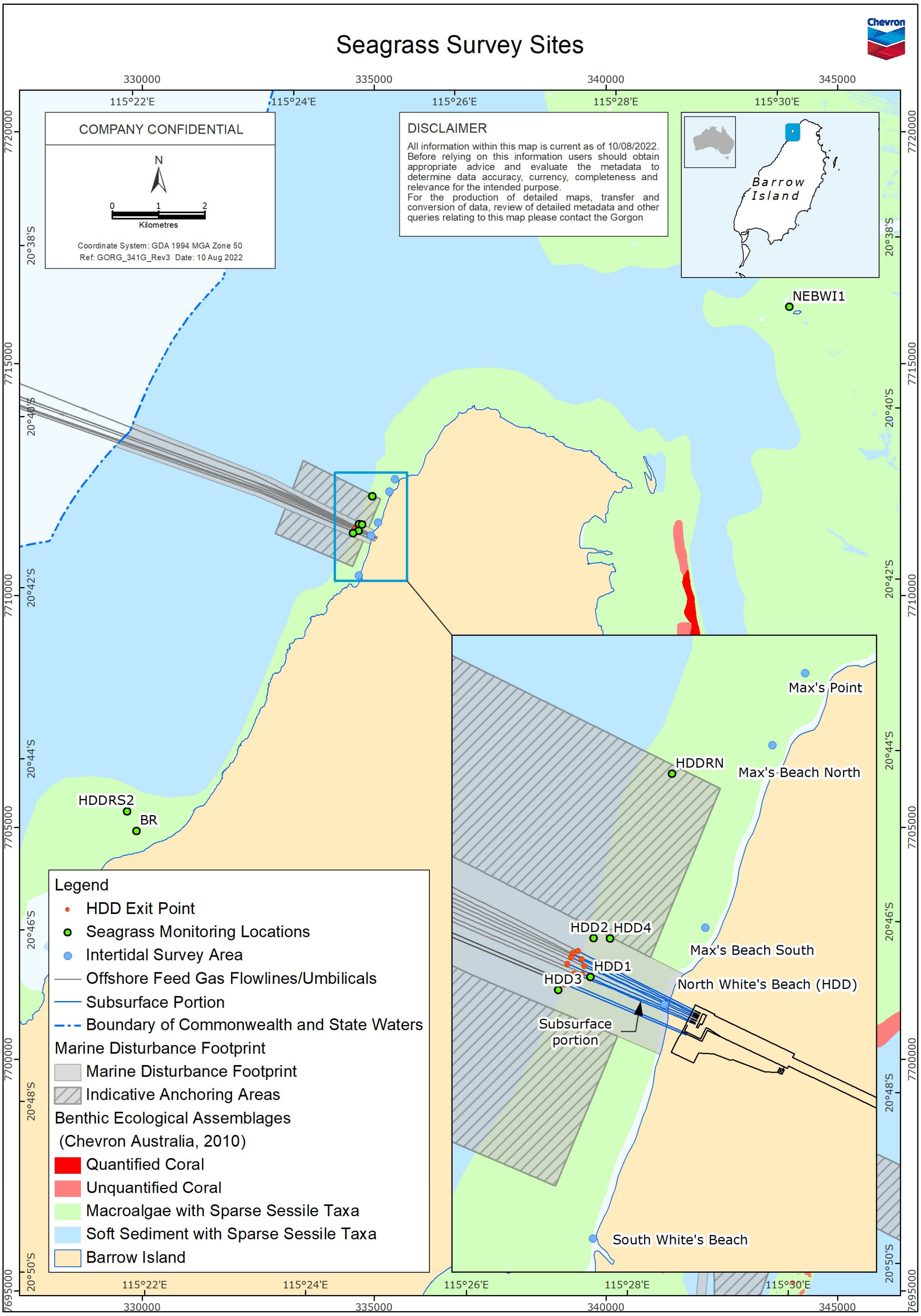

Seagrass Survey Sites
COMPANY CONFIDENTIAL
N
0 1 2
Kilometres
Coordinate System: GDA 1994 MGA Zone 50
Ref: GORG_341G_Rev3 Date: 10 Aug 2022
DISCLAIMER
All information within this map is current as of 10/08/2022. Before relying on this information users should obtain appropriate advice and evaluate the metadata to determine data accuracy, currency, completeness and relevance for the intended purpose.
For the production of detailed maps, transfer and conversion of data, review of detailed metadata and other queries relating to this map please contact the Gorgon
Barrow Island
NEBWI1
HDDRS2
BR
Max's Point
HDDRN
Max's Beach North
HDD2
HDD4
Max's Beach South
HDD1
HDD3
North White's Beach (HDD)
Subsurface portion
South White's Beach
Legend
HDD Exit Point
Seagrass Monitoring Locations
Intertidal Survey Area
Offshore Feed Gas Flowlines/Umbilicals
Subsurface Portion
Boundary of Commonwealth and State Waters
Marine Disturbance Footprint
Marine Disturbance Footprint
Indicative Anchoring Areas
Benthic Ecological Assemblages
(Chevron Australia, 2010)
Quantified Coral
Unquantified Coral
Macroalgae with Sparse Sessile Taxa
Soft Sediment with Sparse Sessile Taxa
Barrow Island
330000
335000
340000
345000
115°22'E
115°24'E
115°26'E
115°28'E
115°30'E
7720000
7715000
7710000
7705000
7700000
7695000
20°38'S
20°40'S
20°42'S
20°44'S
20°46'S
20°48'S
20°50'S

Figure 9-1: Seagrass Survey Sites near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

9.3.2 Methods

Mapping of the ecological elements associated with the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing is described in Section 5.3.

At each pre-selected randomly chosen survey site, three 30 m length transects were laid out from a central clump weight (Ref. 19). The three transects were laid out at approximately 90° from the central clump weight. The coordinates of the start point of each transect were recorded using GPS.

A total area of 1 m^2 (either one 1 m^2 quadrat or four 0.25 m^2 quadrats positioned adjacent to each other) was photographed at 5 m intervals along the right side of each transect (i.e. a total of seven locations along each transect). The species of seagrass present in each quadrat were recorded and the quadrat photographed. The seagrass species present in each quadrat were identified to the lowest reliable taxonomic level (to genus and species level where possible). Voucher samples of those species that could not be reliably identified in the field were collected, preserved, and catalogued for identification by Dr John Huisman (Murdoch University, Western Australia).

The seagrass in replicate 0.25 m^2 quadrats were collected for measurement of total biomass. In November 2008 and September 2009, one 0.25 m^2 quadrat was sampled at 10 m and at 20 m intervals on the left side of each transect (i.e. a total of six biomass samples per site). In July 2009, March 2010, and August to October 2010, two 0.25 m^2 quadrats were sampled at 10 m and 20 m intervals along each transect (i.e. a total of 12 biomass samples per site). If a quadrat was located on bare sand, no biomass sample was collected. Samples were blot-dried and total wet weight was recorded.

The qualitative intertidal survey involved identifying and recording the seagrass species present, including visual identification and collection or photography of samples for subsequent species-level identification (Ref. 78).

9.3.3 Timing and Frequency of Sampling

Sampling was undertaken in spring 2008 (November), winter 2009 (July), late winter/early spring 2009 (September/October), summer 2010 (March), and winter/spring (August to October) 2010 (Table 9-1).

The qualitative intertidal survey HDD shore crossing was undertaken in February 2008 (Ref. 78).

9.3.4 Treatment of Survey Data

Digital images were analysed using Coral Point Count with Excel extensions (CPCe) (Ref. 53). Either 30 (for a single 1 m^2 quadrat) or 32 (for four 0.25 m^2 quadrats) random points were overlain over the image and each point visually classified into the broad categories of benthic cover (macroalgae, seagrass, turf algae, coral, non-coral benthic macroinvertebrates, sand, pavement, rubble, and unidentified). The percentage of all points scored as each benthic ecological element per photograph was calculated and the average (± SE) percentage cover of dominant ecological elements was determined.

Any quadrats with zero biomass values from the Marine Baseline Program were removed and the mean ± SE for each site was calculated. The biomass is a measure of seagrass health, rather than a secondary measure of cover.

9.4 Results

9.4.1 Seagrass in West Coast Barrow Island Waters

Different survey techniques were used for the various components of the Marine Baseline Program, including broadscale mapping (Section 5.1) and small-scale quantitative sampling. These all contributed to the compilation of the seagrass reported in west coast Barrow Island waters. Three species of seagrass were identified during quantitative surveys at HHD1, HDD2, HDD3, HDD4, HDDRN, BR, HDDRS2, and NEBWI1—*Syringodium isoetifolium,* an unidentified species of *Halodule* sp. (Family Cymodoceaceae), and *Halophila ovalis* (Family Hydrocharitaceae) (Figure 9-2). Other species recorded during surveys near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included *Halophila spinulosa* (Section 5.3).

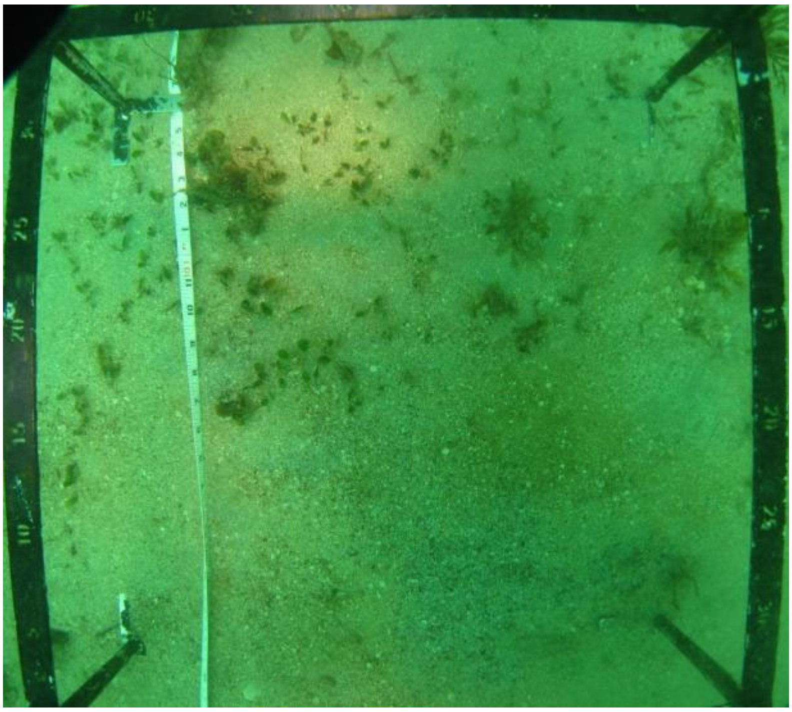


Figure 9-2: Sparsely Distributed *Halophila ovalis* on Shallow Sand Over Limestone Pavement at BR, March 2010

Surveys of the intertidal areas at five sites along the north-west of Barrow Island (South Whites Beach, North Whites Beach, Max's Beach South, Max's Beach North, and Max's Point) recorded one species of seagrass (*Thalassia hemprichii*) at the three northern sites (Ref. 78). *Thalassia hemprichii* was recorded in shallow pools dominated by dense *Sargassum* sp. at Max's Beach South and Max's Point. No seagrass was recorded at the HDD shore crossing at North Whites Beach in February 2008 (Ref. 78).

9.4.2 Dominant Seagrass in West Coast Barrow Island Waters

The dominant (or most common) seagrass in terms of percentage cover recorded in west coast Barrow Island waters was *Syringodium isoetifolium*.

9.4.3 Distribution of Seagrass in West Coast Barrow Island Waters

Figure 9-3 shows the spatial distribution of seagrass near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing as point (presence/absence) observations derived from broadscale mapping (drop camera surveys and diver transect surveys). ‘Null observations’ were recorded where seagrass were not observed. Maps showing the spatial distribution of seagrass in Barrow Island waters, including the west coast, are presented in Ref. 47.

The substrate at all HDD exit alignment survey sites was a relatively flat limestone pavement with a sand veneer of varying, but generally shallow, depth. Seagrass were only recorded at a few locations and at low levels of percentage cover, growing in mixed assemblages with macroalgae and occasionally benthic macroinvertebrates, at sites near the HDD exit alignment and the Offshore Feed Gas Pipeline System in State Waters surveyed with a drop camera and diver transects (Section 5.3.5).

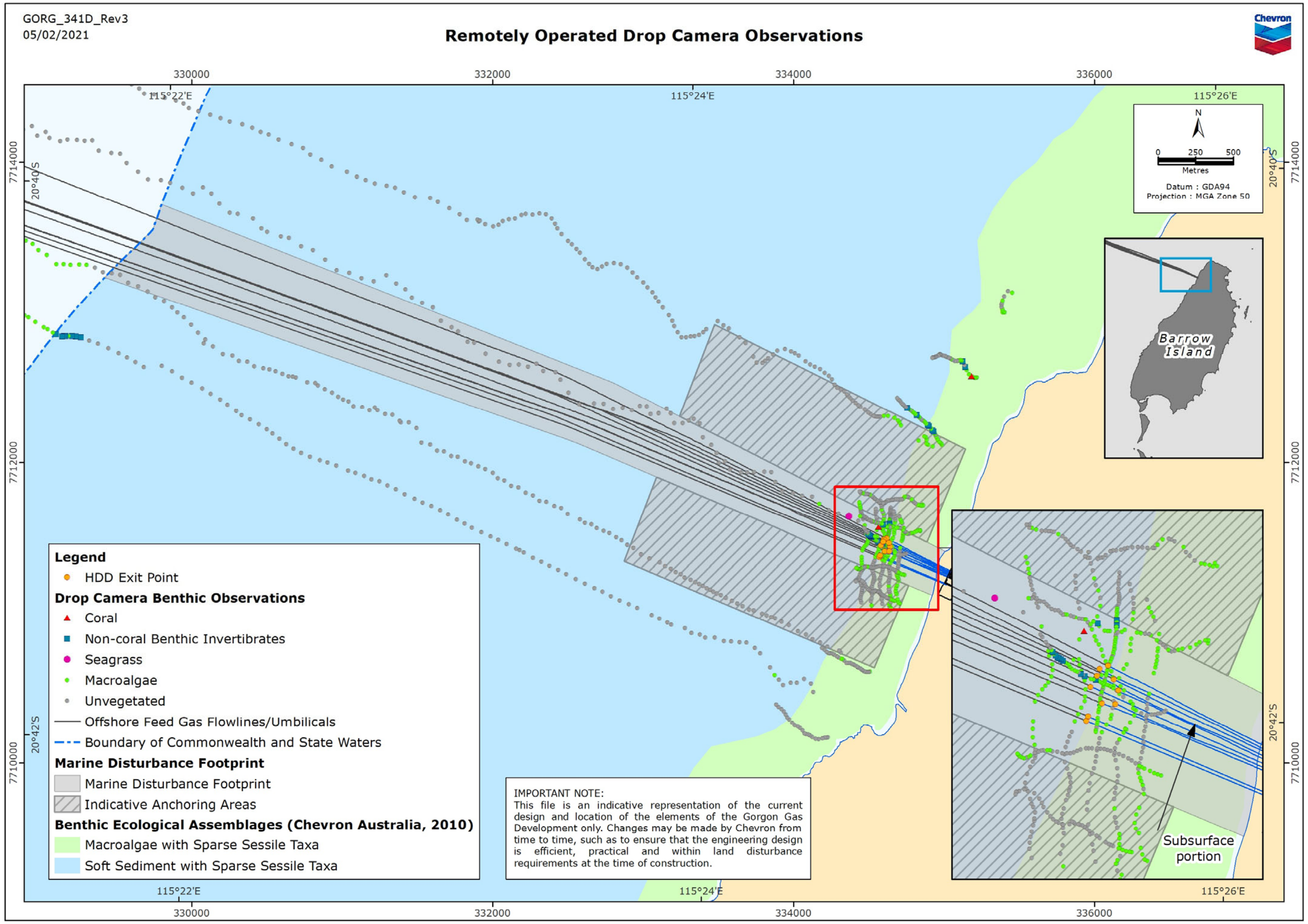


Figure 9-3: Observations of Seagrass in the MDF for the West Coast Marine Facilities, in Areas at Risk of Material or Serious Environmental Harm and in Areas not at Risk of Material or Serious Environmental Harm

9.4.4 Definition and Description of Seagrass Assemblages in the MDF Associated with the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The seagrass in the MDF associated with the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included *Halodule* sp., *Halophila decipiens*, *Halophila spinulosa,* and *Syringodium isoetifolium* (Table 9-3). The presence of seagrass species in sites with zero percentage cover is due to the CPCe points overlaid on the quadrat photograph missing the small amount of seagrass present on the photograph. Seagrass species for those sites came from diver identification and voucher specimens identified by a specialist.

Seagrass were recorded in percentage cover per quadrats at two survey sites in late winter/early spring 2009 (HDD1 and HDD2), at zero sites in summer 2010, and at four sites in winter/spring 2010 (Table 9-3). Estimates of mean percentage cover were low (<1%) at all sites sampled for all surveys. No seagrass were recorded in any of the quadrats sampled for total biomass in spring 2009 or summer 2010. In winter/spring 2010, the seagrass and macroalgae biomass samples were combined so no seagrass biomass is available except for Site HDD2, which had 20.0 ± 0.0 g/m^2 of seagrass (Table 9-3). *Syringodium isoetifolium* was recorded at all four sites, *Halodule* sp. was only recorded at HDD1, and two species of *Halophila* (*Halophila decipiens*, *Halophila spinulosa*) were recorded at Site HDD2.

Table 9-3: Seagrass Mean Percentage Cover (± SE) and Mean Total Biomass (± SE) at Sites within the MDF and at Risk of Material or Serious Environmental Harm

Site	Mean % Cover ± SE/m^2						Mean Biomass (g) ± SE/m^2						Species		
	Sep 2009	n	Mar 2010	n	Aug–Oct 2010	n	Sep 2009	n	Mar 2010	n	Aug–Oct 2010	n	Sep 2009	Mar 2010	Aug–Oct 2010
HDD1	0.3 ± 0.2	20	0.0 ± 0.0	21	0.3 ± 0.2	21	NSQ	-	NSQ	-	Data not available	11a	*Halodule* sp. ***Syringodium isoetifolium***	NR	***Syringodium isoetifolium***
HDD2	0.7 ± 0.5	21	0.0 ± 0.0	21	0.1 ± 0.1	21	NSQ	-	NSQ	-	Data not available	10a	***Syringodium isoetifolium***	***Syringodium isoetifolium***	*Halophila decipiens* *Halophila spinulosa* ***Syringodium isoetifolium***
HDD3	0.0 ± 0.0	18	0.0 ± 0.0	21	0.3 ± 0.2	21	NSQ	-	NSQ	-	20.0 ± 0.0	2	***Syringodium isoetifolium***	***Syringodium isoetifolium***	***Syringodium isoetifolium***
HDD4	0.0 ± 0.0	21	0.0 ± 0.0	21	0.1 ± 0.1	21	NSQ	-	NSQ	-	NSQ#	-a	NR	***Syringodium isoetifolium***	No seagrass

Notes

Bold font indicates dominant taxa

n — *%cover: number of photoquadrats sampled; Biomass: number of quadrats excluding zero biomass quadrats*

Data not available — *Only combined macroalgae and seagrass biomass samples recorded*

NR — *Not Recorded*

NSQ — *No samples in quadrats*

a — *Number of subquadrats for which non-zero seagrass biomass was recorded in Transects 1 and 2*

— *One transect excluded from mean seagrass biomass calculation as the macroalgae and seagrass biomass were combined (36.0 ± 8.0 g/m^2)*

- — *indicates zero sample size*

9.4.5 Definition and Description of Seagrass Assemblages at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The seagrass in the MDF associated with the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing included *Halodule* sp., *Halophila decipiens*, *Halophila spinulosa,* and *Syringodium isoetifolium* (Table 9-3). The presence of seagrass species in sites with zero percentage cover is due to the CPCe points overlaid on the quadrat photograph missing the small amount of seagrass present on the photograph. Seagrass species for those sites came from diver identification and voucher specimens identified by a specialist.

Seagrass were recorded in percentage cover per quadrats at two survey sites in late winter/early spring 2009 (HDD1 and HDD2), at zero sites in summer 2010, and at four sites in winter/spring 2010 (Table 9-3). Estimates of mean percentage cover were low (<1%) at all sites sampled for all surveys. No seagrass were recorded in any of the quadrats sampled for total biomass in spring 2009 or summer 2010. In winter/spring 2010, the seagrass and macroalgae biomass samples were combined so no seagrass biomass is available except for Site HDD2, which had 20.0 ± 0.0 g/m^2 of seagrass (Table 9-3). *Syringodium isoetifolium* was recorded at all four sites, *Halodule* sp. was only recorded at HDD1, and two species of *Halophila* (*Halophila decipiens*, *Halophila spinulosa*) were recorded at Site HDD2.

9.4.6 Definition and Description of Seagrass Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

The seagrass not at Risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing include *Syringodium isoetifolium*, *Halophila ovalis*, *Halophila decipiens,* and *Halophila* sp. (Table 9-4).

Seagrass mean percentage cover was <0.6% at nearly all sites surveyed except for Sites BR (0.8 ± 0.4) and HDDRS2 (1.9 ± 0.5) in winter/spring 2010 (Table 9-4). Seagrass were recorded in quadrats for Site BR in 2009 (9.0 ± 3.8 g/m^2) and in winter/spring 2010 (20.0 ± 0.0 g/m^2), and Site HDDRS2 in Aug/Oct 2010 (37.3 ± 8.2 g/m^2). *Syringodium isoetifolium* was recorded at HDDRN, BR, and HDDRS2. Three seagrass species were recorded at Site BR, while HDDRS2 had two species (Table 9-4). The remaining sites had one species recorded.

Table 9-4: Seagrass Mean Percentage Cover (± SE) and Mean Total Biomass (± SE) at Reference Sites not at Risk of Material or Serious Environmental Harm

Site	Mean % Cover ± SE/m^2								Mean Biomass (g) ± SE/m^2							Species			
	Nov 2008	n	2009*	n	Mar 2010	n	Aug–Oct 2010	n	Nov 2008	2009*	n	Mar 2010	n	Aug–Oct 2010	n	Nov 2008	2009*	Mar 2010	Aug–Oct 2010
HDDRN	NS	-	0.2 ± 0.2	21	0.0 ± 0.0	21	NS	-	NS	NSQ	-	NSQ	-	NS	-	NS	NR	***Syringodium isoetifolium***	NS
BR	0.0 ± 0.0	21	0.5 ± 0.3~	21	0.3 ± 0.2	21	0.8 ± 0.4	21	NSQ	9.0 ± 3.8~	4	NSQ	-	20.0 ± 0.0	2	No seagrass	***Syringodium Isoetifolium~***	***Syringodium isoetifolium*** *Halophila ovalis*	*Halophila decipiens*
HDDRS2	NS	-	NS	-	NS	-	1.9 ±0.5	21	NS	NS	-	NS	-	37.3 ±8.2	9	NS	NS	NS	***Syringodium isoetifolium*** ***Halophila sp.***
NEBWI1	0.5 ± 0.4	21	NS	-	NS	-	0.1 ± 0.1	21	NSQ	NS	-	NS	-	Data not available	12	NR	NS	NS	*Halophila ovalis*

Notes

Bold font indicates dominant taxa

Data not available — *Only combined macroalgae and seagrass biomass samples recorded*

n — *%cover: number of photoquadrats sampled; Biomass: number of quadrats excluding zero biomass quadrats*

NR — *Not Recorded*

NS — *Not Surveyed*

NSQ — *No samples in quadrats*

* — *Site BR surveyed in July 2009; Site HDDRN surveyed in September 2009*

~ — *Site BR data from July 2009 was collected approximately 650 m from the initial site at these coordinates: 20° 44.774' S (7705071)/ 115° 21.589' E (329234)*

\- — *Indicates zero sample size*

9.5 Discussion and Conclusions

Seagrass was sparse in west coast Barrow Island waters near the HDD exit alignment. Serious Environmental Harm, caused by the direct placement of the Marine Facilities on the seabed and physical removal of the substrate, is predicted to affect seagrass within the Marine Facilities Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The areas at risk of Material Environmental Harm include those areas within the MDF that are not within the Marine Facilities Footprint. The patchy distribution of seagrass makes it difficult to estimate the total area of seagrass that may be impacted as a consequence of the construction of the Marine Facilities on the west coast of Barrow Island. The Marine Facilities Footprint may potentially impact ~0.1 ha (~0.015%) of the total area of ‘Macroalgae with Sparse Sessile Taxa’ (≈665 ha) and ≈19 ha (≈1%) of ‘Soft Sediments with Sparse Sessile Taxa’ (≈3085 ha) in Management Unit 1 on the west coast of Barrow Island. The MDF associated with the construction of the Marine Facilities may potentially impact up to ≈11.5 ha (~2%) of the total area of ‘Macroalgae with Sparse Sessile Taxa’ and ≈84 ha (~3%) of ‘Soft Sediments with Sparse Sessile Taxa’ in Management Unit 1.

There were no significant seagrass assemblages observed near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. The quantitative surveys on the west coast of Barrow Island indicated that the estimates of seagrass percentage cover, biomass, species diversity, and composition were similar at sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to the Reference Sites. All seagrass species recorded at sites in the MDF and in areas at risk of Material or Serious Environmental Harm were represented elsewhere in Barrow Island waters (Ref. 31; Ref. 29).

10 Mangroves

10.1 Introduction

Mangroves along the northern coastline of Western Australia increase in species richness and diversity from the arid subtropics in the south, which has relatively small tides, to the tropical and humid Kimberley coast, which has a tidal range of >11 m (Ref. 84). The mangroves in the Pilbara Region form relatively diverse fringing stands (Ref. 85), with trees often stunted but forming extensive forests (Ref. 86). The Grey Mangrove (*Avicennia marina*) and the Red Mangrove (*Rhizophora stylosa*) are the most commonly occurring species along the coastal plain, along with the Yellow-leaf Spurred Mangrove (*Ceriops tagal*) (Ref. 87; Ref. 85). Other species that occur in the region are the Club Mangrove (*Aegialitis annulata*), the River Mangrove (*Aegiceras corniculatum*), and the Ribbed-fruit Orange Mangrove (*Bruguiera exaristata*) (Ref. 11; Ref. 31).

Six species of mangrove are found in the Montebello Islands/Barrow Island region, including the Grey Mangrove, Ribbed-fruit Orange Mangrove, Yellow-leaf Spurred Mangrove, Red Mangrove, Club Mangrove, and the River Mangrove (Ref. 31). Most mangrove forests in the area occur in the Montebello Islands (Ref. 31).

The Grey Mangrove (*Avicennia marina*) is the only species found around Barrow Island. This species is the most widespread mangrove species in Australia, found in coastal areas from Leschenault Estuary, Bunbury, Western Australia (33° 16’ S; 115° 42’ E), throughout northern Australia, to Corner Inlet, Victoria (38° 45’ S; 146° 29’ E) (Ref. 86). *Avicennia marina* is a tree or shrub that can grow to 10 m high and is categorised by its smooth bark that appears green when wet and chalky white when dry. The leaves are ovate-elliptical in shape and are 37–84 mm in length and 18–27 mm in width (Ref. 86). Flowering and maturation of *A. marina* propagules varies with latitude (Ref. 86). In the Barrow Island region, flowering often occurs between December and January, while propagules mature mostly in March (Ref. 86). The pneumatophores of *A. marina* are often tall and slender and can reach heights of 30 cm. It grows in both soft sediments and on rock, as well as where sediment accumulates in the intertidal zone (Ref. 33).

10.2 Scope

This Section records the dominant species of mangroves (Condition 14.8.iii, MS 800; Condition 11.8.iii, EPBC Reference: 2003/1294 and 2008/4178) and describes and maps the mangroves:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 14.6.iii, MS 800; Condition 11.6.III, EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing

(Condition 14.6.iv, MS 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

10.3 Distribution of Mangroves Around Barrow Island

There are no mangrove stands on the west coast of Barrow Island. *Avicennia marina* grows in sparse stands only on the east coast of Barrow Island, where it is distributed in a narrow band along soft sediment and rock substrates in the upper littoral and supra-littoral zones of the intertidal area (Figure 10-1, Figure 10-2). Mangroves have been recorded at Little Bandicoot Bay and Pelican Island, as well as further east at Bandicoot Bay. Sparse stands of trees were also recorded from Stokes Point along the coast up to Shark Point, along with stands of mangroves at Mattress Bay, Ant Point, and Square Bay.

Because mangroves are absent near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing on the west coast of Barrow Island, no field surveys were undertaken to identify the dominant species of mangroves or the demersal fish assemblages that characterise these communities. Field surveys of both the mangrove communities and the associated demersal fish assemblages were undertaken at Reference Sites on the east coast of Barrow Island as part of the Marine Baseline Program for the MOF, LNG Jetty, and DSDG (Ref. 29).

Figure 10-1: Distribution of *Avicennia marina* along the North-east Coast of Barrow Island

Source: Ref. 29

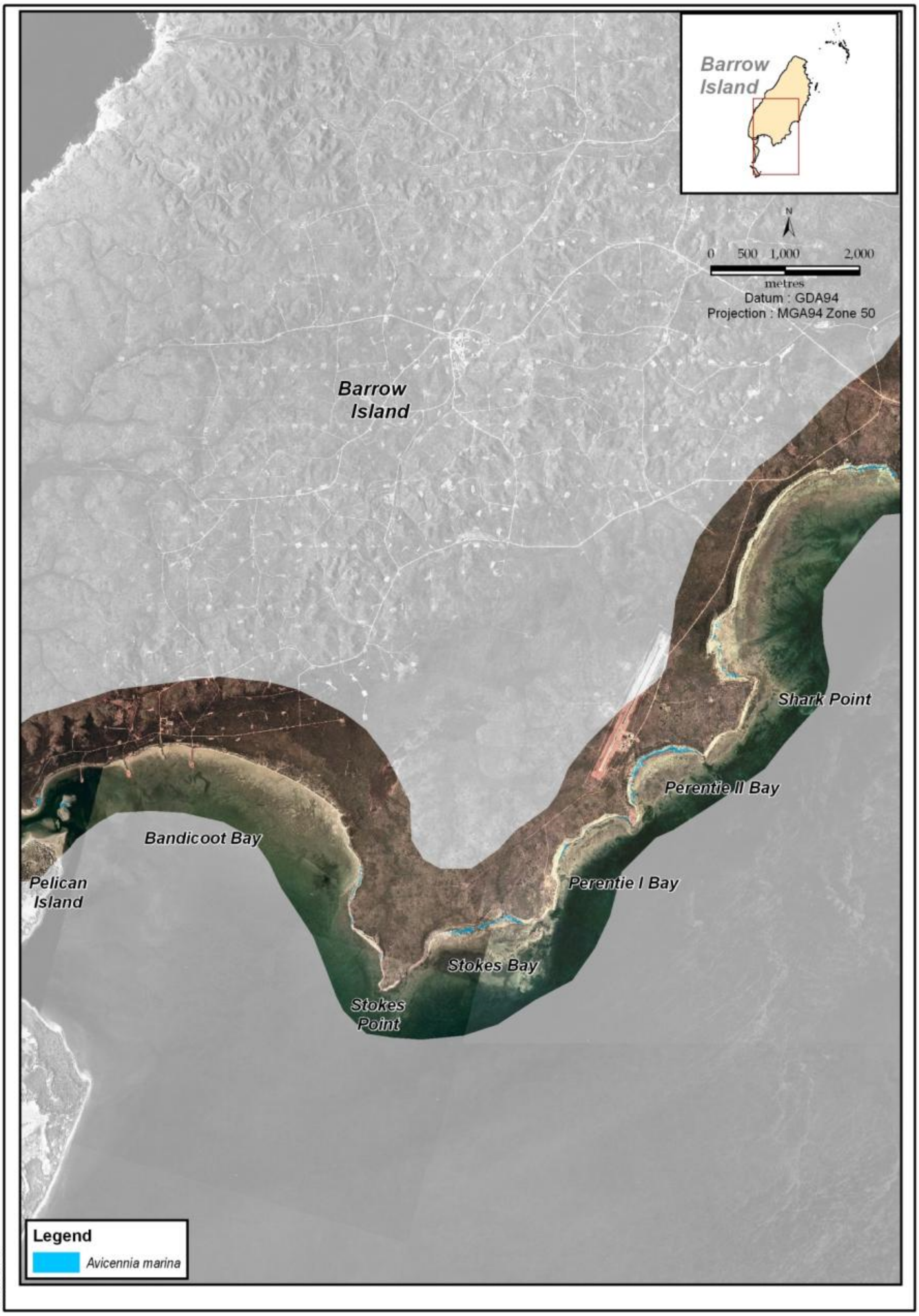


Figure 10-2: Distribution of *Avicennia marina* along the South Coast of Barrow Island

Source: Ref. 29

11 Demersal Fish

11.1 Introduction

Few ecological studies have been conducted on the fish species of north-western Australia, but the survey work to date has revealed a species-rich assemblage (Ref. 88; Ref. 89; Ref. 90; Ref. 91; Ref. 92; Ref. 93), with the North West Shelf in particular being considered a hotspot in terms of species richness (Ref. 94). This reflects the strong biogeographic links with Indonesia and the west Pacific, facilitated by the Indonesian Throughflow and the diversity of available habitats in these waters (Ref. 95). However, the degree of endemism in the fish fauna of the North West Shelf is low when compared to the temperate waters of southern Western Australia (Ref. 94).

Sampling conducted in tropical north-western Australia (in the Kimberley, Canning, and Pilbara regions) between 2000 and 2002, yielded 23 377 fishes representing 32 families, 58 genera and 119 species (Ref. 93). Of these, the most abundant species were *Lethrinus* sp., Stripey Snapper (*Lutjanus carponotatus*), and Grass Emperor (*Lethrinus laticaudis*) (Ref. 93). In the Pilbara Region specifically, the species that were found to typify fish assemblages were *Lethrinus* sp., Stripey Snapper, Grass Emperor, and Starry Triggerfish (*Abalistes stellatus*) (at Cape Preston) and *Lethrinus* sp., Stripey Snapper, and Spangled Emperor (*Lethrinus nebulosus*) (at Locker Point) (Ref. 96; Ref. 93).

The Montebello Islands/Barrow Island region supports a rich diversity of fish fauna with 456 species from 75 families recorded during a Western Australian Museum survey in 1993 (Ref. 97), most of which have wide distribution throughout the Indo–West Pacific region (Ref. 31). Two pipefish species recorded during this survey (*Doryrhamphus multiannulatus* and *Phoxocampus belcheri*) are new records for Australia (Ref. 31). The region's fish fauna is considered to be closely related to that of the Dampier Archipelago (Ref. 92), which, along with other outer reef systems upstream in the Leeuwin Current, is thought to act as a supplementary recruitment source for the Montebello Islands/Barrow Island region (Ref. 31). Similarly, the Montebello Islands/Barrow Island region may act as a source of recruits for locations further south (Ref. 31).

During the first survey in October 2008, 11 393 individuals from 248 species and 52 families were recorded from 150 stereo-BRUV deployments (Ref. 29). On average 17.5 ± 0.8 species were observed during each stereo-BRUV deployment. The highest species richness recorded for a single deployment was 49 species at a coral site within the DSDG ZoI. Numbers recorded in the second survey in March 2009 were similar, with a total of 13 440 individuals from 247 species and 54 families recorded from 183 stereo-BRUV deployments. On average 17.0 ± 0.8 species were observed during each stereo-BRUV deployment. The highest species richness recorded for a single deployment was 50 species at a coral Reference Site located in the Montebello Islands.

Surveys undertaken in Barrow Island waters during 2008–2009 identified distinct fish assemblages, in terms of species richness, relative abundance, composition, and size structure, in different key habitats (Ref. 29). In general, fish assemblages in sand and soft sediments with sessile benthic invertebrate habitats were less species-rich than those in coral or macroalgal habitats. Fish assemblages in coral habitats were the most species-rich, comprising high abundances of small-bodied pomacentrids (e.g. Six-banded Angelfish [*Pomacanthus sexstriatus*], Brown Demoiselle [*Neopomacentrus filamentosus*]; Bengal Sergeant [*Abudefduf* *bengalensis*]) and the common occurrence of larger serranids (e.g. Bar-cheek Coral Trout [*Plectropomus maculatus*]), labrids (e.g. Blue Tuskfish [*Choerodon cyanodus*], Blackspot Tuskfish [*Choerodon schoenleinii*] and Moon Wrasse [*Thalassoma lunare*]), lethrinids (e.g. Yellowtail Emperor [*Lethrinus atkinsoni*]), and lutjanids (e.g. Stripey Snapper [*Lutjanus carponotatus*]). Habitats dominated by macroalgae were characterised by high abundances of labrids (e.g. Bluespotted Tuskfish [*Choerodon cauteroma*], Blue Tuskfish [*Choerodon cyanodus*], Blackspot Tuskfish [*Choerodon schoenleinii*], lethrinids (e.g. Threadfin Emperor [*Lethrinus genivittatus*], Blue-lined Emperor [*Lethrinus* sp.]), nemipterids (e.g. Purple Threadfin Bream [*Pentapodus emeryii*], Northwest Threadfin Bream [*Pentapodus porosus*]), and the presence of juveniles of many different species (in particular *Lethrinus* sp. and *Choerodon* spp.), indicating that macroalgae habitats act as important nursery grounds for numerous fish species, including those where adults were observed in different habitat types.

Sandy areas were often visited by transient predators, including carangids (e.g. Yellowstripe Scad [*Selaroides leptolepis*]) and Scombridae spp. Also high in abundance in sandy areas were monacanthids (e.g. Pigface Leatherjacket [*Paramonacanthus choirocephalus*]), nemipterids (e.g. *Nemipterus* spp., Western Butterfish [*Pentapodus vitta*]), and tetraodontids (e.g. Rusty-spotted Toadfish [*Torquigener pallimaculatus*]). In contrast, fish assemblages in soft sediments with sessile benthic invertebrate communities were less species-rich, with high abundances of carangids (e.g. Gold-spotted Trevally [*Carangoides fulvoguttatus*], Golden Trevally [*Gnathanodon speciosus*], Yellowstripe Scad [*Selaroides leptolepis*]), lethrinids (e.g. Threadfin Emperor [*Lethrinus genivittatus*], Blue-lined Emperor [*Lethrinus* sp.]), and nemipterids (e.g. *Nemipterus* spp., Northwest Threadfin Bream [*Pentapodus porosus*], Western Butterfish [*Pentapodus vitta*]).

Numerous commercial and recreationally important fish species occur around Barrow Island (Ref. 11). The principal commercial fisheries in the North Coast Marine Bioregion (which includes the IMCRA Pilbara Offshore (PIO) Marine Bioregion; Section 3.1) focus on finfish, particularly the emperor, snappers, and cods that are caught by the Pilbara Demersal Fish Trawl Fishery and the Pilbara Demersal Trap Fishery (Ref. 98). These two fisheries target Blue-lined Emperor (*Lethrinus punctulatus*), threadfin bream (Nemipteridae), Brownstripe Snapper (*Lutjanus vitta*), Crimson Snapper (*Lutjanus erythropterus),* Red Emperor (*Lutjanus sebae*), Saddletail Snapper (*Lutjanus malabaricus*), Goldband Snapper (*Pristipomoides multidens*), Spangled Emperor (*Lethrinus nebulosus*), Frypan Snapper (*Argyrops spinifer*), and Rankin Cod (*Epinephelus multinotatus*). Other species targeted commercially and recreationally in Pilbara waters include Spanish Mackerel *(Scomberomorus commerson)* and Grey Mackerel *(Scomberomorus semifasciatus)* (Ref. 98).

A number of species occurring in the area are protected under Western Australian and Commonwealth legislation. These include, but are not limited to, the Potato Cod (*Epinephelus tukula*), the Double-headed Maori Wrasse (*Cheilinus undulatus*), and species of syngnathids (*Hippocampus hystrix* and *Phoxocampus belcheri*). Most of these species are regionally widespread (Ref. 31).

11.2 Scope

This Section records the existing demersal fish assemblages characteristic of sessile benthic macroinvertebrate and macroalgal communities (Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178). The benthic habitat within the MDF and in areas at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing largely comprised unvegetated or bare sand and limestone platform covered with unvegetated sand (Section 5.3), thus the demersal fish assemblages characteristic of these areas has also been surveyed. This Section describes/defines and maps the demersal fish:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.vi, MS 800; Condition 11.6.VI EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.vii, MS 800; Condition 11.6.VII, EPBC Reference: 2003/1294 and 2008/4178).

Because hard and soft corals (Section 6) and seagrass (Section 9) were sparsely distributed and/or present at low levels of cover within the MDF and in areas at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, no surveys of demersal fish assemblages were undertaken in these communities. Similarly, because mangroves (Section 10) were not recorded within the MDF nor in areas at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, no surveys of demersal fish assemblages were undertaken in this community-type.

11.3 Methods

11.3.1 Site Locations

Surveys of the demersal fish assemblages were undertaken at eight sites, in water depths between 12 and 22 m, on the west coast of Barrow Island near the Offshore Feed Gas Pipeline System in State Waters (Table 11-1; Figure 11-1). Sites were selected to represent the major offshore habitats within the MDF and in areas at risk of Material or Serious Environmental Harm and Reference Sites. These communities included unvegetated sand and soft sediments with sessile non-coral benthic macroinvertebrates. In addition, four sites near the HDD exit alignment and along the inshore limestone platform, in depths between 12 and 14 m, were surveyed. Sites were selected to represent the major inshore habitats within the MDF and in areas at risk of Material or Serious Environmental Harm and Reference Sites. These communities included macroalgae and unvegetated sand. For further information, refer to the report Barrow Island Baseline Fish Survey Stereo BRUV Report 2: Domestic Gas Pipeline, Feed Gas Pipeline and Horizontal Directional Drilling Sites (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix C).

Table 11-1: Demersal Fish Assemblage Survey Sites, Community-types, and Survey Dates

Zone	Site Code	Location				March 2009		March 2010	
		Easting	Northing	Latitude	Longitude	Dominant Habitat	Average Depth (m)	Dominant Habitat	Average Depth (m)
		(GDA94, MGA Zone 50)		(GDA94)					
At risk of Material or Serious Environmental Harm	FGI1	333633	7711886	20°41.105' S	115°24.162' E	Sand	19.0	Sand	18.0
	FGI2	332102	7712403	20°40.816' S	115°23.284' E	Sand	20.4	Sand	19.7
	FGI4	330985	7712980	20°40.497' S	115°22.644' E	Not surveyed		Sand	21.9
	HDD1	334650	7711425	20°41.360' S	115°24.745' E	Not surveyed		Macroalgae	12.2
Reference	FGFR1	331682	7709028	20°42.643' S	115°23.022' E	Sessile	18.7	Sand	17.8
	FGFR2	334095	7715577	20°39.107' S	115°24.449' E	Sand	12.5	Sand	13.0
	FGFR3	330217	7710062	20°42.075' S	115°21.184' E	Sessile	20.4	Sessile	21.3
	FGFR4	335302	7714630	20°39.626' S	115°25.139' E	Not surveyed		Sand	12.1
	FGN1	332603	7714032	20°39.936' S	115°23.581' E	Sand	18.9	Not surveyed	
	HDDN1	335552	7713012	20°40.504' S	115°25.274' E	Not surveyed		Macroalgae	13.2
	HDDN2	335954	7713936	20°40.006' S	115°25.510' E	Not surveyed		Macroalgae	14.2
	HDDN3	333646	7709907	20°42.177' S	115°24.159' E	Not surveyed		Sand	9.9

Note: Change in dominant habitat type at FGFR1 between March 2009 and March 2010.

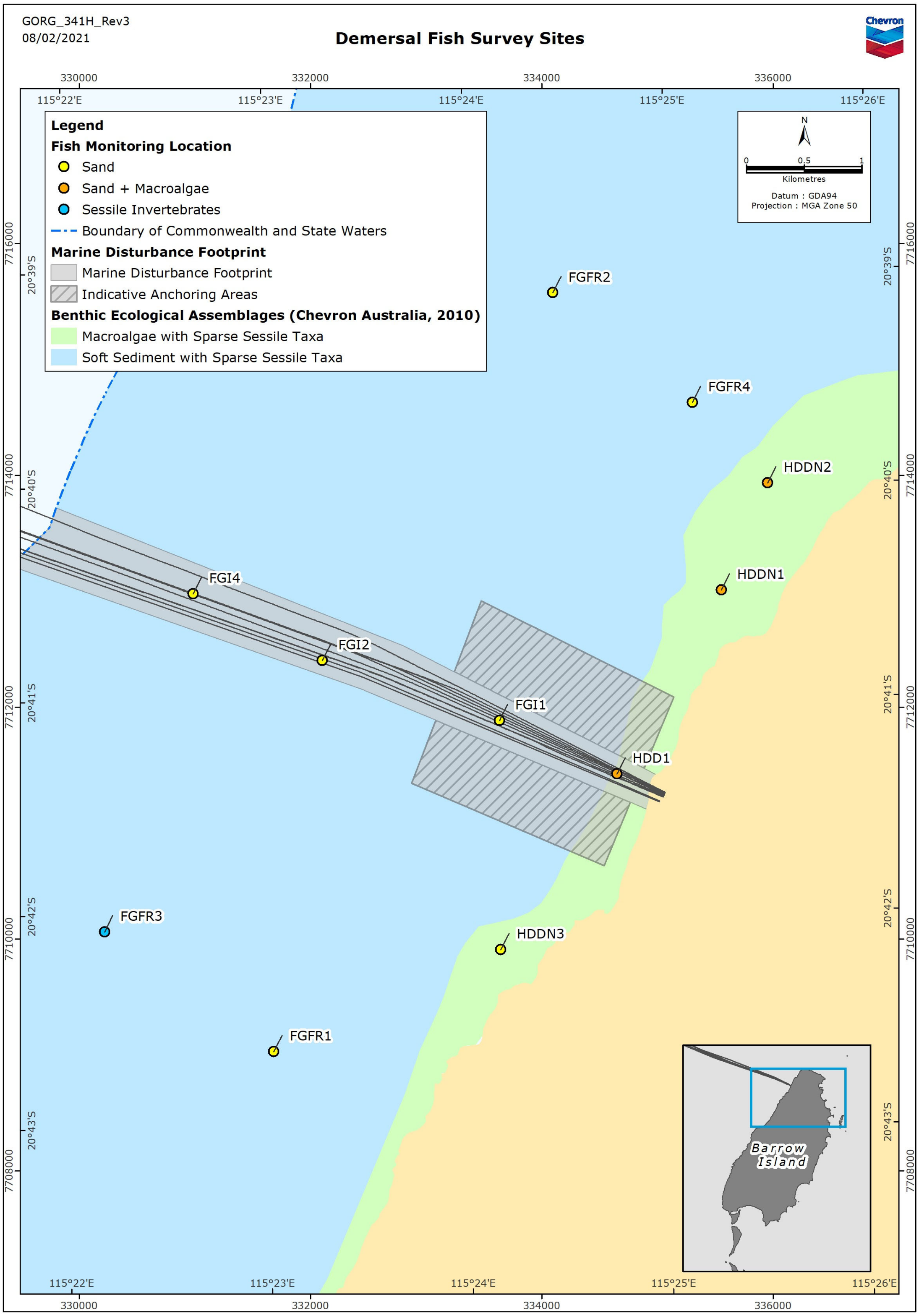


Figure 11-1: Fish Survey Sites near the Offshore Feed Gas Pipeline in State Waters and the Marine Component of the Shore Crossing, March 2010

11.3.2 Methods

The demersal fish assemblages were surveyed using baited remote underwater stereo-video systems (stereo-BRUVs). Five stereo-BRUVs were deployed synchronously at each site for at least one hour, with at least 250 m between each stereo-BRUV to avoid overlap of bait plumes and reduce the likelihood of fish moving between deployments within the sampling period. The stereo-BRUVs used in this study used two SONY HDR-CX7 and CX12 handy cams in waterproof housings mounted 0.7 m apart and inwardly converged at 8° to gain an optimised field of view with visibility of 8 m distance. A synchronising diode and bait basket were positioned in the field of view of both cameras.

Further information on the design, measurement, and calibration procedures are presented in the report Barrow Island Baseline Fish Survey Stereo BRUV Report 2: Domestic Gas Pipeline, Feed Gas Pipeline and Horizontal Directional Drilling Sites (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix C) and references therein.

