Technical Appendices N11 to N15 and O1 to O7

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

July 2010

Wheatstone Project

Title: Draft Environmental Impact Statement/Environmental Review and Management Programme for the Proposed Wheatstone Project: Technical Appendices N11 to N15 and O1 to O7

Appendix N11 to O7

Appendix N11

Intertidal Habitats of the Onslow Coastline

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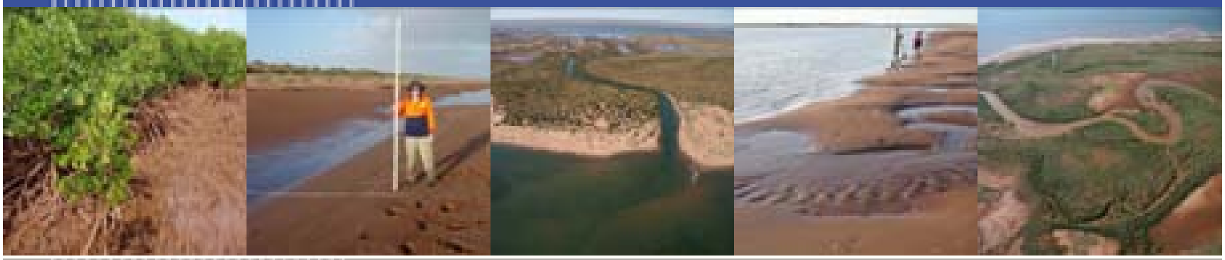

Report

Wheatstone Project

Intertidal Habitats of the Onslow Coastline

6 MAY 2010

Prepared for

Chevron Australia Pty Ltd

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Executive Summary

Chevron Australia Pty Ltd proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south-west of Onslow on the Pilbara Coast at the Ashburton North Strategic Industrial Area (SIA). As part of the environmental impact assessment process for this project, a study was undertaken to document the intertidal habitats and associated biological communities within the project area and collect baseline information on the condition, spatial extent and conservation significance of intertidal habitats.

The study area encompassed by this project comprised the coastal zone extending from Tubridgi Point (south-west limit) to Coolgra Point (north-east limit), a distance of approximately 50 km. The coastal tract is an extensive system of sandy beaches backed by coastal dune systems, limestone barriers and tidal flats. Tidal creek systems have breached gaps between the dunes and beach barriers and formed a network of narrow mangrove-lined drainage channels that are incised into expansive tidal flat systems.

Intertidal habitat surveys were conducted in November 2008, February 2009 and May 2009. A total of 46 sites were selected on the basis of representativeness of the range of intertidal habitats and major coastal types (e.g. sand-dominated shorelines, mud-dominated tidal embayments), habitat complexity and potentially higher biodiversity. Particular focus was placed on the two main intertidal systems located adjacent to the proposed Wheatstone North development site, these being the Hooley Creek to Four Mile Creek tidal embayment and the Ashburton River delta. More distant sites along the Tubridgi Point to Coolgra Point coastline were included to provide regional context.

The main findings of the study are:

- The **Ashburton River Delta** is an accretionary sedimentary structure occupying about 9 km of the coastline from the mouth of the Ashburton River to an area east of Entrance Point. The delta has formed a complex system of spits, cheniers, tidal flats, distributary channels and coastal dune barriers. A net eastward littoral transport system has orientated the main depositional activity towards the eastern side of the delta, immediately adjacent to the Wheatstone project area. In this area, a series of parallel sand deposits are separated by elongate lagoons that are infilling with subtidal, intertidal mangrove and mud flat deposits. The delta supports an extensive area of mangroves (526 ha) and diversity of mangrove assemblages. The Ashburton Delta and the Coolgra Point area (located ~ 20 km east of the project site) are recognised as particularly important mangroves areas by the relevant Environmental Protection Agency (EPA) Guidance Statement and as being of very high conservation value and "regionally significant".
- The **Hooley Creek – Four Mile Creek tidal embayment** is a broad tidal flat area on the eastern side of the project site that includes narrow tidal creeks with fringing mangroves and extensive mud flats. It is drained to the sea by the west and east arms of Hooley Creek and Middle Creek which have a common entrance, and Four Mile Creek which enters the sea separately further to the east. The distribution of habitat types within the tidal embayment is a progression from tidal creek – mangroves – samphire and bioturbated high tidal mud flat – algal-mat covered high tidal flat – salt flat – hinterland margin (i.e. the beginning of the surrounding dunes). A similar geomorphology and pattern or sequence of intertidal habitats also occurs within the extensive tidal flat embayments at Tubridgi Point (Urala Creek) and east of Onslow between Beadon Creek to Coolgra Point.
- The intertidal habitats occurring within the study area are sandy beaches, sand bars and shoals at the mouth of tidal creeks, rocky shores, mangroves, lagoon flats and a large high tidal mud flat unit which contains the habitats of bioturbated mud flats with samphire communities, algal mats

and supratidal salt flats. The study documents the characteristics of the intertidal habitats with respect to their physical and biotic attributes and provides detailed mapping (and area estimates) for the habitats and mangrove associations.

- Mangroves in the study area occur mostly within river mouth and tidal creek systems where they form a nearly continuous ribbon of vegetation fringing the creek channels. At Hooley Creek, Middle Creek, Four Mile Creek, Beadon Creek, and Second and Third Creeks, mangroves are confined to a narrow fringe adjacent to the creek channel that is typically only 10-20 m wide. More expansive mangrove areas are found at the Ashburton River Delta and Coolgra Point where a far greater area and diversity of habitats exist that are suitable for mangrove colonisation. The relationship between tidal elevation and frequency of tidal inundation establishes salinity gradients across the mangrove zone that influences both the occurrence of the different mangrove species (due to differing salinity tolerance limits) and the mangrove community structure.
- Landward of the mangrove zone, large areas of mud flats typically extend to the hinterland margin or merge with the supratidal salt flats. These mud flat areas occur in the upper sections of the intertidal zone and hence are not regularly inundated by tides. Two habitat types are recognised within the mud flats, these being bioturbated mud flats with samphire communities and algal mats. Together with the mangrove habitat, the two mud flat habitats above are considered as Benthic Primary Producer Habitat (BPPH) for the purposes of the Wheatstone environmental assessment. The samphire plants and algal mats, like mangrove trees, are primary producers in the strict sense, while the bioturbated mud flats are areas of high secondary production essential to the output of nutrients by the plants in the ecosystem.
- Mangroves and associated mud flats have a high organic content, support high microbial activity and large densities of invertebrate fauna. These organisms perform the critical 'secondary production' role of breaking down organic material into forms that become available to the mangrove ecosystem and beyond. Within that upper intertidal zone, much of the mud flat areas are heavily burrowed by ocypodid and sesarmid crabs, generally in vast numbers. The burrowers have very important functions in maintaining favourable geochemical conditions in the substrate. Ocypodides (fiddler crabs - genus *Uca*) feed mainly on the micro-epibenthos on the substrate surface while the sesarmids (marsh crabs – genera *Neosarmatium*, *Perisesarma*, *Parasesarma*) feed on detrital material they gather from the mud flat surface. The sesarmids play a particularly important role as they drag the plant material into their burrows where they shred it, thereby resizing and redistributing organic material throughout the soil profile.

Introduction

1.1 Project background / description and assessment context

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

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). An Environmental Scoping Document was prepared by Chevron (2009), setting out the relevant factors and scope of work required for the Environmental Review and Management Programme (ERMP). This document was subsequently approved by the EPA and forms the basis of the forthcoming environmental assessment. The intertidal habitat investigations outlined in this report have been conducted to support the environmental impact assessment process.

1.2 Study area

The study area encompassed by this project comprises the coastal zone extending from Tubridgi Point (south west limit) to Coolgra Point (north east limit), a distance of approximately 50 km (Figure 1-1). The coastal tract is an extensive system of sandy beaches backed by coastal dune systems, limestone barriers and tidal flats. Tidal creek systems have breached gaps between the dunes and beach barriers and formed a network of narrow mangrove lined drainage channels that are incised into expansive tidal flat systems.

The study area includes the Local Assessment Units (LAUs) that are proposed for use in assessing potential impacts to Benthic Primary Producer Habitats (BPPH) as per EPA Environmental Assessment Guidelines No.3; Protection of Benthic Primary Producer Habitats In Western Australia (EAG 3) (EPA 2009a). Particular focus was placed on the two main intertidal systems located adjacent to the proposed Wheatstone North development site, these being the Hooley Creek to Four Mile Creek tidal embayment and the Ashburton River Delta. These systems encompass all the mainland intertidal areas that may potentially be affected by the development.

1.3 Scope and objectives of study

Objectives of the study were to:

- Document the intertidal habitats and associated biological communities at selected localities within the study area.
- Collect information on the distribution and conservation significance of intertidal habitats, to provide the necessary inputs to facilitate an assessment as per EAG 3 to be undertaken in the EIS.

This document provides an account of the intertidal habitats of the study area from surveys between November 2008 and May 2009. Potential impacts to intertidal habitats will be assessed as part of the

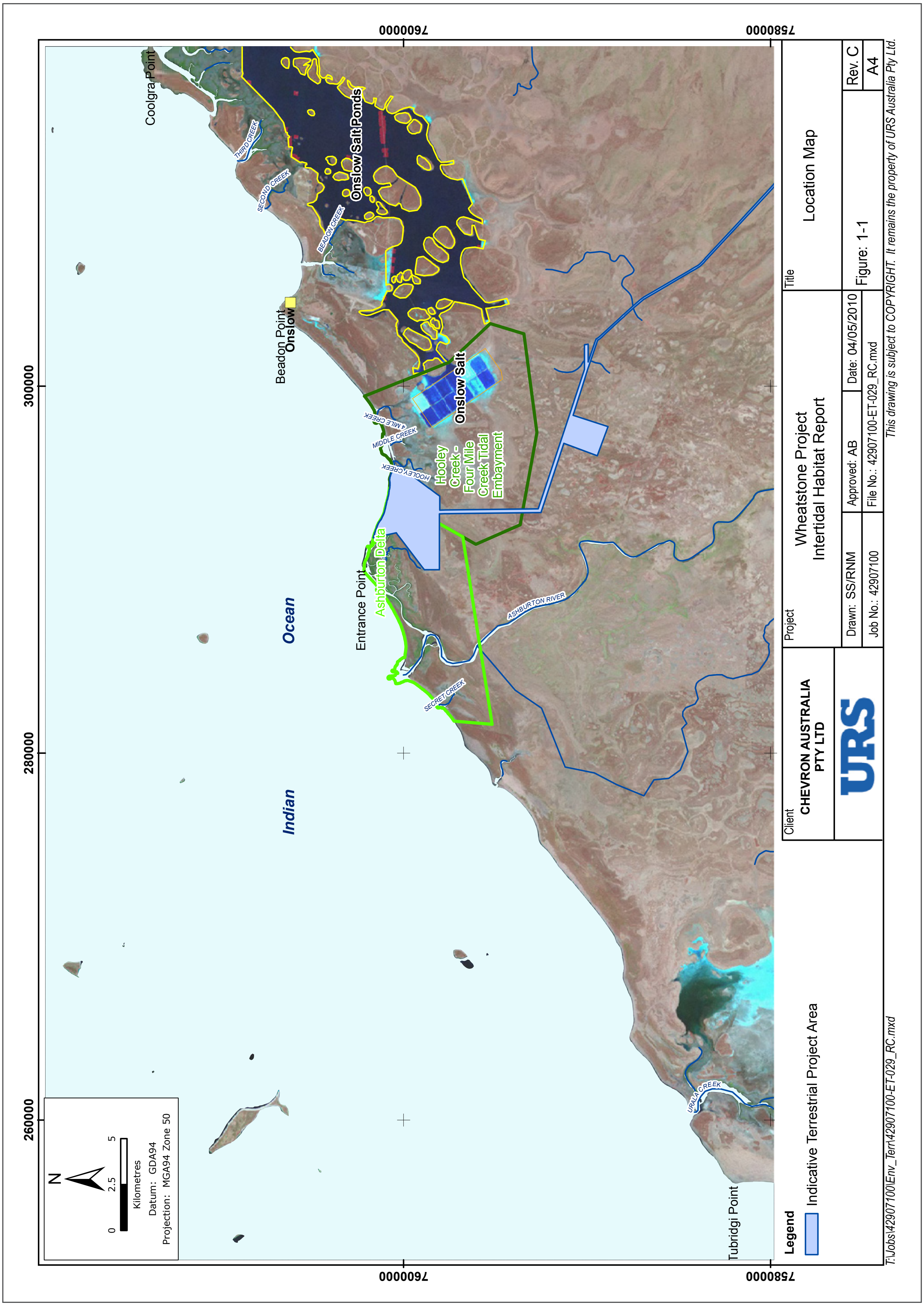
ERMP, with reference to a range of project related information such as coastal stability and hyrdrodynamic modelling, engineering design etc.

Specific application of the data provided in the report includes:

- identification of BPPH and appropriate loss assessment units as per EAG 3(BPPH)
- regional context/significance of habitats and biodiversity
- natural and anthropogenic changes
- future/ongoing management and monitoring programmes.

1.4 Study team

This study was primarily completed by Dr Barry Wilson (Murex Consulting) and Anthony Bougher (URS) with field assistance provided by Luke Skinner (URS). Mapping and cartographic assistance was provided by personnel from the URS Geographic Information System (GIS) department and Peter Chalmer (Environmental GIS). Analysis and identification of invertebrate fauna was undertaken by Barry Wilson and relevant experts from the Western Australian Museum, and Dr Peter Davie of Queensland Museum.


Coolgra Point
Onslow Salt Ponds
THIRD CREEK
SECOND CREEK
BEADON CREEK
Beadon Point
Onslow
Onslow Salt
MIDDLE CREEK
HOOLEY CREEK
Hooley Creek - Four Mile Creek Tidal Embayment
Entrance Point
Ashburton Delta
ASHBURTON RIVER
SECRET CREEK
Indian Ocean
URALA CREEK
Tubridgi Point
Kilometres
Datum: GDA94
Projection: MGA94 Zone 50
Legend
Indicative Terrestrial Project Area
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Intertidal Habitat Report
Title
Location Map
Drawn: SS/RNM
Approved: AB
Date: 04/05/2010
Figure: 1-1
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2 Methods

Surveys of intertidal habitats in the vicinity of the Ashburton North SIA and along the adjacent coastline were undertaken between November 2008 and May 2009 as per the following schedule:

- An initial survey conducted during the spring tide period of 13-18 November 2008 focused primarily on beach, sand flat and rocky shore habitats for which low spring tides are required. Reconnaissance visits to some mangrove and mud flat habitats were also undertaken as part of the initial survey.
- Subsequent surveys on 13-14 February and 4-9 May 2009 focused on mangroves and adjoining high tidal mud flats in the Ashburton Delta, Hooley Creek area and a selection of regional sites. This work was split into two surveys due to heavy rain (~ 200 mm) in coastal areas of the west Pilbara on 15-17 February that caused the February survey to be abandoned.

2.1 Site selection

The major habitats and physical features discernible from aerial photography were identified to develop the programme for each survey. The location of sites were selected with consideration of:

- Representativeness of the range of intertidal habitats and major coastal types (e.g. sand dominated shorelines, mud dominated tidal embayments).
- Areas of habitat complexity and potentially higher biodiversity.
- Areas identified in the preliminary design as being either close to the Ashburton North SIA and/or potentially directly impacted by the Project, hence focus was placed on the Hooley Creek to Four Mile Creek tidal embayment and the Ashburton River Delta.
- Regional context - sites along the Tubridgi Point to Coolgra Point coastline that are more distant from the development site.

A total of 46 sites were visited during the intertidal habitat surveys (16 sites in November 2008, 12 sites on February 2009 and 18 sites in May 2009). The following locations /sites were visited during the surveys:

- Tubridgi Point (~ 20 km south-west of the Project site): Site 40.
- Secret Creek (~ 6 km south-west of the Project site): Sites 28, 41.
- Ashburton Delta: Sites 8, 10, 17-27, 32-37, 42.
- Beach/sand spit between Entrance Point and the mouth of Hooley Creek: Sites 5, 6, 9, 14.
- Hooley Creek mouth and associated tidal flats: Sites 4, 7, 11-13, 15, 30, 31, 38, 39.
- Four Mile Creek (~ 2 km east of the Project site): Sites 1-3, Site 3 was re-visited in the May 2009 survey to collect crab specimens.
- Beadon Point and Beadon Creek (~ 10 km north-east of the Project site): Sites 16, 29.
- Second Creek (~ 15 km north-east of the Project site): Site 43.
- Coolgra Point (~ 12 km north-east of the Project site): Sites 44-46.

Figure 2-1 shows the location of the sites in the central study area (i.e. the Hooley Creek to Four Mile Creek tidal embayment and the Ashburton River Delta area). Locations and habitat descriptions of the sites for all the surveys are given in Appendix A.


Legend
Intertidal Survey Sites (Points)
Intertidal Survey Sites (Transects)
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Intertidal Habitat Report
Title
Location of Intertidal Survey Sites
Drawn: SS/RNM
Approved: DO
Date: 05/05/2010
Rev. A
Job No.: 42907100
File No.: 42907100-ET-030.mxd
Figure: 2-1
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Aerial Photography: Fugro Feb 2009 and Landgate, August 2007.
Kilometres
Datum: GDA94
Projection: MGA94 Zone 50
Onslow Salt
Sunset Beach
Entrance Point
ASHBURTON RIVER
SECRET CREEK
MIDDLE CREEK
4 MILE CREEK
BEADON CREEK
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2.2 Survey methodology

Prior to undertaking the surveys, the modes of access were assessed for each area to be visited to provide for safe and efficient access to sites by vehicle, boat or helicopter. A boat (larger vessel plus tender) was used to access the seaward sections of the Ashburton Delta, while a four wheel drive vehicle was used access the landward parts of the delta, the sand spit between Entrance Point and the Hooley Creek mouth, the section of the Hooley Creek tidal flat embayment close to the Project site and coastal areas between Four Mile Creek and Beadon Creek. During the May 2009 survey a helicopter was used to visit the less accessible sections of the study area and more regional sites between Tubridgi Point and Coolgra Point. In addition to providing access to the more remote sites, the coastal fly-overs provided by the helicopter were an ideal way to gain an understanding of the type and extent of intertidal habitats that occur outside of the Ashburton Delta/Hooley Creek area.

Survey methodologies employed were intended to be a largely qualitative assessment and groundtruthing/mapping exercise to provide for an assessment of the intertidal habitats in the area. At each site the area was traversed and information collected on habitat characteristics, vegetation types (if present) and fauna. Data were collected on the range of mangrove associations present at each site and the structure and composition of those associations.

At the six beach sites (Sites 1, 2, 5, 6, 9, 14) a line transect method was used in order to relate habitats and species distributions to beach profiles and sea level. A base point was located at the previous high tide mark and a transect was set normal to the shoreline, running out to the low water mark at the time of the survey, generally at or close to Mean Low Water Springs (MHWS). Using a dumpy level, the heights at relevant points were measured and site profiles provided in the final report were corrected to Mean Sea Level (MSL). Points on the transect line where change of slope, sediment or fauna were observed were marked on the transect which was thus divided into habitat zones. Species present in each habitat zone were then recorded.

At various sites, information was also collected to assist the coastal geomorphology survey (see Damara 2009) with developing an understanding of the evolution of coastal landforms in the area. Evidence of previous coastal shorelines and marine/estuarine habitats of either Holocene and Pleistocene origin was found some distance landward of the current coastlines. The locations of these sites were established on aerial photographs (and by GPS coordinates) and, where possible, fossil deposits were sampled for species identification and dating analysis.

Invertebrate fauna sampling - Due to the important role played by invertebrate fauna within mangrove and mud flat habitats and the extensive crab population evident at many sites, considerable effort was employed to obtain a representative range of fauna samples, particularly of the crab fauna which are known to play important functions in nutrient and energy cycles in mangrove ecosystems. Invertebrate communities were characterised using crustaceans and molluscs as the main indicator groups.

Samples were collected via a range of techniques including crab burrow excavation, pitfall traps and searching the surface of mangrove roots, trunks and leaves for epifauna.

Invertebrate fauna that could not be readily identified in the field were collected and preserved in formalin and methanol solutions. Due to uncertainty regarding the identification and taxonomic status of many of the crab species encountered, an extensive collection of crab specimens (~200) was made from the surveys. These specimens were sent to the WA Museum for identification.

2.3 Habitat mapping

Aerial photography and satellite imagery of the study area flown from a range of dates between 2001 and February 2009 were used during the field surveys to groundtruth the range and distribution of intertidal habitats. It was evident that, while the distribution of habitats in many areas had remained unchanged during this time period, there were some areas (such as at Entrance Point and the mouth of Hooley Creek) where considerable coastal changes had occurred. For this reason the February 2009 aerial photography and February 2009 IKONOS imagery (0.8 m colour) were used to capture the habitat mapping information provided by the field mapping/groundtruthing exercise. Both sets of imagery were ortho-rectified and colour balanced by AAMHatch image providers.

The boundaries of habitats identified from groundtruthing and post fieldwork analysis of imagery were manually delineated onto enlargements and then scanned and geographically registered in ArcGIS v9.3. Fine-scale adjustments of the resultant 'habitat' polygons were then made on-screen in ArcGIS by using the rectified digital imagery as background mapping and correcting any local spatial inaccuracies. The polygons were cross-referenced to the habitat type codes and total areas for each habitat within locations were then calculated using ArcGIS.

The mapping of five mangrove assemblages or zones within the mangrove habitat type was also undertaken as part of the mapping process described above. These recognisable structural and physiognomic zones were identified during groundtruthing and could be related to particular photo-tones within the imagery. Biota (2005) used these same five assemblage types for mangrove mapping in areas immediately south of the study and these units were also applicable to the mangroves for this study. This consistency in mapping between the two studies from adjacent coastal sectors established a more detailed level of mangrove mapping than was available previously and provided regional context.

2.4 Other relevant surveys of intertidal habitats from the region

Information available from previous surveys undertaken in the Onslow area and adjacent mangrove systems on the east side of Exmouth Gulf were reviewed and referenced where appropriate. In chronological order these were:

- *Onslow Salt ERMP Volume 2: Technical Appendix C Report on the Biological Environments near Onslow, Western Australia* (Paling 1990): documents mangrove, algal mat and salt flat habitats from Hooley Creek to Coolgra Point, and provides mapping based area estimates for mangroves and algal mats prior to construction of the salt ponds.
- *Roller Oilfield Development CER - Appendix 2: Intertidal Habitats of the Onslow to Tubridgi Point coast and Locker Island* (LEC 1991). This report documents the range and distribution of intertidal habitats, describes the major biotic assemblages and identifies some particular areas that should receive priority protection from an oil spill.
- *Yannarie Salt Project ERMP, Appendix 4: Mangrove and Coastal Ecosystem Study. Baseline Ecological Assessment* (Biota 2005). Field surveys and mapping of mangroves and algal mats along the entire eastern side of Exmouth Gulf from Giralia Bay to Tubridgi Point where these habitats occupy extensive areas (~11,000 ha). This study included a detailed assessment of factors related to mangrove and algal mat distribution, nutrient and carbon cycles, productivity and conservation significance. Much of the information provided by this study is of direct relevance to the mangrove and associated high tidal mud flat habitats of the Onslow area due to the similarity

2 Methods

of mangrove habitats and the prevailing factors that determine their distribution, maintenance and ecological function.

- *Coastal Geomorphology of the Ashburton Delta and adjacent areas* (Damara 2009). Assessment of the coastal landforms (including their evolution and development) and related aspects such as coastal processes, historical coastline movements, shoreline stability and longshore transport. This assessment is based on field survey results and a review of a range of relevant data (historical aerial photography, metocean data, etc.)

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Physical Framework

3.1 Regional setting and coastal geomorphology

The stratigraphy and geomorphology of the Pilbara coast has been described by Semeniuk (1993). Also, the Final Report of the North West Shelf Joint Management Study (Lyne et al. 2007) designated coastal "biogeomorphic units" along the Pilbara coast, one of which, the Onslow coastal unit from Locker Point to the mouth of the Cane River, encompasses the study area. Additional information on the study area is found in LEC (1991). Relevant information also may be found in a report by Biota Environmental Sciences on the mangrove and mud flat systems along the eastern side of Exmouth Gulf adjacent to the area considered in this report (Biota 2005).

Semeniuk (1993a) characterised the Pilbara coast as "a riverine coastal plain in a tropical arid setting". Lying at the western end of the Pilbara, the Onslow coast is part of the Carnarvon Basin. The modern shore is developed on Quaternary sediments overlying Tertiary sedimentary rocks at shallow depth. The Quaternary deposits and geomorphic structures reflect the repeated rise and fall of sea level and repositioning of the coastline during that period, and the modern complex coastal geomorphology and habitats are a direct outcome of those events.

The hinterland of the Onslow sector, referred to as the Onslow Plain, is low lying with vast areas of high tidal mud flats and supratidal salt flats. It has a highly dynamic coastline that is characterised by an exposed, sandy coast with both constructional and erosional processes ongoing. The shore is predominantly beach/dune although limestone headlands and barrier islands occur at several places, e.g. Beadon Point and Coolgra Point (Figure 1-1). These are generally Pleistocene structures, of either terrestrial aeolianite or marine limestone, or both, outcropping at the shore but overlain by Holocene dunes. They form the 'anchors' controlling much of the shoreline development. There are also outcrops along the shore of Holocene limestone beach deposits. Nearshore there are numerous small low sandy and limestone islands with surrounding rock platforms and coral communities in the lower littoral zone.

Rivers in the Pilbara are subject to flash floods and episodically discharge very large volumes of freshwater and terrestrial sediments into the coastal zone. Two major rivers, the Ashburton and the Cane, both have active deltas with extensive mangroves. In addition, there is a series of tidal creeks along the coast, all of which have fringing mangrove habitats and small alluvial fans at their mouths. Tidal creek and mangrove systems that are developed behind the beach/dune and limestone barrier islands are protected by them from wave action. Broad areas of high tidal mud flats and supratidal salt flats behind the mangrove-fringed creeks are a major feature of the intertidal zone in this region.

Throughout the Onslow coastal unit, modern mangrove and tidal flat deposits are superimposed upon a pre-existing, semi-consolidated shell bed pavement, likely to be of Holocene and/or Late Pleistocene origin (exposed at Sites 39, 40 and 46). In addition, fossiliferous marine deposits were observed at various locations in the vicinity of the Ashburton North SIA, representing positions of the coastline during earlier periods of high sea level. These shell beds are provisionally identified as being of Late Pleistocene age (Stage 5), possibly with several phases. Even older marine deposits were reported by Murray-Wallace et al. (2000) further inland on Urala Station, dated at Middle Pleistocene (Stage 7).

The fossil shells of these Quaternary sites represent a range of marine habitats that were quite different to the beach, mangrove and mud flat habitats of the present time. The Holocene shell beds beneath the mud flats represent a coastal embayment environment with sand flat and rocky shore assemblages. The earlier Pleistocene deposits represent estuarine and shallow embayment environments. One (Site 38) features fossil, *in situ* coral communities indicating an open oceanic setting, apparently equivalent to the coral communities seen today on limestone platforms around many of the nearshore islands off the Onslow coast.

The Late Pleistocene marine shell bed deposits are overlain in many places (e.g. Sites 38, 39, 43) by a hard, aeolianite (wind blown) limestone that contains fossils of a camaenid land snail, apparently representing a Last Glacial, terrestrial phase of deposition that preceded the Holocene sea level rise.

Considered together, these fossil deposits within the study area indicate a complex Quaternary history of dramatic change in coastal habitats within the region, related to climate and sea level change on a coastline of low relief and little slope (see also Semeniuk 1993).

3.1.1 Major coastal geomorphic units in the Ashburton North area

A geomorphic classification of coastal habitats published by Semeniuk (1986) has been applied in this study. Within the Ashburton North area three coastal geomorphic units at Semeniuk's regional scale occurred. The three units are:

- Onslow Coastal Tract
- Ashburton Delta
- Hooley Creek – Four Mile tidal embayment complex.

Within these units sets of medium/small scale geomorphic habitat units occur. Further afield (west and east of the Project site between Tubridgi Point and Coolgra Point), several additional sites were visited for comparative purposes, each exhibiting similar medium/small-scale habitats. Structure and distribution of intertidal habitats are largely controlled by the pre-existing geomorphology and underlying geology. The coastal geomorphology of the study area is described and discussed separately in the report by Damara (2009). In this report, aspects of geomorphology that bear on characterisation of intertidal habitats are considered.

The characteristics of the three regional scale geomorphic units within the Ashburton North area may be described as follows.

(i) Onslow coastal tract

The coastal tract between Tubridgi Point and Coolgra Point is an extensive system of sandy beaches backed by coastal dune systems, limestone barriers and tidal flats. Long stretches of sandy beach/dune systems are interrupted only by the Ashburton River Delta and several narrow tidal creek entrances. The tidal creeks have breached gaps in the dune barrier systems and their network of narrow drainage channels provides tidal flows to (and from) expansive tidal flat embayments that in some cases extend several kilometres landward of the coastal beach/dune system. Typical examples of these features are shown in Plates 3-1 and 3-2.

Localised areas of sand bars and shoals have formed at the mouth of tidal creeks and the Ashburton River where fine- to medium-grained sands have been deposited and re-worked into small delta shaped formations (see Section 4.2).

For the most part, the sandy beaches are backed by steep, vegetated foredunes forming the beach/dune geomorphic unit that characterises the Onslow coast.

3 Physical Framework

Plate 3-1

Plate 3-2

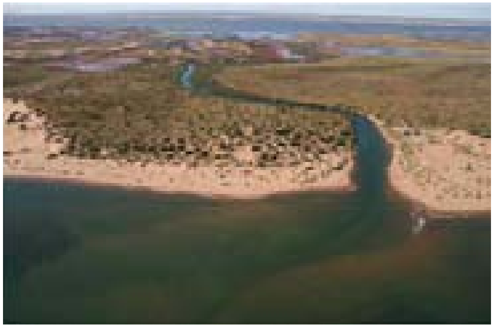

Plate 3-1 **Secret Creek located 2 km south-west of the Ashburton River. A tidal creek system that has breached a narrow a gap through the coastal dunes**

Plate 3-2 **Second Creek located 2 km east of Onslow. A narrow creek mouth through coastal dunes with extensive areas of tidal mud flats further landward**

(ii) Ashburton Delta

The Ashburton River Delta is an accretionary sedimentary structure occupying about 9 km of the coastline from the mouth of the Ashburton River (Site 22) to an area east of Entrance Point (in the vicinity of Sites 9 and 14). It comprises the active contemporary delta and a series of older deltas, now inactive, built along a Pleistocene shore during periods of high sea level. The delta has formed a complex system of spits, cheniers, tidal flats, distributary channels and coastal dune barriers. The present day entrances at the Ashburton River mouth and Entrance Point are separated by a long (3 km), narrow dune barrier. Behind the coastal barrier there are extensive tidal flats that have been incised by a network of distributary channels and tidal creeks. The delta system has prograded through development of sand bars, spits and cheniers at its main mouth in the west and at Entrance Point in the east.

The intertidal habitats within the delta include fluvial channels of the river, extensive mangal flats with structurally complex mangrove forests and shrublands, high tidal mud flats, lagoons and tidal creeks. There are no mid and low tidal mud flats seaward of the mangroves bordering the tidal creeks and the invertebrate species typically living in that habitat are missing in this system.

The lower 6 km of the present sinuous entrance channel of the Ashburton River is an estuarine habitat (fluvial channel), up to 300 m wide and fringed with mangroves and tidal mud flats (Sites 24, 25, 33). The main contemporary entrance channel is 4-5 m deep. A secondary channel that runs north-east to an entrance at Entrance Point is at present partly occluded by an advancing beach/dune.

The contemporary, active, triangular delta lies on the eastern side of the river channel and the Wheatstone Project site is immediately adjacent to this area. It consists of a series of vegetated Holocene cheniers and dunes with winding drainage channels (tidal creeks) in the swales. Although much of the sediment that has built the delta has come originally from the river, the delta is extending to the east by both estuarine (lagoonal) deposition and the development of beach ridges along the north-eastern side and the progressive addition of cheniers that, in time, become vegetated linear dunes. A net eastward littoral transport system, combined with the influence of the major dunal barrier located between Entrance Point and the main channel mouth, has orientated the main depositional activity towards the eastern side of the delta. In this area, a series of parallel sand deposits are separated by elongate lagoons that are infilling with subtidal, intertidal mangrove and mud flat deposits. Figure 3-1 illustrates the main features of the eastern section of the delta as described above.

At the present time there is a narrow, blind ending lagoon between the contemporary beach ridge along the north-eastern side of the delta and the most recent Holocene chenier. The 2004 aerial photographs show that at that time the lagoon was a channel opening to the sea (Site 14) about 2 km west of the mouth of Hooley Creek. However, at the time of the November 2008 survey that entrance had closed and the main entrance was located near Entrance Point (Site 17). The lagoon is today a shallow, muddy, still estuarine habitat without wave action.

(iii) Hooley Creek – Four Mile Creek tidal flat embayment

This geomorphic unit comprises a very broad tidal flat area on the eastern side of the Project site that includes narrow tidal creeks with fringing mangroves and extensive mud flats. The unit occupies an area of approximately 70 km^2, protected from the sea by a barrier beach/dune system. It is drained to the sea by the west and east arms of Hooley Creek and Middle Creek which have a common entrance, and Four Mile Creek which enters the sea separately further to the east. Due to the dynamic nature of coastal processes operating along the ocean-facing shoreline, the orientation of sand spits and creek entrances has undergone considerable change (see Section 3.2 Coastal Processes and Stability). Figure 3-2 illustrates the main features described above.

The arrangement of habitat types within the tidal embayment is a pattern from tidal creek – mangal flat – samphire and bioturbated high tidal mud flat – algal mat-covered high tidal flat – salt flat – hinterland margin (i.e. the beginning of the surrounding dunes). A similar geomorphology and pattern or sequence of intertidal habitats also occurs within the extensive tidal flat embayment systems at Tubridgi Point (Urala Creek) and east of Onslow from Beadon to Coolgra Point (Beadon Creek, Second Creek, Third Creek and Coolgra Creek).

This sequence of habitats is repeated at other tidal embayments in the Tubridgi Point to Coolgra Point area and is discussed further in Sections 4.4 and 4.5.

The mud flats comprise muds and muddy sand deposits, usually several metres deep, developed over a richly fossiliferous, unconsolidated shell bed thought to be of Holocene (post Last Glacial) age, representing a species-rich, shallow marine embayment habitat with mainly sand substrate species but some rocky shore and mangrove molluscs present. That shell bed, in turn, appears to overlay an older, consolidated marine limestone, also fossiliferous, probably of Late Pleistocene age. The Holocene and Pleistocene deposits are exposed at Site 39 where there is a hard limestone pavement forming a bar with the mud flat developed behind it. Fossil shell and coral specimens, believed to be derived from this deposit, are scattered on mud flats and adjacent dunes and beaches throughout the area, probably by the agency of storms and tides.

There are several sandy ‘islands’ on the mud flats, relicts of the Pleistocene dunal landscape prior to the post Last Glacial flooding.

3 Physical Framework

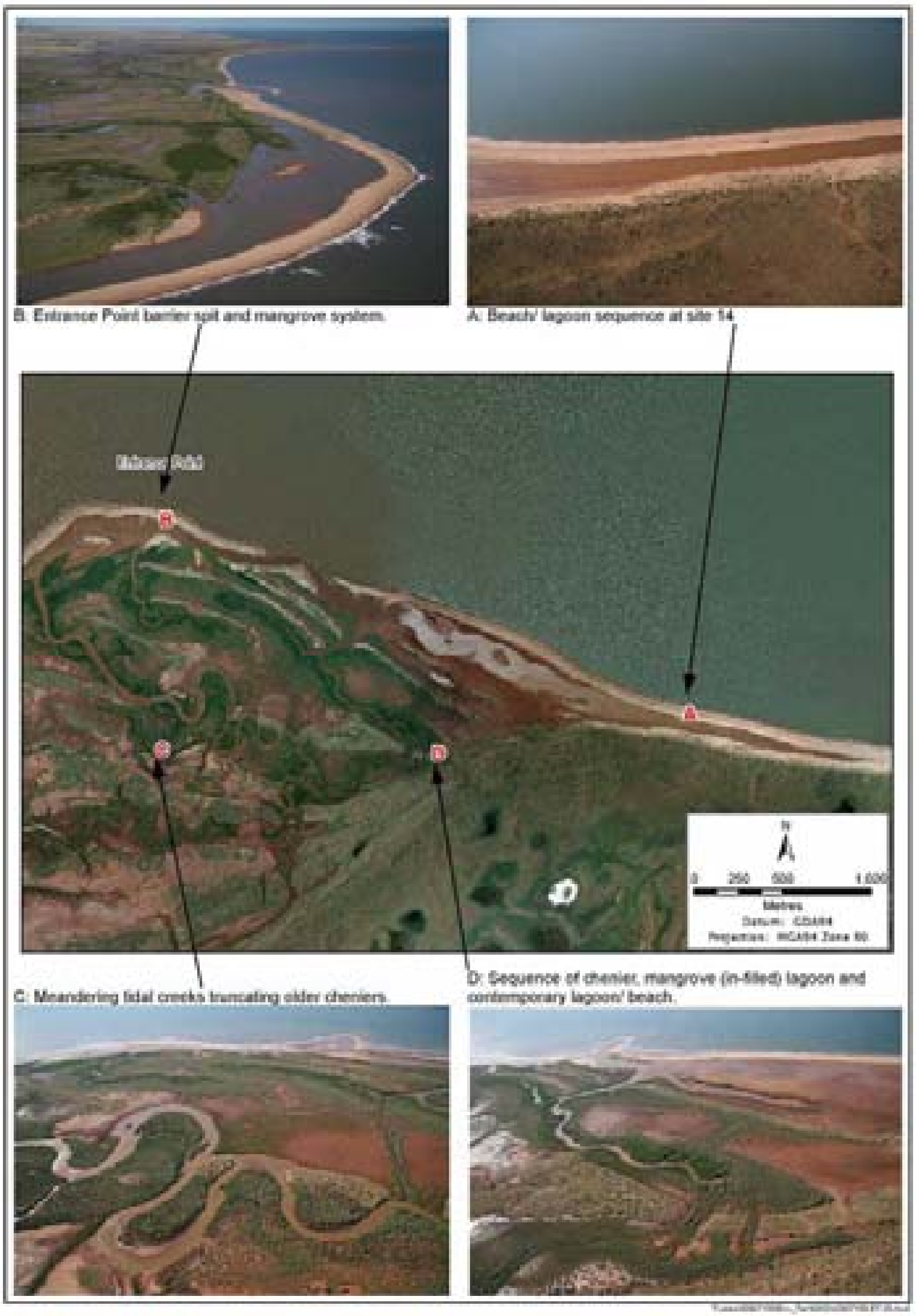

Figure 3-1 The main features of the eastern section of the Ashburton River Delta.

Figure 3-2 **The main features of the eastern section of the Hooley Creek - Four Mile Creek tidal flat embayment.**

3.2 Coastal processes and coastal stability/movements

A detailed study of coastal geomorphology of the study area undertaken by Damara (2009) identified a series of regional scale coastal compartments comprised of a complex array of physical landforms and coastal processes. The Ashburton compartment, extending from Turbridgi Point to Coolgra Point, is a single sediment cell extending over 70 km, and contains the active delta of the Ashburton River, long sandy beaches and dunes, and the island chains running approximately parallel to the shore. A sediment cell is a reach of coast, including the nearshore terrestrial and marine environments, within which the movement of sediment is readily identifiable, if not largely self-contained (Komar 1996). Sediment cells are segments of the coast in which sediments derived from a common origin can be traced along transport paths to a sink, where they are temporarily or permanently lost to the coast.

Damara (2009) identifies the Ashburton compartment as a single sediment cell that has two sectors: the western shore between Tubridgi Point and the mouth of the Ashburton River, and the eastern shore from the river mouth to Coolgra Point. The net sediment movement within the cell is easterly, although reversible from time to time due to onshore winds. As a result, sediment in the western sector is largely sediment reworked by erosional processes and littoral drift along the shore. In contrast to this, sediment in the eastern sector is of fluvial origin and littorally reworked as chenier spits migrating eastwards from the mouth of the Ashburton River.

Major sources of sediment in the eastern sector of the Ashburton compartment include:

- erosion of saltflats and mud flats by fluvial run-off and tidal creeks after flooding and tidal inundation
- alluvial sediments discharged by the Ashburton River
- erosion of dunes and rocky shores by nearshore processes
- bioproduction and reworking of material from the inner continental shelf.

The major transport path in the cell is along the shore at the beach face, with much of the material being supplied as littoral drift along spits fed from the Ashburton River. Sediment sinks include long chenier spits, coastal dunes and inshore shoals, as well as deposition on mud flats by tidal creeks (Damara 2009).

At a finer scale, tidal creeks play a role in exchanging sediment between the terrestrial and marine environments. Sediment is exchanged between the coastal wetlands (tidal mud flat areas) and inshore waters via tidal creeks. Two interchangeable, and to some extent reversible, processes are apparent, and both have implications for the bioproductivity of nearshore waters. First, inundation of the coastal wetlands by fluvial runoff during flood conditions reinforces ebb currents and may contribute to erosional scour of the wetland margins as water levels fall after the flood peak. The tendency for erosion is indicated by gullying at the headwaters of the tidal creeks. Erosion patterns of this kind are apparent in parts of the Ashburton Delta and the western margin of the Onslow salt flats, where tidal creeks are becoming entrenched in the swales between recently formed cheniers. Second, in places where the flood-tide flows are dominant, the tidal creeks may deposit silty sands and mud on the mud flats. This deposition is apparent in the eastern part of the Onslow salt flats where distributary fans are present at the headwaters of the tidal creeks. The fans are slightly higher than the surface on which they are developed and may be indicative of a slight, short-term rise in sea level or settling of the salt flats in the area where they occur (Damara 2009).

3 Physical Framework

Interpretation of historical aerial photographs, together with field data collected during the coastal geomorphology and intertidal habitat surveys, show that some sand spit, beaches and creek entrances are highly dynamic, particularly in areas between Entrance Point and the mouth of Hooley Creek. Historic coastline movements from 1973 to 2009 were plotted by Damara (2009).

A summary of the coastline movements are:

- Historical movements of the Ashburton River Delta include internal channel movements, and external coastal evolution. The main flow path of the Ashburton River across the delta has switched between channels historically, as the river previously exited near Entrance Point. The old channel silted up, and switching of the channel to its present position occurred between 1921 and 1973.
- The north-west facing coastline between the Ashburton River mouth and Entrance Point appears to have receded (shoreline erosion of ~ 1.5 m/yr between 1993 and 2001). Evidence of the receding shoreline was observed at Site 22 (1 km south-east of Entrance Point) where large mangrove trunks (from dead trees) had become exposed along the current shoreline as the beach/dune sands migrated landward across mangrove flats (this was concurrently causing localised mortality of mangroves due to sediment burial of mangrove aerial roots or pnuematophores) (see Plates 3-3 and 3-4).

Plate 3-3

Plate 3-4

Plate 3-3 **Coastal erosion at Site 22 (1 km south-east of Entrance Point) has exposed old mangrove trunks**

Plate 3-4 **A receding shoreline and associated landward migration of beach/dune sands at Site 22 has buried the pneumatophores of *Avicennia* mangroves resulting in mortality**

- Concurrent with erosion described above, there has been significant accretion of a barrier spit eastwards of Entrance Point. The eastwards migration of the barrier spit has formed the beach/lagoon sequence observed at Sites 5, 9 and 14. This behaviour is consistent with an eastwards migration of the delta sediments. A stratigraphic profile surveyed at Site 14 (see Figure 3-3) highlights the coastal changes experienced at this site due to sand spit migration. During an intertidal habitat survey in 1991 for the Roller Oilfield Development (LEC 1991) the area at Site 14 was a narrow rocky shore and this has now become a broader lagoon/beach sequence as shown by the 2009 profile in Figure 3-3. Damara (2009) estimates that the barrier spit has migrated eastwards by about 2.2 km between 1973 and 2009 and the rate of eastward migration since 1993 has been in the order of 100 m/yr.

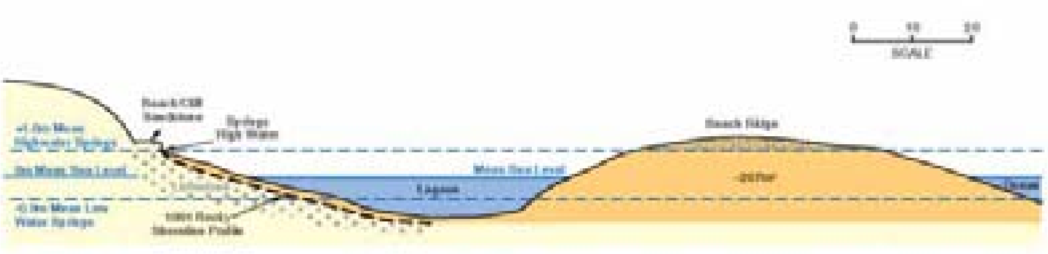

Figure 3-3 Surveyed profile showing the beach-lagoon sequence at Site 14

- The historic photography of Hooley Creek suggests this entrance spit and orientation of the creek entrance is highly dynamic and subject to ongoing change. The spit has been deflated and rebuilt a number of times during the last thirty years. The entrance bar configuration in 1993 was similar to the 2009 configuration but had deflated and progressively rebuilt during this period, most likely as a result of Tropical Cyclone Vance in 1999 (Damara 2009). The 2001 photography shows deflation of the entrance bar with isolated, disconnected subaerial bars evident in the entrance. The western spit of Hooley Creek had re-established in 2004 and elongated by about 700 m between 2004 and 2009. The eastward migration of sand is expected under typical conditions.

3.3 Tidal regime

Onslow is one of the national standard port tidal reference stations (62470), with a tide gauge located in Beadon Creek, maintained by the WA Department of Transport. The tides are mesotidal with a spring tide range of 1.9 m, and mixed, mainly semi-diurnal (Table 3.1).

Table 3-1 Summary of tidal levels from the Australian 'National Tide Tables'

Tidal level		Level (m CD)	Level (m AHD)
Highest Astronomic Tide	HAT	+3.0 m CD	+1.5 m AHD
Mean High Water Springs	MHWS	+2.5 m CD	+1.0 m AHD
Mean High Water Neaps	MHWN	+1.8 m CD	+0.3 m AHD
Mean Sea Level	MSL	+1.5 m CD	0.0 m AHD
Mean Low Water Neaps	MLWN	+1.2 m CD	-0.3 m AHD
Mean Low Water Springs	MLWS	+0.6 m CD	-0.9 m AHD
Lowest Astronomic Tide	LAT	+0.0 m CD	-1.5 m AHD

Key water level processes affecting Onslow include tides, cyclonic surges, seasonal ranging and inter-annual mean sea level variations. The tidal forcing contains a range of cycles, including the semi-diurnal ranging, the monthly spring-neap cycle, a bi-annual cycle due to movement of the solar equator and a 4.4 year cycle developed from lunar elliptic motion (Damara 2009).

The seasonal variations of tides, surges and mean sea level are generally not in phase:

- Tidal peaks occur near the equinoxes in March and September
- Surge peaks mainly occur in January to March due to tropical cyclones, and from June to August due to mid-latitude systems
- The seasonal mean sea level peaks during April.

This relative timing means that there is opportunity for high water level events (>2.8 m CD) over the majority of the year. The relative timing of the tidal and mean sea level peaks provide increased potential for extreme water level events to occur as a result of late season tropical cyclones, in March or April (Damara 2009).

Modelling of extreme cyclonic water levels for the Onslow town site and Onslow Salt (GEMS 2000; Nott & Hubbert 2005) has estimated the 100-year ARI water level as 4.7 m AHD (6.2 m CD), including allowance for wave setup.

3.4 Groundwater regime

The predominant known groundwater resources of the Pilbara coast occur in valley floor alluvial and calcrete channel deposits beneath downstream reaches of the De Grey, Yule, Fortescue, Robe and Ashburton rivers. These aquifers are formed by relict fluvial sand and gravel deposits in ancient river beds that occur beneath and/or adjacent to the current watercourses. It is expected that similar deposits beneath the watercourses of the George, Maitland, Yanyare and Cane rivers might also host groundwater resources, although the catchments—and hence yield potentials—are smaller (URS 2004). Groundwater recharge to these resources occurs mostly from surface water flows and, less significantly, by direct infiltration as a result of rainfall (DoW 2008).

Regionally, unconfined aquifers occur in alluvial aquifer systems along major river systems within partly calcretised alluvial sediments of the Ashburton and Cane rivers. Dune beach sands also host unconfined aquifers. Groundwater flow is to the north-west, towards the coast, with groundwater levels typically less than 10 m below ground level in inland areas and within a few metres of (or at) ground surface near the coast. Shallow groundwater is generally brackish with total dissolved solids (TDS) of around 6,000 mg/L, increasing to become saline towards the coast (>10,000 mg/L TDS). Fresh groundwater resources may occur locally near major river systems (Wheatstone ERMP Chapter 6) (Chevron 2010).

Typically the alluvial successions of the superficial formations are less than 30 m in thickness and at greatest thickness beneath the river systems. Groundwater yields from the superficial formations are moderate to small. Minor groundwater resources occur along the smaller rivers such as the Maitland and Harding. Elsewhere on the coastal plain, pastoral supplies of brackish to saline groundwater are drawn from low-yielding bores and wells. Low salinity groundwater from alluvial palaeochannel aquifers beneath the Cane, Yule and De Grey rivers is currently used for the Onslow town water supply (URS 2009c).

Groundwater is also hosted in aquifers in the deeper Carnarvon Basin successions. Confined aquifers underlying the Wheatstone Project site are formed by the Windalia Radiolarite, Birdrong Sandstone (confined by the Muderong Shale) and Mungaroo Formation (URS 2009c).

Most of the aquifer systems are untested locally except for the superficial formations, however the Birdrong Sandstone is a major regional aquifer and has been utilised locally to supply industrial quality

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groundwater. It is located in the vicinity of Onslow approximately 350 m below ground level and dips to the north-west. It is predominantly a glauconitic sandstone with minor siltstone and conglomerate, and generates yields of between 500 and 4,500 kL/day across the Carnarvon Basin. The groundwater in the sandstone under Onslow is saline with TDS of 12,000 mg/L increasing to 30,000 mg/L TDS offshore (URS 2010a).

Within the intertidal zone shallow saline groundwater conditions occur that are maintained by tidal inundation. The groundwater salinities in mangrove and mud flats areas are linked closely to the relative influence of tidal inundation (as determined by tidal elevation), and a natural gradient of salinities occurs across the tidal flat in response to differences in tidal inundation patterns (Semeniuk 1983). These salinity gradients are an important factor in regulating the distribution of mangrove species and assemblages. Salinity data collected in the various studies on the Pilbara coast show that a gradient of increasing salinities exist from the seaward or tidal creek fringing mangrove zone through to the more landward mangrove zones and then out across high tidal mud flats and samphire zone. Data obtained from similar mangrove habitats on the Pilbara coast showed that salinities increased from approximately 40-55 ‰ (*Rhizophora* zone) to approximately 70-90 ‰ TDS (Total Dissolved Salts) in the low open *Avicennia* shrubland (Semeniuk 1983; LDM 1998).

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Intertidal Habitats of the Study Area

The distribution of the various intertidal habitats and adjacent supratidal areas has been mapped and is provided in an overview map (Figure 4-1) and detailed mapping in Figures 4-2 and 4-3 for the Hooley Creek – Four Mile Creek tidal embayment and the Ashburton Delta respectively. Estimates of the areas (ha) occupied by the intertidal habitats have been calculated from the mapping and are provided in Table 4-1.

Sections 4.1 to 4.8 describe the characteristics of each habitat with respect to their physical and biotic attributes. These habitats are:

- sandy beaches
- sand bars and shoals at the mouth of tidal creeks
- rocky shores
- mangroves
- lagoon flat,

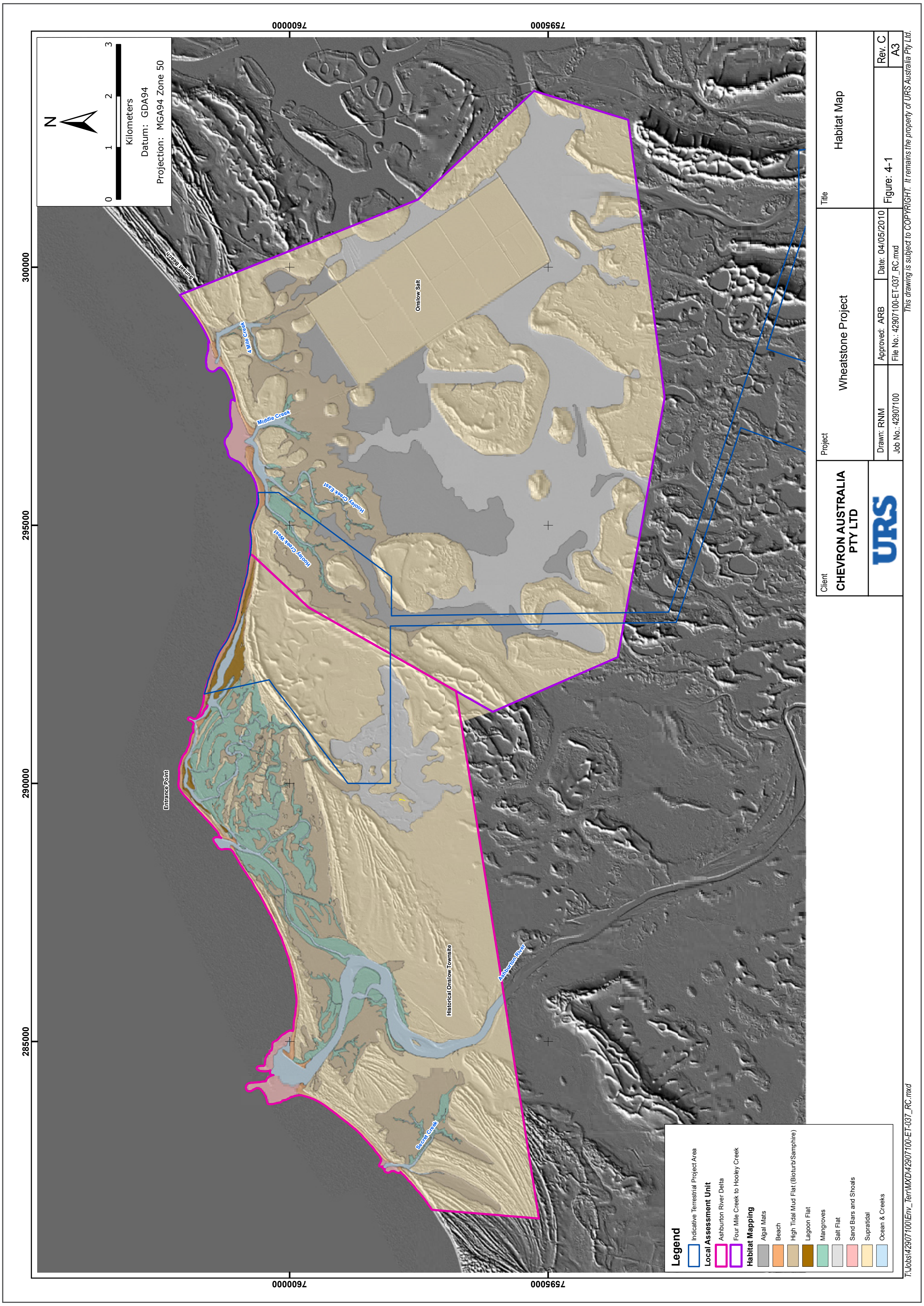
and a large high tidal mud flat unit (i.e. mud flat areas located further landward of the mangrove-fringed tidal creeks) which contains the habitats of:

- bioturbated mud flats with samphire communities
- algal mats
- supratidal salt flats.