11.3.3 Timing and Frequency of Sampling

Surveys of demersal fish assemblages were undertaken between 16 and 27 March 2009 at Offshore Feed Gas Pipeline System survey sites, and between 24 February and 2 March 2010 at Offshore Feed Gas Pipeline System survey sites and HDD survey sites. Multiple surveys were undertaken to provide additional power to detect impacts and to ensure adequate coverage of community-types. Demersal fish assemblages were surveyed using the stereo-BRUVs during daylight hours. Crepuscular (twilight) and night-time sampling of fish assemblages was not undertaken, noting that what is required under Condition 12.8.iii, MS 769; Condition 14.8.iii, MS 800; Condition 11.8.III, EPBC Reference: 2003/1294 and 2008/4178 is a representative baseline against which change could be measured after completion of the construction of the Marine Facilities. Recent work with stereo-BRUVS has indicated low species richness and abundance at night and there are difficulties associated with comparing day and night fish assemblages given the likely varying behaviour of fish, particularly to different coloured lights and towards bait (Barrow Island Baseline Fish Survey Stereo BRUV Report 2: Domestic Gas Pipeline, Feed Gas Pipeline and Horizontal Directional Drilling Sites, unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix C).

11.3.4 Treatment of Survey Data

High definition stereo-BRUV footage was converted from .m2ts to .mpeg format using Elecard Converter Studio AVC HD V 3.0. EventMeasure (Ref. 99) was used to view and analyse footage for measures of relative abundance of all fish species. Sixty minutes of bottom-time was analysed for all video recordings. Relative abundance counts were obtained as the maximum number of fish belonging to each species, present in the field of view of the stereo-BRUV at one time (MaxN). This measure avoids repeated counts of the same individual and provides a conservative measure of relative abundance, as only a portion of the total number of individuals in the area may be viewed at one time.

PhotoMeasure (Ref. 99) was used to collect length measurements from the left and right stereo pair of images. To avoid making repeated measurements of the same individuals, measures of length (snout to fork, i.e. fork length) were made at the time of MaxN. To ensure good measurement accuracy and precision, as well as consistency across samples, all measures of fish length were limited to those individuals within a maximum distance of 8 m from the cameras.

Demersal fish assemblages that characterised soft sediments with sessile benthic macroinvertebrates, macroalgae, and sand communities were described in terms of the number of species, the dominant species (i.e. abundance of species, species commonality [number of sites]), and size structure. Sampling was designed to examine differences in fish assemblage structure (composition, richness, abundance, size) across community-types and between sites at risk of Material or Serious Environmental Harm and Reference Sites. Three-factor multivariate analyses were undertaken with factors including: Community-type (two levels, fixed: sand, sessile benthic macroinvertebrates or sand, macroalgae), Zone (two levels, fixed: at risk or Material or Serious Environmental Harm, Reference), and Site (nested in Community-type × Zone, random with varying levels). The multivariate abundance data were analysed using permutational multivariate analysis of variance with 9999 permutations (PERMANOVA; Ref. 100) in the Primer-E software package (Plymouth Routines in Multivariate Ecological Research; Ref. 101). This permutational approach was used for analyses because the relative abundances of fish are highly skewed and contained many zero counts (non-normal data). Data were fourth-root transformed prior to analysis to down weigh the influence of very abundant species. The multivariate analysis was undertaken using the Bray Curtis dissimilarity matrix. Univariate species richness analyses were analysed using the Euclidean Distance dissimilarity measure. Where significant relationships were evident, similarity percentages (SIMPER; Ref. 102) on fourth-root transformed data, were used to examine which individual species contributed to any observed differences in assemblage composition by identifying those with a ratio of dissimilarity to standard deviation greater than 1. Patterns in the size structure of assemblages were compared using length-frequency histograms and tested using a Kolmogorov-Smirnov distribution test.

Further information on the image analysis and statistical analysis are presented in the report Barrow Island Baseline Fish Survey Stereo BRUV Report 2: Domestic Gas Pipeline, Feed Gas Pipeline and Horizontal Directional Drilling Sites (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix C) and references therein.

11.4 Results

The results are presented in full in the report Barrow Island Baseline Fish Survey Stereo BRUV Report 2: Domestic Gas Pipeline, Feed Gas Pipeline and Horizontal Directional Drilling Sites (unpublished report prepared by the Centre for Marine Futures, University of Western Australia; Appendix C). Demersal fish assemblages are difficult to map because, while they may often exhibit distinct habitat associations, they are not always spatially restricted to the sampling sites and individual species within the assemblage may exhibit varying levels of site attachment. The relative abundance and diversity of demersal fish characteristic of macroalgae, soft sediments with sessile benthic macroinvertebrates, and sand communities in Barrow Island waters are presented in the form of interactive Excel charts (Appendix D).

While the focus of the surveys was on describing the demersal fish assemblages that characterised soft sediments with sessile benthic macroinvertebrates, macroalgae, and sand communities, pelagic and more mobile species (e.g. mackerel species [scombrids], trevally species [*Carangoides* spp.]) were also recorded and included in the analyses as a number of these species were consistently observed regardless of survey period, habitat, or location and they likely comprise an important component of the fish assemblages in Barrow Island waters.

11.4.1 Definition and Description of Demersal Fish Assemblages Characteristic of Soft Sediments with Sessile Benthic Macroinvertebrates, Macroalgae and Sand Communities at the Offshore Feed Gas Pipeline System Survey Sites in State Waters

During the first survey in March 2009 at the Offshore Feed Gas Pipeline System survey sites, a total of 696 individuals from 56 species and 28 families were recorded at the six sites (25 stereo-BRUV deployments). In February/March 2010, 1262 individuals from 70 species and 31 families were recorded from seven sites (35 stereo-BRUV deployments). The highest number of species observed on a single deployment in 2009 was 25 compared to 32 in 2010, both at soft sediment with sessile benthic macroinvertebrates sites.

The Offshore Feed Gas Pipeline System survey sites were characterised by the families Scombridae, Nemipteridae, and Carangidae. The most numerically abundant species observed in 2009 were Yellowstripe Scad (*Selaroides leptolepis*), Northwest Threadfin Bream (*Pentapodus porosus*), Mackerel (Scombridae spp.), Barred Yellowtail Scad (*Atule mate*), and Threadfin Pearl Perch (*Glaucosoma magnificum*). In 2010, the most numerically abundant species were Yellowstripe Scad, Rusty-spotted Toadfish (*Torquigener pallimaculatus*), Northwest Threadfin Bream, Threadfin Emperor (*Lethrinus genivittatus*), and whiting (*Sillago* spp.). The most common species observed during the 2009 survey were Scombridae spp., Starry Triggerfish (*Abalistes stellatus*), Northwest Threadfin Bream, Yellowstripe Scad, Barred Yellowtail Scad, and Threadfin Bream (*Nemipterus* spp.). The most common species observed during the 2010 survey included Scombridae spp., Rusty-spotted Toadfish, Synodontidae spp., Sharksucker (*Echeneis naucrates*), and Razorfish (*Iniistius* spp.).

In 2009, there were no significant differences in the species richness of fish assemblages between Reference Sites (FGFR1, FGFR2, FGFR3, FGN1) and those at risk of Material or Serious Environmental Harm (FGI1, FGI2), or across sites. However, there was a significant effect of habitat driven by greater species richness at sessile invertebrate sites (mean species richness 12 ± 2.1) compared to bare sand sites (mean 3.9 ± 0.43). In 2010 species richness was significantly higher at the soft sediment with sessile macroinvertebrate site (mean species richness 23.2 ± 4) than at the sand sites (mean 6.3 ± 0.8). A comparison of species richness between the two surveys indicated that of the 56 species recorded in 2009, 39 (70%) were recorded again in 2010. Species unique to the 2009 survey were not common, with their presence recorded at fewer than 15% of deployments. Of the 70 species recorded in 2010, 32 (46%) were unique to this survey. The most common of these species were Silver Toadfish (*Lagocephalus sceleratus*), which was recorded on 25% of deployments, and Monocle Bream (*Scolopsis monogramma*), which was recorded on 20% of deployments in 2010. Differences in the levels of uniqueness likely reflect differences in sampling effort (25 deployments in 2009 compared to 35 in 2010) and/or that different sites were surveyed on different dates (FGN1 was only surveyed in 2009; FGFR4 and FGI4 were only surveyed in 2010).

The relative abundance and composition of fish assemblages were not significantly different between sites at risk of Material or Serious Environmental

Harm and Reference sites, although a trend was indicated for 2009 data. However, in both 2009 and 2010 the relative abundance and composition of fish assemblages differed significantly between habitats and sites. In 2009, 5 species contributed to differences between sand and sessile invertebrate habitats—Northwest Threadfin Bream, Starry Triggerfish, *Nemipterus* spp. (threadfin bream), Threadfin Emperor, and Scombridae spp. (mackerel). All, except Scombridae spp., were more abundant in sessile invertebrate habitats. In 2010, 19 species were more abundant at the soft sediment with sessile benthic macroinvertebrates site than at the sand sites, including Northwest Threadfin Bream, Bludger Trevally (*Carangoides gymnostethus*), Starry Triggerfish, Threadfin Emperor, Dusky Rabbitfish (*Siganus fuscescens*), Blacksaddle Goatfish (*Parupeneus spilurus*), Variegated Emperor (*Lethrinus variegatus*), Bicolour Goatfish (*Parupeneus barberinoides*), Smoky Puller (*Chromis fumea*) and Monocle Bream. The two species present in higher abundance at sand sites than at soft sediment with sessile benthic macroinvertebrates sites were Rusty-spotted Toadfish and Scombridae spp.

In 2009 and 2010, the size structure of the fish assemblages differed significantly between the soft sediment with sessile benthic macroinvertebrates sites and the sand sites. In both 2009 and 2010, sand sites had a higher proportion of the fish assemblage within the size-class 81 mm to 120 mm fork length, reflecting higher abundances of small-bodied Yellowstripe Scad, Rusty-spotted Toadfish, and Pigface Leatherjacket at these sites. In contrast, there were two distinct peaks in size-class (41–80 mm and 121–160 mm fork lengths) at soft sediment with sessile benthic macroinvertebrates sites in 2009 compared with a single peak in 2010 (121–160 mm fork length), reflecting the absence of small-bodied Yellowstripe Scad in 2010 and high abundances of Northwest Threadfin Bream in both 2009 and 2010. Despite sand sites having a high proportion of the fish assemblage in small size categories, the mean length of the fish assemblage at these sites was greater than that at the soft sediment with sessile benthic macroinvertebrates sites due to the presence of many large-bodied individuals including Mackerel, Silver Toadfish, Whitespotted Guitarfish (*Rhynchobatus australiae*), and Sharksucker.

11.4.2 Definition and Description of Demersal Fish Assemblages within the MDF Associated with the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters

Two sites within the Offshore Feed Gas Pipeline System MDF were surveyed in March 2009 (FGI1 and FGI2) and three were surveyed in February/March 2010 (FGI1, FGI2 and FGI4). In 2009, 122 individuals from 10 species were observed at FGI1, and 20 individuals from five species were observed at FGI2. The most abundant species observed was Yellowstripe Scad and the most common were Scombridae spp. In 2010, 73 individuals from 16 species were recorded at FGI1, 159 individuals from 12 species at FGI2, and 101 individuals from 18 species at FGI4. The most abundant species observed included Yellowstripe Scad, Rusty-spotted Toadfish, and Scombridae spp., and the most common included Rusty-spotted Toadfish, Scombridae spp., and Northwest Threadfin Bream.

There were significant differences in the size frequencies of the fish assemblages between the 2009 and 2010 surveys, with a higher proportion of the assemblage recorded in 2009 measuring between 81 and 120 mm fork length. The narrow size frequency and reduced mean length recorded for 2009 reflects the high number of small-bodied Yellowstripe Scad measured at FGI1.

In 2009 and 2010, there were no significant differences in the species richness of fish assemblages between Reference Sites and sites in the MDF. Similarly, in both 2009 and 2010, the relative abundance and composition of fish assemblages were not significantly different between sites in the MDF and Reference Sites.

In 2009, the distribution of lengths within fish assemblages at Reference Sites were significantly different to those at the one site (FGI1) in the MDF where measurements were possible (visibility was too low for length measurements at FGI2). Site FGI1 had a smaller mean length than observed at the Reference Sites, reflecting that a large proportion of the assemblage measured (particularly Yellowstripe Scad) were between 81 and 120 mm fork length. There were two distinct peaks in size-class at the Reference Sites, corresponding to a broad range of small-bodied species (41–80 mm fork length) and a large number of Northwest Threadfin Bream (120–200 mm fork length). There was no difference in the size structure of fish assemblages at the Reference Sites and the sites in the MDF in 2010.

11.4.3 Definition and Description of Demersal Fish Assemblages at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters

Two sites at risk of Material or Serious Environmental Harm due to the construction or operation of the Offshore Feed Gas Pipeline System were surveyed in March 2009 (FGI1 and FGI2) and three were surveyed in February/March 2010 (FGI1, FGI2, and FGI4). In 2009, 122 individuals from 10 species were observed at FGI1, and 20 individuals from five species were observed at FGI2. The most abundant species observed was Yellowstripe Scad and the most common were Scombridae spp. In 2010, 73 individuals from 16 species were recorded at FGI1, 159 individuals from 12 species at FGI2, and 101 individuals from 18 species at FGI4. The most abundant species observed included Yellowstripe Scad, Rusty-spotted Toadfish, and Scombridae spp., and the most common included Rusty-spotted Toadfish, Scombridae spp., and Northwest Threadfin Bream.

There were significant differences in the size frequencies of the fish assemblages between the 2009 and 2010 surveys, with a higher proportion of the assemblage recorded in 2009 measuring between 81 and 120 mm fork length. The narrow size frequency and reduced mean length recorded for 2009 reflects the high number of small-bodied Yellowstripe Scad measured at FGI1.

In 2009 and 2010, there were no significant differences in the species richness of fish assemblages between Reference Sites and sites at risk of Material or Serious Environmental Harm. Similarly, in both 2009 and 2010, the relative abundance and composition of fish assemblages were not significantly different between sites at risk of Material or Serious Environmental Harm and Reference Sites.

In 2009, the distribution of lengths within fish assemblages at Reference Sites were significantly different to those at the one site (FGI1) at risk of Material or Serious Environmental Harm where measurements were possible (visibility was too low for length measurements at FGI2). FGI1 had a smaller mean length than at the Reference Sites, reflecting that the large proportion of the assemblage measured (particularly Yellowstripe Scad) were between 81 mm and 120 mm fork length. There were two distinct peaks in size-class at the Reference Sites, corresponding to a broad range of small-bodied species (41–80 mm fork length) and a large number of Northwest Threadfin Bream (120–200 mm fork length).

There was no difference in the size structure of fish assemblages at the Reference Sites and the sites at risk of Material or Serious Environmental Harm in 2010.

11.4.4 Definition and Description of Demersal Fish Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters

In both March 2009 and February/March 2010, four Reference Sites were surveyed (FGFR1, FGFR2, FGFR3, and FGN1 in 2009; and FGFR1, FGFR2, FGFR3 and FGFR4 in 2010). The Reference Sites FGFR1 (2009) and FGFR3 (2009 and 2010) were dominated by sessile invertebrates, particularly large sea whips. Species richness was higher at these sites than at the sand Reference Sites.

At the sand Reference Sites surveyed in 2009, 33 individuals from eight species were recorded at FGFR2, with 45 individuals from 12 species recorded at FGN1. The most abundant species observed included Scombridae spp. and whiting, which were also the most common. In 2010, a total of 109 individuals from 29 species were recorded at FGFR1, 107 individuals from 11 species at FGFR2, and 250 individuals from 16 species at FGFR4. The most abundant species observed included Yellowstripe Scad, Rusty-spotted Toadfish, and whiting, and the most common included Largescale Saury, Scombridae spp., Rusty-spotted Toadfish, and Sharksucker.

There was a significant difference in the length-frequency distribution at sand sites recorded in 2009 and 2010. In 2010 fish assemblages comprised high proportions of small-bodied individuals (81–120 mm fork length) and 13% of individuals had greater than 560 mm fork length, with very few individuals in between these sizes. During 2009 far fewer fish were measured (33 compared to 271). The highest proportion of individuals measured between 121 and 160 mm fork length, and again a large proportion (21%) of fish measured had greater than 560 mm fork length. These peaks in frequency both appear to reflect the presence of juvenile Golden Trevally (*Gnathanodon speciosus*) and small whiting, as well as large Scombridae, Sharksucker, and Giant Trevally (*Caranx ignobilis*).

At the soft sediment with sessile benthic macroinvertebrate sites surveyed in 2009, 237 individuals from 37 species were recorded at FGFR1, and 239 individuals from 24 species were recorded at FGFR3. The most abundant species included Northwest Threadfin Bream and Yellowstripe Scad, while the most common species included Threadfin Bream, Northwest Threadfin Bream, and Starry Triggerfish. In 2010, 463 individuals from 50 species were recorded at FGFR3. The most abundant species included Northwest Threadfin Bream, Threadfin Emperor, and Dusky Rabbitfish, while the most common species included Northwest Threadfin Bream, Starry Triggerfish, and Bludger Trevally.

In 2009, the highest proportion of measurements were of fish between 40 mm and 160 mm fork length reflecting measurement of a broad range of species, while in 2010 the highest proportion of length measurements were within the 121–160 mm fork length size range.

11.4.5 Definition and Description of Demersal Fish Assemblages Characteristic of Soft Sediments with Sessile Benthic Macroinvertebrates, Macroalgae and Sand Communities at the Horizontal Directional Drilling Survey Sites

A total of 1015 individuals from 70 species and 31 families were recorded at the four HDD survey sites (20 stereo-BRUV deployments) in February/March 2010. The highest number of species observed on a single deployment was 21 at a macroalgae site. Species richness did not differ significantly between community-types (macroalgae vs. sand) or across sites.

Of the 70 species recorded, 47 (67%) were also recorded at Offshore Feed Gas Pipeline System survey sites further offshore. Of the 23 species unique to the inshore areas, the most common were Cloud Wrasse (*Halichoeres nebulosus*; 30% of deployments) and Shoulderspot Wrasse (*Leptojulis cyanopleura*; recorded on 25% of deployments), both of which were only associated with macroalgae.

The relative abundance and composition of fish assemblages were not significantly different between the two community-types surveyed or among sites. The HDD survey sites were characterised by high abundances of Yellowstripe Scad (*Selaroides leptolepis*), Northwest Threadfin Bream (*Pentapodus porosus*), Rusty-spotted Toadfish (*Torquigener pallimaculatus*), Neon Damsel (*Pomacentrus coelestis*), and Pixy Wrasse (*Coris pictoides*). The most common species observed across all sites included Scombridae spp., Northwest Threadfin Bream, Pixy Wrasse, Chinamanfish (*Symphorus nematophorus*), and Cloud Wrasse.

The size structure of the fish assemblages differed significantly between the sand site and the macroalgae sites. The fish assemblages at the sand site were smaller (highest proportion of length measurements within the range 41–80 mm fork length) than those at the macroalgae sites (highest proportion of length measurements within the range 41–120 mm fork length), reflecting the occurrence of small Rusty-spotted Toadfish and Yellowstripe Scad at the sand site.

The inshore macroalgae communities at the HDD survey sites did not appear to act as important nursery areas (with few juveniles observed) compared to the macroalgae communities on the east coast of Barrow Island (Ref. 29), which is likely due to the macroalgae being more patchily distributed and restricted in area, with low-lying/turfing algae and greater exposure to the open ocean.

11.4.6 Definition and Description of Demersal Fish Assemblages within the MDF Associated with the Marine Component of the Shore Crossing

In February/March 2010, one site (HDD1) was surveyed in the marine component of the shore crossing MDF. A total of 253 individuals were recorded from 28 species at HDD1. The most abundant species included Northwest Threadfin Bream and Yellowstripe Scad, while the most common species included Northwest Threadfin Bream and Pixy Wrasse.

Although a high proportion of the fish assemblage at this site were between 41 and 120 mm fork length, the mean length at this site was higher, reflecting a number of measurements of large-bodied individuals including Scombridae spp., Giant Queenfish (*Scomberoides commersonnianus*), Golden Trevally (*Gnathanodon speciosus*), and Chinamanfish.

Species richness did not differ significantly between Reference Sites and the single site in the MDF. The relative abundance and composition of fish assemblages were not significantly different between the site in the MDF and Reference Sites. However, there was a difference in the size structure of fish assemblages between Reference Sites and the site in the MDF (HDD1). The greatest frequency of length measurements of fish assemblages at Reference Sites was between 41 and 80 mm fork length, reflecting the occurrence of small Rusty-spotted Toadfish and Yellow Stripe Scad at sand site HDDN3. Site HDD1 showed a peak in length measurements between 81 and 120 mm fork length and a second peak between 401 and 480 mm fork length, reflecting the occurrence of a school of trevally (*Carangoides fulvoguttatus*) at this site.

11.4.7 Definition and Description of Demersal Fish Assemblages at Risk of Material or Serious Environmental Harm Associated with the Marine Component of the Shore Crossing

In February/March 2010, one site was surveyed that is at risk of Material or Serious Environmental Harm associated with the marine component of the shore crossing (HDD1). A total of 253 individuals were recorded from 28 species at HDD1. The most abundant species included Northwest Threadfin Bream and Yellowstripe Scad, while the most common species included Northwest Threadfin Bream and Pixy Wrasse.

Although a high proportion of the fish assemblages at this site were between 41 mm and 120 mm fork length, the mean length at this site was higher, reflecting a number of measurements of large-bodied individuals including Scombridae spp., Giant Queenfish, Golden Trevally, and Chinamanfish.

Species richness did not differ significantly between Reference Sites and the single site at risk of Material or Serious Environmental Harm. The relative abundance and composition of fish assemblages were not significantly different between the site at risk of Material or Serious Environmental Harm and Reference Sites. However, there was a difference in the size structure of fish assemblages between Reference Sites and the site at risk of Material or Serious Environmental Harm (HDD1). The greatest frequency of length measurements of fish assemblages at Reference Sites was between 41 and 80 mm fork length, reflecting the occurrence of small Rusty-spotted Toadfish and Yellowstripe Scad at sand site HDDN3. Site HDD1 showed a peak in length measurements between 81 and 120 mm fork length and a second peak between 401 and 480 mm fork length, reflecting the occurrence of a school of trevally (*Carangoides fulvoguttatus*) at this site.

11.4.8 Definition and Description of Demersal Fish Assemblages at Reference Sites not at Risk of Material or Serious Environmental Harm Associated with the Marine Component of the Shore Crossing

In February/March 2010, three Reference Sites were surveyed (HDDN1, HDDN2, and HDDN3). A total of 315 individuals from 12 species were recorded at the sand Reference Site (HDDN3). The most abundant species included Yellowstripe Scad and Rusty-spotted Toadfish, while Scombridae spp. were the most common species recorded at HDDN3.

At the two macroalgae Reference Sites, a total of 216 individuals from 41 species were recorded at HDDN1, while 231 individuals from 37 species were recorded at HDDN2. The most abundant species included Northwest Threadfin Bream and Neon Damsel, while the most common species included Northwest Threadfin Bream and Scombridae spp. Most of the measured fish in the assemblages at these sites were within the size range 41–120 mm fork length.

11.5 Discussion and Conclusions

The surveys of demersal fish assemblages on the west coast of Barrow Island indicate high species richness and distinct differences in the abundance, composition, and size structure of fish assemblages across different community-types, reflecting the varying reliance of different fish species for different aspects of habitat. In addition, the demersal fish assemblages differed to a lesser degree between surveys, although temporal variability was relatively low compared to among community-type variability, and in some instances from site to site, the latter suggesting a highly complex and dynamic marine ecosystem. However, there were no differences in the relative abundance or composition of the demersal fish assemblages at sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to Reference Sites.

In 2009, the size structure of the demersal fish assemblages differed between the Reference Sites and sites in the MDF and in areas at risk of Material or Serious Environmental Harm, most likely as a result of the high abundance of small schooling Yellowstripe Scad (*Selaroides leptolepis*) and the limited size information that could be incorporated into the analysis due to reduced visibility. In 2010 there were no significant differences in the size structure of the fish assemblages at sites in the MDF and in areas at risk of Material or Serious Environmental Harm and Reference Sites; however, a significant difference was detected for the HDD sites due to a large number of small-bodied fish at site HDDN3. This site was dominated by sand, while macroalgae dominated the other HDD sites.

12 Surficial Sediments

12.1 Introduction

Barrow Island lies on the shallow (generally <5 m depth) limestone shelf that supports the Montebello Islands/Barrow Island group. There is a broad intertidal platform adjacent to Barrow Island that grades to the subtidal limestone shelf. Veneers of carbonate sands overlay limestone rock and generally vary in thickness between 0 and 0.5 m in the MOF area and 0.5–4.5 m further offshore in the deeper waters (Ref. 11; Ref. 103; Ref. 104). On the east coast of Barrow Island, particle grain sizes of surface sediments are predominantly medium-to-fine grained sand fractions with a silt and clay content (reported as <75 µm) generally ranging between 1% and 15% (Ref. 105). Increased quantities of rubble are present on exposed pavement reef where strong water currents are present (Ref. 11; Ref. 47). The surficial sediments of the Montebello Islands/Barrow Island region are generally in an undisturbed condition, apart from localised areas affected by drilling and aquaculture (Ref. 31).

On the west coast of Barrow Island, unconsolidated sediments overlay a cemented calcarenite substrate (Ref. 11). These sediments are mostly calcareous, are dominated by sand, and contain shells and shell fragments (Ref. 11). Off the coast of North Whites Beach, outcropping cemented sediments and prominent sand ripples are present that are orientated north-east to south-west (Ref. 20). The presence of sand ripples and the patchiness of exposed sediments are characteristic of the high-energy environment and relatively mobile sand (Ref. 41).

12.2 Scope

This Section reports on the distribution and characteristics of surficial sediments where the consequences of seabed disturbance may affect the environment (Condition 12.8.ix, MS 769) and describes/defines and maps the surficial sediment characteristics:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.iii, MS 800; Condition 11.6.III, EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.iv, MS 800; Condition 11.6.IV, EPBC Reference: 2003/1294 and 2008/4178).

12.3 Methods

12.3.1 Site Locations

During the Marine Baseline Program, surficial sediment samples were collected from 185 locations in the waters around Barrow Island (Ref. 29). Nineteen of these sites were located on the west coast of Barrow Island, including near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, as well as Reference Sites located to the north and south (Table 12-1).

Table 12-1: Sediment Sampling Sites on the West Coast of Barrow Island

Site Code	Easting	Northing	Latitude	Longitude
	(GDA94, MGA Zone 50)		(GDA94)	
Sites in the MDF and at risk of Material or Serious Environmental Harm from the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing				
HDD	334656	7711447	20° 41.348' S	115° 24.749' E
Sites in the Indicative Anchoring Area				
SS1	334671	7711951	20° 41.075' S	115° 24.761' E
SS48	334211	7711156	20° 41.503' S	115° 24.491' E
Sites not at risk of Material or Serious Environmental Harm from the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing				
HDD-N-REF	338255	7719053	20° 37.245' S	115° 26.863' E
SS46	338472	7714252	20° 39.848' S	115° 26.962' E
SS45	337623	7714529	20° 39.693' S	115° 26.475' E
SS44	336653	7714436	20° 39.739' S	115° 25.916' E
SS42	334669	7713901	20° 40.018' S	115° 24.770' E
SS43	335490	7713236	20° 40.383' S	115° 25.239' E
SS41	334659	7712959	20° 40.529' S	115° 24.759' E
NW BWI 1	335123	7712472	20° 40.795' S	115° 25.024' E
HDD-N	334745	7712431	20° 40.815' S	115° 24.806' E
HDD-S	334318	7710463	20° 41.879' S	115° 24.549' E
SS47	333632	7710357	20° 41.933' S	115° 24.153' E
SS2	332083	7708795	20° 42.771' S	115° 23.252' E
SS3	329881	7706207	20° 44.162' S	115° 21.968' E
HDD-S-REF	330087	7705312	20° 44.648' S	115° 22.082' E
FLACOURT	329234	7705071	20° 44.774' S	115° 21.589' E
BIG	328237	7702674	20° 46.068' S	115° 21.001' E

Over the period September–October 2009, an additional 29 sites near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing were sampled, as well as Reference Sites located to the north and south (Table 12-2; Figure 12-1).

Table 12-2: Sediment Sampling Sites near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Site Code	Easting	Northing	Latitude	Longitude
	(GDA94, MGA Zone 50)		(GDA94)	
Sites in the MDF and at risk of Material or Serious Environmental Harm from the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing				
HDD-1	334666	7711398	20° 41.374' S	115° 24.755' E
HDD-2	334663	7711553	20° 41.290' S	115° 24.753' E
HDD-3	334527	7711357	20° 41.396' S	115° 24.674' E
HDD-4	334736	7711524	20° 41.307' S	115° 24.796' E
Sites in the Indicative Anchoring Area				
HDD	334649	7711741	20° 41.188' S	115° 24.747' E
Sites not at risk of Material or Serious Environmental Harm from the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing				
SED10	329999	7713966	20° 39.958' S	115° 22.082' E
SED11	330638	7713748	20° 40.079' S	115° 22.448' E
SED21	333679	7714038	20° 39.938' S	115° 24.201' E
SED22	335150	7713108	20° 40.450' S	115° 25.043' E
SED23	333304	7714001	20° 39.956' S	115° 23.985' E
SED24	334699	7713207	20° 40.394' S	115° 24.784' E
SED25	334449	7713381	20° 40.299' S	115° 24.641' E
SED26	333751	7713707	20° 40.118' S	115° 24.241' E
SED27	331199	7714896	20° 39.460' S	115° 22.778' E
SED28	331978	7714433	20° 39.715' S	115° 23.224' E
SED29	332294	7714591	20° 39.631' S	115° 23.407' E
SED30	334054	7713629	20° 40.162' S	115° 24.415' E
SED31	332731	7714253	20° 39.817' S	115° 23.656' E
SED1	331817	7710630	20° 41.776' S	115° 23.109' E
SED2	331651	7710970	20° 41.590' S	115° 23.016' E
SED3	331060	7710991	20° 41.576' S	115° 22.675' E
SED8	331592	7712204	20° 40.921' S	115° 22.989' E
SED9	330409	7712673	20° 40.661' S	115° 22.310' E
SED15	333159	7710279	20° 41.973' S	115° 23.880' E
SED16	330364	7711302	20° 41.403' S	115° 22.276' E
SED17	332900	7710447	20° 41.880' S	115° 23.732' E
SED18	328549	7711927	20° 41.055' S	115° 21.235' E
SED19	333343	7709979	20° 42.136' S	115° 23.985' E
SED20	329886	7711609	20° 41.234' S	115° 22.003' E

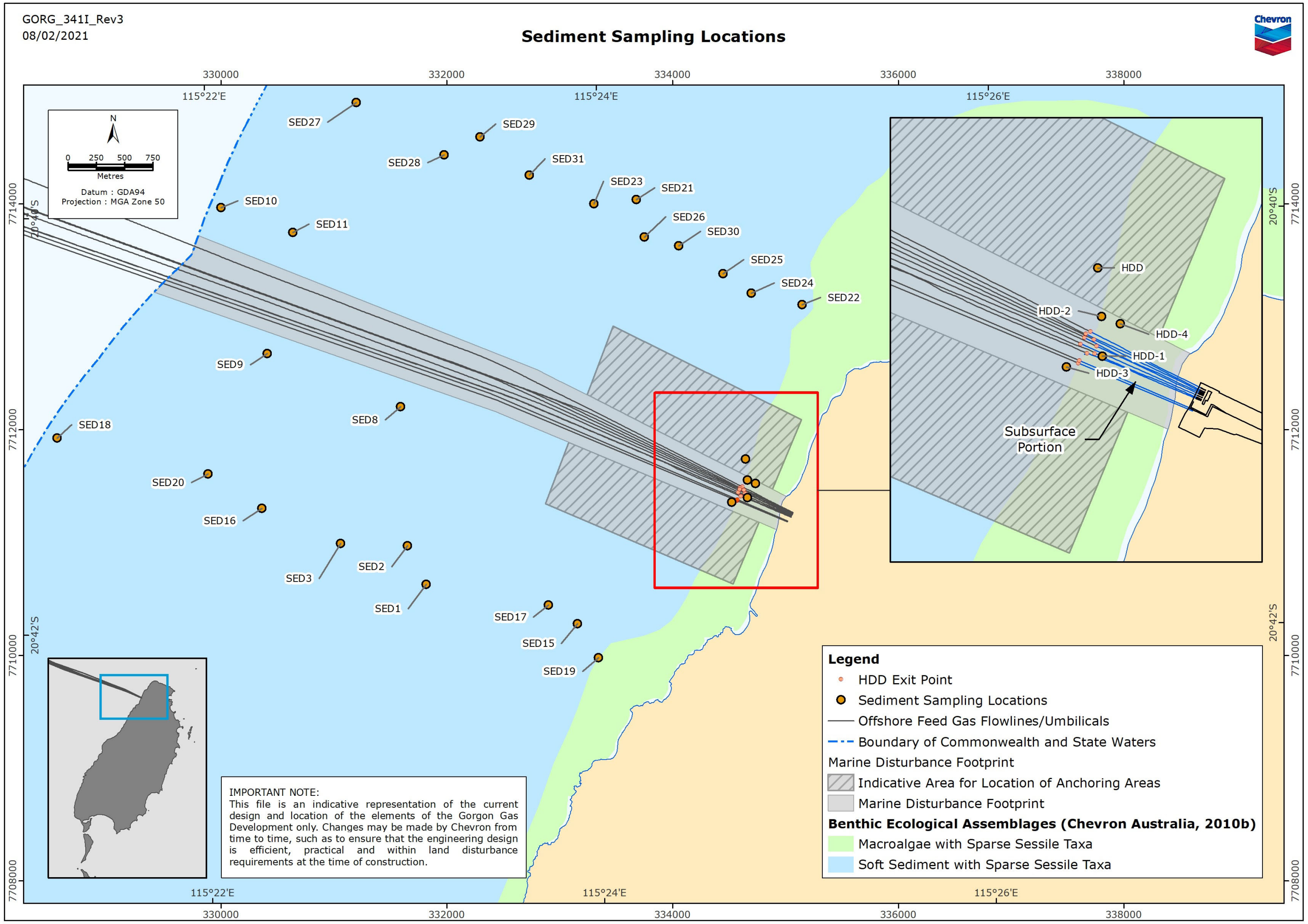


Figure 12-1: Surficial Sediment Sampling Sites West Coast of Barrow Island, September–October 2009

12.3.2 Methods

Surficial sediments collected in September–October 2009 were sampled using a 0.15 m^2 stainless steel Van Veen grab. Representative samples of the surficial sediments were collected in 500 mL sample containers. Only the surficial sediments were sampled as these are considered to be the most recent and active layer sedimentologically, representing an important part of the sediment profile in terms of biological effects (benthic habitat, sediment feeding, water/sediment interactions) and the most likely to influence the distribution and abundance of benthic macrofauna. Surficial sediments collected in July–August 2006 were sampled using a 0.25 m^2 stainless steel Van Veen grab, and those collected in September 2008–April 2009 were sampled using a corer or surface scrapes (Ref. 29).

Standard laboratory analytical procedures were employed, and laboratories with National Association of Testing Authorities (NATA)-accredited methods (or laboratories with demonstrated Quality Assurance/Quality Control [QA/QC] procedures in place) undertook the analyses (Ref. 19). The sediment samples were analysed for:

- Particle-size Distribution (PSD) – laser diffraction and wet sieving
- Total Organic Carbon (TOC) (organically bound carbon) – furnace combustion
- Total Inorganic Carbon (TIC) – furnace combustion.

Particle-size analysis was undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Minerals. The results were expressed as a cumulative percentage volume of particles that occupied six different size ranges.

Analysis of sediment organic and inorganic carbon content was undertaken by Australian Laboratory Services Environmental (ALS). Samples were analysed for total carbon by combustion in a LECO furnace in the presence of strong oxidants/catalysts and the evolved carbon (as CO_2) measured by infra-red detection. Samples were analysed for TOC by acidification to remove inorganic carbonates, followed by combustion in a LECO furnace in the presence of strong oxidants/catalysts and the evolved organic carbon (as CO_2) measured by infra-red detection. TIC was determined as the difference between total carbon and total organic carbon. TOC and TIC content were reported as a percentage of dry weight of the total sample.

12.3.3 Timing and Frequency of Sampling

Twenty-nine sites near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, as well as Reference Sites located to the north and south, were sampled over the period September–October 2009. Sampling of west coast sites as part of the Marine Baseline Program was undertaken in July–August 2006 and September 2008–April 2009 (Ref. 29).

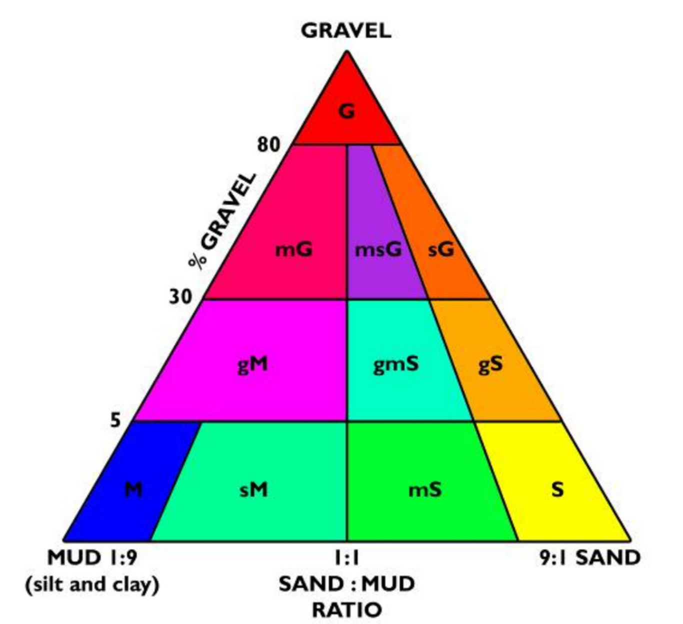
12.3.4 Data Analysis

Based on the results of particle-size analysis, each sediment sample was classified into a sediment type according to a simplified version of the scheme proposed by Folk (Ref. 106). This scheme was also used for the National Marine Sediments Database and Seafloor Characteristics Project (Ref. 107). The sediment classification scheme is based on a triangular diagram divided into sediment textural groups, according to measured percentages of gravel, sand, and mud constituents (Figure 12-2). The method provides an approach to describing the sediments with a complete range of mixtures of the three components, producing a single description and classification value (Ref. 107). The simplified version has four fewer categories than the full version as it amalgamates some categories that contain less than 5% gravel content.

According to the classification scheme, sediments were first categorised into three size-classes based on their grain-size:

- mud <0.063 mm
- sand 0.063–2 mm
- gravel >2 mm.

The percentage composition of each of the grain-size classes and the ratios between them were then used to classify the sediment into 11 discrete sediment types (Figure 12-2).



Abbreviation	Description
G	Gravel
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
gM	gravelly Mud
gmS	gravelly muddy Sand
gS	gravelly Sand
M	Mud
sM	sandy Mud
mS	muddy Sand
S	Sand

Figure 12-2: Simplified Folk Triangle Sediment Classification Scheme

Note: This diagram is not to scale – it is a representation of the classification subdivisions.

12.4 Results

The spatial distribution of sediment types within the waters around Barrow Island is presented as spatially rectified point observations (Figure 12-3 and Figure 12-4).

12.4.1 Definition and Description of Surficial Sediment Characteristics within the MDF Associated with the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Surficial sediments at sites in the MDF had very low (0%) clay (particle size <4 µm) and silt (particle size 4–62 µm) contents and low (0.1–1.6%) gravel (particle size >2000 µm) contents (Figure 12-3). The sediments were categorised as 'Sand', with compositions varying between 36.8% and 51.3% fine sand (particle size 62–250 µm), 45.2–55.8% medium sand (particle size 250–500 µm) and 2.4–15.9% coarse sand (particle size 500–2000 µm).

TOC varied between 0.09% and 0.2% wet weight, and TIC between 9.3% and 10.1% wet weight at sites in the MDF.

Surficial sediments at the site in the indicative anchoring area similarly had very low (0%) clay (particle size <4 µm) and silt (particle size 4–62 µm) contents and a low (0.6%) gravel (particle size >2000 µm) content (Figure 12-3). The sediment was categorised as 'Sand', with a composition of 34.4% fine sand (particle size 62–250 µm), 58.6% medium sand (particle size 250–500 µm), and 6.4% coarse sand (particle size 500–2000 µm). TOC content was 0.1% wet weight and TIC was 9.7% wet weight.

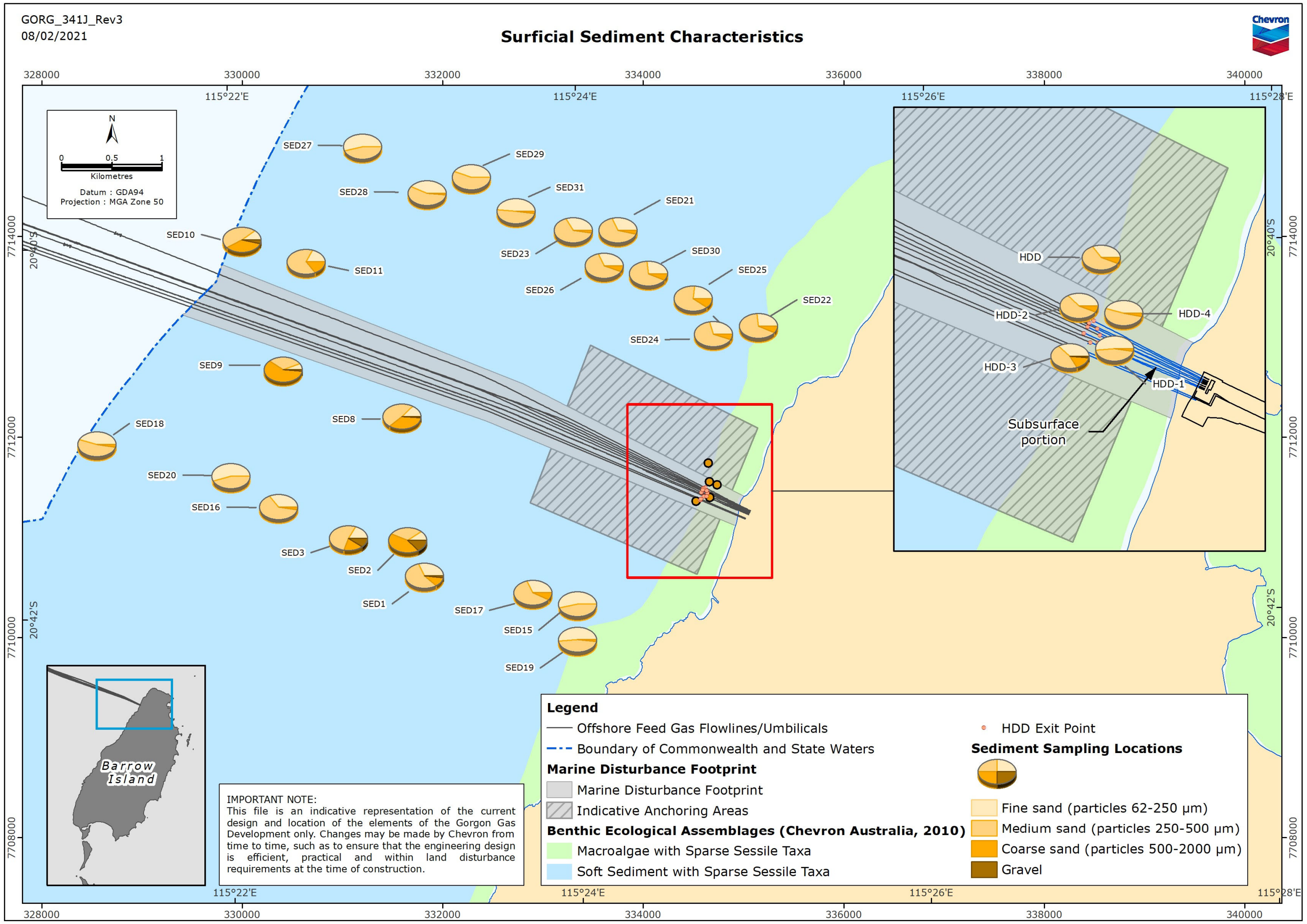


Figure 12-3: Surficial Sediment Characteristics in the MDF for the West Coast Marine Facilities, in Areas at Risk of Material or Serious Environmental Harm and in Areas not at Risk of Material or Serious Environmental Harm

12.4.2 Definition and Description of Surficial Sediment Characteristics at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Surficial sediments at HDD-1, HDD-2, HDD-3, and HDD-4—the sites at risk of Material or Serious Environmental Harm—had very low (0%) clay (particle size <4 µm) and silt (particle size 4–62 µm) contents and low (0.1–1.6%) gravel (particle size >2000 µm) contents (Figure 12-3). The sediments were categorised as ‘Sand’, with compositions varying between 36.8% and 51.3% fine sand (particle size 62–250 µm), 45.2–55.8% medium sand (particle size 250–500 µm), and 2.4–15.9% coarse sand (particle size 500–2000 µm).

TOC varied between 0.09% and 0.2% wet weight, and TIC between 9.3% and 10.1% wet weight at sites at risk of Material or Serious Environmental Harm.

Surficial sediments at the site in the indicative anchoring area similarly had very low (0%) clay (particle size <4 µm) and silt (particle size 4–62 µm) contents, and a low (0.6%) gravel (particle size >2000 µm) content (Figure 12-3). The sediment was categorised as ‘Sand’, with a composition of 34.4% fine sand (particle size 62–250 µm), 58.6% medium sand (particle size 250–500 µm), and 6.4% coarse sand (particle size 500–2000 µm). TOC content was 0.1% wet weight, and TIC was 9.7% wet weight.

12.4.3 Definition and Description of Surficial Sediment Characteristics at Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Surficial sediments at the seven nearshore Reference Sites (SED15, SED17, SED19, SED22, SED24, SED25, SED30) had very low (0%) clay (particle size <4 µm) and silt (particle size 4–62 µm) contents, and low (0–0.3%) gravel (particle size >2000 µm) contents (Figure 12-3). The surficial sediments were categorised as ‘Sand’, with compositions varying between 23.2% and 53.1% fine sand (particle size 62–250 µm), 45.9–66.4% medium sand (particle size 250–500 µm), and 1.0–10.3% coarse sand (particle size 500–2000 µm). TOC was between 0.07% and 0.1% wet weight, and TIC varied between 9.9% and 10.5% wet weight at nearshore Reference Sites.

At the offshore Reference Sites, surficial sediments had very low clay (0–0.6%) and silt (0–0.5%) contents, and low (0–13.5%) gravel contents (Figure 12-3). The sediments were categorised as ‘Sand’ at all sites, except SED2 and SED3 where sediments were categorised as ‘gravelly Sand’. The composition of the sand fractions varied from 6.5% to 54.4% fine sand, 33.4–66.5% medium sand, and 0.7–58.5% coarse sand. At SED2 and SED3, compositions varied from 10.2% to 17.2% fine sand, 32.9–52.8% medium sand, and 20.0–43.2% coarse sand. TOC was between 0.07% and 0.15% wet weight, and TIC varied from 9.6–10.6% wet weight at the offshore Reference Sites.

Similar results were reported for samples collected over the period September 2008–April 2009, with most surficial sediments collected from nearshore sites categorised as ‘Sand’ and ‘gravelly Sand’ (Figure 12-4) (Ref. 29). Clay (0–7.7%), silt (0–12.9%), and gravel (0–63.4%) contents were generally low, while the fine sand content varied between 0.9% and 43.1%, the medium sand content between 5.1% and 68.0%, and the coarse sand content between 3.5% and 83.9%. The greater range in percentage composition of the fine, medium, and coarse sand in this study reflects the greater range of habitats sampled, with many of the samples collected from the limestone platform covered with unvegetated sand.