Table 4-1 Estimates of areas occupied by the intertidal habitats

Intertidal habitat	Hooley – Four Mile Creek (ha)	Ashburton Delta (ha)
Beach	40	86
Sand bars and shoals at the mouth of tidal creeks	42	48
Mangroves	83	526
Bioturbated mud flats with samphire communities	637	679
Algal mats	815	0
Supratidal salt flats	1,753	296
Lagoon flat	0	48

It should be noted that the distribution of some intertidal habitats is likely to be both temporally and spatially dynamic due to aspects related to coastal processes and coastal stability (as described in Section 3.2) and the mapping depicted in Figures 4-2 and 4-3 represents the distribution of habitats captured by the February 2009 imagery.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Kilometers
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Projection: MGA94 Zone 50
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Sunset Beach
4 Mile Creek
Middle Creek
Hooley Creek East
Hooley Creek West
Onslow Salt
Entrance Point
Historical Onslow Townsite
Ashburton River
Beadon Creek
Legend
Indicative Terrestrial Project Area
Local Assessment Unit
Ashburton River Delta
Four Mile Creek to Hooley Creek
Habitat Mapping
Algal Mats
Beach
High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Mangroves
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
Client
CHEVRON AUSTRALIA PTY LTD
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Project
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Title
Habitat Map
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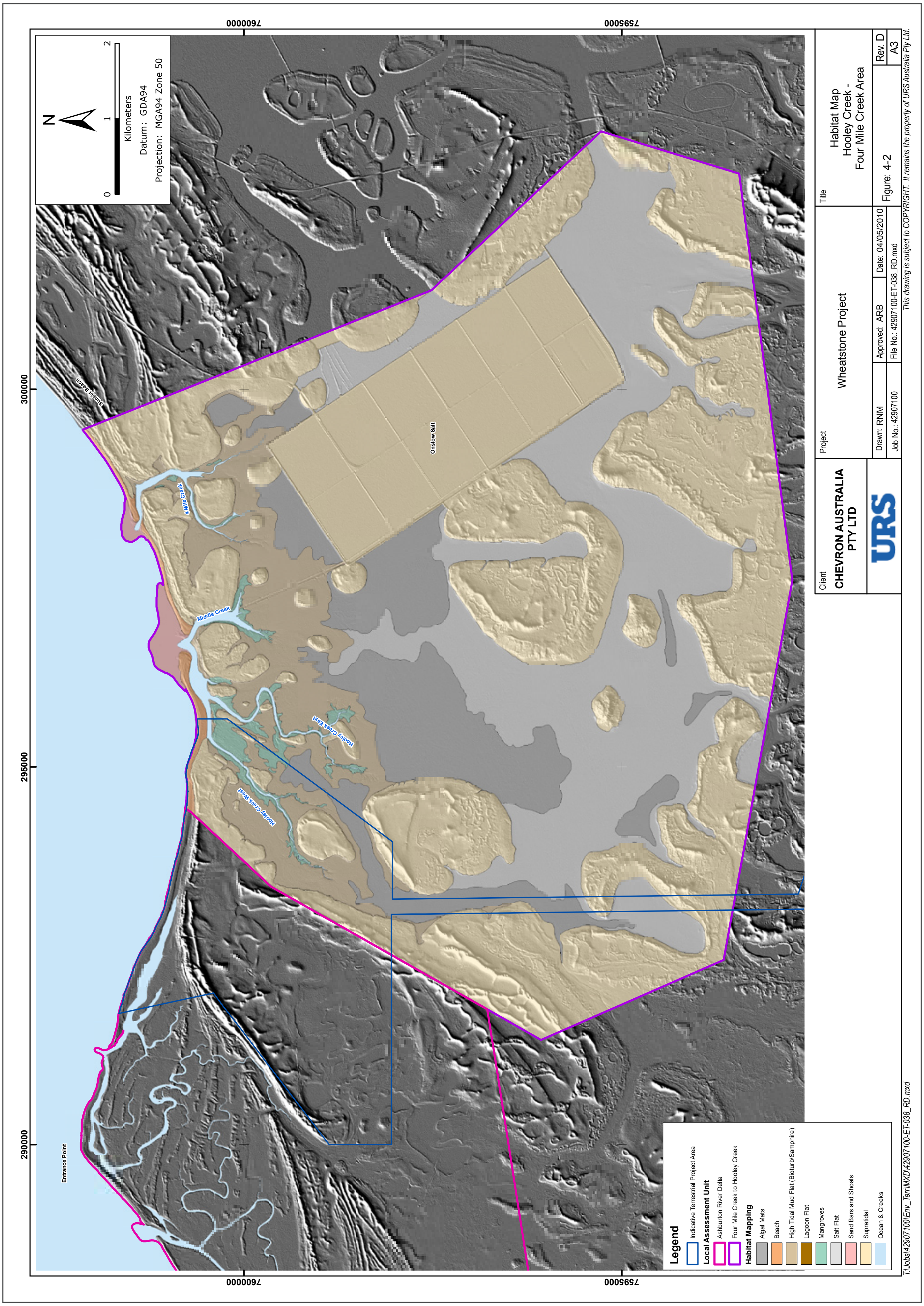

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High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Mangroves
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
Client
CHEVRON AUSTRALIA PTY LTD
Project
Wheatstone Project
Title
Habitat Map
Hooley Creek -
Four Mile Creek Area
Drawn: RNM
Approved: ARB
Date: 04/05/2010
Figure: 4-2
Rev. D
Job No.: 42907100
File No.: 42907100-ET-038_RD.mxd
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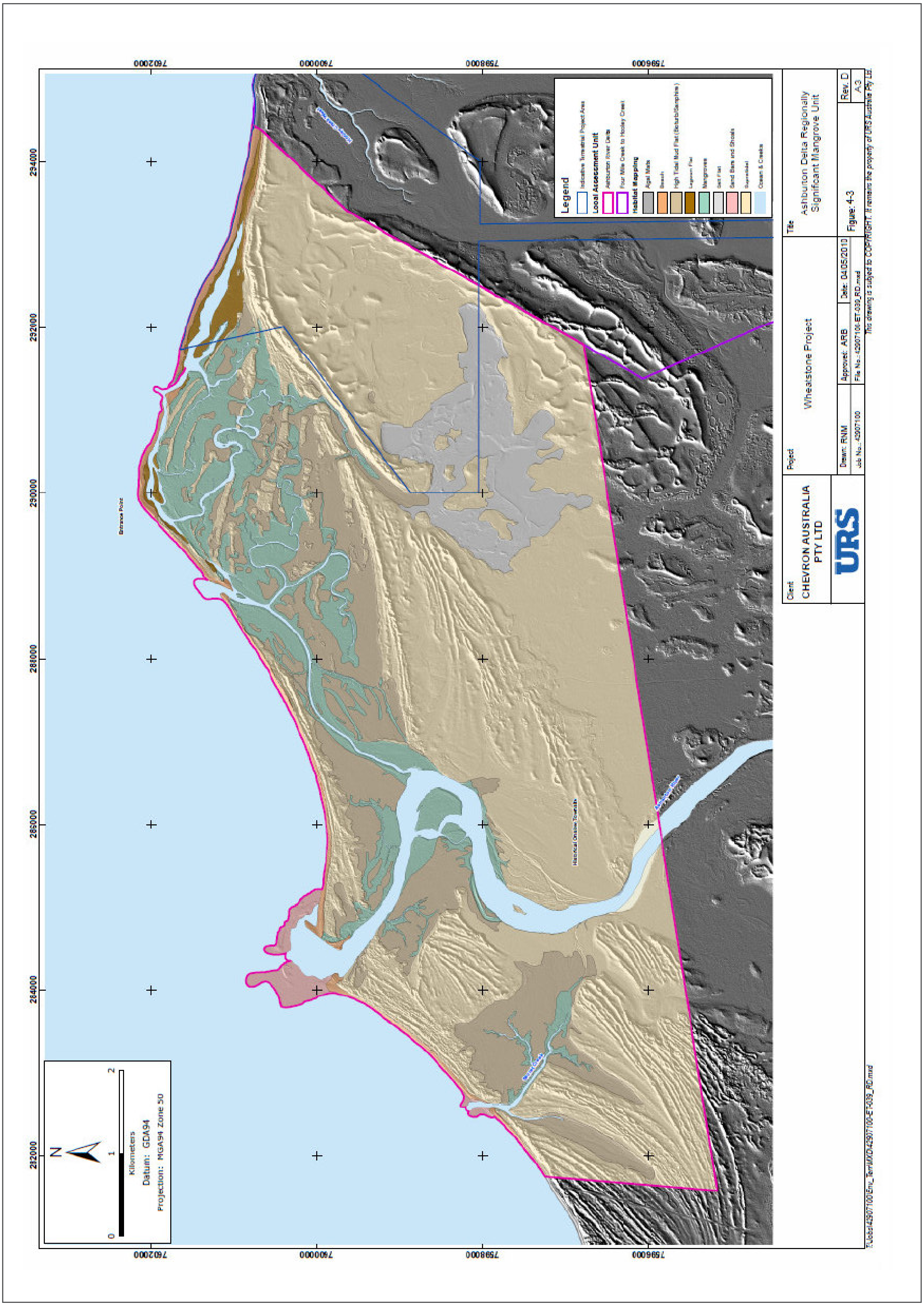
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CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Ashburton Delta Regionally Significant Mangrove Unit
Drawn: RNM
Approved: ARB
Date: 04/05/2010
Figure: 4-3
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4 Intertidal Habitats of the Study Area

In the following sections a general account is given of medium/small-scale geomorphic habitats and their biota observed within the study area, following the classification of biogeomorphic units proposed by Semeniuk (1986). It is common practice to apply a two or three tiered system to habitat classification, using tidal level and geomorphic units at the upper levels and, where necessary, biotic assemblages or conspicuous species at the third level, for example: "high tidal mud flat with samphire" or "lower littoral rock pavement with coral community". This approach is followed in this report using the terminology of geomorphic units proposed by Semeniuk (1986).

Descriptions and coordinates for each of the 46 sites visited during the surveys, together with information collected on mangrove and samphire and other halopyhtic plant assemblages, are provided in Appendix A. Information on the invertebrate fauna recorded from the sites is provided Appendix B, together with notes on their geographic distributions and micro-habitats.

The frequency of tidal inundation across the intertidal zone is an important determining factor that controls the distribution of habitats. Hence a series of cross section profiles are provided within Section 4 to schematically represent the position various habitats occupy and the relationship to tidal elevation and frequency of inundation.

4.1 Sandy beaches

Six beach transect sites were spread along the coast between Sunset Beach near Onslow and Entrance Point (Figure 2-1). They were remarkably consistent in profile and sediment characteristics and fauna.

The beaches comprised fine, well sorted sand with a near-horizontal supratidal ramp and a steep intertidal beach slope (Plate 4-1). There was a conspicuous 'black mineral sand' component that formed distinct bands on the seaward beach slopes in some locations. There was very little change of slope from the upper to lower intertidal zones, except for a transient escarpment 20-40 cm high, cut into the upper slope by the previous high tide. The surface of the beach slope was very smooth without bioturbation except for occasional crab burrows. There was no mid-lower littoral sand flat, the beach simply sloping into the sublittoral zone.

Along the top of the beach ridge of all the sites studied, there were large numbers of mollusc shells, mostly bivalves. By far the most abundant species was the semi-twisted arc shell *Trisidos semitortus*. While it was clear that some of the shells were of recent origin derived from living populations in the adjacent subtidal zone, it is believed that the majority are re-worked from the underlying Holocene shell beds, i.e. the deposit is primarily a post-mortem assemblage.

Sand beaches, composed of medium to coarse-grained calcareous sands and shelly sands, are widespread along the coastline. The beaches are backed by low foredunes (vegetated by coastal species, e.g. *Spinifex longifolius*, *Rhagodia preissii* and *Ipomea brasiliensis*) which front parabolic dune blowouts or vegetated parallel dune systems (e.g. the long curving beach between the Ashburton River mouth and Entrance Point).

The fauna of the seaward beach slopes throughout the study area was extremely limited in all the transects and at all sites visited. With the exception of the alluvial fans, sand flats were not developed along this coast and that usually species-rich element of the regional fauna was missing (at least in the intertidal zone). The beach habitat comprised only the steep beach slope covering the entire upper to lower littoral profile.

The most common and conspicuous invertebrates observed in this beach slope habitat were the ghost crab (*Ocypode ceratopthalmus*) (Plate 4-2) and the predatory naticid gastropod *Polinices conicus*.

Burrows of the ghost crab were common near MHWS and on the slope. Large numbers of these animals were observed several times at extreme low tide foraging along the water line. Burrows of colonies of a bubble crab *Scopimera* sp. were observed at several locations.

Polinices conicus were common tracking in smooth sand at the bottom of the slope, close to MSL. Also seen in this habitat were the filter-feeding bivalve *Donax* sp. but that species was not common. No other molluscs were seen.

No evidence of turtle nesting was seen.

Plate 4-1

Plate 4-2

Plate 4-1 **Typical beach habitat with numerous washed-up arc shells (*Trisidos semitortus*).**
Plate 4-2 **The ghost crab (*Ocypode ceratopthalmus*) - common to beach habitats in the study area.**

4.2 Sand bars and shoals at the mouth of tidal creeks

A series of sand bars and shoals have formed at the mouth of tidal creeks and the Ashburton River where fine to medium-grained sands have been deposited and re-worked into small delta-shaped formations (Plates 4-3 and 4-4). In the regional context, while the areal extent of the sand bars and shoals was limited, these areas were consistent in their formation and characteristics at the sites where they were encountered (i.e. the mouth of Secret Creek, Ashburton River, Entrance Point, Hooley Creek, Middle Creek, Four Mile Creek). They comprised fine grey sand that was rippled in the lower areas but smooth where there was a little elevation. The sand appeared to be the same material as that on the beach slope, though slightly different in colour.

Like that of the beach slopes, the fauna of sand bars and shoals at the mouths of the river and tidal creeks was found to be extremely restricted. *Polinices conicus* and *Donax* sp. were both present (all juvenile). Also present, though uncommon, were juveniles of the scavenging gastropod *Nassarius dorsatus* and a small, detrital-feeding, clypeastoid echinoid (“sand-dollar”). Colonies of a bubble crab, *Scopimera* sp., were seen at several localities. A bright green polychaete worm was common crawling in shallow pools. The only other living invertebrate seen was a single specimen of a pebble crab (unidentified).

4 Intertidal Habitats of the Study Area

Plate 4-3

Plate 4-4

Plate 4-3 **Sand bars and shoals at the mouth of Four Mile Creek have formed a small delta-shaped deposit.**

Plate 4-4 **Sand bar at the mouth of the Ashburton River.**

4.3 Rocky shore / reef flat

This habitat is not well-developed along the sandy Onslow Coast, although extensive rock platforms occur around the shores of most of the nearshore islands in the region (URS 2010b).

a) Beach rock outcrops

At the time of the November 2008 survey, west of the Hooley Creek mouth (Site 6) a short and narrow, sloping, intertidal limestone ramp was exposed at the base of the beach slope, presumed to be either Holocene beach rock or Pleistocene limestone (Plate 4-5). This was clearly sand scoured and a hostile habitat for the organisms that normally live in rocky shore habitat. During flights along the coast between Tubridgi Point and Coolgra Point, small stretches of similar rock platforms were seen.

b) Rock platforms

At Beadon Point (Site 16) an intertidal exposure of limestone formed a wide rock platform with a moderately well-developed rocky shore fauna and flora (Plate 4-6). In this location there was no upper littoral rock bench and that part of the rocky shore community was missing. Instead there was a steep beach slope in the upper littoral zone with a narrow, muddy sand flat at its base. The inner rock platform (i.e. mid littoral) was mud covered and populated only by a low muddy algal turf with very little invertebrate fauna. The outer mid littoral and lower littoral rock platform, however, had a moderately diverse invertebrate fauna and there was moderate, patchy growth of leafy algae and low seagrasses. Some shallow lower littoral pools had small but numerous coral colonies.

4 Intertidal Habitats of the Study Area

Plate 4-5

Plate 4-6

Plate 4-5 **A narrow band of beach rock exposed seaward of the beach at Site 6, immediately west of Hooley Creek mouth**

Plate 4-6 **A wide limestone rock platform at with a moderately well-developed rocky shore fauna and flora (Beadon Point, Site 16)**

At Coolgra Point (Site 44) there was also a limestone outcrop in the mid to upper tidal zone, in this case partially mud-covered and with moderately dense growth of mangroves. The invertebrate fauna observed here was a diverse, mixed assemblage of mangrove and rocky shore species. A more extensive area of limestone platform extended along the north-western shoreline of Coolgra Point.

At Site 14 (between Hooley Creek and Entrance Point) there was a rock bench landward of the current beach/lagoon sequence that was a remnant of a previous rocky shoreline (see Figure 3-3). This site was photographed by a survey team in 1990 when it was the upper part of a narrow but well-developed rock platform with a typical flora and fauna including scattered coral colonies (Plate 21 of LEC 1991). At the time of the 2008/2009 surveys, most of this rock platform was covered by sand with only the rock bench at the high tide level remaining exposed (see the 1991 and 2008 profiles in Figure 3-3). The rocky shore fauna and flora had been obliterated except for a few patches of live rock oysters. None of the characteristic rocky shore, upper littoral littorinid molluscs or barnacles were present there at the time of this survey.

c) Rock bars

At the time of the November 2008 survey, there was a small rock bar exposed in the mouth of Hooley Creek (Site 13). The bar had a rough surface extending from the upper littoral zone into the bottom of the channel. It was heavily covered with mud and supported a very restricted fauna.

Invertebrate fauna

The rock platform at Beadon Point bore a moderate flora and fauna representative of this habitat in the West Pilbara region. On a muddy sand flat at the base of the beach slope the gastropods *Polinices conicus*, *Nassarius dorsatus* and *N*. cf. *clarus*, were present although not common. There was an algal turf on rock pavement of the middle and outer platform and small clusters of seagrass (*Halophylla* sp. and *Thalassia* sp.) in shallow sandy pools. The herbivorous gastropods *Trochus hanleyanus* and *Angaria delphinus* were common in that zone. The barnacle *Balanus* sp. and rock oyster *Saccostrea cucullata*, with their gastropod predators *Morula margariticola* and *Cronia crassulnata*, were present on higher rocks and there was a variety of cryptic molluscs and other invertebrates under stones and ledges.

In shallow pools on the outer platform there were scattered coral colonies, mostly massives like *Goniastrea*, *Favites*, *Favia*, *Pleisiastrea* and *Porites*. Foliose *Turbinaria* spp. were also common. Small colonies of *Pocillopora damicornis* were present but uncommon. Some of the *Porites* colonies were of the flat-topped 'micro-atoll' form. Approximately 15 coral species were seen (not collected for positive identification). These scattered corals growing on the limestone pavement comprised a coral community but not a coral reef.

At Site 6, west of the Hooley Creek mouth, the beach rock habitat was severely sand scoured and populated by a sparse algal turf and a very restricted invertebrate fauna. On higher rocks there were a few patches of the barnacle *Balanus* sp., the mussel *Brachidontes ustulatus* and the gastropod predator *Morula* sp.

4.4 Mangroves

Mangroves in the area occur mostly within river mouth and tidal creek systems where they form a nearly continuous ribbon of vegetation fringing the creek channels. These mangroves are protected and partially isolated from the sea by barrier dune systems through which tidal creeks have breached narrow channels. Areas of mangroves also occur along the outer, coastal shoreline on the western and northern sides of Coolgra Point.

At Hooley Creek, Middle Creek, Four Mile Creek, Beadon Creek, and Second and Third Creeks, mangroves were confined to a narrow fringe adjacent to the creek channel that is typically only 10-20 m wide. More expansive mangrove areas were found at the Ashburton River Delta and Coolgra Point where a far greater area and diversity of habitats suitable for mangrove colonisation existed. Estimates of mangrove areas and species diversity recorded from these locations are provided in Table 4-2.

Table 4-2 Mangrove species and areas for each mangrove system

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

4 Intertidal Habitats of the Study Area

4.4.1 Mangrove flora

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

- *Avicennia marina* – grey mangrove
- *Rhizophora stylosa* – spotted-leaved red mangrove
- *Bruguiera exaristata* – ribbed mangrove
- *Ceriops australis* – spurred mangrove
- *Aegialitis annulata* – club mangrove
- *Aegiceras corniculatum* – river mangrove.

The six species represent four families: Avicenniaceae (*Avicennia marina*), Rhizophoraceae (*Rhizophora stylosa*, *Bruguiera exaristata*, *Ceriops australis*), Plumbaginaceae (*Aegialitis annulata*) and Myrsinaceae (*Aegiceras corniculatum*).

Within the study area, *Avicennia marina* (Grey mangrove) was a widespread and dominant species that occurred within the majority of mangrove associations present. It was found growing monospecifically in many areas and in a range of structural forms (e.g. from dense low forests to open shrubland) (Plates 4-7 and 4-8), but also occurred in association with the other five species in particular locations. The local dominance by *A. marina* reflected the broader regional pattern with this species being the most widespread and abundant mangrove species in the Pilbara coastal region (Semeniuk 1993b).

Plate 4-7

Plate 4-8

Plate 4-7 **Dense low forest of *Avicennia marina* near the mouth of the Ashburton River**

Plate 4-8 **Open shrubland of *Avicennia marina* with samphire vegetation at the landward edge of the mangrove zone**

Rhizophora stylosa was the next most common mangrove species and typically formed dense stands (thickets and low forests) in the lower reaches or more seaward sections of the tidal creek systems, which provide a muddy protected environment that is subject to regular tidal inundation (Plate 4-9). *R*. *stylosa* occurred mostly as monospecific stands but in some areas was mixed with taller *A. marina*.

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Both aerial photography and ground survey confirmed that the most extensive stands of *R. stylosa* occurred along the Coolgra Point main channel and in the north-eastern sector of the Ashburton Delta where they lined the tidal creeks and tributaries draining into lagoons near Entrance Point. This species is relatively widespread along the Western Australian coastline, occurring from the Kimberley to Exmouth Gulf.

Ceriops australis was less common than the above two species and typically occurred in association with *A. marina* to form open scrub along the landward margin of the mangrove zone in locations either where the mangrove zone intergraded with the high tidal mud flat (samphire/bioturbated habitat) or along the mangrove – hinterland fringe or along the margins of cheniers (supratidal sand deposits occurring with mangrove and tidal flat areas) (Plate 4-10). This species is considered a minor species in terms of abundance along the Pilbara coast, however, it occurs regularly in the more landward sections of the mangrove creeks. Within Western Australia it is distributed from the Kimberley to Exmouth Gulf, and is common across the north of Australia and extends down the east coast to southern Queensland.

Plate 4-9

Plate 4-10

Plate 4-9 ***Rhizophora stylosa*** **fringing a small tidal creek near entrance point**
Plate 4-10 ***Ceriops australis*** **occurring along the landward margin of the mangrove zone**

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

Stands of the river mangrove (*A. corniculatum*) were locally common in some parts of the Ashburton Delta, particularly the central and north-eastern sectors where it formed a narrow band (~ 2-5 m wide) along the tidal creeks. The meandering pattern of channel development evident in many of the tidal creeks and tributaries in the delta (Figure 3-1), had led to differences in species composition between opposite banks. Thus the gently shelving, prograding banks of the 'point bar' generally displayed a higher species diversity compared with the steep and eroding edges of the opposite shore (i.e. on the cut bank). In these circumstances *A. corniculatum* were usually present on the shallower slopes of the prograding bank and typically absent from the cut bank. The club mangrove (*A. annulata*) occurred as an understorey species to *A. marina* on some locations but was not widespread.

The ribbed mangrove (*Bruguiera exaristata*) was recorded from only two sites (Site 20 – Ashburton Delta; Site 44 - Coolgra Point) during the surveys. It occurred as a minor species amongst a dense *A. marina* dominated tall shrubland (Plates 4-11 and 4-12). In addition, *B. exaristata* was also recorded during a 1990 survey of the Ashburton Delta in a similar locality (transect T in LEC 1991) to Site 20 within the north-east sector of the delta. At all three sites, *B. exaristata* occurred only as isolated stands consisting of approximately 10-15 trees.

Plate 4-11

Plate 4-12

Plate 4-11 ***Bruguiera exaristata*** **occurs in a few isolated stands at Coolgra Point and the Ashburton Delta**

Plate 4-12 **Fruit and hypocotyl of** ***Bruguiera exaristata*** **(Site 20, Ashburton Delta)**

Salt tolerant halophytic shrubs (i.e. non-mangrove species) were a conspicuous component of the vegetation within the mangrove zone at several locations (see Plate 4-8), while they were largely absent in others. Where present, these shrubs were established at varying degrees across the tidal gradient. Close to tidal creeks, they usually comprised a single species such as *Hemichroa diandra* occurring as an understory or heath amongst *A. marina* mangroves. Sometimes *H. diandra* extended beyond the mangrove shrubs and partly down the slope of the tidal creek bank. Halophytic vegetation within the mangrove zone was common amongst the more landward *A. marina* open shrubland and consisted of a mixture of species (e.g. *H. diandra*, *Halosarcia halocnemoides* and *Halosarcia pruinosa*). Like the mangroves, the halophytic shrubs recorded during the survey were typical of those found in similar habitats in other mangrove environments on the Pilbara coast (Craig 1983; Biota 2005) and have been recorded for the Onslow area in previous surveys (Paling 1990; LEC 1991).

4.4.2 Mangrove associations and their distribution

Tidal exchange and flows are the dominant and prevailing processes that maintain the Pilbara mangroves as they regulate many of the physical, chemical and biological functions. Groundwater and sediment salinity gradients are established across the tidal flats in response to decreasing frequencies

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of seawater (tidal) recharge with increasing tidal flat elevation, and these gradients have produced recognisable structural and physiognomic zones or associations within the mangroves. The five mangrove associations used for the detailed mangrove mapping were consistent with those mapped along the eastern side of Exmouth Gulf by Biota (2005). This similarity in mangrove associations reflects the similar mangrove habitats occurring along concurrent sections of the coast that are subject to the same factors that influence or determine the type and distribution of mangroves (e.g. very similar or identical tidal regime). This consistency in mapping between the two studies from adjacent coastal sectors can help establish a more detailed level of mangrove mapping over a larger area of coast than was available previously and provide regional context.

The mangrove associations and the area they occupied within both the Ashburton Delta and Hooley Creek area are shown in Table 4-3. Codes used to denote the various associations reflect the dominant mangrove species. Detailed mapping of mangrove associations is provided in Appendix C.

Table 4-3 Mangrove associations recorded from areas adjacent to the Project study area

Code	Association	Ashburton Delta (ha)	Hooley Ck – Four Mile Ck area (ha)
Am1	Tall dense *Avicennia marina* fringing major tidal creeks and seaward margins	70	-
Am2	Low to moderate, dense *Avicennia marina* shrubland	257	35
Am3	Low, open to very open *Avicennia marina* on landward margins	146	47
AmRs	Mixed, tall *Avicennia marina/Rhizophora stylosa* low forests and thickets	38	1
Rs	Mixed, dense *Rhizophora stylosa* low forests and thickets	15	0
	Total	**526**	**83**

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

This association was typically limited to locations along the major tidal creeks and the river channel of the Ashburton Delta and the lower reaches of other tidal creeks (Plate 4-13). The structure of this association varied from dense thickets (2-4 m high) to low forests (4-5 m high). In the Coolgra Point area, low forests of *A. marina* occurred along the coastal shoreline (e.g. western side of Coolgra Point) and both dense thickets and low forest fringed much of the main channel that separates Coolgra Point from the mainland.

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

Together with the more open shrubland unit (Am3), this association was the most widespread in the study area. It occurred as a fringe along the mid-upper reaches of the tidal creek systems and in some areas also extended landward across tidal flats from behind the taller associations (units Am1, AmRs, Rs) (Plate 4-13). This association was predominantly monospecific *A. marina*, approximately to 2 m in height and with a variable moderate to dense canopy cover. This unit was often backed by, and intergraded with, the open scrub unit (Am3) described below (Plate 4-14).

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

Extensive areas of this unit occurred along the uppermost reaches of the tidal creeks and at the landward extent of the mangrove zone on tidal flat areas (Plate 4-14). As tidal elevation increased and the frequency of inundation decreased, the density of trees within these areas became generally low to scattered and they grew in a stunted, recumbent form due to high soil salinities that were approaching (or at) the threshold level tolerated by mangroves. Areas of low open *A. marina* scrub mangroves were often interspersed with the high tidal mud flat habitat (samphire and bioturbated mud flat zone) described in Section 4.5.

Plate 4-13

Plate 4-14

Plate 4-13 Low dense *Avicennia marina* forests (Am1) along main channel in the Ashburton Delta. Further away from the channel the mangroves grade into dense *Avicennia marina* shrubland (Am2)

Plate 4-14 Open *Avicennia marina* scrub interspersed with samphire communities

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

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

Tall dense *Rhizophora stylosa* thickets or low forests (Rs)

Low forests and dense thickets of monospecific *R. stylosa* were observed in the seaward or lower sections of the larger tidal creek systems and in the north-eastern sector of the Ashburton Delta (Plate 4-15). Within the tidal range occupied by mangroves, the dense *R. stylosa* stands usually occurred close to the lower limit of mangrove occurrence and in areas of muddy substrates. This is typical of the position occupied by *R. stylosa* in the Pilbara region (Semeniuk 1983).

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Plate 4-15

Plate 4-15 Entrance Point area showing dense *Rhizophora styosa* (dark green areas) amongst dense *Avicenna marina* (lighter green areas)

Other mangrove habitats

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

Factors controlling mangrove distribution

Mangroves in the study area occupied the section of the intertidal gradient that was approximately between Mean Sea Level (1.5 m Chart Datum or 0 m AHD) and an elevation of approximately 2.2 m CD (0.7 m AHD), a level between Mean High Water Neaps (1.8 m CD or 0.4 m AHD) and Mean High Water Springs (2.5 m CD or 1.0 m AHD).

4 Intertidal Habitats of the Study Area

The relationship between tidal elevation and frequency of tidal inundation plays a central role in controlling the distribution of mangrove species and assemblages by developing salinity gradients across the tidal zone. Inundation by seawater during flood tides is the main recharge mechanism that regulates the intertidal zone with lower salinities occurring in mangrove areas of lower tidal elevation (e.g. lower reaches of tidal creeks and more seaward locations). The salinity gradients influence both the occurrence of the different mangrove species (due to differing salinity tolerance limits) and the mangrove community structure. This factor largely determines the zonation of mangrove associations shown in the schematic profile below (Figure 4-4) and as shown in the detailed mangrove association mapping provided in Appendix C. Data obtained from similar mangrove habitats on the Pilbara coast show that salinities increase from approximately 40-55‰ (ppt) at the more seaward areas (e.g. seaward and taller *Avicennia* zone and *Rhizophora* zone) to approximately 70-90‰ in the more landward sections of the mangrove zone where low open *Avicennia* shrubland occurs (Semeniuk 1983; LDM 1998, Biota 2005). The dominant species in the study area (*Avicennia marina*) has the greatest salinity tolerance of the Pilbara mangrove species and occurs in areas where groundwater salinity reaches up to 90‰ (approximately 2.5 times seawater) (Gordon 1988).

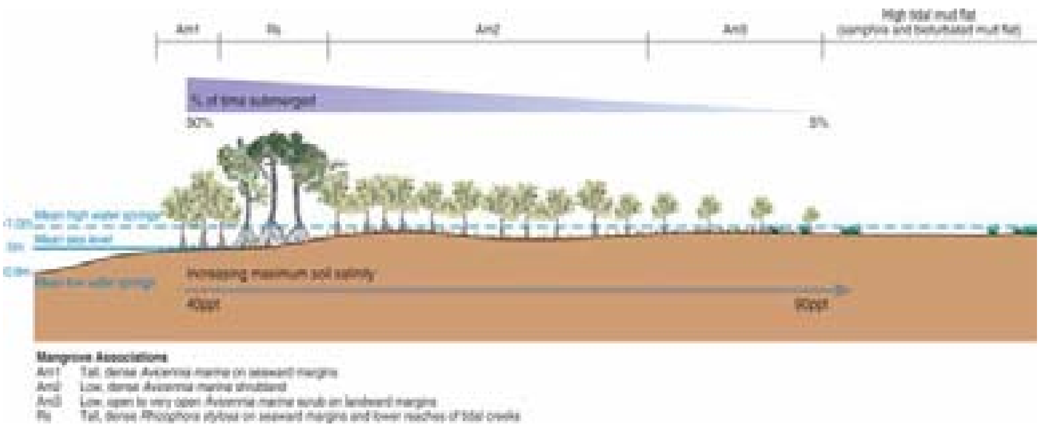

Figure 4-4 Distribution of mangrove associations in relation to the salinity gradient

With increasing tidal elevation through landward sections of the mangrove zone, the reduction in tidal inundation in combination with high evaporation rates results in groundwater and soilwater conditions (including salinity) that are beyond the threshold tolerated by mangroves. In these areas the mud flats are devoid of mangrove vegetation and the habitat becomes a zone of bioturbated mud flat with scattered patches of samphire (see Figure 4-4) as described in Section 4-5. Plate 4-16 shows an aerial view of the mangrove zonation described above and represented schematically in Figure 4-4.

4 Intertidal Habitats of the Study Area

Plate 4-16

Plate 4-16 Coolgra Point main channel. Aerial view shows the typical zonation through the mangrove zone to the high tidal mud flat - bioturbated/samphire zone (brown areas)

While the model of mangrove distribution across the tidal creek to high tidal mud flat zone described above accounts for the majority of mangrove habitat within the study area, variations to this scenario occur, particularly in the eastern sector of the Ashburton Delta where the presence of cheniers provides localised freshwater seepage at their margins with the surrounding tidal flats and with a different substrate type (calcareous sands) (see Figure 4-5).

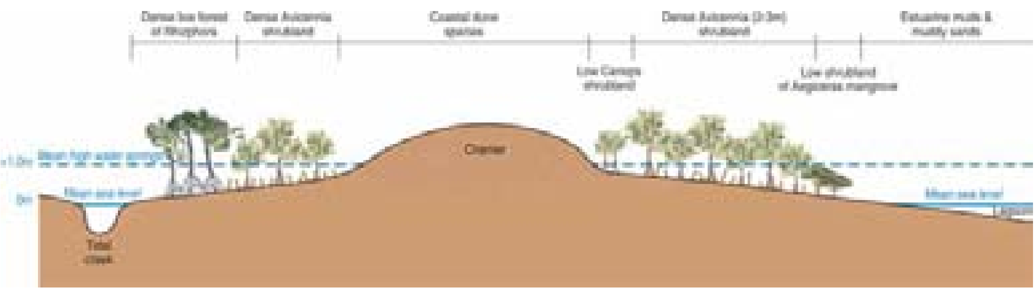

Figure 4-5 Surveyed profile showing the chenier-mangrove-lagoon sequence at Site 32

Freshwater input from hinterland flood events and groundwater seepage can be important in reducing salinities and delivering nutrients to mangroves in more tropical locations (Semeniuk 1983). In tropical Australia this has resulted in the development of a particular mangrove zone (the hinterland fringe zone) that is dependent to a large extent on freshwater input from hinterland sources to maintain suitable groundwater/soilwater conditions (Semeniuk 1985; URS 2005). The importance of freshwater input in maintaining mangrove systems generally decreases with increasing aridity (Semeniuk 1983; Gordon 1988). A recent study in the adjacent (and similar) mangrove habitats on the east side of Exmouth Gulf concluded that freshwater input related mechanisms appear to be of negligible importance in the routine maintenance of mangrove systems with the tidal flat systems being considered as a 'dry' estuary, due to the high evaporation rate, small catchment, low rainfall and lack of perennial runoff (Biota 2005). This conclusion is also applicable to the tidal flat systems in the Onslow area as evidenced by the lack of mangroves along the margin of the salt flat and the hinterland, indicating that this is a typical arid zone mangrove system of Semeniuk (1983), with no freshwater groundwater flow from the hinterland. Therefore, it is the tidal exchange and associated groundwater recharge function that regulates salinities and provides for the maintenance of the mangrove zone.

4.4.3 Mangrove invertebrate fauna

The mangrove zone is one of moderately high invertebrate fauna biodiversity and high primary productivity. The ecosystem comprises a suite of mangrove species and a suite of invertebrate and fish species that, together, make up a 'mangrove assemblage' that is characteristic of tropical coastal and estuarine habitats throughout the Indo-West Pacific region (see Section 5.1).

Key invertebrate species representing a typical 'mangal assemblage' were present in the mangal flat habitats of the study area but, with the exception of the burrowing ocypodid and sesarmid crabs, they were relatively low in species diversity and sparse in abundance.

Most of the mangal-obligate mollusc species expected in this habitat were present but they were very patchily distributed and rare. No oysters (*Saccostrea*) or mussels (*Brachidontes*) were observed. The littorinids normally abundant on trunks and branches of the mangrove trees were extremely rare. The only species seen were *Littoraria articulata* on dead mangroves trunks on the beach front at Site 22, and *L. cingulata* at Sites 8, 17 and 24. Small colonies of the potamidids *Cerithidea reidi* (grazing on mangrove trunks) and *Terebralia palustris*, *T. semistriata*, *Telescopium telescopium* and *Cerithidea largillierti* (ground-dwelling detritivores) were seen but none were common and they were absent at most sites.

Within the mangrove zone, however, there was a moderately diverse and abundant fauna of burrowing crabs (families Ocypodidae and Sesarmidae). These detritivores are key secondary producers in the mangrove ecosystem. The ocypodid crabs *Uca flammula* and *U. elegans* were very common and widespread along the muddy banks of the creeks (Plates 4-17 and 4-18). Three other species of *Uca* (*U. dampieri*, *U. capricornis* and *U. mjobergi*) were also common but patchy in their distributions. The sesarmid species, *Neosamartium meinerti* and *Parasesarma* sp. were also abundant at most mangal flat sites throughout the study area. *Perisesarma semperi* (Plate 4-20) and *Perisesarma* sp. were also present at some sites.

A predatory grapsid crab, *Metopograpsus frontalis* was abundant at nearly all the mangal flat sites, running on the surface among the tree roots or hiding under logs (Plate 4-19). The mangrove portunid crab *Scylla serrata* was commonly seen in the tidal creeks and sometimes burrowing on the muddy banks. Both these crabs are common and widely distributed in the Indo-West Pacific region.

Three species of barnacles were found on mangroves, none of them common within the study area. One, *Fistulobalanus* n.sp., an undescribed species also known from the Dampier Archipelago, was found at one site on the banks of the Ashburton River. It is probably a mangal-obligate. The non-mangal-obligate barnacles *Chthamalus malayensis* and *Microeuraphia withersi* were found on mangrove trunks in the sea-front mangal at Coolgra Point but not within the Ashburton Delta or Hooley Creek areas.

The fish known as mud-skippers (*Periopthalmus* spp.) are often conspicuous living in shallow pools and gutters within the mangrove zone and immediately adjacent tidal flats. Specimens were collected but identification is pending.

Plate 4-17

Plate 4-18

Plate 4-19

Plate 4-20

Plate 4-17 ***Uca flammula*** **– a very common fiddler crab that lives along the muddy banks of tidal creeks**

Plate 4-18 ***Uca elegans*** **– an abundant fiddler crab in the mangroves and high tidal mud flats. Feeds on minute plant species gathered from the mud flat**

Plate 4-19 ***Metopograpsus frontalis*** **- a common predatory graspid crab that hunts its prey among the mangroves and adjacent samphire flats**

Plate 4-20 ***Perisesarma semperi*** **– a marsh crab that is very common on mangal flats. A detritivore that gathers plant material from the mangrove floor**

4.5 Bioturbated mud flats with samphire communities

Landward of the mangrove zone, large areas of mud flats typically extend to the hinterland margin or merge with the supratidal salt flats. These mud flat areas occur in the upper or higher sections of the intertidal zone and hence are not regularly inundated by tides. Two habitat types are recognised within the mud flats:

- bioturbated mud flats with samphire communities (described below)
- algal mats (described in Section 4.6).

Together with the mangrove habitat, the two habitats above have been considered as BPPH for the purposes of the Wheatstone environmental assessment. The samphire plants and algal mats, like mangrove trees, are primary producers in the strict sense while the bioturbated mud flats are areas of

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high secondary production essential to the output of nutrients by the plants in the ecosystem. The bioturbated/samphire zone is a mappable habitat and it is usually possible to distinguish from adjacent algal mat areas, however, the boundaries between samphire communities and bioturbated areas are often indistinct (or often interspersed within the same area) and hence they have been mapped together in this study.

At locations where the extent of mud flat development was limited or truncated by the hinterland or low islands, algal mats did not occur and the bioturbated/samphire mud flat habitat occupied the full extent of the mud flat zone between the landward edge of the mangroves and the hinterland margin. The schematic profile shown in Figure 4-6 presents this scenario. During both ground and helicopter-based surveys it was noted that high tides above 2.2 m CD (0.7 m AHD) were required to inundate these areas. In many locations this habitat was hundreds of metres wide, while in others the bioturbated/samphire mud flat habitat zone was only a few metres wide and abutted the base of supratidal sandy cherniers or dunes with a well-defined high tide mark.

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

- bioturbated mud flats - devoid of macro-vegetation but heavily worked-over by burrowing crabs (Plate 4-21)
- samphire flats and/or discrete patches of samphires - dominated by halophytic shrubs but with some crab burrows (Plate 4-22).

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

Invertebrate fauna

In gutters and shallow pools along the inner margins of high tidal mud flats, close to the back line of mangrove trees/shrubs, there were sometimes colonies of the detrital-feeding potamidid gastropods *Terebralia semistriata*, *Cerithidea largilliertii* and *Cerithideopsila cingulata*, the latter sometimes in large numbers. However, compared with this habitat in the Kimberley and other more northern regions, such colonies were uncommon. No other living molluscs were observed in this habitat anywhere within the study area.

Ocypodid and sesarmid crabs were extremely abundant in this habitat at almost all the sites visited. Fiddler crabs of the genus *Uca* were present in vast numbers over wide areas of the high tidal mud flats and accounted for most of the bioturbation there. They feed by scraping micro-flora and fine organic particles from the mud surface. Most abundant and almost ubiquitous throughout this habitat was *Uca elegans*. Less common, and usually found on narrow high tidal mud flats abutting sand dunes or cheniers, was *U. mjobergi. Uca dampieri* and *U. capricornis* were also uncommon and found on creek banks or close to the mangrove tree line.

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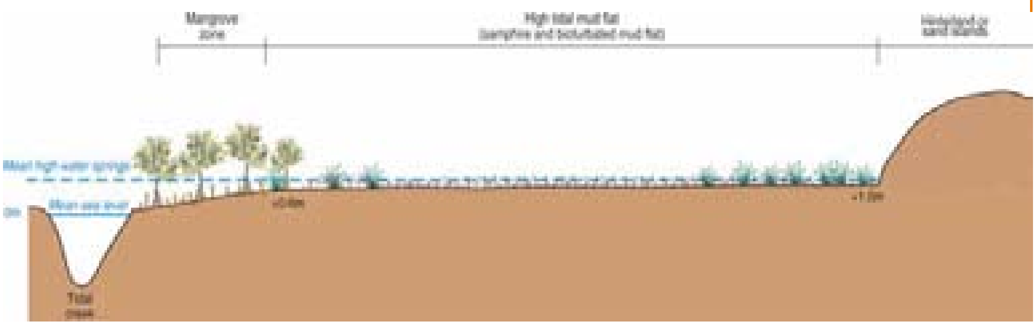

Figure 4-6 Schematic profile showing the high tidal mud flat truncated by the hinterland

Plate 4-21

Plate 4-22

Plate 4-21 Bioturbated mud flats showing numerous crab burrows
Plate 4-22 Patches of samphire plants amongst bioturbated mud flats

Also present along the fringe of narrow high tidal mud flats that abutted sand cheniers or dunes was the large ocypode ghost crab *Ocypode fabricii* which dug conspicuous burrows in the sandy substrate and foraged for plant detritus in the dunes above high tide mark. This was not the same species of ghost crab found along the open beaches.

The four species of sesarmid crabs were also conspicuous burrowers across the width of the high tidal mud flats. The larger of them, *Neosarmatium meinerti*, made large, hooded burrows (Plate 4-24). The others, *Parasesarma* sp., *Perisesarma semperi* and *Perisesarma* sp. (Plate 4-23), made smaller turreted burrows. These crabs tend to make their burrows beneath samphire shrubs. They collect detrital plant material from the mud flat surface and drag it down into their burrows where they shred and consume it, thereby distributing organic material deep into the soil profile.

Two small and inconspicuous species of ghost shrimps were found in the bioturbation zone, *Upogebia giralia* is fairly common in northern Australian mangroves and was found at one site within the study area (Site 4, west arm of Hooley Creek). The other was a new species of *Lepidopthalmus* found at one site in the Ashburton Delta (Site 36). This genus had not previously been found in Australian waters. It is likely that both these were widespread in the high tidal mud flat habitats of the study area.

Plate 4-23

Plate 4-24

Plate 4-23 ***Parasesarma*** **sp. nov. - a marsh crab common on mangrove and adjacent mud flats. A detritivore that gathers plant material from the mangrove floor.**

Plate 4-24 **Large, hooded burrow of *Neosarmatium meinerti***

4.6 Algal mats

At locations where expansive mud flats extended further landward of the bioturbated/samphire habitat, areas of cyanobacterial mats, also referred to as algal mats, occurred. The schematic profile shown in Figure 4-7 presents this scenario.

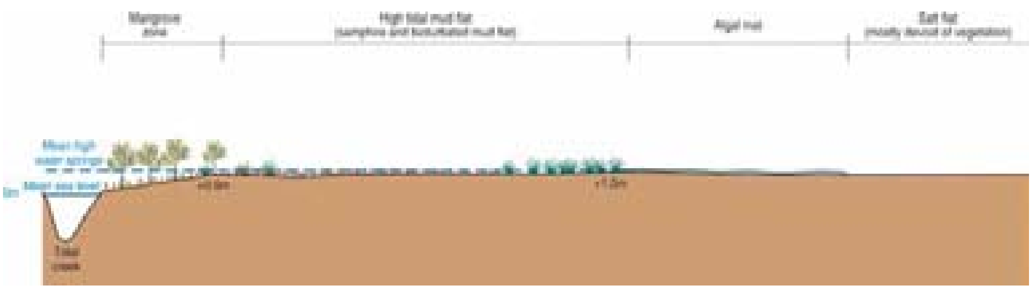

Figure 4-7 Schematic profile showing an expansive mud flats with algal mats

The distribution of algal mats was limited in terms of tidal elevation but, due to the flatness of the tidal flat terrain, they could occupy large spatial areas as is evident by the dark colouration of this zone on aerial photographs. Such expansive areas of mud flats with algal mats were observed at Tubridgi Point (Urala Creek), the Hooley Creek-Four Mile Creek system and the Second Creek-Coolgra Point system. Algal mat areas were only rarely inundated by the larger of the spring tides and, during helicopter flights on 8 and 9 May, it was observed that high tides (2.6 m CD) partly inundated the algal mat areas (Plate 4-25).

The algal mats varied from a sheet form to a pustular or crinkled form. In the most commonly observed sheet form, the mat was typically 5-10 mm in thickness and could be easily rolled and

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peeled back from the underlying mud flat surface (see Plate 4-26). Where the algal mats still retained moisture, they took on a dark colouring and texture that made them readily identifiable from a distance.

Plate 4-25

Plate 4-26

Plate 4-25 **Extensive area of algal mat on expansive high tidal mud flat at Urala Creek, Tubridgi Point. Note: Water line of a 2.6 m CD tide wetting the algal mats bottom left hand corner (on 8/5/09).**

Plate 4-26 **Algal mat (dark colour) peeling back from the underlying mud flat**

The algal mats of the coastline near Onslow have been examined and described previously as part of the Onslow Solar Salt Project environmental assessment (Paling 1990) and more recently a detailed investigation of algal mats within a similar coastal setting was undertaken along the east side of Exmouth Gulf for the Yannarie Salt Project ERMP (Biota 2005). Analysis of algal mat samples collected in May 2009 in the Hooley Creek – Four Mile Creek tidal flat area and observations on algal mat distribution made during surveys in the Tubridgi Point to Coolgra Point area were consistent with the findings of the previous studies, as summarised below:

- Algal mats consisted of dehydrated algal material on the surface with a moister layer below consisting of tangled filaments, mostly *Oscillatoria* sp.
- The upper limits or elevation of algal mat distribution were likely to be controlled by dehydration and high salinity due to low frequency of tidal inundation. Biota (2005) estimated that algal mats are only submerged by tides for between 1-3% of the time.
- The lower limits or elevation may be related to a greater frequency of tidal inundation (and hence exposure to greater tidal currents) and grazing by invertebrates such as the extensive crustacean populations that occurred in the high tidal mud flat habitat (i.e. this being the next habitat located at lower elevation adjoining algal mat areas).

Cyanobacterial mats have been demonstrated to fill an important ecological function in coastal arid zone systems, fixing atmospheric nitrogen into biologically available forms (Paling et al. 1989). Crabs are absent or rare in these areas but insects and insect larvae are sometimes seen under the algal mats.

4.7 Supratidal salt flats

Supratidal mud flats in the Pilbara bioregion are highly saline and are referred to here as salt flats. Where they occur they do not provide habitat for marine invertebrate fauna. However, they are part of the drainage catchments of the mangrove ecosystem and are included here for that reason.

Where expansive and wide mud flats extended landward from algal mat and high tidal mud flat habitats, the tidal flats graded into supratidal salt flats, often without clear demarcation between them. These salt flats were inundated only on rare occasions by either extreme sea levels events (e.g. cyclone-induced storm surges) or by freshwater during flood periods. Extensive areas of salt flats occur in the tidal flat embayments at Tubridgi Point, Hooley Creek- Four Mile Creek area and east of Coolgra Point.

There were no burrowing crabs or other marine invertebrates living in this zone. Salt flats were predominantly devoid of vegetation; however areas of samphire shrubs may have been present in some locations, particularly at the interface of salt flats with the hinterland.

4.8 Lagoon

A shallow shore-parallel lagoon extended from Entrance Point to an area approximately 1 km west of Hooley Creek. The role that the lagoon played in the development and eastward extension of the delta is described in Sections 3.1 and 3.2, and a typical profile across the beach/lagoon sequence is shown in Figure 3-3.

The outer bank of the lagoon was steep, with muddy sand that was sometimes undercut and collapsing. The inner bank of the lagoon comprised a narrow mud flat of soft muds and firmer sandy muds. The base of the lagoon was not exposed during low tide and this subtidal portion of the profile was a shallow estuarine habitat protected from wave action by the outer beach ridge.

On the western end of the lagoon between Site 32 and Site 9, the sandy mud flats fringing the lagoon were becoming colonised by mangrove seedlings (*Avicennia marina*) and invertebrate fauna. In this area there was a gradation of colonisation from west to east with a higher density of mangrove seedlings occurring near Site 32 (Plate 4-27) and a very low density occurring at Site 9. The approximate area of seedling recruitment is shown in Figure 3 of Appendix C. In November 2008, there were vast colonies of the potamidid gastropod *Cerithideopsila cingulata* on the inner mud flats of the lagoon in this area, all juvenile and representing a settlement event probably only weeks earlier. These observations were taken as evidence that the lagoon was filling in, at least in its older, western part, as part of the ongoing and dynamic development of the Ashburton Delta.

Further east of Site 9, the mud flats fringing the lagoon were almost devoid of living plants or benthic animals (Plates 4-28 to 4-30). This was interpreted as a recent and transient habitat that may become a mangrove-lined creek or lagoon habitat should the eastwards colonisation process continue and the beach-lagoon structure be maintained. Damara (2009) described the beach and sand spit areas between Entrance Point and the Hooley Creek mouth as highly dynamic and subject to rapid change from cyclone events.

A small bright green and very mobile polychaete worm was common crawling in wet areas. Also present, in patches, were colonies of bubble crabs (*Scopomera* sp.), and burrows of another crab, probably a species of *Uca*. A large species of ghost crab, *Ocypode fabricii*, was observed burrowing in sand at the base of the dunes bordering the inner mud flat (a different species to the ghost crab of the open beach). Juvenile individuals of the predatory gastropod *Polinices conicus* were seen along the

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outer margin of the lagoon but these were rare. Neither macro-algae nor filamentous green algae were observed in the lagoon.

Plate 4-27 **Plate 4-28**

Plate 4-27 Mangrove seedlings (Avicennia marina) colonising mud flats that fringe the lagoon. Photo taken near Site 32 located at the western end of the lagoon.

Plate 4-28 Lagoon at Site 9 – view from outer bank of lagoon, across the lagoon and towards the mainland.

Plate 4-29 **Plate 4-30**

Plate 4-29 Lagoon at Site 14 – view from inner bank of lagoon, across the lagoon and towards the outer beach.

Plate 4-30 Eastern end of lagoon at Site 5.

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5

Biodiversity and Regional Perspective

5.1 Geographic distribution patterns

Within the Indo-West Pacific region, there is a centre of species-richness and ecosystem complexity in the central part, which is in the Indo-Malay archipelago, south-east Asia and northern Australia, which applies to almost all the major groups of coastal marine animals and plants, including coral reef, mangrove and benthic shelf faunas. The coastal marine flora and fauna of the West Pilbara, though generally with lower biodiversity than the Indo-Malay Archipelago to the north, is species-rich in global terms (Jones 2004). In this region, the majority of marine species are widespread in the Indo-West Pacific Region, although there is a relatively high degree of endemism (Wilson & Gillett 1971; Wells 1980; Wilson & Allen 1987). However, all of the corals found on rock platforms (and the subtidal zone) within the study area are Indo-West Pacific species. Further comments on the geographic distribution of particular species are found in the notes on the biota of habitats in Appendix B.

On account of the endemism of the regional marine fauna, and recognising also the distinctive geomorphology of the West Pilbara coast, the nearshore and coastal portion of the western North West Shelf has been designated a distinct bioregion, referred to as the Pilbara (nearshore) Bioregion (IMCRA, Commonwealth of Australia 2006). The Ashburton North study area lies within this bioregion.

5.1.1 Mangroves and associated fauna

The tropical coast of northern Australia falls within the range of optimal temperature for mangroves but other climatic, tidal and physiographic conditions play key roles in determining their regional development (Semeniuk 1983; Woodroffe & Grindrod 1991; Duke et al. 1998). Mangrove ecosystems are most developed, and most rich in species, on shores with high rainfall and suitable geomorphology with river-fed estuaries characterised by terriginous sediments (Thom 1982, 1984).

In Western Australia, mangrove habitats are well developed on the Kimberley and Pilbara coasts and occur on the temperate west coast as far south as Bunbury (as a single mangrove species ecosystem). Semeniuk et al. (1978), Johnstone (1990) and Semeniuk (1993b) recognised sets of mangrove “biogeographic regions” or “coastal sectors”, characterised by distinctive climatic and geomorphic settings and stepped reduction in mangrove species-richness from north to south. The seven mangrove sectors of Semeniuk (1993b) relate closely to the northern Western Australia IMCRA bioregions (Commonwealth of Australia 2006).

Mangroves

The North West Kimberley, with its tropical sub-humid climate, high rainfall, ria coastline and major rivers and estuarine systems, is a centre of moderate to high mangrove biodiversity. There have been 18 mangrove species recorded from the Kimberley Bioregion. The Pilbara (nearshore) Bioregion has a tropical arid climate and, although there are major rivers, estuaries are poorly developed. Only eight mangrove species have been recorded from the Pilbara coast and, accordingly, mangrove ecosystems are less complex than those of the North West Kimberley.

The floristics, structure and geomorphic settings of Western Australian mangals, including those of the Pilbara, have been described by Johnstone (1990) and Semeniuk (1993a,b, 1996). As well as being floristically less complex, the Pilbara mangals are geomorphically and structurally very different to those of the North West Kimberley. Typically, they are characterised by broad expanses of high tidal mud flats and supratidal salt flats along the landward margin. Mangrove forests are poorly developed in this zone. Several mangrove species that are typical of the landward margin in the Kimberley are absent in the Pilbara due to the lack of freshwater input from hinterland sources, contributing in part to the lower number of mangrove species in the more southerly region.

As a result of varied adaptations to salt, immersion, desiccation and other environmental circumstances, mangrove species generally arrange themselves spatially in patterns of ecological association and distribution (zones) that are repeated and recognisable on a regional basis (Macnae 1968). In Western Australia, common zonation patterns have been described by several writers (Semeniuk et al. 1978; Semeniuk 1993b). In this regard, the ecological associations of mangroves within the study area exhibit characteristics peculiar to the Pilbara (nearshore) Bioregion.

Associated mangrove fauna

Associated with mangrove ecosystems world-wide there is an assemblage of fishes and invertebrates that utilise the food resources of mangals on a temporary basis. There are some fish and invertebrate taxa whose adult populations are restricted to mangrove habitats – variously referred to as the "mangal dependants" or "mangal obligates". Conspicuous among these animals are the fishes known as "mud-skippers" (*Periopthalmus),* certain gastropod molluscs of the families Neritidae, Littorinidae, Potamididae and Ellorbiidae*,* some barnacles, some sesarmid and ocypodid crabs, and several species of mud lobster and ghost shrimps.

It is believed that the mangal obligate fish and invertebrate communities co-evolved with the mangrove ecosystems in the late Tertiary and Quaternary periods (Reid et al. 2008). Although critically important in coastal ecology, very little is known of the diverse communities that depend on this life strategy in the West Pilbara. This is evident from the number of undescribed species collected from the study area during this survey (six species).

In this study of intertidal habitats, primary attention is given to key invertebrate species, including certain mangal obligate species, which dominate the faunas of mangrove habitats. Like the mangroves themselves, it seems that there is a stepped, north to south decrease in invertebrate biodiversity in mangrove habitats along the Western Australian coast (Wells 1986). All of the species observed during this study belonged to taxa that are widespread in the Indo-West Pacific region or are endemic to the shores of the North West Shelf but have biogeographic affinities with that region.

The most conspicuous and abundant mangal-obligate macro-invertebrates that inhabit mangals on a permanent basis belong to certain genera of Mollusca, Crustacea and Polychaeta. Collection and identification of mud-dwelling polychaetes was beyond the resources of this study in the given time-frame. A general account is given here of the common and better known mangrove molluscs and crustaceans found in the study area and the apparent ecological roles they play. Further details on species' geographic distributions, their occurrence within the study area, and the ecological roles they play may be found in Appendix B.

Molluscs

A number of bivalved molluscs live in mangroves but few are burrowers in mud (Wells 1984). Most bivalve species associated with mangrove habitats actually live on the mid-littoral mud flats in front of the tree line (the "pneumataphore zone" – Wells 1986) or among trees of the outer fringe of mangroves exposed to the open sea. This habitat was virtually absent from the study area. At Coolgra Point (Site 44) where there was a narrow mangrove fringe on a limestone pavement along the sea-front, the rock-oyster *Saccostrea cucullata* was common, along with the mussel *Brachidontes* sp.

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nestling in crevices. Neither of these species is a mangal-obligate. Species of wood-borer, Teredinidae, play a very important role in the breakdown of mangrove wood. Teredines were obvious and abundant in the study area but the taxonomy and distribution of this group on the Pilbara coast is very poorly known and they have not been studied in this report.

There are many species of gastropod found on mud flats and rock pavements along the seaward front of mangroves but, as noted above, that part of the mangrove ecosystem was largely missing in the study area. That habitat was present only at Coolgra Point (Site 44) where there was a mixed fauna of rocky shore and mangrove gastropod species [see Wells (1986) for a description of the molluscan fauna of this zone in Exmouth Gulf]. However, there are four families of gastropod molluscs with species that include mangal-obligates, living in the mangrove forest itself and playing key roles in the consumption and breakdown of particulate matter (plant litter and/or microbial) in the mangrove ecosystem. These families are the Neritidae, Littorinidae, Potamididae and Ellorbiidae.

Most species of the genus *Nerita* (family Neritidae) inhabit the intertidal zone of rocky shores. One Indo-West Pacific species, *Nerita balteata,* is a mangal obligate that is present though rare in mangrove habitats in the study area. It is a micro-phagous grazer on mangrove tree trunks. Species of the family Littorinidae also generally inhabit the intertidal zone of rocky shores but there is one genus, *Littoraria*, that includes species that live in mangrove habitats, some of them mangal obligates. There are seven species of this genus in mangroves along the tropical coast of Western Australia, five of them present in the study area - *Littoraria* (*Littorinopsis*) *cingulata*, *Littoraria (Littorinopsis) filosa, Littoraria (Palustorina) sulculosa, Littoraria (Palustorina) articulatata* and *Littoraria (Palustorina) undulata. Littoraria articulata* and *L. undulata*, are not mangal obligates but were common on mangrove trees along the sea-front at two sites within the study area (Sites 21 and 44). The mangal obligate species *L. filosa* was found in that habitat at Coolgra Point (Site 44) but nowhere else. The other two mangal obligate species, *L. cingulata* and *L. sulculosa*, were found at only a few sites within the Ashburton Delta and were nowhere common. The rarity of littorinids on the mangroves of the Ashburton Delta and Hooley Creek system is unusual in comparison with their abundance in other mangrove habitats of the Pilbara coast.

In northern Australia there are four genera of the family Potamididae containing species that are mangal obligates living in mangrove habitats, either crawling on the mud substrate or climbing on the tree trunks. The mud-crawlers are detritivores and often occur in vast colonies. The tree-creepers are microphagous grazers that feed on the micro-organisms on the trunks and branches of mangrove trees. These species normally live in vast colonies in mangrove habitats but in the study area they were present in small isolated colonies or, more often, absent altogether. The five species of mud-creeper which occurred in the mangals within the study area were *Telescopium telescopium*, *Terebralia palustris*, *Terebralia semistriata*, *Cerithideopsila cingulata* and *Cerithidea largillierti*.

There was one tree-climbing species of Potamididae in mangroves of the study area, *Cerithidea reidi*.