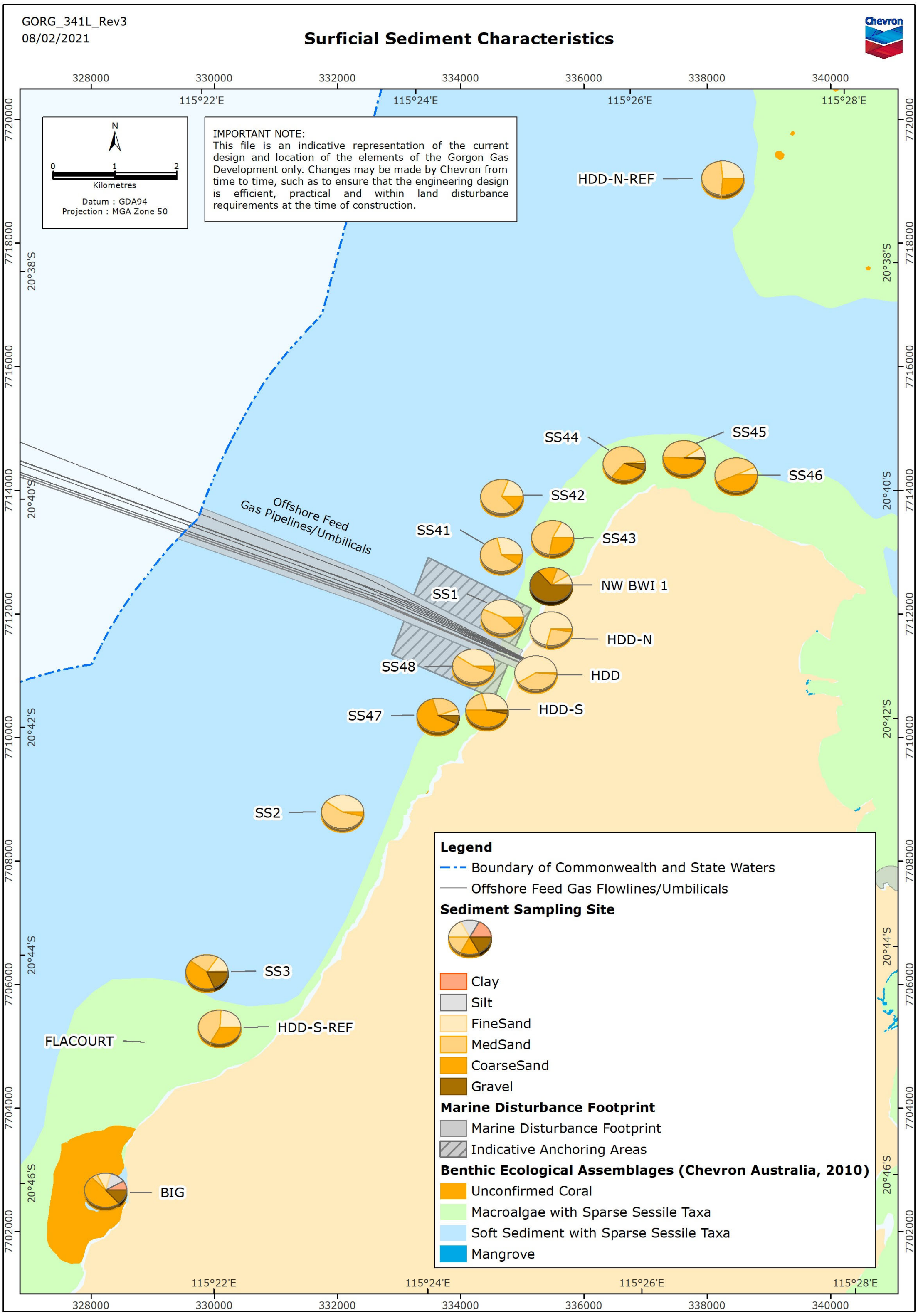


Figure 12-4: Surficial Sediment Characteristics

Note: SS3, HDD-S, SS46, etc. are site codes. See Ref. 47 for more information on site locations.

12.5 Discussion and Conclusions

The surficial sediments in the waters surrounding Barrow Island were characterised by six sediment types: 'Sand', 'gravelly Sand', 'sandy Gravel', 'muddy Sand', 'gravelly muddy Sand', and 'muddy sandy Gravel' (Ref. 29). The surficial sediments on the west coast of Barrow Island were predominantly 'Sand' and were generally less variable than on the east coast, with lower proportions of mud and gravel. The differences between the surficial sediment grain-size distributions at the different sites reflect the hydrodynamic characteristics at each site. In areas where there is more water movement, as on the west coast of Barrow Island (Section 3.4), the sediments are coarser-grained and non-cohesive with low depositional rates. TOC varied between <0.1% and 0.2% wet weight, and TIC between 9.3% and 10.6% wet weight, similar to the percentage wet weights recorded at east coast sites (Ref. 29).

There was no indication of marked differences in the characteristics of surficial sediments at sites in the MDF and at risk of Material or Serious Environmental Harm and at Reference Sites not at risk of Material or Serious Environmental Harm. Particle-size distribution and percentage wet weight of TOC and TIC were similar at survey sites in the MDF and in areas at risk of Material or Serious Environmental Harm compared to the Reference Sites.

13 Water Quality (Turbidity and Light)

13.1 Introduction

The prevailing oceanographic processes and water circulation (Section 3.4) influence the transport, dispersal, and mixing of sediments, biota, and pollutants and, consequently, the quality of the waters of the Montebello Islands/Barrow Island region (Ref. 31). Nearshore water movement and mixing patterns in the region are primarily driven by strong currents, moderate tidal ranges and winds, with wave action, seabed topography, and the effect of islands and reefs in the area also playing important roles (Ref. 31).

The water quality of the Montebello Islands/Barrow Island region is generally considered pristine, apart from some areas of localised disturbance (Ref. 31). Sources of localised disturbance include sewage outfalls from the accommodation facilities on Barrow Island and Varanus Island, and vessel discharges from the pearling and recreational and commercial fishing industries. Water clarity in the region varies according to water movement and sediment type, but is generally clearer on the western side of Barrow Island. Water turbidity generally increases towards the south-eastern side of Barrow Island, mainly due to the influence of coastal water discharges that have a high load of fine sediments (Ref. 31).

13.2 Scope

This Section reports on the background water quality (including measures of turbidity and light) where the consequences of seabed disturbance may affect the environment (Condition 12.8.viii, MS 769), the natural rates and spatial patterns of sediment deposition, and the physical characteristics of the deposited sediment where the consequences of seabed disturbance may affect the environment (Condition 12.8.x, MS 769). Water quality data and data on natural rates and spatial patterns of sediment deposition are required to be collected for at least one full annual cycle prior to the construction of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.9, MS 769).

This Section also describes/defines the water quality, including turbidity and light attenuation:

- within the Marine Disturbance Footprint of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.i and 12.8.v, MS 769; Condition 14.7.iii, MS 800; Condition 11.7.III, EPBC Reference: 2003/1294 and 2008/4178)
- that are at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Conditions 12.6.ii and 12.8.vi, MS 769; Condition 14.6.vi, MS 800; Condition 11.6.VI, EPBC Reference: 2003/1294 and 2008/4178)
- at Reference Sites that are not at risk of Material or Serious Environmental Harm due to construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing (Condition 12.6.iii, MS 769; Condition 14.6.vii, MS 800; Condition 11.6.VII, EPBC Reference: 2003/1294 and 2008/4178).

Turbidity (measured as Nephelometric Turbidity Units [NTU]) was used in the Marine Baseline Program as a surrogate for concentrations of Total Suspended

Solids (TSS). While TSS is of more relevance to coral health and survival, it is not practicable to measure TSS continuously in situ. However, there is no universal relationship between turbidity and suspended solids as TSS depends on the total weight of particles in suspension and is a direct function of the number, sizes, and specific gravities of the particles, while turbidity is a direct function of the number, surface areas, and refractive indices of the particles, but is an inverse function of their size (Ref. 108). Turbidity can be only used to estimate suspended solids concentrations if site-specific algorithms are developed based on field data. Site-specific correlation curves between TSS and turbidity have been derived for each site through laboratory measurements of the instrument response to water containing known (measured) concentrations of sediment collected from each site (Section 13.3.2.2.1; Appendix E).

13.3 Methods

13.3.1 Site Locations

13.3.1.1 LTD Loggers

As part of the Marine Baseline Program, Light-Turbidity-Deposition (LTD) loggers were deployed at 16 sites in the waters surrounding Barrow Island to provide a semi-continuous record of temporal changes in water quality and light climate at the seabed (Figure 13-1) (Ref. 29). Two of the LTD loggers were deployed on the west coast (Table 13-1).

The LTD logger at the HDD site is located approximately 500 m offshore in 15 m water depth, on a limestone platform covered with sand and a sparse to medium cover of macroalgae. The LTD logger is located approximately 250 m north of the HDD exit alignment, as this is the general direction in which currents are predicted to disperse sediments or suspended materials from the HDD activities (Ref. 27).

The LTD logger deployed at Biggada Reef, located south of the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, represents a site that is not at risk of Material or Serious Environmental Harm due to the construction or operation of these Marine Facilities. The Biggada Reef LTD logger site is in shallow water (1.5 m) on the leeward (landward) side of a fringing coral reef. The site is exposed to the prevailing westerly swell and unlike the LTD logger sites on the east coast of Barrow Island, wave conditions are predominantly influenced by a combination of swell and tidal stage (height and flow rate), rather than the localised wind-generated conditions that are most common on the east coast (Ref. 29).

Table 13-1: LTD Logger Sites

Site Name (Code)	Easting	Northing	Latitude	Longitude	Depth (m)
	(GDA94, MGA Zone 50)		(GDA94)		
HDD (HDD)	334648	7711741	20° 41.188' S	115° 24.746' E	15.0
Biggada Reef (BR)	328237	7702674	20° 46.068' S	115° 21.001' E	1.5

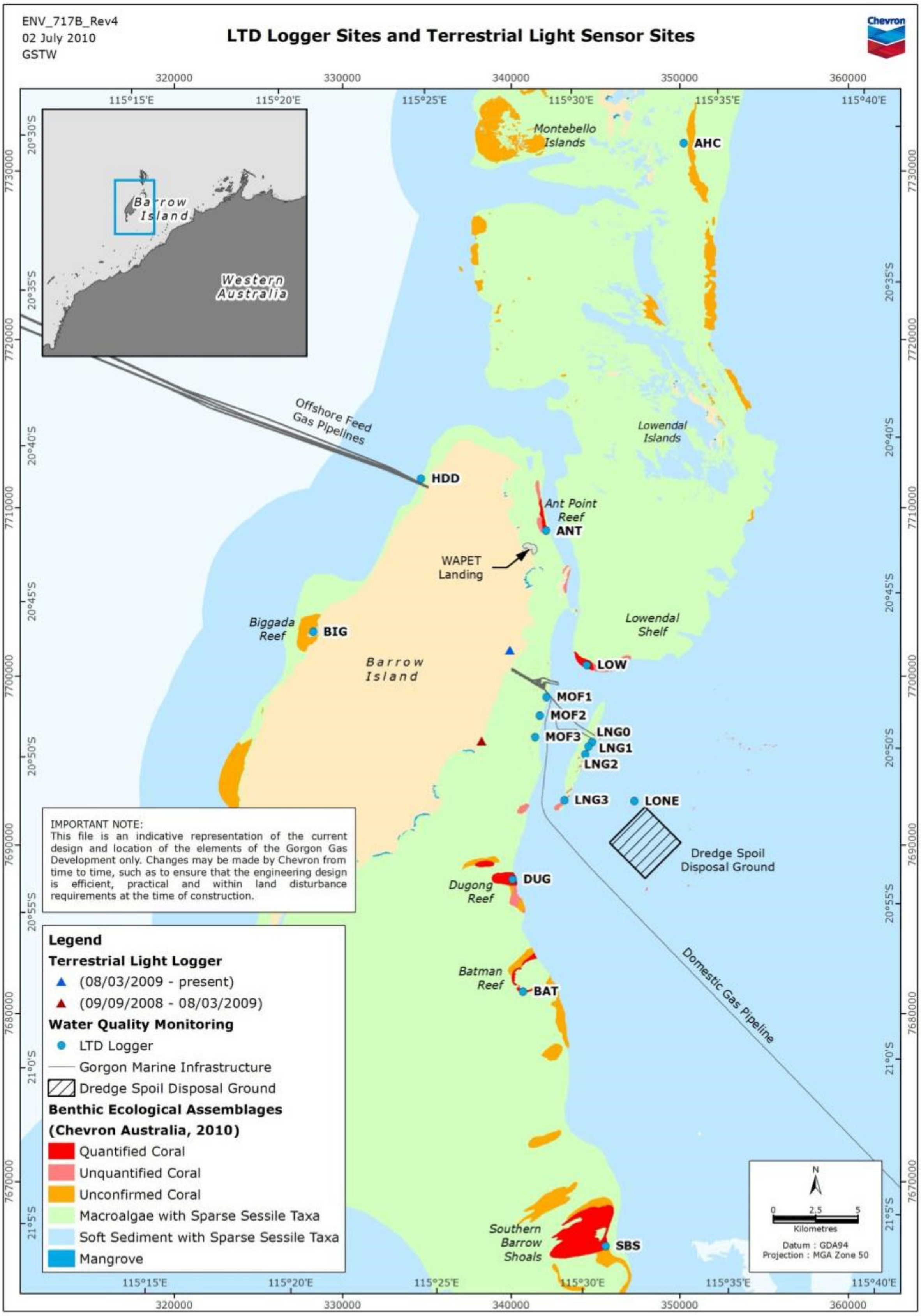


Figure 13-1: LTD Logger Sites and Terrestrial Light Sensor Sites

13.3.1.2 Water Column Profiles

Water column profiles were routinely collected at the HDD LTD logger site to provide in situ information on the physical-chemical structure of the water column. In addition, to provide a snapshot of physical-chemical water column characteristics over a wider spatial scale around the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, water column profiles were collected at 14 sites in May 2009 and 24 sites in October 2009 (Table 13-2, Figure 13-2). Water column profiles for these sites, as well as an additional 18 sites, were also collected in June 2010 to provide information over one year.

Table 13-2: Water Column Profile Sampling Dates and Sites near the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Site Code	Easting	Northing	Latitude	Longitude	May 2009	Oct 2009	June 2010
	(GDA94, MGA Zone 50)		(GDA94)				
Sites in the MDF and at risk of Material or Serious Environmental Harm from the construction or operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing							
HDD0(10)	334616	7711404	20°41.371' S	115°24.726' E	X		X
HDD0(16)	334204	7711375	20°41.385' S	115°24.488' E	X		X
50N(16)	334507	7711780	20°41.167' S	115°24.665' E	X		X
100S(16)	334530	7711657	20°41.233' S	115°24.678' E	X		X
150SHDD0(16)	334207	7711184	20°41.488' S	115°24.489' E	X		X
200N(16)	334694	7711928	20°41.087' S	115°24.774' E	X		X
250S(10)	334694	7711509	20°41.320' S	115°24.771' E	X		X
250S(16)	334412	7711519	20°41.308' S	115°24.609' E	X		X
300SHDD0(16)	333944	7711070	20°41.548' S	115°24.337' E	X		X
Sites in the Indicative Anchoring Area (Offshore)							
N6	333469	7712592	20°40.721' S	115°24.072' E			X
N7	333747	7712421	20°40.815' S	115°24.231' E			X
N8	334072	7712236	20°40.917' S	115°24.417' E			X
N9	334346	7712097	20°40.994' S	115°24.574' E			X
S7	333065	7711653	20°41.228' S	115°23.834' E			X
S8	333514	7711495	20°41.316' S	115°24.092' E			X
S9	333908	7711357	20°41.393' S	115°24.318' E			X
Sites in the Indicative Anchoring Area (Nearshore)							
50N(10)	334840	7711799	20°41.158' S	115°24.857' E	X		X
100S(10)	334753	7711636	20°41.246' S	115°24.806' E	X		X
150SHDD0(10)	334592	7711293	20°41.431' S	115°24.711' E	X		X
200N(10)	334904	7712008	20°41.045' S	115°24.895' E	X		X
300SHDD0(10)	334559	7711114	20°41.528' S	115°24.691' E	X		X

Site Code	Easting	Northing	Latitude	Longitude	May 2009	Oct 2009	June 2010
	(GDA94, MGA Zone 50)		(GDA94)				
Reference Sites (Central Sites)							
SED10	330009	7713972	20°39.954' S	115°22.087' E		X	X
SED11	330646	7713743	20°40.082' S	115°22.453' E		X	X
N1	331085	7713602	20°40.161' S	115°22.705' E			X
N2	331569	7713440	20°40.251' S	115°22.983' E			X
N3	332110	7713223	20°40.372' S	115°23.293' E			X
N4	332643	7713014	20°40.488' S	115°23.599' E			X
N5	333050	7712814	20°40.598' S	115°23.832' E			X
SED13	333392	7713152	20°40.417' S	115°24.031' E		X	X
S1	329404	7712890	20°40.538' S	115°21.733' E			X
S2	329897	7712773	20°40.604' S	115°22.016' E			X
S3	330549	7712558	20°40.724' S	115°22.390' E			X
S4	331123	7712320	20°40.856' S	115°22.719' E			X
SED8	331587	7712200	20°40.923' S	115°22.986' E		X	X
S5	331998	7712067	20°40.998' S	115°23.222' E			X
S6	332554	7712087	20°40.990' S	115°23.542' E			X
Reference Sites (Southern Transect)							
SED2	331587	7710916	20°41.619' S	115°22.978' E		X	X
SED3	331048	7710974	20°41.585' S	115°22.668' E		X	X
SED4	330759	7711044	20°41.545' S	115°22.502' E		X	X
SED15	333159	7710279	20°41.973' S	115°23.880' E		X	X
SED16	330328	7711289	20°41.410' S	115°22.256' E		X	X
SED17	332909	7710458	20°41.875' S	115°23.737' E		X	X
SED18	328485	7711872	20°41.084' S	115°21.198' E		X	X
SED19	333363	7710003	20°42.124' S	115°23.996' E		X	X
SED20	329859	7711540	20°41.272' S	115°21.987' E		X	X
Reference Sites (Northern Transect)							
SED21	333720	7714072	20°39.920' S	115°24.225' E		X	X
SED22	335106	7713122	20°40.443' S	115°25.018' E		X	X
SED23	333352	7714050	20°39.930' S	115°24.013' E		X	X
SED24	334709	7713224	20°40.385' S	115°24.789' E		X	X
SED25	334459	7713400	20°40.288' S	115°24.647' E		X	X
SED26	333727	7713719	20°40.112' S	115°24.227' E		X	X
SED27	331162	7714874	20°39.472' S	115°22.756' E		X	X
SED28	332000	7714478	20°39.691' S	115°23.237' E		X	X
SED29	332300	7714651	20°39.599' S	115°23.410' E		X	X
SED30	334087	7713657	20°40.147' S	115°24.434' E		X	X

Site Code	Easting	Northing	Latitude	Longitude	May 2009	Oct 2009	June 2010
	(GDA94, MGA Zone 50)		(GDA94)				
SED31	332755	7714263	20°39.812' S	115°23.670' E		X	X

Note: Reference Sites are grouped only with regard to groupings of water quality profile figures (Figure 13-18, Figure 13-19, Figure 13-20 Figure 13-21, Figure 13-22 and Figure 13-23).

13.3.1.3 Terrestrial Light Logger

To measure the irradiance incident at the sea surface, a Licor LI-192 2π light sensor attached to a Licor LI-1400 data logger (the ‘terrestrial light logger’) (Figure 13-3) was installed on the east coast of Barrow Island adjacent to the camp facilities (338251E, 7696175N), remote from any source of non-atmospheric shading. The sensor was subsequently relocated to the Terminal Tanks Facility near Town Point (339974E, 7701581N) (Figure 13-1). The 2π sensor only records downward irradiance and therefore avoids any potential errors as a result of light being reflected upwards from surfaces below the sensor (e.g. the ground). The sensor provided a measure of the incident Photosynthetically Active Radiation (PAR) reaching the sea surface and enabled the calculation of Light Attenuation Coefficients (LAC) at each site using information from the terrestrial light sensor and the subsurface LTD loggers.

Appendix F sets out the details of a pilot study undertaken to assess the validity of this approach to the measurement of light attenuation in the waters around Barrow Island compared to the measurement of light attenuation using two in-water sensors (e.g. Ref. 109). This study demonstrated a significant, strong positive correlation between the results obtained from both methods, indicating that the variation in light attenuation is adequately captured by the above-water to in-water method and that the results are comparable to the measurement of light attenuation using two in-water sensors.

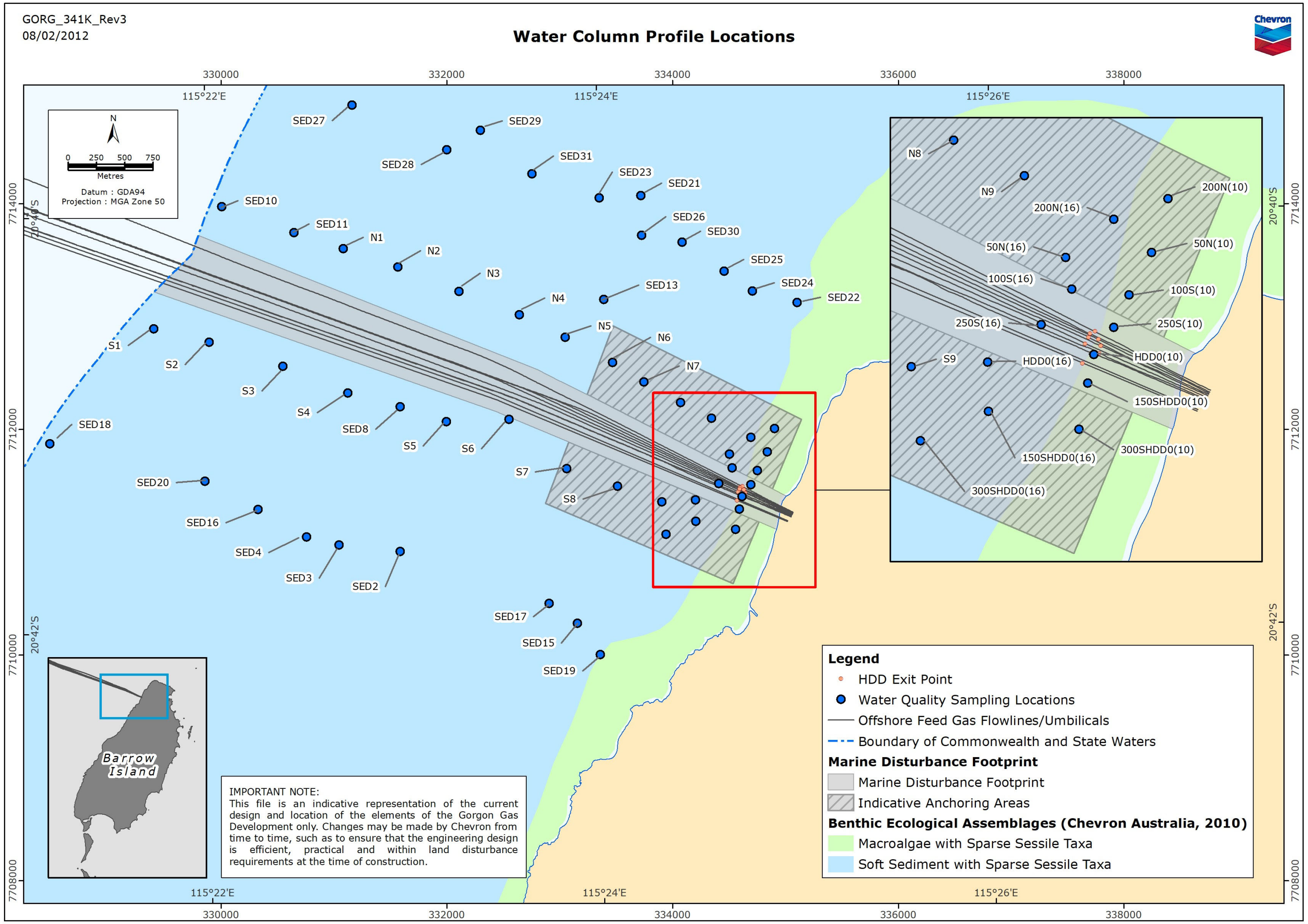


Figure 13-2: Water Quality Profile Locations on the West Coast of Barrow Island, May and October 2009 and June 2010

13.3.2 Methods

13.3.2.1 Meteorological Data

Meteorological data recorded at the weather station on Barrow Island (Station ID 005094) were obtained from the Bureau of Meteorology (BOM). The weather station is situated at the Barrow Island airport (334210E, 7691864N), located approximately 1 km from the east coast. Meteorological data recorded for the period November 2007 to May 2010 included:

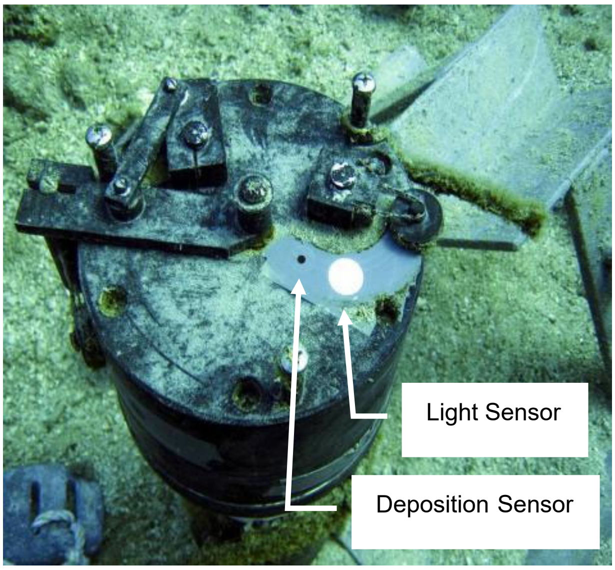
- wind speed
- wind direction
- maximum wind gusts
- air temperature
- rainfall.

13.3.2.2 Physical–Chemical Parameters

13.3.2.2.1 LTD Loggers

Simultaneous measurements of sediment deposition, turbidity and light (PAR) at the seabed, as well as pressure, were recorded by the LTD loggers deployed at each site.[4] Each sensor was mounted in a common housing and the entire unit attached to a steel frame during deployment, such that the sensors were positioned approximately 40 cm from the seabed (Figure 13-3). The external surface of each sensor was automatically wiped clean every two hours by an automated wiper assembly to allow longer deployment periods where biofouling would affect the readings. The data were logged to an internal hard drive and downloaded during routine maintenance visits.

LTD Logger



LTD Logger Showing Cleaned Light and Deposition Sensors

[4] The LTD loggers were developed by Professor Peter Ridd and colleagues at James Cook University, Queensland. Similar loggers have been used in other dredging programs in Western Australia (Pluto LNG, Woodside; Cape Lambert 85 MTPA Port Upgrade, Pilbara Iron).

Figure 13-3: LTD Loggers Deployed During the Marine Baseline Program

Turbidity was recorded using a sideways-orientated Optical Backscatter Sensor (OBS; also known as a nephelometer). Sediment deposition was measured using an upward-orientated OBS. The OBS response increases as particles accumulate on the sensor and the output is related to the amount of accumulated sediment. The difference in reading before and after wiping gives a measure of the mass of sediment deposited per unit area. The sediments that deposit on the sensor are subject to resuspension by hydrodynamic forces and the accumulation of sediments is not considered to be significantly biased by the design of the sensor and housing. If there is no deposition, the upward-orientated sensor records a value similar to the sideways-orientated turbidity sensor, as it is effectively the same sensor. The difference between the two sensors thus gives an indication of the quantity of material that has accumulated on the deposition sensor (Ref. 110). Light was recorded through an upward-orientated, 2π quantum sensor (Figure 13-3). Pressure was measured using an absolute pressure sensor, which is calibrated to give depth in metres. Ten readings are taken sequentially and used to calculate Root Mean Square Water Depth, which gives an indication of wave height.

13.3.2.2.2 Water Column Profiles

A Seabird Electronics SBE19 SEACAT Profiler was deployed on each occasion the LTD logger was accessed to undertake in-water maintenance and data download, and to provide in situ information on the physical-chemical characteristics of the water column. The SEACAT Profiler, a high-precision Conductivity-Temperature-Depth (CTD) meter with auxiliary sensors, measured conductivity, temperature, depth, dissolved oxygen (DO), pH, turbidity, and PAR at 0.5 second intervals. This information supplemented the continuous measures at the seabed provided by the LTD loggers. The SEACAT Profiler uses a different turbidity sensor to that used by the LTD loggers, thus the turbidity data from the SEACAT Profiler are not comparable with the LTD logger data.

13.3.3 Timing and Frequency of Sampling

13.3.3.1 LTD Loggers

The LTD logger at Biggada Reef was deployed over the period December 2007 to October 2009 and the LTD logger at the HDD site was deployed in May 2009. Data collection is ongoing at the HDD LTD logger site (Appendix G).

Table 13-3: Deployment Dates of LTD Loggers and Number of Days of Data Collection

Site Name (Code)	Deployment Date	Demobilisation Date	No. of Days Deployed	No. of Data Days[5]
HDD (HDD)	18 May 2009	Ongoing	400*	348*
Biggada Reef (BR)	8 Dec 2007	15 Oct 2009	674	655

*Note: * From deployment to 22 June 2010*

[5] A ‘data day’ is considered to be any day where data were collected from at least one of the four sensors on the LTD logger. The number of data days reported was the maximum number of days of data recorded by any one of the individual sensors at a site. This underestimates the total number of data days as it is likely that data would have been recorded by other sensors on at least some of the days.

The LTD loggers measure light, turbidity, and deposition in a burst of samples over a 1 s period, with depth measurements taken over a period of 10 s (10 bursts of samples). The average of each burst is logged to the internal memory as a single data point (see Ref. 110). The sampling interval at Biggada Reef was initially programmed to 20 minutes over the first deployment period (December 2007–mid-January 2008) and was subsequently decreased to 10-minute sampling intervals. The LTD logger at the HDD site was originally programmed for a 30-minute sampling interval to extend the battery life, but from May 2010 this was decreased to 10-minute sampling intervals.

Due to rapid biofouling, all subsurface equipment was serviced at a maximum interval of eight weeks. During these times, the LTD loggers were removed from the seabed, the data downloaded, checked, and visually verified, batteries replaced as required, and the sensors cleaned and anti-fouled as necessary. The wiper arm design was modified early in the Marine Baseline Program following damage to the wiper assemblies from fish interference and the consequent deterioration of data recovery and data quality. However, ongoing fish interference has resulted in deterioration of data recovery throughout the Marine Baseline Program, including periods of complete data loss. This has been a particular issue at the HDD LTD logger site given the nature of the environment where the LTD logger is deployed. LTD logger malfunctions were less common, but on occasion resulted in periods of data loss. Overall, data recovery rates from the LTD logger at the HDD site were between ≈55% and ≈80% across all parameters measured. This dataset is considered to be representative of a full annual cycle and is appropriate for use in further data analysis (Section 13.3.4).

13.3.3.2 Water Column Profiles

Water column profile measurements were collected at Biggada Reef (January, March, June, September, and October 2008; and August 2009) and at the HDD LTD logger site (May, August, October, and November 2009; and June 2010). As the field surveys were generally scheduled around neap tides, the profiles are mostly representative of the water column during periods of lower tidal flow and therefore may not be representative of conditions during periods of greater tidal flow. In addition, profiles were only undertaken during periods when wind speeds were <15 knots and thus do not represent the conditions that may occur during periods of rough weather.

To provide a snapshot of physical-chemical water column characteristics over a wider spatial scale around the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing, water column profile measurements were collected in May and October 2009 and June 2010.

13.3.3.3 Terrestrial Light Logger

The terrestrial light logger was installed on 9 September 2008 and relocated on 8 March 2009.[6] The sensor measures the incident irradiance in a burst of samples taken once every minute and averages the readings over 15-minute logging intervals. For the purposes of the Marine Baseline Program, only the data recorded during the midday period were used to calculate the LAC.

[6] The terrestrial light logger was relocated in March 2009 because the original location was cleared for construction activities.

13.3.4 Data Processing and Analysis

13.3.4.1 Processing of Raw Data

13.3.4.1.1 Meteorological Data

The meteorological data were visually checked for consistency and any incomplete or erroneous data records removed.

13.3.4.1.2 LTD Loggers

On completion of each LTD logger in-water maintenance visit, the raw data downloaded from the LTD loggers were visually checked for accuracy and erroneous data (including those associated with periods of instrument malfunction that required recalibration) and those suspected to be influenced by fouling of the sensors while in service were removed. The LTD loggers were rotated through the monitoring sites such that any variability (and thus bias) was distributed among the sites. The data were converted and calibrated to units of measurement using site-specific algorithms to provide values of SSC in mg/L (which is equivalent to TSS)[7], Accumulated Sediment Surface Density (ASSD) in mg/cm^2, and light ($\mu E/m^2/s$). Refer to Appendix E for more detailed information.

All light measurements were coded according to whether the measurement fell within the midday period (Section 13.3.4.2). The use of midday period light was also supported by statistically significant autocorrelation results that showed a consistent cyclical pattern of light during midday periods (Ref. 29). Absent and zero values were excluded from the data on the premise that zero light during the day was extremely unlikely at the depths of the loggers and instead reflected missed data recordings by the logger. The daily median light values for the midday period were calculated using SYSTAT v12 (Cranes Software International Pty. Ltd.) and a time-series plot and summary statistics generated for each season.

Using similar techniques, distributions of daily median turbidity and SSC values were calculated for each season. In contrast to the light values, measurements were not excluded based on the time of day. Null and zero turbidity and SSC values were considered erroneous and excluded from the analysis as it was unlikely that the waters surrounding Barrow Island would ever be as clear as pure sea water (the zero reading).

Examination of the raw ASSD data indicated that patterns of increasing ASSD readings before clearing, generally observed with cumulative deposition and subsequent removal by the wiper mechanism (Ref. 111), were not evident. Where deposition was detected, the readings were generally short term (fewer than two hours). The lack of accumulation and periodic removal by the wiper suggests that the natural hydrodynamic regime of the area was sufficient to remove whatever sediment had deposited on the sensor prior to a wiping event. Because of the difficulty of establishing when a wiping event had occurred and when deposition was removed naturally, the 95th percentile of the calculated hourly deposition rates that occurred each day was selected as an indicative measurement of the maximum potential deposition rate. The 95th percentile was selected rather than the maximum, to remove erroneous data from the calculations that may have been caused by transitory fauna interfering with the sensor. The ASSD values

[7] The NTU-SSC conversion factor was: SSC = 1.942 × NTU.

were first divided by two to give an hourly deposition rate (as the measurement period is two hours), then the 95th percentile of the deposition rates was calculated for each day using SYSTAT v12. Time-series plots and summary statistics of the daily values were generated; however, because the data were considered to be below the limits of accurate quantification[8], the ASSD data are not presented in this Marine Baseline Report.

The water quality data presented in the Marine Baseline Report are subject to QA/QC procedures that periodically involve some post-recovery amendments to data. These corrections are applied to the data when there is an indication that a calibration error has occurred; however, the correction often cannot be applied until there is sufficient contextual information to identify those data that require correction. Similarly, for data that require a correction through application of more recent calibration equations, the correction cannot be implemented until the LTD logger is recalibrated. Therefore, some (corrected) data may not be issued until some months after the initial reporting. Thus, data presented in this revision of the Marine Baseline Report represent the most reliable data from the information available at the time of analysis.

13.3.4.1.3 Water Column Profiles

Water column profile data collected using the SEACAT Profiler were downloaded and converted into units of measurement using instrument-specific software (SEASOFT-WIN32). The raw data were imported into Microsoft Excel and visually checked to ensure all sensors had operated correctly during each profile.

Erroneous data associated with equilibration periods and any data that showed interference when the instrument was at shallow depths (e.g. depths <60 cm) were removed. Adjustments to pH data were applied as necessary, based on calibrations performed at the conclusion of each field program.

13.3.4.1.4 Terrestrial Light Logger

The terrestrial light logger was regularly downloaded using instrument-specific software which output the data as units of measurement (μE/m^2/s). The sensor-specific calibration coefficient was input into the data logger, thus no calibration or conversion of raw data was required.

13.3.4.2 Calculation of Light Attenuation Coefficients

The daily LAC was calculated for each site using data from the terrestrial light logger on Barrow Island and the underwater light sensors (LTD loggers) deployed on the seabed at each site. The data from the terrestrial light logger were used to represent the average incident light falling on the sea surface at each site for each time period. The daily mean surface irradiance value was derived by averaging all measurements from the terrestrial light logger for the midday period (10:00–14:00 Australian Western Standard Time [WST]). Values outside this period may be subject to a continuum of variation associated with the angle of incidence of the sun, which changes incrementally (cyclically) due to the earth's orbit. Similarly, the

[8] Generally the full range at low range, which is normally used in these types of environments, is around 0–100 NTU. The raw data has a 12-bit resolution, which can give 0.1 NTU resolution between consecutive readings in a time-series. The resolution of differences over longer time periods, or between sites, is more problematic as it depends on longer term drifts in the instrument (which is common for all instruments) and is especially problematic at very low turbidity levels (around 1 NTU). Thus, it is not usually possible to resolve differences of <1 NTU between sites or over long time periods. The accuracy of the reading is considered at best 1 NTU at low values and worse at higher values (1% of 100 NTU) (Prof. Ridd, May 2009).

daily mean irradiance at the seabed at each site was calculated by averaging all measurements recorded by the LTD loggers for the midday period.

An approximate measure of the amount of light penetrating the sea surface at each site was derived by applying a correction factor of 0.96 to account for the reflection of light at the air–water interface (Ref. 112; Ref. 113). The LTD loggers also recorded water depth each time a light measurement was made. To account for fluctuating water height and effective vertical separation distance between the two observation points, an average depth for the midday period was calculated from the pressure data recorded by each LTD logger.

The light attenuation path (i.e. the distance that a beam of light travels from the air–water interface to the seabed sensor) is a function of the water depth and the angle of incidence of the incoming light due to the solar zenith angle.[9] To enable comparison of the LAC values throughout the year, these values were normalised to account for the solar zenith angle.

The daily LAC for each site was calculated according to this equation:

$$LAC = [(\log_e \text{average light at seabed} - \log_e \text{average light at surface}) \div \text{average water depth}]$$

This daily value was then normalised to account for changes in solar zenith angle (Ref. 114). This equation was used to calculate the underwater solar zenith angle:

$$S_{ZAUW} = \arcsin(\sin S_{ZA}/1.34)$$

where S_{ZA} is the above-water solar zenith angle, 1.34 is the refractive index of water, and S_{ZAUW} is the underwater solar zenith angle. The above-water solar zenith angle for Barrow Island was sourced from a solar elevation calculator (Ref. 115).

The LAC was then normalised by applying this equation:

$$LAC_n = LAC_m.\cos(S_{ZAUW})$$

where LAC_n is the normalised LAC, LAC_m is the measured LAC, and S_{ZAUW} is the underwater solar zenith angle.

13.3.4.3 Correlating LTD Logger Parameters with Meteorological and Oceanographic Variables

Daily measures of the LTD logger parameters (daily median SSC, daily median NTU, daily median Wave Height Index, LAC, and median midday light) were collated. Each data point was classified into two broad periods—‘summer’ and ‘winter’—based on preliminary analysis of data trends, which suggested that turbidity was largely influenced by season and therefore stratification of the data into seasons would produce clearer relationships. The seasonal periods were chosen to align with those used for modelling the extent of sediment plumes generated by the dredging and spoil disposal activities (Ref. 28), which identified two major wind patterns that occur in the Barrow Island region. The ‘winter period’ was defined as May to October and the ‘summer period’ as November to April (Section 3.3).

[9] The midday solar zenith angle changes incrementally each day, following a cyclical (annual) pattern due to the tilt of the Earth’s rotational axis with respect to its orbital plane. This cyclical change in zenith angle results in a longer light attenuation path for a given water depth when the sun is lower in the sky (e.g. during winter), than when the sun is higher in the sky.

A measure of daily tidal water movement was calculated from BOM tide prediction data by subtracting the lowest daily water height measurement from the highest measurement. Daily measures of average air temperature, rainfall to 09:00 WST, and five measures of wind speed were calculated from the meteorological data. These daily wind measurements were:

- Average of the 30-minute average: In each half-hour sampling interval, the average wind speed for the last 10 minutes of that period is recorded by the Barrow Island weather station. The 'average of the 30-minute average' is the average of all half-hourly average wind speeds.
- Maximum of the 30-minute average: The maximum of the half-hourly average wind speeds.
- Average of the 30-minute maximum: In each half-hour sampling interval, the maximum wind speed (sustained gust) measured in that period is recorded by the Barrow Island weather station. The 'average of the 30-minute maximum' is the average of the half-hourly maximum wind speeds.
- Median of 30-minute maximum: The daily median of the half-hourly maximum wind speeds.
- Maximum of the 30-minute maximum: The maximum of the half-hourly maximum wind speeds.

To reduce the number of variables of interest, the relationships between all LTD logger parameters and meteorological measurements were first investigated in detail at two sites (Ant Point Reef and Ah Chong) using the program R (Ref. 116; Ref. 29). Scatter plots with trend lines, Pearson's R-squared values, and levels of significance (p-values) were created for all pair-wise combinations of variables at these two sites. Visual inspection of the scatter plots and correlations allowed the identification of those relationships of most interest. Variables were eliminated if clear relationships were not evident (e.g. rainfall and SSC) or if more suitable measures of a variable were available (e.g. the daily median of 30-minute maximum wind reading was used instead of the other wind measurements as it had a strong relationship with SSC and reduced the impact of outlier measures).

The refined set of variables of interest was:

- Daily median of daily 30-minute maximum wind: The median of the half-hourly maximum wind speeds recorded on that day.
- Daily maximum tidal movement: The difference in water height between the predicted lowest low tide and the highest high tide on that day.
- Daily median SSC: The median of the SSC measurements recorded on that day.
- Daily median NTU: The median of the NTU measurements recorded on that day.
- LAC.
- Daily median of midday light: The median of the light measurements recorded between 10:00 and 14:00 WST.
- Daily median Wave Height Index: The median of the Wave Height Index (Root Mean Square water depth) measurements recorded for that day.

A matrix of scatter plots with trend lines, Pearson's R-squared values and levels of significance was produced for the refined set of variables of interest. The corresponding scatter plots and correlations for any pair of variables are shown at the intersection of the respective rows and columns for each variable (see Figure 13-8 and Figure 13-9). This matrix was used to assess the type, strength, and ubiquity of relationships between variables.

13.4 Results

13.4.1 Meteorological Data

Box plots of the daily average air temperature data recorded from November 2007 to May 2010 at the Barrow Island weather station are presented in Figure 13-4. There was a marked decrease in the average air temperature between April and June, indicating the transition between summer and winter. The average air temperature was consistent between June and September before rising to approximately 25 °C in October. The average air temperature was similar over the October to December period, prior to another increase to almost 30 °C during the period January to March.

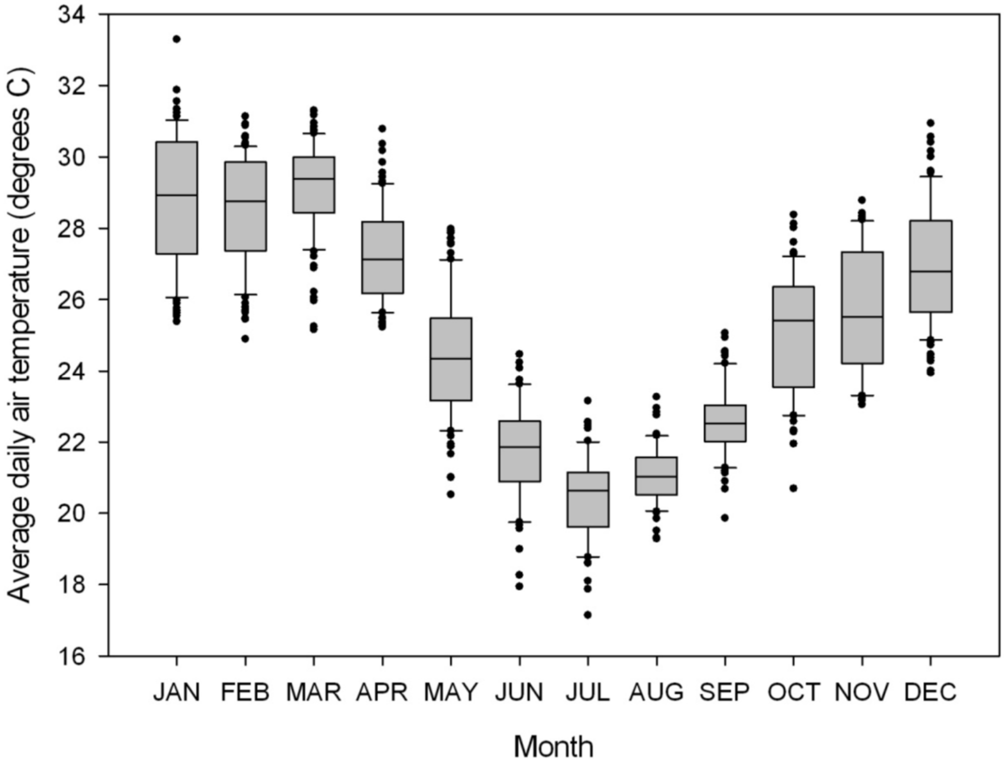


Figure 13-4: Monthly Box Plots of the Daily Average Air Temperature Recorded at the BOM Weather Station on Barrow Island, November 2007–May 2010

Note: Boxes = range of lower and upper quartiles; solid horizontal line within the box = median; whiskers = 10th and 90th percentiles; circles = outliers.

Ten tropical cyclones were recorded off the Western Australian coastline near Barrow Island during the 2007–2008, 2008–2009, and 2009–2010 cyclone seasons (Figure 13-5 shows the travel paths for the 2007–2008 and 2008–2009 seasons). Some of these cyclones had a measurable influence on the water quality at the LTD logger sites, predominantly through the generation of waves.

A brief summary of the cyclones is presented below:

- Cyclone Melanie (Tropical Cyclone [TC] 1): Reached cyclone intensity on 28 December 2007 and passed approximately 350 km west of Barrow Island between 30 and 31 December 2007 as a Category 2 cyclone. No rainfall associated with Tropical Cyclone Melanie was recorded on Barrow Island.
- Cyclone Nicholas (TC 2): Formed in the offshore Kimberley region and tracked parallel to the coast until it passed approximately 150 km west of Barrow Island on 18 February 2008 as a Category 3 cyclone before crossing the coast south of Coral Bay on 20 February 2008. A total of 83 mm of rainfall was recorded on Barrow Island from 11 to 24 February 2008 associated with the cyclone, including falls of 30.6 mm and 19.8 mm on 18 and 19 February 2008 respectively. Wind speeds of over 80 km/h were recorded on Barrow Island.
- Cyclone Ophelia (TC 3): Also formed in the Kimberley region and passed within 400 km to the north and west of Barrow Island as a Category 2 cyclone between 4 and 6 March 2008. No rainfall was recorded on Barrow Island during this period.
- Cyclone Pancho (TC 4): Formed in the Indian Ocean on 24 March 2008 and passed >900 km west of Barrow Island on 27 March 2008 as a Category 4 cyclone. Tropical Cyclone Pancho produced heavy rainfall in the Pilbara and Gascoyne regions, with Barrow Island receiving more than 180 mm of rain in a 24-hour period.
- Cyclone Anika (TC 5): Formed on 19 November 2008 and reached Category 2 intensity by 20 November 2008. Tropical Cyclone Anika was downgraded to a tropical low on 21 November 2008. The cyclone was too far west for strong winds to be experienced at Barrow Island.
- Cyclone Billy (TC 6): Formed in the Kimberley region near Broome and tracked west out to sea. The cyclone reached Category 4 intensity on 24 December 2008 and travelled within approximately 350 km of Barrow Island at its closest point. No rainfall was recorded on Barrow Island as a result of the cyclone.
- Cyclone Dominic (TC 7): Formed within 150 km of Barrow Island from a tropical low that originated in the Kimberley region. Once formed, the cyclone moved south and the eye of the cyclone passed within 10 km of the west coast of Barrow Island on 26 January 2009. A maximum sustained wind gust of 102 km/h was recorded on Barrow Island and approximately 90 mm of rainfall was recorded within a 24-hour period.
- Cyclone Freddy (TC 8): Formed as a cyclone on 7 February 2009 well off the Western Australian coastline and tracked west before weakening to a tropical low on 9 February 2009.
- Cyclone Laurence: Formed as a cyclone west of Darwin on 13 December 2009. The cyclone reached Category 5 intensity on 16 December 2009 before crossing the Kimberley coast and reverting to a tropical low. On 19 December, the low redeveloped into a tropical cyclone near Broome. Cyclone Laurence crossed the Pilbara coast near Wallal, 230 km east of Port Hedland as a

Category 5 cyclone on 21 December 2009. No rainfall or unusually strong winds were recorded on Barrow Island during this time (Ref. 117).

- Cyclone Magda: Formed in the Timor Sea on 20 January 2010. Tracking roughly south, Cyclone Magda varied in intensity before crossing the Kimberly coast on 22 January 2010. No unusual affects were recorded by the Barrow Island weather station (Ref. 117).

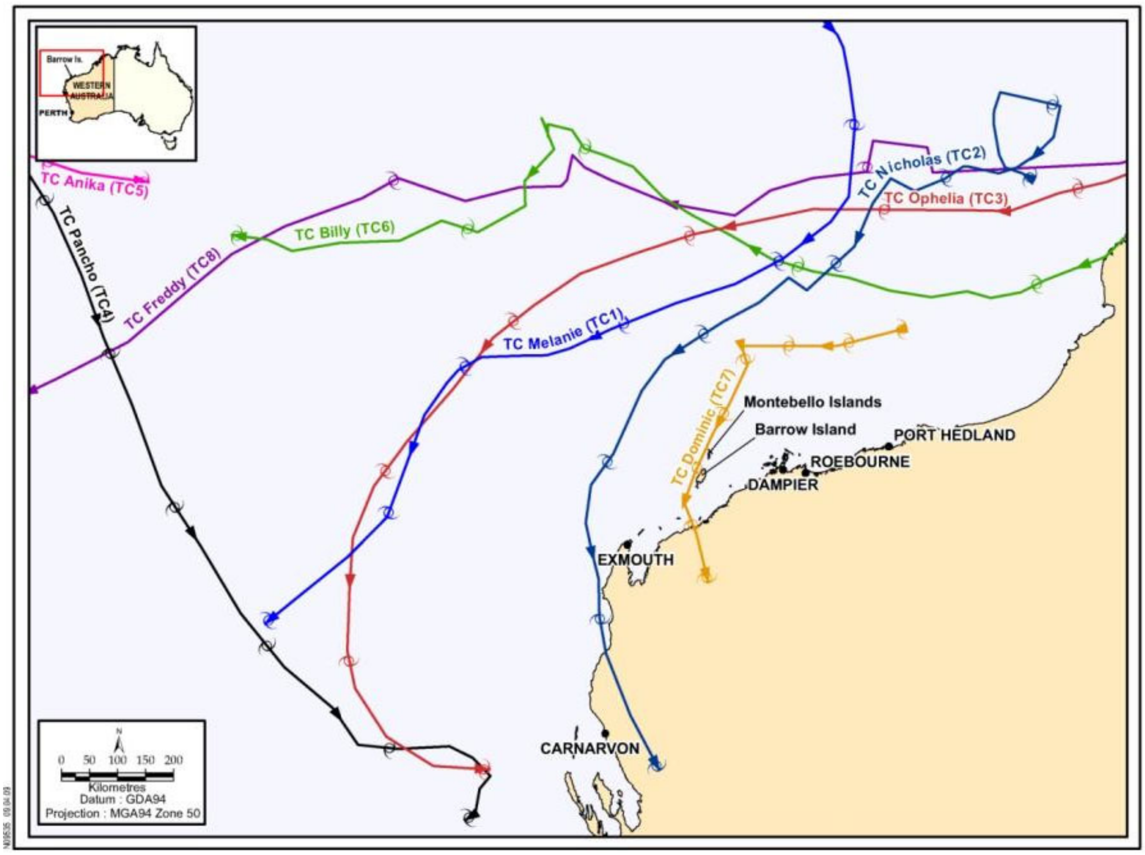


Figure 13-5: Tracks of Tropical Cyclones that Passed near Barrow Island during the 2007–2008 and 2008–2009 Cyclone Seasons

A time-series graph of the daily maximum sustained wind gust recorded at the Barrow Island weather station is provided in Figure 13-6. The figure shows that, in general, winds during the summer period are more consistent but are punctuated by strong wind conditions recorded during the passage of tropical cyclones, depending on the distance of the cyclone from Barrow Island. Winds during the summer period are generally from the south-west and west, shifting towards the south during March (Ref. 118).

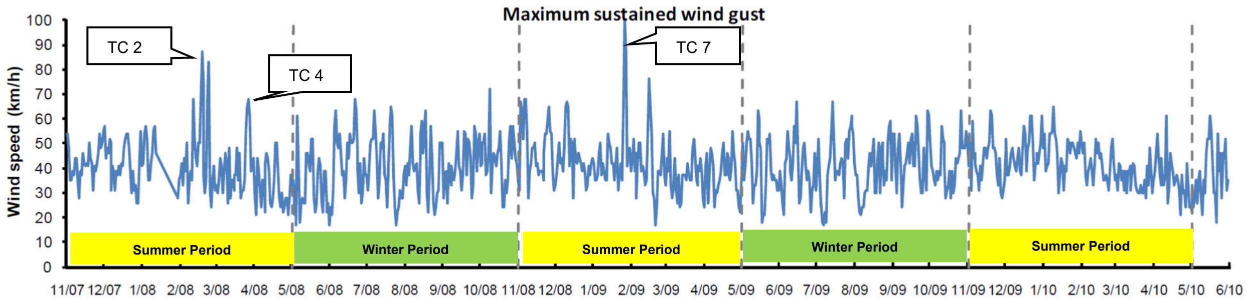


Figure 13-6: Time-Series Graph of the Daily Maximum Sustained Wind Speed Recorded at the Barrow Island Weather Station, 1 November 2007–31 May 2010

The maximum sustained wind in the winter period shows many peaks associated with the strong easterly winds that prevail during the winter months (Ref. 118). These winds often remain consistently strong for extended periods (up to 5–6 days) during certain weather patterns, generating wind seas that propagate into the east coast of Barrow Island. Thus, at most sites on the east coast of Barrow Island, there was a measurable effect on water quality, with SSC generally higher during winter when easterly winds are more common (Ref. 29). The west coast of Barrow Island is exposed to the open ocean and a relatively vigorous wave climate, bringing long-period Southern Ocean swells and shorter-period local wind waves, particularly during the summer months, when winds prevail from the south-west.

13.4.2 LTD Logger Results

13.4.2.1 Water Quality (including measures of turbidity and light attenuation) at a Site Adjacent to the HDD Exit Alignment

The HDD LTD logger site is located in an unprotected area off the west coast of Barrow Island and is exposed to the prevailing westerly swell (Section 3.4). Unlike sites on the east coast, wave conditions at the HDD LTD logger site are predominantly influenced by a combination of swell and tidal stage (height and flow rate), rather than localised wind-generated waves common on the east coast (Section 3.4.4). The median daily Wave Height Index, which reflects the fluctuation in water depth, varied between 0.074 m in summer and 0.100 m in winter (Appendix H) and was higher than the median daily Wave Height Index recorded at the other sites monitored during the Marine Baseline Program (Ref. 29). The median daily Wave Height Index ranged between 0.007 m at Batman Reef on the east coast of Barrow Island and 0.021 m at Biggada Reef in summer, and between 0.008 m at Batman Reef and 0.020 m at Ah Chong, located north of Barrow Island, in winter (Figure 13-1). The median daily Wave Height Index recorded at Biggada Reef in winter was 0.018 m.

Median daily light at the HDD LTD logger site in summer was 83.8 μE/m^2/s and 67.6 μE/m^2/s in winter. These values were lower than those recorded at any other water quality monitoring site in the Marine Baseline Program, where median values ranged between 139.8 μE/m^2/s (Lone Reef) and 495.4 μE/m^2/s (Biggada Reef) in summer, and between 127.6 μE/m^2/s (Lone Reef) and 543.3 μE/m^2/s (Biggada Reef) in winter (Ref. 29). The daily median LAC at the HDD LTD logger site was 0.21 m^{-1} in summer and 0.21 m^{-1} in winter. These values were generally lower than those recorded at other water quality monitoring sites, which ranged between 0.22 m^{-1} (LNG1) and 0.63 m^{-1} (Biggada Reef) in summer, and 0.21 m^{-1} (LNG1) and 0.52 m^{-1} (Biggada Reef) in winter (Ref. 29). Increases in median daily Wave Height Index at the HDD LTD logger site were often accompanied by reductions in the median light available at the seabed and increases in the LAC (Figure 13-7).

Median daily turbidity at the HDD LTD logger site was 1.0 NTU in summer and 1.4 NTU in winter, while median daily SSC was 1.9 mg/L in summer and 2.7 mg/L in winter. Peaks in SSC often coincided with increases in median Wave Height Index (Figure 13-7). At the other water quality monitoring sites, median daily turbidity ranged between 0.7 NTU (Ant Point Reef and Lone Reef) and 2.2 NTU (Southern Barrow Shoals) in summer, and 0.7 NTU (Lone Reef) and 1.7 NTU (Southern Barrow Shoals) in winter (Ref. 29). Median daily SSC at the other monitoring sites ranged between 0.8 mg/L (LNG0 and MOF2) and 3.6 mg/L (Southern Barrow Shoals) in summer, and 0.8 mg/L (LNG0 and MOF2) and 3.1 mg/L (LNG1) in winter (Ref. 29).

The level of significance and the relatively high Pearson's R-squared values indicate that at the HDD LTD logger site, Wave Height Index was correlated with SSC and NTU in both summer (Figure 13-8) and winter (Figure 13-9).

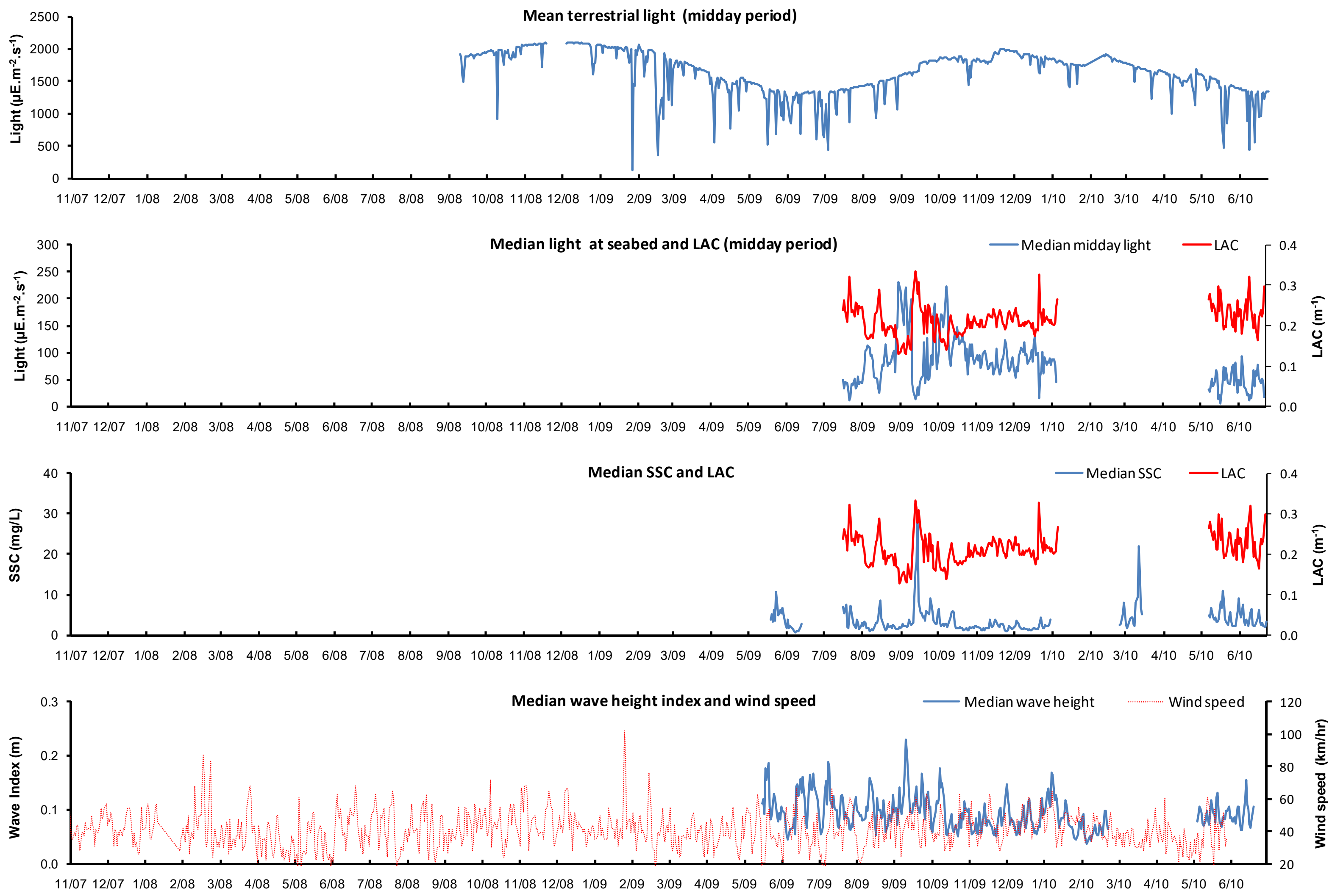


Figure 13-7: Time-series Plots of Daily Light, LAC, Median SSC, and Median Wave Height Index at the HDD LTD Logger Site and Daily Maximum Sustained Wind Speed at Barrow Island

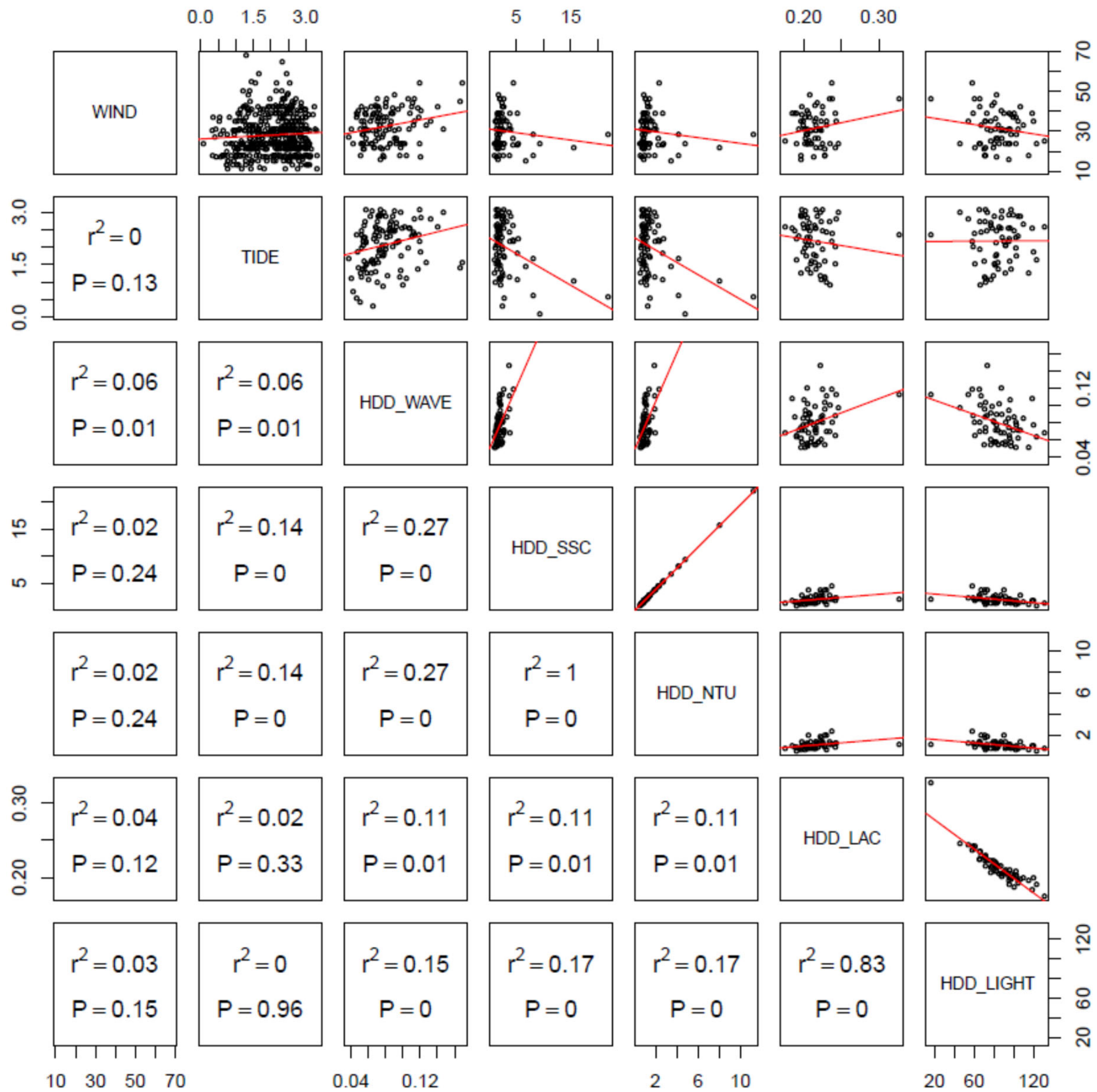


Figure 13-8: Relationship During the Summer Period Between Environmental and Water Quality Variables at the HDD LTD Logger Site

Note: Scatter Plot with Trend Line, Pearson's R-squared, and Level of Significance; P = 0 is equivalent to P<0.005. Data for the summer period is represented from 1 November 2009 to 5 March 2010.

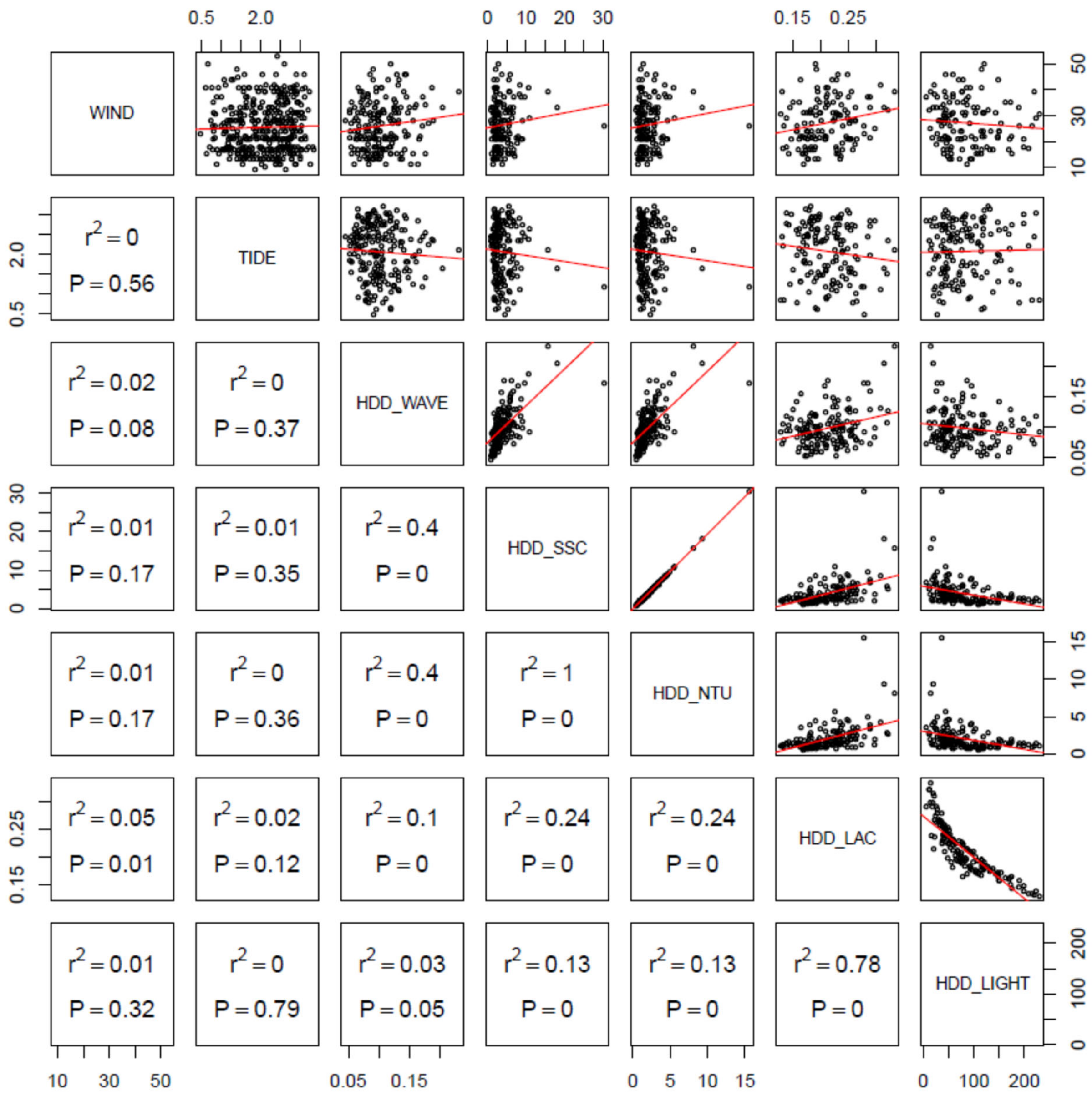


Figure 13-9: Relationship During the Winter Period Between Environmental and Water Quality Variables at the HDD LTD Logger Site

Note: Scatter Plot with Trend Line, Pearson's R-squared, and Level of Significance; P = 0 is equivalent to P<0.005 Data for the winter period is represented from 16 June to 31 October 2009 and 1 May to 21 June 2010.

13.4.2.2 Water Quality (including measures of turbidity and light attenuation) at a Reference Site not at risk or Material or Serious Environmental Harm due to Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Component of the Shore Crossing

Biggada Reef is exposed to the prevailing westerly swell and is in a shallow location on the leeward/landward side of a fringing coral reef. Wave events at Biggada Reef were more frequent in summer than winter, with obvious peaks coinciding with Tropical Cyclones Melanie, Nicholas, and Pancho (Figure 13-10).

Median SSC at Biggada Reef was generally lower in winter (2.6 mg/L) than in summer (3.0 mg/L) (Figure 13-10). Peaks in SSC during summer coincided with the passage of tropical cyclones, where SSC were elevated by a factor more than ten times greater than summer median levels. Due to the shallow depth at this site and the temporary exposure of the LTD logger during periods of spring low tides resulting in inconsistent light measurements, the light data are provided for information only (Ref. 29).

The measured environmental variables were not correlated with any of the analysed water quality variables in either summer or winter (Ref. 29).

13.4.3 Water Column Profiles at LTD Logger Sites

13.4.3.1 Water Column Physical-chemical Characteristics at a Site Adjacent to the HDD Exit Alignment

Salinity at the HDD LTD logger site ranged from 35.1 PSU in August 2009 in both surface and bottom waters to 35.6 PSU in November 2009 in surface and bottom waters (Table 13-4). The lowest temperature recorded at the site was 22.4 °C in August 2009 in bottom waters. The highest recorded temperature was 25.7 °C in surface waters and 25.6 °C in bottom waters in November 2009. Turbidity ranged from 9.8 NTU in October 2009 (bottom waters) to 11.7 NTU in November 2009 (surface and bottom waters) and June 2010 (bottom waters).

Table 13-4: Near-surface (≈1 m below) and Near-seabed (≈0.5 m above) Physicochemical Water Quality Data from Vertical Water Column Profiles at the HDD LTD Logger Site between May 2009 and June 2010

Month	Salinity (PSU)		Temperature (°C)		Turbidity (NTU)	
	Near-surface	Near-seabed	Near-surface	Near-seabed	Near-surface	Near-seabed
May 2009	35.3	35.4	25.5	25.2	10.3	10.3
Aug 2009	35.1	35.1	22.5	22.4	10.3	10.3
Oct 2009	35.2	35.2	25.0	24.2	10.3	9.8
Nov 2009	35.6	35.6	25.7	25.6	11.7	11.7
Jun 2010	35.5	35.5	24.8	24.8	10.7	11.7

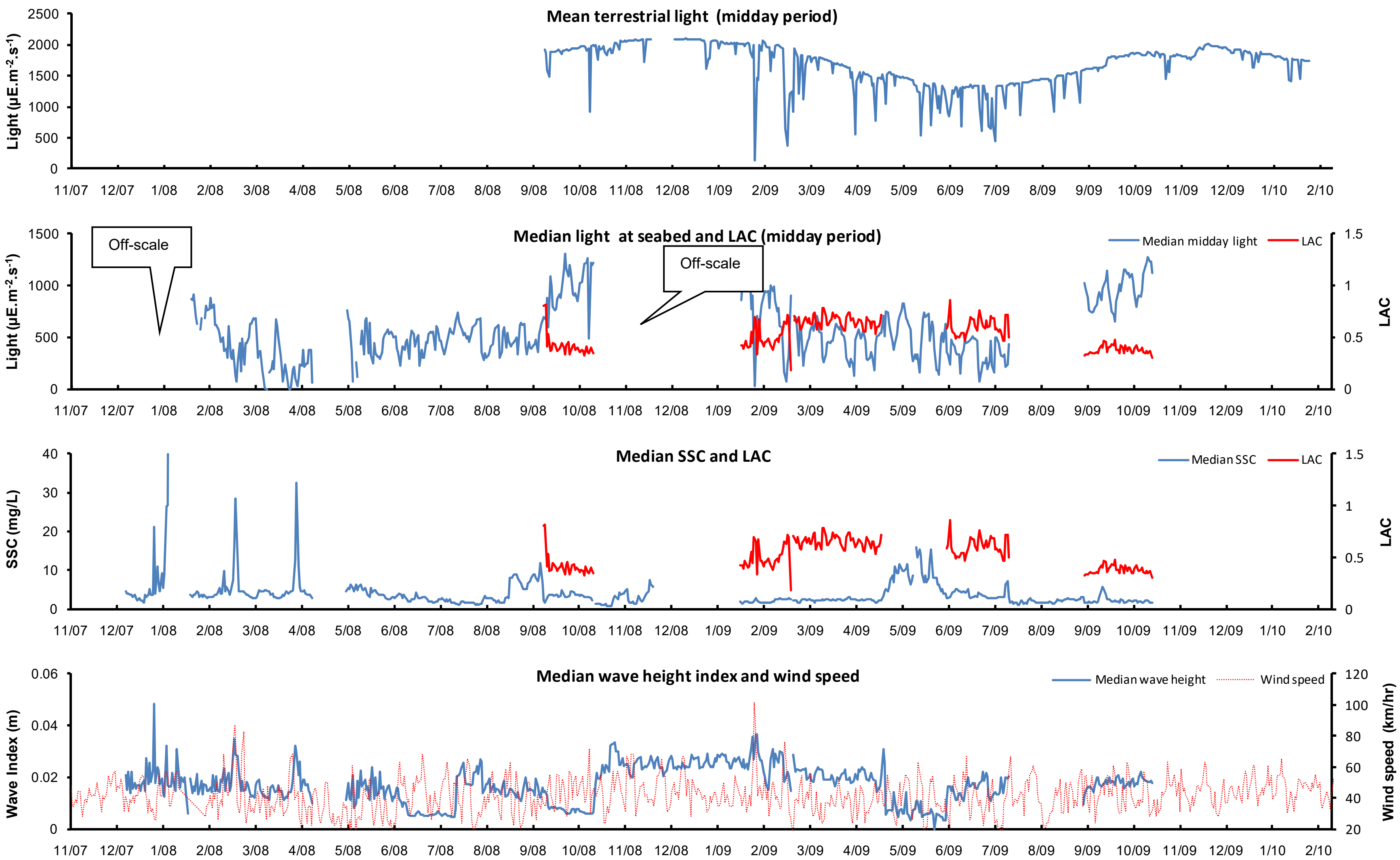


Figure 13-10: Time-series Plots of Daily Light, LAC, Median SSC, and Median Wave Height Index at Biggada Reef and Daily Maximum Sustained Wind Speed at Barrow Island

13.4.3.2 Water Column Physical-chemical Characteristics at a Reference Site not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters and the Marine Components of the Shore Crossing

Salinity at Biggada Reef varied slightly from 34.9 to 35.1 PSU (Table 13-5). The lowest salinity was recorded in June 2008 in both surface and bottom waters. The highest salinity was recorded on all other occasions in both surface and bottom waters, except January 2008 when 35 PSU was recorded in bottom waters. The lowest temperature recorded was 22.4 °C in surface waters and 22.5 °C in bottom waters in August 2009. A maximum temperature of 29.8 °C in surface waters and 29.4 °C in bottom waters was recorded in March 2008. The lowest turbidity recorded was 9.8 NTU in January 2008 in surface and bottom waters; and in June 2008 in bottom waters. The highest turbidity recorded was 11.7 NTU in October 2008 in bottom waters.

Table 13-5: Near-surface (≈1 m below) and Near-seabed (≈0.5 m above) Physicochemical Water Quality Data from Vertical Water Column Profiles at Biggada Reef between January 2008 to August 2009

Month	Salinity (PSU)		Temperature (° C)		Turbidity (NTU)	
	Near-surface	Near-seabed	Near-surface	Near-seabed	Near-surface	Near-seabed
Jan 2008	35.1	35.0	29.7	28.5	9.8	9.8
Mar 2008	35.1	35.1	29.8	29.4	-	-
Jun 2008	34.9	34.9	26.6	26.6	10.3	9.8
Sep 2008	35.1	35.1	23.4	23.4	10.7	11.2
Oct 2008	35.1	35.1	24.5	24.3	11.2	11.7
Aug 2009	35.1	35.1	22.4	22.5	10.9	10.7

13.4.4 Water Column Profiles—May 2009 and June 2010

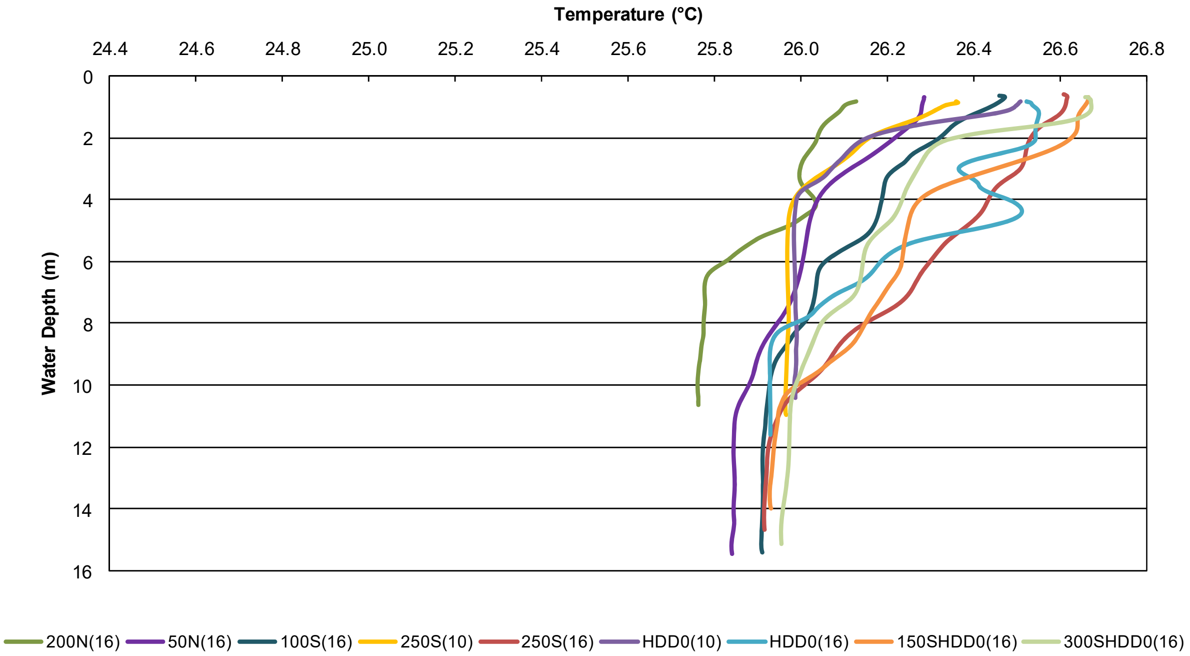
13.4.4.1 Sites in the MDF Associated with the Construction or Operation of the Marine Components of the Shore Crossing

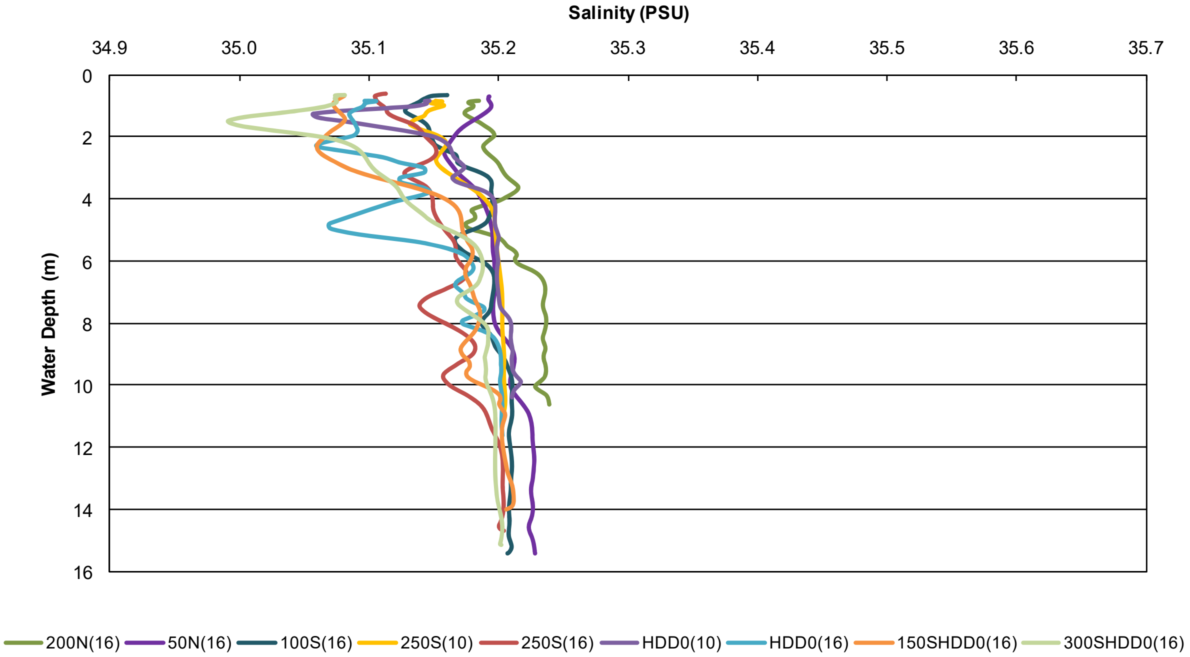
Sites in the MDF and in the indicative anchoring area adjacent to the HDD exit alignment were in approximately 11–18 m water depths. In May 2009, surface temperatures (≈1 m below the surface) varied between 26.1 and 26.7 °C and declined with depth; bottom temperatures (≈0.5 m above the seabed) varied between 25.8 and 26.0 °C (Figure 13-11). Temperatures recorded in June 2010 were lower than those recorded in May 2009, with an indication of a thermocline at some sites (Figure 13-12). Surface temperatures varied between 24.8 and 26.2 °C, and bottom temperatures between 24.5 and 25.0 °C. Surface salinities varied between 35.1 and 35.2 PSU in May 2009, and were higher in June 2010, varying between 35.2 and 35.5 PSU. There was little change with depth as bottom salinities were 35.2 PSU in May 2009 and between 35.5 and 35.6 PSU in June 2010. Turbidity was generally similar (≈10 NTU) at all sites in both May 2009 and June 2010, with an increase in bottom waters. Surface turbidity varied between 5.4 and 10.7 NTU in May 2009 and between 9.3 and 10.7 NTU in June 2010, and increased with depth, with bottom turbidity varying between 10.7 and 16.1 NTU in May 2009 and between 11.2 and 15.1 NTU in June 2010. In May 2009, surface

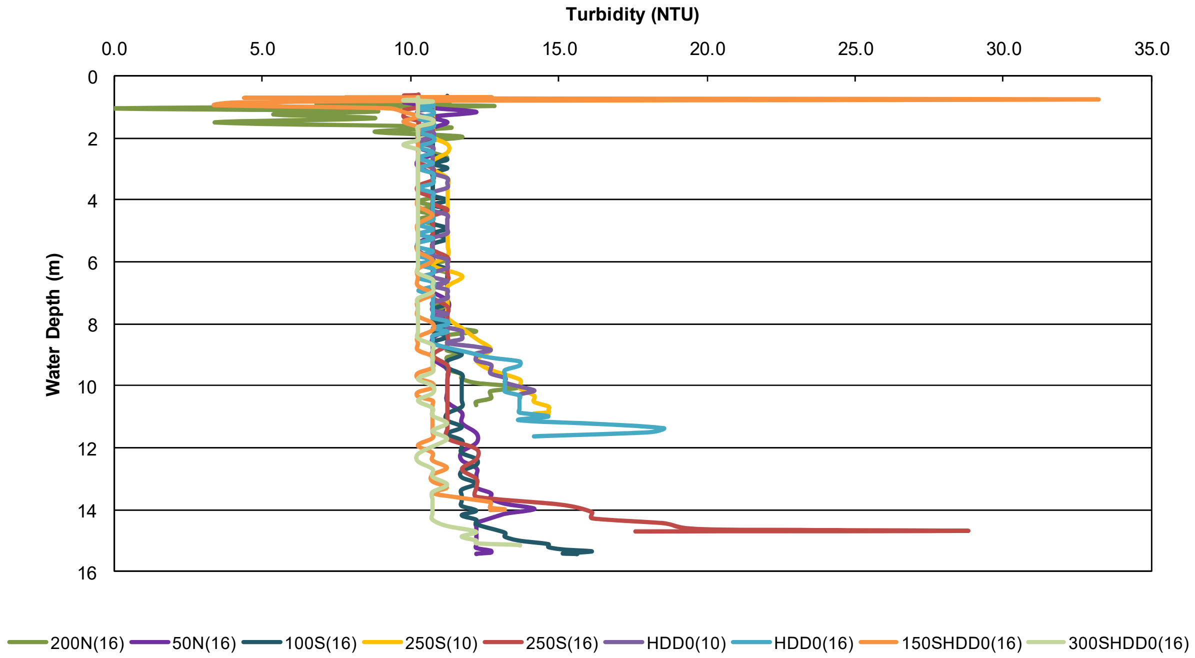
PAR varied between 170 and 1850 $\mu E/m^2/s$, decreasing to 20–75 $\mu E/m^2/s$ in bottom waters. In June 2010, surface PAR varied between 40 and 625 $\mu E/m^2/s$, decreasing to 10–65 $\mu E/m^2/s$ in bottom waters.

Further offshore in the indicative anchoring area, in water depths of 17–20 m, surface temperatures in June 2010 varied between 25.5 and 26.5 °C and declined slightly with depth to between 24.5 and 25.2 °C (Figure 13-13). There was an indication of a thermocline at around 6 m depth for some sites. Surface salinities were between 35.2 and 35.4 PSU, with little change in the bottom waters where salinities were between 35.4 and 35.6 PSU. Surface turbidity varied between 9.3 and 12.2 NTU, increasing with depth to between 10.3 and 13.7 NTU. Surface PAR varied between 50 and 895 $\mu E/m^2/s$, decreasing to 35–90 $\mu E/m^2/s$ in bottom waters in June 2010.

Except for turbidity, water column characteristics were similar in both nearshore and offshore waters. In the case of turbidity, deeper sites showed smaller increases in turbidity than at shallower sites.


Temperature (°C)
24.4
24.6
24.8
25.0
25.2
25.4
25.6
25.8
26.0
26.2
26.4
26.6
26.8
Water Depth (m)
0
2
4
6
8
10
12
14
16
200N(16)
50N(16)
100S(16)
250S(10)
250S(16)
HDD0(10)
HDD0(16)
150SHDD0(16)
300SHDD0(16)


Salinity (PSU)
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
200N(16)
50N(16)
100S(16)
250S(10)
250S(16)
HDD0(10)
HDD0(16)
150SHDD0(16)
300SHDD0(16)



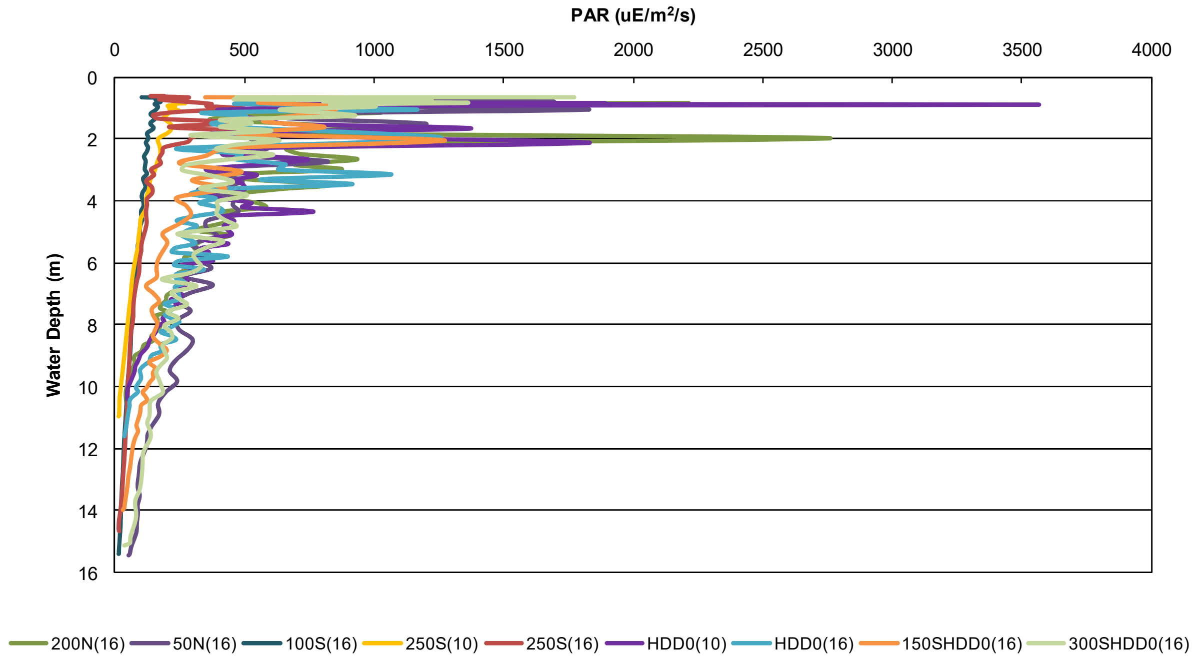
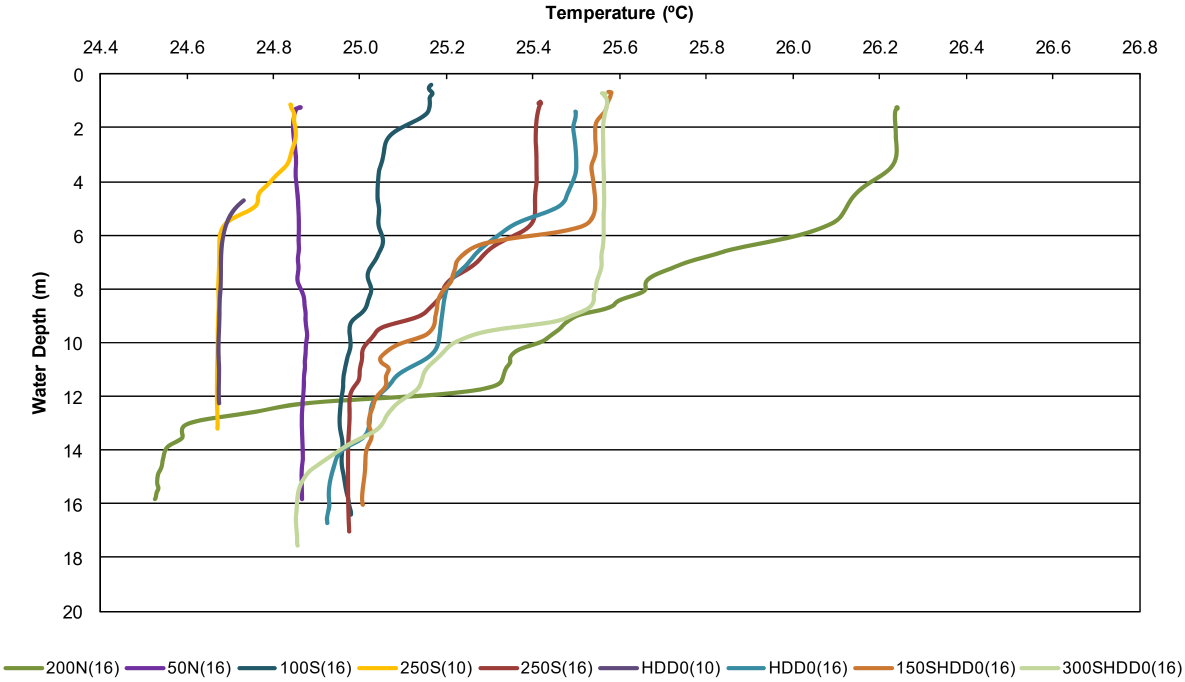
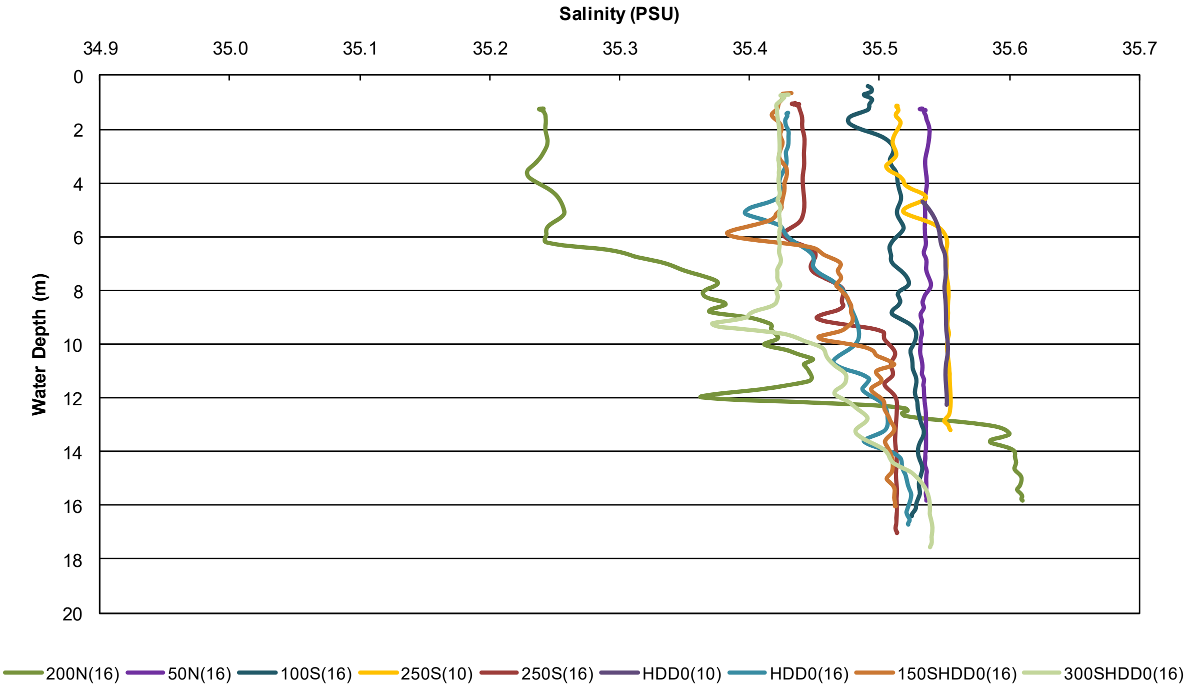
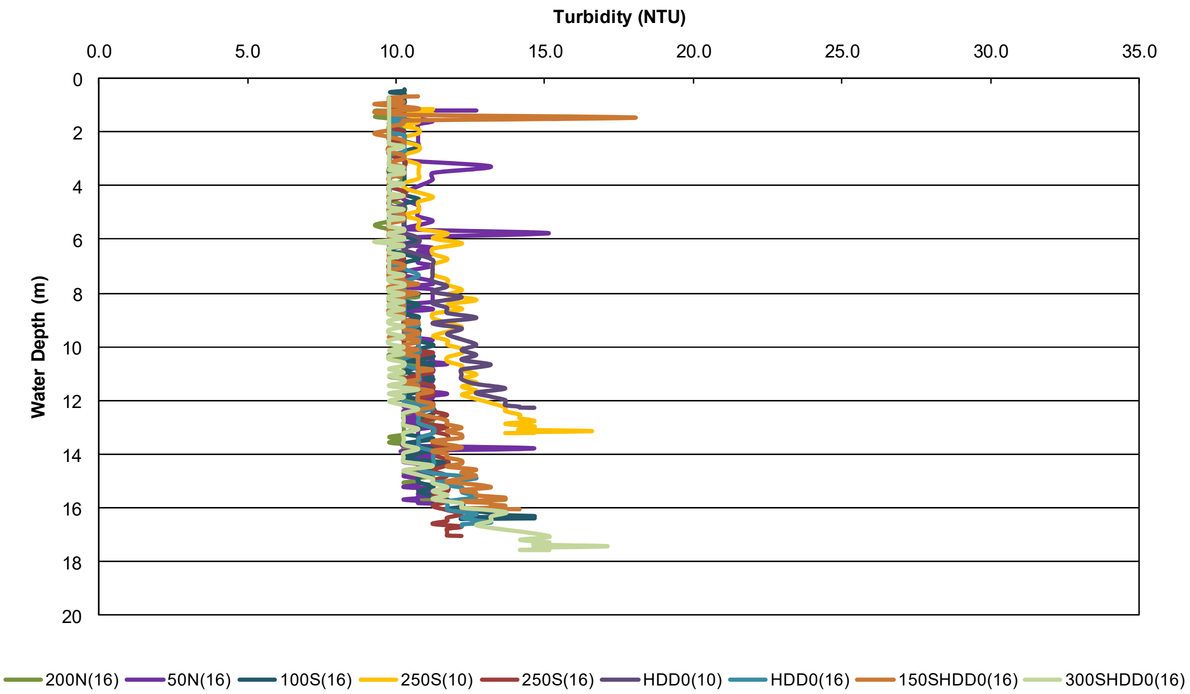