Ellobiids are air-breathing pulmonate snails with many species that inhabit the intertidal and supratidal zone, especially in marshes associated with estuaries. No systematic publications have been made of this family on the Pilbara coast and their role in the mangal ecosystems of this region remains unknown. Two ellobiid genera with large shells, *Ellobium* and *Cassidula*, have been studied in northern Australian mangroves (Wells 1997). A single specimen of one species, *Cassidula aurisfelis*, was collected within the Ashburton Delta during this survey.

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Most species of the Neritidae, Littorinidae and Potamididae are spawners (with or without initial protection within capsules secured to the substrate) that release planktotrophic larvae with potential, at least, for wide dispersal in coastal waters. Some brood their larvae or have direct capsular development without a pelagic larval stage. In studies of the resilience/recovery of a mangal fauna, where connectivity is an all-important issue, it is necessary to consider the life cycle of each species present as there is a large range of larval development and dispersal strategies.

Crustaceans

There are many kinds of small crustaceans that live in litter and wood in mangroves but there is little information on them for northern Australia (Milward 1979; Hutchings & Saenger 1987; Metcalfe 2007). Mangrove barnacles, mud shrimps, mud lobsters and crabs are better known (Davie 1985), the latter playing key roles in mangrove ecosystems (Kristensen 2006). Crustaceans collected within the study area were identified by specialists at the WA Museum (Appendix B).

Brachyuran crabs: Three families, Macrophthalmidae (sentinel crabs), Portunidae (swimming crabs) and Grapsidae (shore crabs), all have species that inhabit mangroves although most of them are not mangal obligates. These crabs are key predators and scavengers in mangrove ecosystems.

A single specimen of a species provisionally identified as *Macrophthalmus* cf. *darwinensis,* was collected at Coolgra Point (Site 44). Nothing is known of the ecology or distribution of this species in Western Australia as this is the first and only record of the genus in the State.

The large portunid crab *Scylla serrata*, a prized sea food species known colloquially as the ‘mangrove crab’, is common in mangrove habitats and was seen at many sites throughout the study area. Another common swimming crab on the Pilbara coast is *Thalamita* sp., seen at open ocean sites but not within the enclosed mangrove habitats of the study area.

The predatory shore crab *Metopograpsus frontalis* is very common in mangrove and other coastal habitats across northern Australia. It was one of the most common crabs in the study area, found in mangal mud flat habitats almost everywhere.

Two families of burrowing crabs, Sesarmidae and Ocypodidae, are adapted for life in the intertidal zone and contain many species that are mangal obligates or commonly found as dominant mangrove inhabitants, feeding on plant litter and/or micro-organisms. As well as their ecological role as key secondary producers, breaking up and redistributing plant material, the bioturbation performed by these crabs has important positive effects on substrate geochemistry. They also comprise a very large biomass that supports mangal predators (e.g. fishes, birds, crocodiles).

One ocypodid genus, *Uca*, the fiddler crabs, contains many species that live in or associated with mangals. These small crabs live in deep burrows, often in dense colonies, and are a conspicuous feature of mangrove forests and mud flats where they feed on fine organic material and micro-phytobenthos on the surface layers of the substrate. In that role they are very important secondary producers in mangrove ecosystems. Seven species of *Uca* are recorded on the Pilbara coast as far west as Exmouth Gulf or beyond and could be expected in mangroves of the study area. However, only five were found there during this survey: *Uca elegans, U. flammula*, *U. mojbergi U. capricornis, U. dampieri*. Of these species, *Uca elegans* was found in dense populations, occupying very large areas of high tidal mud flat within and beyond the tree margins of the mangrove forests. *Uca flammula* was also very common, living in dense populations on mangal flats along the banks of tidal creeks. The other *Uca* species were found less abundantly, usually in smaller, more restricted colonies.

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Three other ocypodid genera, *Ocypode* (ghost crabs), *Scopimera* (bubbler crabs) and *Mictyris* (soldier crabs) are not mangal obligates but live in beach and intertidal sand flat habitats of the study area, Two species of *Ocypode, O. ceratopthalmus* and *O. fabricii,* were found commonly on beaches, the former on open ocean beaches and the latter on the upper intertidal sandy fringes of lagoon and mangrove habitats. An undescribed species of *Scopimera* was common on sand flats of alluvial fans and shoals. An undescribed species of *Myctyris* was common on muddy flats of the Ashburton channel mouth and lagoon. Ghost crabs are scavengers and detrital feeders, gathering leaf litter and other material from the beaches at low tide – their burrows are a conspicuous feature of beaches throughout the study area. The bubbler and soldier crabs feed on micro-organisms gathered from the sand surface at low tide.

Sesarmid crabs are known as ‘marsh crabs’. There are several genera of the family that are characteristic of mangrove habitats in the Indo-West Pacific region. They play key ecological roles as secondary producers (Robertson 1986, 1988; Robertson & Daniel 1989; Lee 1998). There is a large literature on the feeding habitats, reproduction and other biological characteristics of sesarmids. They forage on the mud flat surface for plant material and drag it into their burrows where they shred and consume it, thereby moving fine organic material deep into the soil.

The taxonomy of Western Australian sesarmids has not yet been adequately studied. Three Indo-West Pacific genera that are known to be present in Pilbara mangroves are *Neosamartium*, *Parasesarma* and *Perisesarma*. Four species were collected in the study area. Two of them are thought to be undescribed. The four species, all of them widespread on mangal and high tidal mud flats within the study area, were *Neosarmartium meinteri*, *Perisesarma semperi*, *Perisesarma* n. sp. and *Parasesarma* n. sp.

The mud and ghost shrimps are another group of burrowing crustaceans normally present, if not conspicuous, in northern Australian mangroves. Several families are involved.

The largest of these creatures are three species of mangrove lobster (family Thalassinidae) - *Thalassina squamifera*, *T. emerii* and *T. anomala*, all of which have been reported from Pilbara mangroves. These animals are deep burrowers that build conspicuous conical turrets, usually among the mangrove trees. None of these species, or their burrows, was observed within the study area, although they have been present.

Small and inconspicuous crustaceans known as ghost shrimps are common in northern Australian mangroves but are rarely seen because of their deep and inconspicuous burrows. Two families are involved, the Callianassidae and Upogebiidae. Very little is known of these very strange creatures. They are rarely collected but are likely to play a significant role in mangrove ecosystems as secondary producers. Two species were found deep-burrowing in mud within mangrove habitats of the study area. An undescribed callianassid, *Lepidopthalmus* sp., was found in the Ashburton Delta (Site 36). The upogebid, *Upogebia giralia,* was found on the Hooley Creek mud flats (Site 4).

Barnacles

In northern Australia there are several barnacle species that live on mangrove trees but are found also on rocky shores and wooden structures in the intertidal zone outside mangroves. These include *Chthamalus malayensis* and *Microeuraphia withersi*. There are also mangal obligate barnacles that live attached to the trunks, branches, leaves or pneumatophores of the trees, especially along the

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seaward edges of open bay mangrove systems. These animals are not well studied in northern Western Australia.

Barnacles were rare in mangrove habitats of the Ashburton North study area. Only one species, an unnamed species of *Fistulobalanus*, was found in the Ashburton Delta (Site 24). It was a mangal obligate that lives attached to pneumatophores. No barnacles were found in mangroves of the Hooley Creek system. The two non-obligate species, *Chthamalus malayensis* and *Microeuraphia withersi*, were found on mangroves in the open shore habitat of Coolgra Point (Site 44) but nowhere else.

Two other mangal obligate barnacles present elsewhere in the Pilbara, but not found in the study area, are *Hexaminius popeiana* which lives on mangrove trunks and branches, and *Hexaminius foliorum* which lives on mangrove leaves.

Productivity and Nutrient Cycles

Mangrove habitats play a major role in supporting coastal food webs and nutrient cycles in the coastal zone and they are an efficient sink of dissolved nitrogen, phosphorus and silicon (Alongi 1996). The ecological roles of mangals on arid coasts are less well understood than those of the wet tropics but a significant role in primary and secondary production and nutrient recycling is evident there also. Some key secondary producer species in mangrove ecosystems belong to fish and invertebrate taxa that are restricted to mangal habitats (see Section 5.1.1).

The variety of mangrove plants in a mangal, and the variety of fishes and invertebrates that habitat supports, are not great (compared to other tropical ecosystems) and biodiversity is moderate at best. However, the density of fauna in mangals may be very high. As a direct result of the high primary and secondary productivity in mangrove ecosystems, the standing stock of commercial species may be many times higher than that of adjacent coastal marine habitats (Morton 1990; Robertson & Duke 1990; Rönnbäck 1999). There is a variety of terrestrial and marine vertebrates and invertebrates that utilise the food resources of mangals on a temporary basis (Milward 1979; Hutchings & Recher 1982). Many coastal species, including many that have commercial importance, use mangal habitats as breeding and nursery areas, taking advantage of the protection and rich food resources available there (Dall et al. 1990; Robertson & Blaber 1992). In these ways, the primary and secondary production of mangals have very large impacts on the biodiversity and productivity of other coastal habitats nearby.

6.1 Primary production

Alongi et al. (2000) studied biogeochemical processes in mangrove forests (*Avicennia* and *Rhizophora*) at localities on the arid Pilbara coast. Paling et al. (1989) examined the important role of cyanobacteria in nitrogen fixation on highly saline mud flats in the region.

There are several sources of primary production in Pilbara mangals (including the extensive mud and salt flats along their landward margins):

- mangrove plants produce large quantities of detrital material, derived from fallen leaves and decaying wood
- microphytobenthos (e.g. cyanobacterial layers) of high-tidal mud flats produce and fix significant amounts of nitrogen in the substrate (Paling et al. 1989)
- micro-epiflora and bacteria on the mangrove vegetation
- planktonic micro-flora imported from the coastal waters by tidal flux.

Consequently, the substrate of mangals and associated mud flats has a high organic content and supports high microbial activity and large densities of grazing and detrital-feeding fishes and invertebrates (Odum & Heald 1972; Sutherland 1980; Alongi 1989a, 1989b, Alongi & Sasekumar 1992; Ray et al. 2000). While there are some predatory species, and some suspensory-feeding invertebrates that live in the seaward margins of mangals, the majority of a mangal biomass comprises surface-dwelling and burrowing grazers and detritivores that perform the critical role of breaking down organic materials into its nutrient components. The burrowers also have very important functions in the redistribution of that material in the ecosystem and maintaining favourable geochemical conditions in the substrate.

Because of high primary production from these multiple sources, mangrove habitat is categorised as BPPH by the EPA.

6.2 Secondary production

As a consequence of primary production by macro and micro organisms, the substrate of mangals and associated mud flats has a high organic content and supports high microbial activity and large densities of grazing and detrital-feeding fishes and invertebrates (Odum & Heald 1972; Sutherland 1980; Alongi 1989a, 1989b, Alongi & Sasekumar 1992; Ray et al. 2000).

While there are some predatory species and some suspensory-feeding invertebrates that live in the seaward margins of mangals, the majority of a mangal animal biomass comprises surface-dwelling and burrowing grazers and detritivores. These organisms, mainly invertebrates, perform the critical role of breaking down organic material into its nutrient components. In these ways, the mangal surface-dwelling and burrowing invertebrates are essential secondary producers that convert the organic material created by the primary producers to forms that are made available to the ecosystems of the mangal and beyond.

The arid-climate mangals of the Pilbara are unusual in that the essential secondary production zone extends far beyond the boundaries of the mangrove trees, that is, onto the high tidal mud flats. This was the case within the Project study area. Within that upper intertidal zone, much of the mud flat areas were heavily burrowed by ocypodid and sesarmid crabs, generally in vast numbers. The burrowers have very important functions in maintaining favourable geochemical conditions in the substrate. Ocypodids (fiddler crabs - genus *Uca*) feed mainly on the micro-epibenthos on the substrate surface while the sesarmids (marsh crabs – genera *Neosarmatium*, *Perisesarma*, *Parasesarma*) feed on detrital material they gather from the mud flat surface. The sesarmids play a particularly important role as they drag the plant material into their burrows where they shred it, thereby resizing and redistributing organic material throughout the soil profile.

6.3 Carbon and nutrient cycles

The primary function of tidal inundation and salinity gradients in mangrove survival and distribution has been discussed in Section 4.4. In addition to these processes, carbon and nutrient cycles are also key processes functioning within mangrove ecosystems.

As part of the study by Biota (2005) on mangrove ecosystems in the east side of Exmouth Gulf, a detailed review was undertaken on nutrient cycles and ecological interaction. Biota (2005) presented data on carbon flux estimates and also conceptual models for both carbon and nitrogen cycles for mangrove ecosystems. This information is directly applicable to the mangrove systems adjacent to the Ashburton North SIA and is therefore summarised below.

Carbon cycling in mangrove ecosystems

Carbon is a fundamental element in the structure and function of all living organisms. The relationship between inorganic and organic forms of carbon at different levels of the physical and biological environment is referred to as the carbon cycle (Figure 6-1). The key components of this process in mangroves include:

1. Conversion of atmospheric carbon dioxide to organic compounds via photosynthesis by mangroves (about 15,000 kg/ha) and algal mats.
2. Consumption of carbon compounds from mangrove leaf litter and algal mat by herbivores and grazing by macroinvertebrates.
3. Consumption of herbivores by carnivores.

6 Productivity and Nutrient Cycles

4. Microbial decay of mangrove leaf litter and excretions and remains of herbivore and carnivores resulting in release of carbon dioxide to the atmosphere.
5. Animal respiration converting carbon compounds to carbon dioxide which is released to the atmosphere.
6. Export/import of carbon to and from offshore marine areas through tidal movement.

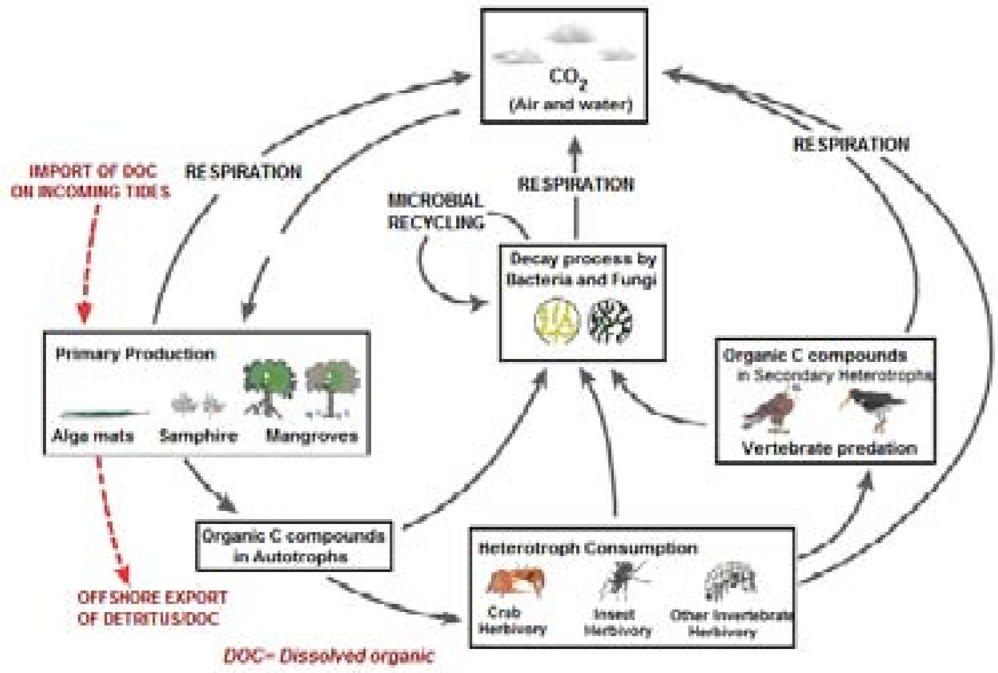

Figure 6-1 Simplified conceptual carbon cycle for mangrove/algal mat ecosystems. Source: Biota 2005

Nitrogen cycle in algal mat/mangrove communities

Export of biologically available nitrogen from algal mats occurs subsequent to the fixation of atmospheric nitrogen (Figure 6-2). The major pathways and components of the nitrogen cycle in algal mat/mangrove communities are as follows:

1. Fixation of atmospheric nitrogen by cyanobacteria into ammonia which can then be incorporated into organic nitrogen compounds.
2. Export of biologically available nitrogen from algal mats through tidal movement and incident rainfall. Paling and McComb (1994) showed that nitrogen is lost from algal mats during tidal inundation and localised intertidal runoff from incident rainfall. Export is principally organic nitrogen and estimates for the Pilbara coast indicate export values of 68 kg of N/ha/yr (Paling & McComb 1994).
3. Uptake of nitrogen by plants through root systems. Plant uptake typically represents a relatively small component of available nitrogen with most nitrogen recycled in microbial processes or exported in tidal movement.
4. Consumption and excretion by herbivores.

6 Productivity and Nutrient Cycles

5. Consumption of herbivores and excretion by carnivores.
6. Nitrification (conversion of ammonium nitrogen to nitrate) and dentification (conversion of nitrate to nitrogen gas) which is believed to be low in mangroves.

Organic nitrogen, nitrates and ammonium are all lost from the mats and enter a relatively complex cycle of offshore export, uptake by primary producers (mangroves and samphires) and geochemical mineralisation and immobilisation in intertidal sediments. Mats are also grazed directly by invertebrates in their lower tidal range limit, providing a direct source of organic nitrogen.

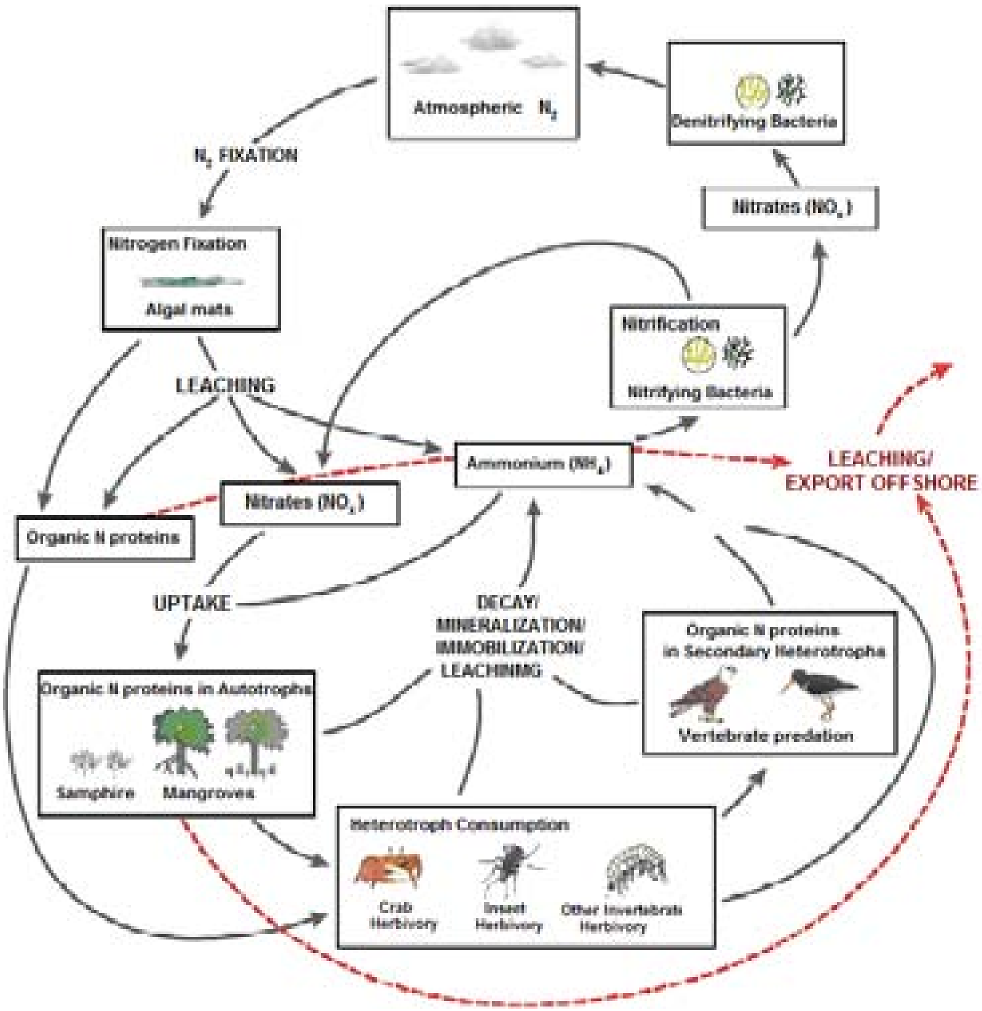

Figure 6-2 Simplified conceptual nitrogen cycle for algal mat/mangrove ecosystems. Source: Biota 2005

Conservation Significance

7.1 Statutory and Policy Framework

7.1.1 Recommended marine conservation areas

In coastal waters under Western Australian jurisdiction, marine and estuarine areas may be reserved for conservation and fish habitat protection under the *Conservation and Land Management Act 1997* and *Fish Resources Management Act 1994*. No marine conservation reserves (CALM Act) or fish habitat protection areas (Fish Resources Management Act) have been declared or proposed within the vicinity of the proposed Project development site.

The Marine Parks and Reserves Selection Working Group (MPRSWG 1994, Section 3.8) made no recommendation for the establishment of marine reserves anywhere on the Onslow coast. The Working Group noted that the coastal sector between the Fortescue and Ashburton Rivers “contains perhaps the most diverse mangals on the Pilbara coast”. It recommended that “unless the results of the [proposed] survey indicate that the most desirable areas for marine conservation are elsewhere within the sector”, consideration should be given to reservation of part of the mangal coast encompassing the inactive delta of the Robe River, one of two inactive deltas in the Pilbara.

The Working Group overlooked the significance of the active Ashburton Delta as a unique mangal system. Subsequently, in an unpublished discussion paper presented to the EPA, Semeniuk (1997) identified the Ashburton River Delta as a mangrove system of regional significance with very high conservation value. The Ashburton Delta was given that status in Guidance Statement No. 1 (EPA 2001) thus affording that area with “the highest degree of protection” under environmental protection processes, but to date reservation of the area as a marine conservation reserve has not been proposed.

7.1.2 EPA Position and Guidance Statements (PS No. 7, GS 1 and EAG 3)

The relevant EPA Position and Guidance Statements relevant to the assessment of impacts on mangroves and other adjacent intertidal habitats are:

EPA Position Statement No. 7 - Principles for Environmental Protection

The purpose of the EPA Position Statement No. 7 (EPA 2004) was to provide the community and other key stakeholders with a summary of the key relevant principles of environmental protection that the EPA considers to be important in guiding its decisions and advice to government on matters of environmental protection.

An assessment of conservation significance of the intertidal habitats in the study area with respect to this position statement was provided in Section 7.2.

Guidance Statement for the protection of tropical arid zone mangroves along the Pilbara coastline (EPA Guidance Statement No. 1, May 2001)

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

Within the GS No. 1 framework, both the Ashburton River Delta and Coolgra Point areas were identified as being Guideline 1 area and of very high conservation value and “regionally significant”

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(Areas 4 and 5 in Figure 7-1). The EPA's operational objective for Guideline 1 areas was that no development should take place that would adversely affect the mangrove habitat, the ecological function of these areas and the maintenance of ecological processes which sustain the mangrove habitats. The EPA therefore recommended that these areas have the highest degree of protection with respect to geographical distribution, biodiversity, productivity and ecological function.

The Hooley Creek to Four Mile Creek area was classified by Guidance Statement 1 as a Guideline 4 area: all other mangrove areas that occur inside areas that have been designated as industrial areas, associated ports or other development and not covered by Guideline 3. The EPA's operational objective for Guideline 4 areas was that the impacts of development on mangrove habitat and ecological function of the mangroves in these areas should be reduced to the minimum practicable level.

Benthic Primary Producer Habitat Protection for Western Australia's Marine Environment (EPA Environmental Assessment Guidelines No.3 (EAG3), Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment).

The Guidance for acceptable level of impact on marine environments in WA is the Environment Protection Agency's (EPA) EAG 3 Protection of Benthic Primary Producer Habitats (BPPH) in WA's marine environment (EPA 2009b). This document has recently been revised (EPA 2009a) by the EPA Service Unit (EPASU) and released for comment by the marine policy settings review stakeholder working group and is still very much a draft. However, it does substantially clarify the EPASU's expectations of proponents and their consultants when assessing the direct and indirect loss of benthic primary producers as a result of development proposed for the marine environment.

The WA EPA EAG3 (EPA 2009a) set out a framework for the assessment of proposals that may impact on Benthic Primary Producers (BPP) and the habitats that can or do support such communities, termed Benthic Primary Producer Habitats (BPPH). The Guidance considered that BPP are "predominantly marine plants (e.g. seagrasses, mangroves, salt marshes, algal mats, seaweeds and turf algae), but include invertebrates such as scleractinian corals …".

In EAG 3, the EPA provided a set of principles to be applied by proponents and the EPA when considering development proposals that may result in removal or destruction of, or damage to, marine benthic primary producer communities or the habitats which support them. The EPA used the term BPPH throughout this Guidance Statement to mean the ecological units that are BPPH including the dominant BPP communities they support.

The EPA also defined six categories of marine ecosystem protection and provided guidance on the amount of BPPH that may be lost due to development as a percentage of BPPH within a defined loss assessment unit (LAU) for each category. These percentages are termed 'cumulative loss guidelines' that, if exceeded, will be used by the EPA as indicative of potential non-acceptability. However, given the difficulty of reliable measurement of the area of some BPPH and considering the difficulty of quantifying the ecological significance of their loss, these guidelines will not be used as rigid limits. The acceptability of BPPH damage/loss will in all cases be a judgement of the EPA based primarily on its assessment of the overall risk to the ecosystem integrity within a LAU if a proposal were allowed to be implemented.

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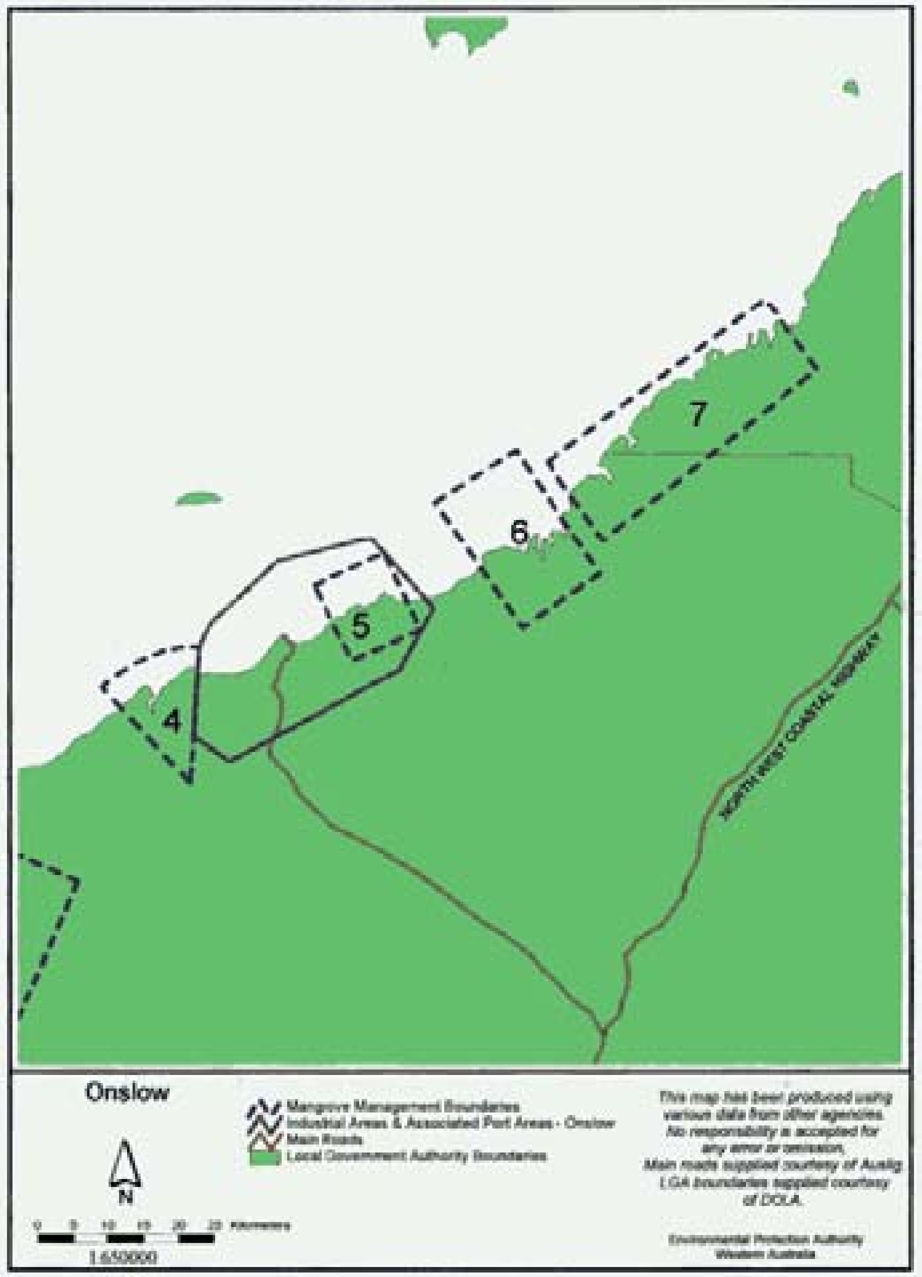

Figure 7-1 Mangrove management area boundaries identified for the study area by EPA Guidance Statement No 1. Source: EPA 2001

7 Conservation Significance

The report *Wheatstone LNG Hub: Justification of BPPH Management Unit Boundaries* (URS 2009d) presents an ecosystem approach based on geomorphic and biological attributes of three large Ecosystem Units (nearshore, offshore, inner shelf) and proposes a range of smaller management units (Local Assessment Units or LAUs) that occur within the larger ecosystem units. These LAUs will be used for estimating potential impacts to BPPH from the Project and will form the basis for Chevron's calculation of cumulative BPPH loss assessments as required by the EPA.

Figures 4-1 to 4-3 show the boundaries for proposed LAUs for the Ashburton Delta area and Hooley Creek to Four Mile Creek tidal embayment. It is recognised that the EPA will make the final decision as to the spatial extent and boundaries of the intertidal BPPH management units during the formal assessment of the Wheatstone project.

7.2 Assessment of conservation significance using Principles of Environmental Protection

Of the five Principles of Environmental Protection adopted by the EPA, the third is "*The principle of the conservation of biological diversity and ecological integrity*" which "… *should be a fundamental consideration*" (EPA 2004, Position Paper No. 7). This will be the guiding principle in this section when considering the conservation significance of the intertidal ecosystems of the project study area.

Biological diversity is defined by the EPA to encompass three levels – ecosystem diversity, species diversity and genetic diversity.

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

7.2.1 Biodiversity

At each of the three levels, biodiversity of intertidal habitats within the study area is either low or moderate. Accordingly, the conservation significance of the project area in terms of biodiversity is also low to moderate.

Ecosystem diversity

Section 4 identifies the range of intertidal habitats within the Project study area, according to the biogeomorphic classification published by Semeniuk (1986). They group into two main categories, mangrove and tidal flat habitats and sandy beach habitats. Rocky shore habitats are also present at two sites, Beadon Point and Coolgra Point, but are poorly developed and neither site lies within or close to the Project site.

Sandy beach habitats of the study area are uniform and representative of the 'coastal compartment' between Turbridgi Point and Coolgra Point, characterised by moderate beach slopes and seasonal changeability. These habitats are not significant ecosystems in their own right. However, they provide barriers that help protect and sustain intertidal mangal/mud flat ecosystems and terrestrial habitats of the hinterland.

Mangrove and associated habitats of the study area are varied, including river channels, tidal creeks, lagoons, mangal flats with varied floristic and faunal assemblages, high tidal mud flats and salt flats.

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These habitat types are characteristic of the arid zone mangrove systems of the West Pilbara. Two different units of mangrove habitat systems were included.

i) The Ashburton Delta is a discrete biogeomorphic unit characterised by sinuous river channels and tidal creeks bordered by moderately dense mangrove forests, almost enclosed behind beach/dune barriers. The delta is active and growing, contains an array of mangal habitat types and is unique as a biogeomorphic feature on the Western Australian coast.

ii) The Hooley Creek – Four Mile Creek tidal embayment system comprises tidal creeks bordered by narrow mangrove vegetation and draining large areas of high tidal mud and salt flats. It is also virtually enclosed by beach/dune barriers. This biogeomorphic unit is representative of mangrove systems in the West Pilbara. Within the study area similar tidal embayments, supporting a similar range and distribution of habitats, occur east of Onslow, between Beadon Creek and Coolgra Point.

The Ashburton Delta, as a unique biogeomorphic unit, may be assessed as having high conservation significance at the level of ecosystem diversity. On the other hand, the Hooley Creek – Four Mile Creek biogeomorphic unit has an array of habitat types that are representative of mangals in the Pilbara (nearshore) Bioregion so that, in terms of ecosystem diversity, its conservation significance may be assessed as low to moderate.

Species diversity

Species-richness

Species diversity is assessed here in terms of species-richness, which is the measure of diversity commonly applied in conservation studies (see IUCN and National Heritage criteria). Diversity indices that take account of species' relative abundance require sophisticated quantitative data that are not available.

The species diversity of both beach and mangrove habitats within the Project study area is low from a broad biogeographic point of view (i.e. relative to these habitats across tropical northern Australia). The conservation significance of this habitat in the project area is assessed as very low. The beaches, lower littoral sand flats and alluvial fans of the study area were found to be extremely impoverished in both species-richness and species abundance. The ghost crab *Ocypode ceratopthalmus* was the most common invertebrate in this habitat. The only common molluscs found in the lower littoral zone of the lower beach slope and sand flats were the gastropod *Polinices conicus* and an unidentified bivalve of the genus *Paphies*. This impoverished beach fauna is interpreted as a result of the constant movement of the fine sand of which the beaches and alluvial fans are built and a feature of this highly dynamic and unstable shoreline.

The mangrove habitats of the arid West Pilbara coast are less species-rich than those found on the wet Kimberley coast. For example, in the Project study area there were just six species of mangrove compared to 18 in the north Kimberley. Invertebrates of mangrove habitats in the West Pilbara illustrated the same relatively low species-richness.

A more meaningful consideration from the biological conservation point of view would be a measure of the species-richness of the study area compared with that of other arid zone mangrove systems within the Pilbara (nearshore) Bioregion. The number of high tidal mud flat crabs (five species of *Uca* and four species of sesarmid – see Appendix B) represented the approximate crab diversity expected in West Pilbara mangroves. Similarly, the number of species of mangrove molluscs in the Ashburton Delta was also about what would be expected. However, none of the expected mollusc species were found in the Hooley Creek mangroves and that mangrove system was severely depauperate in regards to this group.

The species diversity of Ashburton Delta mangal habitats appeared to be typical of the Pilbara (nearshore) Bioregion and the conservation significance of mangal habitats in that biogeomorphic unit are assessed as moderate.

Except for the mud flat crab assemblages, species diversity in the Hooley Creek-Four Mile Creek unit was low and restricted in comparison with other localities within the bioregion and at this level the conservation significance of this biogeomorphic unit is assessed as low to very low.

Species endemism

The presence of endemic species is a useful measure of the distinctiveness of a regional flora and fauna compared to that of other regions. A region with high endemism has high conservation significance because that proportion of its biota is found nowhere else. However, assessment of conservation significance of endemism at a local level must consider the question of scale, i.e. the distribution of 'endemic' species beyond the local area.

Within mangal habitats of the project area around 47% of the invertebrate species recorded by this survey were endemic to the North West Shelf but all of them are believed to be, or likely to be, widely distributed along the shores of that region. There is no evidence that any of these North West Shelf endemic species were restricted to the Pilbara (nearshore) Bioregion. The high level of species endemism found in intertidal habitats of the Project study area may be seen as representative of habitats of the northern coast of Western Australia with no special local conservation significance.

Genetic diversity

Many marine species are characterised by disjunct distributions due to recent vicarious events or disjunct habitats which have created populations with distinctively divergent genomes, but this survey found no evidence of distinctive local populations of any invertebrate species within mangal or beach habitats of the Project area.

7.2.2 Primary and secondary productivity

Primary and secondary production in the mangrove/mud flat habitats of the study area are described in Section 6. High output of nutrients is assumed and this is the prime reason these habitats are considered to have high conservation significance, that is, by virtue of their support of ecosystems beyond their own boundaries. However, it is not possible to determine the level of that significance in the regional context for there are no data on the rate of productivity of the Ashburton Delta and Hooley Creek mangrove units. The only means of estimating the relative importance of these units regionally is to measure their spatial extent and their proportion of the regional total. That is the purpose of the mapping of BPPH (i.e. mangroves and associated high tidal mud flats, including algal mats) provided in Section 4.

The EPA Guidance Statement No. 1 argued that Pilbara arid zone mangroves "are of relatively lower productivity than the mangrove communities of the wet tropics …". Neither of the publications on primary productivity of arid zone mangroves in the Pilbara (Alongi et al. 2000; Paling et al. 1989) discuss this aspect of the matter. Furthermore, the Alongi report deals with mangrove communities that are open to the sea, unlike the semi-enclosed Ashburton Delta and tidal embayments in the

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Hooley - Four Mile Creek area and Beadon Creek to Coolgra Point area, while the Paling report deals with productivity of the algal mats.

An observation of this survey was that mangrove ecosystems of the Pilbara (nearshore) Bioregion were characterised by extensive high tidal mud flats that supported vast numbers of microphagous and detritivorous crabs that play important secondary production roles. While not quantified, it is suggested here that in this respect the arid zone Pilbara mangrove ecosystems are likely to have significantly different nutrient pathways to those of the wet tropic mangroves of the Kimberley and elsewhere. Until productivity of the Pilbara mangroves, and the role of key secondary producers have been adequately researched, it is unwise to assume that they are either more or less productive than their wet tropic equivalents.

7.2.3 Conclusions

When applying the principles of the EPA Position Statement No. 7 (EPA 2004) the conservation significance of the mangrove/mud flat habitats within the intertidal LAUs may be regarded as:

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

Biodiversity

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

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

The Ashburton Delta was unique as a biogeomorphic unit and in that respect it has high conservation value in terms of regional ecosystem diversity. The Hooley Creek - Four Mile Creek system was representative of mangrove/mud flat ecosystems of the Pilbara (nearshore) Bioregion and has moderate conservation value in terms of regional ecosystem diversity.

Productivity

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

The mangrove/mud flat habitats in the study area are likely to exhibit productivity processes and pathways that are different to those of the better researched wet tropics. In this regard they are

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representative of arid zone mangrove systems of the Pilbara (nearshore) Bioregion. Whether their productive output is greater or less than mangrove ecosystems in the wet tropics is unknown.

Glossary

Terminology	Definition
Barrier islands/ limestone barriers	Narrow, shore-parallel limestone or sand ridges which bar and protect tidal embayments. Barrier islands may be mantled by dunes, beach ridges, soils and tidal deposits; surrounded by water at high tides.
Benthic Primary Producer communities	Are biological communities, including the plants and animals, within which benthic primary producers are the more prominent components.
Benthic Primary Producer Habitats (BPPH)	Are both the BPP communities described above as well as the areas of substratum that can and/or does support these communities.
Benthic Primary Producers (BPP)	Are predominantly photosynthetic marine autotrophs, mainly plants and algae (some examples include seagrasses, mangroves, attached macroalgae), but also include scleractinian corals and some other filter feeding invertebrates such as some sponges and soft corals, which obtain a proportion of their energy requirements from photosynthetic symbiotic microalgae that live in animal tissues. All BPP organisms grow on the seabed either subtidally or intertidally, or as epiphytes.
Bioturbation	Turnover of substrate by fauna from burrowing, excavation and other activities.
Chenier	Detached shoestring or sinuous sand deposit built to high tidal or supratidal levels surrounded by muddy tidal-lands.
Genome	The genetic material characteristic of a particular species.
Halophytic shrubs	Plants that are adapted to living in saline conditions. Some of these plants survive by excreting salt through the leaves; others rely on storage capacity and high salt content (e.g. samphires).
Holocene	Refers to the younger subdivision of the Quaternary in which we are living, the previous subdivision being the Pleistocene. The Holocene, or Recent, is approximately the time since the last glaciation, or about the last 10 000 years.
Intertidal	Environment between the high and low levels of spring tides.
Littoral	The intertidal zone of the sea.
Littoral drift	The movement of material in littoral currents within the surf zone.
Local Assessment Unit	A specific geographical area which provides the most effective boundaries for management of cumulative environmental impacts on marine habitats.
Mangal	A mangrove plant community.
Mangrove	A plant that grows in sediments regularly inundated by seawater.
Mesotidal	Coastal ocean or waterway with a moderate mean tidal range, between 2 and 4 meters.
Nitrogen fixation	The conversion of atmospheric nitrogen into organic nitrogen compounds. This enriches the soil and is carried out by certain bacteria and blue-green algae.
Pelagic	Applied to organisms of the plankton or nekton which inhabit the open water of a sea or lake.
Pleistocene	Refers to the older subdivision of the Quaternary. The Pleistocene, usually ranking as a epoch, was the time of the most recent glaciation, and is generally thought to have lasted from about 2 million years ago to about 10 000 years ago.
Pneumatophore	Breathing roots of some mangrove species. A respiratory root which rises above the soil surface.

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Terminology	Definition
Ria	Flooded landmass
Sediment Cell	A sediment cell is a section of coast within which the movement of sediment is readily identifiable, if not largely self-contained.
Semi-diurnal	Having a period of, occurring in, or related to approximately half a day.
Supratidal	Areas located above the influence of tides.
Terriginous	Refers to sediments derived from the land.
Vicarious events	An event that divides a species' population into isolated parts that are no longer in reproductive contact – with speciation being the outcome. Examples of such events would be tectonic activity or sea level change.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd, and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

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

This report was prepared between July and October 2009 and finalised in May 2010, and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

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Appendix A Intertidal Survey Habitat Description

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Appendix A

Site	Latitude	Longitude	Comments
1 14/11/08 0600 hrs	7602138 N 7602167 N	0299499 E 0299475 E	Sandy beach approximately 1 km north-east of Four Mile Creek (Sunset Beach). Sloping beach face with a small cliffed berm (0.4 m) at high water mark. Taken from the top of the splash zone, to the low water zone (bearing 320˚).
2 14/11/08 0645 hrs	7601568 N Transect 1 7601620 N 7601418 N Transect 2 7601479 N	0298627 E Transect 1 0298606 E 0298408 E Transect 2 0298381 E	Mouth of Four Mile Creek. Transect 1: On east side of small delta-shaped deposit of sand bars/shoals at the mouth of Four Mile Creek. Sloping beach face with small cliffed berm (0.2 m high) at high water mark. Sand bar/shoal habitat extends seaward from bottom of beach face. Transect 1 starts at top of the splash zone and extends to the low water zone (transect bearing 336^{o}). Transect 2: At mouth of Four Mile Creek. Transect 2 extends from the creek channel, over the supratidal low dune habitat, down beach slope and out onto the sand bar habitat extending seaward from bottom of beach face (transect bearing 10^{o}).
3 14/11/08 0930 hrs	7601145 N	0298915 E	Eastern bank of 4 Mile Creek. Muddy creek backed by a small area of samphire flat. Zonation of samphire (mostly *Halosarcia* sp.) and other halophytic (salt tolerant) shrubs was evident within the samphire flat and in the transition between the samphire communities and the adjacent terrestrial vegetation (hinterland) which was dominated by spinifex and buffel grass.
4 14/11/08 1530 hrs	7600345 N	0295233 E	Western bank of the western arm of Hooley Creek. Muddy creek backed with low scattered mangroves (mostly *Avicennia marina*), bioturbated mud flats and samphire flats.
5 15/11/08 0700 hrs	7600706 N 7600853 N	0294114 E 0294134 E	Sandy beach with tidal lagoon approximately 1 km west of Hooley Creek. Progradation of the Ashburton Delta to the east via a series of beach/chenier deposits and tidal lagoons has resulted in this area changing from a narrow sandy beach (in ~ 2004) to a broader beach/tidal lagoon habitat. Transect includes complete beach/lagoon sequence. Transect commences from the high water mark on the landward side of the lagoon (at base of dunes), extends through the tidal lagoon, over a low supratidal sand bank/beach and down the seaward beach face to the low water mark (transect bearing 10^{o}).
6 15/11/08 0800 hrs	7600638 N 7600684 N	0295269 E 0295284 E	Shoreline west of Hooley Creek mouth. Sandy beach with a narrow rock platform at mid to low tidal level. Transect extends from the high water mark on the beach to the low water level on the rock platform (bearing 30^{o})

Appendix A

Site	Latitude	Longitude	Comments
7 15/11/08 0915 hrs	7600059 N 7599783 N	0294408 E 0294637 E	Western arm of Hooley Creek – middle reaches. Extensive area of samphire flats and bioturbated mudflats between terrestrial vegetation (hinterland) and the west side of Hooley Creek. Most of the samphire flat/mudflats area had been inundated by the overnight high tide (2.7 m CD tide) with pools of water still remaining. An open shrubland of *Avicennia* mangroves fringed the tidal creek channel.
8 15/11/08 1200 hrs	7600440 N	0291215 E	Eastern side of the Ashburton Delta where mangrove system abuts hinterland. Small tidal creek channel fringed by a dense shrubland and thickets of mangroves (mixed community of *Avicennia marina* and *Ceriops australis*).
9 16/11/08 0645 hrs	7600907 N 7601223 N	0292777 E 0292841 E	Eastern side of the Ashburton Delta: extensive beach and lagoon sequence (~300 m wide). The tidal lagoon contained two muddy channels approximately 40 m across at low tide – mud flats adjacent to the lagoon are being colonised by *Avicennia* mangrove seedlings and colonies of juvenile gastropods (density of seedlings increases towards the east, i.e. closer to the delta). Site is in the approximate location of the old Onslow jetty, however none of the remnant jetty piles are visible (possibly covered by sand via easterly progradation of the delta). Transect extends from the high water mark on the landward side of the lagoon (at base of dunes), through two lagoon channels, over a supratidal sand spit, down seaward facing beach face to the low water zone of the beach (transect bearing 15°).
10 16/11/08 0945 hrs	7600700 N 7600959 N	0292067 E 0291461 E	Eastern side of the Ashburton Delta: Red sand dune (terrestrial origin?) truncated by the surrounding mangrove system and tidal flats. A range of mangrove communities occurs in the area: landward mangroves - open shrubland and thickets of *Avicennia marina*; tidal creek fringing mangroves – dense thickets of *Avicennia marina* and *Rhizphora stylosa* with a low shrubland of *Aegiceras corniculatum* (river mangrove) on creek bank.
11 17/11/08 0700 hrs	7601162 N	0296353 E	Mouth of Hooley Creek – delta-shaped deposit of sand bars with shallow channels that extend seaward (~500 m wide) from mouth of Hooley Creek.
12 17/11/08 0800 hrs	7600782 N	296400 E	Mouth of Hooley Creek - sandy creek bank on eastern side of Hooley Creek mouth.
13 17/11/08 0930 hrs	7600518 N	0295958 E	Mouth of Hooley Creek - small muddy rock bar near the convergence of the eastern and western arms of Hooley Creek.

Appendix A

Site	Latitude	Longitude	Comments
14 17/11/08 1115 hrs	7600863 N 7601015 N	0293306 E 0293333 E	Eastern side of the Ashburton Delta: beach and lagoon sequence (~150 m wide). Progradation of the Ashburton Delta to the east via a series of beach/chenier deposits and tidal lagoons has resulted in this area changing from a narrow rock platform (as per Site S in Roller EIS survey - LEC 1991) to a broader beach/tidal lagoon habitat. Remnant of the rock platform (wave cut bench/platform) is now visible only at base of the sand dunes. Transect extends from the upper surface of the remnant rock bench/platform (at high water mark) on landward side of the lagoon, through the lagoon, over a sand spit and down the seaward facing beach slope to the low water zone of the beach (transect bearing 10^{o}). The levels (relative heights) of the underlying old rock platform were also surveyed as part of this transect.
15 17/11/08 1200 hrs	7599557 N 7599270 N	0293483 E 0293768 E	Western arm of Hooley Creek – upper reaches. Extensive area of samphire flats and mud flats between terrestrial vegetation and the west side of Hooley Creek. Most of the samphire flat/mudflats area had been inundated by the overnight high tide (2.7 m CD tide) with pools of water still remaining. Scattered *Avicennia* mangroves form a band (~20 m wide) that fringe the narrow (~10 m wide) tidal creek channel.
16 18/11/08 0700 hrs	7606589 N 7606927 N	0304544 E 0304665 E	Beadon Point, Onslow - extensive rocky platform (~300m wide). Small areas of sandy beach and mud flat habitat on landward side of the rock platform. Taken from the high water mark on the beach, across small area of the mudflat (muddy sands) and out across the rocky platform to the low water mark (transect bearing 45^{o}).
17 13/2/09 0700-0900hrs 1100-1145hrs	7601968 N 7601721 N	0290949 E 0290896 E	Entrance Point, Ashburton Delta: Sand spit with sand bars and shoals flats seaward of a small creek mouth that were exposed at low tide. Sand spit is backed by a complex system of tidal creek channels, narrow cheniers and mangrove fringed lagoons. On viewing the August 2007 aerial photography it is evident that prevailing coastal processes have modified the orientation of sand spits and channels (i.e. very dynamic/mobile area) with easterly progradation of the seaward sand spit and erosion of older spits/cheniers and the seaward mangrove shoreline in other areas. Transect traverses the creek/dune/lagoon/chenier/creek/sand spit/low tidal sand flat sequence. From landward to seaward extent this is a mangrove fringed tidal channel (mixed *Avicennia*/*Rhizophora* dense forest); a low, narrow dune (*Spinifex longifolius, Grevillia* sp., *Neobassia* sp.); a narrow lagoon (with low *Avicennia* shrubland and fringed by samphires); a chenier that is eroding on the seaward side (and is also undermining *Avicennia* mangroves); major tidal channel (which enters ocean on east side of Site 17); low sand spit (is submerged by spring high tides) and low tidal sand flat at mouth of tidal creek.
18 13/2/09 1020 hrs	7601548 N	0291432	Entrance Point area, Ashburton Delta: Tidal creek channel that extends south-east of Entrance Point. The same channel forms the shore-parallel lagoon that extends towards Hooley Creek along the east side of the delta (this beach/lagoon sequence was surveyed in November 2008 at Sites 5, 9, 14). Tidal channel is fringed by dense mangrove thickets - mixed *Avicennia*/*Rhizophora* (3-4 m) with a band of low *Aegiceras* (1 m) on creek edge in front of dense thickets. Substrate varied from muddy-sands to muds (stands of monospecific *Rhizophora* occurred in soft muds).

Appendix A

Site	Latitude	Longitude	Comments
19 13/2/09 1150 hrs	7601499 N	0290271 E	Entrance Point area, Ashburton Delta: Narrow tidal channel (~20 m wide) that extends south from Entrance Point. Dense *Rhizophora* forest (~4 m) with a narrow band of low *Aegiceras* (1 m) on creek edge in front of dense forest.
20 13/2/09 1220 hrs	7601355 N	0289037 E	Entrance Point area, Ashburton Delta: Moderate size mangrove fringed tidal creek (~60 m wide) extending south-west from Entrance Point. Closed canopy *Avicennia* (tall scrub 2-3 m) with scattered *Rhizophora*, *Ceriops* and a small stand (~15 trees) of *Bruguiera exaristata* (2 m high). Low shrubs *Aegiceras* (1 m) also on creek edge. Site is on located on the boundary between tall *Avicennia* scrub and dense *Rhizophora* forest which fringed the creek further downstream. Muddy substrate.
21 13/2/09 1630 hrs	7601355 N 7601319 N	0289037 E 0289037 E	Entrance Point Area: Sandy beach/dune/tidal lagoon sequence ~1 km south-west of Entrance Point area. Tidal creek mouth has re-opened in this area (was closed in August 2007 aerial photo and closed in 2001 aerial photo) and fast-flowing, highly turbid water was exiting out of creek on ebbing tide. In some areas the low coastal dune (with *Spinifex longifolius*) has moved landward and encroached into mangrove habitat that fringe the tidal lagoon (sediment burial impact). On west (seaward) side of the lagoon, *Avicennia* seedlings are colonising new habitat (soft unconsolidated muddy sands); on east side of lagoon is dense forests of mixed *Avicennia*/*Rhizophora* (~4 m) with scattered *Ceriops*.
22 13/2/09 1730 hrs	7600980 N	0288507 E	Entrance Point Area: Sandy beach and eroding mangrove shoreline ~1.5 km south-west of Entrance Point area. On west side of creek mouth described for Site 21. This site displays the sequence of sediment burial (by the landward migrating dune) impacting seaward mangroves (*Avicennia* woodland ~4 m) and the subsequent erosion of remnant dead trees/trunks along the current shoreline. Same site and sediment burial/shoreline erosion sequence has been described previously in LEC (1991) and Semeniuk (1993).
23 14/2/09 0700 hrs	7599827 N	0284029 E	Mouth of Ashburton River: west side of river mouth. Moderately sloping sandy beach with an extensive area of sand bars/shallow pools/channels.
	7600494 N	0284327 E	Inside river mouth an area of very soft mudflats occurred along the west bank (numerous mudskippers of various different sizes, most commonly ~10 cm size but also some larger 25-30 cm size).
24 14/2/09 1030 hrs	7599011	0285104	Ashburton River: west bank of main channel approximately 1 km upstream from mouth. Extensive area of samphire flat extends away from river bank (*Halosarcia auriculata* and salt couch *Sporobolus virgincus*). River bank immediately upstream is fringed by dense mangroves (*Avicennia* with scattered *Ceriops* and *Aegiceras*).

Appendix A

Site	Latitude	Longitude	Comments
25 14/2/09 1050 hrs	7598920 N	0285579 E	Ashburton River: west bank of main channel approximately 1.5 km upstream from mouth. Dense *Avicennia* forest (~4 m) with an area of *Avicennia* seedlings/saplings colonising new mudflat habitat seaward of existing dense forest.
26 14/2/09 1145 hrs	7600223 N	0288250 E	Ashburton Delta: main distributary channel that branches from the Ashburton River and flows north-east towards Entrance Point. Dense *Avicennia* forest (~4-5 m) with a narrow band of *Aegiceras* (1-2 m) on creek edge in front of dense forest.
27 14/2/09 1230 hrs	7599117 N	0286692 E	Ashburton Delta: main distributary channel that branches from the Ashburton River and flows north-east towards Entrance Point (site is located on north bank of channel, approximately 500 m from junction with Ashburton River). Large area of samphire flat that extends north (for ~500 m) to the coastal dunes and south-west (for ~500 m) to the east bank of the Ashburton River. Immediately next to channel was a narrow band (~10 m wide) of dense heath comprised of *Muellerolimon salicorniaceum, Sporobolus virginicus* (Marine Couch) and *Frankenia ambita* with scattered emergent low *Avicennia* shrubs (~1 m). Landward of this band was the extensive samphire flat that had been inundated by the recent high tides (2.8-2.9 m CD). Dominant samphire species were *Halosarcia halacnemoides* and *H. pruinosa*.
28 14/2/09 1700 hrs	7597861 N	0282542 E	Secret Creek: a small tidal creek approximately 2 km south-west of the Ashburton River mouth. A narrow creek (~20 m wide) exits through a low dune system. Mid to upper reaches of the creek are fringed by open to closed scrub (1-3 m) of predominately *Avicennia* mangroves with scattered *Rhizophora* and *Ceriops*. Extensive areas of bioturbated mudflat and samphire flat further landward of the mangrove zone.
29 4/5/09 0830 hrs	7604664 N	0306356 E	Beadon Creek: Samphire flat and mangrove lined tidal creek south east of Beadon Creek wharf. Tidal flat sequence is samphire flat (mostly *H. halacnemoides*)/bioturbated mud flat/mangrove zone fringing creek (dense *Avicennia* scrub 2-3 m with scattered *Rhizophora* and *Ceriops*).
30 4/5/09 1030 hrs	7599139 N 7599046 N	0293372 E 0293670 E	Western arm of Hooley Creek – upper reaches. Area of samphire flats and bioturbated mudflats between terrestrial vegetation (hinterland) and the west side of Hooley Creek (~300 m upstream from Site 15). Tidal flat sequence from the hinterland to the tidal creek is samphire flat (*H. halacnemoides* and *H. pruinosa*)/bioturbated mud flat/samphire flat (monospecific *H. halacnemoides*)/ mangrove zone fringing creek (scattered *Avicennia* 2-3 m).
31 4/5/09 1230 hrs	7598796 N 7598734 N	0293432 E 0293525 E	Western arm of Hooley Creek – high tidal mudflats adjacent to the upper most reaches (transect intersects the erosional headwater of Hooley Creek west arm – i.e. the upper limit of the very small erosional channels). Extensive areas of samphire flats (*H. halacnemoides* and *H. pruinosa*) interspersed with small areas of bioturbated mudflats and algal mats

Appendix A

Site	Latitude	Longitude	Comments
32 5/5/09 1100 hrs	7601325 N 7601377 N	0291493 E 0291503 E	Ashburton Delta: eastern edge, long narrow chenier amongst mangrove flats and tidal channels. Mangroves fringing the seaward side of the chenier were a low forest to scrubland of *Avicennia* with an understorey of either *Aegiceras* (River Mangrove) or *Aegialitis* (Club Mangrove) in some areas. Scattered *Avicennia* and *Ceriops* mangroves occur along the chenier/tidal flat interface. Dense *Avicennia* and *Rhizophora* thickets fringe the landward side of the chenier. Coastal spinifex (*S. longifolius*) growing on chenier ridge.
33 6/5/09 0930 hrs	7598009 N	0286176 E	Ashburton River main channel: East bank adjacent to the old Onslow townsite. Fringing band of dense *Avicennia* thickets (3-4 m) with scattered *Rhizophora* and *Ceriops*. Subsrate of very fine material (red/brown clays). Very extensive samphire flat landward of the mangroves - mixed *H. halacnemoides/ H. pruinosa* with patches of *Sporobolus virginicus*.
34 6/5/09 1030 hrs	7599253 N 7599253 N	0287026 E 0287026 E	Ashburton Delta: tidal flats adjacent to the main distributary channel that branches from the Ashburton River and flows north-east towards Entrance Point (site is located on south bank of channel, approximately 500 m from junction with Ashburton River, opposite Site 27). Landward portion of tidal flats is an extensive samphire flat of mostly *H. halacnemoides/ H. pruinosa* with some *Sporobolus virginicus*, *Muellerolimon salicorniaceum,* and *Frankenia ambita*. Seaward of the samphire flats is a series of narrow drainage lines (with dense mangroves) separated by a more open community of scattered *Avicennia* mangroves amongst large samphire plants. Many dead *Avicennia* mangroves trees noted in the more open community and along the margins of the small drainage lines. This area may have been part of the main distributary channel (or the main Ashburton River channel) and changes to channel orientation have resulted in subsequent changes to hydrology and mangrove occurrence (and caused the observed historical mortality).
35 6/5/09 1130 hrs	7599212 N 7599534 N	0287896 E 0287912 E	Ashburton Delta: Landward section where tidal flats meet the hinterland ~2 km north of the old Onslow townsite. Extensive area of high tidal mudflats that include a narrow samphire zone, larger area of bioturbated mudflat and narrow mangrove zone fringing the upper most reaches of tidal creek that extends south and west from the main distributary channel. Samphire community is mostly *H. halacnemoides* with some areas of *H. pruinosa*. Mangrove zone is *Avicennia* shrubland (1-3 m).
36 6/5/09 1400 hrs	759953 N	0290365 E	Ashburton Delta: Landward section, narrow tidal flat (~80 m wide) with a small tidal creek, located between the old Onslow hinterland and the Ashburton north hinterland. Scattered *Avicennia* mangroves (2-3 m) fringe the tidal flat and an small area of bioturbated mudflat and samphires are landward of the mangroves.
37 7/5/09 1030 hrs	7600338 N	0291322 E	Ashburton Delta: Landward south-east section of delta ~50 m south of site 8. Site is located along the tidal flat/hinterland margin where a *Sporobolus* grassland meets a small mudflat area with scattered *Avicennia* mangroves (2-3 m). A narrow samphire zone (~2 m wide) which occurs between the grassland and the mudflat was sampled for crab fauna and a similar suite of crab species were collected as has been found in more expansive (~100 m wide) samphire flats.