Figure 13-11: Water Column Profiles at Sites in the MDF, Sites at Risk of Material or Serious Environmental Harm and Sites in the Indicative Anchoring Area, May 2009


Temperature (ºC)
24.4
24.6
24.8
25.0
25.2
25.4
25.6
25.8
26.0
26.2
26.4
26.6
26.8
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
200N(16)
50N(16)
100S(16)
250S(10)
250S(16)
HDD0(10)
HDD0(16)
150SHDD0(16)
300SHDD0(16)


Salinity (PSU)
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
200N(16)
50N(16)
100S(16)
250S(10)
250S(16)
HDD0(10)
HDD0(16)
150SHDD0(16)
300SHDD0(16)



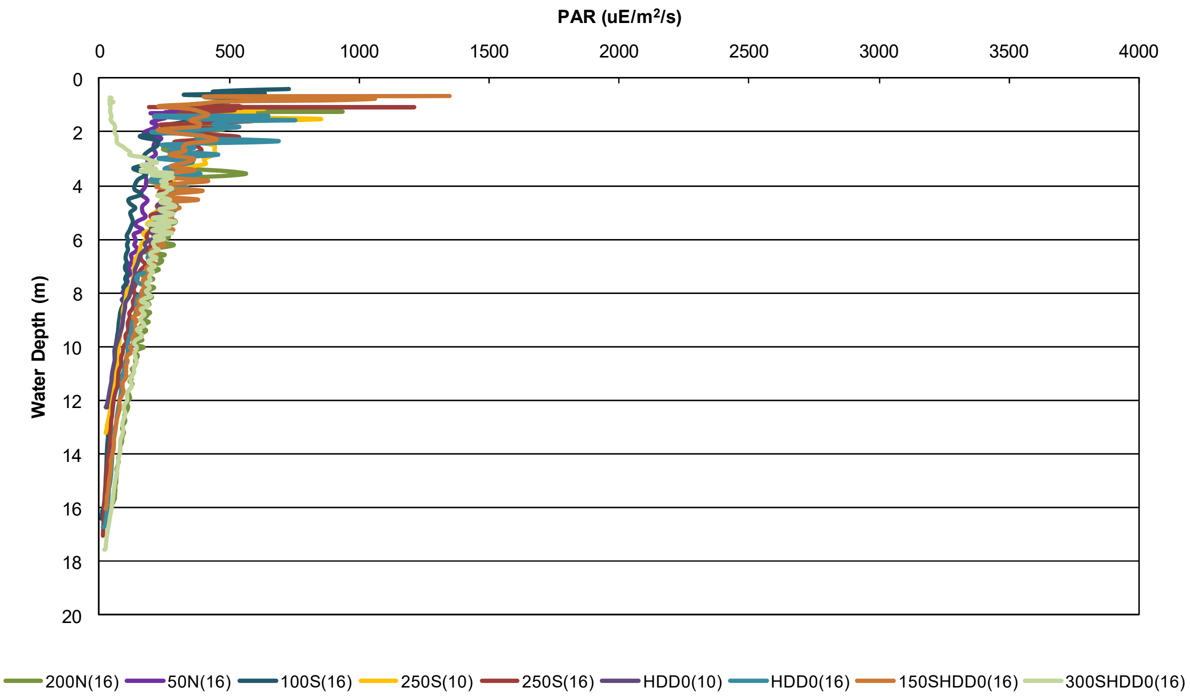
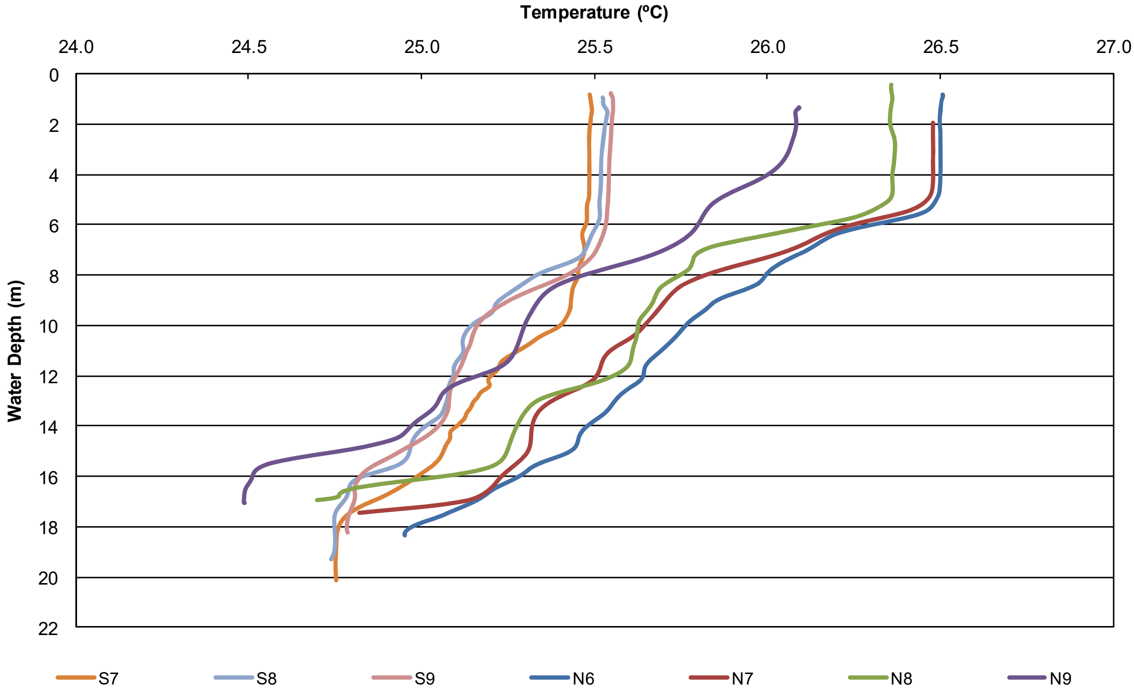
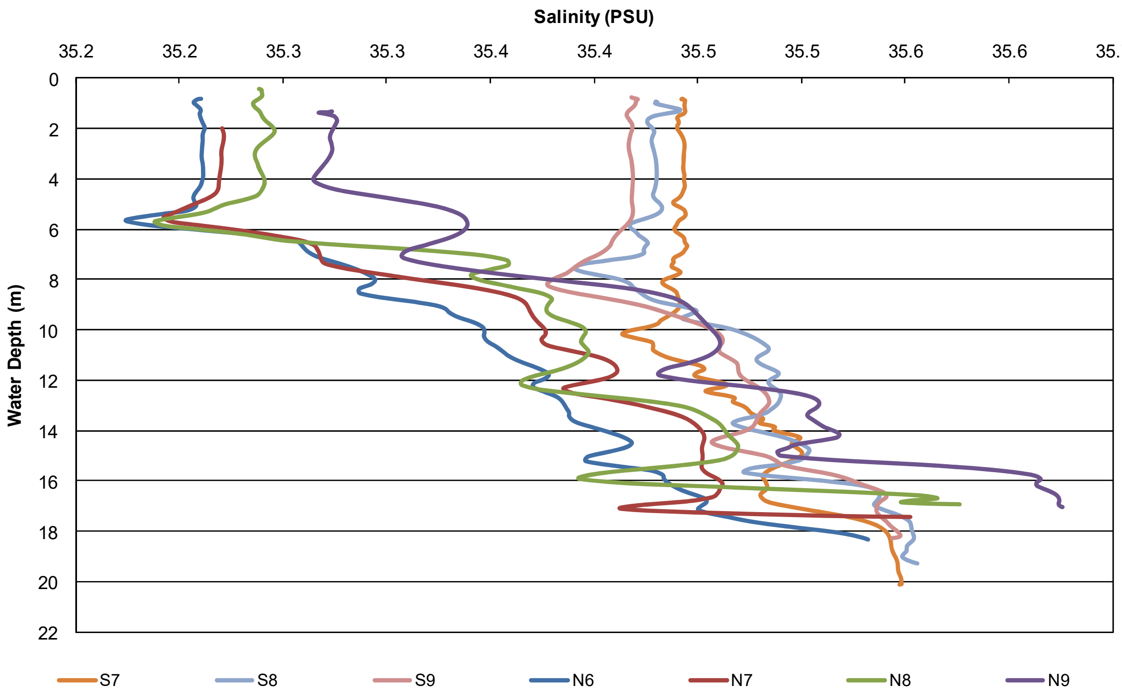


Figure 13-12: Water Column Profiles at Sites in the MDF, Sites at Risk of Material or Serious Environmental Harm and Sites in the Indicative Anchoring Area, June 2010


Temperature (ºC)
24.0
24.5
25.0
25.5
26.0
26.5
27.0
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
S7
S8
S9
N6
N7
N8
N9


Salinity (PSU)
35.2
35.2
35.3
35.3
35.4
35.4
35.5
35.5
35.6
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
S7
S8
S9
N6
N7
N8
N9

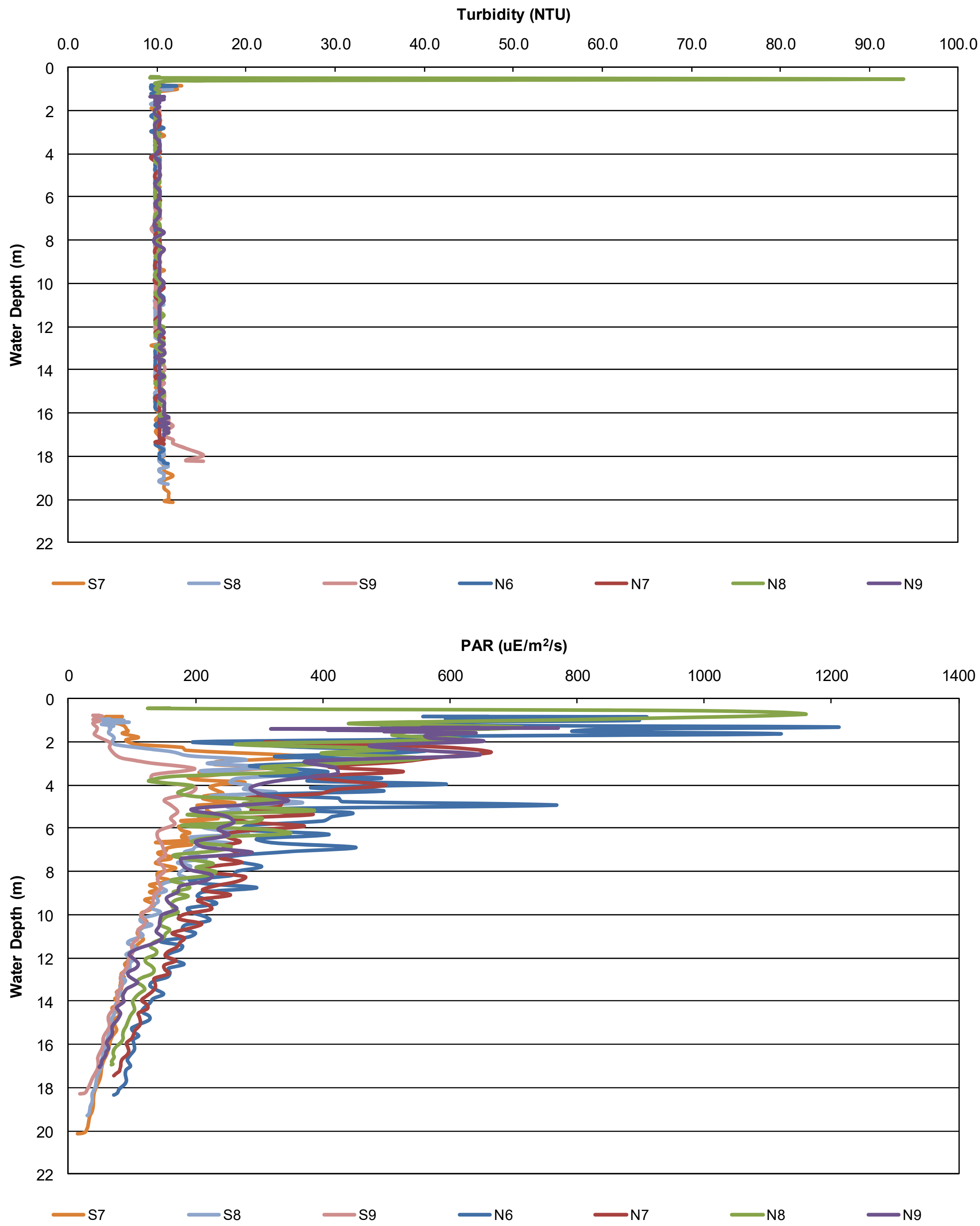
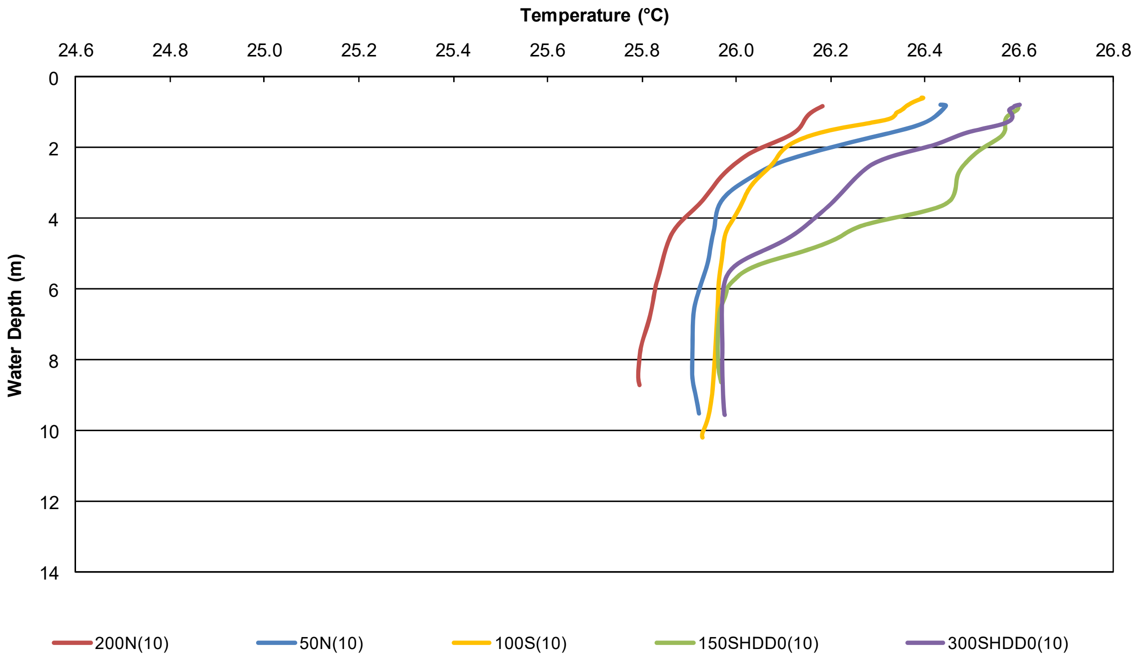
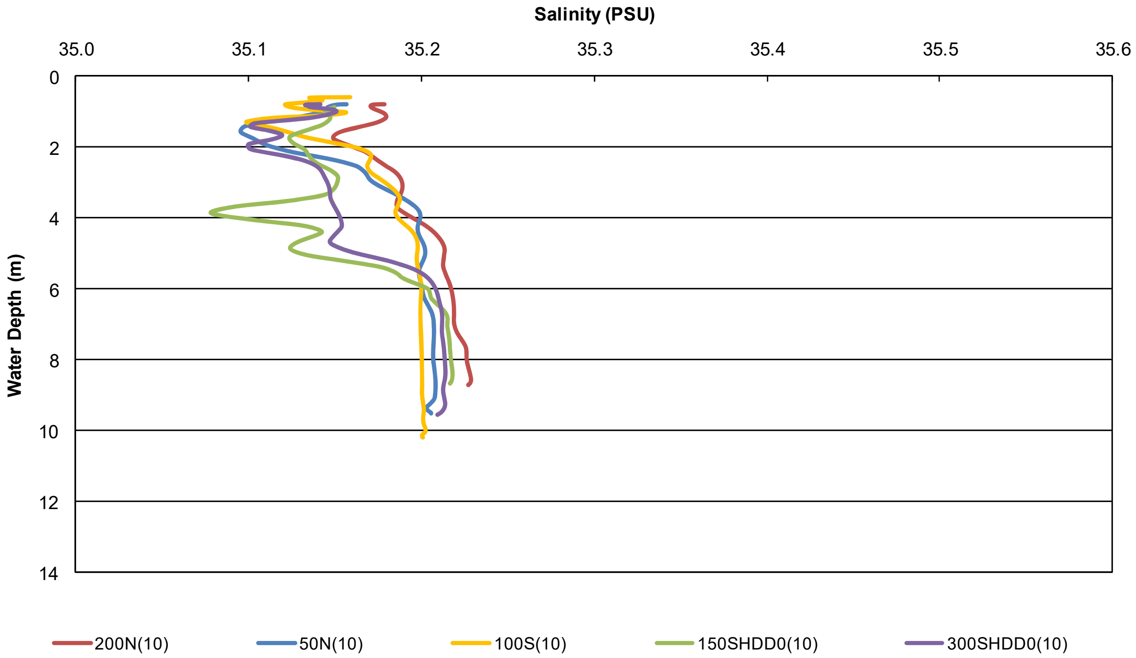


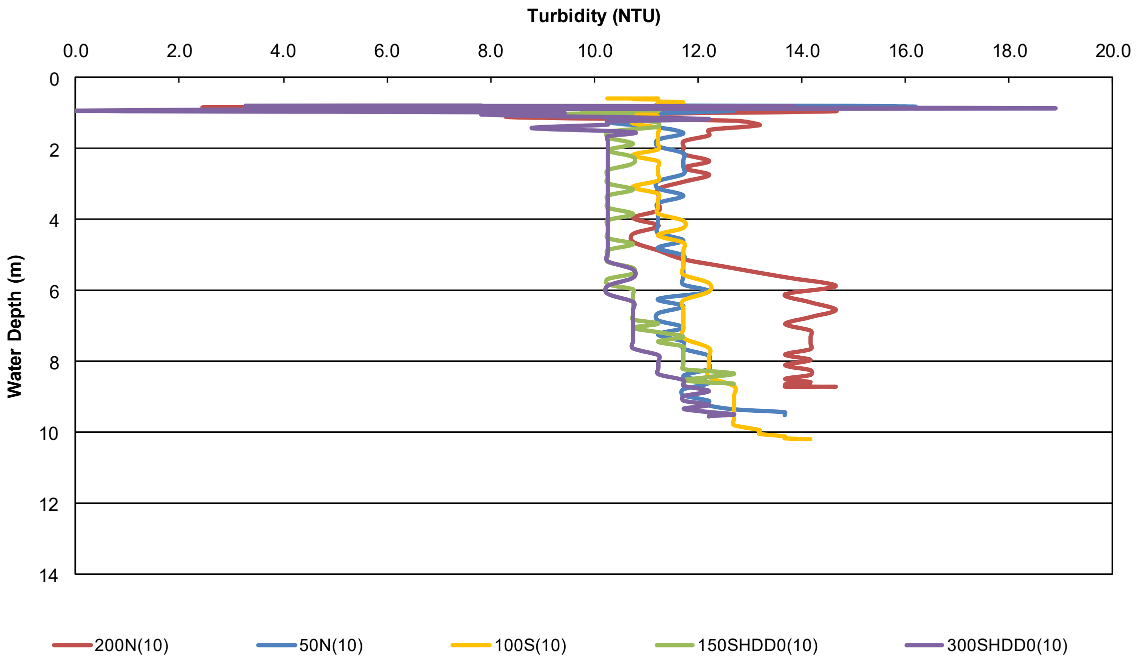
Figure 13-13: Water Column Profiles at Offshore Sites in the Indicative Anchoring Area, June 2010

In the nearshore indicative anchoring area, sites were in approximately 8.5–12 m water depth. Surface temperatures varied between 26.2 and 26.6 °C in May 2009 and declined with depth, with bottom temperatures varying between 25.8 and 26.0 °C (Figure 13-14). Surface and bottom temperatures were lower in June

2010, varying between 24.8 and 24.9 °C and between 24.6 and 24.7 °C, respectively (Figure 13-15). Salinities were higher in June 2010 than May 2009. Surface salinities varied between 35.1 and 35.2 PSU and there was little change with depth as bottom salinities were 35.2 PSU at all the sites in May 2009. A surface salinity of 35.5 PSU and a bottom salinity of 35.6 PSU were recorded in June 2010. Surface turbidity varied between 9.3 and 11.2 NTU in both May 2009 and June 2010, and increased with depth, with bottom turbidity varying between 11.7 and 14.2 NTU in May 2009 and between 11.2 and 13.7 NTU in June 2010. Surface PAR varied between 580 and 1750 μE/m²/s, decreasing to 70–150 μE/m²/s in bottom waters in May 2009. In June 2010, surface PAR varied between 545 and 880 μE/m²/s, decreasing to 45–95 μE/m²/s in bottom waters.




Salinity (PSU)
35.0
35.1
35.2
35.3
35.4
35.5
35.6
0
2
4
6
8
10
12
14
Water Depth (m)
200N(10)
50N(10)
100S(10)
150SHDD0(10)
300SHDD0(10)


Turbidity (NTU)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
0
2
4
6
8
10
12
14
Water Depth (m)
200N(10)
50N(10)
100S(10)
150SHDD0(10)
300SHDD0(10)

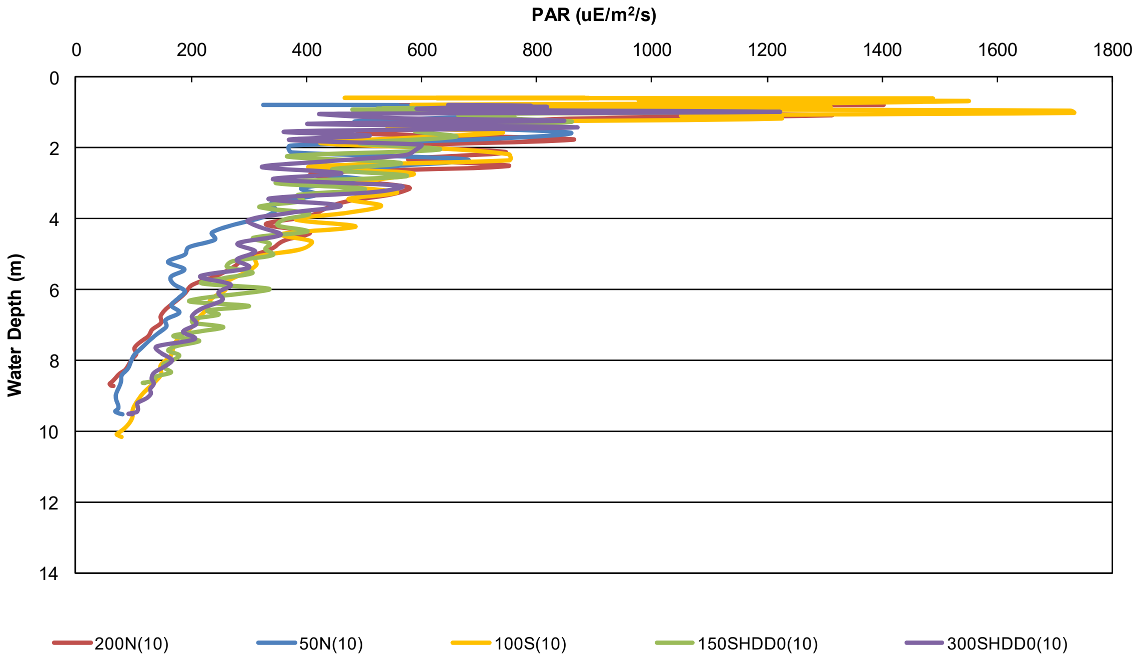
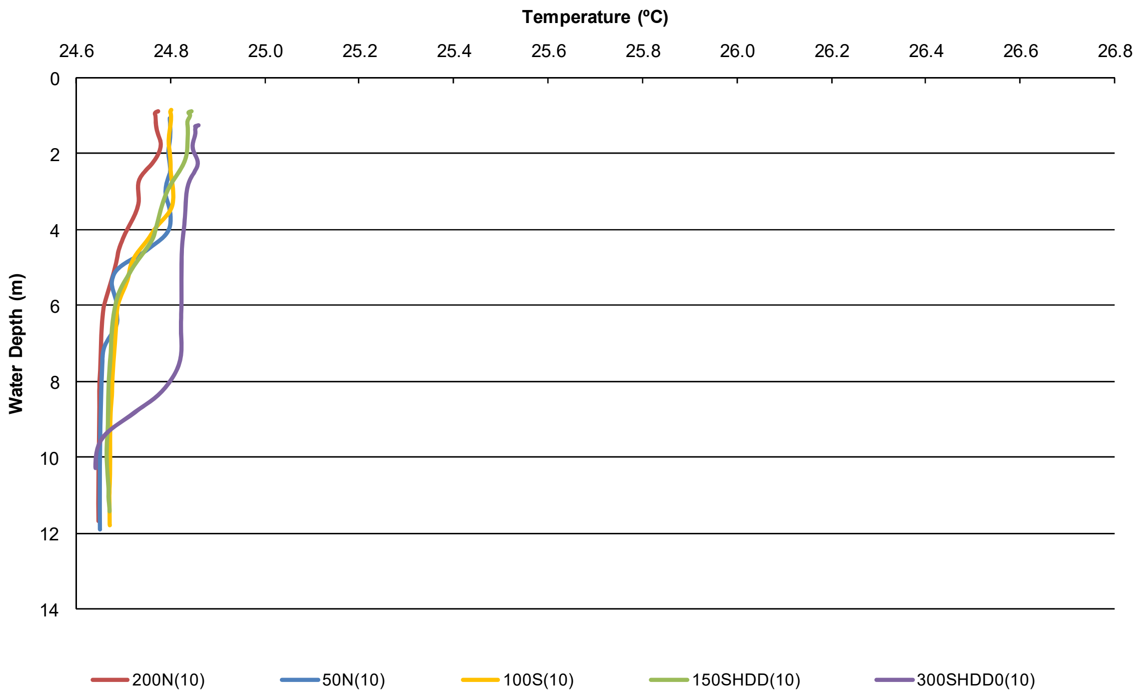
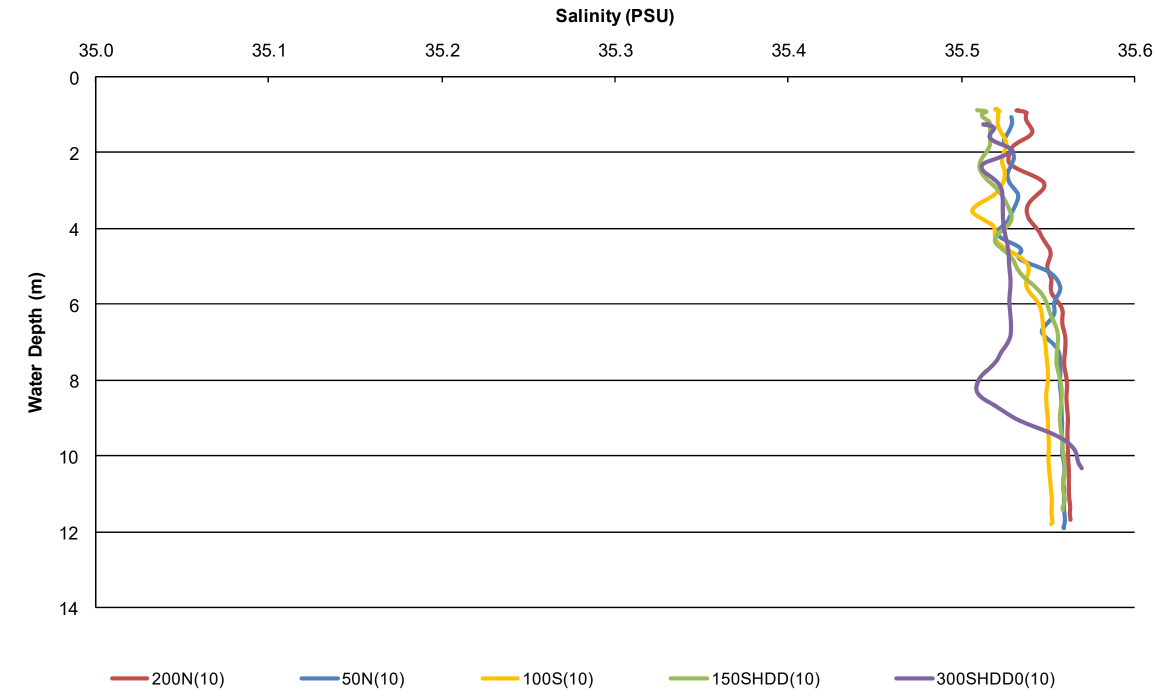
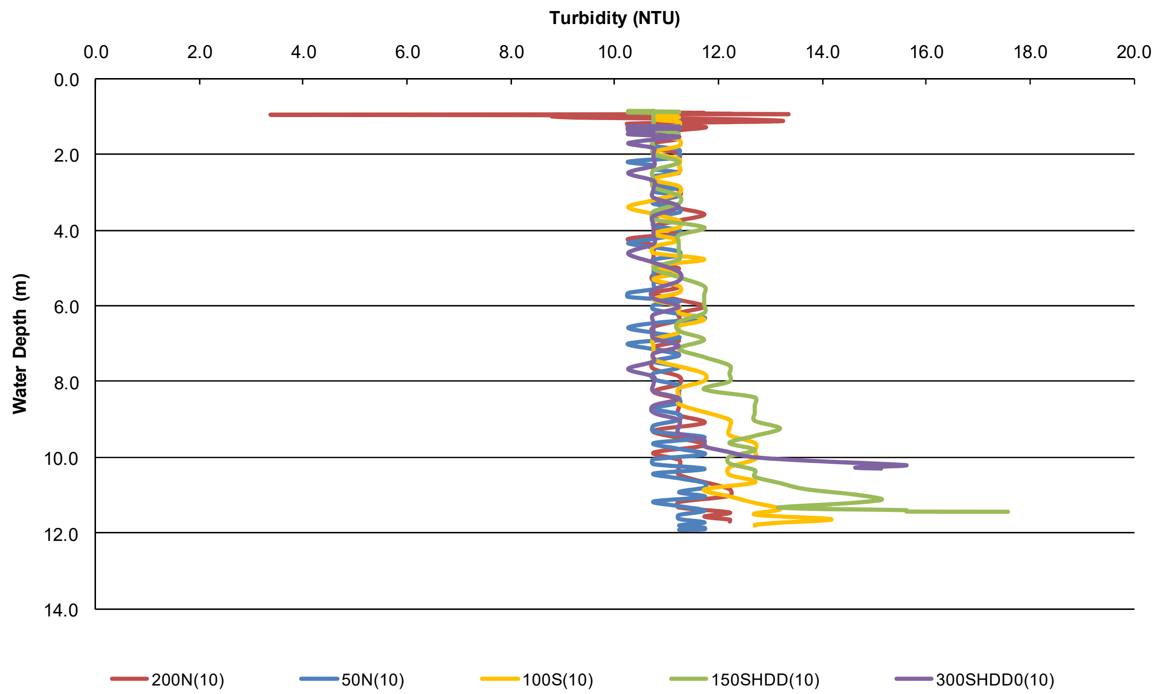


Figure 13-14: Water Column Profiles at Nearshore Sites in the Indicative Anchoring Area, May 2009




Salinity (PSU)
35.0
35.1
35.2
35.3
35.4
35.5
35.6
Water Depth (m)
0
2
4
6
8
10
12
14
200N(10)
50N(10)
100S(10)
150SHDD(10)
300SHDD0(10)


Turbidity (NTU)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Water Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
200N(10)
50N(10)
100S(10)
150SHDD(10)
300SHDD0(10)

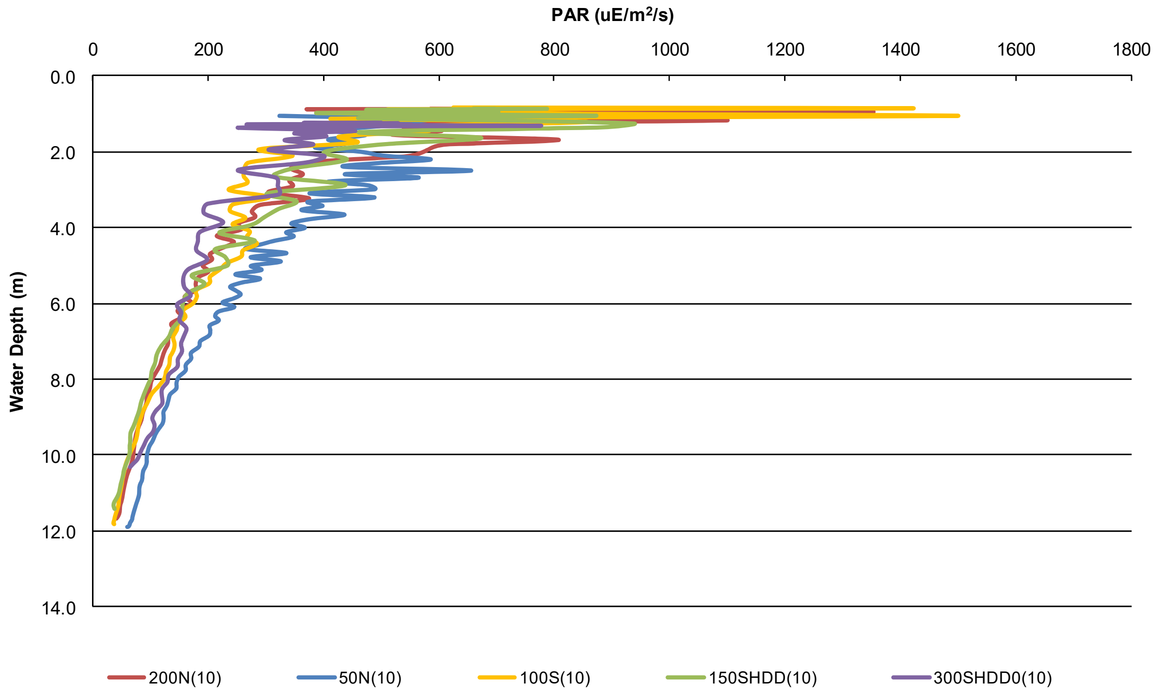
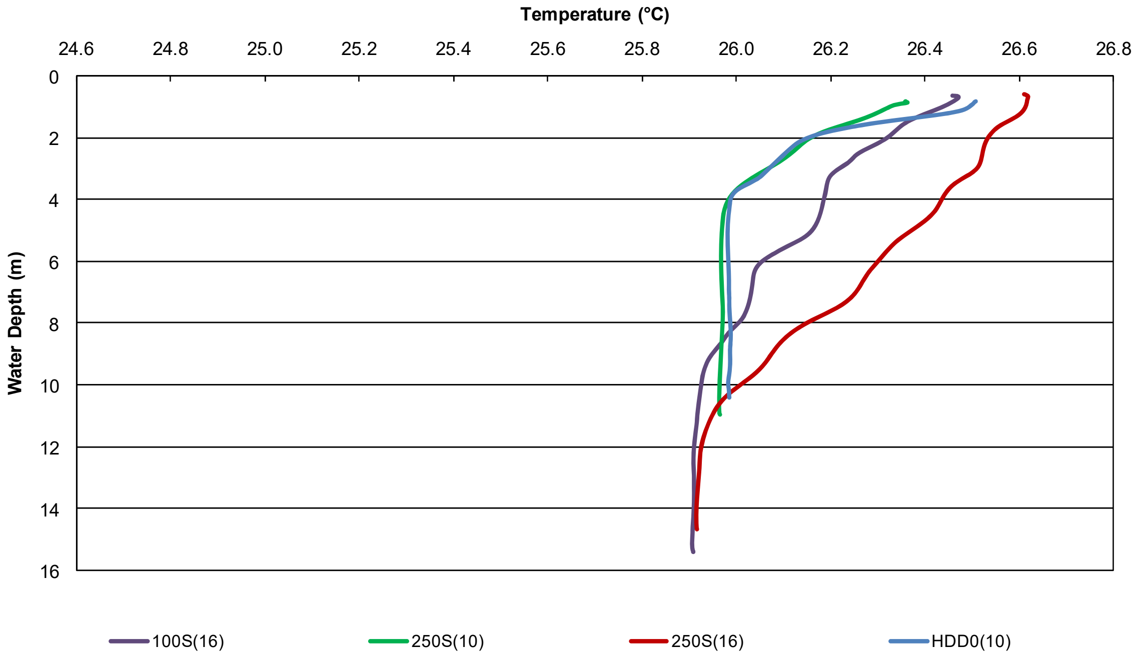


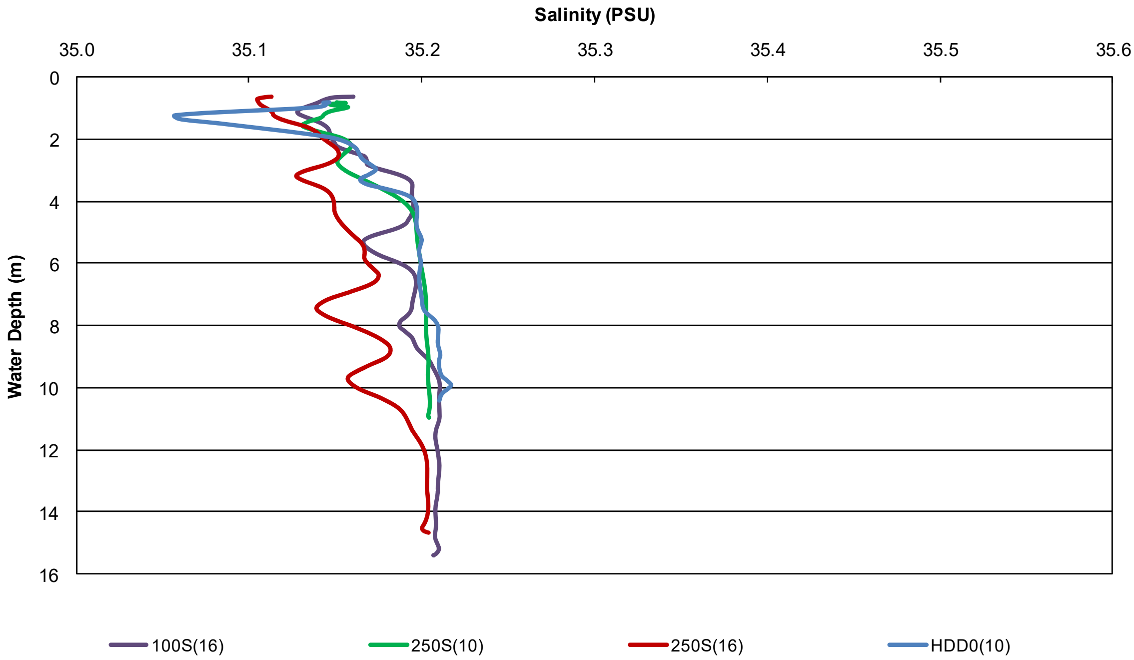
Figure 13-15: Water Column Profiles at Nearshore Sites in the Indicative Anchoring Area, June 2010

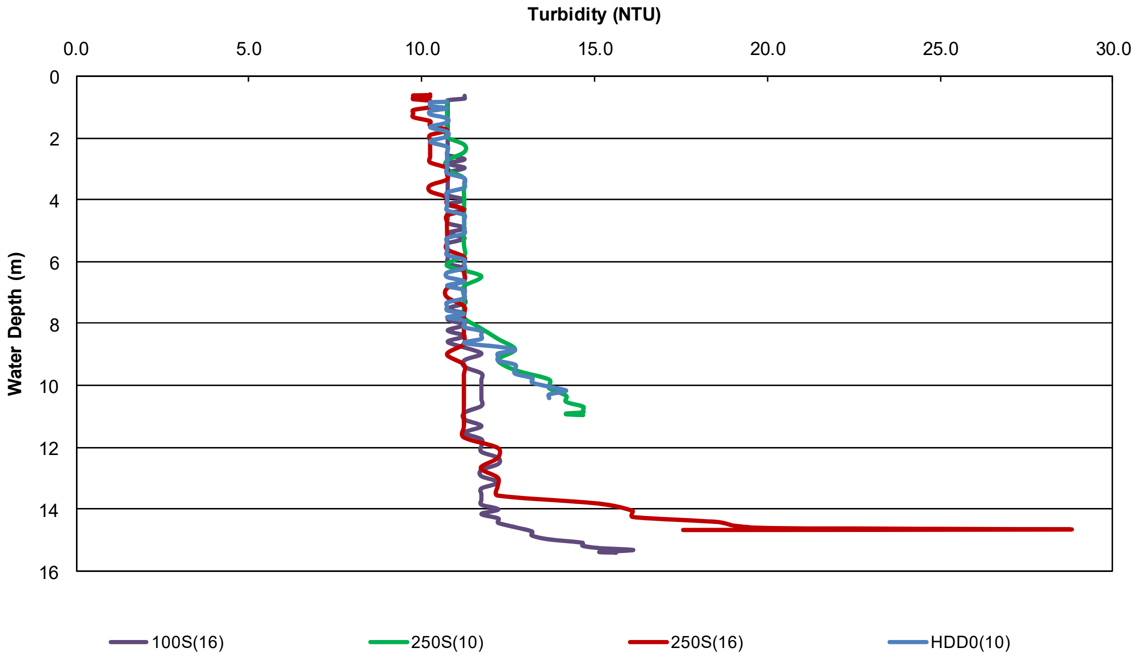
13.4.4.2 Sites at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Marine Components of the Shore Crossing

Sites at risk of Material or Serious Environmental Harm were in approximately 11–17 m water depths. Surface temperatures (≈1 m below the surface) at the sites at risk of Material or Serious Environmental Harm varied between 26.3 and 26.6 °C and declined with depth; bottom temperatures (≈0.5 m above the seabed) varied between 25.9 and 26.0 °C in May 2009 (Figure 13-16). Temperatures were lower in June 2010. Surface temperatures were between 24.8 and 25.4 °C, decreasing to between 24.7 and 25.0 °C in bottom waters (Figure 13-17). Salinities were higher in June 2010 than in May 2009. Surface salinities were between 35.1 and 35.2 PSU in May 2009 and between 35.4 and 35.5 PSU in June 2010; there was little change with depth as bottom salinities were 35.2 PSU in May 2009 and between 35.5 and 35.6 PSU in June 2010.

A surface turbidity of between 10.3 and 10.7 NTU was recorded at these sites in May 2009, and between 9.8 and 10.7 NTU in June 2010. Turbidity increased with depth, with bottom turbidity varying between 12.7 and 16.1 NTU in May 2009, and between 11.2 and 14.7 NTU in June 2010. Surface PAR varied between 170 and 670 μE/m^2/s, decreasing to 20–75 μE/m^2/s in bottom waters in May 2009. In June 2010, surface PAR was between 345 and 625 μE/m^2/s in surface waters, decreasing to 15–40 μE/m^2/s in bottom waters.