Appendix A

Site	Latitude	Longitude	Comments
38 7/5/09 1315 hrs	7598445 N 7598422 N	0294437 E 0294878 E	Hooley Creek area: high tidal mudflats between the upper reaches of the west and east arms of Hooley Creek. The transect extended from a large island, across the mudflats to a small tidal creek (upper most reaches of the east arm). The north-east corner of the island has an exposed fossil coral reef/limestone pavement that represents a previous coastline (most likely Pleistocene period – to be confirmed). Tidal flat sequence is algal mat/bioturbated mudflat/narrow samphire flat (*H. halacnemoides*)/mangrove zone fringing creek (scattered *Avicennia* ~2 m).
39 7/5/09 1415 hrs	7599924 N	0295069 E	Hooley Creek: low sandy/shell islands and tidal flats between the mid reaches of the west and east arms of Hooley Creeks. The low islands are fringed by a samphire grassland (mostly *Sporobolus virginicus* and *Muellerolimon salicorniaceum*). The east bank of the west arm and adjacent tidal flats support a open to dense mangrove shrubland of *Avicennia* with some *Ceriop*s and *Aegailitis.* A limestone pavement with in situ fossil shell beds (mostly ark shells) extends across the tidal flats between the two small islands - in combination (i.e. small islands and the limestone pavement) this structure extends between the two arms of Hooley Creek and is likely to represent a previous coastal shoreline of more recent age than that seen at Site 38.
40 8/5/09 1300 hrs	7584229 N	0261862 E	Tubridgi Point area: mangrove fringed tidal creek which branches east from the main northern channel. A low sandy/shelly island is surrounded by samphire flats of varying widths (20-150 m) and mangrove-lined creek channels (open to dense shrublands of *Avicennia* with some low forests fringing the main channel).
41 8/5/09 1430 hrs	7596934 N	0283634 E	Secret Creek: a small tidal creek approximately 2 km south-west of the Ashburton River mouth. Site is located in the upper reaches of main mangrove fringed channel. Low open to dense *Avicennia* with a narrow bioturbated mud flat landward of the mangroves. Extensive crab activity was evident in this narrow bioturbation zone.
42 8/5/09 1430 hrs	7600191 N	0288370 E	Ashburton Delta: tidal flats adjacent to central section of the main distributary channel that branches from the Ashburton River and flows north-east towards Entrance Point (site is located on south bank of channel, opposite Site 26). A small flat chenier vegetated by *Sporobolus virginicus*, *Muellerolimon salicorniaceum,* and *Frankenia ambita* occurs amongst a samphire flat with low scattered *Avicennia*. Dense thickets of *Avicennia* (~3-4 m) fringe the channel as a band ~20 m wide. Mangroves on landward side of this band grade into a low open shrubland of *Avicennia* and *Ceriops*.
43 9/5/09 0800 hrs	7607238 N	10310700 E	Second Creek approximately 1 km upstream from mouth (site located on the north bank). Dense *Avicennia* (3 m) mangroves fringing the narrow creek (~30 m wide). A bioturbated mudflat zone and narrow samphire flat occurs landward of the mangrove zone and a low sandy island close to the creek supports grassland of *Sporobolus virginicus*, *Muellerolimon salicorniaceum* and *H. halacnemoides.*

Appendix A

Site	Latitude	Longitude	Comments
44 9/5/09 1300 hrs	7613759 N	0318513 E	Coolgra Point: Mangrove shoreline on Coolgra Point – northeast corner at the mouth of Coolgra Point creek. Areas of fractured limestone outcropping amongst mangroves. Fringing *Avicennia* (3-4 m) forests with some areas of *Rhizophora*. In the more open areas, low *Aegialitis* (club mangrove), *Aegiceras, Ceriops* and *Bruguiera* occurred amongst an *Avicennia* dominated shrubland (i.e. all six mangrove species occurring on the western Pilbara coast are found at this site). *Bruguiera* were also found along the landward edge of mangroves at the base of a sandy/limestone ridge.
45 9/5/09 1400 hrs	7610996 N	0316643 E	Coolgra Point: Extensive tidal flat area extending southwards from main Coolgra Point creek. Areas of samphire flats (mostly *H. halacnemoides*) and bioturbated mud flats amongst a low open to dense shrubland of *Avicennia* mangroves (also scattered *Ceriops).* Dense *Avicennia* thickets (3 m) fringe the creek that extends south-east from the main Coolgra Point creek.
46 9/5/09 1445hrs	7609683 N	0315494 E	Coolgra Point: Creek branching southwards from main Coolgra Point creek. *Rhizophora/Avicennia* thickets (3-4 m) fringe the creek and are backed by *Avicennia* scrub, bioturbated mud flats and samphire flats (*H. halacnemoides* and *Hemichroa diandra*). Sand island/tidal flat margin supports a grassland or heath of *H. halacnemoides*, *H. pruinosa, Sporobolus virginicus*, *Muellerolimon salicorniaceum,* and *Frankenia ambita*

B

Appendix B Onslow Intertidal Habitats Survey - Invertebrate Fauna Data and Western Australian Museum Identification of Crustacean Samples Report

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Table 1. Summary table of macro-invertebrates recorded from intertidal habitats in the Onslow area.

Group	Species	Sites	Geographic Distribution	Habitat Categories	Feeding
MOLLUSCA					
Bivalvia – Mytilidae	*Brachidontes cf. ustulatus*	6, 14, 44	Western Australia - endemic	Mangal flat (sea front) - crevices rocky shore - crevices	Suspensory feeder
Ostreidae	*Saccostrea cucullate*	44, 13	Indo-West Pacific	Mangal flat (sea front) - on trunks rocky shore – on rocks	Suspensory feeder
Mesodematidae	*Paphies* sp. indet.	2, 5, 11, 12, 17, 23	Unknown	Beach slope	Suspensory feeder
Teredinidae	*Gen.*spp. indet.	Various	-	Mangal flat – boring in dead mangrove wood	Suspensory feeder
Gastropoda – Neritidae	*Nerita balteata*	8, 10, 32	Indo-West Pacific	Mangal flat – on tree trunks	Grazer – epiphytic microorganisms
Littorinidae	*Littoraria (Littorinopsis) cingulate*	24, 26, 44	North West Shelf - endemic	Mangal flat – on tree trunks/branches	Grazer – epiphytic microorganisms
	Littoraria (Littorinopsis) filosa	44	Indo-west Pacific	Mangal flat – on tree trunks/branches	Grazer – epiphytic microorganisms
	Littoraria (Palustorina) sulculosa	10, 22	North West Shelf - endemic	Mangal flat – on tree trunks/branches	Grazer – epiphytic microorganisms
	Littoraria (Palustorina) undulata	22,	Indo-West Pacific	Rocky shores & wood structures Mangal flat – on tree trunks/branches	Grazer – epiphytic microorganisms
	Littoraria (Palustorina) articulata	22, 44	Indo-West Pacific	Rocky shores & wood structures Mangal flat – on tree trunks/branches	Grazer – epiphytic microorganisms
Potamididae	*Telescopium telescopium*	10, 17, 18, 44	Indo-West Pacific	Mangal flat – substrate crawler	Detritivore – substrate detritus
	Terebralia palustris	10, 17, 18, 26	Indo-West Pacific	Mangal flat – substrate crawler	Detritivore – substrate detritus

Appendix B

Group	Species	Sites	Geographic Distribution	Habitat Categories	Feeding
	Terebralia semistriata	10, 17, 44	Northern Australia - endemic	Mangal flat – substrate crawler	Detritivore – substrate detritus
	Cerithideopsila cingulata	5, 15, 17, 24	Indo-West Pacific	Mud flat – substrate crawler	Detritivore – substrate detritus
	Cerithidea largillerti	10, 35	Indo-West Pacific	Mud flat – substrate crawler	Detritivore – substrate detritus
	Cerithidea reidi	8, 32, 45	North West Shelf – endemic	Mangal flat – tree trunks/branches	Grazer – epiphytic microorganisms
Naticidae	*Polinices conicus*	1, 2, 5, 9, 11, 12, 17, 23	Circum-Australian	Beach slope	Predator
	Natica gualteriana	23	Indo-West Pacific	Alluvial fan – sand flat	Predator
Nassariidae	*Nassarius dorsatus*	2, 11	Indo-West Pacific	Alluvial fan – sand flat	Scavenger
	Onchidium sp. indet.	10	?	Mangal flat – substrate crawler	
Ellobiidae	*Cassidula aurisfelis*	24	Indo-West Pacific	Mangal flat – under logs etc	Detritivore – substrate detritus

Appendix B

Group	Species	Sites	Geographic Distribution	Habitat Categories	Feeding
CRUSTACEA					
Brachyura					
Portunidae - Swimming crabs	*Scylla serrata*	7, 10,15, 26	Indo-West Pacific	Tidal creeks – swimming and shallow burrows	Predator/scavenger
	Thalamita sp.	44	Indo-West Pacific	Tidal creeks – swimming	Predator/scavenger
Grapsidae - Shore crabs	*Metopograpsus frontalis*	4, 20,24, 25, 27, 30, 36, 37, 38, 39,41, 42,43, 44, 45, 46	Indo-West Pacific	Mangal flats – free running	Predator/scavenger?
Macrophthalmidae - Sentinel crabs	*Macrophthalmus cf. darwinensis*	44	North West Shelf - endemic	Mangal flats/rock platform	Predator/scavenger?
Ocypodidae - Ghost crabs	*Ocypode ceratothalmus*	1, 2, 5, 9, 11, 12, 17, 21, 22, 23, 34	Indo-West Pacific	Beach slope – deep burrows	Detritivore/scavenger – plant detritus
	Ocypode fabricii	9, 32, 34, 36, 37	Indo-West Pacific	Beach slope – deep burrows	Detritivore/scavenger – plant detritus
Ocypodidae – Bubbler crabs	*Scopimera* n. sp.	23	? North West Shelf - endemic	Beach slope; sand flat – deep burrows	Grazer – substrate surface microorganisms
Ocypodidae – Soldier crabs	*Myctyris* n. sp.	15	? North West Shelf - endemic	Sand/mud flat – deep burrows	Grazer – substrate surface microorganisms

Appendix B

Group	Species	Sites	Geographic Distribution	Habitat Categories	Feeding
Ocypodidae – Fiddler crabs	*Uca elegans*	7, 8, 15, 20, 23, 25, 27, 30, 31,32, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 45, 46	North West Shelf - endemic	High tidal (bioturbated) mud flat & mangal mud flat – deep burrows	Grazer – substrate surface microorganisms
	Uca flammula	4,7, 15, 23, 32, 38, 39, 18, 44, 45	North West Shelf - endemic	Mangal mud flat (creek banks) – deep burrows	Grazer – substrate surface microorganisms
	Uca dampieri	2, 4	North West Shelf - endemic	High tidal mud flat – deep burrows	Grazer – substrate surface microorganisms
	Uca mjobergi	35, 40	North West Shelf - endemic	High tidal mud flat – deep burrows	Grazer – substrate surface microorganisms
	Uca capricornis	2, 22, 24, 44	Northern Australia - endemic	High tidal mud flat – deep burrows	Grazer – substrate surface microorganisms
Sesarmidae (Marsh crabs)	*Neosamaretim meinteri*	10, 25, 27, 34, 43	Indo-West Pacific	Mangal and high tidal (bioturbated) mud flat – deep burrows	Detritivore/herbivore – substrate plant detritus & mangrove leaves
	Perisesarma semperi	41, 46	Indo-West Pacific	Mangal and high tidal (bioturbated) mud flat – deep burrows	Detritivore – substrate plant detritus
	Perisesarma n. sp	3, 43, 45	? North West Shelf - endemic	Mangal and high tidal (bioturbated) mud flat – deep burrows	Detritivore – substrate plant detritus
	Parasesarma n. sp	3, 20, 30, 32, 34, 35, 36, 40, 41, 43	? North West Shelf - endemic	Mangal and high tidal (bioturbated) mud flat – deep burrows	Detritivore – substrate plant detritus

Appendix B

Group	Species	Sites	Geographic Distribution	Habitat Categories	Feeding
Thalassinidea - Ghost shrimps					
Callianassidae	*Lepidopthalmus* n. sp	36	? North West Shelf - endemic	High tidal (bioturbated) mud flat – deep burrows	Unknown, presumed detritivore
Upogebiidae	*Upogebia giralia*	4	North West Shelf - endemic	High tidal (bioturbated) mud flat – deep burrows	Unknown, presumed detritivore
Cirripedia - Barnacles					
Chthamalidae	*Chthamalus malayensis*	44	Indo-West Pacific	Mangal flat – tree trunks /branches; Rocky shores	Suspensory feeder
	Microoeuraphia withersi	44	Northern Australia - endemic	Mangal flat – tree trunks /branches; Rocky shores	Suspensory feeder
Balanidae	*Fistulobalanus* n. sp.	24	? North West Shelf - endemic	Mangal flat – tree rhizomes;	Suspensory feeder

Appendix B

Table 2. Invertebrate fauna recorded from each location and site

Area	Site ID	EastingG	Northing	Habitat Categories	Species
Hooleys	4	295233	7600345	upper littoral mangal flat; upper littoral mud flat (bioturbated and samphire)	**Molluscs:** none observed **Crustaceans:** *Upogebia giralia; Metopograpsus frontalis; Uca dampieri; Uca flammula*
	6	295269	7600638	upper littoral beach slope; mid - lower littoral rock flat (beach rock)	**Molluscs:** *Brachidontes* sp.; *Morula* sp.; *Thais echinata* **Crustaceans:** not collected
	7	294408	7600059	upper littoral mangal flat; bioturbated/samphire mud flat; algal mat mud flat	**Molluscs:** none observed **Crustaceans:** *Uca elegans; Uca flammula*
	11	296353	7601162	mid-littoral alluvial fan	**Molluscs:** donacid sp.; *Polinices conicus; Nassarius bicallosus; Nassarius dorsatus* **Crustaceans:** None observed
	12	296400	7600782	mid-littoral tidal creek bank (sandy)	**Molluscs:** donacid sp.; *Polinices conicus* **Crustaceans:** None observed
	13	295958	7600518	mid-littoral tidal creek channel (rock barrier)	**Molluscs:** *Saccostrea cucullata; Martesia* sp.; *Planaxis sulcata* **Crustaceans:** None observed
	15	293483	7599557	upper littoral mangal flat; upper littoral bioturbated/samphire mud flat	**Molluscs:** *Cerithideopsila cingulata* **Crustaceans:** *Myctyris* sp.; *Uca elegans; Uca flammula*
	30	293372	7599139	upper littoral mangal flat; upper littoral bioturbated/samphire mud flat; algal mat mud flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Parasesarma* sp.
	31	293432	7598796	upper littoral mangal flat; upper littoral bioturbated/samphire mud flat; algal mat mud flat	**Molluscs:** None observed **Crustaceans:** *Uca elegans*

Appendix B

Area	Site ID	EastingG	Northing	Habitat Categories	Species
	38	294437	7598445	upper littoral mangal flat; upper littoral bioturbated/samphire mud flat; algal mat mud flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Uca flammula*
	39	295069	7599924	upper littoral mangal flat; upper littoral bioturbated/samphire mud flat; algal mat mud flat; shell pavement	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis* sp; *Uca elegans; Uca flammula*
Ashburton Delta	5	294114	7600706	upper-lower littoral beach slope; lagoon	**Molluscs:** *Polinices conicus;* donacid sp.; *Cerithideopsila cingulata* **Crustaceans:** *Ocypode ceratopthalmus*
	8	7600440	7600440	tidal creek; mangal mud flat	**Molluscs:** *Nerita balteata; Cerithidea reidi* **Crustaceans:** *Uca elegans*
	9	292777	7600907	upper-lower littoral beach slope; lagoon with lower littoral mud banks	**Molluscs:** None observed **Crustaceans:** *Ocypode ceratopthalmus; Ocypode fabricii*
	10	292067	7600700	tidal creek; mangal mud flat	**Molluscs:** *Telescopium telescopium; Terebralia palustris; Terebralia semistriata; Cerithidea largillierti; Cerithideopsila cingulata; Nerita balteata; Littoraria sulculosa; Onchidium* sp. **Crustaceans:** *Neosamarium meinerti*
	14	293306	7600863	upper-lower littoral beach slope; lagoon with lower littoral mud banks; upper-mid littoral rocky shore (now sand scoured)	**Molluscs:** *Brachidontes* sp.; *Planaxis sulcata* **Crustaceans:** *Myctyris* sp.; *Ocypode ceratopthalmus*
	17	290949	7601968	upper littoral beach slope; channel; mangal mud flat	**Molluscs:** donacid sp.; *Polinices conicus; Terebralia semistriata; Terebralia palustris; Telescopium telescopium; Cerithideopsila cingulata* **Crustaceans:** *Ocypode ceratopthalmus*
	18	291432	7601548	tidal creek; mangal mud flat	**Molluscs:** *Terebralia palustris; Telescopium telescopium* **Crustaceans:** *Uca flammula*

Appendix B

Area	Site ID	EastingG	Northing	Habitat Categories	Species
	19	290271	7601499	tidal creek; mangal mud flat	**Molluscs:** None observed **Crustaceans:** **N**one observed
	20	289037	7601355	tidal creek; mangal mud flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Parasesarma* sp.
	21	289037	7601355	beach slope; tidal creek; mangal flat	**Molluscs:** None observed **Crustaceans:** *Ocypode ceratopthalmus*
	22	288507	7600980	beach slope (with remnant mangroves); mangal flat	**Molluscs:** *Littoraria articulata; Littoraria undulosa; Littoraria sulculosa* **Crustaceans:** *Ocypode ceratopthalmus; Uca capricornis*
	23	284029	7599827	alluvial fan; beach slope; river channel	**Molluscs:** *Solen* sp.; donacid sp.; *Polinices conicus; Natica gualteriana* **Crustaceans:** *Scopimera* sp.; *Ocypode ceratopthalmus; Uca elegans; Uca flammula*
	24	285104	7599011	river channel; mangal flat	**Molluscs:** *Cassidula* sp.; *Littoraria* sp. **Crustaceans:** *Fistuobalanus* sp.; *Metopograpsus frontalis; Uca capricornis*
	25	285579	7598920	river channel; mangal flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Neosarmatium meinerti*
	26	288250	7600223	river channel; mangal flat	**Molluscs:** *Terebralia palustris; Littoraria cingulata* **Crustaceans:** None observed
	27	286692	7599117	river channel; mangal flat	**Molluscs:** None onbserved **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Neosarmatium meinerti*

Appendix B

Area	Site ID	EastingG	Northing	Habitat Categories	Species
	32	291493	7601325	chernier; mangal flat; bioturbated mud flat	**Molluscs:** *Nerita balteata; Cerithidea reidi* **Crustaceans:** *Ocypode fabricii; Uca elegans; Uca flammula; Parasesarma* sp.
	33	286176	7598009	river channel; mangal flat	**Molluscs:** None observed **Crustaceans:** None observed
	34	287026	7599253	bioturbated mud/samphire flat; mangal flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Ocypode fabricii; Uca elegans; Parasesarma* sp.; *Neosamartium meinteri*
	35	287896	7599212	bioturbated mud/samphire flat; algal mud flat; mangal flat	**Molluscs:** *Cerithidea largillierti* **Crustaceans:** *Uca elegans; Uca mjobergi; Parasesarma* sp.
	36	290365	7599453	chernier; mangal flat; bioturbated mud flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Ocypode fabricii; Uca elegans; Parasesarma* sp.
	37	291322	7600338	chernier; mangal mud flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Ocypode fabricii; Uca elegans*
	42	288370	7600191	chernier; mangal mud flat; bioturbated/samphire mud flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Ocypode fabricii; Uca elegans; Neosamartium meinteri*

Appendix B

Area	Site ID	EastingG	Northing	Habitat Categories	Species
OTHERS					
Four Mile Creek	1	299499	7602138	upper - lower littoral beach slope	**Molluscs:** *Polinices concus* **Crustaceans:** *Ocypode ceratopthalmus*
	2	298627	7601568	upper - mid littoral beach slope; lower littoral alluvial fan	**Molluscs:** *Nassarius dorsatus; Polinices conicus;* donacid sp. **Crustaceans:** *Ocypode ceratopthalmus; Uca capricornis; Uca dampieri*
	3	298915	7601145	upper littoral mud (samphire) flat	**Molluscs:** None observed **Crustaceans:** *Parasesarma sp.; Perisesarma sp.*
Coolgra Point	44	318513	7613759	fissurred rocky shore/mangal; bioturbated mud flat over rock pavement	**Molluscs:** *Telescopium telescopium; Terebraia semistriata; Nerita balteata; Littoraria articulata; Littoraria filosa; Littoraria cingulata* **Crustaceans:** *Chthalamus malayensis; Microeuraphia withersi; Metopograpsus frontalis; Macrothalmus cf. darwinensis; Uca capricornis; Uca elegans; Uca flammula*
	45	316643	7610996	bioturabted/samphire mud flat; mangal flat	**Molluscs:** *Cerithidea reidi* **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Uca flammula; Perisesarma* sp.
	46	315494	7609683	chernier; bioturbate/samphire mud flat; mangal flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Perisesarma semperi*
Secret Creek	28	282542	7597861	tidal creek; mangal flat	**Molluscs:** None observed **Crustaceans:** None observed
	41	283634	7596934	bioturbated/samphire mud flat; mangal flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Perisesarma semperi; Parasesarma* sp.

Appendix B

Area	Site ID	EastingG	Northing	Habitat Categories	Species
Second Creek	43	310700	7607238	tidal creek; mangal flat; bioturbated/samphire flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca elegans; Parasesarma* sp.; *Perisesarma* sp.; *Neosamartium meinerti*
Beadon Point	16	304544	7606589	rock platform; beach slope	**Molluscs:** *Septifer bilocularis; Astrea stellata; Calthalotia* sp.; *Angaria delphinus; Clypeomorus* sp.; *Natica solida; Cypraea moneta; Morula crassicostata; Nassarius dorsatus; Nassarius bicallosus* **Crustaceans:** not collected
Beadon Creek	29	306356	7604664	bioturbated/samphire mud flat; mangal flat	**Molluscs:** None observed **Crustaceans:** *Metopograpsus frontalis; Uca capricornis; Uca flammula; Uca elegans; Parasesarma* sp.
Tubridgi Point	40	261862	7584229	chernier; tidal creek; bioturbated/samphire mud flat; mangal flat	**Molluscs:** None observed **Crustaceans:** *Uca elegans; Uca mjobergi; Parasesarma* sp.

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C

Appendix C Mangrove Association Mapping

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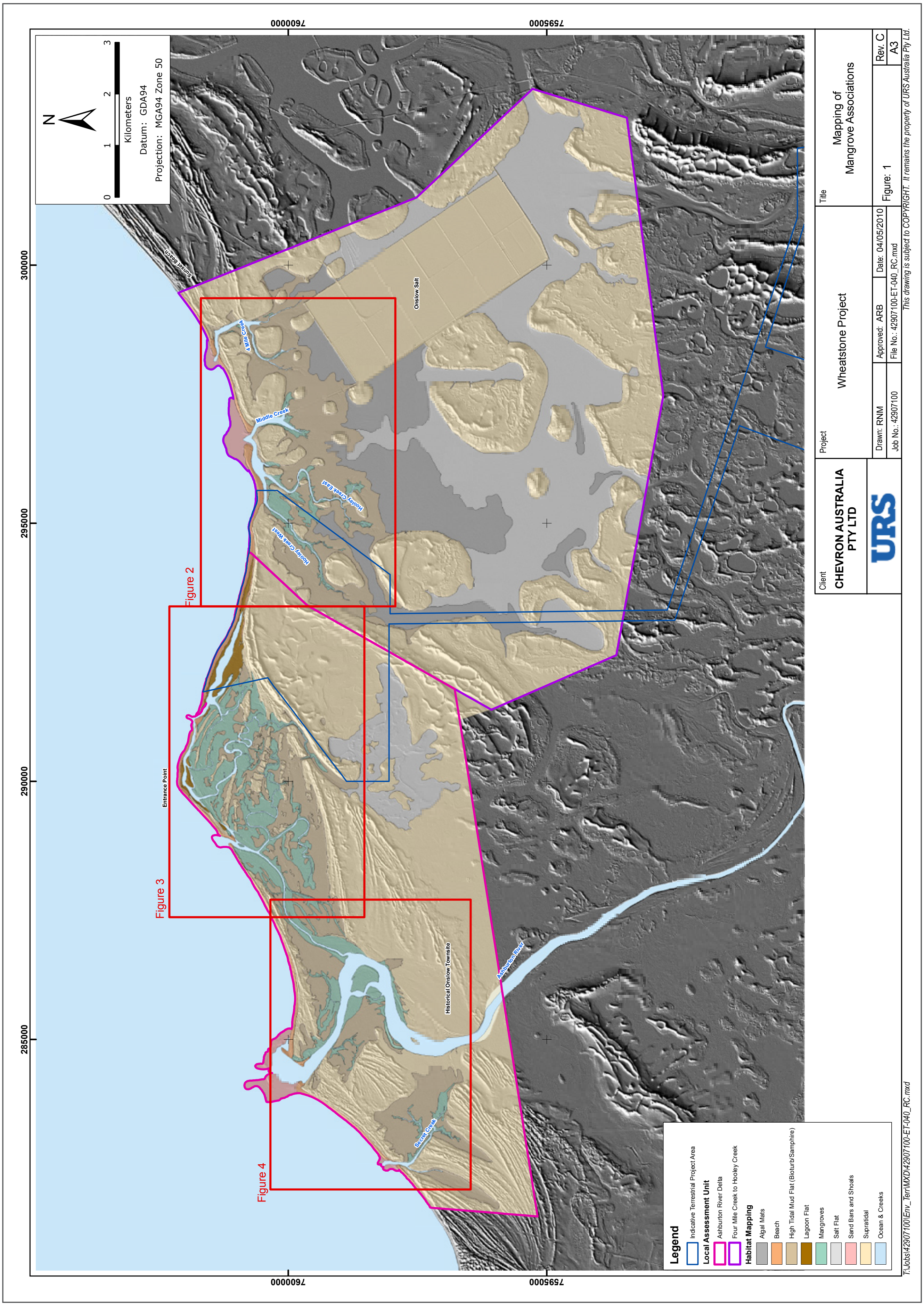
Figure 2
Figure 3
Figure 4
4 Mile Creek
Middle Creek
Hooley Creek East
Hooley Creek West
Onslow Salt
Entrance Point
Historical Onslow Townsite
Ashburton River
N
0 1 2 3
Kilometers
Datum: GDA94
Projection: MGA94 Zone 50
7600000
7595000
300000
295000
290000
285000
Legend
Indicative Terrestrial Project Area
Local Assessment Unit
Ashburton River Delta
Four Mile Creek to Hooley Creek
Habitat Mapping
Algal Mats
Beach
High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Mangroves
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Mapping of Mangrove Associations
Drawn: RNM
Approved: ARB
Date: 04/05/2010
Figure: 1
Rev. C
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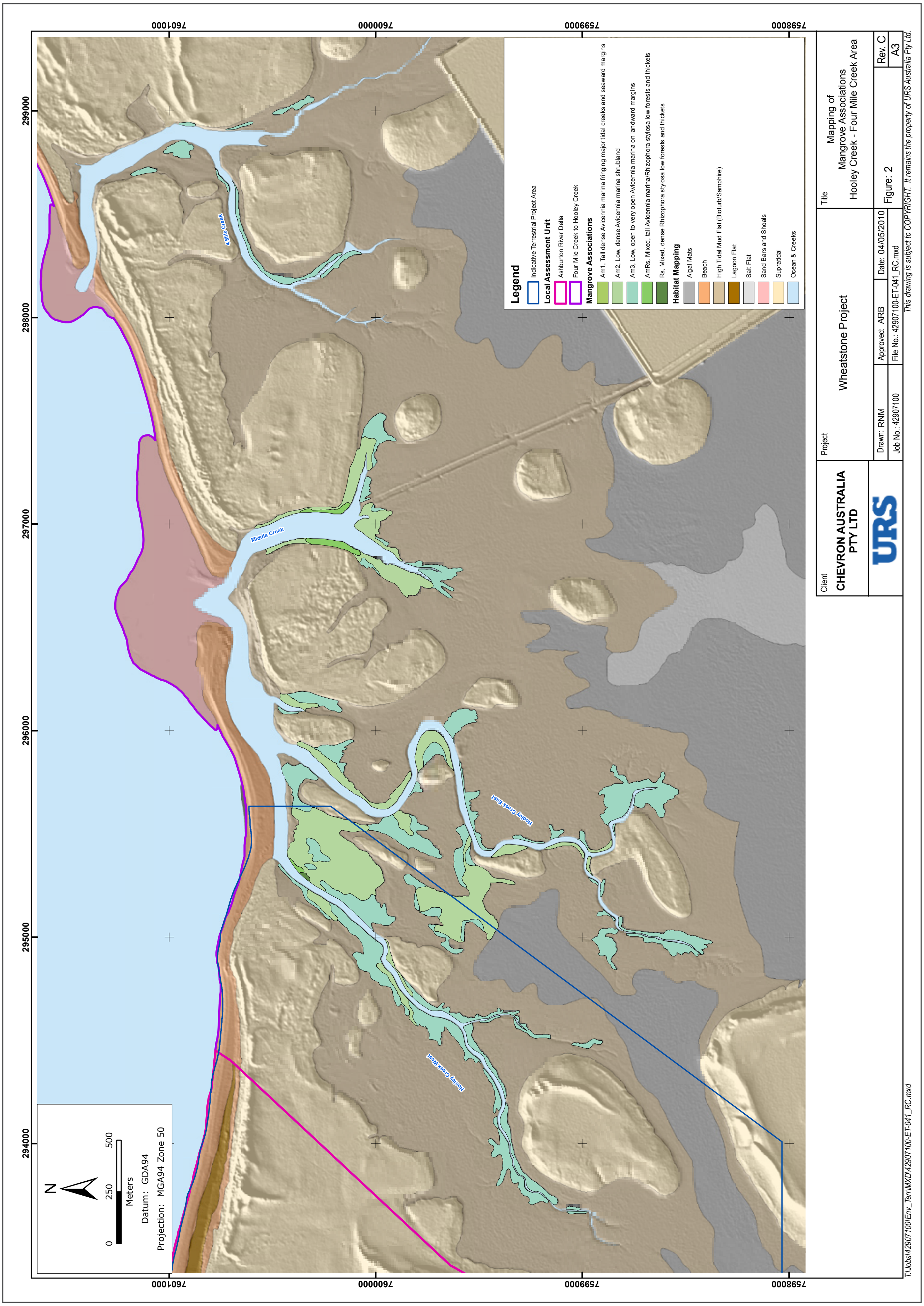
Legend
Indicative Terrestrial Project Area
Local Assessment Unit
Ashburton River Delta
Four Mile Creek to Hooley Creek
Mangrove Associations
Am1, Tall dense Avicennia marina fringing major tidal creeks and seaward margins
Am2, Low, dense Avicennia marina shrubland
Am3, Low, open to very open Avicennia marina on landward margins
AmRs, Mixed, tall Avicennia marina/Rhizophora stylosa low forests and thickets
Rs, Mixed, dense Rhizophora stylosa low forests and thickets
Habitat Mapping
Algal Mats
Beach
High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
Middle Creek
4 Mile Creek
Hooley Creek East
Hooley Creek West
0 250 500
Meters
Datum: GDA94
Projection: MGA94 Zone 50
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Mapping of Mangrove Associations Hooley Creek - Four Mile Creek Area
Drawn: RNM
Approved: ARB
Date: 04/05/2010
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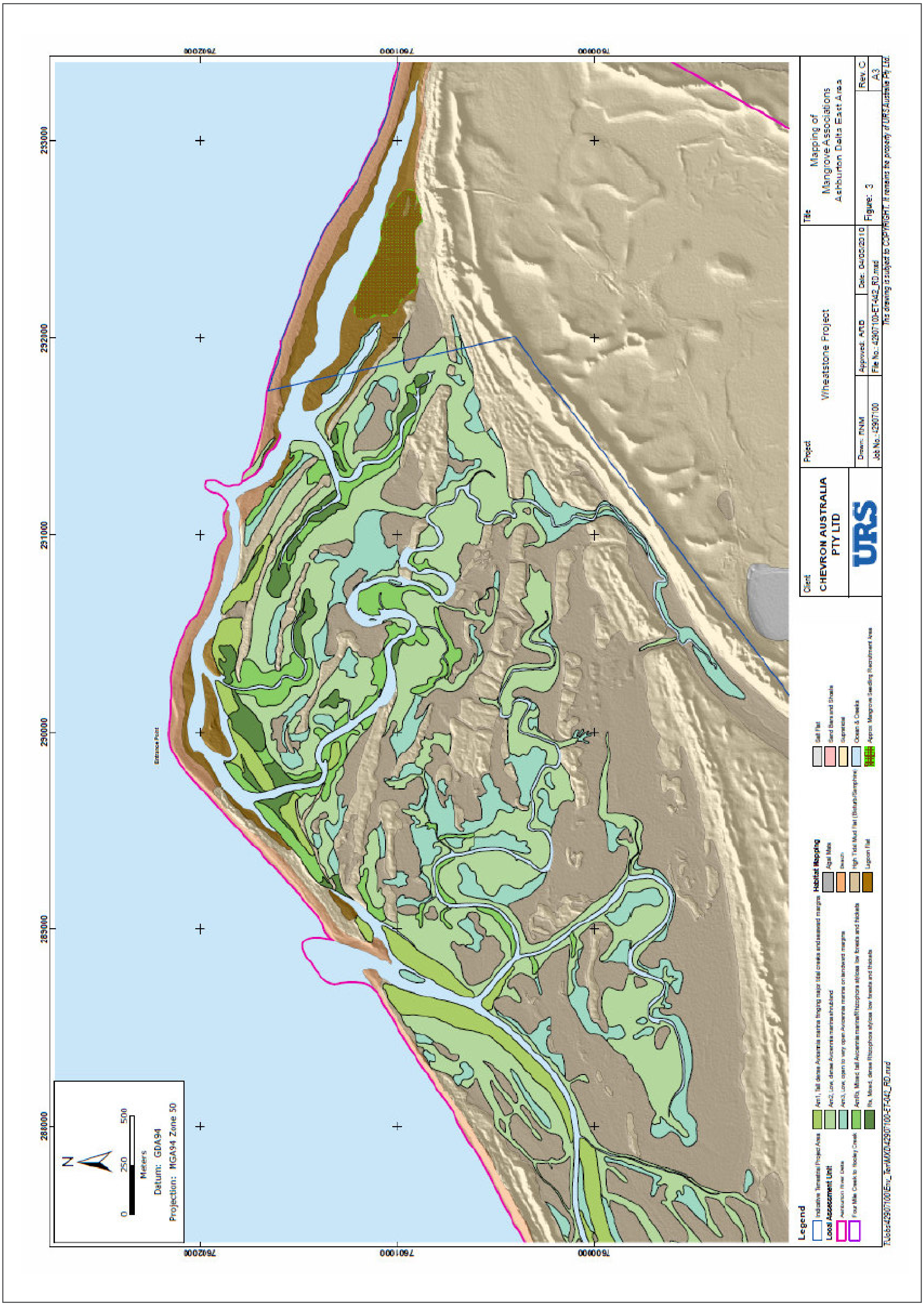

Mapping of Mangrove Associations Ashburton Delta East Area
Wheatstone Project
CHEVRON AUSTRALIA PTY LTD
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Figure: 3
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Habitat Mapping
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Projection: MGA94 Zone 50
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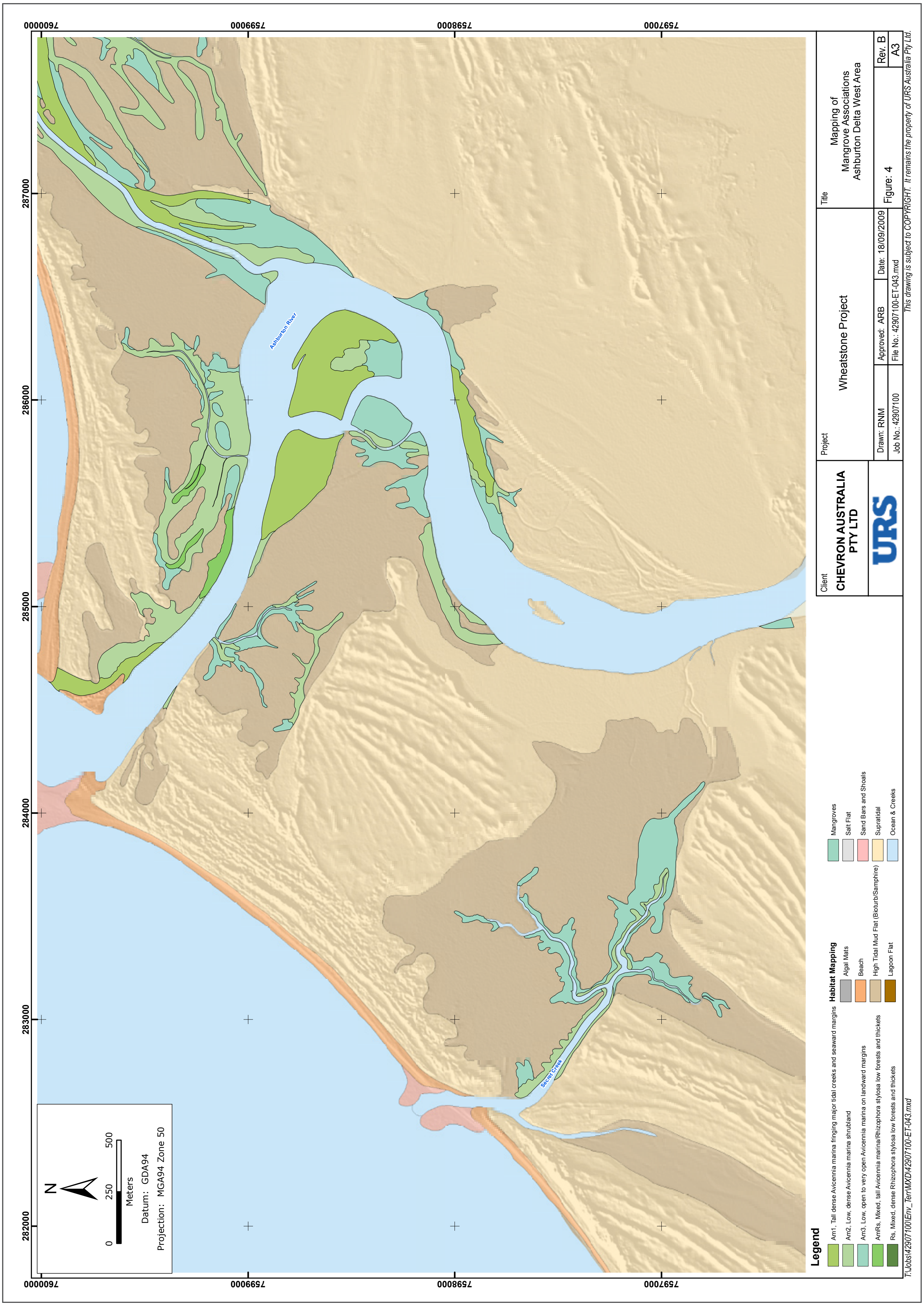
Ashburton River
Secret Creek
Legend
Habitat Mapping
Am1, Tall dense Avicennia marina fringing major tidal creeks and seaward margins
Am2, Low, dense Avicennia marina shrubland
Am3, Low, open to very open Avicennia marina on landward margins
AmRs, Mixed, tall Avicennia marina/Rhizophora stylosa low forests and thickets
Rs, Mixed, dense Rhizophora stylosa low forests and thickets
Algal Mats
Beach
High Tidal Mud Flat (Bioturb/Samphire)
Lagoon Flat
Mangroves
Salt Flat
Sand Bars and Shoals
Supratidal
Ocean & Creeks
N
0
250
500
Meters
Datum: GDA94
Projection: MGA94 Zone 50
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Mapping of Mangrove Associations Ashburton Delta West Area
Drawn: RNM
Approved: ARB
Date: 18/09/2009
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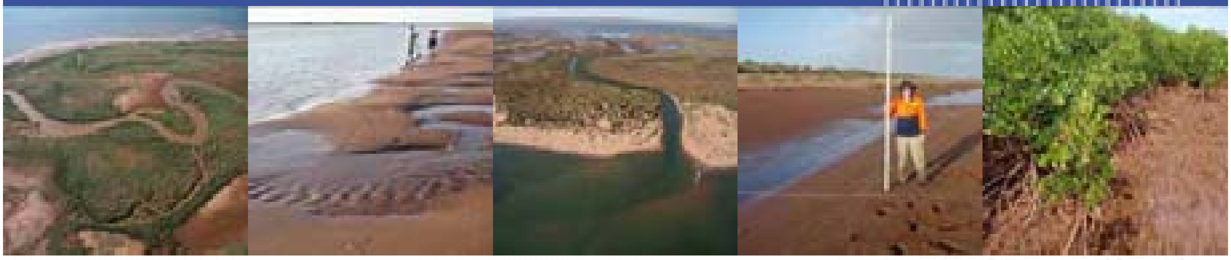

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Appendix N12

Survey of Subtidal Habitats Off Onslow, WA

Figures

Appendices

Appendix E Plates of the Benthic Habitats (cont'd)

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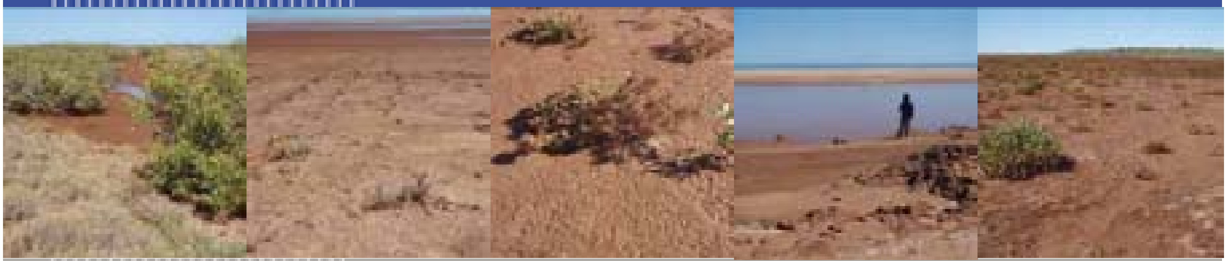

Report

Wheatstone Project

Biota of Subtidal Habitats in Pilbara Mangroves, with Particular Reference to the Ashburton Delta and Hooley Creek

11 MAY 2010

Prepared for

Chevron Australia Pty Ltd

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Executive Summary

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

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

A combination of desktop studies and field surveys of intertidal, subtidal and deepwater benthic habitats has been undertaken by URS to document the marine bottom communities of the Wheatstone Project Area and place them into regional context. The present report on the shallow subtidal habitats completes the benthic surveys of the Wheatstone Project Area.

Sites were chosen to include the major subtidal features (reefs, shoals, subtidal platforms, pavements and sand plains) present in the area investigated. Three field surveys were conducted using Remotely Operated Vehicles (ROVs):

- 150 transects were surveyed from 4 to 14 December 2008.
- 47 transects were surveyed from 1 to 7 May 2009.
- 155 transects were surveyed from 13 to 19 August 2009.

The uneven surface of the seafloor in the study area meant that a variety of habitats were present. The open areas between reefs were dominated by sandy bottoms; this was the most common habitat found during the surveys. Infauna predominated in these habitats, with relatively few epifaunal species occurring. There was a gradation from silty sands inshore of the 10 m isobath to sandy gravels seaward of the 10 m isobath. The silty sand habitat was found to support a lower density of sessile invertebrates than the gravels offshore.

Macroalgae were present at low density at most sites where there was an underlying hard bottom to provide attachment. Seagrasses were absent at most sites. When they were encountered, the seagrasses were sparsely distributed in small patches. Three species of the genus *Halophila* were recorded. These species were small and are sparsely distributed; they did not form the dense seagrass communities that are found in southern Western Australia.

Rocky areas near islands, isolated shoals, fringing reefs, outcrops, etc., tended to be colonised by a variety of species, including corals, other invertebrates such as gorgonians and sponges, and macroalgae. Coral cover was generally low, though a number of areas were found that would be potentially useful as monitoring sites to determine the effects of activities such as dredging on coral communities. The information generated in this report was subsequently used to establish coral monitoring transects at a number of sites (MScience 2009).

The habitats along the proposed channel alignment, turning basin and MOF were all soft sediment, with sands and silts more common inshore of the 10 m isobath, and sands and gravels seaward of the 10 m isobath. The seabed at the nominal spoil grounds was also a soft bottom habitat comprised of sandy silt with sparsely distributed sponges, ascidians and hydroids.

Executive Summary

The habitats along the proposed Wheatstone trunkline route were predominantly soft sediments composed of silts and fine sands with occasional patches of gravel. Sparse macroalgae were the dominant biota. Apart from the shoals which occurred along the 10 m isobath, hard substrate was encountered at only two sites along the pipeline route. Both of these sites had low (5%) coral cover, other sessile invertebrates and associated fish species.

The spoil grounds used by Onslow Salt in dredging their channel and turning basin were comprised of soft sediments (predominantly silty sands), but there was no obvious differentiation between the sediment in the spoil grounds and sediments from adjacent areas. The presence of benthic fauna, such as hydroids and bryozoans on the spoil ground, sparse seagrass (*Halophila spinulosa*) and burrows illustrated the occurrence of natural recolonisation, and suggested that areas disturbed by the Wheatstone Project will similarly develop new benthic communities.

The majority of the survey area comprised a soft sediment substrate which supported less than 10% coverage of biota. Habitats which supported greater than 10% biota cover were restricted to fringes of islands, small shoals and rock outcrops along the 10 m isobath, and areas of shallow subtidal hard pavement or sand veneered pavement. Corals were sparsely distributed and only found around island fringes and on shallow subtidal shoals. Dense macroalgae tended to occur on the shallow subtidal pavements that surround most islands in the region, Large areas of sand veneered pavement in waters deeper than 10 m Chart Datum (CD) supported a filter feeder complex of sponges and sea whips and fans. Seagrasses were sparsely distributed, but tended to occur in shallow (<10 m CD) protected waters nearshore. The distribution of the major biotic groups which occurred within the study area has been mapped to provide the basis for impact assessment of the effect of the major marine construction activities.

1

Introduction

1.1 Background

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara Coast (Figure 1). The LNG and Domgas plants will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin and future yet-to-be determined gas fields. The project is referred to as the Wheatstone Project and Ashburton North is the proposed site for the LNG and Domgas plants. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State Waters and on land. The LNG plant will have a maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

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

1.2 Marine Project Description

In order to construct the LNG plant, Chevron will need access to a Materials Offloading Facility (MOF) at Ashburton North where heavy lift loads can be brought ashore in modules and assembled on site. Chevron proposes to construct a MOF by dredging an inland harbour on low-lying flats adjacent to Hooley Creek. This will require the dredging and disposal of some one million cubic metres (1 Mm^3) plus seawalls and groynes to protect the harbour and access channel.

To export the LNG, Chevron proposes to construct a 3 km long Product Loading Facility (PLF) and approximately 16 km long navigation channel dredged to -14 m CD to enable fully laden LNG ships to exit the jetty at all tides. Construction of the navigation channel will require the dredging of up to 45 Mm^3 of sediment and its placement in the nearshore and offshore. Up to 10 Mm^3 may be used onshore for reclamation of low-lying parts of the plant site. Stilling basins will be required to settle entrained silts before the dredge return water is discharged back to nearshore waters. This large dredging and reclamation program is expected to take up to at least two years to complete.

To supply the gas to the LNG plant, Chevron proposes to install a trunkline between the fields and mainland shore. The trunkline route to shore will probably cross the shallow nearshore shelf between Thevenard and Bessieres Islands, and skirt Ashburton Island before coming ashore at the plant site. Nearshore, where there is a wedge of sediment, the trunkline will be weight coated and buried. Further offshore, where the sediments are thinner, the trunkline will probably be weight coated and rock armoured to stabilise it.

Based on information available from the dredging of the Onslow Salt channel in recent years, it is clear that the sediments to be dredged are likely to include fine silts and clays, as well as calcarenite sands and gravel. The anticipated dredging strategy suggests that at least two dredges will be required. One large Cutter Suction Dredge (CSD) will be required to handle hard and cohesive sediments, and one medium sized Trailer Hopper Dredge (THD) and a large THD will be required to relocate to the offshore spoil disposal ground the unconsolidated sediments and hard material cut by the CSD and left in place.

1.3 Purpose and Scope of Work

The purpose of this study was to determine the range of marine benthic habitat types that occur within the Wheatstone Project area and to map their distribution. A further purpose of this study was to assist with the identification of subtidal Benthic Primary Producer Habitats (BPPH) present, as specified within Environmental Protection Authority Guidance Statement no. 29 (EPA 2004) as coral reefs, dense and patchy seagrass meadows and seabed where macroalgal, coral or seagrass communities have grown or could grow. Benthic Primary Producers (BPP) that were identified in this study were seagrasses, macroalgae, turf algae and scleractinian corals.

A total of three Remotely Operated Vehicle (ROV) surveys were undertaken in the nearshore (<20 m CD) areas from December 2008 to August 2009 to gather data over a large spatial area, focusing on the proposed marine infrastructure footprint and surrounding reefs, shoals and islands. The spatial extent of the surveys included the footprint for dredging the navigation channel and spoil disposal, dredging of the MOF and trenching and installation of the trunkline; as well as adjacent areas of potential impact. The ROV surveys captured oblique images of both seafloor substrate and epibiota. Three ROV surveys were conducted as follows:

ROV summer survey

Conducted in December 2008, focus was on navigation channel, pipeline and disposal ground options and contiguous potential impact areas.

ROV coral survey

Conducted in May 2009, focus was on hard substrate areas (reef, bommies, shoals, islands) looking for suitable areas to establish coral dive transects for impact monitoring using Before After Control Impact (BACI) design.

ROV winter survey

Conducted in August 2009, focus of the survey was on:

- "Ground-truthing" gaps in potential hard substratum areas (reef, bommies, shoals, islands) derived from Admiralty chart and URS interpolated nearshore bathymetry surface map.
- Revisiting soft sediment BPPH areas identified in the summer ROV survey to look for seasonal trends in seagrass.
- Far field areas and new proposed offshore disposal sites were also surveyed.

1.4 Study Team and Acknowledgements

Paul Everson of URS Australia undertook the ROV fieldwork. The report was written by Paul Everson and Dr Fred Wells, and reviewed by Peter Collins of URS. Operation and supply of the ROV was by Steve Watchorn of Underwater Inspection Systems, with vessel supplied by Broadsword Marine Contractors and Bhagwan Marine. The considerable assistance provided by local charter boat operator Andy Young of Northcoast Charters is gratefully acknowledged.

2 Survey Methods

Sites were chosen to include the major subtidal features (reefs, shoals, subtidal platforms, pavements and sand plains) present in the area investigated.

Three field surveys were conducted:

- 150 transects were made from 4 to 14 December 2008.
- 47 transects were made from 1 to 7 May 2009.
- 155 transects were made from 13 to 19 August 2009.

The same methods were used for all three surveys. Transects were recorded using an ROV and video camera with a remote feed to a surface mounted display and digital recorder. Information recorded on each transect included: the date of survey, geographical location of the start and finish of each transect (recorded on GPS), water depth, a description of the physical features of the seabed, including the presence of burrows in soft substrates, and a description and estimate of the density of the dominant benthic macrobiota (Appendix A, B and C for December 2008, May 2009 and August 2009 respectively). Transect lengths ranged from 10 m to 400 m, with the average length being 50 m. A video record was made of all transects to characterise the habitat type (reef, pavement, gravel, sand, silt, etc.), and invertebrate fauna and flora present.

In reef areas, coral cover and structure were noted, together with the dominant genera/species present. Percentage coral cover was qualitatively estimated over the entire length of the transect. As it was not feasible to collect vertical ROV records, these were “order of magnitude” estimates based upon the imagined plan view of the coral colonies. The estimates were made by personnel with considerable experience in the assessment of coral communities.

On soft sediments, invertebrate communities were characterised using sessile species such as soft corals (sea fans, sea whips, etc.), sponges and algae, which were the most abundant forms in this habitat type. The presence of burrows was also noted as an indicator of the abundance of burrowing invertebrates. Observations were also made on other features noted.

Observations on fish and other significant fauna were made, and any species identified visually was recorded. Due to the large extent of the area being surveyed and the limited time available, fish and other mobile fauna were recorded on an opportunistic basis only.

2.1 December 2008 Survey

The December 2008 survey followed immediately after a geophysical survey of the area. The major habitats and physical features discernible from bathymetric survey, previous broad-scale ecological surveys and navigation charts were identified to develop the survey program. In selecting sites, locations were chosen with the aim of collecting information on a representative sample of subtidal habitats and expanding existing data where the data were considered insufficient for the purpose of the environmental impact assessment. In the case of the proposed navigation channel and nearshore spoil grounds, a higher site density was used to ascertain local habitat variability. The locations of sites from this survey are shown in Figure 2.

2.2 May 2009 Survey

In May 2009 ROV investigations were carried out in the vicinity of the proposed development, on previously identified hard coral areas from the URS December 2008 survey, previous broad-scale ecological surveys and navigation charts, to establish spatial extent and densities of coral communities present. The May survey also identified sites to be visited in a subsequent diver-based coral reef survey conducted by URS and MScience in June 2009 (MScience 2009). Establishing suitable coral monitoring site areas was achieved by locating dense coral assemblages (>50% live coral cover over >50 m) on shoals and around islands in the vicinity of the proposed marine development. Sites visited during the May survey are shown in Figure 3.

2.3 August 2009 Survey

A third ROV survey was carried out in August 2009 to extend the spatial area sampled. Sites were chosen to address new potential spoil ground areas in the nearshore area to the 20 m isobath and to the east of Thevenard Island, together with sites previously visited in December 2008 to provide some indication of seasonal changes. Sites visited are shown in Figure 4.

Further sites were chosen to address geotechnical results from areas indentified in April 2006 (EGS 2006) and December 2008 (Fugro 2008) as hard, reflective substrate interpreted as coral.

Shoals and reefs along the 10 m isobath were also investigated to determine the extent of hard substrate in these areas.

Soft sediment BPPH areas identified in the summer ROV survey were revisited to look for seasonal trends in seagrass.

An overview showing the location of all sites visited over the three surveys is shown in Figure 5.

Key Results

3.1 December 2008 Survey

The findings of this survey are generally consistent with those of previous investigations of habitat distribution undertaken in the region (Saladin Oilfield ERMP [LSC 1987], West Australian Mining [LEC 1990], Onslow Solar Saltfield ERMP [Paling 1990], West Australian Petroleum [LEC 1991], Griffin Gas Pipeline Development CER [LEC & Astron 1993]). The additional survey sites recorded as part of this study have allowed the existing benthic habitat maps for the Onslow region to be refined, and additional details to be presented on current reef condition.

Soft bottom communities occurred extensively throughout the study area and were the dominant habitat. They broadly comprised silty sands inshore of the 10 m isobath and sandy gravels seaward of the 10 m isobath (Appendix E, Plates 1 & 2). Whilst coarse material would typically be expected in shallower wave prone areas, the Ashburton Delta adjacent to the development area is a major source of fine fluvial sediment which blankets the inshore area. The silty sand habitat generally was found to support a lower cover of sessile invertebrates than the gravels offshore.

Sparse cover of macroalgae was present at most sites, with a higher percentage cover present on pavement and at the reef and shoal sites. The dominant algae were large brown algae of the genera *Sargassum, Padina* and *Dictyopteris*, and red algae of the genera *Gracilaria* and *Laurencia*. Less common were green algae of the genera *Halimeda* and *Caulerpa*. Further discussion on macroalgae can be found in *Benthic Primary Producer (Seagrass and Macroalgae) Habitats of the Wheatstone Project Area*. (URS 2009a).

Previous surveys in the region have found seagrasses to be absent at most sites, or when encountered, sparsely distributed in small patches (URS 2009a). Seagrasses encountered at sites on this survey had a similar distribution and abundance. Species recorded were *Halophila spinulosa*, *H. decipiens* and *H. ovalis*. Seagrasses were found both within the proposed development footprint and the surrounding areas, indicating that they occur in sparse quantities regionally.

A number of reefs and shoals occur along the 10 m isobath. Hastings Shoal, Weeks Shoal and Gorgon Patch were found to support a diverse and healthy coral habitat with up to 100% cover over tens of square metres. Elsewhere along the 10 m isobath, reefs and shoals were found to generally have a lower coral cover, typically 10 to 20% (e.g. Australind Shoal and Miles Shoal), with the exception of Saladin Shoal which had moderate coral cover (50%). The corals were typically small individuals of the genera *Porites*, *Turbinaria* and *Montipora*. Hydroids, gorgonians, sponges and macroalgae were also encountered in these locations. As mentioned in the methodology section, these percentage estimations were based on qualitative observations of oblique ROV video footage analysed both in the field and the office.

Closer to shore, the shoals and exposed pavements were generally found to have a lower coral cover, typically less than 10%. However, Ward Reef, which lies between the nearshore reefs and the chain of shoals along the 10 m isobath, had a very high (up to 100%) cover of corals over areas of hundreds of square metres. Roller Shoal and the most eastern shoal of Glennie Patches supported moderate coral cover of 50%. Shoals located a similar distance offshore to the west (the remainder of the shoals comprising Glennie Patches) and east of Ward Reef were found to support much lower coral cover.

The fringing reefs surrounding the nearshore islands (e.g. Tortoise, Ashburton, Thevenard, Direction and Twin Islands [Appendix E, Plates 10 - 14]) were found to support a low to moderate, but variable, coral cover with the exception of the east side of Direction Island which had areas of tens of square metres of up to 100% healthy coral cover. There was some visual evidence of cyclone related damage

3 Key Results

on these fringing reefs: fragmentation of vase and branching corals and overturning of more massive colonies. In general, coral condition and cover at the island sites visited were rated low to moderate, but variable. There was some uncertainty as to the overall condition of corals because of the small number of sites visited at each location. This was due to the inability to access all areas with the ROV due to the rough sea conditions experienced.