Temperature (°C)
24.6
24.8
25.0
25.2
25.4
25.6
25.8
26.0
26.2
26.4
26.6
26.8
Water Depth (m)
0
2
4
6
8
10
12
14
16
100S(16)
250S(10)
250S(16)
HDD0(10)


Salinity (PSU)
35.0
35.1
35.2
35.3
35.4
35.5
35.6
Water Depth (m)
0
2
4
6
8
10
12
14
16
100S(16)
250S(10)
250S(16)
HDD0(10)



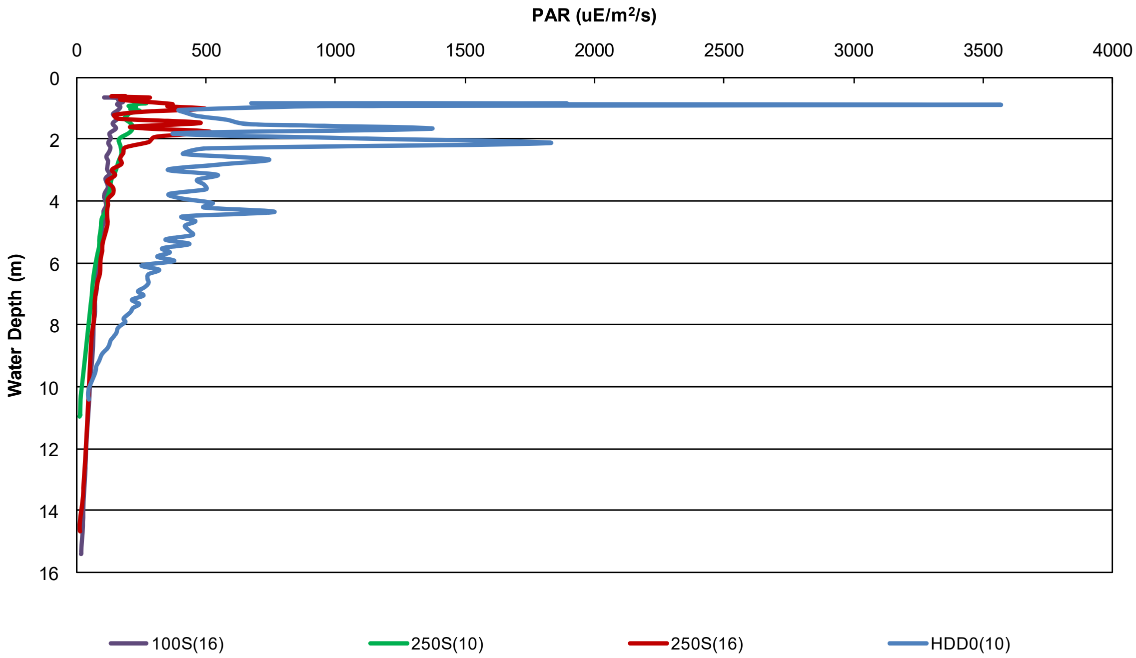
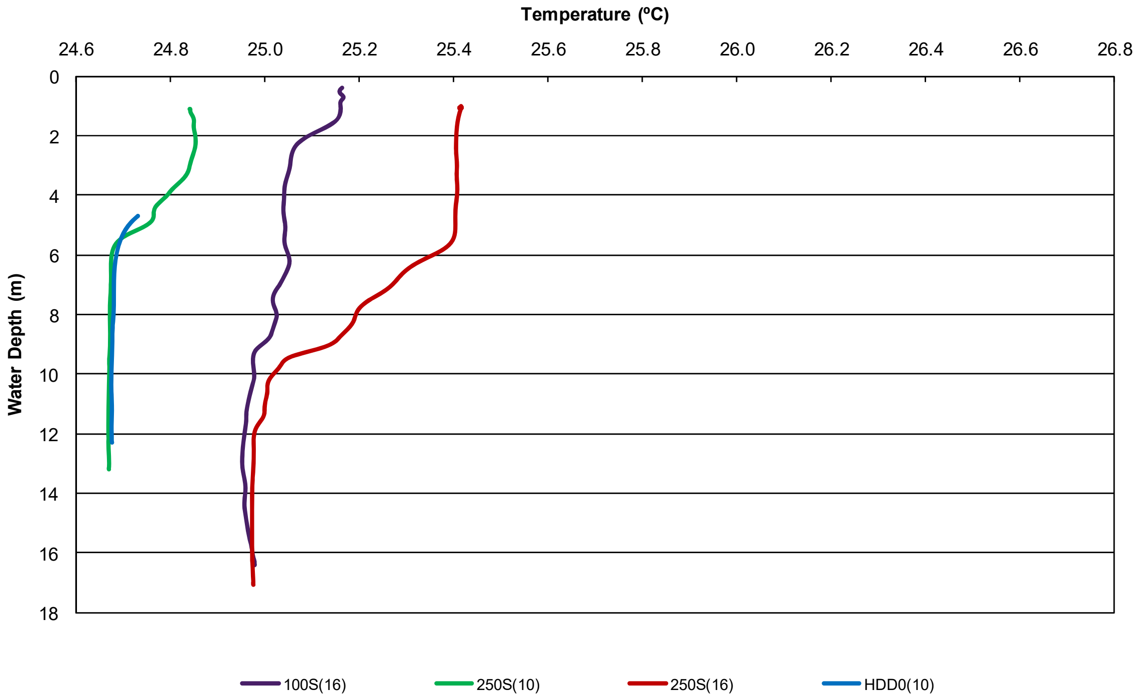
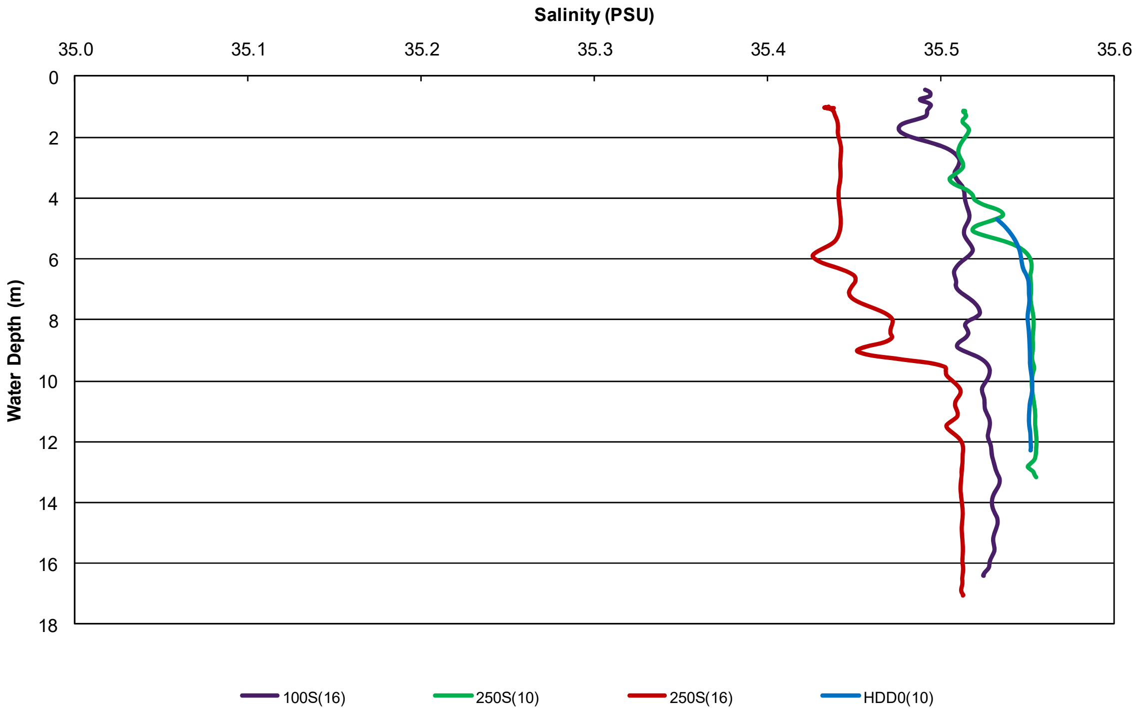
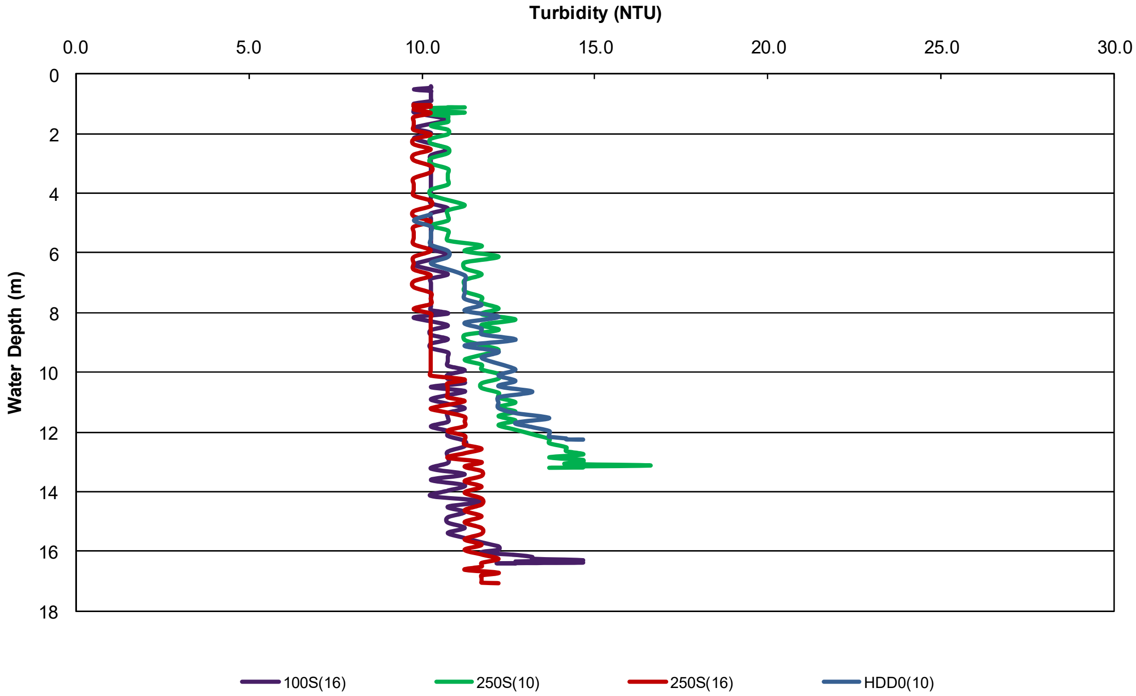


Figure 13-16: Water Column Profiles at Sites at Risk of Material or Serious Environmental Harm, May 2009


Temperature (ºC)
24.6
24.8
25.0
25.2
25.4
25.6
25.8
26.0
26.2
26.4
26.6
26.8
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
100S(16)
250S(10)
250S(16)
HDD0(10)


Salinity (PSU)
35.0
35.1
35.2
35.3
35.4
35.5
35.6
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
100S(16)
250S(10)
250S(16)
HDD0(10)



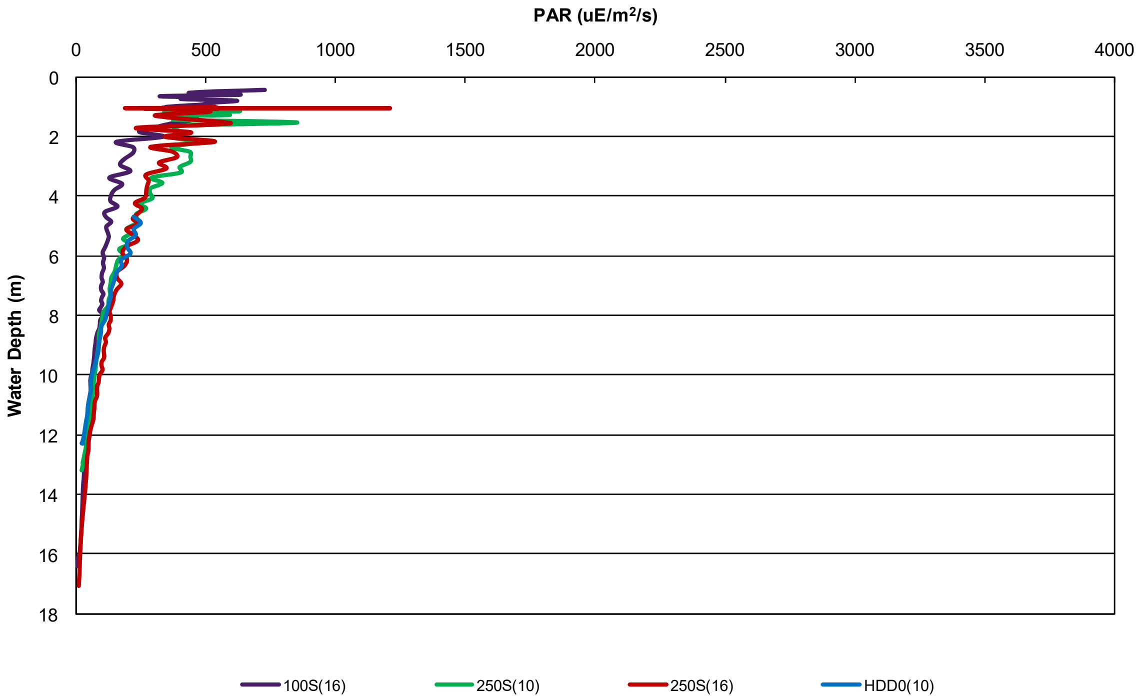
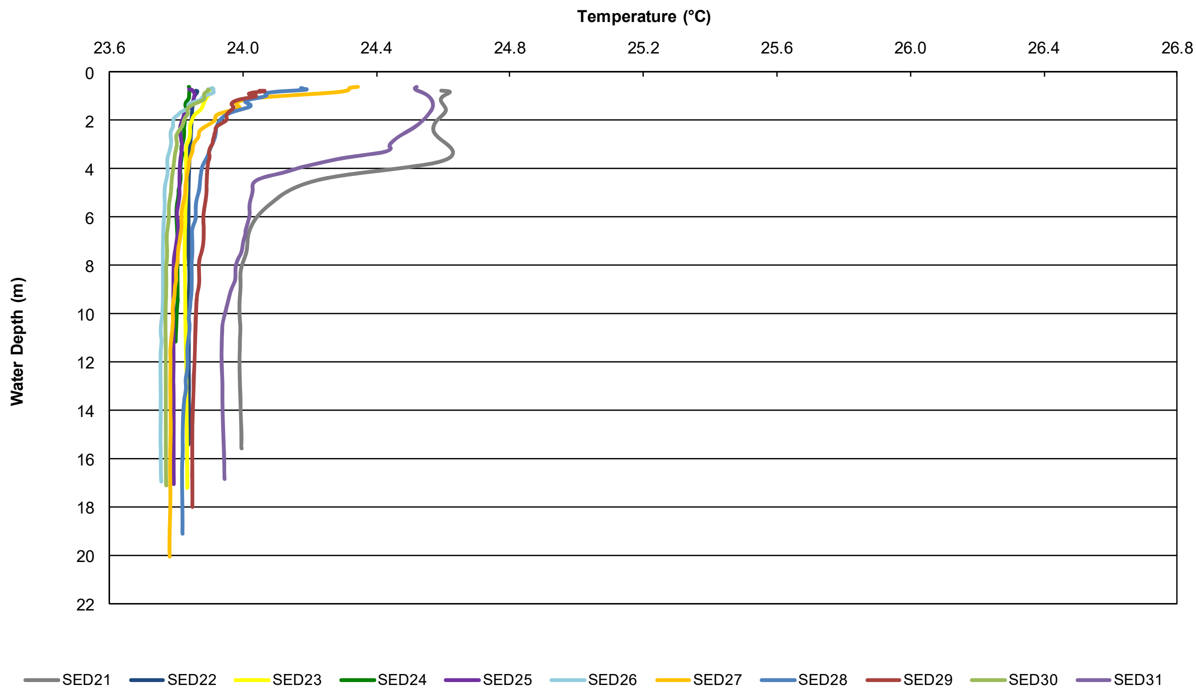


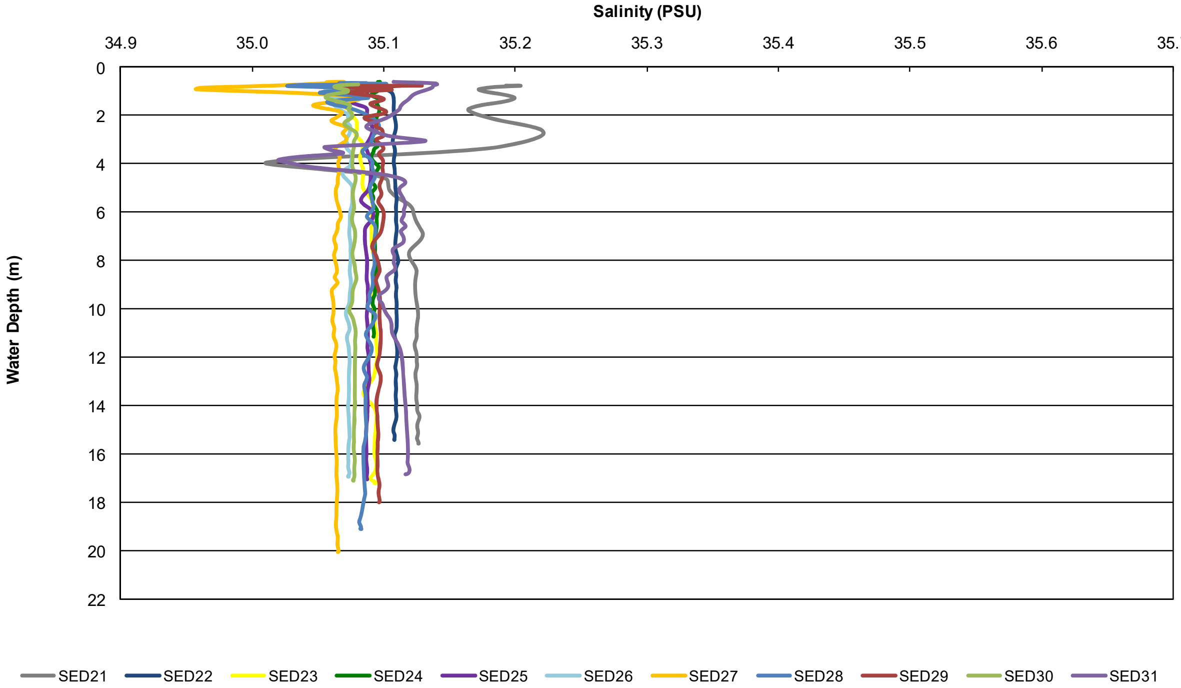
Figure 13-17: Water Column Profiles at Sites at Risk of Material or Serious Environmental Harm, June 2010

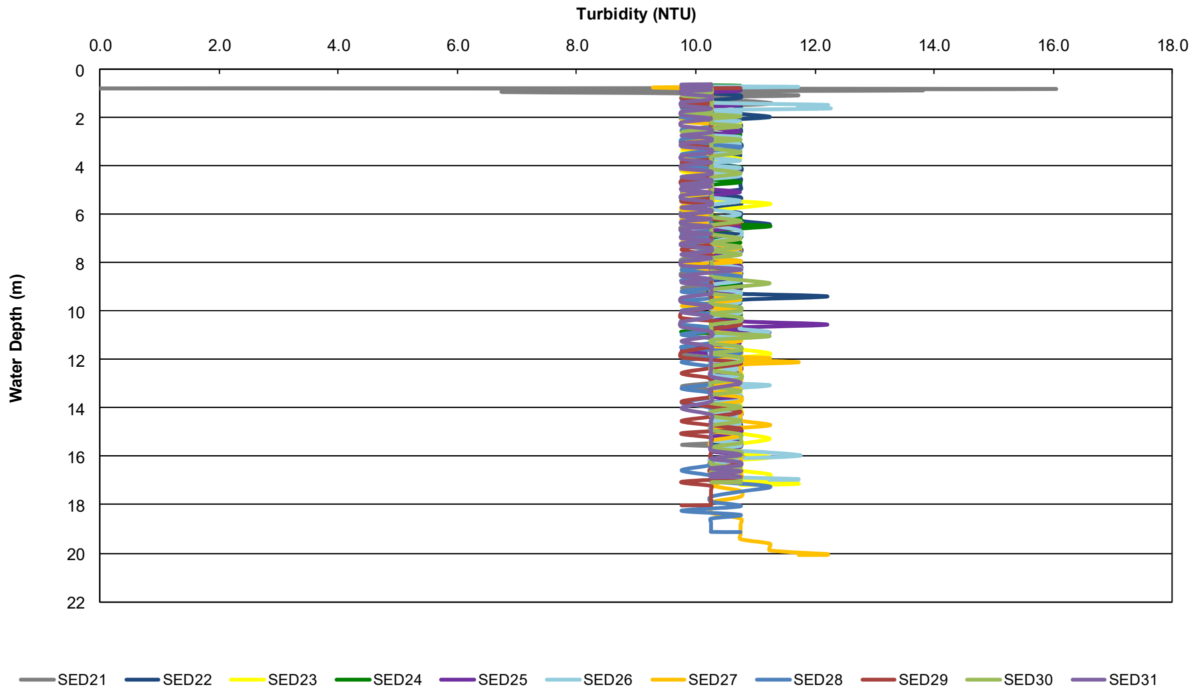
13.4.5 Water Column Profiles—October 2009 and June 2010

13.4.5.1 Reference Sites not at Risk of Material or Serious Environmental Harm due to the Construction or Operation of the Offshore Feed Gas Pipeline System in State Waters

The Reference Sites located north of the Offshore Feed Gas Pipeline System in State Waters (Figure 13-2) were in approximately 10–20 m water depths, with most in approximately 17 m of water. Surface temperatures (≈1 m below the surface) in October 2009 varied between 23.8 and 24.6 °C and declined with depth, with bottom temperatures (≈0.5 m above the seabed) varying between 23.8 and 24.0 °C (Figure 13-18). Higher temperatures were recorded in June 2010, with surface temperatures varying between 24.8 and 26.6 °C and bottom temperatures between 24.6 and 25.7 °C (Figure 13-19). Salinities were higher in June 2010 than in October 2009. Surface salinities varied between 35.0 and 35.2 PSU in October 2009 and there was little change with depth as bottom salinities were 35.1 PSU at all sites. In June 2010, surface salinities varied between 35.2 and 35.5 PSU and between 35.4 and 35.6 PSU in bottom waters. There was greater between site variability in both temperature and salinity in June 2010 compared to October 2009. Turbidity was generally similar (≈10 NTU) at all sites in both October 2009 and June 2010. Surface turbidity varied between 9.8 and 10.3 NTU in October 2009 and between 9.8 and 11.2 NTU in June 2010, and increased with depth, with bottom turbidity varying between 10.3 and 11.2 NTU in October 2009 and between 9.8 and 11.2 NTU in June 2010. Surface PAR varied between 370 and 2400 µE/m^2/s, decreasing to 55–155 µE/m^2/s in bottom waters in October 2009. In June 2010, PAR was lower in both surface and bottom waters, varying between 185 and 665 µE/m^2/s in surface waters and between 20 and 80 µE/m^2/s in bottom waters.




Salinity (PSU)
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
SED21
SED22
SED23
SED24
SED25
SED26
SED27
SED28
SED29
SED30
SED31


Turbidity (NTU)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
SED21
SED22
SED23
SED24
SED25
SED26
SED27
SED28
SED29
SED30
SED31

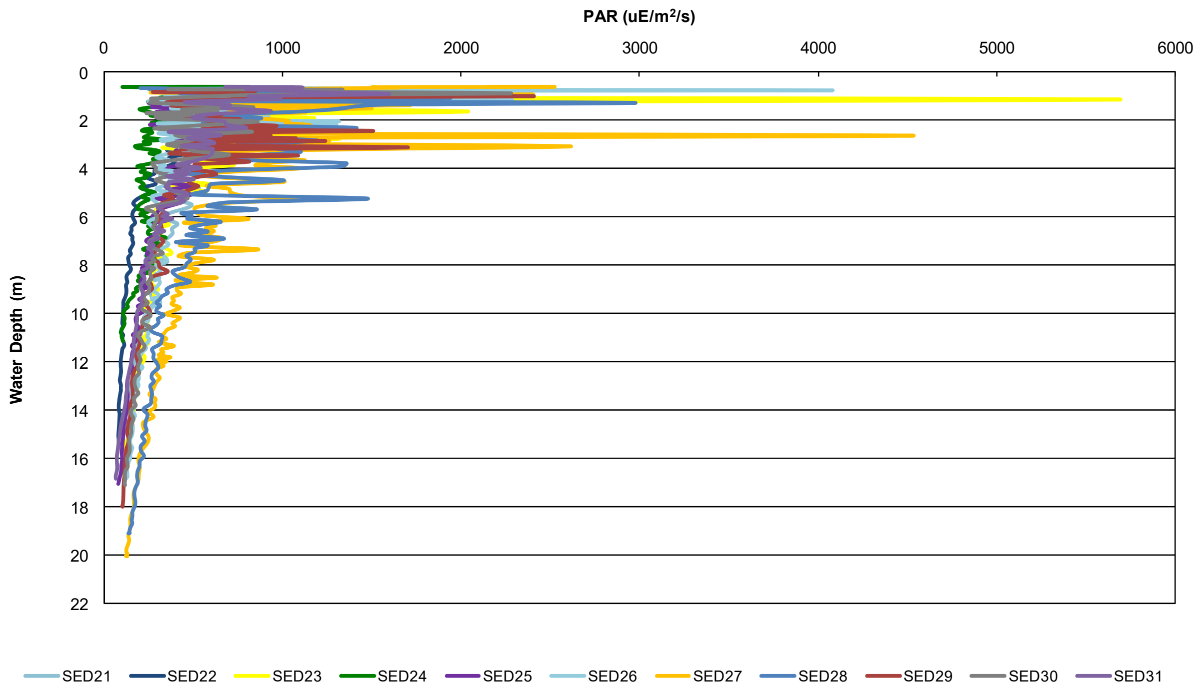
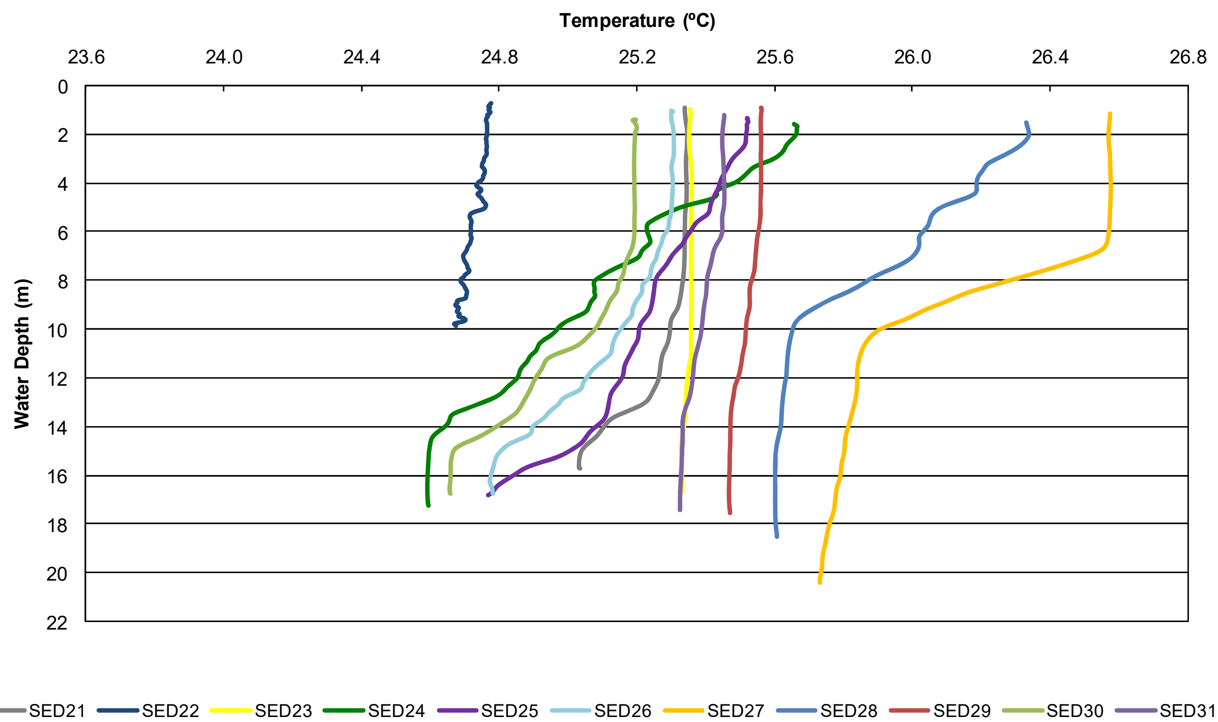
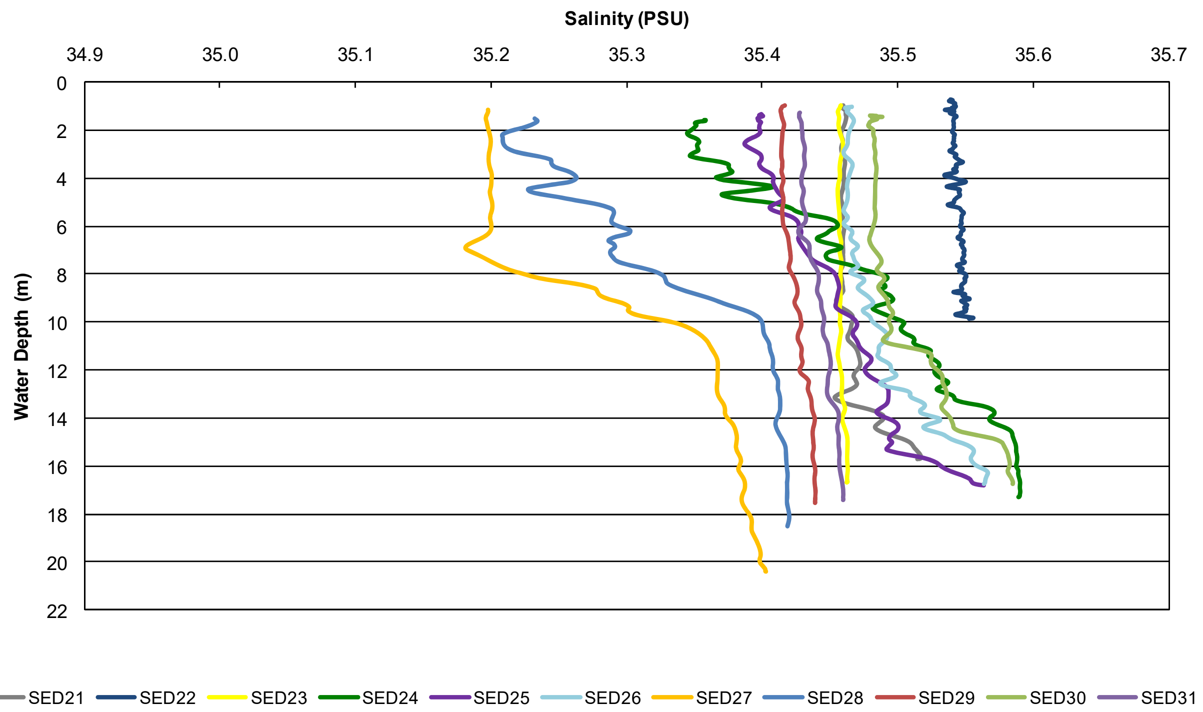
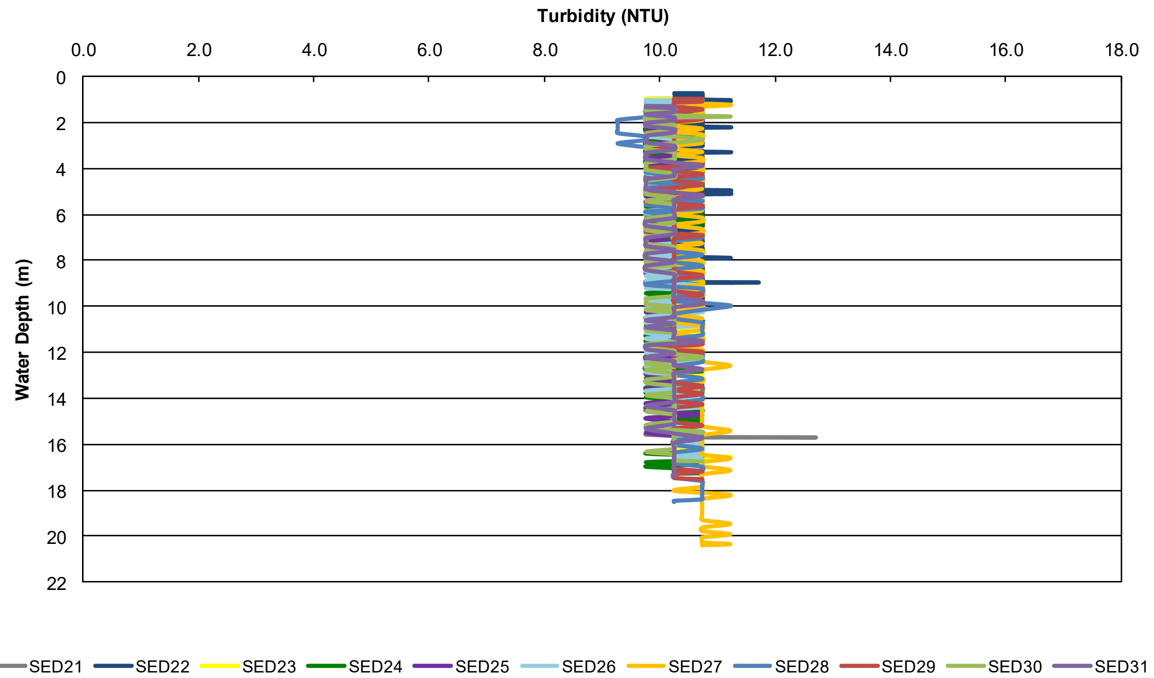


Figure 13-18: Water Column Profiles at Northern Reference Sites along the Offshore Feed Gas Pipeline System in State Waters, October 2009




Salinity (PSU)
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
SED21
SED22
SED23
SED24
SED25
SED26
SED27
SED28
SED29
SED30
SED31


Turbidity (NTU)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
SED21
SED22
SED23
SED24
SED25
SED26
SED27
SED28
SED29
SED30
SED31

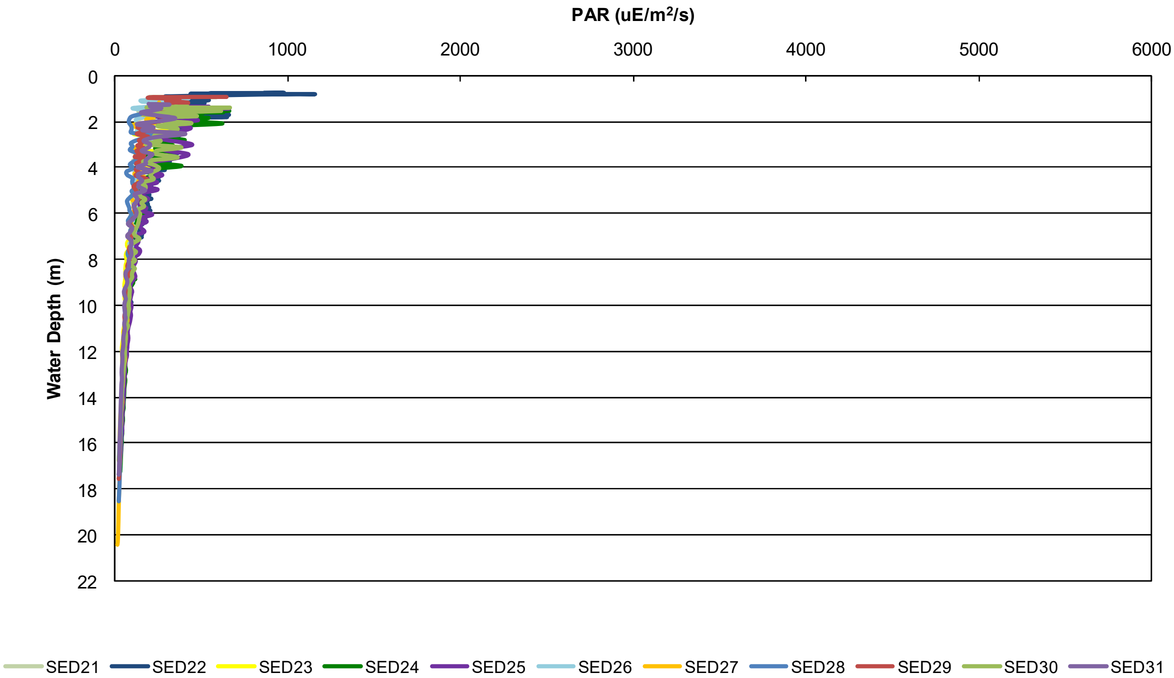
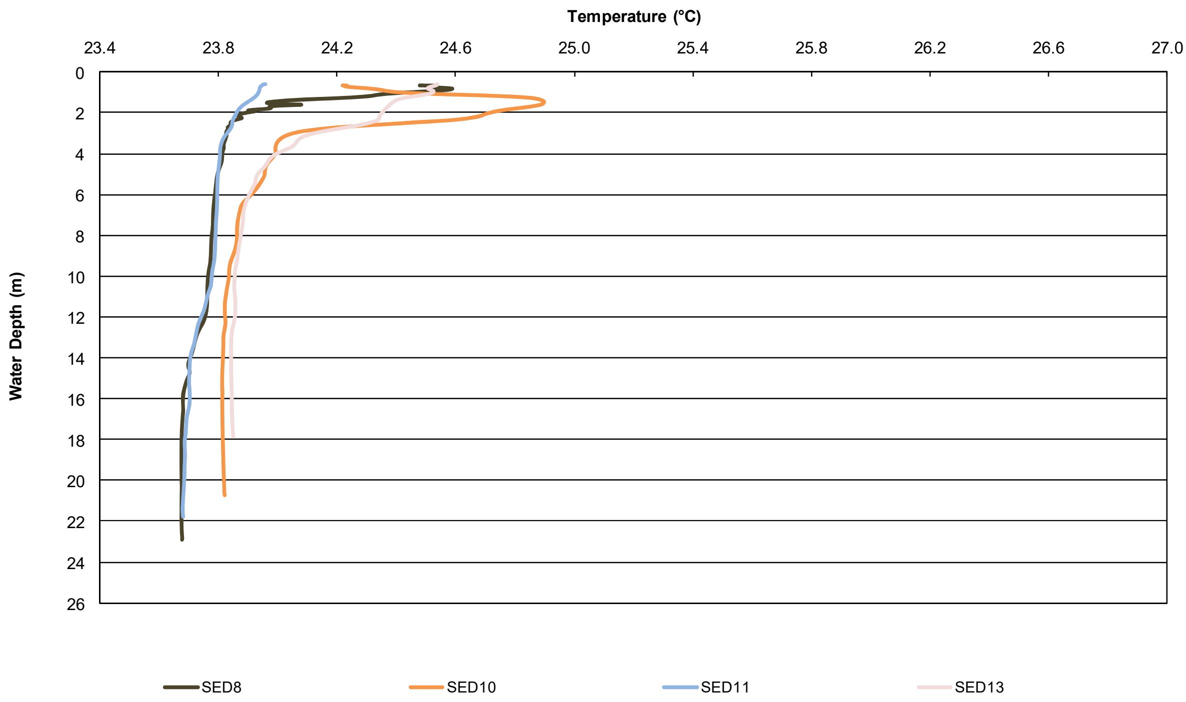
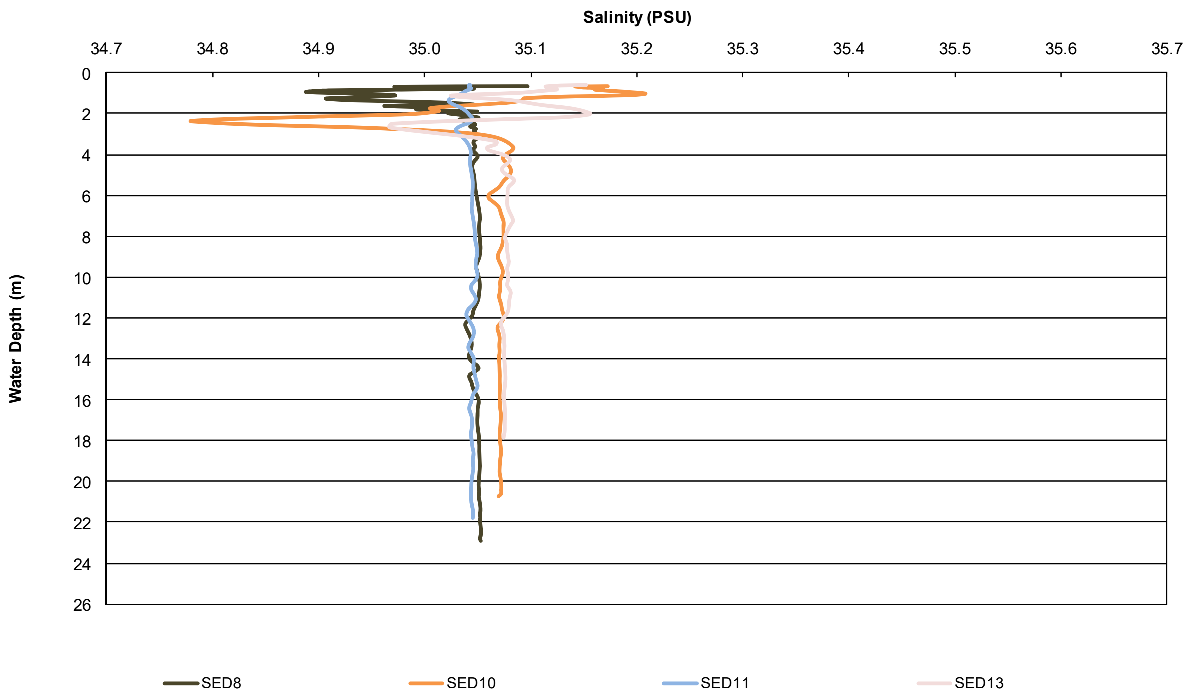
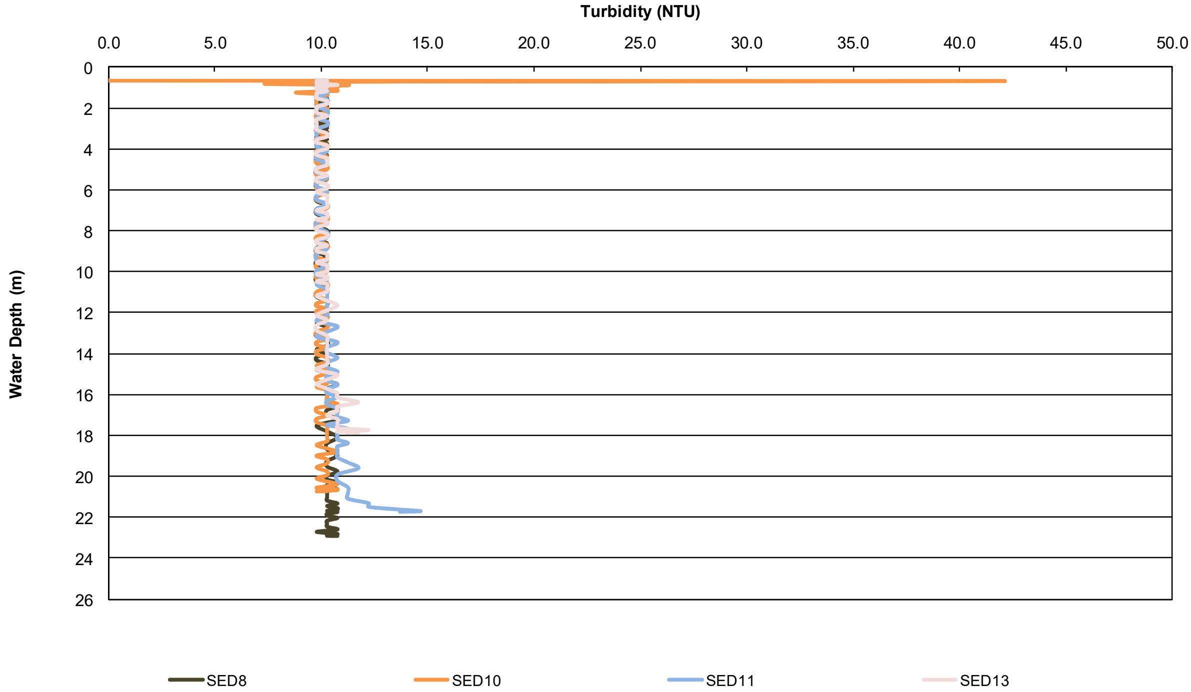


Figure 13-19: Water Column Profiles at Northern Reference Sites along the Offshore Feed Gas Pipeline System in State Waters, June 2010

The sites closest to the Offshore Feed Gas Pipeline System in State Waters (Figure 13-2) were in approximately 18–25 m water depths. In October 2009, surface temperatures varied between 23.9 and 24.5 °C and declined slightly with depth, with bottom temperatures varying between 23.7 and 23.8 °C (Figure 13-20). Water temperatures were higher in June 2010 with an indication of a thermocline at some sites (Figure 13-21). Surface temperatures varied between 26.1 and 26.8 °C, and bottom temperatures between 24.7 and 25.6 °C. In October 2009, surface salinities varied between 34.9 and 35.2 PSU and there was little change with depth as bottom salinities varied between 35.0 and 35.1 PSU. In June 2010, salinities were higher, with surface salinities varying between 35.2 and 35.3 PSU and bottom salinities between 35.4 and 35.6 PSU. Turbidity was generally similar (≈10 NTU) at all sites in both October 2009 and June 2010. Surface turbidity varied between 9.8 and 10.7 NTU in October 2009 and between 9.8 and 12.7 NTU in June 2010, and in October 2009 increased with depth, with bottom turbidity varying between 10.3 and 12.2 NTU. In June 2010, bottom turbidity varied between 9.8 and 12.2 NTU. Surface PAR varied between 510 and 2100 μE/m^2/s in October 2009 and between 55 and 845 μE/m^2/s in June 2010, decreasing to 110–135 μE/m^2/s in bottom waters in October 2009 and between 25 and 90 μE/m^2/s in June 2010.


Temperature (°C)
23.4
23.8
24.2
24.6
25.0
25.4
25.8
26.2
26.6
27.0
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
SED8
SED10
SED11
SED13


Salinity (PSU)
34.7
34.8
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
SED8
SED10
SED11
SED13



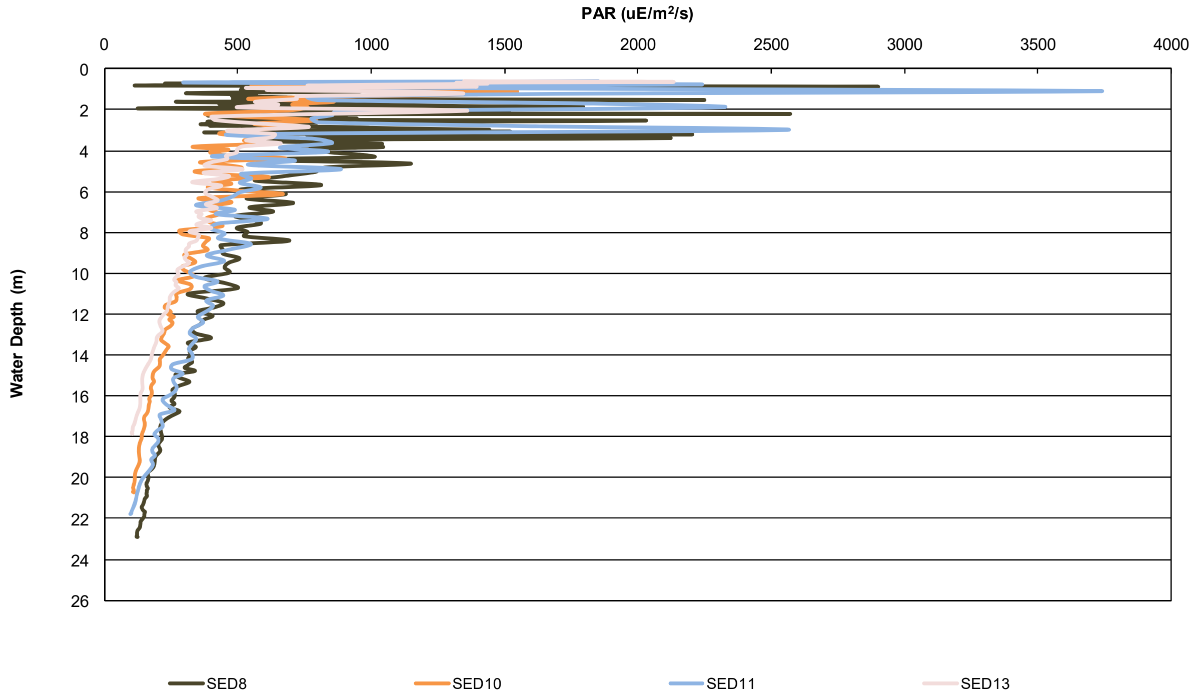
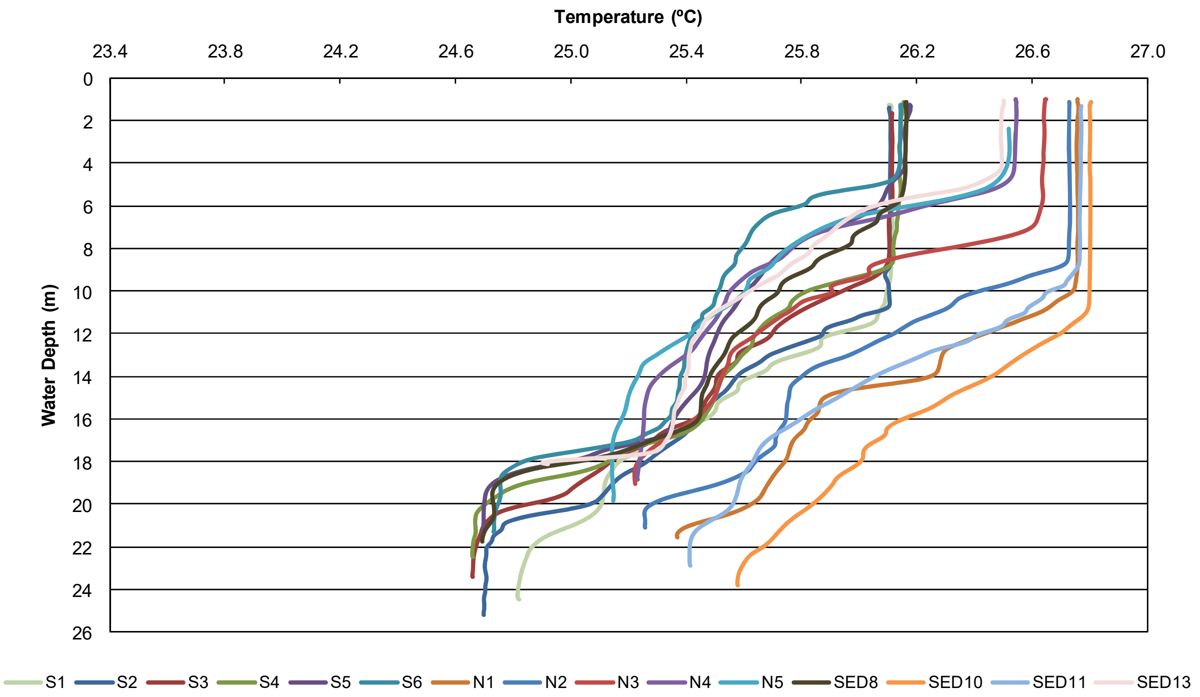
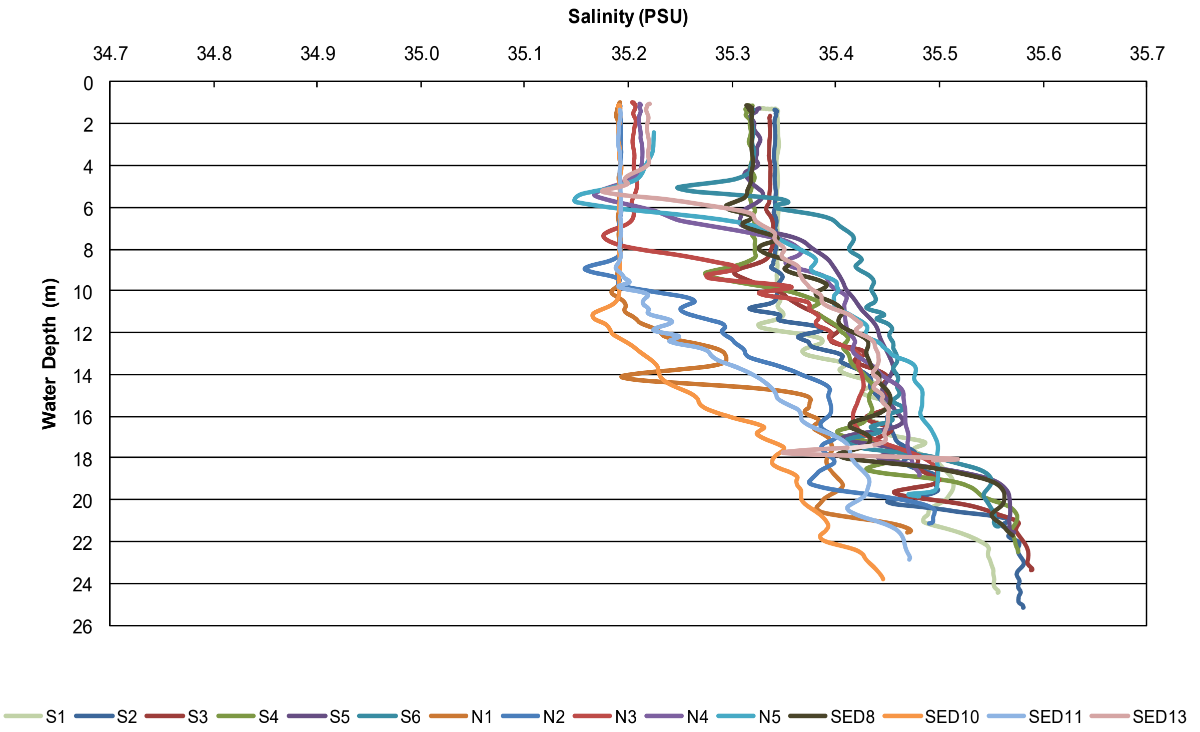