The habitats along the proposed channel alignment, turning basin and MOF (23 sites inspected) were all soft sediment (Appendix E, Plates 1 - 6), with sands and silts more common inshore of the 10 m isobath, and sands and gravels seaward of the 10 m isobath. No outcropping rock (reef) was encountered in the area of the 10 m isobath (sites ROV002 to ROV005), however Saladin Shoal was in the near vicinity (site ROV025 supporting up to 50% coral cover [Appendix E, Plate 19]). The seabed at the two nominal spoil grounds (Figure 4; Appendix E, Plates 27 - 30) was also a soft bottom habitat comprised of sandy silt with sparsely distributed sponges, ascidians and hydroids.

The dredge placement grounds used by Onslow Salt in dredging their channel and turning basin were comprised of soft sediments (predominantly silty sands), but there was no obvious differentiation between the sediment in the spoil grounds and sediments from adjacent areas. The presence of benthic fauna, such as hydroids and bryozoans on the spoil ground, sparse seagrass (*Halophila spinulosa* [Appendix E, Plate 7]) and burrows suggested natural recolonisation had occurred. A small patch of *Halophila spinulosa* seagrass 10% cover and patchy filamentous brown algae 5-10% cover were observed on the nearshore dredge placement ground. The dredge placement ground further off shore nearer Gorgon patch reef had a small patch of *H. spinulosa* seagrass 10% cover, patchy filamentous brown algae 5 -10% cover, a patch of filamentous brown algae 5-15% cover and a patch of green algae - *Caulerpa* with 10% cover.

The habitats along the proposed Wheatstone pipeline route were predominantly soft sediments composed of silts and fine sands with occasional patches of gravel with sparse macroalgae being the dominant biota observed (Appendix E, Plate 23). Apart from the shoals which occurred along the 10 m isobath, hard substrate was encountered at only two sites along the pipeline route (sites ROV121 and ROV128). A small limestone ledge at site ROV121 had sparse coral recruits with around 5% cover, with an overall epibenthic biota cover of around 50% (Appendix E, Plate 24). Site ROV128 was a rock platform with around 5% cover of coral recruits with associated biota and fish life. The other sites surveyed within the same area (sites ROV041, ROV042, ROV049, ROV103, ROV104 and ROV130) had soft sediments of silts and sands with overall epibenthic biota cover of less than 5%.

The gazetted area of the Onslow Prawn Managed Fishery includes the entire study area, but the fishery actually operates only within a very limited area (about 5%) of the total licensed fishing zone. Trawlers avoid coral and sponge habitats due to the net damage and snagging danger which results from trawling in such areas. Prawn trawlers target sandy and muddy habitats where the prawns are concentrated, but studies indicate that there are only minimal impacts to infaunal communities (Department of Fisheries 2003; Sporer et al. 2008; URS 2009b).

Overall, the results of the survey were consistent with findings from previous surveys. Two reefs, Ward Reef and Hastings Shoal, both of which are located in close proximity to the proposed shipping channel, had a very high coral cover which was not encountered elsewhere during this survey. Saladin Shoal, located within the anticipated dredged area, had a moderate coral cover of up to 50%.

3.2 May 2009 Survey

As indicated earlier, the May survey focussed on hard substrate areas only in search of coral assemblages that might be suitable for supporting monitoring sites. Qualitative summaries of the areas investigated in May 2009 are presented below.

Ashburton Island

Two areas with potential for establishment of coral monitoring sites were identified – one off the western reef edge of Ashburton Island, the other off the south-western tip of the reef. Coral cover did not exceed 50% at either site, with the predominant corals being tabulate *Acropora* and *Montipora* plates.

Brewis Reef

This reef had broken pavement with high macroalgal cover (predominantly *Sargassum* and *Padina*) but very low (<1%) hard coral cover.

Direction Island

Several areas of reef were surveyed near Direction Island:

- The north-west shoal off Direction Island had a potential coral monitoring site towards the southern end of the shoal, where there was 50-75% coral cover, predominantly tabulate *Acropora*.
- The western reef platform had a macroalgal dominated pavement inshore, leading to the reef slope and isolated bommies, but the overall coral cover was <25%.
- The eastern reef platform had a potential monitoring site with an area with 25-50% coral cover. *Montipora* was the dominant species present with *Pachyseris* sub-dominant.
- There was a good monitoring site on the north-eastern reef platform. Most of the site had 50% coral cover, but there were patches of 50-75% cover. *Montipora* and *Porites* were dominant, and tabulate *Acropora* sub-dominant.
- The shoal off the south-eastern corner of Direction Island had insufficient coral cover for monitoring.

Hastings Shoal

Areas of 50-75% hard coral cover were found on the western side of the shoal at a depth of - 3 m CD The coral habitat was dominated by *Montipora*, with many *Acropora* and faviids also present. The remainder of the shoal was comprised of coral rubble (mainly branching *Acropora*).

Herald Reef

No areas were found with adequate coral cover for monitoring, including the shoal to the south of the reef.

Middle Mangrove Island

The western side of Middle Mangrove Island was found to have 25% coral coverage around -1 to -2 m CD dominated by encrusting *Montipora* on the edge of the shallow macroalgae dominated pavement. Tabulate *Acropora*, *Lobophyllia*, *Platygyra* and faviids were also present. Rock outcrops on the edge of the shoal supported up to 50% coral cover with occasional large *Porites* bommies present.

Miles Shoal

3 Key Results

There was a gently sloping rock pavement 4-6 m below CD with hard coral cover of <10%. There were numerous small *Turbinaria* and a diversity of other coral genera, plus many sponges and gorgonians.

Nares Rock

This was a small, steep walled reef with mostly 25% coral cover and patches of up to 50% on the reef edge, particularly on the western edge. The dominant coral was encrusting *Montipora*, with faviids, *Lobophyllia* and small *Porites* bommies also present. Rock outcrops were also found to support coral communities.

"**NE Koolinda**" (un-named shoal to the north-east of Koolinda Patch)

The coral habitat along the eastern edge of the shoal had a cover of 50-75%. The habitat composition was predominantly tabulate and corymbose *Acropora*, with *Montipora* sub-dominant.

Paroo Shoal

Patches of high coral cover (up to 50-75%) and a diverse community were found on the ridge on the western edge of the shoal, dominated by either corymbose and tabulate *Acropora* or by *Montipora*.

Roller Shoal

The top of the shoal had coral cover of typically 25-50%, reaching up to 75% in patches, dominated by *Montipora* plates.

Saladin Shoal

Potential monitoring sites (50-75% coral cover at -2 to -4 m CD) occurred over most of the survey area. The coral habitat was dominated by tabulate *Acropora* and *Pocillopora* (many of which were bleached) with *Montipora* sub-dominant.

Thevenard Island

Several areas of the reef surrounding Thevenard Island were surveyed:

- Reef extending from the western end, up to the north-east, was dominated by macroalgae, with only scattered hard corals in low abundance (<1%).
- Reef occurred along the northern shoreline. Two high cover coral areas were dominated by tabulate *Acropora*, with a diversity of other genera present.
- Reef occurred off the eastern end of island. One area with substantial coral cover area was dominated by tabulate *Acropora*, with a diversity of other genera present.
- Reef off the south-eastern tip of the island was an algal dominated reef flat. Patchy areas of high coral cover were found along the reef edge.
- Reef occurred along the southern shoreline. The reef slope showed evidence of widespread coral bleaching (e.g. dead standing *Acropora* plates) and cyclone impacts (e.g. overturned colonies, extensive rubble). An area of *Porites* bommies at the western end of the reef was also surveyed.

Trap Reef

Hard coral cover rarely exceeded 10%.

Twin Islands

The north-east corner of SW Twin Island was found to have up to 50% coral cover, predominantly *Montipora* and tabulate *Acropora*. Small patches of individual *Porites* bommies were also present on the north-western side of NE Twin Island.

Ward Reef

The pattern of coral distribution with depth was similar around most of the perimeter of the reef. The exception was along the western side of the reef, where coral cover tended to be lower (and rubble and macroalgal cover higher) than elsewhere. Around the remainder of the reef perimeter, the typical coral communities were as follows:

- At depths shallower than -2 m CD, hard coral cover was typically >50% and often >75%. *Montipora* plates were dominant, with tabulate and branching *Acropora* often sub-dominant. Diversity was low relative to other communities around the reef.
- At depths between -2 and -4 m CD, coral cover was typically slightly lower (though usually >50%) and diversity was often higher. *Montipora* and *Acropora* were often co-dominant, faviids were common, and genera such as *Porites*, *Lobophyllia* and *Pocillopora* were usually present.
- At depths greater than -4 m CD, coral cover was lower, often <50% (but still >25%), on a broken reef slope with silt-covered rubble and areas of sand. Off the base of the slope (at about 6 m) there were several large bommies around the perimeter of the reef, typically *Porites* though some were encrusted with *Montipora* colonies.

Weeks Shoal

An area between the middle and the southern end of the shoal had coral cover of typically 25-50%, with *Montipora* plates dominant and a diversity of other genera present.

3.3 August 2009 Survey

As indicated earlier, the purpose of this survey was to extend the spatial scale of area sampled to accommodate nearshore spoil grounds, and also to revisit selected previously sampled sites to obtain a seasonal perspective in abundance and cover of epibiota. Survey outcomes of note included the following:

- The northern edge of NE Twin Island was found to support coral cover of 10-25%.
- The potential spoil grounds were found to be predominantly a flat substrate with sparse epibenthic biota.
- A reef outcrop north-west of Ward Reef and close to spoil ground B (site ROV237) was about 50 m long and supported 50-75% coral cover. This was a potential coral monitoring location.
- Site ROV179 of Little Shoals and sites ROV183 and ROV184 of Moresby Shoals, both groups north of the Twin Islands and east of proposed outer spoil grounds (CVX Site C), were found to have 10-25% hard coral cover but all three sites were too small for coral monitoring transects to be established.
- Small coral assemblages (again too small to establish coral monitoring sites) were found at Weeks Shoal and next to the Onslow Salt shipping channel, with 25-50% coral coverage (sites ROV219, ROV222 and ROV223).
- Results from a geophysical survey by EGS (EGS 2006) were reviewed. A small coral assemblage to the east of the nearshore development area, south of Ward Reef (site ROV259), was found to have 25-50% coral cover, but was too small to establish a coral monitoring site. Most other previously identified coral areas were found to support sparse sessile filter-feeder communities.
- Ward Reef was investigated to establish the extent of the reef. Hard substrate did not extend as far as indicated on Admiralty charts.

3 Key Results

- Sites ROV265-ROV268 close to the turning basin were pavement with sparse filter-feeding communities present.
- A large isolated coral outcrop with 10-25% coral cover (site ROV271) and two large moderate coverage seagrass areas were found at Glennie Patches (sites ROV272 and ROV273).
- Sites along the proposed trunkline route previously classified by the Fugro geophysical survey P0903 in December 2008 (Fugro 2008) as "outcropping cemented sediments (calcarenite)" (sites ROV277 and ROV278) revealed sand and sparse filter-feeding communities. This indicated that there may be a thin sand veneer over many of the areas classified in the Fugro survey as outcropping calcarenite.
- In the vicinity of Coolgra Point, seagrass abundance was lower than in December 2008. Thin seagrass was present that was not observed during the December survey. This was identified as *Syringodium* sp. and *Halodule* sp. The presence of seagrasses and algae in the Pilbara region and their temporal nature is discussed in URS (2009a).
- Sites investigated at Thevenard Island were found to be predominantly algae-dominated limestone platforms. Short transects were carried out at Taunton Reef and Airlie Island. Exposed outcrops with a sand-veneered pavement with sparse biota were found at Taunton Reef (site ROV313), while algae-dominated pavement was found at Airlie Island (site ROV314).
- Sites on the eastern side of Rosily Shoal were predominantly filter-feeding communities, with abundance decreasing with depth to around 16 m, where sediment was dominant.

3.4 Habitat Mapping

ROV footage was analysed both in the field and in the office for further identification of biota observed and classification of overall substrate and biota present at each site. This site classification allowed a habitat mapping process of the area to be carried out to identify existing as well as potential areas of BPPH. Transects were classed into the following categories for soft and hard substrates by identifying the substrate that occurred most often along the transect:

- Sand
- Sand-veneered limestone pavement
- Sand/gravel
- Sand/silt
- Sand/silt/dead shells
- Intertidal hard substrate
- Subtidal coral
- Subtidal pavement
- Potential hard substrate.

Potential hard substrates were identified by interpreting bathymetric features present on Admiralty Charts that were unable to be investigated by ROV. A map of these soft and hard substrates is presented in Figure 6.

Overall, biota cover in the study area was typically low, with localised areas of biota associated with islands, shoals and sand-veneered pavements. Large areas of substrate had <10% biota cover and were categorised according to their predominant sediment type, though sparse foliose macroalgae were often present.

3 Key Results

In addition to the broadscale mapping of hard and soft substrates, sites at which hard corals (e.g. Appendix E, Plate 10), filter feeders (e.g. Appendix E, Plate 23), seagrasses (e.g. Appendix E, Plate 9) or macroalgae (e.g. Appendix E, Plate 5) were present at >10% cover were categorised accordingly. Statistical analyses and a kriging process (described in Appendix D) were then applied to produce interpolated distribution maps for these communities (Figures 7 to 10).

Areas in which there was >10% cover of hard coral are shown as “subtidal coral” in Figure 6. These occurred predominantly around islands and shoals in localised areas, particularly along the 10 m isobath.

Areas in which there were sites with >10% cover of filter feeders were most prevalent on sand-veneered limestone pavements to the south-west of Thevenard Island and at Rosily Shoals (Figure 7).

Seagrasses were present in greatest percentage cover (12%) along localised areas of shoreline extending north-east along Beadon Bay towards Coolgra Point, with lower percentage cover (5-10%) extending from this shoreline towards Direction and Twin Islands (Figure 8). Low percentage cover of seagrass (5%) was also present around Glennie Patches extending in a north-east direction towards Brewis Reef.

The greatest macroalgae coverage was near Thevenard Island and Mangrove Islands (Figure 9), typically on subtidal limestone platforms, with localised lower abundances present at a number of other shoals and islands in the region. They also occurred in association with the filter-feeding communities which were found on large areas of sand-veneered pavement in waters deeper than -10 m CD. Macroalgae occurred throughout most of the remainder of the study area in varying degrees of cover.

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Conclusions

A variety of habitats were present in the study area due to a combination of hard substratum (of varying topographical complexity) and soft substratum under different exposure and depth gradients and tidal currents. The seabed areas between reefs were predominantly sandy substrates; the most common habitat found during the surveys. Infauna predominated in these habitats, with relatively few epifaunal species occurring. There was a gradation from silty sands inshore of the 10 m isobath to sandy gravels seaward of the 10 m isobath. The silty sand habitat generally was found to support a lower cover of sessile invertebrates than the gravels offshore.

Macroalgae were present at low to medium density at most sites where there was an underlying hard bottom to provide attachment. Seagrasses were absent at most sites. When they were encountered, they were sparsely distributed in small patches. Three species of the genus *Halophila* were recorded. These species were small and are sparsely distributed; they did not form the dense seagrass communities that are found in southern Western Australia (URS 2009a).

Rocky areas near islands, isolated shoals, fringing reefs, outcrops, etc., tended to be colonised by a variety of species, including corals, other invertebrates such as gorgonians and sponges, and macroalgae. Coral cover was generally low, though a number of areas were found that would be potentially useful as monitoring sites to determine the effects of activities such as dredging on coral communities. The information generated in this report was subsequently used to establish coral monitoring transects at a number of sites (MScience 2009).

The habitats along the proposed channel alignment, turning basin and MOF were all soft sediment, with sands and silts more common inshore of the 10 m isobath, and sands and gravels seaward of the 10 m isobath. The seabed at the two nominal offshore dredge sediment placement grounds was also a soft bottom habitat comprised of sandy silt with sparsely distributed sponges, ascidians and hydroids.

The habitats along the proposed Wheatstone pipeline route were predominantly soft sediments composed of silts and fine sands with occasional patches of gravel. Sparse macroalgae were the dominant biota. Apart from the shoals which occurred along the 10 m isobath, hard substrate was encountered at only two sites along the pipeline route. Both of these sites had low (5%) coral cover, other sessile invertebrates and associated fish species.

The dredge sediment placement grounds used by Onslow Salt in dredging their channel and turning basin were comprised of soft sediments (predominantly silty sands), but there was no obvious differentiation between the sediment in the spoil grounds and sediments from adjacent areas. The presence of benthic fauna, such as hydroids and bryozoans on the spoil ground, sparse seagrass (*Halophila spinulosa*) and burrows illustrated the occurrence of natural recolonisation, and suggested that areas disturbed by the Wheatstone Project will similarly develop new benthic communities.

The majority of the survey area comprised a soft sediment substrate which supported less than 10% coverage of biota. Habitats which supported greater than 10% biota cover were restricted to fringes of islands, small shoals and rock outcrops along the 10 m isobath, and areas of shallow subtidal hard pavement or sand veneered pavement. Corals were sparsely distributed and only found around island fringes and on shallow subtidal shoals. Dense macroalgae tended to occur on the shallow subtidal pavements that surround most islands in the region, Large areas of sand-veneered pavement in waters deeper than -10 m CD supported a filter-feeder complex of sponges and sea whips and fans. The distribution of the major biotic groups which occurred within the study area has been mapped to provide the basis for impact assessment of the effect of the major marine construction activities.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the CTR dated December 2008.

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

This report was prepared between December 2008 and November 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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Subtidal Habitats

Figures

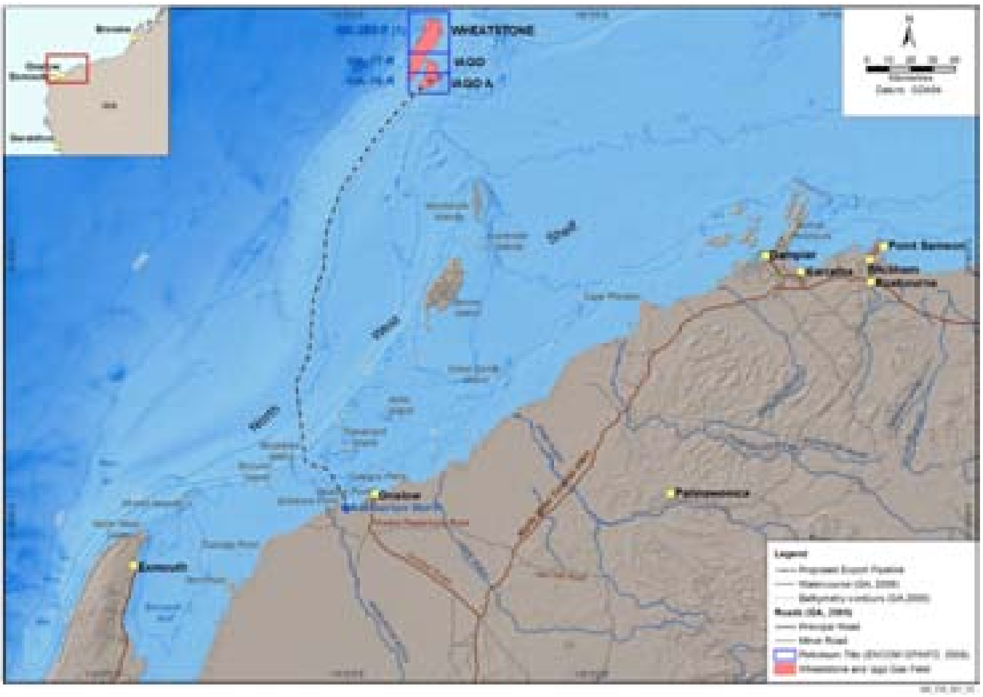

Figure 1 Location Map

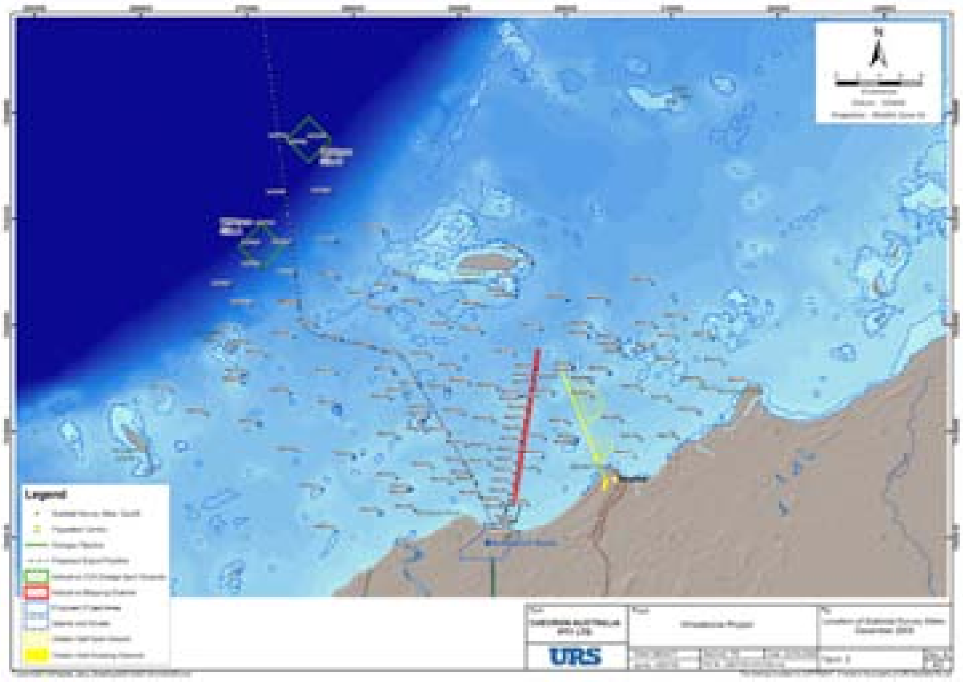

Figure 2 Location of Subtidal Survey Sites – December 2008

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Figures

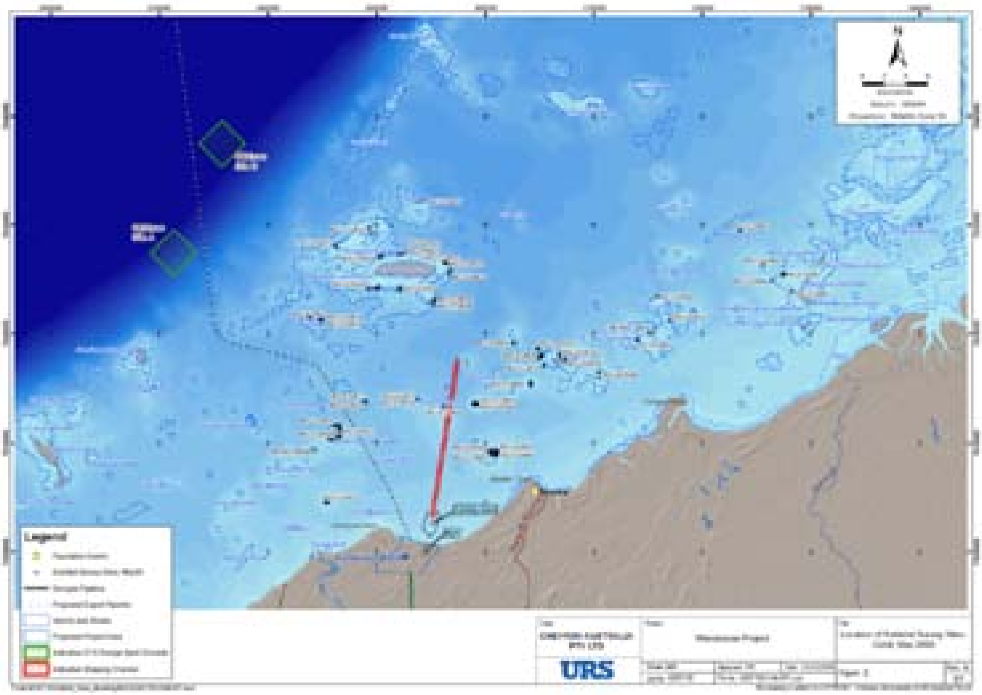

Figure 3 Location of Subtidal Survey Sites – Coral, May 2009

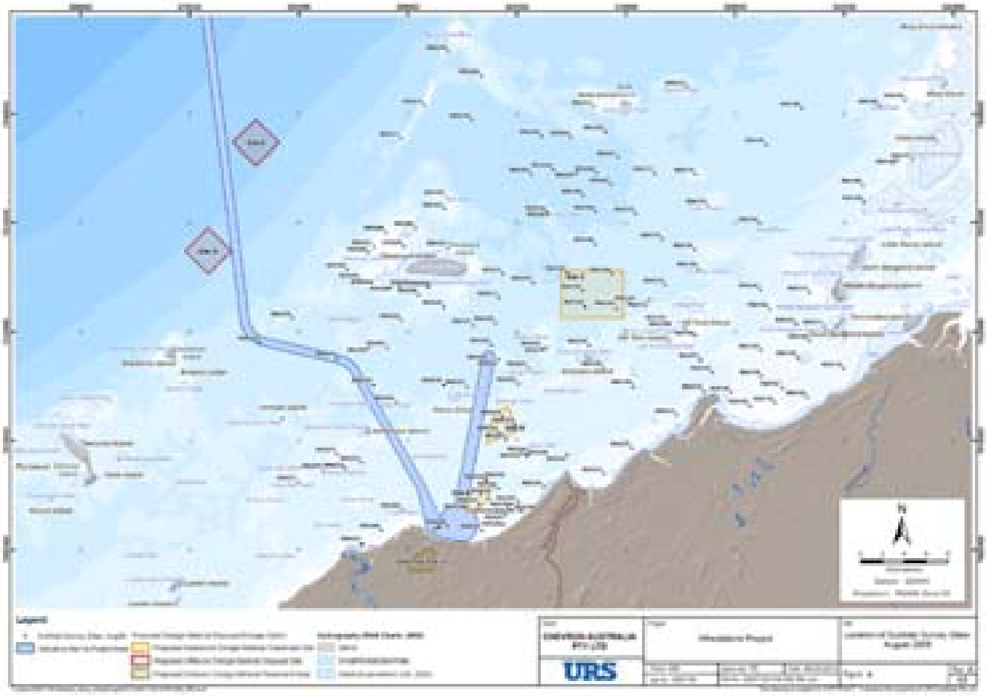

Figure 4 Location of Subtidal Survey Sites – August 2009

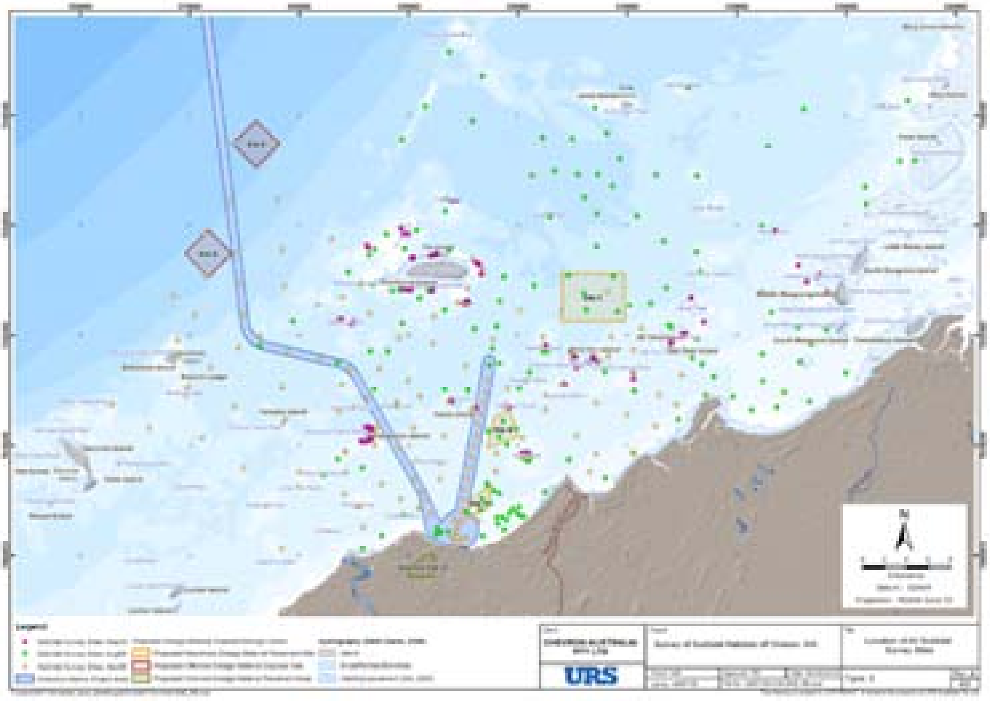

Figure 5 Location of All Subtidal Survey Sites

Subtidal Habitats

Figures

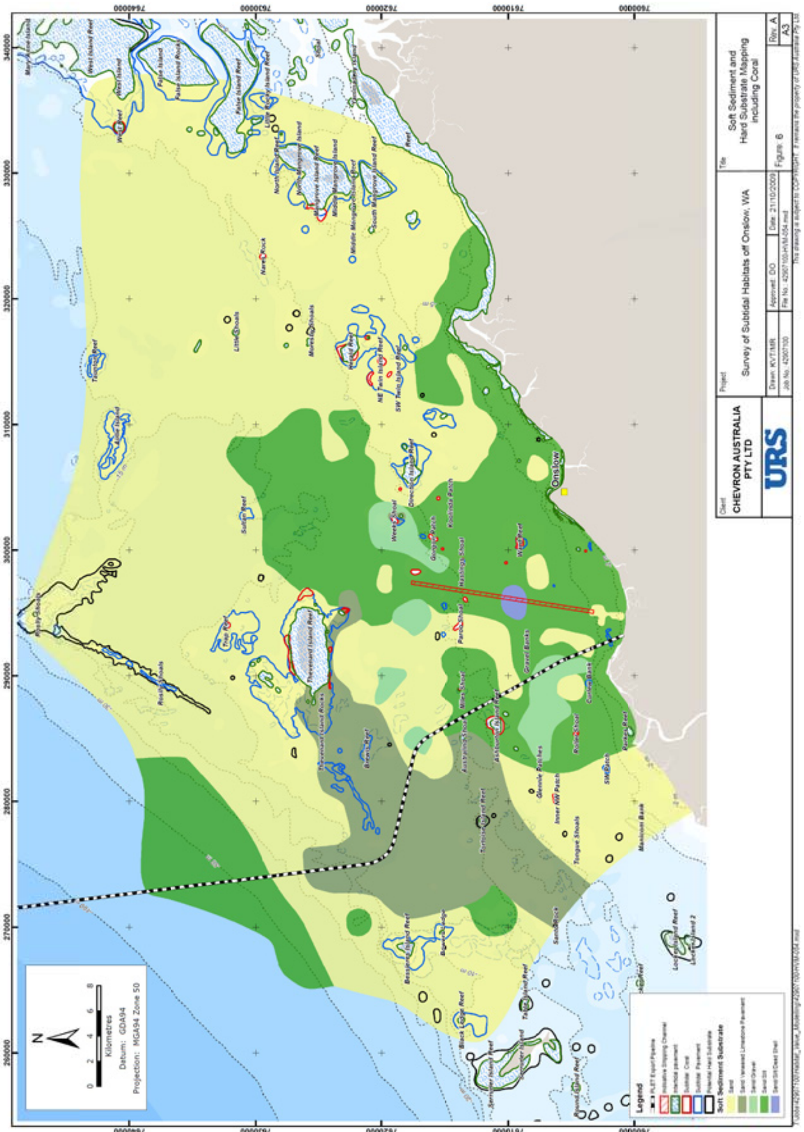

Figure 6 Soft Sediment and Hard Substrate Mapping including Coral

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Figures

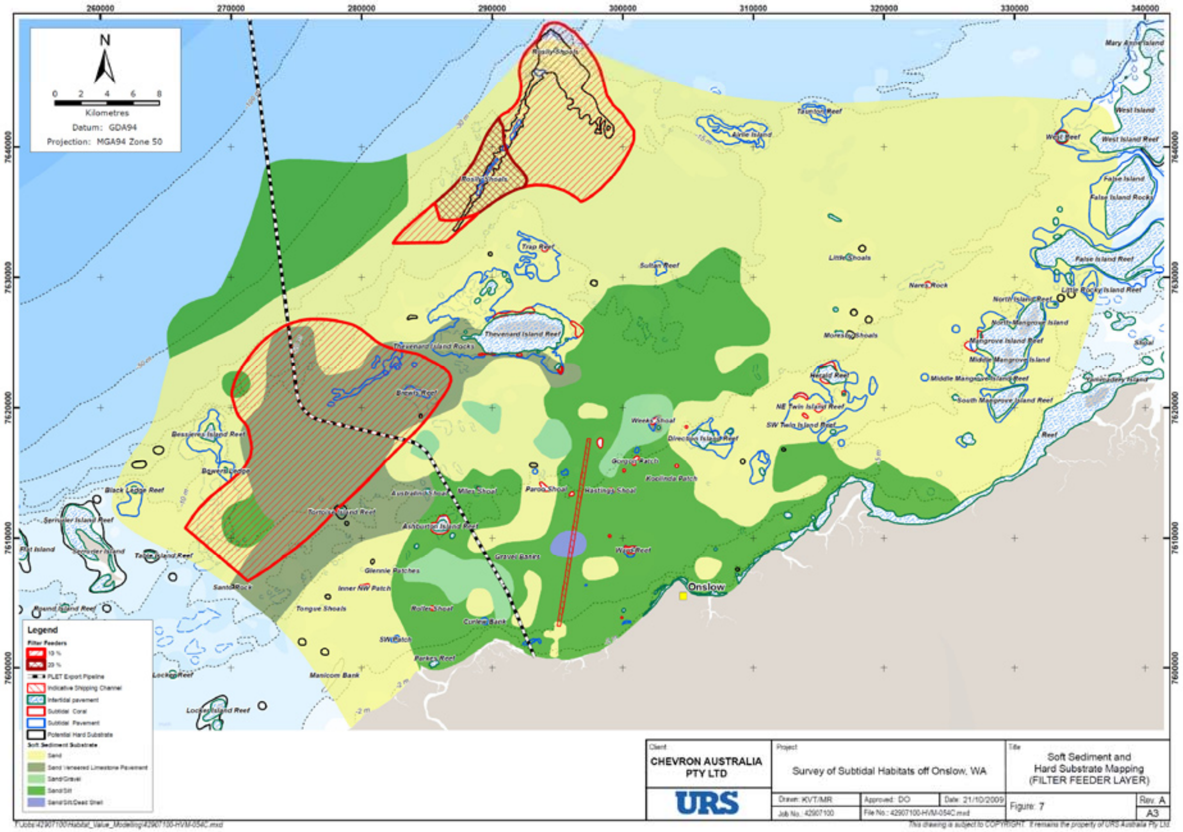

Figure 7 Soft Sediment and Hard Substrate Mapping (Filter Feeder Layer)

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Subtidal Habitats

Figures

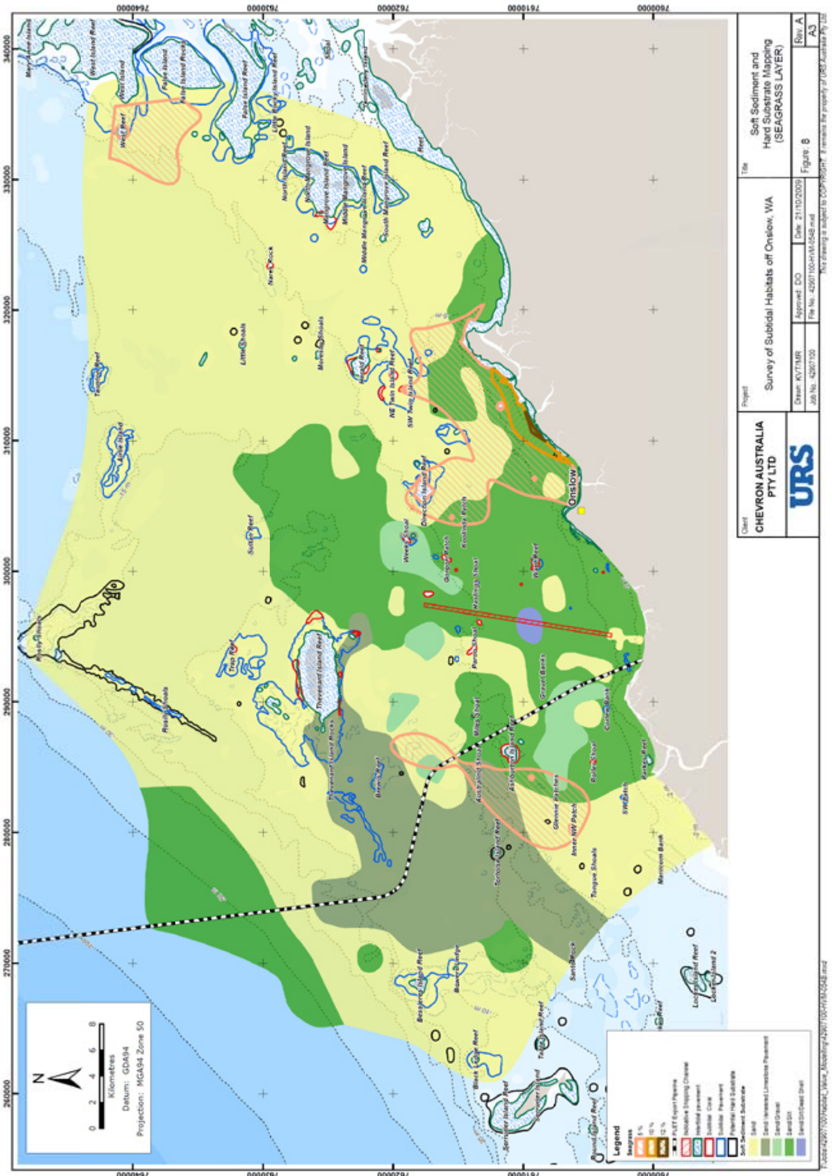

Figure 8 Soft Sediment and Hard Substrate Mapping (Seagrass Layer)

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Figures

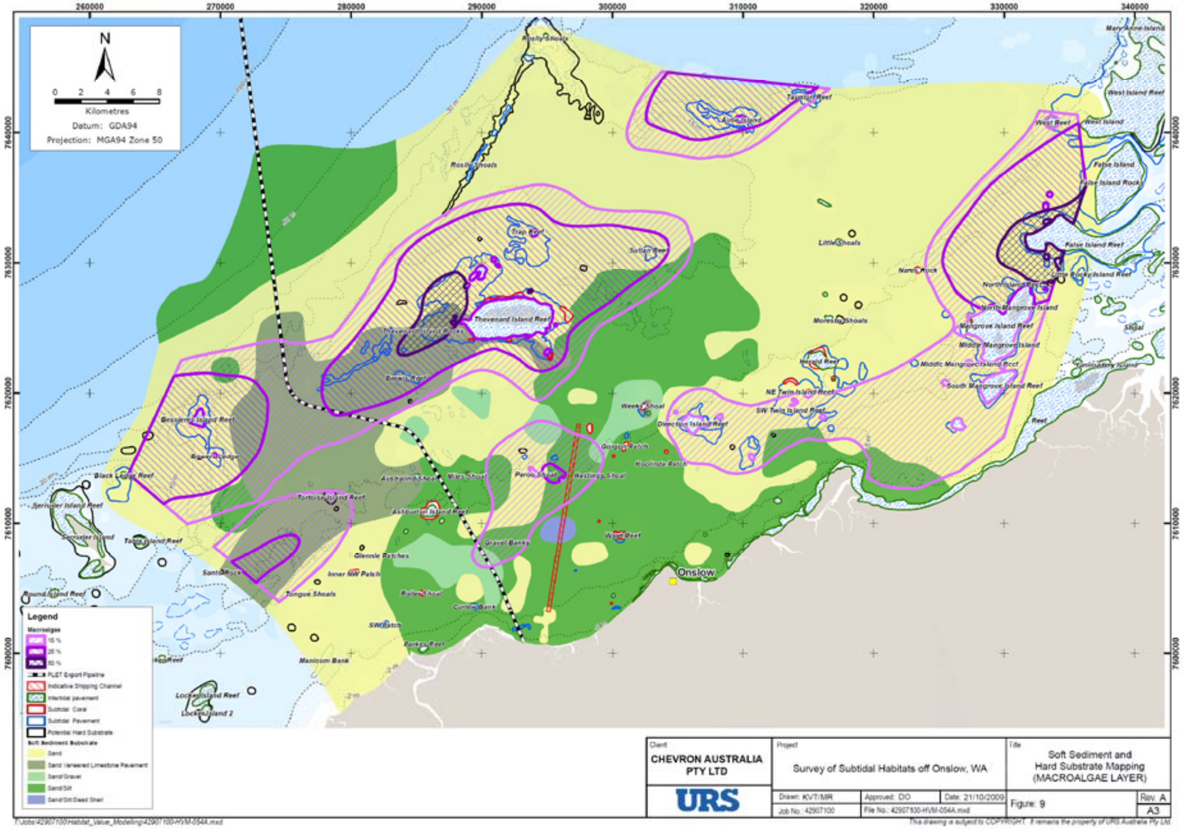

Figure 9 Soft Sediment and Hard Substrate Mapping (Macroalgae Layer)

Subtidal Habitats

Figures

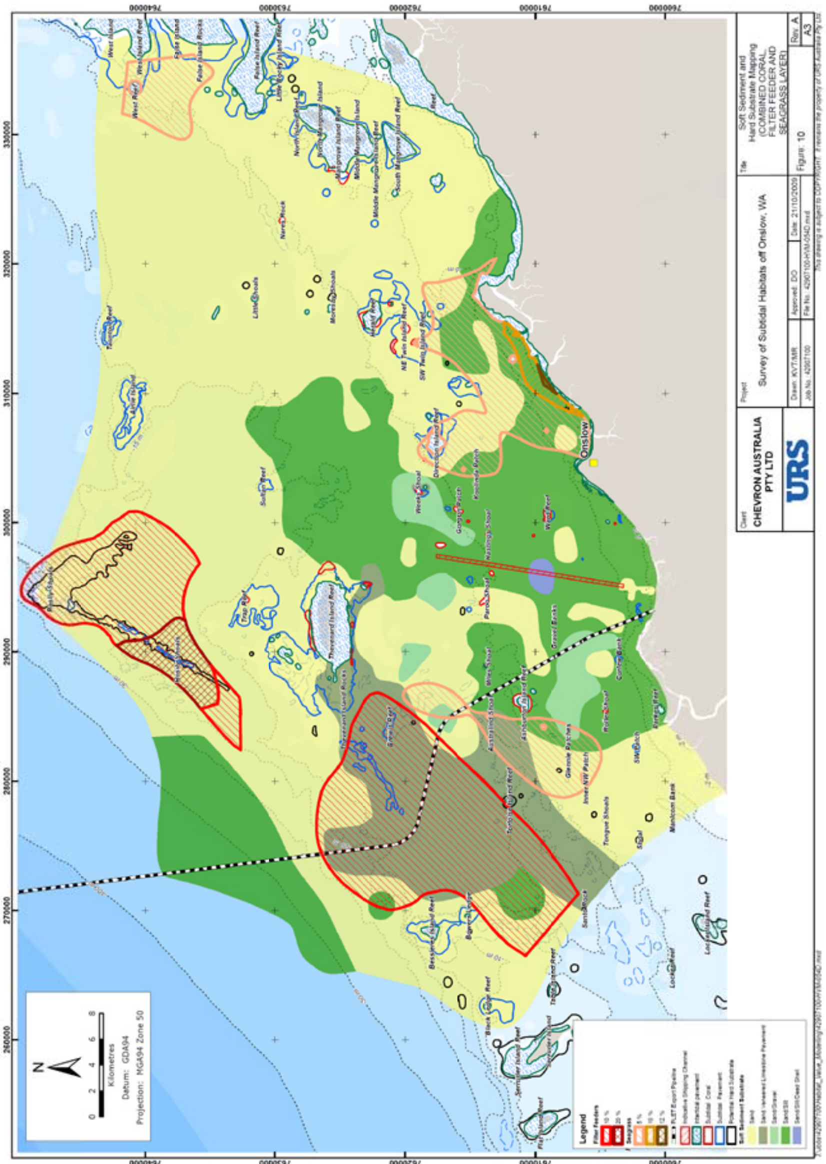

Figure 10 Soft Sediment and Hard Substrate Mapping (Combined Coral, Filter Feeder and Seagrass Layer)

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A

Appendix A Description of Sites – December 2008

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV001	4/12/2008	859	297209.300,	7615831.700,	297218.520,	7615873.450,	12.2	Potential borehole 1 - Sand and silt with fine shell fragments. No visible hard substrate. Sparse bioturbation. Patchy algae, with up to 25% coverage in places, (*Caulerpa* sp.)
ROV002	4/12/2008	915	297000.400,	7614871.650,	297014.920,	7614899.830,	11.5	Potential borehole 2 - silty sand with shell fragments. Patchy filamentous green algae.
ROV003	4/12/2008	930	296997.380,	7614865.480,	297026.100,	7614896.810,	11.8	Potential borehole 2 - Repeat of site closer to potential borehole. Silty sand, with fine shell fragments. Very patchy filamentous epiphytic brown algae. Sparse hydroids, ascidians, seapens. Sparse *Caulerpa* sp. patches. One nudibranch. Overall very patchy biota - <10%.
ROV004	4/12/2008	945	296789.570,	7613860.630,	296848.710,	7613881.700,	10.3	Potential borehole 3 - Sandy silt and shell fragments. Patchy foliose coralline red algae and filamentous epiphytic brown algae. One *Nepthia* sp. Occasional hydroids. Sparse bioturbation. Overall <25% algal coverage.
ROV005	4/12/2008	1005	296583.360,	7612881.340,	296637.540,	7612896.130,	9.7	Potential borehole 4 - Sandy silt and shell fragments. Patchy foliose coralline red algae and filamentous epiphytic brown algae. One *Nepthia* sp. Occasional hydroids and seawhips. Sparse bioturbation. Overall <25% algal coverage.
ROV006	4/12/2008	1020	296408.910,	7611906.790,	296433.420,	7611936.680,	10.1	Potential borehole 5 - Silty sand with patchy Caulerpa sp. and filamentous epiphytic brown algae. Some hydroids and colonial ascidians.Overall <25% algal coverage.
ROV007	4/12/2008	1040	296178.400,	7610924.560,	296254.610,	7610913.490,	10.8	Potential borehole 6 - Sandy silt and shell fragments. Sparse bioturbation. Sparse patches of seagrass (*Halophila ovalis*) and filamentous epiphytic brown algae, patchy dense dead ark shells (*Trisidos* sp.) shells and moderate bioturbation with occasional large holes (possible crustacean or cephalopod origins). Overall algal cover <10%.
ROV008	4/12/2008	1055	295973.790,	7609948.010,	296039.300,	7609964.500,	10.7	Potential borehole 7 - Sand and silt with coarse shell fragments. Large dense patches of dead ark shells (*Trisidos* sp.). Overall very little biota - one sea pen and very occcasional filamentous epiphytic brown algae. Overall algal cover <10%.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV009	4/12/2008	1110	295757.680,	7608963.600,	295842.920,	7608961.820,	10.1	Potential borehole 8 - sediment covering dense dead ark shells *(Trisidos* sp.) beds. Some algal turf. Occasional green and red filamentous algae, and sparse *Caulerpa* sp. in patches with overall biota <15%. One anenome and few ascidians. (Possible *H. ovalis).* Overall algal cover <10%.
ROV010	4/12/2008	1125	295550.700,	7607979.950,	295589.870,	7607987.480,	10.0	Potential borehole 9 - silt and sand with moderate bioturbation. Very patchy *Caulerpa* sp. Epibenthic cover <5%
ROV011	4/12/2008	1140	295345.190,	7607001.590,	295405.200,	7607030.460,	7.5	Potential borehole 10 - "Sponge and fan garden" <50% biota on sand and silt with coarse shell fragments. Gorgonians, sponges (barrel and vase types). One large (~1m) Porites bommie, with two smaller bommies. Overall algal cover <10%.
ROV012	4/12/2008	1151	295138.220,	7606024.960,	295223.230,	7606009.040,	8.8	Potential borehole 11 - Silt and sand with coarse shell fragments with sparse bioturbation on gently undulating seabed. Occasional very patchy seagrass (*H. ovalis*) and fine filamentous epiphytic brown algae. Overall algal cover <10%.
ROV013	4/12/2008	1245	292883.801,	7608351.637,	293040.222,	7608348.570,	9.4	Silt and sand with shell fragments <15% epibenthic biota dominated with green and some red filamentous algae. Few dead dead ark shells (*Trisidos* sp.). One ascidian and anenome.
ROV014	4/12/2008	1258	292848.340,	7606917.030,	292954.490,	7606905.620,	10.9	Gravel Banks - Coarse sand and shell fragments with sparse biotubation and <10% epibenthic biota. Dominated by green filamentous algae with very occasional seagrass patches and sparse red algae.
ROV015	4/12/2008	1318	290675.010,	7608610.150,	290869.290,	7608636.300,	10.6	West of Gravel Banks - Silt sand and shell fragments, with low bioturbation. Occasional dense patches of seagrass and very patchy red alage and *Padina* sp. Occasional digitated and laminar sponges and rubble with gorgonians.
ROV016	4/12/2008	1350	286870.620,	7610039.320,	287018.380,	7610066.310,	7.6	Shoal to southeast of Ashburton Island. Reef, hard substrate with numerous bommies, some up to 3m+, up to 50% hard coral cover in places. *Porites,* faviids dominant species with small young recruits in places. Some silt and sand patches with occasional covering of red filamentous algae, reducing to bare sand at end of transect. Numerous reef fish including striped snapper *(Lutjanus sp.),* yellow tailed fusiliers (*Caesio teres*), banner fish *(Heniochus* sp.), angelfish (Pomacanthidae).

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV017	4/12/2008	1405	286704.570,	7611075.270,	286785.050,	7611044.430,	4.1	East side of Ashburton Island. Large bommies with up to 75% live hard coral cover. *Acropora, Porites,* faviids. Coarse sand and silt areas with moderately dense beds of seagrass. Low diversity of coral. Schools of yellow tailed fusiliers, striped snapper and occasional Blue bone (*Choerodon* sp.) .
ROV018	4/12/2008	1435	287007.930,	7611399.510,	286978.860,	7611368.880,	10.7	East side of Ashburton on 5m contour. Sand and silt with low bioturbation. Very sparse biota, <10%. Fine green and red foliose algae with very occasional seagrass. Very occasional hydroid and one crinoid.
ROV019	4/12/2008	1454	287156.320,	7611875.530,	287224.740,	7611889.510,	10.5	Ashburton Island, far eastern side of 5m contour. Coarse sand and fine shell fragments. Rippled seabed with very sparse bioturbation and biota. One sea pen, hydroid.
ROV020	4/12/2008	1527	289000.210,	7613864.730,	289108.840,	7613915.590,	10.7	Miles Shoal – Coarse sand and fine shell fragments. Sparse bioturbation and brown, red and green algae (including *Padina* sp.). Moderately sparse seagrass. Occasional sponge.
ROV021	4/12/2008	1547	291004.680,	7614476.350,	291062.290,	7614512.180,	12.1	Alternative shipping channel – Sand and silt with coarse shell fragments. Filamentous green algae dominant biota, with ~15% coverage. Some *Padina* sp. present. Occasional digitated sponge.
ROV022	4/12/2008	1605	289969.880,	7615869.980,	290009.770,	7615923.560,	10.3	Alternative shipping channel – Coarse sand with shell fragments and sparse bioturbation. Moderate biota coverage (up to 25%), including patchy green and red algae, hydroids, seawhips, ascidians and occasional barrel sponge. Some seagrass.
ROV023	4/12/2008	1628	293597.620,	7613969.760,	293609.100,	7614013.780,	11.9	Paroo Shoal – Sand and shell fragements. Up to 50% biota coverage in areas – *Halophila ovalis*, *Caulerpa* sp., filamentous green and red algae with one seastar (echinoderm).
ROV024	4/12/2008	1645	295686.520,	7613280.650,	295704.580,	7613319.400,	9.2	Saladin Shoal – Sand and silt with moderate biota cover. Deeper area of shoal with no coral present. Green filamentous algae, *H. ovalis, Padina* sp.
ROV025	4/12/2008	1710	295913.110,	7613336.840,	295925.460,	7613369.890,	6.3	Saladin Shoal – Repeat of survey 23 in shallower area. Moderate to high live hard coral cover (up to 50% in places), with patches of sand and silt with coarse shell fragments. One large >2m *Porites* bommie. Plateau of algae dominated sand.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV026	5/12/2008	843	296848.350,	7625766.800,	296917.080,	7626039.890,	6.8	East side of Thevenard Island – Algae dominated rock platform with occasional large *Porites* bommies (~1m) with several smaller. One very large bommie (over ~4m in width) with up to 80% live hard coral coverage. Sand and coarse shell fragment patches with gorgonians and sponges. Overall area dominated by red and brown algae with occasional *Padina* sp., *Caulerpa* sp. and hydroids. Few echinoderms (sea cucumbers). Moderate fish life, including one queenfish (*Scomberoides sp.*), yellow tailed fusiliers, catfish (Siluriformes) and striped damsels (Pomacentridae).
ROV027	5/12/2008	915	295766.030,	7626917.300,	295844.680,	7626943.910,	5.4	East northeast side of Thevenard Island. Rock platform dominated by up to 80% live hard coral cover in places with patches of dense algae, including red and foliose green. Patch of dense soft corals, including *Nepthia* sp. and *Sinularia* sp. Patches of sand and shell fragments, with one barrel sponge.
ROV028	5/12/2008	1113	293251.350,	7610874.680,	293346.250,	7610912.210,	10.3	East northeast of Skate monopod, east of Ashburton Island. Silt and sand with fine shell fragments. Sparse biota – occasional red algae and foliose green. Small patch of *Halophila ovalis*. Sparse to moderate bioturbation. Hydroids and ascidians.
ROV029	5/12/2008	1132	290437.600,	7611599.300,	290524.090,	7611624.520,	10.8	South of Miles Shoal. Silt over sand with fine shell fragments. Sparse bioturbation. Overall low abundance of epibenthic biota. Occasional patch of *Caulerpa* sp. and *H. ovalis*.
ROV030	5/12/2008	1153	290539.650,	7606958.790,	290646.340,	7606995.160,	9.5	West southwest of Roller C monopod, south of Ashburton Island. Coarse sand and gravel with dense patches of red and green foliose algae with occasional ascidian and hydroid.
ROV031	5/12/2008	1218	291622.680,	7605176.730,	291711.760,	7605191.460,	8.2	West of potential borehole 11. Very bad visibility due to weather conditions. Undulating silt and sand bottom with very sparse biota over rocky substrate with large shell fragments. Occasional green foliose algae. Very turbid water.
ROV032	5/12/2008	1245	289248.360,	7605098.140,	289339.350,	7605122.880,	10.6	East of Roller Shoal. Very bad visibility due to weather conditions. Bare sand and silt with occasional hydroid.
ROV033	5/12/2008	1315	297955.590,	7607621.260,	298019.840,	7607651.890,	7.7	East of potential borehole 9. Very bad visibility. Predominantly sand with silt and coarse shell fragments and sparse bioturbation, with patches of dense beds of dead ark shells (Trisidos sp.). Occasional dense patches of long foliose green macro algae.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV034	5/12/2008	1326	298057.540,	7609266.970,	298101.070,	7609297.300,	10.9	West of Ward Reef. Silt covered sand with moderate to high bioturbation, with occasional large holes (~10cm). Low biota cover, with occasional hydroid and very occasional *H. ovalis* and *H. decipiens*.
ROV035	6/12/2008	1010	262949.170,	7613797.520,	262966.470,	7613832.420,	4.8	Black Ledge, east side. Coarse sand and shell fragments on algae dominated rock platform. Young *Turbinaria* juvenile recruits (~5-10% cover). Occasional seawhip and barrel sponge. Only deeper areas surveyed as weather too rough for ROV – may warrant further investigation with diver.
ROV036	6/12/2008	1032	266271.460,	7611586.320,	266296.550,	7611623.850,	8.7	South of Bowers Ledge. Sand and fine shell fragments with small ripples. Very occasional crinoid, no algae.
ROV037	6/12/2008	1053	271167.200,	7610706.140,	271221.320,	7610759.250,	12.0	South of Bowers Ledge. Silt over sand with shell fragments and sparse bioturbation. Overall around 5% epibenthic biota, with occasional gorgonians, digitated and vase sponges, ascidians and sparse red algae. One very sparse patch of *H. ovalis*.
ROV038	6/12/2008	1120	269679.520,	7614577.200,	269840.040,	7614571.250,	4.4	Bowers Ledge, southern edge. Algal covered rock platform with ~1-2% *Turbinaria* juvenile recruits. Patches of coarse sand and shell fragments. Occasional sea whip and ascidian. Two seastars. Few wrasse (Labridae) and blue *Chromis* sp.
ROV039	6/12/2008	1134	269914.390,	7615393.660,	269931.400,	7615416.230,	3.2	Bowers Ledge, west side. Algal covered rock platform with 1-5% live hard coral on ridge. *Caulerpa* sp. and filamentous green algae dominant with one pin cushion seastar (echinoderm). Diverse fish life, including Blue bone (*Choerodon* sp.), blue *Chromis* sp., coral trout (*Plectropomus sp.*), and one spiny box puffer fish (*Chilomycterus sp.*).
ROV040	6/12/2008	1150	271908.110,	7617093.690,	271945.740,	7617108.870,	13.0	West of Bessiers Island. Coarse sand with fine shell fragments and occasional depressions and sparse bioturbation. Sparse epibenthic biota (~<10%), dominated by filamentous green algae, with occasional digitated and vase sponges with hydroid clumps. One Spanish mackerel (*Scomberomorus* sp.).
ROV041	6/12/2008	1205	274414.760,	7618863.610,	274460.210,	7618876.090,	15.7	West of Bessiers Island. Coarse sand and shell fragments with flat relatively featureless seabed. Very occasional filamentous green algae and *Caulerpa* sp. with very occasional barrel sponge and ascidians.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV042	6/12/2008	1220	276445.780,	7619956.730,	276491.300,	7619959.130,	14.2	North end of pipeline corridor on east side. Coarse sand with shell fragments. Patchy, very sparse red coralline filamentous algae with occasional *Caulerpa* sp. One small dense patch of *H. decipiens*. Very sparse bioturbation.
ROV043	6/12/2008	1252	268872.900,	7619510.420,	268943.480,	7619515.880,	4.4	Bessiers Island northeast end. Algal covered rock platform with patches of coarse sand and shell fragments with some bare rock exposed. Dominated by green filamentous algae, occasional barrel sponges with very occasional live hard coral bommies (<0.5m) (possible *Porites).* Blue *Chromis* sp., blue tang surgeon fish (*Acanthurus sp.*) and damsels and occasional wrasses.
ROV044	6/12/2008	1312	268979.520,	7618031.380,	269004.810,	7618057.190,	4.2	Bessiers Island, east side. Coarse sand and shell fragments with one large bommie (3m diameter) with around 10% live hard coral cover *(Acropora* plates). Abundant fish life including a large school of Golden Trevally – (*Gnathanodon sp.*), angelfish, blue *Chromis* sp. and stripey snapper (*Lutjanus sp.*).
ROV045	6/12/2008	1400	274064.990,	7613511.420,	274099.680,	7613510.210,	12.6	West of Tortoise Island. Coarse sand and silt with shell fragments with sparse bioturbation. Abundant sea whips, occasional ascidians and digitated and barrel sponges.
ROV046	6/12/2008	1555	274931.430,	7607936.000,	275023.320,	7607968.840,	15.3	West of Outer NW Patch, southwest of Tortoise Island. Sand and silt on broken shell fragments with sparse bioturbation. Moderate abundance of green filamentous algae, with very occasional *Caulerpa* sp.
ROV047	6/12/2008	1616	277013.190,	7604509.710,	277061.700,	7604536.260,	7.1	Tongue Shoals. Sand with small ripples (10cm apart) and shell fragments. No observable epibenthic biota or bioturbation.
ROV048	6/12/2008	1634	278373.560,	7600637.470,	278418.200,	7600676.810,	6.5	Manicom Banks. Coarse sand with small ripples (10cm apart) with shell fragments. One sea whip. Very sparse bioturbation.
ROV049	7/12/2008	818	274223.000,	7627477.000,	274292.000,	7627486.000,	32.6	End of pipeline at 30m contour. Sand with shell fragments. Overall very sparse biota including occasional seawhips, crinoids and sea pens. One hermit crab in cone shell, few fauna trails in seabed.

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ROV050	7/12/2008	1033	278710.360,	7612382.720,	278766.500,	7612328.610,	3.5	Tortoise Island, east side. Reef, with up to 50% live hard coral cover close to shore. *Lobophilia, Turbinaria, Porites* and faviids present, dominated by *Montipora* with occasional large *Acropora* plates. Patches of coarse sand and shell fragments along with patches of brown algae with occasional gorgonians. Varied reef fish life observed in small numbers.
ROV051	7/12/2008	1113	280039.950,	7607543.820,	280087.530,	7607575.660,	6.7	Outer NW Patch. Sand with small ripples, with moderately dense patches of algae including *Caulerpa* sp, and seagrass including *Halophila spinulosa*.
ROV052	7/12/2008	1141	284211.830,	7609368.940,	284242.800,	7609416.910,	5.5	Glennie Patches. Rippled sand with large rock outcrop (approximately 15m+ long) with up to 80% live hard coral coverage with some large bommies and occasional small patches of algae. *Montipora, Turbinaria, Acropora* plates and large *Porites* bommies, with some *Nephthya* sp. Diverse fish life including coral trout (*Plectropomus sp.*), damsels and yellow tailed fusiliers (*Caesio teres*).
ROV053	7/12/2008	1217	284138.950,	7605582.670,	284257.550,	7605632.000,	8.3	Midway between Roller A and B oil pipeline monopods. Silt and sand with occasional large shell fragments. Occasional sea pens, hydroids and sparse macro red and green algae individuals. Sparse patches of *Halophila decipiens* and *H. spinulosa*.
ROV054	7/12/2008	1240	285250.310,	7604434.050,	285286.800,	7604453.140,	4.6	Roller Shoal. Survey abandoned due to weather conditions
ROV055	7/12/2008	1255	287541.820,	7606524.440,	287622.940,	7606562.650,	9.7	South of Roller C monopod. Sand and silt with gravel and broken shells on rubble bottom. Around 10% algae cover, including red and green foliose algae. Occasional dead dead ark shells (*Trisidos* sp.) beds.
ROV056	7/12/2008	1312	291158.330,	7605785.530,	291219.400,	7605801.000,	8.6	Pipeline proposed east of Roller Shoal. Silt and sand covered rubble, with shell fragments and sparse bioturbation. Very sparse green and red algae patches (10% cover).
ROV057	7/12/2008	1333	294994.200,	7605049.830,	295051.600,	7605065.060,	7.6	Potential borehole 12. Sand and silt with some sparse bioturbation including larger depressions. Very sparse patches of H. decipiens. Overall algal cover <10%.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV058	8/12/2008	738	282603.640,	7602248.460,	282599.870,	7602286.480,	6.7	SW Patch. "Sponge and fan garden". Rocky platform, with coarse sand shell fragments and silt and occasional exposed areas. Approximately 20% epibenthic biota cover, including gorgonian fans, sea whips, laminar and digitated sponges, anemones and occasional young hard coral recruits *(Turbinaria)*. *Nephthya* sp. and occasional algae patches including *Caulerpa* sp.
ROV059	8/12/2008	810	285844.150,	7602580.060,	285865.520,	7602597.910,	8.3	South of Roller Shoal and east of SW Patch. Silty sand with no obvious bioturbation. Very sparse covering of small tufts of green algae.
ROV060	8/12/2008	830	290877.000,	7604286.050,	290883.920,	7604314.240,	8.6	West side of proposed shipping channel, north of Curlew Bank. Fine sands and silt covering rubble. Sparse bioturbation with occasional bryozoans and ascidians.
ROV061	8/12/2008	848	291978.860,	7603848.640,	291990.590,	7603869.610,	8.6	Proposed pipeline, close to shore. Sand and silt with very sparse biota and bioturbation. Flat and relatively featureless seabed with occasional low mounds. One ascidian.
ROV062	8/12/2008	905	294760.630,	7604076.420,	294778.250,	7604097.520,	7.2	Potential borehole 13. Reduced visibility through bad weather. Silt and sand with occasional bioturbation. Very sparse patches of algae, including occasional H. decipiens and red algae tufts. One small patch of rubble with hydroids and occasional bryozoans and one sea star. Overall algal cover <10%.
ROV063	8/12/2008	928	294025.600,	7603271.640,	294034.270,	7603280.230,	6.9	Potential borehole 14, west side of turning circle. Very reduced visibility. Sand with silt and sparse bioturbation. One hydroid, one filamentous red alga and one crinoid. Overall algal cover <10%.
ROV064	8/12/2008	944	294545.690,	7603096.880,	294540.250,	7603097.410,	6.6	Potential borehole 16, centre of turning circle. Silt and sand with very sparse bioturbation. One bryozoan and crinoid. Overall algal cover <10%.
ROV065	8/12/2008	1050	294942.290,	7603113.010,	294940.890,	7603130.820,	6.2	Potential borehole 15, east side of turning circle. Silt covered sand with moderate bioturbation. Very occasional sparse patches of H. decipiens and fine filamentous green algae. Overall very sparse biota (<5% cover). Some large bioturbated holes, and anemone on rubble with bryozoans.

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ROV066	8/12/2008	1110	294433.190,	7602606.060,	294437.990,	7602628.670,	5.8	Potential borehole 17, south of turning circle. Very reduced visibility due to weather. Silt covered sand with sparse to moderate bioturbation. Very reduced epibenthic biota (<2%) including H. decipiens.
ROV067	8/12/2008	1128	294336.570,	7602115.000,	294340.360,	7602127.160,	5.0	Potential borehole 18, south of turning circle. No results as visibility too low for survey so propose to repeat in better conditions.
ROV068	8/12/2008	1146	297522.040,	7606208.940,	297542.880,	7606242.730,	7.3	South-southwest of Ward Reef. Sand and silt with shell fragments. Overall very sparse epibenthic biota. Moderately dense patch of small sea pens, very occasional *H. decipiens* and filamentous green algae. One colonial ascidian and sparse hydroids.
ROV069	8/12/2008	1225	300865.440,	7608876.020,	300999.620,	7608877.000,	4.2	Ward Reef, south side. Reef platform, dominated with >25% macroalgal cover, with very occasional young *Turbinaria* recruits. *Caulerpa* sp., *Halimeda* sp. and *Padina* sp. Rubble patches with silt cover in areas.
ROV070	8/12/2008	1244	301119.620,	7609196.200,	301129.360,	7609139.200,	6.4	Ward Reef, east side. Diverse and abundant live hard coral cover reef (~90% cover) with very little damage and dead coral present from storm damage (typically *Acropora*) with patches of silt. *Montipora, Lobophyllia, Platygyra, Turbinaria, Porites* and many *Acropora* plates.
ROV071	9/12/2008	715	294343.260,	7602113.900,	294371.780,	7602115.840,	5.3	Potential borehole 18 repeat. Sand with silt and shell fragments and sparse bioturbation. Sparse patchy areas of algae (<2% coverage) including H. decipiens. Occasional hydroids.
ROV072	9/12/2008	730	294235.230,	7601629.410,	294231.140,	7601628.140,	4.6	Potential borehole 19. Sand with silt and shell fragments and sparse bioturbation. Moderate to sparse cover of algae including fine filamentous green algae and H. decipiens. Occasional sea pens. Overall algal cover <25%.
ROV073	9/12/2008	745	293864.620,	7601660.990,	293841.460,	7601681.830,	4.6	Potential borehole 21. Sand silt and shell fragments. Occasional large depressions in seabed (ray feeding). Up to 25% coverage of H. decipiens in places. Occasional hydroids and bryozoans.
ROV074	9/12/2008	759	294135.540,	7601140.330,	294131.700,	7601131.070,	2.4	Potential borehole 20, close to shore. Very reduced visibility, at times only 100mm. Silt and sand with occasional depression. Very sparse H. decipiens. Overall algal cover <10%.

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ROV075	9/12/2008	815	294701.900,	7601056.200,	294713.020,	7601065.360,	3.7	Potential borehole 23, MOF area. Fine sand with occasional shell fragments with rippled seabed and very low abundance of biota (<1%). One digitated sponge and two crinoids. Overall algal cover <10%.
ROV076	9/12/2008	828	294820.070,	7601577.140,	294812.780,	7601603.650,	4.7	Unidentified steel object revealed by Fugro survey. Approximately 20m of exposed length at approximately 5m depth. Very reduced visibility, but exposed edges have soft sessile biotic growth including sponges, bryozoans and ascidians, possible soft corals, with surrounding area having patchy coverage of algae including *H. decipiens* .
ROV077	9/12/2008	847	295285.460,	7601567.240,	295268.640,	7601558.830,	4.7	Potential borehole 22, furthest east, close to shore. Silt and sand with moderate bioturbation. Moderate cover (>30%) of H. decipiens. Occasional bryozoans and one crinoid.
ROV078	9/12/2008	905	296422.110,	7603122.390,	296444.530,	7603111.610,	6.0	East of turning circle within footprint. Silt and sand with no observed epibenthic fauna.
ROV079	9/12/2008	1041	298803.080,	7613488.030,	298846.210,	7613574.130,	7.6	Hastings Shoal (SW to NE transect). Reef with up to 80% live hard coral cover in places and some very large bommies. Corals include *Montipora, Turbinaria, Porites,* faviids, *Lobophyllia* and *Acropora* . Occasional gorgonians and barrel sponges, with small patches of dead coral with algal cover. Diverse fish life including masked angelfish (*Pomacanthus* sp.), Yellow tailed fusiliers, damsels, butterfly fish, parrot fish (Scaridae) and Fingermark or spotted-scale sea perch (*Lutjanus sp.*).
ROV080	9/12/2008	1111	299055.690,	7615153.510,	299052.540,	7615155.250,	10.0	North of Hastings Shoal, east of potential borehole 2. Rubble with silt and algae cover. Patches of Caulerpa sp. (15-20% cover) with occasional filamentous green algae and hydroids.
ROV081	9/12/2008	1127	300663.100,	7615834.910,	300655.210,	7615872.610,	10.8	Gorgon Patch, southeast side. Sand and silt with coarse shell fragments. Seawhips, gorgonian fans and hydroids present (up to 10% cover)
ROV082	9/12/2008	1143	300858.800,	7615993.350,	300863.630,	7616008.980,	7.1	Gorgon Patch. Steep walled reef with up to 80% hard live coral cover in middle of shoal. Corals include *Montipora, Acropora, Platygyra, Turbinaria, Porites* and *Nephthya* sp. Patches of algae, with barrel and digitated sponges and gorgonians. Fish life included damsel fish, angel fish and yellow tailed fusiliers.

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ROV083	9/12/2008	1212	302245.050,	7618925.780,	302266.000,	7618957.370,	4.6	Weeks Shoal. Flat topped reef with steep walls, with >75% live hard coral cover in patches including *Montipora, Turbinaria, Acropora* and Faviids. Colonial ascidians, algal patches and gorgonians also present. Fish life included yellow tailed fusiliers, stripey snapper and a common lionfish (*Pterois sp.*).
ROV084	9/12/2008	1236	302309.940,	7619841.170,	302336.050,	7619871.860,	13.9	Patch just to the north of Weeks Shoal. Sand, silt and rubble with shell fragments and sparse bioturbation. Very sparse biota (<5% cover), occasional gorgonian, laminar and digitated sponges, ascidians and green filamentous algae patches.
ROV085	9/12/2008	1258	304144.330,	7615544.000,	304202.560,	7615511.030,	3.2	Shoal east northeast of Koolinda Patch, southwest of Direction Island. Large reef with 50-75% live hard coral cover patches on the top. Dominant coral was tabular *Acropora*; with *Lobophyllia*, faviids and *Turbinaria* present. Density was greatest on western side, with eastern side having more patches of red short foliose algal cover. Fish life included angelfish (*Pomacanthus* sp.), fusiliers, wrasses and damsels.
ROV086	9/12/2008	1327	302499.430,	7614619.510,	302515.460,	7614657.180,	8.9	Koolinda Patch. Marked as 2m on Admiralty Chart but unable to find. At 9.5m, sand with silt and fine shell fragments. Epibenthic biota ~10% cover, including *Caulerpa* sp., *H. spinulosa* and *H. decipiens*. Occasional hydroids.
ROV087	9/12/2008	1341	302525.810,	7613254.820,	302561.060,	7613309.110,	9.7	Onslow Salt spoil ground. Silty sand with moderate bioturbation. Overall biota cover very sparse (<1%), but including *Caulerpa* sp., *H. decipiens*, bryozoans and hydroids.
ROV088	12/12/2008	720	305339.400,	7610918.720,	305387.620,	7610929.050,	8.3	East of Onslow salt spoil ground, south of Direction Island. Sand and silt with patches of large shell fragments. Overall <5%biota. Hydroid, sea pen, bryozoan. Occasional green filamentous macro algae, very patchy *H. decipiens* and *H. ovalis*.
ROV089	12/12/2008	747	305568.990,	7617165.410,	305625.150,	7617142.860,	3.1	Direction Island, SW edge. Rubble and cobbles with silt, sand and shell fragments. Occasional moderately thick patches of *H. spinulosa* and *H. decipiens*. Occasional large *Porites* bommies (~2m).

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ROV090	12/12/2008	805	305043.100,	7617859.960,	305087.130,	7617869.250,	2.8	Direction Island, west side. Reef, up to 25-50% hard coral cover in places with occasional algal patches. Indication of storm damage with overturned *Acropora* plates. *Lobophyllia* , *Porites* bommies, *Turbinaria, Montipora,* faviids and *Goniopora* present. Fish present included damsels and coral trout. Occasional sand patches with barrel sponges and gorgonian fans.
ROV091	12/12/2008	830	304940.990,	7618596.080,	304944.580,	7618613.510,	11.5	Northwest of Direction Island, very steep walled reef from 13 – 4m. Reef with up to 50% live coral cover with algae dominated in areas. *Montipora, Lobophyllia, Acropora* and occasional *Porites* bommies (~2m). Stripey snapper, butterfly and surgeon fish, *Chromis* sp., striped damsels and yellow tailed fusiliers present.
ROV092	12/12/2008	1043	304010.900,	7622152.770,	304071.160,	7622232.860,	13.9	North of Direction Island. Silt and sand with shell fragments. Patches of algae with up to 25% cover, including red foliose and strap macroalgae. Very sparse *H. decipiens* and *H . spinulosa* with occasional hydroid.
ROV093	12/12/2008	1106	300185.960,	7622314.160,	300237.880,	7622423.360,	16.2	Northeast of Weeks Shoal. Silt on sand with coarse shell fragments. Patchy short red algal tufts. Overall biota cover <5%. Occasional *Halimeda* , *Caulerpa* sp., hydroids, bryozoans and green foliose algae. Very sparse bioturbation.
ROV094	12/12/2008	1133	295373.270,	7624280.780,	295350.540,	7624287.120,	9.5	East side of Thevenard Island, south of Q.Y mooring. Silt covered sand with sparse bioturbation on sloping seabed (1% epibenthic biota). One digitated sponge, very sparse *H. spinulosa* and *Caulerpa* sp.
ROV095	12/12/2008	1155	295253.160,	7622785.320,	295237.910,	7622793.300,	4.9	Southeast Thevenard Island. Algal dominated rock platform (*Sargassum* and *Halimeda* sp. dominant). Occasional young *Turbinaria* recruits and bryozoans (~1-2% biota coverage)
ROV096	12/12/2008	1215	294520.640,	7622969.600,	294520.260,	7622897.760,	1.9	Southeast Thevenard Island. Algal dominated rock platform (*Sargassum* and *Halimeda* sp. dominant).
ROV097	12/12/2008	1245	292296.040,	7621720.310,	292183.520,	7621694.920,	11.6	Southeast of Yammerderry monopod, South Thevenard Island. Silt covered coarse sand with shell fragments. Very sparse biota (~1-2%) with numerous Fungiids (mushroom corals ~80mm diameter). Occasional ray feeding depression, sparse bioturbation and occasional hydroid.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV098	12/12/2008	1305	289146.550,	7619755.680,	289039.630,	7619790.210,	12.4	North of Cowle monopod, south of Thevnard Island. Coarse sand and shell fragments with occasional rubble and cobble. Occasional mushroom corals, bryozoans and small barrel sponges. Algae patches included tufts of red algae and *Caulerpa* sp. and the seagrass *H. spinulosa.* Overall <5% biota cover.
ROV099	12/12/2008	1319	286436.970,	7621987.580,	286304.720,	7622060.300,	12.3	East of Brewis Reef, South west of Thevenard Island. “Sponge and fan garden”. Gorgonian fans, sea whips, barrel, vase, encrusting and digitated sponges, hydroids and bryozoans. Red coralline algae tufts with coarse sand and shell fragment patches. Overall 25-50% epibenthic biota.
ROV100	12/12/2008	1340	285658.650,	7624422.150,	285588.460,	7624403.620,	3.0	West side of Thevenard Island, north of Brewis Reef. Algae (*Sargassum* sp.) dominated rock platform with occasional large patch of fine sand.
ROV101	12/12/2008	1353	283955.930,	7623436.470,	283853.660,	7623458.920,	3.5	Single shoal north of Brewis Reef, west of Thevenard. Algae dominated (*Sargassum* sp.) large shoal with ~5% *Turbinaria* and *Montipora* young recruits. One small *Porites* bommie with occasional fine sand and shell fragment patches. Turtle sighted.
ROV102	12/12/2008	1410	283430.660,	7621295.770,	283313.800,	7621298.900,	4.0	Brewis Reef northwest side. Algae dominated rock platform reef (*Caulerpa* sp., *Padina* sp. and *Sargassum* sp.), sea cucumbers, *Chromis* sp., small wrasses and blacktail damsels (*Dascyllus sp.*). Occasional small *Turbinaria* and *Acropora* juvenile recruits (~1%). Encrusting sponges and ascidians.
ROV103	12/12/2008	1432	281907.670,	7617899.210,	281883.140,	7617990.830,	15.1	Proposed pipeline, running west to east, eastern end. Coarse sand with shell fragments. Sparse gorgonian fans, sea whips, barrel and digitated sponges, sea pens and sparse *Caulerpa* sp. (<5% cover). Butterfly fish.
ROV104	12/12/2008	1448	284596.280,	7616994.960,	284625.140,	7617036.920,	14.7	Proposed pipeline, running west to east, edge of turn. Coarse sand and gravel with shell fragments. Overall <5% biota cover. Occasional *Caulerpa* sp, red coralline algae tufts, *Halimeda* sp. and *H. ovalis* and *H. spinulosa* . Colonial and solitary ascidians.
ROV105	12/12/2008	1507	283881.720,	7615488.780,	283896.410,	7615509.120,	11.4	Shoal north northwest of Australind Shoal. Rippled sand (~10cm apart and 5cm high). Very occasional tufts of filamentous algae (<1%). No bioturbation.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV106	12/12/2008	1521	283603.200,	7613038.000,	283669.400,	7613069.140,	12.1	10m contour west southwest of Australind Shoal. Coarse rippled sand. Algae cover of ~10% dominated by *Caulerpa* sp. and including *H. spinulosa* and *H. decipiens*. Very sparse bioturbation.
ROV107	12/12/2008	1536	285017.450,	7613538.360,	285056.970,	7613557.650,	5.7	Australind Shoal. Algae dominated reef with 10-20% young recruiting coral individuals. Hard corals included *Montipora, Acropora, f*aviids and *Turbinaria*. Algae included *Padina, Sargassum* and red coralline foliose. Digitated laminar and barrel sponges, hydroids, sea whips and sea cucumbers.
ROV108	12/12/2008	1601	287324.200,	7616991.520,	287349.060,	7617004.680,	12.6	Recommended shipping route, north of Miles Shoal. Sand with coarse shell fragments. Epibenthic biota <5%, including barrel and digitated sponges, sea whips, colonial and solitatry ascidians with very occasional small patches of *H. decipiens*.
ROV109	12/12/2008	1621	292192.030,	7619265.410,	292189.940,	7619292.550,	13.1	Recommended shipping route, south of Thevenard Island. Coarse sand with coarse shell fragments. Biota ~5%. Abundant fungiids (mushroom corals ~10cm). Hydroids, crinoids and sparse bioturbation. Occasional depression (possible ray feeding) and one hermit crab (Paguroidea). One small patch of *Caulerpa* sp. with some *H. decipiens*.
ROV110	12/12/2008	1641	297694.140,	7619609.750,	297731.800,	7619658.380,	15.0	North of Saladin Shoal, east of Weeks Shoal. Coarse sand and shell fragments, Overall <2% biota). Sparse bioturbation with occasional *Padina* sp. and green macroalgae, filamentous tufts and sparse patchy *H. decipiens*.
ROV111	12/12/2008	1659	295191.120,	7617219.580,	295230.730,	7617243.630,	12.5	North northeast of Paroo Shoal. Coarse sand with gravel and large shell fragments, ~10% biota cover. Abundant small fungiids. Green filamentous algae patches.
ROV112	13/12/2008	835	277570.270,	7637455.330,	277646.640,	7637400.590,	61.4	Alternative spoil ground – east. Silt on fine sand with patches of shell fragments. Overall <1% epibenthic biota. Sparse bioturbation. One sea snake, very small cephalopod (squid), one small crustacean (crab). Occasional anemones, hydroids, crinoids, sea pens, sea whips.
ROV113	13/12/2008	856	275774.070,	7637452.050,	275820.890,	7637435.720,	67.1	Alternative spoil ground, centre of footprint. Silt on sand in small clumps. Very sparse biota and bioturbation - <1% biota. Crinoid, hydroids, occasional anemones, sea whips, sea pens and one small crab.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV114	13/12/2008	917	273973.510,	7637480.360,	274118.890,	7637634.800,	71.5	Alternative spoil ground, west side. Silt on sand. Very abundant bioturbation. Strong current. Very sparse biota, <1% cover, consisting of hydroids with no other biota observed.
ROV115	13/12/2008	945	273719.360,	7632174.420,	273707.530,	7632108.850,	54.0	Midway of Alternative and Base case spoil ground. Silt covered sand with, with sparse to moderate bioturbation with occasional large hole. Very sparse biota (<1%). One sea snake, one small crab.
ROV116	13/12/2008	1004	271354.060,	7629258.920,	271332.970,	7629102.730,	52.1	Spoil ground base case northern point. Silt and sand with rubble bottom with shell fragments. Overall <1% biota, with sparse to moderate bioturbation. One shark and one silver trevally (*Pseudocaranx sp.)* sighted. Laminar sponges, sea whips and sea pens, hydroids, ascidians and gorgonian fans.
ROV117	13/12/2008	1046	271355.690,	7627425.550,	271344.530,	7627333.620,	44.8	Spoil ground base case, centre. Silt on sand with moderate bioturbation with some large holes and occasional shell fragments. Overall <1% biota. Hydroids, crinoids and ascidians.
ROV118	13/12/2008	1100	271361.270,	7625434.200,	271326.540,	7625334.380,	40.7	Spoil ground base case southern end. Silt on coarse sand with large shell fragments. Abundant hydroids. Sparse bioturbation. Overall 1-5% biota
ROV119	13/12/2008	1123	268536.430,	7623595.090,	268492.790,	7623548.850,	41.7	West of base case spoil ground, North of Bessiers Island. Silt on sand with occasional shell fragments. Overall <1% biota. Sparse to moderate bioturbation with occasional large holes. Crinoids, anemone, hydroids, sea whips and sea pens.
ROV120	13/12/2008	1143	270430.090,	7621835.180,	270438.320,	7621754.160,	21.2	Shoal Northeast of Bessiers Island. Silt and sand with occasional fine shell fragments. Overall <1% biota. Sparse bioturbation, very sparse *Caulerpa* sp. patches and occasional small tufts of red coralline filamentous algae and occasional crinoid and hydroid.
ROV121	13/12/2008	1205	274942.540,	7621810.180,	274942.730,	7621648.040,	17.3	Proposed pipeline, east of Bessiers Island. “Sea whip, sponge and fan garden” – 50% epibenthic biota cover including hydroids, crinoids, gorgonians, digitated and barrel sponges. Small 2m reef ledge with ~5% small young corals (*Turbinaria* and *Montipora*) and moderately varied fish life including angel fish, *Chromis* sp. and damsels. Occasional patch of sand with macroalgae (possible *Caulerpa* sp.) and some tufts of small red algae. One turtle sighted.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV122	13/12/2008	1225	274586.150,	7624695.410,	274574.660,	7624592.080,	23.0	Proposed pipeline, northeast of Bessiers Island. "Fan and sponge garden" ~ 80% biota cover. Gorgonian fans, sponges and bryozoans and patches of *Caulerpa* sp. Area changes to barren coverage of biota (1-5%) at end of transect, dominated by sand and occasional algae patch (*Caulerpa* sp.)
ROV123	13/12/2008	1250	278429.100,	7627795.180,	278414.580,	7627727.900,	24.5	20m contour west of Thevenard Island, northwest of Brewis Reef. Slightly rippled fine sand, no silt with sparse bioturbation. Occasional crinoid and no algae.
ROV124	13/12/2008	1309	277976.690,	7632349.630,	277901.760,	7632292.730,	39.8	West of Saladin marine terminal, north northwest of Thevenard Island. Silt on fine sand with some shell fragments. Sparse bioturbation with occasional large hole and <1% biota. Occasional crinoid and anemone.
ROV125	13/12/2008	1338	282920.110,	7628719.650,	282905.800,	7628717.610,	10.7	West side of Thevenard Island. Fine, slightly rippled sand with fine shell fragments. No epibenthic biota observed.
ROV126	13/12/2008	1400	278639.620,	7624438.860,	278582.080,	7624428.450,	16.3	West side of Thevenard Island. Fine undulating sand with shell fragments. Very sparse biota - <1%. Occasional sea pen, crinoid and small tuft of red algae.
ROV127	13/12/2008	1420	281692.260,	7622717.450,	281581.910,	7622776.380,	7.0	Reef running west to east, northwest of Brewis Reef and west of Thevenard. Reef ledge (1.5m high) with ~1% hard live juvenile *Turbinaria* corals. Top of reef dominated by sea pens and edge by bryozoans, sponges, soft corals and fish life including angel fish, *Chromis* sp. and parrot fish. Surrounding area ~15% biota dominated by algae, with further surrounding area changing into rippled bare sand.
ROV128	13/12/2008	1440	278984.990,	7618579.920,	278872.020,	7618582.320,	12.5	Proposed pipeline, mid point of west – east section.Rock platform with ~5% hard coral cover of young recruits, including *Porites, Turbinaria, Montipora, Goniopora* and *f*aviids. Digitated and barrel sponges, gorgonian fans and whips and algae including short red tufts of coralline algae and *Padina* sp. Varied fish life including angelfish, small wrasses, damsels, butterfly fish, cleaner wrasse and surgeon fish.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV129	13/12/2008	1501	278425.300,	7615330.940,	278346.630,	7615352.570,	14.2	South of west – east proposed pipeline. Silt on sand with patches of fine shell fragments. Overall 5-10% biota including digitated, barrel and vase sponges, gorgonian fans, solitary ascidians and crinoids. Algae included red tufted coralline algae, *Halimeda* sp., *Caulerpa* sp. and sparse patches of *H. spinulosa* and *H. decipiens*.
ROV130	13/12/2008	1528	286210.180,	7614256.470,	286111.210,	7614255.620,	13.4	Proposed pipeline north of Australind Shoal. Silt on fine sand with shell fragments. Sparse bioturbation and overall sparse biota (<1%). Occasional laminar and digitated sponges, gorgonian fans, bryozoans, solitary ascidians and one pincushion seastar.
ROV131	13/12/2008	1547	289120.930,	7609857.840,	289087.650,	7609802.590,	10.4	Proposed pipeline east southeast of Ashburton Island. Sand with fine shell fragments. Overall biota ~5%. Algae included *Caulerpa* sp., the seagrasses *H. spinulosa, H. decipiens* and fine green filamentous algae. Occasional sea pens, hydroids and solitary ascidians.
ROV132	13/12/2008	1614	285367.490,	7604531.800,	285357.440,	7604503.090,	5.8	Roller Shoal. Reef of up to 50% cover in places of hard live coral with surrounding sand patches. Dominant coral was *Montipora*, with *Goniopora*, *Platygyra*, *Porites*, *Acropora* plates and faviids present. Hydroids, large barrel sponges and algae patches also present with fish life including stripey snapper, *Chromis* sp. and damsels.
ROV133	14/12/2008	732	308262.840,	7618158.990,	308313.370,	7618162.610,	7.7	Direction Island, east-northeast edge. Reef with moderate live coral cover with increased cover on edges. *Montipora* dominant with *Acropora* and *Pocillopora* sp. also present. Diverse and abundant fish life including banner fish, stripey snapper, damsels, *Chromis* sp. and butterfly fish. Algae patches included red coralline foliose algae and *Sargassum* sp.
ROV134	14/12/2008	759	307430.600,	7617732.060,	307472.570,	7617738.760,	5.6	Direction Island, east-northeast edge. Up to 100% hard live coral cover in very healthy condition, with occasional small patch of algae. *Montipora, Acropora, Pocillopora, Turbinaria,* faviids, *Lobophyllia, Goniopora* and *Porites* all present. Many encrusting and foliose growth forms and bommies present. One coral trout and occasional angel fish.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV135	14/12/2008	823	308511.380,	7619844.760,	308603.960,	7619803.120,	9.5	Direction Island, east-northeast. Silt covered sand with moderate bioturbation and occasional large holes. Overall ~1% biota. One very small patch of *H. spinulosa* , and bryozoans, solitary ascidians and hydroids also present.
ROV136	14/12/2008	843	308198.770,	7623931.120,	308277.030,	7623898.500,	12.5	North-northeast of Direction Island,. Silt covered sand with very sparse bioturbation and occasional patches of shell fragments. Overall biota 1-5%. Algae include *Caulerpa* sp., *Halimeda* sp. and very sparse seagrass, *H. decipiens* . Hydroids and one sea whip.
ROV137	14/12/2008	904	311269.000,	7620593.100,	311359.940,	7620589.640,	9.7	West of NE Twin Island. Silt on sand with sparse bioturbation with occasional large hole. Overall <1% epibenthic biota. Hydroids and bryozoans with very occasional *H. spinulosa* and *H. decipiens* .
ROV138	14/12/2008	920	310549.780,	7618677.410,	310675.010,	7618664.480,	8.0	Between Direction Island and SW Twin Island. Silt on sand with sparse bioturbation with occasional large holes. Overall <1% biota, including *Halimeda* sp., *H. decipiens* and *H. spinulosa* . Hydroids and occasional sparse red tufted algae. One small crab.
ROV139	14/12/2008	945	313877.670,	7618776.040,	313844.240,	7618755.970,	4.3	SW Twin Island – south side. Dense seagrass beds (up to 75% cover in places) - *H. decipiens* . Algae dominated sand veneer patches on presumed rock platform with <5% live hard coral cover. One large *Porites* bommie (~3m) with *Montipora* . One turtle and one ray sighted. Occasional reef fish. Hydroids and colonial ascidians.
ROV140	14/12/2008	1010	314942.210,	7616405.950,	315072.960,	7616392.690,	8.6	Between SW Twin Island and Coolgra Point. Overall very sparse biota (<1%). Silt and sand with coarse shell fragments. Sparse bioturbation and occasional larger holes with occasional lace coral (bryozoans).
ROV141	14/12/2008	1033	317246.000,	7614477.670,	317238.940,	7614501.220,	3.0	Northwest point of Coolgra Point. Sand rippled with patches of dense seagrass (*H. decipiens* – 50-75% in places with occasional *H. spinulosa*).
ROV142	14/12/2008	1051	314484.380,	7613746.050,	314542.550,	7613763.860,	7.3	West of Coolgra Point. Silty sand with moderate bioturbation with occasional large bioturbated holes. Occasional hydroid and bryozoan.
ROV143	14/12/2008	1106	312888.420,	7614620.170,	312948.370,	7614628.860,	9.2	West of Coolgra Point, further offshore. Silt and sand with moderate bioturbation with occasional large bioturbated holes. Occasional hydroid and bryozoan. Very sparse epibenthic biota -<1%.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV144	14/12/2008	1128	310487.240,	7616489.040,	310537.870,	7616539.650,	2.8	Shoal southeast of Direction Island, northern end. Algae dominated reef with up to 50% live hard coral patches, mostly on edge of reef. *Turbinaria, Porites, Platygyra, Montipora,* faviids and *Pocillopora*. Diverse and abundant fish life including coral trout, surgeon fish, stripey snapper, damsels and *Chromis* sp. Algae include *Sargassum* and *Caulerpa* sp. Occasional sponge.
ROV145	14/12/2008	1152	307170.860,	7613858.790,	307251.250,	7613824.170,	8.5	South of Direction Island. Sand with fine shell fragments. Moderate patches of seagrass of up to 25%, including *H. spinulosa* and *H. decipiens* and also *Caulerpa* sp. Digitated and laminar sponges and solitary ascidians.
ROV146	14/12/2008	1208	309947.780,	7612829.710,	309993.630,	7612866.980,	8.8	East-southeast of Direction Island. Silt on sand with occasional shell fragments. Highly bioturbated. Overall low abundance of biota – 1-5%. Sparse patches of *H. decipiens*.
ROV147	14/12/2008	1225	312507.500,	7611738.120,	312540.340,	7611705.170,	4.0	North northwest of Beadon Bay, isolated reef patch on chart, nearshore. Reef with up to 25% live hard coral cover in patches. *Montipora, Turbinaria, Pocillopora, Platygyra,* faviids, *Porites* bommies and *Acropora* plates. Small patches of sand with *H. decipiens* and other algae. Evidence of storm damage to reef with overturned *Acropora* plates. Sparse reef fish including stripey snapper and *Chromis* sp.
ROV148	14/12/2008	1249	310634.590,	7609254.560,	310684.430,	7609255.000,	5.3	West side of Outer Beadon Bay, nearshore. Sand with moderately dense patches of seagrass, including *H. decipiens, H. spinulosa* and the alga *Halimeda* sp. Overall ~25% biota cover.
ROV149	14/12/2008	1311	307150.190,	7609201.070,	307131.260,	7609175.830,	7.2	Northwest of Onslow township on 5m contour. Rock platform with scattered reef patches of ~5-10% cover surrounded by coarse sand and shell fragments. *Montipora, Goniopora, Turbinaria* and *Platygyra*. Encrusting, digitated and barrel sponges, with hydroids and ascidians. Very sparse scattered seagrass *H. decipiens*. Sparse fish life including *Chromis* sp. and one boxfish. Evidence of storm damage with broken corals present.
ROV150	14/12/2008	1336	300381.440,	7610698.540,	300387.130,	7610715.800,	11.2	North of Ward Reef. Silt on Sand with occasional shell fragments with high bioturbidity. Very sparse *H. decipiens* (~1% cover) with hydroids and ascidians.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV151	14/12/2008	1358	306549.890,	7607589.580,	306515.100,	7607606.750,	5.5	Beadon Bay, middle of bay. Rippled sand with occasional large shell fragments. Occasional large bioturbation. Small occasional patch of *H. decipiens* , overall 1-2% biota, including *Halimeda* sp., lace coral, hydroids and digitated sponges.

(*) Northings and Eastings GDA Zone 50

B

Appendix B Description of Sites - May 2009

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
Ward Reef								
ROVCOR01	2/05/2009	835	7609229	300490			0-2	Move in westerly direction along north edge of reef. 50-75% cover, predominantly *Montipora* plates, occasional *Acropora* and faviids.
		840	7609288	300390			2-4	25-50% cover *Montipora* and faviids. Along 1 m chart contour.
		850			7609321	300311	5	Isolated *Porites* bommies.
ROVCOR02	2/05/2009	925	7609190	300507			0-2	West end of reef, moving south. 50-75% cover, predominantly *Montipora* plates (minor bleaching), occasional *Acropora* and faviids.
			7609144	300443			0-2	25-50% cover *Montipora* and *Acropora.* Along 1 m chart contour. Large areas of Acropora rubble (silt and algal covered) and dead standing tabulate *Acropora.*
			7609114	300426			2	<25% cover (diverse - *Montipora, Acropora* and faviids), macroalgae and rubble dominant. West of 1 m contour, heading south.
		947	7609010	300450			3	<5% coral cover - mainly sand and macroalgae. Off SW corner of reef. Change heading to NE. Increasing rubble.
		950	7609011	300460			0-2	<25% cover *Montipora,* faviids and *Acropora.* 1 m chart contour. Large areas of *Acropora* rubble (silt and algal covered).
		1002	7609015	300488			0-2	Change heading to SE. <25% cover *Montipora,* faviids and *Acropora,* occasional *Porites.* 1 m chart contour. Large areas of *Acropora* rubble (silt and algal covered).
		1032	7609070	300620			0-2	25-50% cover *Montipora* and *Acropora.* Some patches of 50-75% cover (tens of metres). Large areas of *Acropora* rubble (silt and algal covered).
		1040	7608890	300707			2	Change heading to north. Increasing coral cover, mainly branching *Acropora.*
		1044	7608900	300702			0-1	South side of reef, moving NE. 50-75% cover, predominantly *Montipora* plates, *Acropora* and faviids.
		1047	7608930	300717			0-1	South side of reef, moving NE, then SE. >75% cover, predominantly *Montipora* plates, *Acropora* and faviids.
		1102	7608887	300788			2	South side of reef, moving SE. Area of high branching *Acropora* cover, then into sand and rubble with <10% cover. Change heading to NE.
		1109	7608852	300840			1	South side of reef, moving NE. Area of high branching *Acropora* cover, including dead standing. Total coral cover 25-50%.
		1112	7608882	300840			0-1	South side of reef, moving NE. 50-75% cover, predominantly *Montipora* plates and *Acropora,* occasional *Pocillopora* and faviids. Some patches of >75% cover (tens of metres) along 2 m contour.
		1118	7608947	300884			0-1	South side of reef, moving NE. >75% cover, predominantly *Montipora* plates. Between 1 & 2 m contours.
		1130	7608925	300912			1-2	South side of reef, moving NE. 50-75% cover, predominantly *Montipora* plates and *Acropora,* occasional faviids.
		1132			7608920	300936		End dive. SE corner of reef,
ROVCOR03	2/05/2009	1300	7608881	300969			5	SE corner of reef, heading north. Rubble and silty sand, scattered algae, soft corals, gorgonians, sponges and ascidians. Occasional *Goniopora* and *Turbinaria.*

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
		1310	7608958	301019			4	<25% cover *Montipora,* branching *Acropora* and faviids, isolated *Turbinaria, Porites* and *Lobophyllia.* Large presence of coral rubble.
		1315	7608964	301013			4	Bommies - *Porites, Montipora,* and *Turbinaria,* change heading to NW.
		1320	7608990	301037			1-2	50-75% cover *Montipora,* branching and tabulate *Acropora* and faviids, occasional *Pavona, Porites, Pocillopora.*
		1330	7609049	301003			0-1	25-50% cover, predominantly tabulate *Acropora* with *Montipora* (a few bleached) and faviids. Change heading to NE.
		1337	7609060	301026			1	>75% cover, predominantly *Montipora,* some branching *Acropora.*
		1344	7609065	301090			2-4	Broken bottom with 50-75% coral cover, predominantly *Montipora,* branching and tabulate *Acropora,* with occasional *Porites.* One barrel sponge. Change heading to north.
		1350	7609096	301124			2-3	East side of reef. Bommie with encrusting *Montipora,* then large area of mostly dead branching *Acropora,* then 50-75% cover Montipora and branching *Acropora,* some *Porites* and *Lobophyllia.*
		1358	7609170	301114			2-4	Large *Porites* and *Lobophyllia* colonies, surrounding corals as above.
		1403	7609209	301119			5-7	Change heading to east - straight down slope into sand. Change heading to SW.
		1408	7609217	301136			3	East side of reef. 50-75% cover *Montipora* and branching *Acropora.*
		1411	7609172	301095			1-2	>75% cover, predominantly *Montipora,* some branching *Acropora,* occasional faviid and *Lobophyllia.* Change heading to NW.
		1424	7609203	301040			0-1	>75% cover, predominantly Montipora, some branching *Acropora,* occasional faviid and *Lobophyllia.* Change heading to north.
		1432	7609209	301074			1-3	50-75% cover predominantly *Montipora,* occasional *Porites* and *Lobophyllia.*
		1436			7609242	301106	4	End dive. SE corner of reef,
ROVCOR04	2/05/2009	1520	7609320	301038			7-3	NE corner of reef, heading SW. Bioturbated sand, then up rocky slope with 50-75% cover predominantly *Montipora,* occasional *Porites* and faviids.
		1524	7609288	301018			1-2	Change heading to west. 50-75% cover predominantly *Montipora* with small faviids and branching *Acropora,* occasional *Porites.* Broad areas of >75% *Montipora* cover.
		1540	7609304	300864			1-3	Change heading to NW. 50% cover, higher diversity - predominantly *Montipora* but also tabulate *Acropora,* faviids, *Goniopora.*
		1546	7609353	300839			3	Marker float? North side of reef. Down slope to sand at 9 m. Change heading to SW.
		1550	7609349	300838			2-4	50-75% cover predominantly *Montipora* with faviids and occasional *Porites* and *Acropora.*
		1555	7609343	300767			0-2	50% cover predominantly *Montipora* and *Acropora* (including dead standing tabulate) with faviids and occasional *Lobophyllia* and *Porites.*
		1613			7609310	300657		End dive. NW corner of reef.
Hastings Shoal								
ROVCOR05	3/05/2009	723	7613539	299322			8	East side of shoal, heading WNW. Sand (coarse, with shell fragments), clumps of algae, occasional sponges (including cup and laminar), ascidians, sea whips, seagrass (*Halophila ovalis*)
	3/05/2009	737	7613594	299278			8	Few *Turbinaria* and *Montipora* with occasional *Acropora* and faviid (<10% cover), occasional sponge and sea fan.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
	3/05/2009	742	7613600	299274			5-6	Base of broken slope. <25% cover, mainly *Turbinaria, Montipora, Acropora, Porites* and faviids, many sponges, some macroalgae.
	3/05/2009	749	7613604	299223			4-5	Broken gentle slope. 25-50% cover, mainly *Porites* and *Montipora,* some *Pavona* and *Acropora,* few faviids and *Lobophyllia,* many sponges, some macroalgae. Small patch (10-20 m only), then rubble with isolated outcrops.
	3/05/2009	758	7613632	299179			4-2	Upper slope and top of shoal - rubble (mainly *Acropora* branches). Diversity of corals (mainly *Porites* and faviids, with occasional *Pocillopora)* and sponges on occasional outcrops on upper slope. Sea star, purple calcareous algae, *Padina* abundant on top of shoal.
	3/05/2009	821	7613697	299014			2-3	Crest of western slope - rubble (mainly *Acropora* branches) with scattered small corals on rubble - *Porites,* faviids, *Montipora, Acropora,* <10% cover.
	3/05/2009	830	7613745	298960			4-5	Outcrops (<5 m diameter) with mainly *Montipora* and *Porites,* some *Acropora,* faviids, sponges. Typically <10% cover on outcrops - mainly dead standing coral. Sand at bottom of slope. Heading changed to SW.
	3/05/2009	853	7613661	298880			3	Broken gentle slope. 25-50% cover, mainly *Montipora,* many *Acropora* and faviids and several large *Porites* (more common at 4 m LAT). Some areas 50-75%.Heading changed to south. Coral trout *(Plectropomus* sp.).
	3/05/2009	917	7613565	298847			4	Change heading to SE. <25% overall cover. *Porites* bommies, tabulate *Acropora, Montipora,* faviids and *Turbinaria.*
	3/05/2009	923	7613539	298844			3	Change heading to east. Broken gentle slope. 25-50% cover, mainly *Montipora* and small *Porites,* many *Acropora* and faviids, some *Pavona.*
	3/05/2009	930			7613509	298846		End dive - SW corner of shoal. Relocate to SE corner.
ROVCOR06	3/05/2009	940	7613500	299155			6	Head west along southern edge of shoal. Rubble bottom, <1% coral cover - *Porites* bommie, scattered *Montipora* and *Acropora.* Scattered sponges, including barrel *(Xestospongia),* black and laminar.
	3/05/2009	947	7613526	299151			5-4	Gentle rubble slope, change heading to NW. Black volcano sponges, ascidian. Very occasional coral - faviids, *Montipora, Porites,* <<1% cover. Turtle.
	3/05/2009	958	7613575	299102			4	Change heading to SW. Rubble with scattered purple calcareous algae, *Halimeda,* small sponges.
	3/05/2009	1009			7613530	299049		End dive - south side of shoal. Relocate to shoal to NE to Koolinda Patch.
NE Koolinda								
ROVCOR07	3/05/2009	1041	7615533	304287			7	East side of shoal, heading west. Sand (coarse, with shell fragments and cobbles), scattered sponges and sea fans and whips.
	3/05/2009	1050	7615538	304227			5-2	Base of broken slope. 25-50% cover, mainly *Montipora* and tabulate *Acropora,* some faviids and musiids.
	3/05/2009	1056	7615535	304197			2	Top of shoal. 25% cover, mainly tabulate *Acropora,* some *Montipora, Turbinaria* and faviids.
	3/05/2009	1102	7615509	304158			2-3	Top of shoal. 25% cover (patches ~50%), mainly *Montipora* and faviids, several large tabulate *Acropora,* occasional *Porites* and *Turbinaria,* couple of *Mycedium* and *Lobophyllia.* Many sponges and small ascidians.
	3/05/2009	1119	7615510	304061			3	Gentle broken western slope of shoal, coral cover declining (taxa as above).

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
	3/05/2009	1126			7615480	304063		End dive - west side of shoal. Relocate to centre of shoal.
ROVCOR08	3/05/2009	1132	7615597	304205			8	East side of shoal, heading west. Sand (coarse, with shell fragments and cobbles), scattered algae, ascidians, sponges and sea fans and whips
	3/05/2009	1147	7615555	304180			5-2	Steep shoal edge, then west across top of shoal. 50-75% cover at edge, mainly tabulate and corymbose *Acropora,* some *Montipora, Turbinaria, Lobophyllia* and faviids.
	3/05/2009	1155			7615517	304166		End dive. Relocate to Gorgon Patch - only two small pinnacles found on sounder, move to Saladin Shoal.
Saladin Shoal								
ROVCOR09	3/05/2009	1340	7613362	296159			4-2	Eastern edge of shoal, heading west. Algal covered rock pavement at edge, <10% coral cover, then into 25-50% cover (areas of 50-75%), mainly tabulate *Acropora, Pocillopora* (large proportion bleached) and *Montipora,* also faviids, *Lobophyllia.*
	3/05/2009	1403	7613406	296128			3	Western edge of shoal (8 m at bottom of slope). 50-75% cover, predominantly tabulate *Acropora, Pocillopora* (many bleached) and *Montipora,* also faviids and *Lobophyllia.* Several coral trout.
	3/05/2009	1409			7613395	296131		End dive. Relocate to Paroo Shoal.
Paroo Shoal								
ROVCOR10	3/05/2009	1453	7614060	293880			7	Eastern edge of ridge, heading west. Pavement with 15-25% cover, mainly *Turbinaria,* faviids, *Porites* and *Acropora.* One large *Goniopora.* Many sponges.
	3/05/2009	1510			7614063	293918		End dive - unable to make headway to west. Relocate to west side of ridge.
ROVCOR11	3/05/2009	1520	7614023	293805			4-5	Western end of ridge, heading east. Patchy 50-75% cover at start, mainly corymbose *Acropora.* High diversity - *Montipora,* faviids, musiids, *Porites, Goniopora, Lobophyllia.* Adjacent areas of algal covered dead standing coral, couple of *Dendronephthya.*
	3/05/2009	1532	7614014	293846			4	Patch of 50-75% cover, mainly *Montipora,* with other species as above.
	3/05/2009	1540			7614025	293851		End dive. Relocate to Miles Shoal.
Miles Shoal								
ROVCOR12	3/05/2009	1607	7613775	288941			7	South side of shoal, heading east. Pavement with <10% cover, mainly *Turbinaria,* some small *Acropora, Porites, Montipora* . Many sponges, several sea fans and whips.
	3/05/2009	1613			7613769	288968		End dive. Relocate to shallower part of shoal.
ROVCOR13	3/05/2009	1623	7613767	288954			6-4	South edge of shoal, heading north. Pavement with <10% cover, mainly small *Turbinaria,* some small *Acropora, Porites, Montipora.* Numerous sponges and sea fans.
	3/05/2009	1635			7613902	288958		End dive. No potential monitoring sites.
Brewis Reef								
ROVCOR14	4/05/2009	807	7621275	284949			4-2	North side of eastern "peak", heading SW. Pavement with <1% coral cover - mainly small *Turbinaria,* some *Porites,* faviids, *Acropora* and *Montipora.* High macroalgal cover (mainly *Padina,* some *Sargassum).* Scattered colonial ascidians, sponges. Several ledges.
	4/05/2009	822	7621183	284750			4-2	Change heading to east. Areas of rippled sand with macroalgae (<1%) on pavement with <1% coral cover - mainly small *Turbinaria.* High macroalgal cover (mainly *Padina,* some *Sargassum).*
	4/05/2009	828			7621192	284831		End dive, relocate to centre of eastern "peak".