Figure 13-20: Water Column Profiles at Central Reference Sites along the Offshore Feed Gas Pipeline System in State Waters, October 2009


Temperature (ºC)
23.4 23.8 24.2 24.6 25.0 25.4 25.8 26.2 26.6 27.0
Water Depth (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26
S1 S2 S3 S4 S5 S6 N1 N2 N3 N4 N5 SED8 SED10 SED11 SED13


Salinity (PSU)
34.7 34.8 34.9 35.0 35.1 35.2 35.3 35.4 35.5 35.6 35.7
Water Depth (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26
S1 S2 S3 S4 S5 S6 N1 N2 N3 N4 N5 SED8 SED10 SED11 SED13

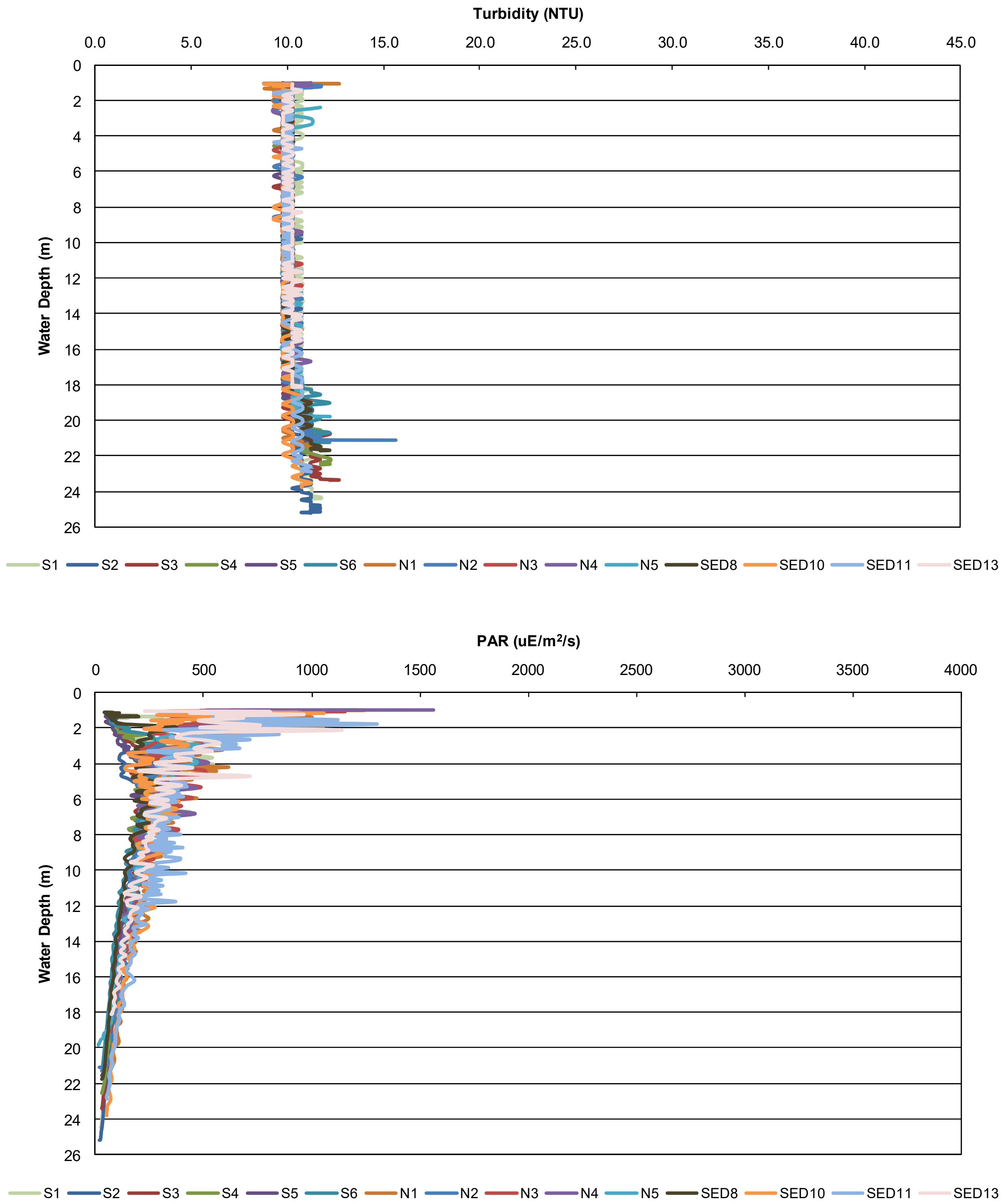
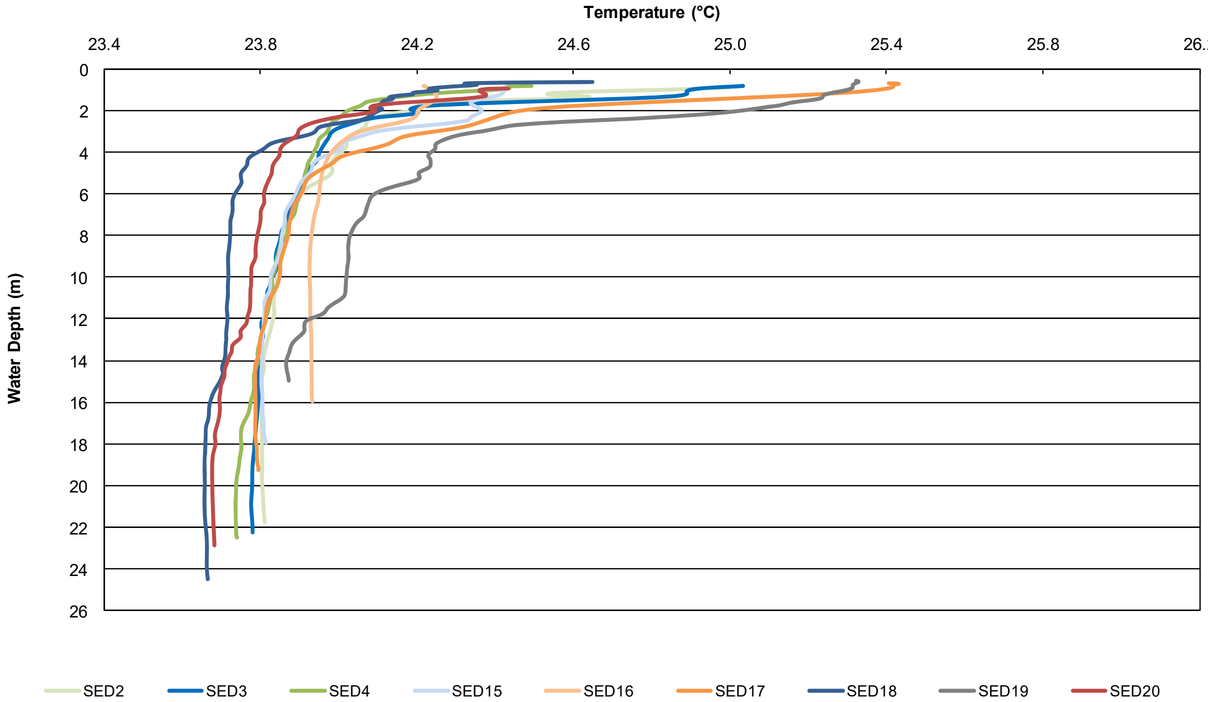
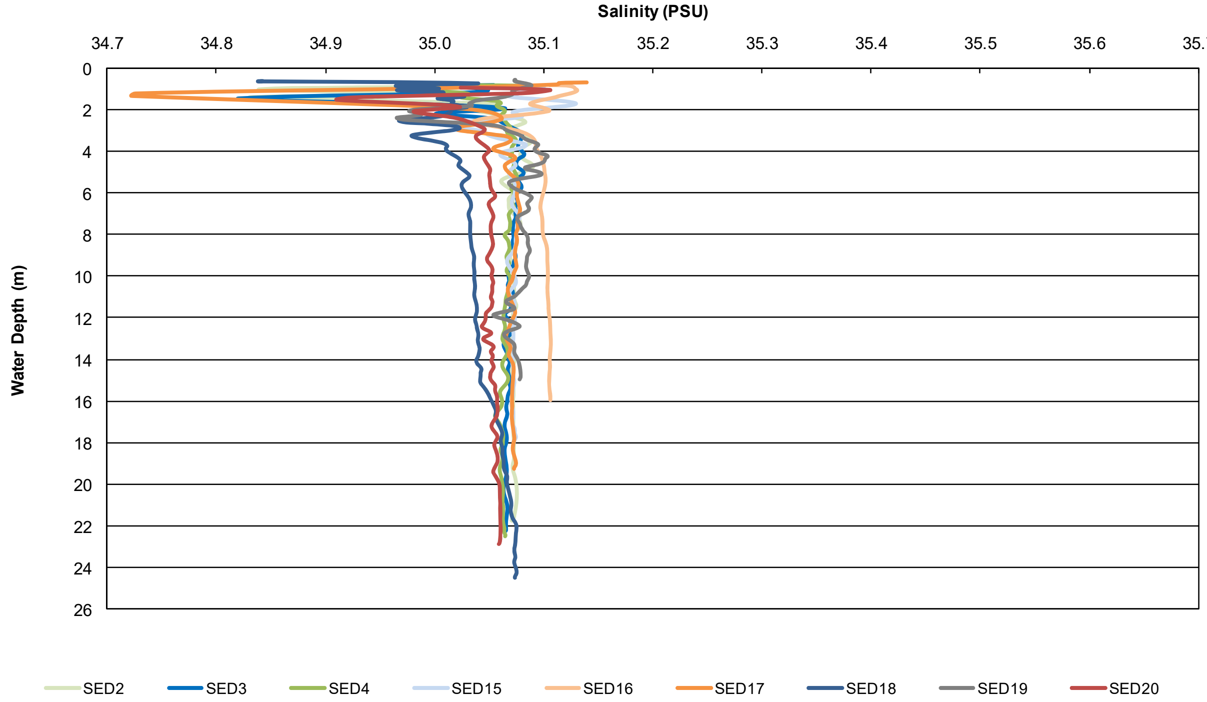


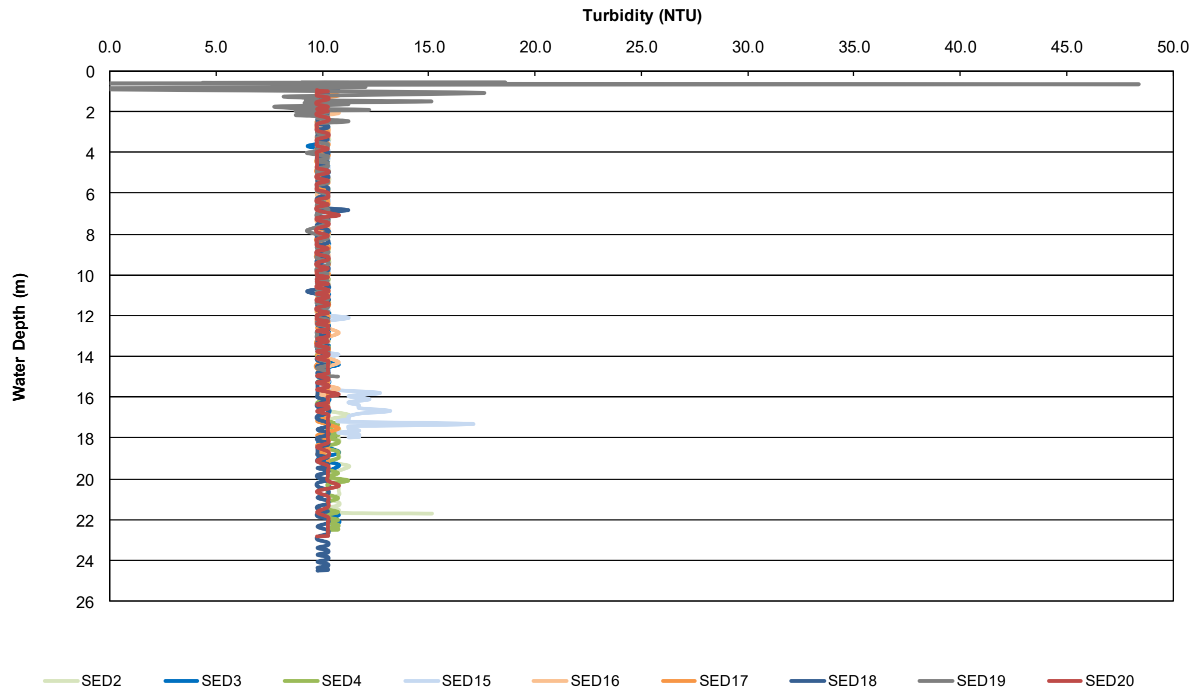
Figure 13-21: Water Column Profiles at Central Reference Sites along the Offshore Feed Gas Pipeline System in State Waters, June 2010

The Reference Sites located south of the Offshore Feed Gas Pipeline System in State Waters (Figure 13-2) were in approximately 15–25 m water depths, with most in depths greater than approximately 20 m. Surface temperatures in October 2009 were lower than those recorded in June 2010, varying between 24.2 and

25.4 °C; and declined slightly with depth, with bottom temperatures varying between 23.7 and 23.9 °C (Figure 13-22). In June 2010, surface temperatures varied between 25.5 and 26.1 °C and bottom temperatures between 24.6 and 25.2 °C (Figure 13-23). Surface salinities varied between 34.8 and 35.1 PSU and there was little change with depth as bottom salinities were 35.1 PSU at all sites in October 2009. In June 2010, salinities were higher. Surface salinities varied between 35.3 and 35.4 PSU and bottom salinities between 35.5 and 35.6 PSU. Surface turbidity varied between 9.8 and 10.3 NTU in October 2009 and between 8.8 and 13.2 NTU in June 2010, and increased with depth, with bottom turbidity varying between 9.8 and 11.2 NTU in October 2009. In June 2010, bottom turbidity varied between 10.7 and 13.2 NTU. Surface PAR varied between 115 and 1650 μE/m^2/s, decreasing to 120–185 μE/m^2/s in bottom waters in October 2009. In June 2010, surface PAR varied between 80 and 950 μE/m^2/s, decreasing to 20–70 μE/m^2/s in bottom waters.




Salinity (PSU)
34.7
34.8
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
SED2
SED3
SED4
SED15
SED16
SED17
SED18
SED19
SED20


Turbidity (NTU)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
SED2
SED3
SED4
SED15
SED16
SED17
SED18
SED19
SED20

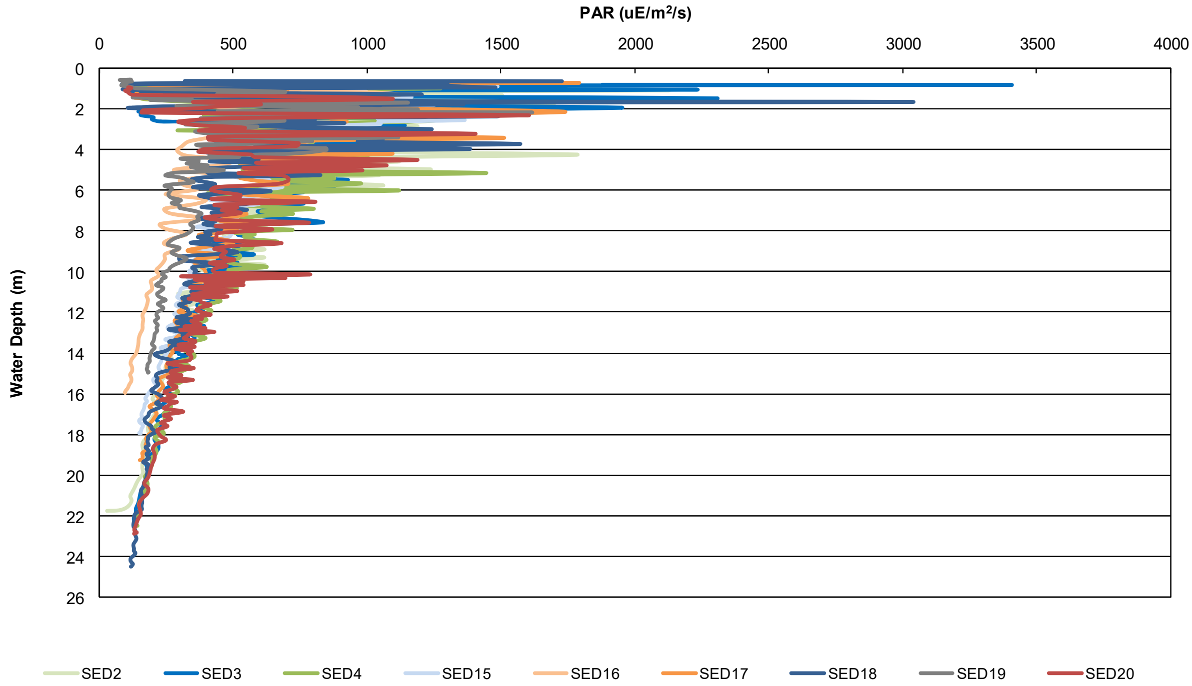
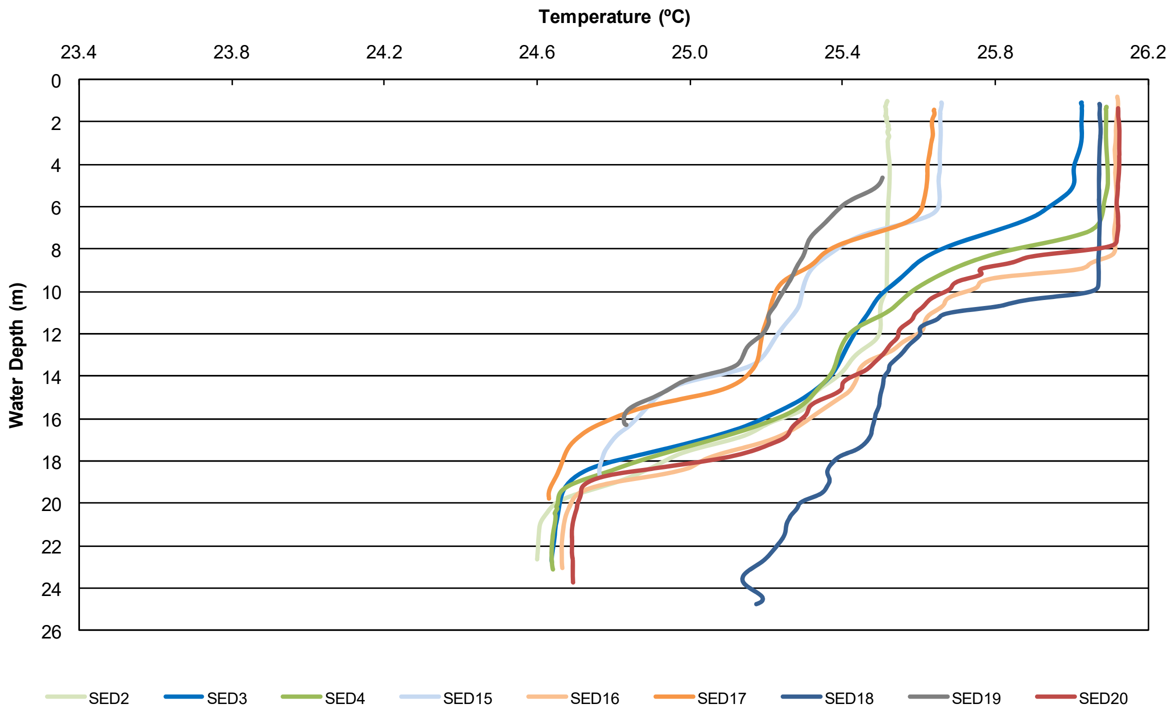
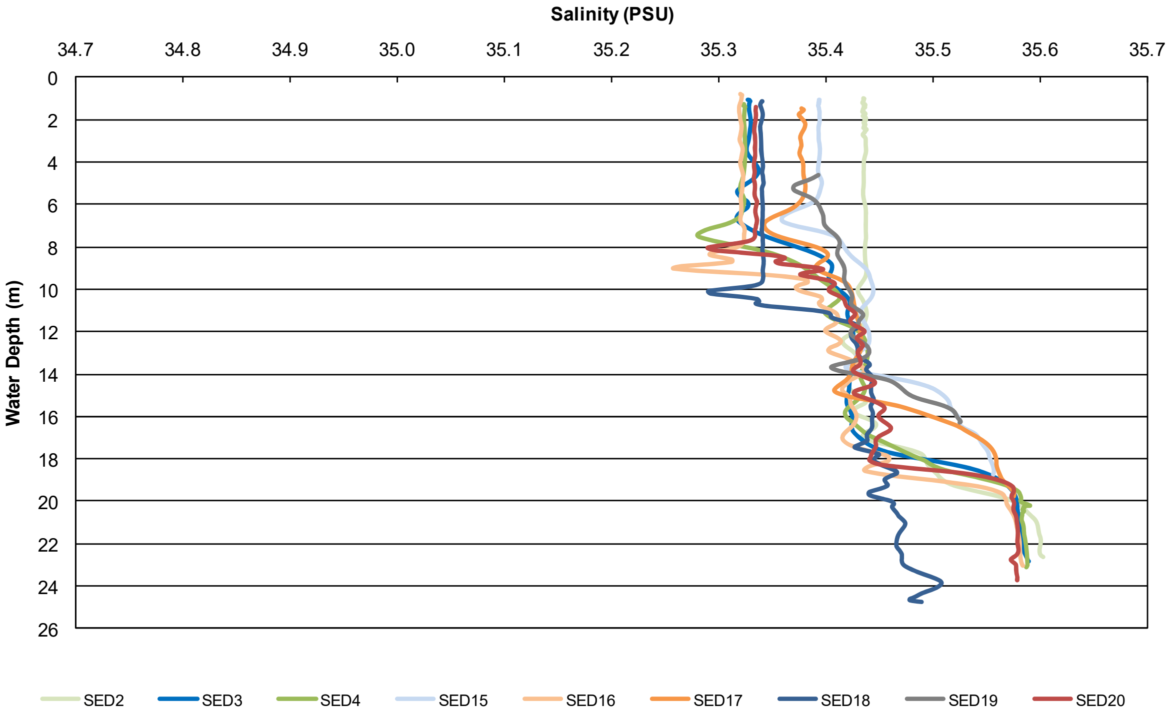
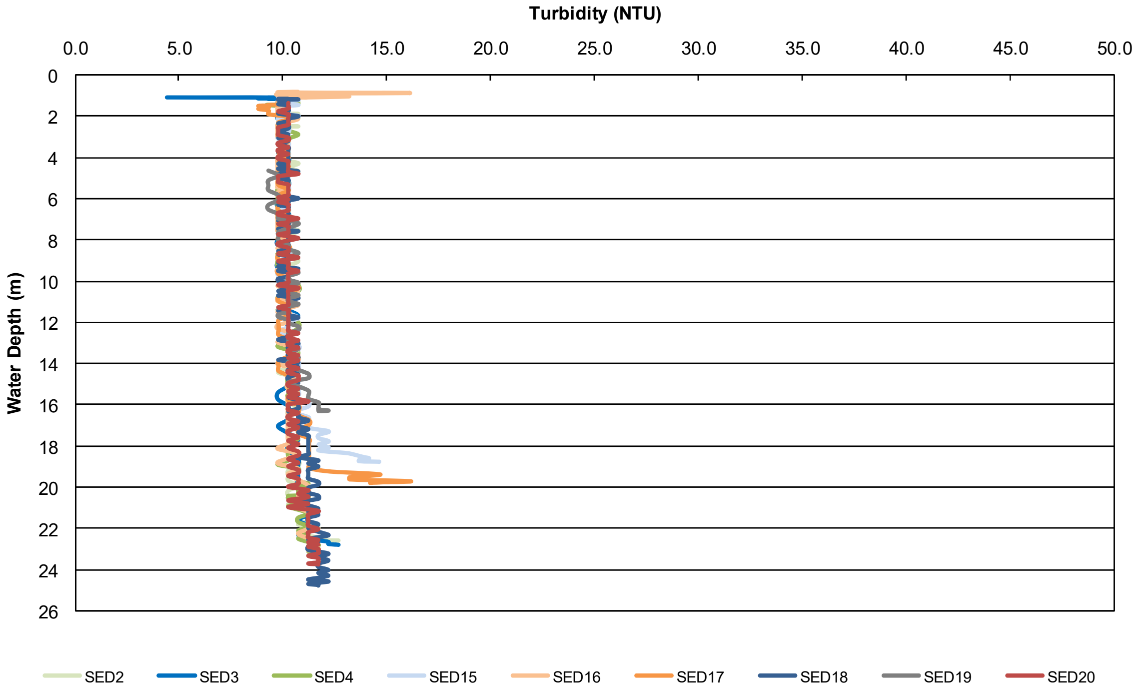


Figure 13-22: Water Column Profiles at Southern Reference Sites along the Offshore Feed Gas Pipeline System in State Waters, October 2009




Salinity (PSU)
34.7
34.8
34.9
35.0
35.1
35.2
35.3
35.4
35.5
35.6
35.7
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
SED2
SED3
SED4
SED15
SED16
SED17
SED18
SED19
SED20


Turbidity (NTU)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
SED2
SED3
SED4
SED15
SED16
SED17
SED18
SED19
SED20

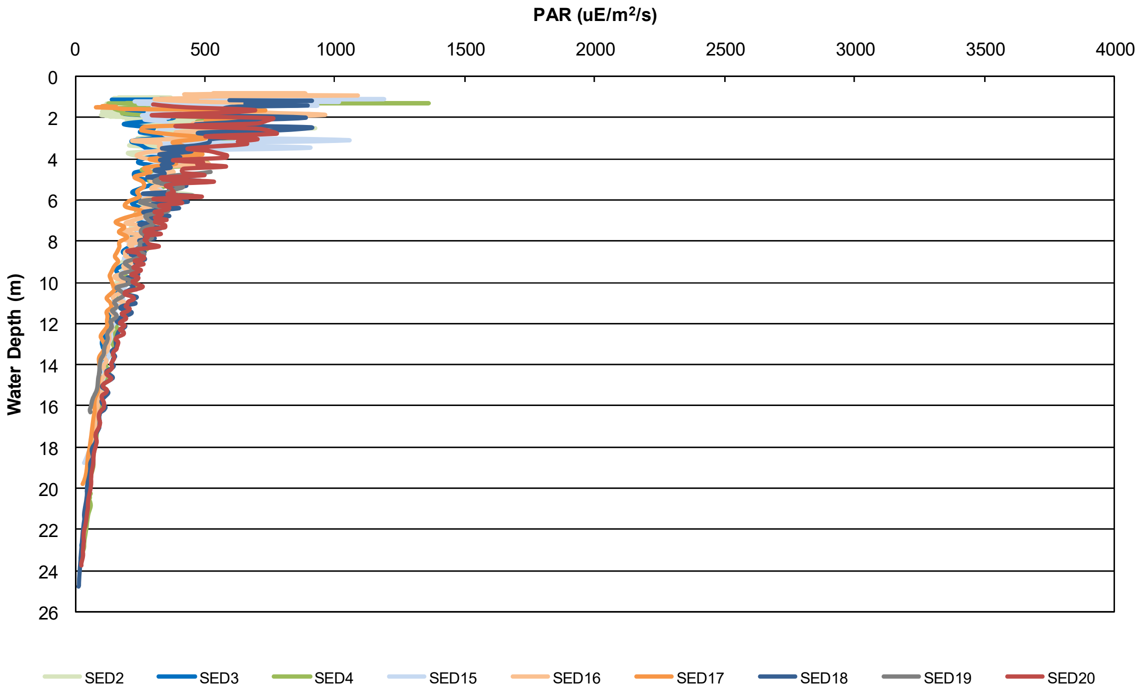


Figure 13-23: Water Column Profiles at Southern Reference Sites along the Offshore Feed Gas Pipeline System in State Waters, June 2010

In general, the water column profile data demonstrate a consistently well-mixed water column in the coastal waters off the west coast of Barrow Island, with no indication of trends in physical-chemical characteristics either along the shore or from nearshore to offshore. The profiles were indicative of an offshore area with limited influence from surface water run-off and groundwater inflow, combined with good flushing and mixing by tidal and atmospheric forcing.

Overall, there was little difference in salinity between the surface and bottom waters or over the year at any of the monitoring sites. Over the period of baseline measurements, surface temperatures varied between 22.5 °C and 26.8 °C, and bottom waters between 22.4 °C and 26.0 °C near the Offshore Feed Gas Pipeline System in State Waters and the marine component of the shore crossing. Surface waters were generally slightly warmer by 0.1–0.6 °C and occasionally by more than 1 °C. There was a clear seasonal trend, with the warmest surface and bottom waters reported in late summer and the coolest waters in winter. There was no indication of temperature stratification on any sampling occasion. Water temperatures in the open coast waters were slightly cooler than those reported at sites on the east coast (Ref. 29). Turbidity varied between 5.4 and 13.2 NTU in surface waters and 9.8 to 16.1 NTU in bottom waters. Turbidity was generally higher in bottom waters than in surface waters.

13.5 Discussion and Conclusions

The results from the baseline water quality (light and turbidity) and sediment deposition monitoring program indicate that in the west coast waters of Barrow Island, turbidity and concentrations of suspended sediments were generally low (<5 mg/L) and indicative of clear water environments. There were low levels of sediment deposition (below the limits of instrument detection) and any deposition that did occur was temporary and rapidly resuspended by waves and tidal flow.

Wave conditions at the HDD LTD logger site, which is located in an unprotected area off the west coast, are predominantly influenced by a combination of swell and tidal stage (height and flow rate), rather than localised wind-generated waves that are common at the east coast sites. The median daily Wave Height Index recorded at the HDD LTD logger site was higher in both summer and winter than the median daily Wave Height Index recorded at sites on the east coast of Barrow Island monitored as part of the Marine Baseline Program. Median daily light ($\mu E/m^2/s$) and LAC (m^{-1}) were generally lower at the HDD LTD logger site than at the deeper sites on the east coast of Barrow Island (LNG0, LNG1, and Lone Reef) in both summer and winter. Median daily turbidity (NTU) was also generally higher at the HDD LTD logger site in both summer and winter, while median daily SSC (mg/L) was only higher at LNG1 than at the HDD LTD logger site in both summer and winter.

Wave activity was important in contributing to local resuspension of sediments, resulting in elevated turbidity and SSCs. Extreme weather events, such as tropical cyclones, also had a strong influence on water quality. Short periods of elevated SSCs, reduced light levels, and elevated light attenuation as a consequence of increased turbidity in the water column, generally coincided with the passage of tropical cyclones. Seabed light levels were primarily influenced by depth and there were seasonal patterns in the daily average light levels.

Water column profiles consistently demonstrated that the water column on the west coast was well mixed, with little evidence of stratification, indicative of an offshore environment with limited influence from surface water run-off and groundwater inflow, combined with good flushing and mixing by tidal and atmospheric forcing.

14 Acronyms and Abbreviations

Table 14-1 defines the acronyms and abbreviations used in this document.

Table 14-1: Acronyms and Abbreviations

Acronym / Abbreviation	Definition
μE/m^2/s	Microeinsteins per second per square metre
μm	Micrometre. 1 μm = 10^{-6} metre = 0.000001 metre or one millionth of a metre
2π quantum sensor	A light sensor that records down-welling irradiance, or light from one hemisphere
3CCD	Three charge-coupled devices; technology that allows a camera to record red, green, and blue light on three separate signals for better video quality
ABU	Australian Business Unit
ALS	Australian Laboratory Services Environmental
ANOVA	Analysis of Variance, which is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. In its simplest form, ANOVA gives a statistical test of whether the means of several groups are all equal.
APASA	Asia-Pacific Applied Science Associates
ARI	Assessment on Referral Information (for the proposed Jansz Feed Gas Pipeline dated September 2007) as amended or supplemented from time to time.
ASSD	Accumulated Sediment Surface Density
At risk	Being at risk of Material Environmental Harm or Serious Environmental Harm and/or, for the purposes of the EPBC Act relevant listed threatened species, threatened ecological communities, and listed migratory species, at risk of Material Environmental Harm or Serious Environmental Harm.
Autocorrelation	The relationship between the values of a variable taken at certain times in the series and values of a variable taken at other times (i.e. the similarity between observations as a function of the time separation between them).
Bathymetric	Relating to measurements of the depths of oceans or lakes
Benthic	Living upon or in the seabed
Benthic Habitats	Areas of the seabed that support living organisms; examples include, limestone pavement, reefs, sand and soft sediments
Benthic Primary Producer	Photosynthesising organisms (mangroves, seagrasses, algae) or organisms that harbour photosynthetic symbionts (corals, giant clams)
Bentonite clay	Clay formed from volcanic ash, which can absorb large amounts of water and expands to many times its normal volume
Biofouling	Unwanted marine growth on vessels or marine infrastructure
Biomass	The total mass or amount of living organisms in a particular area or volume
Biota	All the plant and animal life of a particular region
Biotic	Of or relating to living organisms
BOM	Australian Bureau of Meteorology
Bombora	Raised, dome-shaped, limestone feature, >1 m high, often formed by coral of the genus *Porites*
BPPH	Benthic Primary Producer Habitat; benthic habitats that support primary producers

Acronym / Abbreviation	Definition
BR	Biggada Reef
BRUV	Baited Remote Underwater Video system
Calcarenite	Rock formed by the percolation of water through a mixture of calcareous shell fragments and quartz sand causing the dissolved lime to cement the mass together
CALM	Former Western Australian Department of Conservation and Land Management (now DPaW)
CALM Act	Western Australian *Conservation and Land Management Act 1984*
Carbon Dioxide (CO_2) Injection System	The mechanical components required to be constructed to enable the injection of reservoir carbon dioxide, including but not limited to compressors, pipelines and wells.
CDEEP	Construction Dredging Environmental Expert Panel
Clade	A group of biological taxa or species that share features inherited from a common ancestor
cm	Centimetre
cm^2	Square centimetre
CO_2	Carbon dioxide
Commonwealth Marine Waters	Zoned areas of waters of the sea, the seabed and the airspace above the waters of the sea, defined under section 24 of the EPBC Act (Cth).
Construction	Construction includes any Proposal-related (or action-related) construction and commissioning activities within the Terrestrial and Marine Disturbance Footprints, excluding investigatory works such as, but not limited to, geotechnical, geophysical, biological and cultural heritage surveys, baseline monitoring surveys and technology trials.
Coral	Marine organisms from the class Anthozoa that exist as small sea-anemone-like polyps, typically in colonies of many identical individuals. Includes ‘hard corals’ within the order Scleractinia which secrete calcium carbonate to form a hard skeleton and form reefs; and ‘Soft corals’ within the order Alcyonacea which have no hard skeleton and are not considered reef-building organisms.
Coral Definitions	*Coral Assemblages* are benthic areas (minimum 10 m^2) or raised seabed features over which the average live coral cover is equal to or greater than 10%. *The Change in coral mortality* is determined by subtracting the baseline extent of Gross coral mortality from the extent of Gross coral mortality measured on a sampling occasion. *Detectable Net Mortality* is the result of subtracting the Change in coral mortality at the Reference Site(s) from the Change in coral mortality at the Monitoring Site. *Average Net Detectable Mortality* is the result of averaging the net detectable mortality of all monitoring sites within the Zone i.e. the mean of net detectable mortality of any Zone. *Gross coral mortality* at a site is expressed as a percentage of total coral cover at the time of sampling at that monitoring location. In determining the coral loss, measurement uncertainty is to be taken into consideration.
CPCe	Coral Point Count with Excel extensions (software for the determination of coral cover from photographs)
Crustose	Forming a crust that is firmly attached to the substrate over its entire area
CSIRO	Commonwealth Scientific and Industrial Research Organisation

Acronym / Abbreviation	Definition
CTD	Conductivity-Temperature-Depth
DBCA	Western Australian Department of Biodiversity, Conservation and Attractions
DEC	Former Western Australian Department of Environment and Conservation (now DBCA)
Demersal	Living on the seabed or just above the seabed
DEW	Former Commonwealth Department of the Environment and Water (now DCCEEW)
DEWHA	Former Commonwealth Department of the Environment, Water, Heritage and the Arts (now DCCEEW)
Diurnal	Daily
DMA	Decision Making Authority
DO	Dissolved Oxygen
DoF	Former Western Australian Department of Fisheries (now DPIRD)
DomGas	Domestic Gas
Dominant	Most common (relating to the following ecological elements: macroalgae, seagrass, mangroves, non-coral benthic invertebrates and demersal fish)
Dominant Coral Species	Species with the highest relative percentage cover. Percentage cover is expressed as the proportion of total coral cover.
DoT	Western Australian Department of Transport
DCCEEW	Commonwealth Department of Climate Change, Energy, the Environment and Water
DPaW	Former Western Australian Department of Parks and Wildlife (now DBCA)
DPI	Former Western Australian Department for Planning and Infrastructure
DPIRD	Western Australian Department of Primary Industry and Resources Development
DSDG	Dredge Spoil Disposal Ground
DWER	Western Australian Department of Water and Environmental Regulation
Ebb Tide	The period between high tide and the next low tide in which the sea is receding
Ecological Element	Element listed in listed in Condition 14.2 of MS 800, Condition 12.2 of MS 769 and Condition 11.2 of EPBC Reference: 2003/1294 and 2008/4178.
EIS/ERMP	Environmental Impact Statement/Environmental Review and Management Programme (for the Proposed Gorgon Gas Development dated September 2005) as amended or supplemented from time to time.
Environmental Harm	Has the meaning given by Part 3A of the *Environmental Protection Act 1986* (WA)
EP Act	Western Australian *Environmental Protection Act 1986*
EPA	Western Australian Environmental Protection Authority
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
EPBC Reference: 2003/1294	Commonwealth Ministerial Approval (for the Gorgon Gas Development) as amended or replaced from time to time.
EPBC Reference: 2005/2184	Commonwealth Ministerial Approval (for the Jansz Feed Gas Pipeline) as amended or replaced from time to time.

Acronym / Abbreviation	Definition
EPBC Reference: 2008/4178	Commonwealth Ministerial Approval (for the Revised Gorgon Gas Development) as amended or replaced from time to time.
EPCM	Engineering, Procurement and Construction Management
ESRI	Environmental Systems Research Institute
Feed Gas Pipeline	Pipeline from the wells to the Gas Treatment Plant
Feed Gas Pipeline System	Pipelines and umbilicals from the wells to the Gas Treatment Plant
Fines	Fine particles
Flood Tide	The period between low tide and the next high tide in which the sea is rising
Foundation Project	The Gorgon Gas Development Foundation Project, as amended from time to time, which comprises: • the 'initial Gorgon Gas Development', the two-train development proposed in the Environmental Impact Statement/Environmental Review and Management Programme (EIS/ERMP) (Ref. 11) • the 'Revised and Expanded Gorgon Gas Development', the additional (third) train development proposed in the Public Environmental Review (PER) (Ref. 13) • the 'Jansz Feed Gas Pipeline', the development assessed via Assessment on Referral Information (ARI) (Ref. 14) • the 'Gorgon Gas Development Additional Support Area', the changes to the Gorgon Gas Development for an Additional Construction, Laydown and Operations Support Area described in the Assessment on Proponents Information document (Ref. 122).
Frac-out	Caused when drilling fluid pressure exceeds ground strength, typically resulting in drilling mud rupturing to the surface (ground or seabed) and collapse of the drill hole
g	Gram
GDA	Geocentric Data of Australia
GEMS	Global Environmental Modelling Systems
Geostrophic	The horizontal movement of surface water arising from a balance between the pressure gradient force and the Coriolis force
GIS	Geographic Information System
Globose	Having the shape of a sphere or ball
Gorgon Gas Development	The Gorgon Gas Development as approved under MS 800 and EPBC Reference: 2003/1294 and 2008/4178 as amended or replaced from time to time.
GPS	Global Positioning System
Ground Truth	To verify the correctness of remote sensing information by use of ancillary information such as field studies
ha	Hectare
Habitat	The area or areas in which an organism and/or assemblage of organisms lives. It includes the abiotic factors (e.g. substrate and topography) and the biotic factors.
HDD	Horizontal Directional Drilling, a trenchless installation process by which a pipeline is installed beneath obstacles or sensitive areas. It is often the preferred method for pipeline shore crossings.
Hermatypic	Hermatypic corals are corals that contain and depend upon zooxanthellae (algae) for nutrients.

Acronym / Abbreviation	Definition
HSE	Health, Safety and Environment
Hydrotest	Method whereby water is pressurised within pipes and vessels to detect leaks
IMCRA	Integrated Marine and Coastal Regionalisation of Australia
ISO	International Organization for Standardization
Isobath	A line on a chart joining places of equal depth of water; a depth contour
ITIS	Integrated Taxonomic Information System (http://www.itis.gov)
Jansz Feed Gas Pipeline	The Jansz Feed Gas Pipeline as approved in MS 769 and EPBC Reference: 2005/2184 as amended or replaced from time to time.
KJVG	Kellogg Joint Venture Gorgon
km	Kilometre
km/h	Kilometres per hour
L	Litre
LAC	Light Attenuation Coefficient
LADS	Laser Airborne Depth Sounder (used for bathymetry mapping)
Light Attenuation	The absorption and scattering of light underwater
Littoral	A shore; the zone between high tide and low tide; of, or related to the shore, especially the seashore
LNG	Liquefied Natural Gas
LTD	Light-Turbidity-Deposition
m	Metre
m/s	Metres per second
m^{-1}	Incident light absorbed per metre water depth
m^2	Square metre
Macroalgae	Benthic marine plants that are non-flowering and lack roots, stems and vascular tissue. Can be seen without the aid of a magnification; includes large seaweeds.
Macrofauna	Animals whose shortest dimension is ≥0.5 mm and can be seen without the aid of magnification; includes polychaetes, snails and amphipods
Macroinvertebrates	An invertebrate animal (an animal without a backbone [vertebral column]) large enough to be seen without the aid of magnification; includes sponges, crinoids, hydroids, sea pens, sea whips, gorgonians, snails, clams, crayfish and sea cucumbers
Mangrove	Tropical evergreen trees or shrubs with stilt-like roots and stems that grow in shallow coastal water
Marine Disturbance Footprint	The area of the seabed to be disturbed by construction or operations activities associated with the Marine Facilities listed in Condition 14.3 of MS 800 and Condition 12.3 of MS 769 and Condition 11.3 in EPBC Reference: 2003/1294 and 2008/4178 (excepting that area of the seabed to be disturbed by the generation of turbidity and sedimentation from dredging and dredge spoil disposal) and as set out in this Report.
Marine Facilities	In relation to MS 800 and EPBC Reference: 2003/1294 and 2008/4178, the Marine Facilities are the: • Materials Offloading Facility (MOF) • LNG Jetty

Acronym / Abbreviation	Definition
	• Dredge Spoil Disposal Ground • Offshore Feed Gas Pipeline System (in State Waters) and the marine component of the shore crossing • (Offshore) Domestic Gas Pipeline Condition 14.3 of MS 800 relates only to components of the Marine Facilities within State Waters (i.e. specifically the Offshore Feed Gas Pipeline System). For the purposes of MS 800 Marine Facilities also include: • Marine upgrade of the existing WAPET landing. In relation to MS 769, Marine Facilities are the Offshore Feed Gas Pipeline System and the marine component of the shore crossing.
Marine Facilities Footprint	The area of seabed associated with the physical footprint of the Marine Facilities, but excluding the area of the seabed disturbed by dredging an dredge spoil disposal, or for example, by anchoring.
Material Environmental Harm	Environmental Harm that is neither trivial nor negligible
MaxN	Maximum number of fish belonging to each species, present in the field of view of the stereo-BRUVs at any time during the footage.
MBACI	Multiple Before–After, Control–Impact statistical design.
MDF	*See* Marine Disturbance Footprint
MEG	Monoethylene glycol
Metocean	Meteorological and oceanographic conditions
mg/cm	Milligrams per centimetre
mg/L	Milligrams per litre
MGA 50, GDA 94	Map Grid of Australia Zone 50 (WA); projection based on the Geocentric Datum of Australia 1994
mL	Millilitre
mm	Millimetre
MOF	Materials Offloading Facility
Motile	Capable of movement
MS 748	Western Australian Ministerial Statement No. 748 (for the Gorgon Gas Development) as amended from time to time [superseded by MS 800].
MS 769	Western Australian Ministerial Statement No. 769 (for the Jansz Feed Gas Pipeline) as amended from time to time.
MS 800	Western Australian Ministerial Statement No. 800 (for the Gorgon Gas Development) as amended from time to time.
MS 865	Western Australian Ministerial Statement No. 865 (for the Gorgon Gas Development).
MTPA	Million Tonnes Per Annum
NATA	National Association of Testing Authorities
Neap Tide	A less than average tide occurring at the first and third quarters of the moon
Nearshore	Close to shore; or within 3 nautical miles of Barrow Island
NS	Not surveyed
NTU	Nephelometric Turbidity Unit
OBS	Optical Backscatter Sensor

Acronym / Abbreviation	Definition
OE	Operational Excellence
OEMS	Operational Excellence Management System
Operations (Gorgon Gas Development)	In relation to MS 800 and EPBC Reference: 2003/1294 and 2008/4178, for the respective LNG trains, this is the period from the date on which the Gorgon Joint Venturers issue a notice of acceptance of work under the Engineering, Procurement and Construction Management (EPCM) contract, or equivalent contract entered into in respect of that LNG train of the Gas Treatment Plant; until the date on which the Gorgon Joint Venturers commence decommissioning of that LNG train.
Operations (Jansz Feed Gas Pipeline)	In relation to MS 769, for the pipeline, this is the period from the date on which the Proponent issues a notice of acceptance of work under the Engineering, Procurement and Construction Management (EPCM) contract, or equivalent contract entered into in respect of that pipeline; until the date on which the Proponent commences decommissioning of that pipeline.
PAR	Photosynthetically Active Radiation
Pelagic	Living in the open sea rather than in coastal or inland waters
PER	Public Environmental Review for the Gorgon Gas Development Revised and Expanded Proposal dated September 2008, as amended or supplemented from time to time.
PERMANOVA	Permutational Multivariate Analysis of Variance
pH	Measure of acidity or basicity of a solution
PIO	Pilbara Offshore Marine Bioregion
PLET	Pipeline End Termination
Practicable	Practicable means reasonably practicable having regard to, among other things, local conditions and circumstances (including costs) and to the current state of technical knowledge. For the purposes of the conditions of EPBC Reference: 2003/1294 and 2008/4178 which include the term ‘practicable’, when considering whether the draft plan meets the requirements of these conditions, the Commonwealth Minister will determine what is ‘practicable’ having regard to local conditions and circumstances including but not limited to personnel safety, weather or geographical conditions, costs, environmental benefit and the current state of scientific and technical knowledge.
PSD	Particle-size Distribution
PSU	Practical Salinity Units, equivalent to parts per thousand
PTS	Pipeline Termination Structure
p-value	In statistical hypothesis testing, the probability of obtaining a result at least as extreme as the one that was actually observed, assuming that the null hypothesis is true
QA/QC	Quality Assurance/Quality Control
Quadrat	A rectangle or square measuring area used to sample living things in a given site; can vary in size
Reference Sites	Specific areas of the environment that are not at risk of being affected by the Proposal or existing developments, that can be used to determine the natural state, including natural variability, of environmental attributes such as coral health or water quality
Regionally Significant Areas	Are the regionally significant areas outside the Zones of High Impact, Moderate Impact, and Influence on the eastern margins of the Lowendal Shelf to the

Acronym / Abbreviation	Definition
	southern boundary of the Montebello Islands Marine Park, and Dugong Reef, Batman Reef, and Southern Barrow Shoals
Root Mean Square Water Depth	Shows the variation in water depth within a time and is an indication of wave height. Calculated as follows: $D_{rms} = \sqrt{\sum_{n=1}^{10} (D_n - \overline{D})^2 / n}$ where D_n is the *nth* of10 sequential readings and $\overline{D}$ is the mean water depth of the *n* readings.
s	Second (time)
Scleractinian	Corals that have a hard limestone skeleton and belong to the order Scleractinia
SE	Standard Error
SEACAT Profiler	Seabird Electronics SBE19 SEACAT Profiler
Seagrass	Benthic marine plants which have roots, stems, leaves and inconspicuous flowers with fruits and seeds much like terrestrial flowering plants. Unrelated to seaweed.
Serious Environmental Harm	Environmental harm that is: irreversible, of a high impact or on a wide scale; or significant or in an area of high conservation value or special significance and is neither trivial nor negligible.
Sessile	Permanently attached directly to the substrate by its base (i.e. immobile), without a stalk or stem
SEWPaC	Former Commonwealth Department of Sustainability, Environment, Water, Population and Communities (now DCCEEW)
SIMPER	Similarity Percentages
sp. (plural: spp.)	Species
Spoil Disposal Ground	The area where dredged and excavation material is to be disposed of at sea
Spring Tide	The highest tides in a lunar month, occurring near new and full moons
SSC	Suspended Sediment Concentration
State Waters	The marine environment within three nautical miles of the coast of Barrow Island or the mainland of Western Australia
Stressor	An environmental condition or influence that stresses (i.e. causes stress for) an organism
Subdominant Coral Species	Species—excluding Dominant Coral Species—that have greater than or equal to 5% cover. Percentage cover is expressed as the proportion of total coral cover.
Substrate	The surface a plant or animal lives upon. The substrate can include biotic or abiotic materials. For example, encrusting algae that lives on a rock can be substrate for another animal that lives above the algae on the rock.
Super-span	A longer free span than is normally dealt with in pipeline design that behaves more like a cable than a ‘traditional’ beam
Surficial	Of or pertaining to the surface
Taxon (plural: taxa)	A taxon (plural taxa), or taxonomic unit, is a name designating an organism or a group of organisms.
TBA	To be advised

Acronym / Abbreviation	Definition
TC	Tropical Cyclone
Temporal	Relating to, or limited by, time
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
Transect	The path along which a researcher moves, counts and records observations
TSS	Total Suspended Solids
t-test	A statistical test to determine whether the difference between two sample means is statistically significant
Turbidity	The cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality.
Umbilicals	Connections between topside equipment and subsea equipment
Vessel	Craft of any type operating in the marine environment including hydrofoil boats, air-cushion vehicles, submersibles, floating craft and fixed or floating platforms. Also includes seaplanes when present on and in the water.
WA	Western Australia (or Western Australian)
WAPET	West Australian Petroleum Pty Ltd.
WAPET Landing	Proper name referring to the site of the barge landing existing on the east coast of Barrow Island prior to the date of MS 800.
Waters Surrounding Barrow Island	Refers to the waters of the Barrow Island Marine Park and Barrow Island Marine Management Area (approximately 4169 ha and 114 693 ha respectively) as well as the port of Barrow Island representing the Pilbara Offshore (PIO) Marine Bioregion which is dominated by tropical species that are biologically connected to more northern areas by the Leeuwin Current and the Indonesian Throughflow, resulting in a diverse marine biota is typical of the Indo–West Pacific flora and fauna.
West Coast Marine Facilities	In relation to MS 800 and EPBC Reference: 2003/1294 and 2008/4178, the West Coast Marine Facilities are the: • Offshore Feed Gas Pipeline System (in State Waters) and the marine component of the shore crossing Condition 14.3 of MS 800 relates only to components of the Marine Facilities within State Waters (i.e. specifically the Offshore Feed Gas Pipeline System). In relation to MS 769, Marine Facilities are the • Offshore Feed Gas Pipeline System and the marine component of the shore crossing.
WST	Western Standard Time (Australia)
ZoHI	*See* Zone of High Impact
ZoI	*See* Zone of Influence
ZoMI	*See* Zone of Moderate Impact
Zone of High Impact	An area where long-term impacts to corals are predicted to result directly from disturbance during Horizontal Directional Drilling, dredging or construction of infrastructure on the seabed and burial during dredge spoil disposal, or indirectly from smothering due to elevated sedimentation and/or from deterioration in water quality. As set out in Schedule 1 of MS 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.
Zone of Influence	This area is predicted to be indirectly influenced by dredging and spoil disposal activities (e.g. marginal increases in turbidity and sedimentation), but at levels

Acronym / Abbreviation	Definition
	that will have no measurable impact on corals. As set out in Schedule 1 of MS 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.
Zone of Moderate Impact	An area where short-term moderate impacts (e.g. some partial mortality of corals) is predicted to result indirectly from Horizontal Directional Drilling, dredging, dredge spoil disposal, due to deterioration in water quality and/or an increase in sedimentation rates. Moderate impacts are likely to include some partial mortalities among fast growing, more sensitive coral species (e.g. *Acropora* spp.) but less, if any, mortality of longer living, generally more resilient species (e.g. *Porites* spp., *Turbinaria* spp.). As set out in Schedule 1 of MS 800 and Schedule 5 of EPBC Reference: 2003/1294 and 2008/4178.