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROVCOR15	4/05/2009	838	7621180	284931			3	Centre of eastern "peak", heading SW. Pavement with <1% coral cover - mainly *Turbinaria,* some faviids, *Acropora* and *Montipora.* Dense macroalgal cover (mainly *Sargassum* and *Padina).* Scattered sponges. Broad areas of rippled sand. Large school of Long Toms (Belonidae).
	4/05/2009	847			7621011	284793		End dive, relocate to western "peak".
ROVCOR16	4/05/2009	855	7621441	283727			2	Centre of western "peak", heading east. Pavement with <1% coral cover - mainly small *Acropora* (including *Acropora palifera* ?), some *Lobophyllia, Montipora.* High macroalgal cover. Frequent soft corals (incl. *Sinularia)* at start.
	4/05/2009	910			7621459	283875		End dive, relocate to Thevenard Is.
Thevenard Is.								
ROVCOR17	4/05/2009	940	7627928	286300			0-6	Western reef slope, heading to NW down slope. Gently sloping sand veneered pavement with heavy *Sargassum* cover. Ledge at 3-4 m LAT.
	4/05/2009	957	7628146	286206			6-9	Gently sloping sand veneered pavement with sparse *Sargassum* and *Halimeda,* sponges, sea whips.
	4/05/2009	1000			7628209	286176		End dive.
ROVCOR18	4/05/2009	1025	7629256	289916			+1.5-1.0	Horseshoe reef on northwestern end of Thevenard, inside northern end. Limestone platform dominated by algae *(Sargassum, Halimeda).* Patchy individual isolated corals *(Turbinaria, Acropora.)*
	4/05/2009	1047	7629194	289502			+1.5-1.0	Algae dominated sandy substrate *(Sargassum).* Occasional ascidian. Headed to north. More of same.
	4/05/2009		7629693	289302			1-4	Scattered isolated sparse juvenile *Turbinaria* (<1%)
	4/05/2009		7629798	289286			4	Isolated reef lump. One isolated tabulate *Acropora* (~1m).
	4/05/2009	1108			7629798	289286		End dive, relocate to Trap Reef.
Trap Reef								
ROVCOR19	4/05/2009	1140	7632278	294461			5	Eastern end of reef, heading west. Broken reef bottom, <10% coral cover, predominantly juvenile *Turbinaria,* together with *Montipora* and faviids and occasional tabulate *Acropora.* Few soft corals (*Sarcophyton, Sinularia). Holothurian*. Barrel sponge.
	4/05/2009	1147	7632294	294402			4	Reef ledge with scattered juvenile *Porites,* single *Symphyllia* and *Echinopora?* Broad area of soft coral (mainly *Sarcophyton)* - 50-70% cover. No areas of monitorable coral.
	4/05/2009	1157	7632284	294177			2	Bare broken reef top with <10% cover of small faviids, *Acropora, Porites*. Frequent soft corals.
	4/05/2009	1202	7632271	294048				Descending from top of coral reef, <10% coral cover.
	4/05/2009	1208			7632267	293852	4	End of dive.
Thevenard Isl.								
ROVCOR20	4/05/2009	1335	7627050	290276			5	Northern side (western end) of Thevenard Island. Patchy *Halophila decipiens* on shelly sandy substrate.
	4/05/2009	1341	7627028	290257			0	Very large individual coral bommies. Large *Goniopora,* around 5 m. *Porites* bommies, encrusting and digitate *Montipora, Porites cylindrica*, tabulate *Acropora*, faviids, *Platygyra*. Patches greater than 75% coverage.
	4/05/2009		7626989	290247			+1	Patches of small *Acropora* plates with dual dominant *Montipora* plates. Headed east. Shallow reef areas dominated by *Acropora* and *Mycedium* up to 50% cover.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
	4/05/2009	1357	7626958	290339			+1	Large area of columnar *Galaxea*, change heading to NE.
	4/05/2009	1403	7627057	290373			+1	Up to 75% coral cover, tabulate *Acropora* dominant, also *Lobophyllia*, *Pavona*, *Pectinia* . Potential similarities to some inner reef sites. Large 2 m *Porites* bommie
	4/05/2009	1409	7627069	290442			2	Potential anchoring site for vessel. Sandy bottom. Large bommie of *Diploastrea* sp.
	4/05/2009	1413			7627079	290464		End of dive.
ROVCOR21	4/05/2009	1428	7627340	292339			1	Northern side of Thevenard, northern point. 50-75% coral cover, *Montipora* and tabulate *Acropora* dominant, also branching *Acropora* and *Porites.* However, entered large expanse of *Acropora* rubble to east.
	4/05/2009	1437	7627371	292487				Up to 25-50% cover of *Montipora* plates, *Acropora* plates, with occasional *Porites.* Areas of algae covered coral rubble.
	4/05/2009				7627451	292521	2	End of dive.
ROVCOR22	4/05/2009	1450	7627225	292010			1	Northern side of Thevenard Island, northern end, west of previous site. 50-75% coral - branching and tabulate *Acropora* (dominant), *Porites, Montipora* , faviids, *Oxypora, Lobophyllia, Galaxea.*
	4/05/2009				7627225	291972		End of dive
ROVCOR23	4/05/2009	1515	7626585	296164			3	Eastern side of Thevenard Island. Dominated by *Acropora* plates, 50-75% cover, in places >75%. *Porites,* overturned *Acropora* plates indicating highly dynamic environment. Heading to SE. Faviids, columnar *Galaxea, Mycedium, Pocillopora* .
	4/05/2009	1526	7626458	296314			1	Small patches of juvenile *Pocillopora* sp, turning into algae dominated limestone platform, before returning to sparse cover of juvenile corals (<10%) within areas of broken branching corals.
	4/05/2009	1532	7626448	296406			2	Edge of reef - dense area of coral next to edge, rapidly reducing in cover away from this area. Potentially monitorable along edge (especially if transect start was further to the north-western edge). Tabulate *Acropora* dominant, also faviids and *Pavona.*
	4/05/2009	1537	7626423	296406			2.0	End of monitorable reef edge. Change direction to south. Severe damage to reef present.
	4/05/2009	1540	7626390	296436			1.5	Start of potential site. 50-75% cover. Pocillopora and tabulate *Acropora* dominant, but insufficient areal coverage.
	4/05/2009	1545			7626396	296491	1.0	End of dive.
ROVCOR24	4/05/2009	1555	7625849	296771			2.0	Further south of previous dive on eastern edge. Dominated by macroalgae with sand patches. Heading south, brief area of reef exposed, rapidly turning into algae dominated substrate with areas of dead reef with occasional encrusting *Montipora* (<10% cover).
	4/05/2009	1607	7625606	296644			6.0	Deeper area of sand and occasional coral, change direction to south. Even deeper area of barren sand.
	4/05/2009	1609			7625522	296600		End of dive.
ROVCOR25	4/05/2009	1627	7626592	296165			2.0	Back to start of transect 23 to establish possible NW extent of monitorable coral. 25-50% cover, tabulate *Acropora* dominant, *Pocillopora* sub dominant, also *Porites* and faviids, areas of up to 75% cover.
	4/05/2009		7626587	296172			2.0	Continuation of reef edge towards south-western direction, following contour.
	4/05/2009	1634	7626582	296121			2.0	End of dive.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROVCOR26	4/05/2009	1652	7623090	295330			2.0	SE edge of Thevenard Island reef, heading SW. Limestone platform dominated by macroalgae *(Sargassum),* then 25-50% coral cover. *Turbinaria,* faviids, *Pocillopora,* tabulate *Acropora, Platygyra.* Soft corals including *Sarcophyton.*
	4/05/2009		7623084	295313			2.0	Algae dominated platform *(Sargassum),* change direction to west.
	4/05/2009		7623063	295324			2.0	Back to edge of reef, 50-75% coral cover. *Platygyra, Acropora,* faviids, *Turbinaria.* Inadequate areal coverage for monitoring.
	4/05/2009		7622975	295352			3.0	Large area of soft coral (Sinularia).
	4/05/2009		7622959	295429			5.0	*Porites, Lobophyllia, Oxypora* , reef with 2m wall. Non monitorable. South heading.
	4/05/2009	1716	7622966	295411			5.0	End of dive.
Thevenard Island South East corner								
ROVCOR27	5/05/2009	836	7622876	295032			2	SE Thevenard Island. SE direction heading. Very occasional foliose *Turbinaria bifrons* (30-50 cm diameter), <10% coral cover on macroalgae dominated limestone platform with sandy patches. Occasional barrel sponge.
	5/05/2009	850			7622737	295198	6	End of dive.
Thevenard Island South								
ROVCOR28	5/05/2009	907	7624259	292216			1	Southern edge of Thevenard Is. Macroalgae dominated sandy substrate with occasional *Halimeda.* Southerly heading towards gently sloping seabed towards reef edge.
	5/05/2009	914	7624105	292068			1	Reef platform with lack of macroalgae - overall mostly dead coral assemblages, including tabulate *Acropora* plates. Occasional live juvenile *Pocillopora, Porites* and faviids with occasional *Acropora,* but overall impression of a devastated reef.
	5/05/2009	920	7624022	291970			4-2	Bottom of reef edge with individual *Porites* bommies up to 3 m in height. Easterly heading. Platform with very occasional individual juvenile *Acropora* corals. Padina dominant in places. Occasional small *Porites* with one *Goniastrea.*
	5/05/2009	928	7623984	292171			2	Small patch of *Porites,* not monitorable.
	5/05/2009	931			7623984	292174		End of dive.
ROVCOR29	5/05/2009	945	7624410	290221			6	Heading in northerly direction. Sandy substrate with silt veneer.
	5/05/2009	948	7624117	290172			5	Base of rubble slope with outcrops including *Porites,* tabulate *Acropora,* faviids, encrusting *Montipora,* overall <10% cover. Dead standing *Acropora* plates. Large *Diploastrea(?)* assemblage.
	5/05/2009	951	7624174	290144			1	Occasional encrusting *Montipora* on bare pavement, with large sand and coral rubble patches.
	5/05/2009	954	7624219	290046			0-4	Isolated patch of small bommies, *Porites* etc. Non monitorable. Dead standing plates. Overall <1% cover. Evidence of heavy storm damage to corals.
	5/05/2009	958	7624144	289921			2	Cluster of large *Porites* bommies up to 3 m height. Occasional encrusting *Montipora,* juvenile faviids, *Acropora.* Reef in recovery. Heading to west.
	5/05/2009	1010	7624142	289669			5	Continuation of scattered large bommies (predominantly *Porites),* with occasional dead bommie with juvenile corals including *Goniopora, Acropora* and *Montipora* plates.
	5/05/2009	1016	7624156	289567			2	Base of rubble slope, heading up to shallow area. Occasional individual small bommies. Overall reef composed of a number of individual *Porites* bommies in 2-4 m LAT.
	5/05/2009	1026	7624164	289252			2	Anchor and chain wedged in reef.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
	5/05/2009	1029	7624161	289223			1	Bommies start to be less numerous. Head to south over platform with rubble veneer. Cluster of *Diploastrea* bommies.
	5/05/2009	1035	7624117	289132			1	End of dive.
Ashburton Island								
ROVCOR30	5/05/2009	1119	7610683	286654			6	North-eastern edge of reef. Sand and silt substrate. Patchy *Halophila* seagrass.
	5/05/2009	1126	7610608	286565			3	*Montipora* plates on coral outcrops and bommies. Tabulate *Acropora, Turbinaria* and *Porites* bommies, 50-75% coral cover on bommies.
	5/05/2009	1129	7610550	286485			0-2	Shallow broken coral substrate with occasional smaller bommie. Large *Lobophyllia* bommie. *Porites* bommies. Small tabulate *Acropora, Goniopora.* Monitorable in small patches, but insufficient overall cover.
	5/05/2009	1134	7610482	286391			0	Top of reef - broken coral rubble - turn south. Overturned *Acropora* tables.
	5/05/2009	1141	7610416	286295			3	Small isolated coral outcrops, dominated encrusting *Montipora, Acropora* plates.
	5/05/2009	1145	7610386	286228			3	Collection of old transect markers surrounding small *Montipora*-encrusted bommies. 10-25% coral cover with small tabulate *Acropora* dominant. Occasional *Porites* bommie, columnar *Galaxea* and faviids. Heading west.
	5/05/2009	1156	7610355	286006			1-4	Large areas of *Acropora* rubble. Patches of small un-monitorable coral outcrops. Areas of overturned tabulate *Acropora* colonies. Sandy patches more prevalent towards west.
	5/05/2009	1206	7610363	285740			1-4	Large individual *Porites* bommie.
	5/05/2009	1209	7610392	285698			2	Dominated by *Porites,* also faviids, *Lobophyllia, Montipora, Galaxea, Pavona* and small tabulate *Acropora.* 10-25% coverage.
	5/05/2009	1212			7610431	285599	4	End of dive.
ROVCOR31	5/05/2009	1343	7611363	286666			6	Predominantly *Porites* and *Montipora,* also faviids, tabulate *Acropora* and *Galaxea,* ~50% cover.
	5/05/2009	1348	7611407	286655			5	Rope going into reef.
	5/05/2009	1351	7611421	286611				Patches of up to 50% coral cover. Tabulate *Acropora* and *Montipora* dominant. Sub-dominant *Porites.* Also *Pocillopora, Turbinaria,* faviids and *Pavona.*
	5/05/2009	1355	7611443	286568			2-4	Isolated scattered coral outcrops with <25% cover. Occasional *Porites* bommie.
	5/05/2009	1359	7611541	286563			6	Bottom of slope, greater coverage of coral (including *Lobophyllia)* between 4-6 m LAT.
	5/05/2009	1405	7611654	286487			6-5	Broken reef slope. Heading north into brief 50% coral cover of *Montipora* and *Lobophyllia.* Coverage reduces to juvenile *Turbinaria* of <25%.
	5/05/2009	1412	7611673	286289			4	Isolated scattered coral outcrops with <25% cover. Occasional large *Porites* bommie. *Platygyra.*
	5/05/2009	1415	7611640	286165			3-1	Around 10 m of monitorable coral, dominated by tabulate *Acropora* and *Porites* bommies.
	5/05/2009	1420	7611617	286118			3-1	25-50% cover, tabulate *Acropora* dominant, *Montipora* sub-dominant. Also faviids, *Porites, Lobophyllia* and *Pocillopora.*
	5/05/2009	1431			7611609	286025	3	End of dive.
ROVCOR32	5/05/2009	1441	7611388	286662			8.0	Back to beginning of transect 31, to head south along reef. Dominated by encrusting and plate *Montipora.* Also tabulate *Acropora, Porites* and faviids. No ROV recording made.
	5/05/2009	1446	7611300	286658			2.0	25-50% coral cover, recording ROV footage.
	5/05/2009	1452			7611270	286632		End of dive.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
Glennie Patches								
	5/05/2009	1500	7609440	284182			8-5	Soundings only, no ROV. Deemed too small to be monitorable - around 30 m in length.
Roller Shoal								
ROVCOR33	5/05/2009	1524	7604553	285412			4.0	Dominated by *Montipora* plates 25-50% cover, *Porites* co-dominant in places. Also juvenile *Turbinaria,* tabulate *Acropora* and *Lobophyllia. Dendronephthya* soft coral. Large patches of rubble and sand covered pavement.
	5/05/2009	1534	7604506	285483			3.0	Isolated bommies with juvenile growth, dominated by *Montipora* plates/encrusting.
	5/05/2009	1542	7604507	285530			5-2	Large isolated *Porites* bommies ~3 m diameter. Large *Lobophyllia.* Heading west. 25-50% cover of encrusting *Montipora.*
	5/05/2009	1551	7604511	285378	7604559	285351	2.0	50% cover with *Montipora* plates dominant, subdominant tabulate *Acropora.*
	5/05/2009	1555	7604559	285306			3-4	Further 75% coral cover suitable for monitoring site. Isolated *Porites* bommies and *Lobophyllia* in deeper areas.
	5/05/2009	1558	7604557	285248				End of dive.
Weeks Shoal								
ROVCOR34	6/05/2009	752	7619061	302498			11	Northern edge of shoal. Sand substrate with sea whips and sponges.
	6/05/2009	756	7619090	302534			5	Steep walled reef from 13 m to 7 m consisting of a number of large reef outcrops with gullies between. *Montipora* plates, tabulate *Acropora, Porites, Turbinaria* . 10-25% cover on northern section of reef.
	6/05/2009	803	7619059	302580			4	Bommie to south.
	6/05/2009	810	7619031	302594			5	*Pocillopora, Montipora, Turbinaria* , faviids, tabulate *Acropora, Platygyra* .10-25% cover.
	6/05/2009	815	7619043	302549			4	Headed southwest. 25-50% cover, *Montipora* dominant, also tabulate *Acropora, Porites* and *Pocillopora.*
	6/05/2009	823	7619015	302552			5	Southern section of reef. Overall sparse coral cover.
	6/05/2009	831	7619029	302568			5	Middle to southern end of Weeks Shoal could be a potential monitoring site, diving investigation will be required to confirm adequate cover.
	6/05/2009	832			7619029	302568	5	End of dive.
Direction Island - Shoal to NW								
ROVCOR35	6/05/2009	900	7618604	304782			4	Steep walled reef. Easterly direction from northern edge. Coral outcrop, 25-50% of co-dominant tabulate *Acropora* and *Montipora* with some patches of 75% cover. *Lobophyllia, Porites* bommies, *Goniastrea,* faviids.
	6/05/2009	910	7618568	304836			5	Reef top - <25% juvenile *Turbinaria,* with occasional *Acropora* plates, *Goniastrea.*
	6/05/2009	911	7618527	304835			5	Heading west, individual *Porites* bommies, 1-2m.
	6/05/2009	916	7618526	304892			4-3	50-75% tabulate *Acropora* dominated. Faviids, *Porites, Montipora.* NE direction.
	6/05/2009	919	7618558	304914			3	Dense areas of coral reduce before increasing to 10-25% then increasing to 50%, dominated by tabulate *Acropora.*
	6/05/2009	922			7618604	304915	4	Reef coverage reduces. End of dive.
Direction Island								
ROVCOR36	6/05/2009	935	7618057	305241			2	North west side of Direction. Macroalgae *(Sargassum* dominant, also *Halimeda* and *Padina)* dominated limestone substrate with sand patches. Headed in SW direction.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
	6/05/2009	946	7617977	305128			3	Reef outcrops with juvenile corals. Sparse coverage.
	6/05/2009	948	7617966	305088			4-6	Increased coral coverage of 10-25% diverse communities. Headed west. *Porites* and *Montipora* dominant, also *Pavona,* dead standing *Acropora,* live *Acropora, Pavona, Lobophyllia,* faviids, *Platygyra* and juvenile *Turbinaria.*
	6/05/2009	953	7617944	305019			7	Edge of reef onto sand, headed south west.
	6/05/2009	955	7617941	305018			6	Individual rock outcrops and bommies at base of broken slope, similar to previous observations.
	6/05/2009	1006	7617830	305054			3	Reef outcrops dominated by macroalgae, then sand dominated substrate.
	6/05/2009	1010	7617799	305037			3	Macroalgae reduces and coral cover increases on rock outcrops with increasing bommies. Edge of reef appearing at 6 m LAT. Headed SE to get back on reef.
	6/05/2009	1016	7617799	304957			4	End of dive. Not enough coral cover for monitoring purposes.
ROVCOR37	6/05/2009	1026	7617239	305458			0	Western side of Direction Island. Limestone platform with moderate algae cover. Southerly direction. Rock outcrops reduce into sand and silt substrate.
	6/05/2009	1038			7617078	305317	5	Sandy substrate - end of dive. Not suitable monitoring site.
ROVCOR38	6/05/2009	1107	7617640	307308			0	Eastern edge of Direction Is. Top of reef.
	6/05/2009	1111	7617651	307282			1	*Turbinaria,* faviids, *Platygyra, Porites,* occasional *Pocillopora, Acropora* , no clear dominance.
	6/05/2009	1116	7617642	307331			0	Edge of reef 10-25% cover of mixture of species. No clear dominance. Expanse of foliose *Montipora* - similar to Ward Reef community. *Lobophyllia. Galaxea, Turbinaria* . Heading NE.
	6/05/2009	1126	7617642	307334			0	Large swell and bad visibility - head to north.
	6/05/2009	1128	7617672	307342			0	Large patches of *Galaxea,* with *Pavona* also present.
	6/05/2009	1131	7617669	307318			6	Patchy area of *Halophila decipiens* . Large ray.
	6/05/2009	1134			7617697	307300	6	End of dive.
ROVCOR39	6/05/2009	1315	7617943	306878			5	North-eastern side of Direction Island. Sand substrate with silt veneer.
	6/05/2009	1317	7617909	306881			5- +1	Base of coral slope. 50% cover, *Porites* and *Montipora* dominated cover. Northerly direction. Tabulate *Acropora* sub-dominant. Large patches of *Montipora.* Occasional vase *Turbinaria.* Patches of 50-75%. Large colonies of *Lobophyllia,* faviids and *Pavona.*
	6/05/2009	1325	7617991	306872			+1 -5	Top of reef, shallow water. NE direction. Reef edge - coral decreases to sand. Short steep wall.
	6/05/2009	1327	7618020	306878			5-2	Coral outcrops and large bommies on reef edge with 75% coverage.
	6/05/2009	1335			7618093	306846	3	End of dive.
Direction Island - Shoal to SE								
ROVCOR40	6/05/2009	1400	7616507	310510			2-0	Northern point of shoal to SE of Direction Island. Reef top and edge with <25% coral cover in places. Juvenile *Turbinaria, Lobophyllia* and tabulate *Acropora.* Encrusting *Montipora. Platygyra. Goniastrea. Pavona.*
	6/05/2009	1425	7616561	310499			4	Edge of reef, with reduced coral cover. Coral band on edge of reef <25% cover.
	6/05/2009	1430			7161600	310505	2-6	25-50% coral cover in small patches, encrusting *Montipora, Porites cylindrica* , large *Goniastrea* bommie, but coral coverage inadequate for monitoring.
SW Twin Island								
ROVCOR41	6/05/2009	1512	7619411	313918			3	North east corner of SW Twin Island. Evidence of severe weather conditions with large *Lobophyllia* overturned. *Goniastrea, Porites cylindrica* , massive *Porites, Platygyra.*

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
	6/05/2009	1515	7619391	313932			+1 -2	25-50% coverage in band on edge of reef between +1 and -2 m LAT. Dominant - *Montipora* and tabulate *Acropora*. *Lobophyllia, Porites, Pocillopora* and faviids also present.
	6/05/2009	1530	7619390	314012			1-3	Large *Porites* bommies on reef edge.
	6/05/2009	1535			7619363	314050		End of dive.
NE Twin Island								
	6/05/2009	1605	7620143	315012			0	NE Twin Island NW side - *Porites* bommie field. Too small to monitor.
	6/05/2009	1613	7620033	315310			0	NE Twin Island NW side - *Porites* bommie field. Too small to monitor.
Herald Reef								
ROVCOR42	6/05/2009	1628	7621184	316960			0	Shoal south of Herald Reef - Large bommies in field. Too small to monitor.
	6/05/2009	1659	7623395	315773			4	Herald Reef - north side in northerly direction. Rock outcrops covered with macroalgae, <10% coral coverage - juvenile *Turbinaria,* tabulate *Acropora, Lobophyllia* , encrusting *Porites.*
	6/05/2009	1704	7623436	315850			4	Isolated bommies returning to isolated rock outcrops with encrusting juvenile corals. <10% cover.
	6/05/2009	1715			7623436	315850	5	End of dive.
Nares Rock								
ROVCOR43	7/05/2009	745	7629421	323473			6-4	Nares Rock, NW of Twin Islands. Steep walled reef dominated by encrusting *Montipora.* NE direction. *Porites,* tabulate *Acropora*. *Lobophyllia.* 25% coverage. Coral density increases on southern edge of reef. Deepest reef surveyed so far.
		755	7629453	323552			8-4	Change direction to west. Sandy substrate at depth at reef edge. Top of reef dominated by low profile encrusting and tabulate *Montipora,* occasional faviids. 25% cover with some patches up to 50%. Small *Porites* bommies. Coral Trout, cray and eagle ray.
		804	7629435	323459			5	Dense coral cover on top of reef (25-50% cover). End on western side of reef.
		808	7629422	323409			5	Large rock outcrops on edge of reef with 25-50% cover. Encrusting *Montipora* dominated. *Lobophyllia.*
		811			7629399	323401	5	End of dive.
Middle Mangrove Island								
ROVCOR44	7/05/2009	839	7625308	327337			3-1	West side of Middle Mangrove Island. Reef edge dominated by encrusting and tabulate *Montipora. Porites* bommies. Northerly direction. Short distance and coral cover rapidly reduces from 25%-<10%.
		853	7625385	327428			2	Reef cover on edge of platform rapidly decreases in places, resulting in difficulty in creating monitorable sites. Top of platform consists of broken coral rubble with macroalgae and algal turf. *Goniopora.*
		902	7625443	327470			2	Large *Porites* bommies on edge of reef.
		907	7625467	327472				50% coral cover on reef edge - *Porites,* tabular *Montipora* and *Acropora,* reducing in cover percentage rapidly as progress north.
		912			7625501	327513	3	End of dive
ROVCOR45	7/05/2009	928	7624887	326404			4	Further south of dive 44. Sand substrate with limestone outcrops, dominated by macroalgae. Occasional juvenile corals *(Turbinaria),* small *Porites* with <10% coral cover. Westerly heading.
		933	7624850	326333			4	End of dive

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROVCOR46	7/05/2009	950	7626333	325611			4	Feature NW of last dive, showing as 5m contour on chart. Limestone pavement dominated with macroalgae. End of dive.
ROVCOR47	7/05/2009	1017	7623867	328202			2	South of last dive - Macroalgae dominated limestone reef. Southeast direction.
		1019	7623867	328206			2-0	Isolated solitary large tabular *Acropora* on rock outcrop.
		1022			7623816	328234	2	End of dive - small patches of seagrass.

WGS-84, UTM Zone 50

(*) Northings and Eastings GDA Zone 50

C

Appendix C Description of Sites - August 2009

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV152	13/08/2009	810	7616243	317890	7616373		7.2	Flat substrate with gravel and sand veneer with shell fragments with some cobbles. Sparse biota 1-2%. Occasional bryozoans (lace corals) with fine cover and patches of foliose algae and occasional *Halimeda* sp. Sparse bioturbation.
ROV153	13/08/2009	838	7614441	319624	7614540	319704	7.2	Flat substrate. Silt and sand veneer with occasional shell fragments. Small patch of digitated sponges, gorgonian fans and colonial ascidians. Occasional bryozoan. Sparse bioturbation. Sparse foliose algae cover. Overall biota1-2%.
ROV154	13/08/2009	904	7613205	321318	7613225	321319	3.3	Flat substrate. Silty sand veneer with moderate small bioturbation with occasional larger holes. Sparse fine covering of tufting algae, with occasional foliose macroalgae (Phaeophycea). Overall biota 1-2%.
ROV155	13/08/2009	924	7613471	323642	761351	323646	4	Flat substrate. Sand and fine shell fragments. Sparse bioturbation. Sparse small tufting algae with occasional foliose macroalgae (Phaeophycea) cover 2-10%. Very sparse occasional seagrass *Halophila* sp.
ROV156	13/08/2009	943	7614010	326610	7614099	326613	4.2	Flat substrate. Silt and sand with sparse bioturbation and shell fragments. Sparse algae covered dead ark shells (*Trisidos* sp.). Sparse foliose macro algae with occasional *Halimeda* sp. Occasional bryozoan. Overall biota 2-10%.
ROV157	13/08/2009	1000	7614853	324303	7614946	324373	3	Flat substrate. Sand and fine shell fragments with occasional dead ark shells. Laminar, vase and digitated sponges, macroalgae (Rhodophyta, *Padina* sp.), bryozoans and small foliose algae. Patches of sparse *Halophila* sp. Overall algae cover 2-10%.
ROV158	13/08/2009	1021	7615850	322379	7615869	322428	6.1	Flat substrate. Fine sand. 10-25% coverage of fine foliose algae, with occasional *Halophila* sp. Sparse bioturbation.
ROV159	13/08/2009	1036	7618276	322322	7618309	322435	6	Flat substrate turning into slightly rippled bare sand. Sand and some silt with sparse bioturbation. Foliose algae 2-10%. Very occasional patches of *Halophila spinulosa* . Occasional hydroid.
ROV160	13/08/2009	1102	7619174	326809	7619155	326943	7	Flat sand and fine shell fragment substrate. Biota 10-25% dominated by various macroalgaes. Very occasional digitated sponge and occasional patches of sparse dead ark shells.
ROV161	13/08/2009	1129	7620725	325624	7620729	325662	3	Hard raised limestone feature ~1m height, dominated by macroalgae and occasional encrusting *Porites* . Sand and fine shell fragment surroundings, with patches of macroalgae. Overall biota 50-75% on hard substrate.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV162	13/08/2009	1158	7622099	323143	7622145	323343	7.5	Hard raised pavement with sand silt veneer. Sparse corals (2-10%) on hard substrate including young *Turbinaria,* tabular *Acropora,* occasional *Goniopora* , *Platygyra, Favia* and faviids. Very sparse algal presence. Digitated, laminar and vase sponges. Occasional colonial ascidians. Transect turns into broken hard substrate with sand and silt patches supporting sessile benthos of sea whips, digitated and laminar sponges and gorgonian fans (2-10%)
ROV163	13/08/2009	1220	7623861	322302	7623881	322435	10	Flat seabed with sand and silt component. Moderate bioturbation. Very sparse foliose algae - overall 1-2% biota. Occasional hydroid.
ROV164	13/08/2009	1315	7640842	333238	7640942	333301	5	Reef. Coral assemblages of 25-50% in places with coarse sand and shell fragment patches. *Porites, Acropora,* faviids, *Pocillopora, Montipora, Lobophyllia.* Broken coral rubble with algae. Overall 10-25% healthy hard coral.
ROV165	13/08/2009	1342	7641353	335596	7641420	335685	3.6	Coarse sand with small ripples. Very sparse seagrass including *Syringodium* sp. and *Halodule* sp. Head east - limestone pavement with sand veneer and rubble dominated by macroalgae (*Padina* sp., *Sargassum* sp. and *Dictyopteris* sp. 10-25% cover) with sparse seagrass including *Halophila* sp. Overall 2-10% seagrasses.
ROV166	13/08/2009	1421	7635838	334896	7635770	334987	8.9	Flat seabed with coarse sand and shell fragments. Foliose algae dominating biota, 10-25%, with sparse patches of seagrass including *Halophila decipiens* and *Halophila spinulosa* (2-10%).
ROV167	13/08/2009	1453	7635887	336255	7635912	336266	3.4	Sand veneered limestone pavement, macroalgae dominated (*Sargassum* sp, *Halimeda* sp., *Padina* sp.) 25-50% cover
ROV168	13/08/2009	1512	7633498	331702	7633488	331797	8	Rubble and coarse sand with fine shell fragment substrate over presumed limestone platform. Macroalgae dominated (10-25%) - including *Sargassum* sp. Occasional barrel and vase sponges and bryozoans. Small lump of exposed hard substrate supporting sparse corals including juvenile *Turbinaria, Pocillopora* and small *Porites* bommies (2-10% cover).
ROV169	13/08/2009	1540	7631917	331789	7631947	331786	5.4	Macroalgae dominated limestone platform (10-25%) with coarse sand pockets and shell fragments.
ROV170	13/08/2009	1622	7623605	326765	7623636	326749	7.5	Slightly rippled coarse sand with fine shell fragments. Very sparse seagrass (thin blades) 2-10% cover
ROV171	13/08/2009	1646	7620523	328158	7620499	328178	3.5	Macroalgae dominated limestone platform (10-25%) with coarse sand pockets and shell fragments. Sparse *Turbinaria, Pocillopora,* faviids and *Acropora* plates (1-2%). Occasional encrusting sponges.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV172	13/08/2009	1711	7616601	329933	7616566	329917	6.7	Coarse sand with large shell fragments on flat substrate. Sparse bioturbation. Fine foliose algae (2-10%) with occasional macroalgae. Very occasional bryozoan and *Halophila* sp.
ROV173	14/08/2009	740	7622877	312115	7622926	312040	13	Gentle undulating sand with silt patches and fine shell fragments with occasional rubble. Moderate bioturbation with some larger holes. Occasional patch of sea whips, colonial and solitary ascidians, bryozoans, crinoids and individual foliose macroalgae. Overall biota 1-2%.
ROV174	14/08/2009	804	7624320	313527	7624337	313471	13.9	Gently undulating coarse sand substrate with occasional patches of silt and fine shell fragments. Sparse to moderate bioturbation. Very occasional sea whip.
ROV175	14/08/2009	835	7628540	313312	7628558	313262	14.9	Flat substrate with sand veneer and silt patches with fine shell fragments. Occasional patches of dead ark shells. Occasional sea whip and sea pen. Sparse bioturbation and individual foliose algae. Biota <1%.
ROV176	14/08/2009	902	7630844	310852	7630889	310804	15.9	Flat substrate with sand veneer and silt patches with fine shell fragments. Occasional sea pens, sea whips, hydroids, one sea star, solitary ascidians and crinoids. Moderate bioturbation and sparse clumps of algae. Biota <1%.
ROV177	14/08/2009	928	7634591	312615	7634626	312608	15.5	Flat substrate with sand veneer and silt patches with fine shell fragments. Occasional patches of dead ark shells. Occasional sea whips and sea pens. One sea star. Very sparse bioturbation with one large (possible octopus) hole, and individual foliose algae. Biota <1%.
ROV178	14/08/2009	1024	7634500	316371	7634555	316445	11	Hard limestone exposed substrate and cobbles with coarse sand and large shell fragment rippled surrounds. Sparse individual corals including small *Porites* bommies and young vase and encrusting *Turbinaria.* Some large plates of encrusting *Montipora.* Coral cover 2-10%. Vase and laminar sponges, hydroids (<2%). Large school of yellow tailed fusiliers (*Caesio teres).* Large covering of zoanthids (*Palythoa* sp.).
ROV179	14/08/2009	1057	7631610	317459	7631676	317580	8.5	Reef. Very small outcrop. Very hard to find with sounder. Rises to 5m. Dominated by encrusting *Montipora.* Overall coral cover 10-25% (patches of 75-100%). Other corals include faviids, occasional *Acropora* plates, *Turbinaria* vase, soft coral (*Nephthea* sp.), colonial ascidians, gorgonian fans. Encrusting and digitated sponges. Not thought to have enough substrate present to establish coral transects, very hard to relocate.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV180	14/08/2009	1301	7640571	326075	7640608	326213	16.5	Flat substrate of coarse sand with fine shell fragments and patches of silt. Moderate bioturbation. Sparse gorgonian fans and digitated and laminar sponges, sea whips. 1-2%. Two six banded angel fish *(Pomacanthus sexstriatus)* . One unidentified large mollusc resembling a baler shell.
ROV181	14/08/2009	1325	7637180	322844	7637223	3222967	16.4	Flat substrate of coarse sand with fine shell fragments and patches of silt. Sparse bioturbation. One sea snake (Elapidae). Solitary small barrel sponge.
ROV182	14/08/2009	1355	7629929	322244	7629960	322342	12	Low mound of coarse sand and large shell fragments with numerous mounds of short foliose algae dead ark shells. Occasional patches of foliose macroalgae.
ROV183	14/08/2009	1440	7627577	316300	7627596	316347	12	Very small reef outcrop, very hard to locate with sounder. Long thin raised reef to 8m. Exposed surround of limestone mound 11m with fine algal cover and patches of coarse sand and shell fragments. Sparse vase, laminar and digitated sponges, occasional *Goniopora* and juvenile *Turbinaria.* Top of reef ridge 25-50% cover dominated by encrusting *Montipora,* with faviids, *Platygyra* , encrusting *Echinopora* and *Turbinaria* . Fish life included coral trout *(Plectropomus* sp.), surgeon fish, Chinaman fish (*Symphorus* sp.), stripy snapper (*Lutjanus carponotatus),* barracuda (*Sphyraena* sp.), banner fish *(Heniochus* sp.), yellow tailed fusiliers (*Caesio teres*). Deemed too small to establish coral transect on.
ROV184	14/08/2009	1511	7625823	316645	7625835	316638	12	Exposed small raised limestone feature with a few large (>3m) mostly healthy *Porites* bommies rising to 8m with one noticeably having 50% algal growth. Limestone ridges joining these bommies dominated by encrusting *Montipora,* with occasional encrusting *Echinopora.* Occasional small *Acropora* plate, juvenile *Turbinaria* and *Lobophyllia.* Coral cover 10-25%. Gorgonian fans, barrel and digitated sponges and hydroids. Surrounding area of exposed limestone pavement with thin algal veneer with occasional sponge and silt cover with biota cover of 2-10%. Fish included school of stripy snapper, surgeon fish (*Acanthurus* sp.), puffer fish (*Arothron* sp.), wrasses and yellow tailed fusiliers.
ROV185	14/08/2009	1559	7617629	325742	7617603	325717	3.2	Limestone pavement with patches of coarse sand and fine shell fragments. Dominated by macroalgae *(Dictyota* sp.) and occasional *Caulerpa* sp. with occasional juvenile *Turbinaria.* Hard corals <1%. Colonial ascidians, laminar and digitated sponges.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV186	14/08/2009	1635	7619652	316380	7629677	316354	8.2	Flat substrate with coarse sand and silt and large shell fragments. Sparse bioturbation and foliose algae (1-2%). Occasional sponge and colonial ascidians.
ROV187	14/08/2009	1655	7617954	315897	7617943	315817	4.5	Flat substrate with coarse sand veneer with shell fragments. Dominated by macroalgae (2-10%). Occasional colonial ascidian, crinoid and no noticeable bioturbation. Occasional barrel and laminar sponges, sea whips and gorgonian fans. One *Porites* bommie (1.5m) and very occasional *Turbinaria* (including *Turbinaria bifrons*) and one *Platygyra*.
ROV188	15/08/2009	730	7614941	310615	7614941	310565	4	Flat limestone pavement with coarse sand and moderate shell fragments. Dominated by macroalgae including *Dictyota* sp. 10-25% cover. Corals include juvenile *Turbinaria,* plating *Acropora,* small faviids and occasional small *Porites* bommies (1-2% cover). Occasional digitated, laminar and barrel sponges and gorgonian fans. Sparse hydroids. No obvious bioturbation.
ROV189	15/08/2009	755	7616703	307909	7616671	307627	5.6	Flat, coarse sand and fine shell fragments. Very sparse macroalgae (1-2%) including *Sargassum* sp. and *Caulerpa* sp. Sparse digitated sponges, sea whips, solitary ascidians and occasional large bioturbated hole. Small sparse individual *Porites* bommies with *Nephthea* sp.
ROV190	15/08/2009	844	7620738	314029	7620674	314075	3	Reef with occasional large *Porites* bommies (2-4m). Patches of 25-50% healthy hard coral cover, with overall 10-25%. Hard substrate predominantly covered with fine foliose algae. *Porites* dominant coral. Edge of hard substrate supports greatest coverage of corals including faviids, *Acropora* plates, encrusting *Montipora, Pavona, Turbinaria*. Fish life included Banner fish, surgeon fish and blue green damsels (Pomacentridae). Inside of edge rapidly reduces into sparse individual corals and algae dominated platform (10-25%) - a distance of 10-15m.
ROV191	15/08/2009	915	7620941	313778	7620937	313742	3	Reef edge, 9m to surface. Hard reef substrate dominated by algae, with occasional small corals (*Turbinaria* vases, *Acropora* plates and very occasional large *Porites* bommie. Overall 2-10% hard coral cover). Top of reef has small faviids, occasional *Pocillopora, Lobophyllia* and encrusting *Porites.*
ROV192	15/08/2009	949	7622688	310174	7622728	310154	11.2	Flat sand and silt substrate with moderate bioturbation. Very sparse biota (<1%) including occasional foliose turf algae and sea whip.
ROV193	15/08/2009	1008	7622179	309117	7622187	309150	12.2	Flat sand and silt substrate with moderate bioturbation. Sparse biota (1-2%) including occasional foliose algae, hydroids and sea whips and sea pens. Small patch of *Halophila spinulosa* (<1%).

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV194	15/08/2009	1028	7622303	306255	7622328	306300	12.8	Flat sand and silt substrate and fine shell fragments with moderate bioturbation. Sparse biota (<1%) including occasional foliose algae, hydroids and sea whips and sea pens. Small patch of *Halophila spinulosa* (<1%).
ROV195	15/08/2009	1040	7623748	306012	7623760	306033	14.5	Flat sand and silt substrate and fine shell fragments with moderate bioturbation. Sparse biota (<1%) including occasional foliose algae. Small patch of *Halophila spinulosa* (<1%). One sea snake.
ROV196	15/08/2009	1056	7625341	308683	7625410	308736	14.4	Flat sand and silt substrate and fine shell fragments with moderate bioturbation. Sparse biota (<1%) including occasional foliose algae, hydroids and sea whips. Small patch of *Halophila spinulosa* (<1%).
ROV197	15/08/2009	1117	7625433	304592	7625452	304673	15.9	Flat sand and silt substrate with moderate bioturbation and occasional large holes. Sparse biota (<1%) including occasional foliose algae, hydroids and small digitated sponges and sea pens.
ROV198	15/08/2009	1135	7628105	307176	7628135	307264	15.3	Flat sand and silt substrate and fine shell fragments with moderate bioturbation. Sparse biota (1-2%) including occasional foliose algae and sea pens. Small patch of *Halophila spinulosa* (<1%).
ROV199	15/08/2009	1155	7631060	307200	7631101	307339	16.7	Flat sand and silt substrate and fine shell fragments with sparse bioturbation. Occasional patch of dead ark shells. Sparse biota (<1%) including occasional foliose algae, sea whips and one digitated sponge.
ROV200	15/08/2009	1211	7633550	308631	7633581	308753	17.5	Flat coarse sand substrate with very sparse bioturbation. Sparse biota (1-2%) consisting of occasional short foliose algae..
ROV201	15/08/2009	1248	7636044	309295	7636080	309419	17.2	Slightly rippled coarse sand with shell fragments. Occasional gorgonian fans and laminar and digitated sponges (<1%).
ROV202	15/08/2009	1304	7638384	308101	7638416	308226	17.4	Flat coarse sand substrate with fine shell fragments and occasional larger fragments. One bryozoan.
ROV203	15/08/2009	1323	7637882	304982	7637917	305118	17.9	Flat coarse sand and fine shell substrate. No bioturbation. Very occasional epibenthic organism - digitated sponges and sea whips (<1%). Sparse strands of *Caulerpa* sp. (<1%)
ROV204	15/08/2009	1344	7637963	302241	7638017	302387	18.3	Slightly rippled coarse sand and fine shell fragment seabed. Occasional sea whips, digitated, barrel and laminar sponges and gorgonian fans. Overall biota 1-2%.
ROV205	15/08/2009	1412	7634520	301301	7634543	301371	18.9	Flat coarse sand and fine shell fragments. Varied sessile filter feeders including digitated and laminar sponges, gorgonian fans and sea whips. Occasional colonial ascidians. Overall biota1-2%.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV206	15/08/2009	1432	7634972	303330	7635014	303400	19	Flat coarse sand with small silt component and fine shell fragments. Very sparse epibenthic biota including one sea star and one digitated sponge (<1%).
ROV207	15/08/2009	1448	7634627	305474	7634659	305529	18.3	Flat coarse sand substrate with small silt component, large shell fragments and occasional patches of algae covered ark shells. Very sparse biota including sea whips, foliose algae and digitated sponges.
ROV208	15/08/2009	1503	7634643	307300	7634680	307354	18.3	Flat substrate with coarse sand and fine shell fragments. Dominated by tufting algae (2-10% coverage) with occasional sea whips. Very sparse bioturbation.
ROV209	15/08/2009	1525	7632550	306057	7632605	306112	18.9	Flat substrate with coarse sand and fine shell fragments. Sparse ark shells, digitated sponges, sea whips and gorgonian fans (1-2% cover).
ROV210	15/08/2009	1600	7624524	301473	7624595	301534	17	Flat substrate with fine sand and silt and fine shell fragments. Very sparse epibenthic biota (<1%). Solitary ascidians and sea whips. Sparse bioturbation.
ROV211	15/08/2009	1619	7625316	298733	7625406	298753	16.5	Flat substrate with fine sand and silt and moderate bioturbation. Very occasional foliose, solitary ascidians, crinoids and sea pens (<1%). One very small patch of *Halophila spinulosa* .
ROV212	15/08/2009	1640	7623081	298360	7623164	298411	16.2	Flat substrate with fine sand and silt with moderate bioturbation.
ROV213	16/08/2009	907	7607037	307943	7607049	307938	4.4	Flat substrate with fine sand and silt and coarse shell fragments. Occasional dense patches of thin bladed seagrass with occasional *Halophila spinulosa* and *H. decipiens* . Occasional *Halimeda* sp. and foliose macroalgae. Sparse bioturbation. Overall 2-10% biota cover
ROV214	16/08/2009	936	7609295	310536	7609318	310564	5	Undulating substrate with fine sand and silt and fine shell fragments. Sparse bioturbation. Short tufting algae with occasional foliose macroalgae and occasional patches of thin bladed seagrass *Halodule* sp and *Syringodium* sp and less occasionally *Halophila spinulosa* and *H. decipiens* . Seagrass 2-10% coverage.
ROV215	16/08/2009	1010	7612352	314624	7612377	314652	5.3	Undulating substrate with fine sand and silt and fine shell fragments. Sparse bioturbation with occasional larger hole. Short tufting algae. Seagrass cover 10-25% (with patches of 25-50%) of *Halophila spinulosa, H. decipiens* and unidentified thin bladed seagrass.
ROV216	16/08/2009	1040	7614546	317099	7614555	317099	5.1	Undulating substrate with fine sand and silt and fine shell fragments. Sparse bioturbation with occasional larger hole. Short tufting algae. Seagrass cover 2-10% of *Halophila decipiens.* Occasional bryozoans, hydroids.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV217	16/08/2009	1105	7617409	316828	7617425	316771	4	Rubble and coarse sand with fine shell fragment substrate over presumed limestone platform. Macroalgae dominated on exposed substrate (10-25%) - including *Sargassum* sp. and *Dictyota* sp. with occasional *Padina.* Occasional barrel and vase sponges. Isolated sparse small rock with encrusting coral and colonial ascidians with one soft coral (*Sarcophyton* sp.).
ROV218	16/08/2009	1140	7618749	306599	7618744	306614	4	Coarse sand and fine shell fragments on presumed limestone pavement. Algae dominated platform *(Sargassum* sp, *Halimeda* sp. *Asparagopsis* sp. and *Dictyota* sp.), with digitated sponges and sea whips. Occasional juvenile vase *Turbinaria,* tabulate *Acropora* and encrusting *Porites* (1-2%). Fish life including long nosed butterfly fish and parrot fish (Scaridae).
ROV219	16/08/2009	1205	7618533	302691	7618546	302708	11-6	Isolated reef outcrop up to 6m depth with surrounds in 11m of sand veneered pavement. Top of feature dominated with encrusting *Montipora* , *Turbinaria, Pocillopora,* individual small *Porites* bommies, *Lobophyllia* , faviids and *Nephthea* sp. (25-50% in places) with large isolated *Porites* bommie on edge (~3m diameter). Fish included Humbug damsels (Pomacentridae), yellow tailed fusiliers, stripy snapper, wrasses and banner fish
ROV220	16/08/2009	1219	7618513	302301	7618550	302346	11	"Sponge and fan garden" on limestone pavement with coarse sand and fine shell fragments. Numerous sea whips, gorgonian fans and digitated and laminar sponges. Crinoid and sea star. Biota 10-25% coverage.
ROV221	16/08/2009	1300	7616663	301050	7616693	301103	11	Flat substrate with sparse cobbles with coarse sand and fine shell fragments with occasional patches of silt. Occasional sea whips, digitated sponges, solitary and colonial ascidians and bryozoans. Overall biota 1-2% coverage.
ROV222	16/08/2009	1318	7615179	300092	7615195	300125	5-11	Outcrop next to shipping channel. Two distinct steep-faced outcrops, with 25-50% hard coral cover on top (~5m). Feature is ~20m in length. Dominant coral cover encrusting *Montipora,* with *Pocillopora,* tabular *Acropora,* faviids, juvenile *Turbinaria,* and *Tubastrea* sp. Numerous *Nephthea* sp. with occasional colonial ascidians, bryozoans and digitated sponges. Fish included cleaner wrasse, stripy snapper, striped damsels, banner fish, yellow tailed fusiliers, Lunar fusiliers (*Caesio lunaris*) and six striped angel fish. Surrounding substrate rubble with sand and silt with occasional juvenile *Turbinaria* and laminar sponges (1-2% coverage)

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV223	16/08/2009	1349	7617464	298328	7617490	298387	5	Outcrop at end of shipping channel. Two distinct steep-faced outcrops, with 50-75% hard coral cover on top (~5m). Feature is ~20m in length. Dominant coral cover encrusting *Montipora* with faviids, *Mycedium* sp. and juvenile *Turbinaria.* Numerous *Nephthea* sp. with occasional digitated sponges. Fish included cleaner wrasse, stripy snapper, striped damsels, banner fish, yellow tailed fusiliers and Moses perch (*Lutjanus russelli).* One large spotted eagle ray *(Aetobatus narinari*). Surrounding substrate rubble with sand and silt with occasional juvenile *Turbinaria* and laminar sponges (1-2% coverage)
ROV224	16/08/2009	1406	7617296	297362	7617347	297416	13.5	Flat substrate with coarse sand and silt and fine shell fragments. Sparse epibenthic fauna including solitary ascidians, sea star and very sparse patches of *Halophila spinulosa* (<1% coverage).
ROV225	16/08/2009	1432	7618815	297633	7618877	297708	14	Flat substrate with coarse sand and fine shell fragments. Occasional foliose macroalgae. Occasional hydroids, crinoids, digitated sponges, barrel sponges and sea whips. One coral trout (*Plectropomus* sp). 14:36 - good shot. Sparse patches of *Halophila spinulosa*. Numerous unidentified tube worms (Polychaeta). Overall 1-2% biota.
ROV226	16/08/2009	1450	7620827	298034	7620901	298130	15.1	Flat substrate with sand and silt and fine shell fragments. Numerous tube worms and one sea star. Occasional colonial and solitary ascidians, gorgonian fans and digitated sponges. Sparse bioturbation. 1-2% coverage.
ROV227	16/08/2009	1506	7620614	295981	7620652	296097	14	Flat substrate with coarse sand and silt with fine shell fragments. Large group of sea urchins (Echinodea) and numerous sand dollars (*Clypeaster* sp.). Occasional mushroom coral (*Fungia* sp.). Occasional digitated sponges and tube worms. Overall biota 1-2%.
ROV228	16/08/2009	1528	7622287	293288	7622323	293447	11	Flat substrate of coarse sand and fines shell fragments. Sparse covering of tufting macroalgae with occasional patch of *Halophila decipiens* and *H. spinulosa* of 2-10% cover. Very occasional sand dollars. Sparse bioturbation. Overall biota 1-2%.
ROV229	16/08/2009	1551	7621092	289391	7621172	289562	11	Flat substrate with rippled coarse sand and fine shell fragments. Patchy *Halophila* sp. cover (2-10%) in places. Very occasional colonial ascidians, bryozoans, sea whips and hydroids. Overall biota 1-2%.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV230	16/08/2009	1624	7615110	293266	7615180	293386	10.4	Limestone pavement with patches of coarse sand and fine shell fragments. Occasional juvenile *Turbinaria* and small *Porites* bommies with foliose macroalgae (*Asparagopsis* sp.). Hard corals 2-10%. Occasional very small (3-4m) outcrop with encrusting *Montipora.* Colonial ascidians, gorgonian fans, laminar, barrel and digitated sponges. Diverse fish life including Banner fish, butterfly fish (*Chaetodon* sp.), surgeon fish, snapper (*Lutjanus* sp.), coral trout, barramundi cod (*Chromileptes altivelis*) and six banded angelfish. One sea snake. Overall biota 2-10%.
ROV231	16/08/2009	1649	7614987	295389	7615084	295478	11.7	"Sponge and fan garden" on presumed limestone pavement with coarse sand and fine shell fragment veneer. Numerous sea whips, gorgonian fans and digitated and laminar sponges. Crinoid and sea star. Butterfly fish. Biota 2-10% coverage. Patches of flat substrate with *Asparagopsis* sp. dominant. One ray.
ROV232	17/08/2009	718	7608730	304646	7608779	304621	9.5	Flat substrate with fine sand and silt. Sparse to moderate bioturbation with occasional larger hole, occasional macroalgae, one bryozoan. Biota <1%.
ROV233	17/08/2009	748	7611507	299815	7611554	299742	12	Flat substrate with fine sand and silt with moderate bioturbation. Very occasional hydroid, colonial ascidians and sparse tufting algae with patches of 2-10%. Sparse *Halophila decipiens,* <1% cover. Overall biota 1-2%.
ROV234	17/08/2009	805	7612231	298644	7612300	298655	12	Flat substrate of fine sand and silt with fine shell fragments. Numerous unidentified tube worms, occasional sponges and bryozoans. Sparse bioturbation. Sparse algae including *Udotea* sp. 1-2% biota.
ROV235	17/08/2009	822	7611335	297257	7611367	297198	12	Flat substrate with occasional large holes and moderate bioturbation of fine sand and silt and fine shell fragments. Occasional hydroids sparse tufting foliose macroalgae and very sparse *Halophila spinulosa*. Overall biota <1%.
ROV236	17/08/2009	835	7610767	298298	7610784	298236	12	Flat substrate with sparse bioturbation of fine sand and silt and fine shell fragments. Sparse tufting foliose macroalgae and very sparse *Halophila spinulosa*. Overall biota <1%. Sparse dead ark shell patches.
ROV237	17/08/2009	854	7610106	299018	7610128	298954	8-3	Reef. Large outcrop with east-west orientation on sand and silt pavement. Outcrop has 50-75% healthy hard coral cover, dominated by encrusting *Montipora,* with tabular and digitated *Acropora* sub dominant. *Platygyra* and faviid also present. Occasional digitated sponges and gorgonian fans. Fish include striped damsels, yellow tailed fusiliers, banner fish, coral trout and stripy snapper.

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV238	17/08/2009	933	7608551	300951	7608503	300940	8.5	Flat substrate with fine sand and silt. Occasional digitated sponges, colonial and solitary ascidians, laminar sponges, sea whip, hydroids and crinoids. Sparse dead ark shells. Sparse to moderate bioturbation. Overall biota <1%.
ROV239	17/08/2009	946	7608705	300777	7608646	300686	5.6	Flat pavement with rubble and broken coral with silt layer and patches of sand and silt. Sparse epibenthic biota, including sponges, *Dictyota* sp., *Asparagopsis* sp., *Padina* sp., *Halimeda* sp., bryozoans, solitary ascidians, one *Sarcophyton* sp. and zoanthid.
ROV240	17/08/2009	1000	7608868	300410	7608819	300339	5-2	Reef. Outcrops dominated by *Acropora* plates, with subdominant encrusting *Montipora.* Occasional large *Porites* bommies, *Platygyra,* faviids, *Lobophyllia.* Coral cover 50-75% in places. Fish include Yellow tailed fusiliers and striped damsels. Transect ends on rippled sand at 6m with sparse covering of *Halophila decipiens*.
ROV241	17/08/2009	1020	7608844	301096	7608851	301080	7.6	Flat substrate of sand and silt with sparse to moderate bioturbation. Occasional digitated sponges. Overall biota <1%.
ROV242	17/08/2009	1041	7606548	297114	7606487	297009	8	Flat substrate with sand and silt and fine shell fragments with patches of rubble. Sparse to moderate bioturbation. Patch of filter feeding biota including numerous gorgonian fans, sea whips and colonial ascidians before turning into bare substrate. Overall biota 1-2%.
ROV243	17/08/2009	1055	7606362	297183	7606312	297067	7.8	Flat substrate with sand and silt and fine shell fragments with patches of rubble on presumed pavement. Sparse to moderate bioturbation. Sparse filter feeding biota including gorgonian fans, sea whips and colonial ascidians with occasional sponges. Overall biota 1-2%. One large *Porites* bommie (3-4m wide), with puffer fish and damsel fish, surrounded by a number of small limestone lumps supporting filter feeders.
ROV244	17/08/2009	1125	7603558	300240	7603517	300234	4	Sand and silt over rubble and broken coral pavement. Occasional dead ark shell. Sparse corals including *Turbinaria* plates both large and juvenile, encrusting *Montipora* sp. and one *Euphyllia* sp. (1-2% cover). Occasional sponges and hydroids.
ROV245	17/08/2009	1140	7603543	300546	7603514	300487	4.4	Sand and silt over rubble and broken coral pavement. Occasional juvenile *Turbinaria,* digitated sponges and hydroids. Isolated outcrop with encrusting coral. Overall biota 1-2%.
ROV246	17/08/2009	1200	7602341	298746	7602304	298739	3.9	Flat substrate with sand and silt with occasional shell fragments. Very occasional *Udotea* sp. and bryozoans. Biota <1%. (Very bad visibility)
ROV247	17/08/2009	1216	7601740	296795	7601718	296783	4.2	Presumed sand and silt (very bad visibility)

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV248	17/08/2009	1313	7603958	295267	7603961	295222	6.5	Slightly rippled fine sand and silt substrate with fine shell fragments. Very sparse bioturbation. Sparse bryozoans. Biota <1%.
ROV249	17/08/2009	1327	7605124	296662	7605102	296632	6.9	Flat substrate with fine sand and silt with fine shell fragments. Very sparse epibenthic biota including bryozoans and tufting algae. Biota <1%.
ROV250	17/08/2009	1338	7605858	297809	7605821	297794	6.6	Flat substrate with fine sand and silt with fine shell fragments. Very sparse epibenthic biota including numerous bryozoans and tufting algae. Biota <1%.
ROV251	17/08/2009	1350	7605677	298317	7605641	298290	6	Flat substrate with fine sand and silt with fine shell fragments. Occasional macroalgae including *Udotea* sp. Solitary ascidians, bryozoans, sponges and occasional large hole. Sparse dead ark shells. Biota <1%.
ROV252	17/08/2009	1404	7604729	297480	7604694	297501	6.4	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae, including *Udotea* sp. Biota <1%.
ROV253	17/08/2009	1414	7604182	296531	7604133	296514	6.1	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae. Biota <1%.
ROV254	17/08/2009	1427	7603454	298031	7603445	298005	5	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae. Biota <1%.
ROV255	17/08/2009	1439	7602872	298161	7602865	298157	4.7	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans, one sea pen and macroalgae, including *Udotea* sp. Biota 1-2%.
ROV256	17/08/2009	1452	7603466	298552	7603426	298575	5.1	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae including *Udotea* sp. and sparse dead ark shells. Biota 1-2% coverage.
ROV257	17/08/2009	1505	7603184	298992	7603196	299016	4.6	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae, including *Udotea* sp. Biota <1%.
ROV258	17/08/2009	1516	7603821	299189	7603778	299205	4.9	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae, including *Udotea* sp. Biota <1%.
ROV259	17/08/2009	1531	7603863	299917	7603869	299900	4.5-1.5	Reef. Steep walled outcrop with a number of large *Porites* bommies and dominated by encrusting *Montipora,* branching *Acropora, Lobophyllia, Goniopora,* faviids and *Platygyra.* Difficult to assess extent of reef due to reduced visibility ~30m in length. One outcrop up to 2m from surface. One small *Porites* bommie showing bleaching. Overall coral cover 25-50%.
ROV260	17/08/2009	1601	7604195	299540	7604203	299575	5.2	Flat substrate with sand and silt with very sparse bioturbation. Occasional bryozoans and macroalgae including *Udotea* sp. and *Sargassum* sp. and sparse dead ark shells. Biota 1-2% coverage.

(*) Northings and Eastings GDA Zone 50

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Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV261	17/08/2009	1619	7604393	300078	7604351	300064	4.5-2	Steep walled small outcrops on presumed limestone pavement with encrusting corals surrounded by broken coral and sand and silt. Dominated by tufting and macroalgae (*Dictyota* sp.). Hard corals include *Porites* bommies, encrusting *Montipora,* branching *Acropora,* faviids, *Goniopora, Turbinaria* vases and *Platygyra.* Overall coral cover 2-10% with patches of 10-25%.
ROV262	17/08/2009	1652	7605739	302437	7605761	302473	4.6	Flat substrate with fine sand and silt with patches of coarse shell fragments. Moderate bioturbation. Occasional patch of *Halophila decipiens* and *H. spinulosa* (1-2% cover) and *Udotea* sp.
ROV263	18/08/2009	742	7603678	289468	7603723	289505	8	Flat substrate with fine sand and silt with fine shell fragments and lesser rubble component on presumed pavement. Biota includes hydroids, digitated sponges, gorgonian fans, crinoids, sea star, bryozoans and abundant sea pens. Sparse bioturbation. Occasional outcrop with epibenthic filter feeding communities present. Overall biota 2-10%.
ROV264	18/08/2009	805	7602490	292596	7602514	292584	6.5	Slightly rippled fine sand and silt substrate with fine shell fragments. Very sparse bioturbation. Sparse hydroids. Biota <1%. (low visibility)
ROV265	18/08/2009	819	7601927	292467	7602010	292461	5	Pavement with rubble and fine sand and silts. Filter feeding community consisting of occasional sponges, gorgonian fans, crinoids, bryozoans and colonial ascidians with occasional macroalgae. Biota coverage 2-10%.
ROV266	18/08/2009	834	7602034	292766	7602095	292757	4.8	Pavement with rubble and fine sand and silts. Filter feeding community consisting of occasional sponges, gorgonian fans, crinoids, bryozoans and colonial ascidians with occasional macroalgae. Biota coverage 2-10%.
ROV267	18/08/2009	850	7602073	292957	7602111	292934	5.5	Pavement with rubble and fine sand and silts. Filter feeding community consisting of occasional sponges, gorgonian fans, crinoids, bryozoans and colonial ascidians with occasional macroalgae. Very occasional juvenile *Turbinaria.* Biota coverage 2-10%.
ROV268	18/08/2009	909	7602171	293620	7602165	293617	6	Pavement with rubble and fine sand and silts. Filter feeding community consisting of occasional sponges, gorgonian fans, crinoids, bryozoans and colonial ascidians with occasional macroalgae. Very occasional juvenile *Turbinaria.* Biota coverage 2-10%.
ROV269	18/08/2009	943	7601787	287547	7601798	287552	5.7	Slightly rippled fine sand and silt substrate with fine shell fragments. Very sparse bioturbation. Sparse macroalgae including *Gracilaria* sp. One possible basket star. Biota <1%.
ROV270	18/08/2009	1005	7600558	285788	7600606	285770	3.8	Slightly rippled substrate with very fine sand and silts. Very bad visibility. Occasional macroalgae. Overall biota <1%

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV271	18/08/2009	1033	7606222	279951	7606241	279996	6	Reef. Isolated outcrop with 10-25% hard coral cover dominated by encrusting *Montipora.* Also encrusting *Porites,* faviids, *Turbinaria, Acropora, Goniopora, Pavona, Platygyra,* and *Nephthea* sp. Hydroids, sea whips, digitated sponges present with one sea cucumber (Cucumaridae). Fish include stripy snapper, blue *Chromis* sp., wrasses, humbug damsel, banner fish, yellow tailed fusiliers and lunar fusiliers
ROV272	18/08/2009	1054	7607307	282228	7607387	282155	5.5	Rippled coarse sand. One sea pen. No observable bioturbation. Dense meadow (~25m) of *Halophila spinulosa* and *H. decipiens* of 25-50%. Transect develops into bare substrate before returning to dense patches. Possible dugong grazing paths in substrate.
ROV273	18/08/2009	1117	7608755	283533	7608926	283435	5.5	Rippled coarse sand. Very large and dense meadow of *Halophila spinulosa* and possible *H. ovalis* of 25-50%. Transect develops into bare substrate before returning to dense patches. Possible dugong grazing paths in substrate. One large sea star.
ROV274	18/08/2009	1138	7607505	284231	7607537	284212	9.5	Flat coarse sand and shell fragments. Sparse foliose macroalgae (2-10% coverage).
ROV275	18/08/2009	1159	7607989	285739	7608035	285726	10.5	Flat substrate with coarse sand and silt with fine shell fragments. Occasional sea whips, digitated and barrel sponges, colonial ascidian, crinoids and gorgonian fans. Sparse *Halophila spinulosa* patches. Sparse bioturbation. Overall biota 1-2%.
ROV276	18/08/2009	1420	7615123	286828	7615134	286807	13.6	Slightly rippled coarse sand and fine shell fragments. Occasional sea whips. Sparse patch of *Halophila sp.* Overall biota <1%.
ROV277	18/08/2009	1442	7617562	283523	7617535	283444	14.1	Flat substrate with coarse sand and shell fragments. Occasional barrel and digitated sponges, sea whips, gorgonians and solitary ascidian. Sparse patches of *Halophila* sp. Biota 1-2%.
ROV278	18/08/2009	1520	7619052	276409	7619060	276280	13.8	Slightly rippled sand with occasional shell fragments. Sparse filter feeding assemblage including sea whips and laminar and digitated sponges. 1-2% biota.
ROV279	18/08/2009	1542	7621256	279430	7621276	279359	10.5	Algae dominated pavement with rubble with patches of fine sand. *Padina* sp. and *Halimeda* sp. predominant. Sea whips, digitated, barrel and laminar sponges. Occasional *Turbinaria* vases, *Goniopora* sp. Schools of blue *Chromis* sp. and striped trevally (Carangidae) . Overall biota 2-10%.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV280	18/08/2009	1614	7618545	286445	7618496	286345	13.5	Flat substrate of sand. Fine ripples. Sparse to moderate cover of *Halophila* sp. Occasional solitary ascidians and prolific bryozoans (16:22). Overall biota 2-10%.
ROV281	18/08/2009	1630	7618547	288094	7618518	288124	13	Flat substrate coarse sand and shell fragments. Sparse *Halophila* sp. Occasional hydroids. No observed bioturbation.
ROV282	18/08/2009	1647	7613551	288916	7613544	288918	10	Rippled sand substrate with fine shell fragments. Individual solitary ascidian and very sparse isolated patches of *Halophila* sp. Overall biota <1%
ROV283	19/08/2009	731	7630711	302887	7630724	302972	11.3	Pavement with rubble and patches of sand and shell fragments. Very sparse hard corals including juvenile *Turbinaria* (1-2%). Occasional barrel and laminar sponges, sea whips, gorgonian fans and fish including butterfly fish and goat fish (Mullidae). Two sea cucumbers (Holothurians). Overall biota 2-10%
ROV284	19/08/2009	744	7631003	302769	7630995	302728	7	Pavement dominated by macroalgae (*Asparagopsis* sp. and occasional *Gracilaria* sp.) with patches of coarse sand. Occasional juvenile *Turbinaria* vase coral and *Pocillopora* (1-2% cover). Occasional barrel sponge. Fish include angel fish, blue *Chromis* and damsel fish. Sea urchin (*Diadema* sp.)
ROV285	19/08/2009	831	7624102	291808	7624072	291785	3.4	Exposed bare pavement with rippled coarse sand patches and shell fragments. Very fine covering of algae on pavement. No macroalgae present. 1-2% corals. Occasional large outcrop with *Pocillopora* and few *Porites* bommies. Stripy snapper, Moses perch and humbug damsels.
ROV286	19/08/2009	837	7624072	291785	7624045	291759	7.5	Flat coarse sand substrate with occasional individual branching *Acropora,* and individual small *Porites* bommies (1-2% cover). Develops into bare rippled sand.
ROV287	19/08/2009	839	7624045	291759	7623984	291734	8.2	Sparse patch of *Halophila* sp. and tufting macroalgae (2-10%) in coarse sand and shell fragments.
ROV288	19/08/2009	848	7623358	290987	7623363	290997	11.7	Flat substrate with coarse sand and sparse silt component. Occasional seagrass *(Halophila* sp) and *Caulerpa* sp. Overall biota 1-2%.
ROV289	19/08/2009	901	7624135	289223	7624127	289191	7	Flat substrate with corase sand and shell fragments with small individual coral outcrops, rapidly reducing to flat substrate with sparse isolated outcrops with very sparse coral cover. Individual small sparse *Porites* bommies.