15 References

The following documentation is either directly referenced in this document or is a recommended source of background information.

Table 15-1: References

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Appendix A Identification and Risk Assessment of Marine Matters of National Environmental Significance (NES)

Appendix B Barrow Island Habitat Classification Scheme

Physical Factors		Biological Factors			Biological Factors	
Relief	**Substrate Type**	**Dominant Ecological Element**	**Dominant Taxa or physical descriptor**	**Cover**	**Sub-Dominant Taxa or physical descriptor**	**Cover**
R0 Flat/micro-ripples (<0.5m height) R1 Gently sloping (5 - 35 deg) R2 Steeply sloping (35 - 70 deg) R3 Vertical wall (70-90 deg) and caves/overhangs R4 Macro-ripples (>0.5m height)	S01 Sand S02 Silt S03 Mud S04 Gravel S05 Rubble S06 Consolidated rubble S07 Limestone pavement S08 Limestone pavement w/ shallow sand veneer S09 Boulders S10 Reef - low profile S11 Reef - high profile S12 Sand with Shell fragments S13 Silt with Shell fragments	H01 **Macroalgae**	*Sargassum* *Padina* *Caulerpa* *Cladophora* Mixed Rhodophyta Mixed Chlorophyta Mixed Phaeophyceae Mixed turfing algae Unidentified Rhodopyhta Unidentified Chlorophyta Unidentified Phaeophyceae Unidentified turfing algae Unidentified macroalgae	C0 Unknown density C1 Sparse (5-25%) C2 Medium (25-75%) C3 Dense (> 75%)	*Sargassum* *Padina* *Caulerpa* *Cladophora* Mixed Rhodopyhta Mixed Chlorophyta Mixed Phaeophyceae Mixed turfing algae Unidentified Rhodopyhta Unidentified Chlorophyta Unidentified Phaeophyceae Unidentified turfing algae Unidentified macroalgae	C0 Unknown density C1 Sparse (5-25%) C2 Medium (25-75%) C3 Dense (> 75%)
		H02 **Seagrass**	*Halophila* *Heterzostera* *Syringodium* *Thallasodendron* Unidentified seagrass	C0 Unknown density C1 Sparse (5-25%) C2 Medium (25-75%) C3 Dense (> 75%)	*Halophila* *Heterzostera* *Syringodium* *Thallasodendron* Unidentified seagrass	C0 Unknown density C1 Sparse (5-25%) C2 Medium (25-75%) C3 Dense (> 75%)
		H03 **Non-coral benthic invertebrates**	Crinoids (sea, brittle and feather stars) Sea pens, whips and fans Gorgonians Sea Urchins Sponges Ascidians Holothurians Bivalaves Bryozoans	Present	Crinoids (sea stars, brittle and feather stars) Sea pens, whips and fans Gorgonians Sea Urchins Sponges Ascidians Holothurians Bivalaves Bryozoans	Present
		H04 **Coral - hard and soft**	A *Acropora* P Coral bombora - *Porites* N Coral bombora - non-*Porites* I Bombora - invert/macroalgae dominated M Mixed coral community	C2 Medium (10-50%) C3 Dense (51-75%) CV Very Dense (>75%)	*Acropora* Coral bombora - *Porites* Coral bombora - non-*Porites* Bombora - invert/macroalgae dominated Mixed coral community	C0 Unknown density C1 Sparse (<10%)
		H05 **Mangroves**	*Avicennia* *Rhizophora* *Ceriops* *Brugeiera* *Aegialitis* *Aegiceras* *Acanthus* Unidentified mangrove	Present	*Avicennia* *Rhizophora* *Ceriops* *Brugeiera* *Aegialitis* *Aegiceras* *Acanthus* Unidentified mangrove	Present
		H06 **Unvegetated**	Undisturbed flat Undisturbed micro-ripples (<0.5m height) Bioturbated (mounds and burrows) Drift macroalgae Drift seagrass	C0 Unknown density C1 Sparse (5-25%) C2 Medium (25-75%) C3 Dense (> 75%) C4 Bare	Undisturbed flat Undisturbed micro-ripples (<0.5m height) Bioturbated (mounds and burrows) Drift macroalgae Drift seagrass	C0 Unknown density C1 Sparse (5-25%) C2 Medium (25-75%) C3 Dense (> 75%) C4 Bare

Appendix C Baseline Fish Survey

Appendix D Interactive Excel and ArcGIS Demersal Fish Mapping

Please refer to the attached CD.

Appendix E Procedures for Calibration of LTD Loggers and Outcomes of Calibrations for the Gorgon Marine Baseline Program

(based on information provided by Dr James Whitney, James Cook University, Queensland)

Pre-deployment Calibration

Prior to deployment in the field, each LTD logger was calibrated against a set of plastic target optical standards that were developed in the James Cook University (JCU) laboratory. These standards are specific to the JCU instruments and allow precise comparison of the output of different instruments. In addition, the turbidity sensors were calibrated to determine the zero reading. Seawater can be far cleaner than tap water and therefore a zero reading was taken in seawater as well as in a salt-water swimming pool.

Quality Control and Conversion of Data into Engineering Units

Upon return from each field trip the LTD logger data were sent to JCU for conversion, analysis and preliminary interpretation. The instrument output readings were visually verified for accuracy and erroneous data, including that caused by fouling, were removed. The data were then converted to engineering units via site-specific algorithms to give values of SSC in mg/L, Accumulated Sediment Surface Density (ASSD) in mg/cm^2 and light ($\mu E/m^2/s$).

Converting NTU to SSC

The output of turbidity sensors is highly sensitive to variations in grain-size and therefore conversion of turbidity readings into SSC is suspension- and site-specific. Turbidity readings were converted to estimates of SSC through calibration of the instrument response to water samples with measured concentrations of SSC.

The calibration procedure was repeated for each site and involved placing an instrument in a large container (50 L or greater) with black sides and recording the output on a computer attached to the logger. Seawater was used to fill the container and sediment from the study site was added to the container and stirred with a paddle connected to a slowly rotating electric drill. Water samples were taken and analysed for total suspended solids (dry mass) using standard laboratory techniques. Approximately six different concentrations of sediment are normally needed to give a good calibration with an r^2 correlation >0.95.

The primary error normally associated with this calibration is that the sediment taken from the bottom sample in the field may not be representative of the sediment in suspension. This may cause a factor of two error in the calibration.

The results of the calibration for each site are tabulated below.

Table AppE.1: Calibration Equations to NTU values to SSC

Site Name	Calibration Equation
AHC	SSC = 3.26 x NTU
ANT	SSC = 1.50 x NTU

Site Name	Calibration Equation
BAT	SSC = 1.79 x NTU
BIG	SSC = 1.90 x NTU
DUG	SSC = 2.08 x NTU
HDD	SSC = 1.94 x NTU
LONE	SSC = 2.31 x NTU
LOW	SSC = 1.58 x NTU
LNG0	SCC = 0.93 x NTU
LNG1	SSC = 2.72 x NTU
LNG2	SSC = 1.86 x NTU
LNG3	SSC = 2.30 x NTU
MOF1	SSC = 1.22 x NTU
MOF1-S	SSC = 1.22 x NTU
MOF2	SSC = 0.80 x NTU
MOF3	SSC = 1.94 x NTU
SBS	SSC = 1.62 x NTU

Typically NTU values need to be multiplied by a factor of between 1 and 4 to produce reasonable SSC results. Results collected to date indicate that the relationships at most sites are relatively similar and it is therefore proposed to use an average value for the conversion of NTU to SSC that can be applied across all sites. During dredging and spoil disposal activities, if the instruments are measuring the effect of dredged material on NTU, it is anticipated the relationship between NTU and SSC produced by the dredged material at all sites should be similar, as the bulk of the material in the water column is likely to be dredged material.

Calculating Accumulated Sediment Surface Density

The deposition sensors were calibrated to the sediment found at each site to give measurements in units of mg/cm^2 using the methodology outlined in Ridd *et al.* (2001) and Thomas *et al.* (2003) and summarised below.

A deposition sensor was placed in a fall tower which consisted of a large acrylic cylinder filled with water. An electronic mass balance was situated at the top of the tower and connected to a weighing pan near the bottom of the cylinder. The scale recordings were recorded on a computer to allow continuous readings to be taken. The OBS sensor was placed in the bottom of the tower such that the sensor's optical aperture was just below a specially cut hole in the pan, wide enough to allow the wiper to activate without touching the pan.

Sediment (from a monitoring site) was introduced to the fall tower by mixing it with water and pouring it gently into the top of the fall tower. Measurements from the OBS sensor and the mass balance were simultaneously recorded. Typically, a calibration run takes a few hours to complete, depending upon the grain size of the sediment. Although each individual instrument has a different calibration curve, the basic form of the curves are similar for all instruments and the curves are repeatable (SD <5%) with the same sediment type.

Using the calibration curves obtained by the laboratory experiments, the amount accumulated over a given area is expressed in accumulated surface density (in mg/cm^2).

Converting pressure data to depth and RMS water depth

All pressure sensors were calibrated by JCU against a pressure gauge and the pressure readings were converted into water depth using a calibration curve. Average water depth and Root Mean Square (RMS) water depth were calculated to provide a measure of tidal fluctuation and an indication wave height. During each sampling event (every 10 minutes), the logger measured a burst of samples (5000) over a 100 second period. From these samples average water depth and Root Mean Square (RMS) water depth were calculated. Change in the average water depth over consecutive times was used to measure the tidal fluctuation. The RMS water depth shows the variation in water depth within a time and is therefore an indication of wave height.

RMS water depth, D_{rms} was calculated as follows:

$$D_{rms} = \sqrt{\sum_{n=1}^{10} (D_n - \overline{D})^2 / n}$$

where D_n is the n^{th} of the 10 readings and $\overline{D}$ is the mean water depth of the n readings.

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Appendix F Pilot Study – Assessment of Light Attenuation in the Water Column Around Barrow Island

(RPS, Perth, Western Australia)

Introduction

Measuring light attenuation in the sea ideally involves measuring light across the entire vertical profile of the water column to determine how quickly light decreases as a continuous function of depth. As an approximation of this, simultaneous measurement of light from just two (identical) in-water sensors at fixed positions is often used instead of many measurements across the entire water column. Light sensors are positioned at least 2 m apart (vertical distance) and the Light Attenuation Coefficient (LAC) calculated as a function of the difference in light recorded over the known (constant) vertical separation distance (Environmental Protection Authority [EPA] 2005). A schematic representation of how paired-sensor monitoring methods might be applied to the sites around Barrow Island is presented in Figure AppF.1.

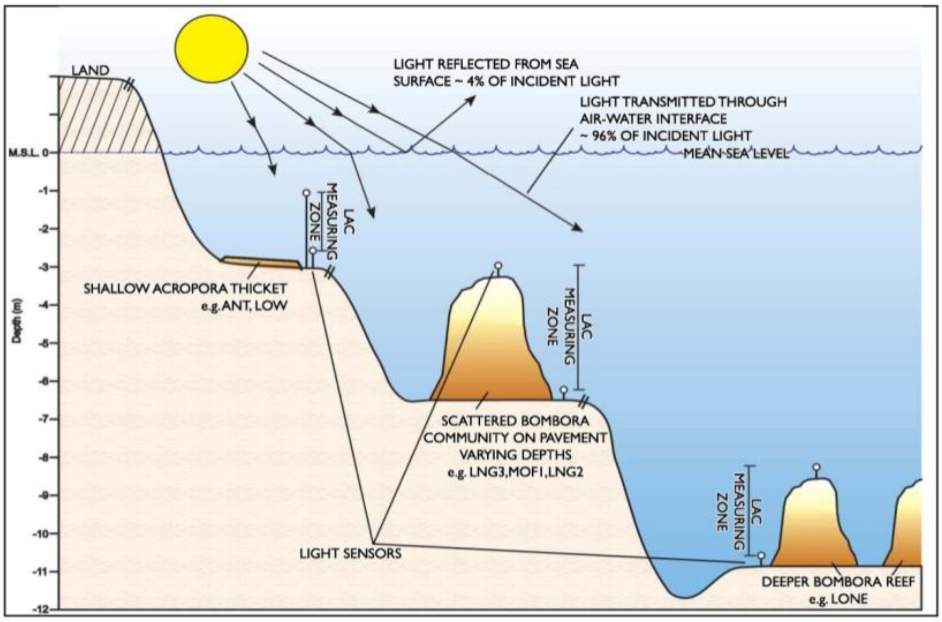

Figure AppF.1: Diagrammatic representation of the measurement of light and light attenuation using paired-sensor methods at sites around Barrow Island

Note: *Schematic representation only. Depths are indicative as are the relative heights of coral bombora and pickets holding the light sensors.*

Whilst widely used and an accepted practice in environmental monitoring, there are actually a number of issues associated with using paired-sensor methods to calculate LAC, particularly in shallow water sites like many of those chosen for water quality monitoring at Barrow Island. These are detailed below, but among the key issues is that a minimum separation distance between the sensors is required (usually 2 m) and both sensors need to remain submerged at all times; which restricts application to sites which are deeper than 2 m at extreme low tides. In reality, the practical range of this technique is actually depths much greater than 2 m, because near-surface equipment can present a navigation hazard to vessels. Furthermore, the potential variation in the light field and light attenuation is greatest near the water surface, so if the upper sensor is very near the surface this can interfere with the accuracy of light readings and hence the light attenuation calculations (see below).

To overcome these constraints, it was proposed to measure light and light attenuation at water quality monitoring sites around Barrow Island using a combination of a terrestrial light sensor on the island and (near bottom) underwater light sensors at each site (RPS 2009). The terrestrial light sensor was used to approximate the light falling on the sea-surface at each site and a correction factor was applied to account for the reflection of light at the air-water interface. To demonstrate that this method would provide reliable LAC estimates, a pilot study was conducted to compare light attenuation data obtained using the more commonly applied paired-sensor method with the above-water and in-water sensor method proposed by RPS (RPS 2009).

This report presents a) a summary of the potential issues associated with using paired- sensor methods at Barrow Island; b) the methodology of measuring light attenuation at monitoring sites around Barrow Island using above-water and in-water sensors; and c) the results of the pilot study comparing simultaneous measurements from the paired-sensor method with those from the above-water and in-water sensor method.

Paired-sensor LAC Monitoring Techniques – Constraints and Potential Inaccuracies at Barrow Island

As above, standard techniques for measuring light attenuation often involve measuring down-welling irradiance at two fixed points in the water column. LAC is then calculated as a function of the difference in light between the points which are a known distance apart (EPA 2005). As the measuring points are fixed, the vertical separation distance only needs to be measured once and the LAC between these points is generally assumed to not be affected by variation in water height above the sensors (e.g. due to tides). However, the effect of fluctuating water levels (i.e. from tide and to a lesser extent atmospheric conditions) can nonetheless actually introduce substantial variability into the measurement of light and light attenuation, especially at shallow locations. In particular, variability due to near-surface effects from surface waves and the variable attenuation of light with depth can both affect measurements, especially where the upper sensor is near the surface. In addition, depth constraints at shallow sites may also affect the accuracy of measurements. These factors are described in detail below.

Near-surface Effects and Depth Constraints

The use of near-surface light sensors to measure downwelling irradiance has been extensively used for calibration of satellite ocean colour sensors (Mueller 2003). However, experience has demonstrated that, due to downwelling irradiance fluctuations associated with the focusing and defocusing of light by surface waves (lens effects), these measurements are far noisier than irradiance measurements taken from above the surface (Zaneveld *et al.* 2001). Reliable readings are difficult to make shallower than 2 m and data associated with this zone generally requires some form of smoothing or averaging prior to use (Mueller 2003). The magnitude of this effect also depends on the measurement period of the light sensor e.g. a longer measurement period has the effect of smoothing the data. Shadow effects are also difficult to avoid when using near-surface sensors deployed from buoys or other solid structures. Thus, the upper sensor in a two sensor system should not be placed too near the water surface.

It is generally accepted that measurements of light attenuation using paired-sensor methods should incorporate a minimum vertical separation of 2 m between the sensors (EPA 2005), although some suggest that a separation of at least 4 m is needed (Smith and Baker 1984, 1986, cited in Mueller 2003). The minimum water depth (to the seabed at spring low tide) at the marine monitoring sites around Barrow Island (not including BR) range from less than 1 m (LOW) to approximately 8 m (LONE), with the majority of sites having a minimum depth of less than 5 m. Thus, due to the shallow nature of many of the monitoring sites, it would be difficult to achieve sufficient separation distance (2 m) between subsurface light sensors to allow accurate measurement of light attenuation. Even where this was possible, at some sites the near-surface sensor would be periodically (if not always) in the zone where strong light fluctuations are experienced from surface waves (as above). At some sites both the separation between the two sensors would have to be less than 2 m and the upper sensor would still be close enough to the surface to be influenced periodically by near-surface effects. Further, the use of near-surface sensors is logistically difficult in sensitive environments as solid or floating structures are required where the relief of the seabed and natural structures do not provide sufficient vertical separation distance between monitoring points.

Variable Attenuation of Light with Depth

Different wavelength bands of light behave and interact differently in pure seawater. For example, infra-red light is strongly absorbed by water molecules in the surface 1 m of water such that all of the energy entering the sea from infra-red is absorbed in the very thin surface layer (Wozniak 2007). The inherent optical properties of seawater are also dependent on the relative composition of dissolved and suspended constituents, plus factors like gas bubbles and turbulence. Typically, bluish-green light penetrates furthest in optically clear oceanic waters as red light is absorbed strongly in the first few metres of the water column, but greenish-yellow light is the most penetrating in seawater containing large amounts of organic substances (Kirk 1994; Wozniak 2007).

The complex and variable interaction of water and its constituents with light results in inconsistencies in the attenuation of light through the water column, with the greatest variability occurring within the first few metres (Kirk 1994; Dierssen and Smith 1996). Due to the differing depths of the monitoring sites, the relative influence of the higher light attenuation in surface waters on the overall light attenuation value will be different at each monitoring site. These effects will also vary through time as a result of the moderately-large tidal variations experienced at Barrow Island (>3 m) and the shallow depths of many of the monitoring sites, meaning that ‘fixed’ sensor points are essentially changing their relative location within the water column due to tide. Because of this, the inherent variability within the light attenuation measurement zone will change with the tide height and throughout the tidal cycle, with the extent of change dependent on water depth (Figure AppF.2). Other than their periodicity, such changes will be indistinguishable from other potential changes to light or light attenuation that might have occurred above the uppermost sensor, such as surface slicks/plumes, shallow clines and atmospheric effects (e.g. cloud).

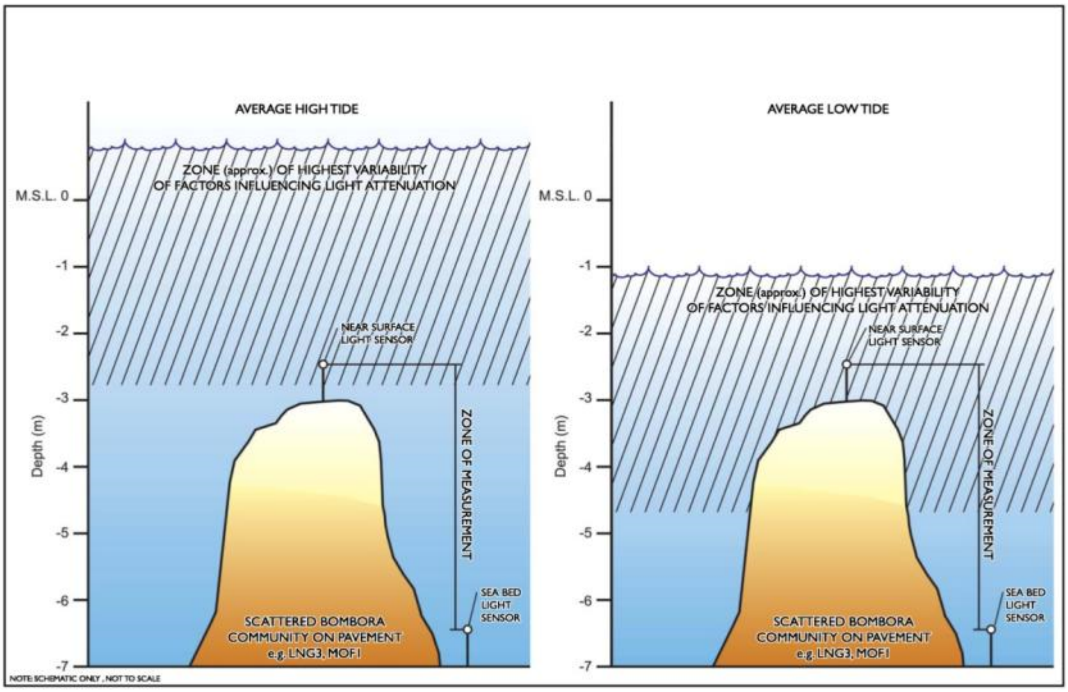

Figure AppF.2: Diagrammatic representation of how the relative zone of measurement can fluctuate throughout the tidal cycle using traditional light attenuation monitoring techniques

Note: Schematic representation only. Depths are indicative as are the relative heights of coral bombora and pickets holding the light sensors.

Proposed Methodology

RPS (2009) proposed measuring light and light attenuation at marine monitoring sites around Barrow Island using a combination of an above-water light sensor (the terrestrial light logger) located on the island and in-water light sensors at each site. The terrestrial light logger is used to approximate the amount of light falling on the sea-surface at each monitoring site and a correction factor applied to account for the proportion of light that would be reflected at the air-water interface. This corrected value is therefore an approximation of the irradiance at the upper boundary of the water column i.e. immediately below the air-water interface. Light at the seabed is measured using an underwater light sensor (see Cooper *et al.* 2008). The water depth at the seabed sensor is measured continuously and therefore the effective vertical separation distance between the two measurement points is known. The LAC can then be calculated according to standard methods.

One potential concern about these methods is that the terrestrial light logger cannot measure the light directly above the monitoring sites coincidently with the subsurface loggers; thus a cloud positioned over a monitoring site might not be accounted for in the light measurement at the terrestrial site, which may be cloudless at the same time. While this is true for individual measurements, the calculations of LAC will use the average of multiple light measurements taken between 10:00 and 14:00 Western Standard Time (WST) each day. Thus any localised effects such as passing clouds over specific sites would be expected to be averaged out and be equal among sites over that four hour period.

A second potential concern might be that the correction factor to account for reflectance at the air-water interface does not replicate reality, so the estimate of the amount of light entering the water column is not well estimated by the terrestrial measurements. When atmospheric light reaches the air-water interface it is either reflected back to the atmosphere or it passes through the interface, undergoing refraction. The amount of light that is transmitted across the interface, however, is primarily determined by the angle of incidence of the sun (Kirk 1994). Atmospheric conditions, such as the relative contribution of (diffuse) skylight and (direct) sunlight (e.g. cloudiness, haze) and roughening of the sea-surface created by wind, play only a minor role (Kirk 1994; Mueller 2003). Similarly, whitecaps from waves have only a small effect on the proportion of light reflected to the atmosphere (Kirk 1994).

The proportion of incident light which is reflected by a flat water surface increases from 2% for vertically incident (overhead) light towards 100% for grazing light i.e. light that is horizontally incident. Reflectance remains low, however, increasing only slowly up to zenith angles (angle of incidence from the vertical) of 50°, but rises rapidly thereafter (Kirk 1994). For this reason LAC is generally calculated from measurements gathered in the middle of the day, when the zenith angle is low and not during the hours close to sunrise and sunset (two hours from sunrise or two hours before sunset; see EPA 2005); this restriction is similarly applied in the proposed above-water and in-water sensor method.

While roughening of the sea surface by wind can increase the transmission of light through the interface at low solar elevations (low angle of incidence), this effect is very limited during the midday period when the solar elevation is high (Kirk 1994; Dierssen and Smith 1996). The influence of wind roughening of the seas surface on transmittance also varies depending on atmospheric conditions, particularly the ratio of sunlight to skylight, such that relatively more light is transmitted under overcast conditions. However, under normal daily fluctuations in atmospheric conditions this further influence generally amounts to <1% at solar elevations <70° (Baker and Smith 1990). Similarly, white caps on the surface can increase the reflectance of the water by up to 0.25% at a wind speed of 36 km/h (≈19.5 knots) and up to 3% at wind speeds of 90 km/h (>50 knots) (Kirk 1994).

Thus, aside from solar angle effects, the cumulative potential effect on the transmission of light through the air-water interface through other factors is minimal and typically amounts to less than a few percent variation. Typical mean reflectance at the sea surface described in the literature ranges from 3-6% (Morel and Mueller 2003; Mueller and Morel 2003; Smith and Baker 1986; Baker and Smith 1990), with 4-5% used in previous studies to calculate irradiance below the interface (Dierssen and Smith 1996; Cooper *et al.* 2008). For this reason, above-water measurements have been used previously to estimate the irradiance immediately below the air-water interface (e.g. Dierssen and Smith 1996).

Similar to previous studies (Dierssen and Smith 1996), a constant transmittance of 96% will be used here. A schematic of the above-water and in-water sensor method monitoring approach proposed by RPS (2009) is depicted in Figure AppF.3.

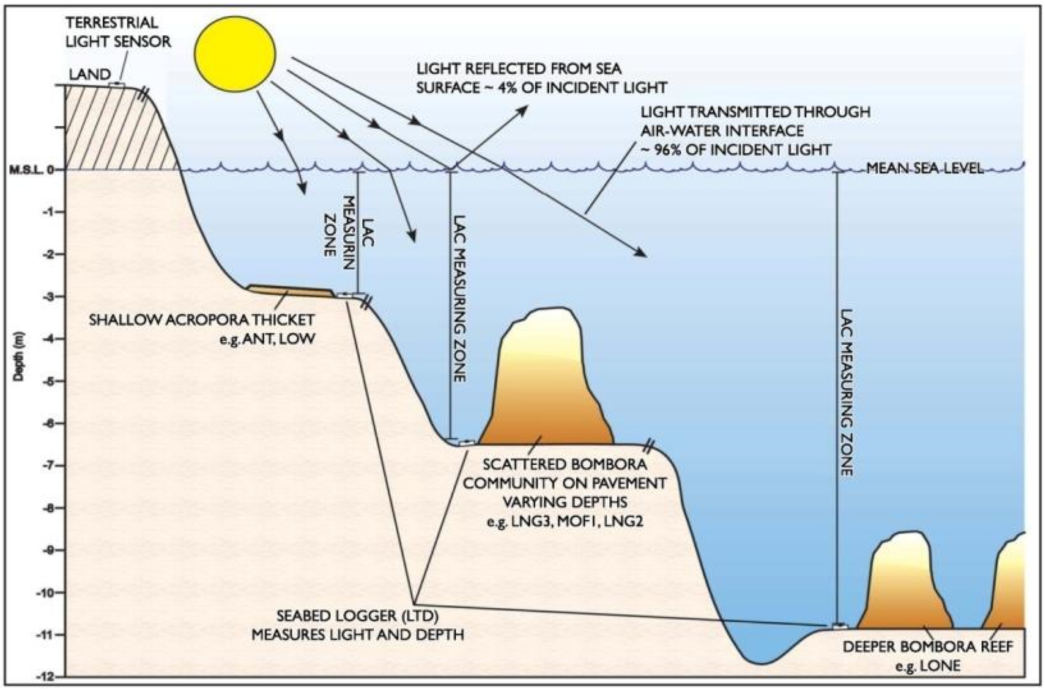

Figure AppF.3: Diagrammatic representation of the measurement of light and light attenuation

Note: Schematic representation only. Depths are indicative as are the relative heights of coral bombora.

Methods – Pilot Study

Incident Irradiance at the Sea Surface

Irradiance is generally described as the radiant flux per unit area through that point from all directions in the hemisphere above the surface i.e. all light received at a point from any direction above that point.

A terrestrial light logger, consisting of a Licor LI-192 2π PAR sensor attached to a Licor LI-1400 data logger, was installed at the Chevron Camp on the east coast of Barrow Island to measure the irradiance incident at the sea-surface in the Barrow Island area (Figure AppF.4; Figure AppF.5). By design, a 2π sensor only records downward irradiance and therefore light reflected upwards from surfaces (such as the ground) below the sensor is not captured.

The sensor measured the incident irradiance in a burst of samples once every minute and averaged the readings over a 15-minute logging interval. The data was used to represent the average incident light falling on the sea-surface at MOF1, approximately 4.5 km away, during that time period. Measurements recorded on a total of 43 days over two periods, 9/9/08–7/10/08 and 6/12/08–19/12/08, were used for the pilot study.

Figure AppF.4: Terrestrial light logger

Measurement of In-water Light

In-water measurements were recorded at two depths at the MOF1 site (light sensors MOF1 and MOF1-S; Figure 4.1). The light sensor at the seabed at MOF1 was approximately 6.4 m below mean sea level, whilst the light sensor at MOF1-S (342030E, 7698750N) was temporarily deployed on top of a large bombora located approximately 70 m from the MOF1 light sensor, at a depth of approximately 3.10 m below mean sea level (Figure AppF.5).

Light was measured using light sensors incorporated into a light, turbidity, deposition (LTD) and pressure logger manufactured by PortMap (School of Maths, Physics and Information Technology) at James Cook University, Townsville (Mk5 series, JCU). The JCU loggers measure light by an upward-orientated 2π quantum sensor. The measurements recorded by the sensor are averaged over a burst of samples taken over a 1 s second period every 10 minutes and the data logged internally. The sensor is automatically wiped at two-hourly intervals to keep it free of biofouling and routine maintenance of the logger unit and download of the data occurred twice during the monitoring periods. The sensors are calibrated against a portable Licor LI-192 underwater light sensor prior to distribution from JCU.

Data recovered from periods coincident with the terrestrial light logger were used for the pilot study.

Figure AppF.5: LTD logger deployed on a large bombora at MOF1-S, approximately 70 m from the LTD logger at the seabed at MOF1

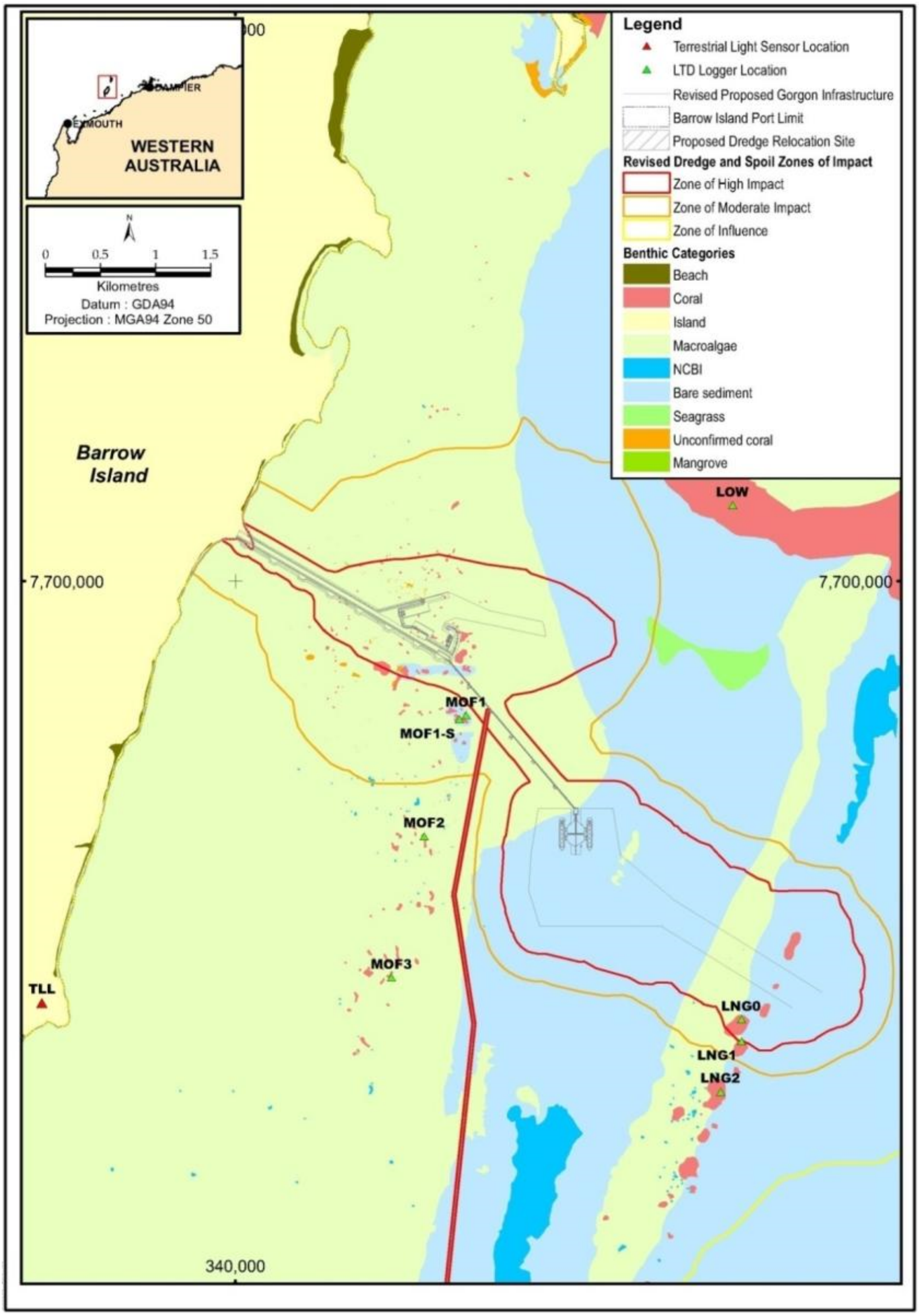

Figure AppF.6: Location of above-water (TLL) and in-water (MOF1, MOF1-S) light sensors

Calculation of Light Attenuation Coefficient

The LAC was calculated separately for data recorded by the JCU loggers at MOF1 and MOF1-S (in-water to in-water) and for the terrestrial light logger and the JCU logger at MOF1 (above-water to in-water). To ensure a consistent period of measurement throughout the year, only data collected in the period 10:00–14:00 WST (the 'midday period') was used in the calculation of LAC.

Above-water to In-water Logger

The daily mean midday surface irradiance value was obtained by averaging all measurements from the terrestrial PAR sensor for the midday period. This daily mean was then multiplied by a factor of 0.96 to estimate the irradiance immediately below the air-water interface (surface) at MOF1. Similarly, the daily mean irradiance recorded by at the seabed at MOF1 was calculated by averaging all measurements recorded by the JCU logger for the midday period.

To account for the fluctuating water height and therefore effective vertical separation distance between the two measurement points, a daily average depth for the midday period was calculated from the pressure data obtained by the JCU logger.

The daily LAC for each monitoring site was then calculated according to the following equation:

$$LAC = [(\mathrm{Log}_e \text{ average light at seabed} - \mathrm{Log}_e \text{ average light at surface}) \div \text{average water depth}]$$

To confirm that the temporal resolution (4 hour average) provided sufficient precision, the LAC was also calculated at a 0.5 hour time resolution on a subset of data. The same methods were used to calculate LAC for each half-hour period in the midday period and these values were averaged to provide the daily LAC. The daily values of LAC varied at the third decimal place between the two time resolutions, indicating that averaging the light and water depth across the four hour midday period provided sufficient precision for LAC calculations.

Correlations between the daily average datasets were examined using SYSTAT v12. Pearson correlation coefficients were calculated, with p-values based on Bartlett chi-square statistic (1 d.f.). Each test period was considered as a separate experiment for these analyses.

Results and Discussion

There were significant, strong positive correlations between the datasets captured by the different methods, with the first test period producing a correlation of $r = 0.88$ ($p < 0.001$) and the second period $r = 0.91$ ($p<0.001$). The LAC calculated from the above-water and in-water measurements (MOF1 TERR-LTD) were generally higher than the LAC calculated from measurements by the two in-water loggers (MOF1 LTD-LTD) during both periods (Figure AppF.7; Figure AppF.8). This probably reflects the fact that the above-water to in-water measurement method captures the light attenuation over the entire water column, including the near-surface zone where higher attenuation of light can occur. More importantly, both methods show the same temporal trends (which are presumably responses to changes in water clarity), demonstrating that the variation in light attenuation is adequately captured by the above-water to in-water method and that the results are comparable to traditional methods.

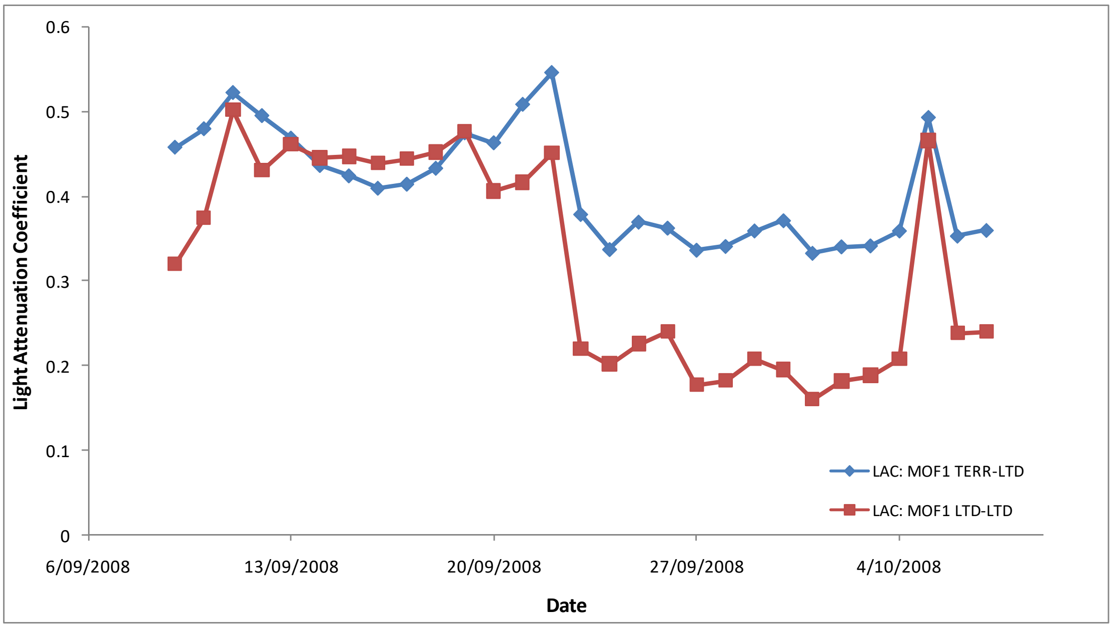

Figure AppF.7: Time-series plot of daily light attenuation at site MOF1, calculated from two in-water light sensors (red line) and an in-water and above-water light sensor (blue line), 9 September to 7 October 2008

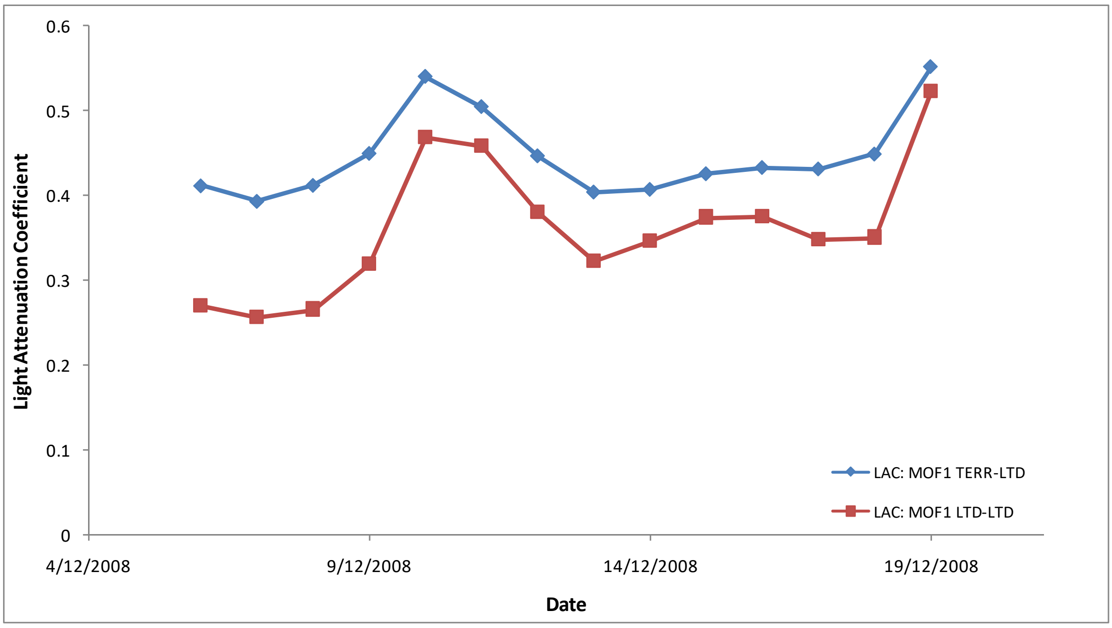

Figure AppF.8: Time-series plot of daily light attenuation at site MOF1, calculated from two in-water light sensors (red line) and an in-water and above-water light sensor (blue line), 6 to 19 December 2008

Conclusion

In the past, measuring light attenuation continuously has generally involved the use of two in-water sensors, separated by a fixed vertical distance. Whilst this method is relatively easy to employ and involves few assumptions, its application and accuracy can be problematic in shallow water environments with high tidal amplitudes.

Measuring LAC over the entire water column by the in-water and above-water light sensor method increases the accuracy of shallow water measurements by reducing the near-surface effects on light from waves. Light attenuation can also be measured over the maximum possible distance (entire water column), not just a lower (site-dependent) subsection, which means that the (near-surface) zone of high variability is always measured. During dredging, this zone may include plumes of surface confined, higher turbidity water that would influence the penetration of light, but the effects of which may not be measured using fixed paired-sensor methods.

Calculating light attenuation using an above-water sensor and in-water sensor, whilst making different assumptions about the spatial consistency of terrestrial irradiance and the transmittance of light, will also allow the accurate monitoring of light attenuation at all of the monitoring sites around Barrow Island, regardless of tidal stage. The amount of in-water monitoring equipment is reduced, which can increase the data recovery rate. Also, the potential for damage to sensitive near-surface equipment and interference with vessels is removed.

The results of this pilot study produced a significant, strong correlation between data collected using the two different methods, showing that the methods proposed in RPS (2009) are suitable for implementation at the water quality monitoring sites.

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Appendix G Water Quality Sampling Matrix

LTD Logger Water Quality Sampling Matrix at the HDD LTD logger site

May-09																														
F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Jun-09																													
M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Jul-09																														
W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Aug-09																														
Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Sep-09																													
T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Oct-09																														
Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Nov-09																													
S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Dec-09																														
T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Jan-10																														
F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Feb-10																											
M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

Mar-10																														
M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Apr-10																													
Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

May-10																														
Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Jun-10																													
T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W	Th	F	Sa	S	M	T	W
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

LEGEND
FULL DATA SET
PARTIAL DATA SET
NO DATA

Appendix H Water Quality Summary Data

Water Quality Summary Data at the HDD LTD logger site in Summer and Winter

		Summer	Winter
Median daily light (μE/m^2/s)	median	64.2	68.7
	5^{th} percentile	44.8	17.4
	10^{th} percentile	48.0	27.3
	20^{th} percentile	52.2	34.5
Daily LAC	median	0.23	0.21
	80^{th} percentile	0.25	0.24
	90^{th} percentile	0.26	0.26
	95^{th} percentile	0.26	0.28
Median daily turbidity (NTU)	median	1.0	1.4
	80^{th} percentile	1.3	2.8
	90^{th} percentile	1.5	3.4
	95^{th} percentile	1.9	4.3
Median daily SSC (mg/L)	median	1.9	2.7
	80^{th} percentile	2.5	5.4
	90^{th} percentile	2.7	6.6
	95^{th} percentile	3.7	8.4
Median daily Wave Height Index (m)	median	0.074	0.100
	80^{th} percentile	0.096	0.131
	90^{th} percentile	0.108	0.151
	95^{th} percentile	0.113	0.170