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV290	19/08/2009	904	7624127	289191	7624049	289166	7.7	Rubble and broken corals with fine algae cover with occasional *Gracillaria* sp. Blue *Chromis* sp. Occasional small *Porites* bommies. Coral cover on outcrops 2-10%.
ROV291	19/08/2009	907	7624049	289166	7624043	289173	8.6	Flat substrate with coarse sand and shell fragments. Very sparse *Halophila* sp.
ROV292	19/08/2009	915	7624016	288492	7623986	288484	5.7	Flat pavement algae dominated. Occasional outcrop with 2-10% coral cover. Small individual corals including *Pocillopora* and *Turbinaria.* Occasional digitated and laminar sponge with solitary ascidians.
ROV293	19/08/2009	929	7624585	286705	7624542	286656	4.2	Pavement dominated with macroalgae, including *Asparagopsis* sp and *Sargassum* sp. Occasional patch of rippled coarse sand.
ROV294	19/08/2009	944	7624774	285657	7624803	285597	5.6	Undulating coarse sand and fine shell fragments on presumed pavement with 25-50% macroalgae cover including *Sargassum* sp. and *Asparagopsis* sp.
ROV295	19/08/2009	954	7625757	284463	7625783	284440	11.5	Rippled coarse sand with occasional shell fragments.
ROV296	19/08/2009	1009	7627324	286403	7627345	286306	4.4	Algae dominated (presumed) pavement with patches of coarse sand and shell fragments. *Sargassum* sp., *Asparagopsis* sp. and encrusting sponges. 25-50% algae cover.
ROV297	19/08/2009	1021	7627812	226863	7627898	286853	4.4	Algae dominated (presumed) pavement with patches of coarse sand and shell
ROV298	19/08/2009	1036	7629168	287945	7629196	287778	3.9	Algae dominated large rippled coarse sand. Algae include *Sargassum* sp. 25-50% coverage. Isolated exposed pavement with two painted rock lobsters (*Panulirus* sp). Occasional *Halimeda* sp, encrusting sponges and blue *Chromis* sp.
ROV299	19/08/2009		7629196	287778	7629198	287696	5.4	Limestone exposed edge with accompanying coral fish and ravine of coarse sand and shell fragments. Continues with algae dominated platform.
ROV300	19/08/2009		7629198	287696	7629170	287494	8.3	Algae dominated pavement (25-50% *Halimeda* sp. and *Sargassum* sp.). Occasional encrusting coral.
ROV301	19/08/2009	1054	7629170	287494	7629170	287494	12	Rippled coarse sand and fine shell fragments - edge of algae dominated platform

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV302	19/08/2009	1116	7632449	293473	7632345	293279	7	Rippled coarse sand with limestone outcrops supporting *Turbinaria* vases, encrusting *Porites* and *Acropora* plates with various small schooling reef fish. Occasional macroalgae and encrusting sponges. Coral 1-2%. Transect turns into exposed algae dominated pavement (including *Halimeda* sp.) with colonial ascidians. Occasional *Platygyra.*
ROV303	19/08/2009	1134	7631273	293343	7631268	293215	10.8	Algae dominated platform (including *Caulerpa* sp. and *Dictyota* sp.) turning into patches of coarse sand with occasional macroalgae. 10-25% coverage.
ROV304	19/08/2009		7631268	293215	7631239	293124	12.5	Coarse sand and occasional macroalgae (2-10%)
ROV305	19/08/2009	1159	7629532	290704	7629475	290561	3.1	Rippled sand with fine shell fragments. Occasional patch of macroalgae (2-10%).
ROV306	19/08/2009	1217	7627859	289626	7627828	289635	5	Rippled coarse sand with fine shell fragments. Occasional macroalgae including *Sargassum* sp. (1-2%)
ROV307	19/08/2009	1237	7627760	293695	7627863	293665	3	Algae dominated platform including *Sargassum* sp. and *Dictyota* sp. 50-75% cover. Individual corals including *Pocillopora* , small *Acropora* plates, small *Porites* bommies.
ROV308	19/08/2009		7627863	293665	7627863	293654	4	Sparse platform with *Asparagopsis* sp., small encrusting corals. Biota 2-10%.
ROV309	19/08/2009	1245	7627855	293654	7627920	293612	4.3	Pavement with patches of sparse corals 2-10% coverage. Isolated outcrop with numerous *Turbinaria* plates, small *Porites* bommies, and faviids (2-10%)
ROV310	19/08/2009	1248	7627920	293612	7628051	293564	5	Limestone pavement mixed with corals on outcrops (10-25%) with macroalgae and patches of sand.
ROV311	19/08/2009	1253	7628051	293564	7628087	293549	5.9	Algae dominated pavement *(Asparagopsis* sp.) (10-25%)
ROV312	19/08/2009	1255	7628087	293549	7628094	293542	8.4	Flat substrate of coarse sand and broken corals and shell fragments with occasional small patches of exposed pavement.
ROV313	19/08/2009	1409	7642531	315570	7642626	315875	4.6	Sand and fine shell fragment and coral rubble substrate over presumed reef outcrop. Occasional pavement outcrops supporting macroalgae *(Asparagopsis* sp.) (2-10%) and sparse corals including *Porites,* faviids, tabular *Acropora, Lobophyllia* and *Turbinaria* (2-10% in patches) with occasional *Porites* bommies. One coral encrusted star picket. Fish include surgeon fish, blue *Chromis* sp., wrasses, six banded angel fish and striped damsels. Algae becomes less dominant from 5m and deeper. Edge of reef at end of transect.
ROV314	19/08/2009	1454	7640697	307006	7640592	306883	5.7	Algae dominated on outcrops on presumed platform with patches of fine sand

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV315	19/08/2009	1459	7640592	306883	7640531	306901	7.8	Rippled sand with macroalgae (25-50%). No observable pavement. School of striped trevally.
ROV316	19/08/2009	1527	7639486	295817	7639491	295767	18.5	Flat substrate with coarse sand and fine shell fragments. Occasional filter feeders, digitated and laminar sponges, sea whips and crionoids. 1-2% coverage.
ROV317	19/08/2009	1549	7637780	289370	7637740	289502	12.7	Pavement with rubble and coarse sand. Filter feeder communities in dense patches with numerous sea whips, gorgonians and laminar sponges (10-25%). *Padina* sp. and *Halimeda* sp. also present. Coarse sand gullies between patches. Occasional *Turbinaria* vase. Filter feeders start to disappear at 15m on eastern side of shoal.
ROV318	19/08/2009	1613	7640831	291496	7640802	291579	10.4	Pavement with short tufting algae, with occasional filter feeders including sea whips, gorgonian fans and sponges. Occasional gullies of coarse sand. Occasional small *Nephthea* sp. Overall biota 2-10% on shallower area. Deeper eastern area (15m) has rippled sand with patches of 2-10% filter feeders, reducing to bare rippled sand at end of transect.
ROV319	19/08/2009	1636	7645753	293703	7645698	293810	13.3	Flat substrate with patches of exposed pavement and coarse sand. Dominant biota *Turbinaria* vases (2-10% in patches) with short tufting algae on pavement areas. Pavement disappears at 16m on eastern side of shoal - sand with rubble and sparse biota including sea whips, laminar sponges, gorgonian fans and sparse encrusting corals, before turning into sand at end of transect with sparse filter feeders.
ROV320	19/08/2009	1654	7643596	296695	7643566	296750	8	Rippled coarse sand. No observed biota.
ROV321	18/08/2009	1308	7609471	289063	7609456	289061	10.8	Existing pipeline survey, western end. Exposed pipe with ascidians, crinoids, sponges and macroalgae. Surrounding substrate fine sand and shell fragments (289070 7609465 given position of pipeline)
ROV322	18/08/2009	1319	7609313	289156	7609277	289115	10.8	Flat substrate with sand and silt patches with fine shell fragments. 1-2% biota of tufting algae with occasional patch of *Halophila spinulosa*. One urchin. (Proposed borehole position MU016 289160, 7609300)

(*) Northings and Eastings GDA Zone 50

Site	Date	Time	Transect start (*)		Transect finish (*)		Depth (m)	Site Description
ROV323	18/08/2009	1329	7609592	289292	7609584	289211	10.8	Existing pipeline survey, central section. Bare substrate of fine sand and silt patches with fine shell fragments. Sparse bioturbation. Occasional hydroid. Biota <1%. No observed pipeline. (Given position of pipeline - 7609585, 289290)
ROV324	18/08/2009	1348	7609726	289518	7609711	289491	10.8	Existing pipeline survey, eastern end. Bare substrate of fine sand and silt patches with fine shell fragments. Sparse bioturbation. Occasional hydroids, urchins, sea stars and digitated sponges. Biota <1%. Short section of pipeline exposed with hydroids and sponges. (Given position of pipeline - 289508 7609704)
ROV325	18/08/2009	1402	7609905	289378	7609896	289381	10.8	Flat substrate with coarse sand and shell fragments. Occasional macroalgae (2-10%). (Proposed borehole position MU014 289390, 7609910)

(*) Northings and Eastings GDA Zone 50

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Appendix D Subtidal Habitat Surveys

D.1 ROV Analysis Methods

D.1.1 ROV Surveys

A total of three ROV surveys were undertaken in the nearshore (<20 m) areas from December 2008 to August 2009 to gather data over a large spatial area, focusing on the proposed marine infrastructure footprint and surrounding reefs, shoals and islands. The spatial extent of the surveys included the footprint for dredging of navigation channel and spoil disposal, dredging of MOF and trenching and installation of submarine pipeline; as well as adjacent areas of potential impact. The ROV surveys captured images of both seafloor substrate and epibiota. Figure D-1 presents the location of all sites sampled.

ROV summer survey

Conducted in December 2008, 150 sites were visited in the Project area consisting of 10 minutes coverage on a tethered (100 m radius from vessel) ROV at specific GPS points. GPS coordinates were recorded at the start and finish of recording for each site. Focus was on navigation channel, pipeline and disposal ground options and contiguous potential impact areas.

ROV coral survey

Conducted in May 2009, 46 sites were recorded in the Project area consisting of 10 minutes coverage on tethered ROV at specific GPS points. Focus was on hard substrate areas (reef, bommies, shoals, islands) looking for suitable areas to establish coral dive transects for impact monitoring using Before After Control Impact (BACI) design.

ROV winter survey

Conducted in August 2009, 155 sites were recorded in the Project area consisting of 10 minutes coverage on tethered ROV at predetermined GPS points. Focus of the survey was on:

- "Ground-truthing" gaps in potential hard substratum areas (reef, bommies, shoals, islands) derived from Admiralty chart and URS interpolated nearshore bathymetry surface map.
- Revisiting soft sediment BPPH areas identified in the summer ROV survey to look for seasonal trends;
- Far field areas and new proposed offshore disposal sites were also surveyed.

D.2 ROV Analysis Methodology

The analysis methodology was the same for all subtidal ROV surveys, which feeds into the same habitat mapping model to keep the process consistent and comparable between surveys.

ROV seabed features derived from analysis of ROV footage included substrate, dominant biota and percentage cover. The same technique was used to analyse all ROV surveys, however the coral ROV survey footage was analysed by University of Western Australia (UWA) and not URS personnel. This assisted in cross-validating the method and precision of the ROV footage analysis. Footage was analysed for each transect using a sampling frame and approximate 30 second intervals between each sampling frame to provide replication, by sub-sampling, and generate confidence intervals for each site x biota. The ROV footage was analysed following the development of a classification matrix (see Table D 1).

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Subtidal Habitats

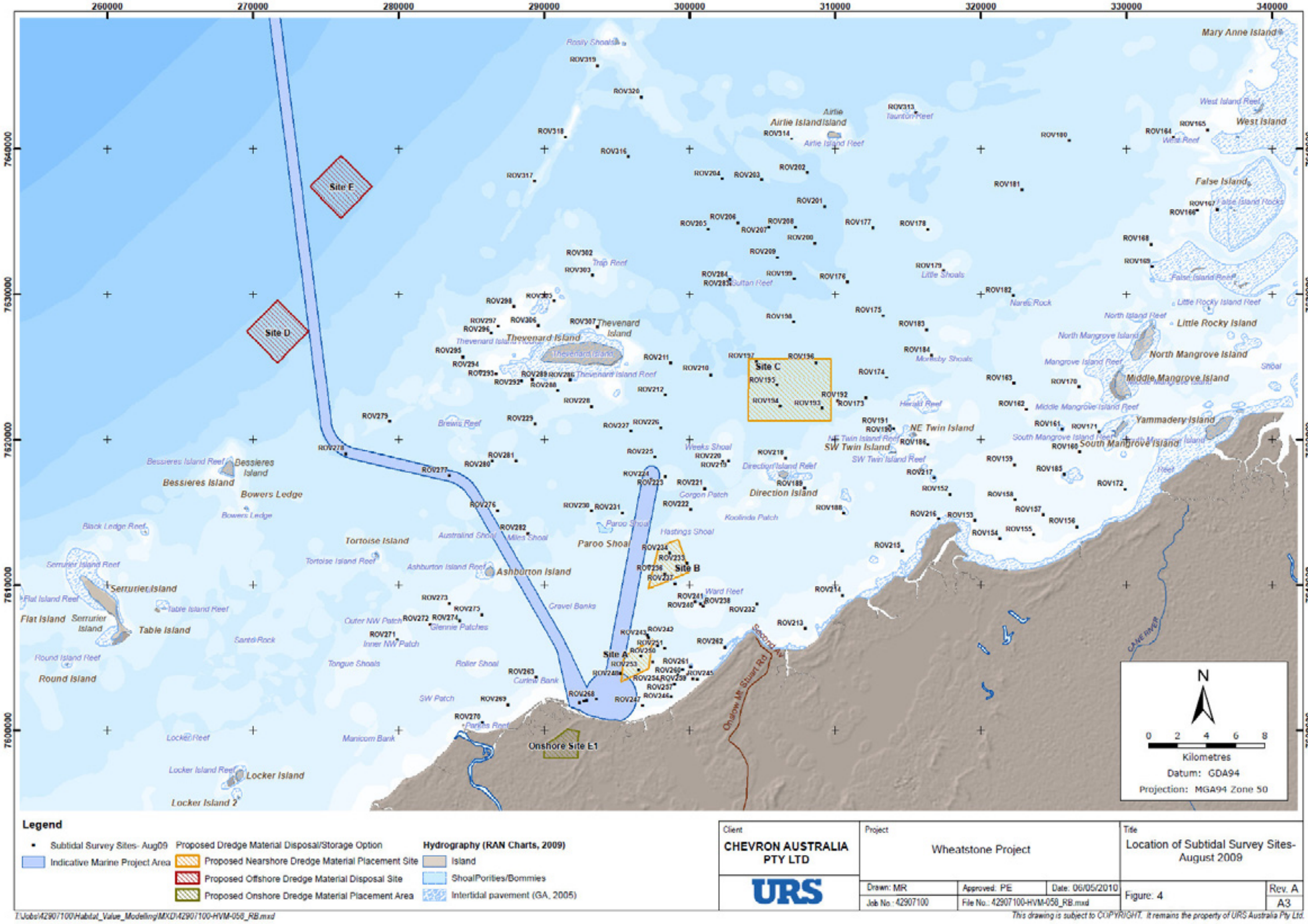

Figure D-1 ROV survey locations and ecosystem units (ECU) management boundaries proposed for the project.

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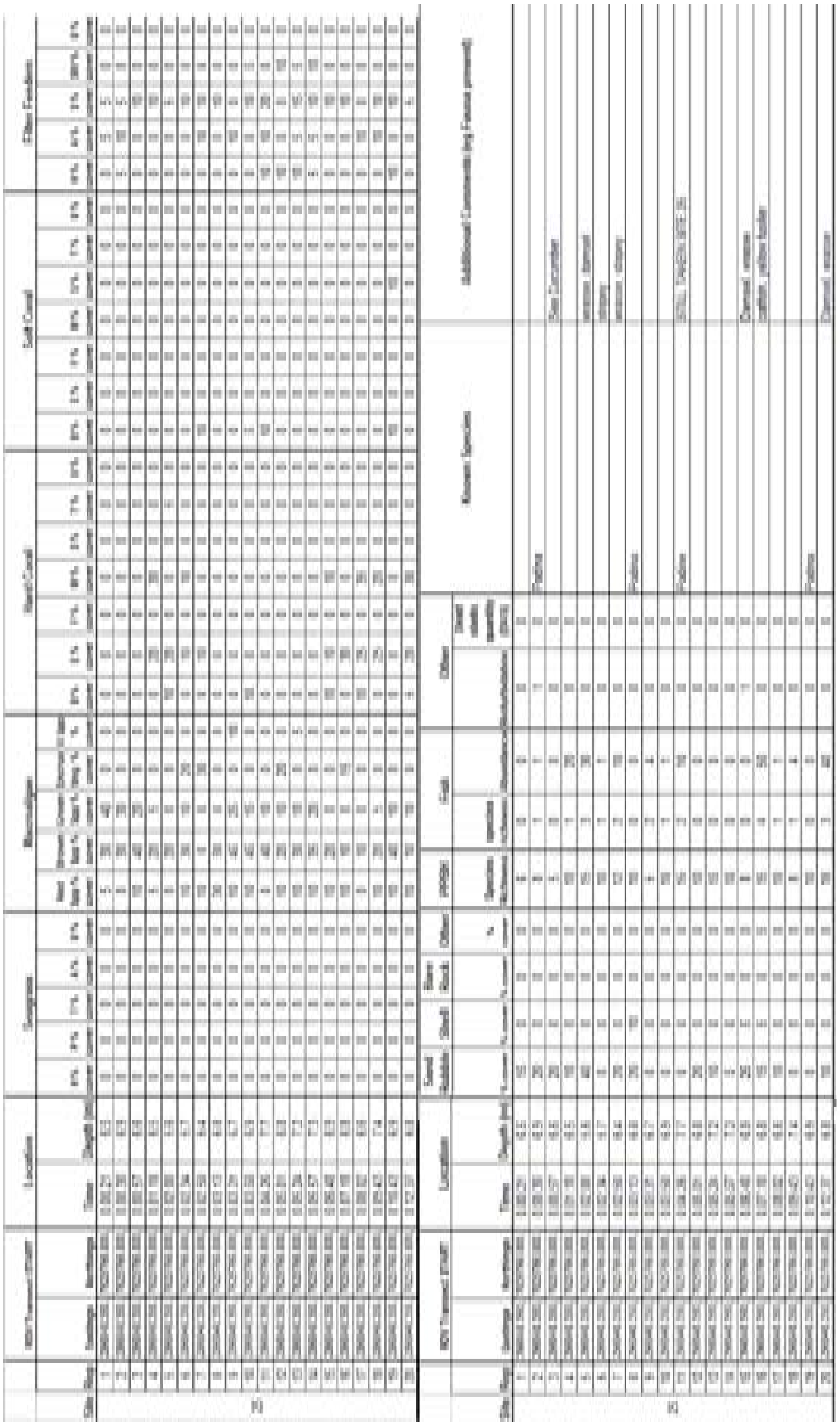
Subtidal Habitats

Table D-1 Example of the matrix used to analyse ROV footage



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Dominant biota identified, assessed and recorded into the matrix included;

1. Macroalgae percentage cover (red, brown, green, encrusting and unknown)
2. Seagrass percentage cover (*Halophila* sp., *Syringodium* sp. and unknown)
3. Hard coral percentage cover (branching, encrusting, foliose, tabulate, massive, sub-massive and unknown)
4. Filter feeders percentage cover (hydroids, ascidians, sponges, sea whips and unknown)

A total of 352 sites were surveyed using ROV. From each of these sites, 20 sub-sample sampling frames were systematically selected to provide a total of 7,040 observations recorded into the matrix.

D.3 Statistical Analysis

The analysis of ROV sites using replicated sampling frames to compute average percentage cover of each class of biota (seagrass, macroalgae, hard coral, filter feeders) at each site was evaluated in terms of the 95% confidence interval for the mean estimates at each site. The respective confidence intervals at each site were plotted against mean percent cover for each class of biota.

From the December 2008 survey results below (Figure D-2 to Figure D-5) the respective response curves indicated that:

- The majority of survey sites had a mean percentage cover for each class of biota <10%.
- The most abundant (>10%) biota was macroalgae followed by, filter feeders, hard coral and seagrass.
- There is strong curvilinear relationship ($p< 0.01$) between mean percentage cover and 95% confidence interval.
- Precision increases as mean cover (abundance) for each class of biota increases.
- Confidence intervals are in the range of ± 5 for 10% mean cover.
- Confidence intervals are in the range of ± 10 for 40% mean cover.
- Precision increases markedly as mean cover exceeds 40%.

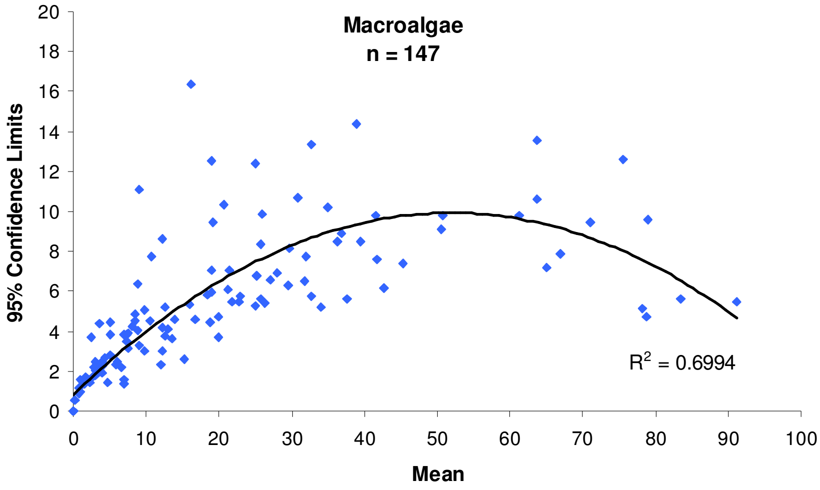

Figure D-2 Mean % cover of macroalgae and respective confidence interval for ROV surveys

Appendix D

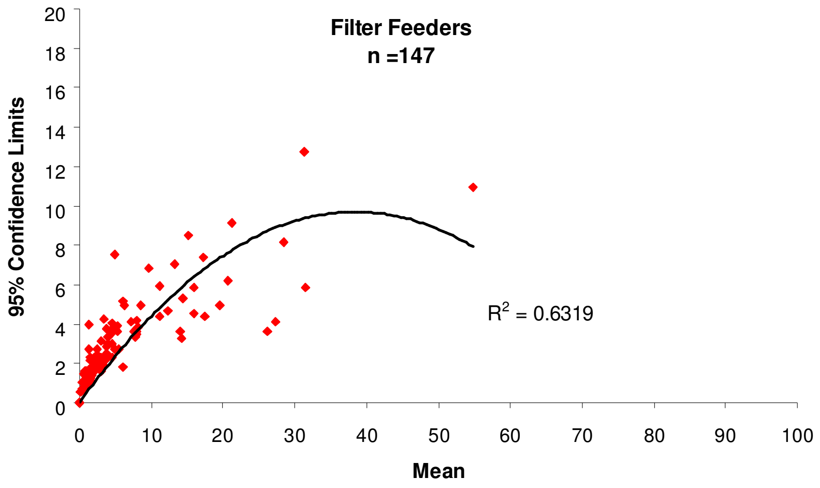

Figure D-3 Mean % cover of filter feeders and respective confidence intervals for ROV surveys

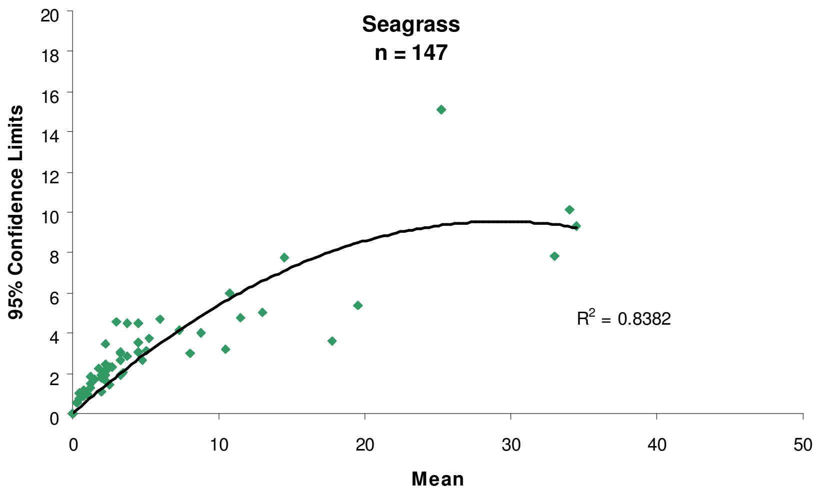

Figure D-4 Mean % cover of seagrass and respective confidence intervals for ROV surveys

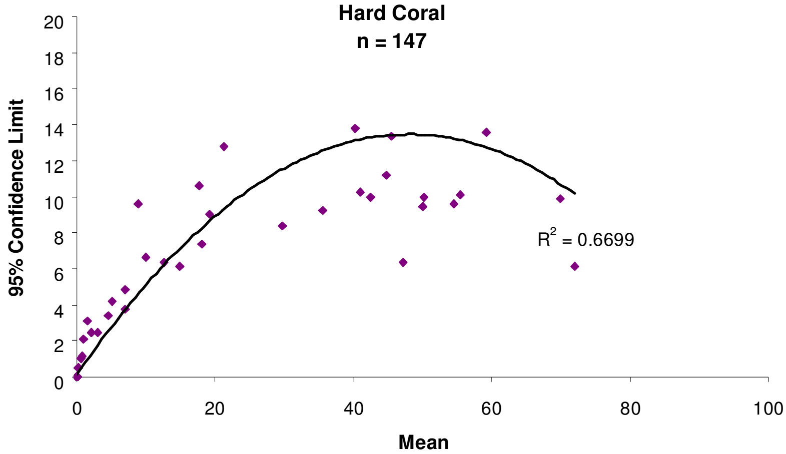

Figure D-5 Mean % cover of hard coral and respective confidence intervals for ROV surveys

D.4 Subtidal Habitat Mapping

Only a small proportion of the subtidal sea floor can be directly observed or sampled in such a large scale survey area (~3,500km^2) using the ROV survey techniques adopted in this project. For purposes of developing habitat maps to be used in the impact assessment process associated with a large scale dredging program the approach used in the habitat surveys and methods adopted for subsequent mapping techniques must be arguably justifiable. The techniques also need to be efficient, timely, quantitatively robust and fit-for-purpose. Given the anticipated spatial extent of likely impact and the relatively sparse and extended mosaic of benthic habitat in the subtidal soft-sediment component of the Project area a geostatistical interpolation approach was adopted based on the method of "kriging". This method was employed for soft substratum areas which dominated the survey area between 0 and - 40 m CD. Geostatistics are based around the principle of spatial dependence which is the likelihood that observations close together in space will be more alike than those further apart. Kriging is based on the assumption that points nearer each other have a certain degree of spatial correlation, but points that are widely spaced are statistically independent. This property may be represented using tools such as the variogram. Kriging fits a mathematical function to a specified number of points, or all points within a specified radius, and determines the best combination of weights to interpolate the data. This interpolation process provides output values for each location to create a prediction surface over the domain of interest. A variety of statistics including variance analysis and error predictions are also derived. Kriging is most appropriate when you know there is a spatially correlated distance or directional influence in the data. For further information a more detailed Mapping Method statement is available on request.

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Appendix E Plates of the Benthic Habitats

Plate 1 Proposed shipping channel (Site ROV001). Macroalgae with soft sand and silt sediments. Offshore end of proposed shipping channel.

Plate 2 Proposed shipping channel (Site ROV002). Macroalgae with solitary ascidian on soft sediments.

Appendix E

Plate 3 Moderate coverage of varied macroalgae and hydroid at Site ROV005 at proposed shipping channel.

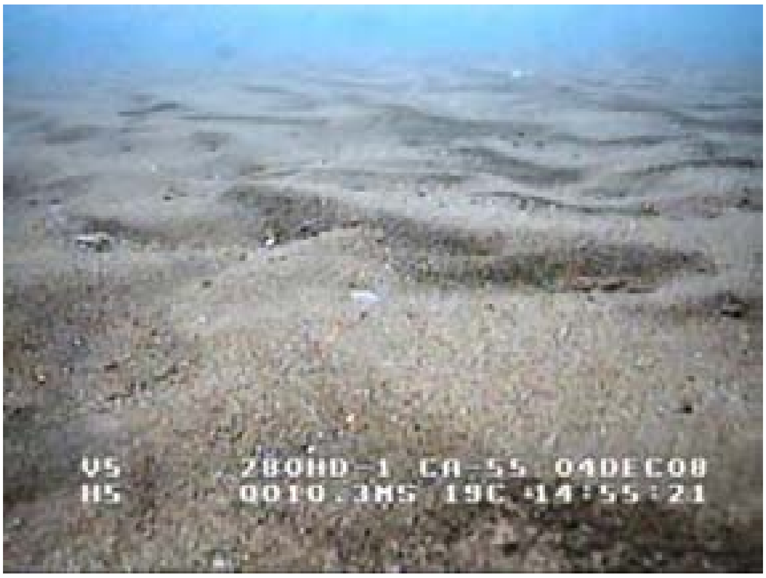

Plate 4 Miles Shoal (Site ROV020). Coarse sand with ripples with very sparse epibenthic biota.

Plate 5 Varied macroalgae on soft sediments shorewards of 10 m isobath east of proposed shipping channel (Site ROV034).

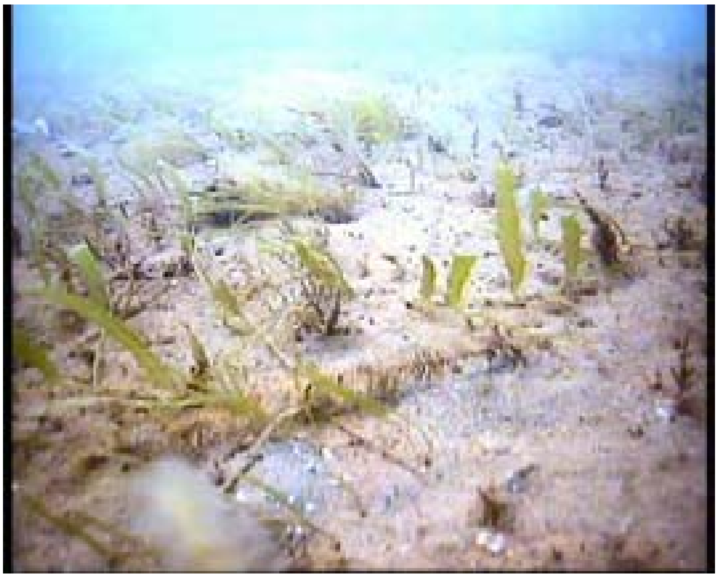

Plate 6 Proposed shipping channel (Site ROV006). Varied macroalgae including *Caulerpa* sp.

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Appendix E

Plate 7 Koolinda Patch (Site ROV086). Sparse seagrasses including *Halophila spinulosa*.

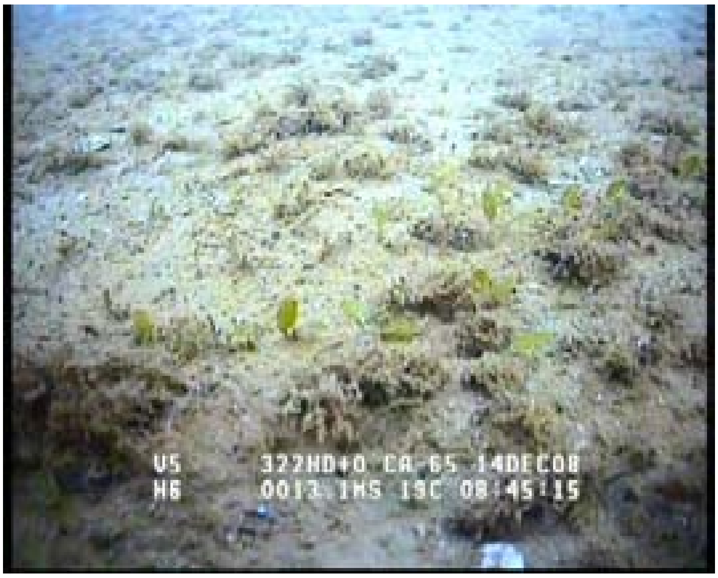

Plate 8 Northeast of Direction Island (Site ROV136). Sparse seagrass *Halophila decipiens*.

Plate 9 Coolgra Point (Site ROV141). Moderately dense seagrass beds consisting of *Halophila decipiens*.

Plate 10 Direction Island (Site ROV134). Large *Montipora* coral.

Appendix E

Plate 11 Direction Island (Site ROV134). Mixed hard coral (species of the genera *Montipora, Porites, Turbinaria* and faviids).

Plate 12 Direction Island (Site ROV134). Hard coral with algae patches with Banner fish (*Heniochus* sp.) and cleaner wrasse (*Labroides dimidiatus*) in foreground.

Plate 13 Ashburton Island (Site ROV017). Mixed hard coral (including corals of the genera *Porites*, *Lobophyllia* and *Turbinaria*, with school of yellow tailed fusiliers (*Caesio teres*) in the background.

Plate 14 Thevenard Island (Site ROV026). Pavement dominated by macroalgae with large *Porites* bommie.

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Plate 15 Thevenard Island (Site ROV027). Algae dominated reef platform with soft coral *Sarcophyton* sp. and large barrel sponge (*Xestospongia* sp.).

Plate 16 South of Thevenard Island (Site ROV096). Coarse sand with mushroom corals (fungiids).

Plate 17 Bessieres Island (Site ROV044). Large school of golden trevally (*Gnathanodon* sp.) with tabulate coral of the genus *Acropora* in the background.

Plate 18 Black Ledge (Site ROV035). Reef platform dominated by macroalgae, with scatted sparse *Turbinaria* with seawhips and sponges.

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Plate 19 Saladin Shoal (Site ROV025). Large *Porites* bommie.

Plate 20 Weeks Shoal (Site ROV083). Numerous hard and soft corals including *Montipora* and *Nephthea* sp.

Plate 21 Weeks Shoal (Site ROV083). Reef edge with coral cover including *Montipora*, *Pocillopora* and *Acropora*, with a common lionfish (*Pterois* sp.).

Plate 22 Gravel Banks (Site ROV013). Ark shells with macroalgae and anemone.

Appendix E

Plate 23 Proposed pipeline (Site ROV103). Sponge and fan garden with gorgonian fans and sea whips.

Plate 24 Proposed pipeline (Site ROV121). Limestone reef edge with sparse scattered juvenile *Turbinaria* corals and solitary angel fish.

Plate 25 Proposed pipeline (Site ROV042). Sparse beds of *Halophila decipiens*.

Plate 26 Alternate shipping channel near Paroo Shoal (Site ROV021). *Porites* bommie with Christmas tree worms (*Spirobranchus giganteus*).

Subtidal Habitats

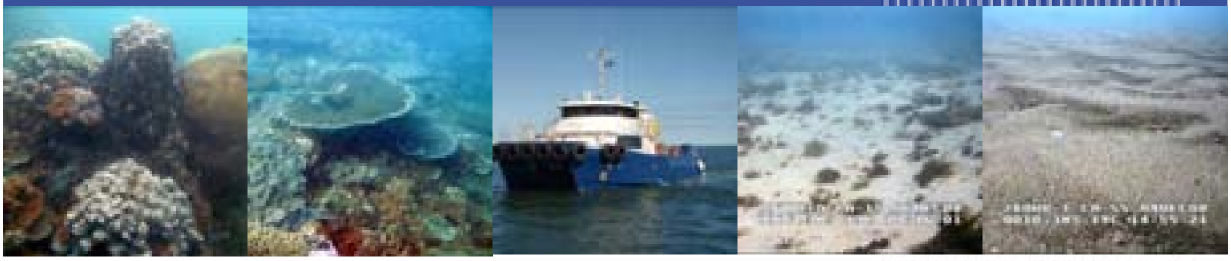
Appendix E

Plate 27 Spoil ground base case (Site ROV119). Large bioturbated hole in soft sediments of silt and sand.

Plate 28 Spoil ground base case (Site ROV118). Moderately abundant hydroids.

Plate 29 Spoil ground alternative (Site ROV112). Large bioturbated hole in silt and sand soft sediments.

Plate 30 Spoil ground alternative (Site ROV113). Soft sediments with solitary sea pen.



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Appendix N13

Biota of Subtidal Habitats in Pilbara Mangroves, with Particular Reference to the Ashburton Delta and Hooley Creek

Tables

Plates

Appendices

Abbreviations

Abbreviation	**Description**
BPPH	Benthic primary producer habitat
CD	Chart datum
CITES	Convention of International Trade in Endangered Species of Wild Fauna and Flora cm centimetre/s
DEWHA	Department of the Environment, Water, Heritage and the Arts
DoF	(Western Australia) Department of Fisheries
DOMGAS	Domestic gas
EPA	Environmental Protection Authority
EPBC	*Environment Protection and Biodiversity Conservation Act 1999*
ERMP	Environmental Review and Management Programme
FRAM	(Western Australia) *Fish Resources Management Act 1994*
IUCN	International Union for Conservation of Nature and Natural Resources
km	kilometre/s
LDM	LeProvost Dames & Moore
LNG	Liquefied natural gas
M	metre/s
Mg	milligram/s
MTPA	Million tonnes per annum
ONPMF	Onslow Prawn Managed Fishery
pers. comm.	personal communication
pers. obs.	personal observation
PFTMF Pilbara	Fish Trawl Interim Managed Fishery
WAM	Western Australian Museum

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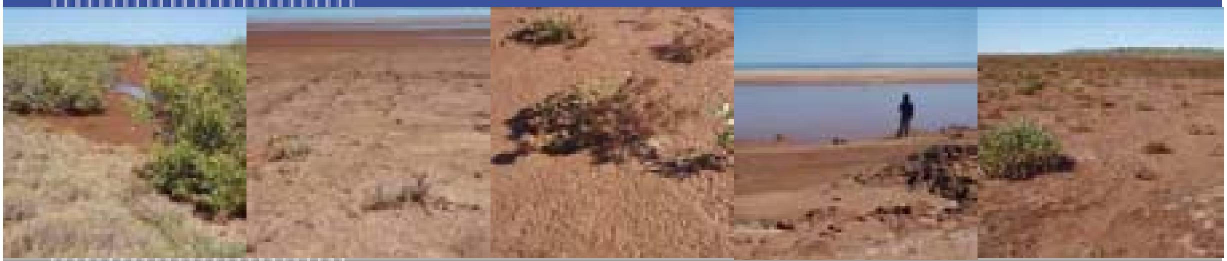

Report

Wheatstone Project

Biota of Subtidal Habitats in Pilbara Mangroves, with Particular Reference to the Ashburton Delta and Hooley Creek

11 MAY 2010

Prepared for

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Executive Summary

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

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

URS has developed a number of studies of the marine habitats of the Ashburton North site to provide the knowledge basis for the environmental assessment of the Project. The key objective of the present project is to provide a desktop review of current scientific knowledge of the fish and key macro invertebrates present in the tidal creek habitats of Pilbara mangroves. Related information has also been obtained on the:

- absence of benthic primary producer habitat in the subtidal creek beds
- zooplankton populations in the water column.

Animal populations in mangroves can be divided into three components:

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

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

There has long been a belief that mangroves are important nursery areas for commercially valuable species of fish and invertebrates. The nursery value of mangroves is a generalisation, with the value of a particular mangrove region depending on a wide variety of physical and biological factors. The nursery role of Pilbara mangroves may be less important that in other regions.

Three protected species of the sawfish genus *Pristis* occur in Western Australian waters, but the narrow sawfish (*Anoxypristis cuspidata*) is more common and is not protected. Several sawfish have recently been seen in the north-eastern lagoon of the Ashburton Delta and in Hooley Creek. The specific identity of these fish is unknown.

The fish biota of Pilbara mangroves is poorly known, but over 120 species have been recorded in mangroves. Many of the fish in mangrove creeks are occasional and sporadic visitors to the system that enter opportunistically during high tides. This includes groups such as sharks, longtoms, trevallies, queenfish, mackerel, pike and flatheads. A minority of species contribute the majority of the catch by numbers. While some species consistently occur in tidal creeks in mangrove areas, none are regarded as obligate mangrove species.

Executive Summary

Protected vertebrate species that occasionally occur in tidal creeks in Pilbara mangroves are:

- saltwater crocodile
- marine turtles
- dugong.

The muddy or sandy sediments of the mangroves may be home to a variety of epibenthic, infaunal, and meiofaunal invertebrates. The composition and importance of these communities vary enormously between habitats depending on the sediment characteristics of the individual mangrove community. Most studies have been in intertidal areas of mangroves, and there has been little study of subtidal habitats, e.g. tidal creeks within the mangroves. Catches in a mangrove creek habitat in Queensland were dominated by crustaceans (caridean shrimp, mysids, tanaids and penaeid prawns), polychaetes and fish. Juvenile banana prawns are concentrated in the Ashburton Delta, which is a nursery area for the fishery.

Little information is available on planktonic species in Australian mangroves. The most comprehensive study was undertaken in Queensland, where juvenile fish in small creeks were four to 10 times more abundant than over seagrass and sandflats in the same area. Most of the juvenile fish in the mangroves are zooplankton feeders. Zooplankton in the Queensland study were diverse, with 170 taxa recorded, 110 of which were copepod crustaceans.

A common user corridor is required for trunkline shore crossings for the Wheatstone Project and planned future developments at Ashburton North. The proposed site for the shore crossings is through a recently developed tidal lagoon at the north-eastern corner of the Ashburton Delta. Both this lagoon and the west arm of Hooley Creek were searched for subtidal benthic primary producer habitats (BPPH), but none were found.

Introduction

1.1 Background

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

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

URS has developed a number of studies of the marine habitats of the Ashburton North site to provide the knowledge basis for the environmental assessment of the Project. In particular, URS (2009a) examined the biotic communities inhabiting the intertidal environment along the Onslow coastline, and provided considerable information on the plants and invertebrate animals inhabiting the Ashburton River delta and the Hooley Creek systems. Following the decision to move the proposed trunkline route into the north-eastern lagoon of the Ashburton River delta, URS (2009a) provided more detail on this lagoon, and Bamford (2009) surveyed migratory birds in the area. Recent planning has increased the potential impact of the LNG plant site on the western creek of Hooley Creek, requiring the development of further information on the biota living in the creek itself, particularly the fish. The present desktop study provides the necessary information for this assessment and contributes to the development of an ecological model of the functioning of the two systems.

1.2 Objectives

The key objective of this project is to provide a desktop review of current scientific knowledge of the fish and key macro invertebrates present in the subtidal habitats of Pilbara mangroves. Related information has also been obtained, relating to:

- the absence of benthic primary producer habitat in the subtidal creek beds; and
- zooplankton populations in the water column.

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Animal Populations in Mangroves

Animal populations in mangroves can be divided into three components:

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

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

2.1 Species Distributions

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

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

The portion of these species that remain in pools and channels in tidal creeks at low tide are included in the present report.

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

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

None of these species occur in the tidal creeks that are the subject of the present study.

2.1.3 Species that remain in mangroves throughout the tidal cycle

A large group of species remains in the water column throughout the tidal cycle. Collectively known as plankton, these are primarily invertebrates, but include some fish, such as mudskippers (e.g. *Periopthalmus*) (Plate 2-1). These animals often have a planktonic larval stage in their life cycle that allows them to be widely distributed between mangrove systems. However, once they settle to the bottom, the animals are restricted to the local area.

This group of species can be divided into species that occur on adjacent shores, such as rocky and sandy shores, and include mangroves as simply one of the habitats in which they live, and species that typically occur only in mangroves. Most of the species in mangroves are there incidentally; only a relatively small proportion is restricted to mangroves. For example, Wells (1983, 1984) examined intertidal invertebrate distributions in a small mangrove community at the Bay of Rest on Exmouth Gulf, finding 163 species of invertebrates. While they were not divided into species characteristic of mangroves and species also found in other areas, URS (2009b) provided a list of mangrove obligate species from the Onslow area, including the Ashburton Delta and Hooley Creek.

2 Animal Populations in Mangroves

Plate 2-1 A mudskipper found in the north-eastern lagoon of the Ashburton Delta at low tide.

Only seven gastropod molluscs, 10 crabs and one barnacle were considered to be largely restricted to mangroves. Table 2-1 shows the habitats of these species. Similarly, Metcalfe and Glasby (2008) recorded 76 species of intertidal worms from mangrove habitats in Darwin Harbour, only seven of which (all polychaetes) appeared to be restricted to the mangroves.

Table 2-1 Intertidal invertebrate species characteristic of mangroves (from URS 2009c)

Family	Species	Habitat
	Molluscs	
Littorinidae	*Littoraria articulata*	On mangrove trees
	Littoraria cingulata	On mangrove trees
Potamididae	*Terebralia palustris*	On mud surface
	Terebralia semistriata	On mud surface
	Telescopium telescopium	On mud surface
	Cerithidea largillierti	On mud surface
	Cerithidea reidi	On mangrove trees. Burrows into mud during neap tides.
	Crabs	
Ocypodidae	*Uca flammula*	Burrows into creek banks
	Uca elegans	Burrows into upper intertidal mudflat
	Uca dampieri	Burrows into creek banks
	Uca capricornis	Burrows into creek banks
	Uca mjobergi	Burrows into creek banks

Family	Species	Habitat
Sesarmidae	*Neosamartium meinerti*	On surface among trees and burrows into sediment.
	Parasesarma sp.	On surface among trees and burrows into sediment.
	Perisesarma semperi	On surface among trees and burrows into sediment.
	Perisesarma sp.	On surface among trees and burrows into sediment.
	Metopograpsus frontalis	On surface among trees and burrows into sediment.
Portunidae	*Scylla serrata*	Common in tidal creeks and burrows into creek banks but is also found on nearby rocky shores. Migrates into deep water to spawn.
Barnacles		
Balanidae	*Fistulobalanus* n.sp.	On mangrove trees

2.2 Distribution of Intertidal Species in Mangroves

Four intertidal habitats were defined in the Bay of Rest (Wells 1983, 1984): open mudflat in the lower intertidal of the mangroves (3.82 km^2); *Avicennia marina* (1.96 km^2) and *Rhizophora stylosa* (0.36 km^2) tree zones and the upper intertidal saltflat shoreward of the mangroves (2.39 km^2). Three characters were used to measure the invertebrate populations: species diversity, density and biomass. The richest area was the mudflat, which had a total of 112 species, a mean of 20.5 species per station, a mean density of 992.m^{-2}, and a mean biomass of 4,056 mg.m^{-2} dry weight. Species diversity and animal densities in the two mangrove zones were lower: 59 species in *Avicennia*, a mean of 7.3 species per station, and a density of 257.m^{-2}; total of 31 species in *Rhizophora*, a mean of 5.1 species per station and a density of 473.m^{-2}. Biomass was high in *Avicennia*, 4,594 mg.m^{-2}, but was only 1,088 mg.m^{-2} in *Rhizophora*. The elevated biomass in *Avicennia* was due entirely to the mudwhelk *T. semistriata*. The fauna of the backflat was impoverished; only five species of crustaceans were collected, with a mean of 0.3 species per station, a density of 1.m^{-2} and a biomass of 193 mg.m^{-2}. The fauna of the mudflat and mangrove zones were dominated by molluscs, crustaceans and polychaetes.

While no quantitative measurements have been conducted, the mangroves at the Ashburton Delta and Hooley Creek would be expected to have similar relationships as they are dominated by *Avicennia* and *Rhizophora* and have extensive upper intertidal saltflats. However, the lower intertidal area seaward of the mangroves at the Project area is sandier and much more exposed than that of the Bay of Rest and has relatively few invertebrates.

Wells (1986) subsequently demonstrated that there was a substantial change in mollusc assemblages in the Bay of Rest where the mudflat occurring seaward of the mangrove zone met the pneumatophores of *Avicennia*. The mudflat association had more species of molluscs, but a lower total density and total biomass than the assemblage in the *Avicennia* zone. Stations among pneumatophores on the seaward fringe of the *Avicennia* zone were more diverse, and had a greater density and biomass than stations among the trees.

The distribution of invertebrates in mangroves is patchy. For example, fiddler crabs are most common on the banks of tidal creeks and are less common in the tree areas (George & Jones 1982). The mudwhelk *Terebralia semistriata* is widely distributed in low numbers, but is very abundant in restricted areas. Isolated individuals of the larger *T. palustris*, which reaches 12 cm in length, may be found, but there are small areas where the species may reach densities of >100 m^{-2} (Wells 1980; Wells & Lalli 2003). Wells (1983, 1984) found very low densities of crabs on the saltflat of the Bay of Rest; the few crabs present were found on the banks of small tidal channels. URS (2009b) has recently demonstrated that crabs are abundant in a narrow zone of the saltflat immediately shoreward of the tree zone in the Onslow area.

All of the above studies relate to intertidal areas of the mangroves; there are no similar studies for subtidal areas.

2.3 Mangroves as Nursery Areas

There has long been a belief that mangroves are important nursery areas for commercially valuable species of fish and invertebrates. Current worldwide information was reviewed by Manson et al. (2005) and Nagelkerken et al. (2008), who found that below water mangrove roots are overgrown by epibionts such as tunicates, algae, sponges and bivalves. This provides an abundance of food and shelter for fish and invertebrates, and the complex habitat, with numerous refuges, reduces predation pressure. The result is that there is an ideal habitat for many animal species during part or all of their life cycle. Both reviews concluded that mangroves may in fact function as nursery habitats for crab, prawn and fish species, some of which are commercially valuable. It may also help to support offshore fisheries.

The nursery value of mangroves, however, is a generalisation, and the value of a particular mangrove region depends on a wide variety of factors.

In Australia, Laegdsgaard and Johnson (1995) investigated the distributions of juveniles of 53 species of fish in three habitats (seagrass, mangroves and open mudflats) in a mangrove lined estuary in Moreton Bay, Queensland. Seven of the 10 commercially harvested fish species in the bay were found in greatest numbers in mangroves. Sheaves (1995) also found that juveniles of two species each of lutjanids (snappers) and serranids (groupers) were more abundant in estuarine areas than in more exposed localities.

Robertson and Duke (1987) monitored fish and crustaceans in mangrove and seagrass (*Halophila/Halodule* community) habitats near Townsville using seine nets with two different mesh sizes. Total fish abundance and relative abundance of small and large fish varied between habitats and seasonally. Post-larval, juvenile and small adult fish captured with the small net (3 mm mesh) were four to 10 times more abundant in mangroves throughout the 13 months of sampling. Mangrove fish abundance was seasonal, with the greatest catches being recorded in the warm, wet-season months of the year. Relative abundances of larger fish (18 mm mesh) in the two habitats varied during the year, but did not show a seasonal pattern. Small crustaceans were significantly more abundant in the mangroves in all but one dry season sample. Fish and crustacean abundance in mangroves varied among sites, indicating that estuaries differ in their nursery value. The juveniles of two commercially important penaeid prawn species (*Penaeus merguiensis* and *Metapenaeus ensis*) were significantly more abundant in the mangrove habitat. Laegdsgaard and Johnson (1995) found that juveniles of seven of 10 commercially species harvested in Queensland were found in greatest numbers in mangrove habitat.

2 Animal Populations in Mangroves

Blaber (1986) and Blaber et al. (1986) examined fish communities in mangroves in the Dampier region, finding that piscivorous fish are unusually abundant in mangrove creeks in the area, particularly at high tide when the clear and deep water in the mangroves at high tide favours predation on juveniles and reduces the effectiveness of such areas as nurseries. The giant trevally *Caranx ignobilis,* blacktip shark *Carcharhinus limbatus,* queenfish *Scomberoides commersonianus* and grey mackerel *Scornberomorus semifasciatus* were the most numerous predators. More than 50% of suitably sized potential prey fish species were consumed; the most common prey were Atherinidae, Gobiidae, *Ambassis* sp. and *Sillago* spp. Small (1-9 cm), permanently resident species constituted 60% of prey, and juveniles of larger species made up the balance. There was virtually no overlap of the mangrove fish fauna with that of the deeper waters (>20 m) of the North West Shelf; the inshore region is not a significant nursery ground for any of the commercially important deeper water species.

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Vertebrates

3.1 Fish

3.1.1 Protected species

URS (2009a) provided information on a wide variety of protected marine species that could potentially occur in the Project area. The genus *Pristis* was mentioned, but little information is available about the fish in the Pilbara, and populations are thought to be small. However, as survey teams have recently sighted three small (<1.2 m) sawfish in the north-eastern lagoon of the Ashburton Delta and one in Hooley Creek, the genus is included here. The most significant sighting was made in a small intertidal pool at Hooley Creek in November 2009, when a school of 12-15 small sawfish was seen feeding on minnows in the shallows (David Shine, Chevron, pers. comm.).

Pristis is a small genus of rays of the family Pristidae. Sawfish have a shark-like appearance but the head is flattened, with an elongated rostrum, known as the saw, which gives rise to the common name of sawfish. The saw has a number of pairs of rostral teeth that extend laterally. Three species of *Pristis* occur in Western Australian waters, and all are protected (Table 3-1). The three all occur in nearshore coastal waters and estuaries. As its name implies, the freshwater sawfish (*P. microdon*) extends past the estuaries well into freshwater habitats, but is not known to occur in the Pilbara. The dwarf sawfish (*P. clavata*) is widely distributed from the Pilbara, WA to southern Queensland. This was originally considered to be a small species, <140 cm in total length, but specimens have been recorded with total lengths up to 318 cm. In contrast, the third species, the green sawfish *P. zijsron* can grow to 5 m in Australian waters (Last & Stevens 1994; Stevens et al. 2008; DEWHA 2009a). Both species tend to occur in shallow water near mangroves (DEWHA 2009a).

Table 3-1 Species of sawfish in northern Australia (data from DEWHA 2009a) potentially introduced marine pests

Family	Species	Habitat	Conservation status
Pristis clavata	Dwarf sawfish Queensland sawfish	Pilbara WA to eastern QLD	EPBC: Vulnerable WA FRMA: Totally Protected CITES: Appendix I IUCN: Critically endangered
Pristis microdon	Freshwater sawfish	Kimberley WA to Torres Strait QLD	EPBC: Vulnerable CITES Appendix II
Pristis zijsron	Green sawfish Narrowsnout sawfish Dindagubba	Broome WA to southern NSW	EPBC: Vulnerable WA FRMA: Totally Protected CITES: Appendix I IUCN: Critically endangered

EPBC = Environment Protection and Biodiversity Conservation Act 1999; FRAM = Western Australia: Fish Resources Management Act 1994. IUCN = International Union for Conservation of Nature and Natural Resources (IUCN) Red List 2008. CITES = Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) 2009.

All sawfish are viviparous, with the eggs hatching and the young developing in the female. The developing young feed on unfertilised eggs and other developing young. The low fecundity, high age at maturity and low intrinsic rate of increase combine to make sawfish very vulnerable to exploitation

(Stevens et al. 2005; DEWHA 2009a). The generation length is estimated to be 16 years, but one sawfish captured as a juvenile lived for 35 years in captivity (Allen 1982; Stevens et al. 2005).

Aboriginal groups traditionally exploited sawfish, but probably at low levels. Saws are collected as curios, but the numbers are not known. The primary threat to the species is considered to be net fishing as the saw is readily entangled in nets, and the active hunting behaviour of sawfish in coastal areas where estuarine and gillnet fisheries operate makes the species particularly vulnerable. Their numbers have been substantially reduced as unwanted bycatch of net fishing (Pogonoski et al. 2002; Salini et al. 2007). Larson et al. (2006) estimated population declines of 30% in three generations.

A combination of fishing pressure and habitat disturbance has substantially reduced the distribution of the green sawfish. Historical records show that the species originally occurred on the east coast of Australia to New South Wales (Table 3-1), but there have been no reports of the species south of Cairns, Queensland since the 1960s (Stevens et al. 2005).

The Pilbara Fish Trawl Interim Managed Fishery (PFTMF) operates off the Pilbara coast using trawl nets. DoF (2004a) cites a 2002 survey of bycatch issues in this fishery in which two green sawfish (*P. zijsron*) and six narrow sawfish (*Anoxypristis cuspidate*, a species in a related genus that is not protected) were caught in 427 trawl shots. DoF (2004a) reported that sawfish are generally killed by fishers to avoid personal injury when removing them from the net. It was estimated that approximately 25 green sawfish and 80 narrow sawfish are caught by the fishery per year. DoF (2004a) further reported that, while the species is more abundant in the Kimberley, the distribution of green sawfish extends at least to the Montebello Islands. Juveniles have been found in Shark Bay and adults have occasionally been caught as far south as Rottnest Island.

DoF (2004b) assessed the environmental sustainability of the Onslow Prawn Managed Fishery (ONPMF), which operates off Onslow. The most productive part of the fishery is located just off the mouth of the Ashburton River. Like the PFTMF, the ONPMF is a trawl fishery but operates much closer inshore. DoF (2004b) did not record any interaction between the ONPMF and sawfish.

3.1.2 Other species

The fish biota of Pilbara mangroves is poorly known. The Western Australian Museum (WAM) has records of only nine species in the Ashburton system and none in Hooley Creek (Sue Morrison, WAM, pers. comm.).

Blaber et al. (1986) compared the species composition and broad trophic structure of mangrove creek and open shore fish communities of the Dampier region. The region is characterised by a lack of freshwater influence, low turbidity and a tidal range in excess of 4 m. The fish communities of both mangroves and open shores are typical of Indo-west Pacific coastal waters. However, physical conditions in Dampier have modified the community structure by excluding a number of families that prefer areas of higher turbidity and reduced salinity, and including others that usually occur only in clear waters. One hundred and thirteen species of fish were found in the mangroves and 106 on open shores; 54 species were common to both.

Hutchins (2003) surveyed the fish fauna of the Dampier Archipelago using a combination of fieldwork, the scientific literature and specimen records in WAM. A total of 736 species were listed. The fish were divided into five habitats (reef, soft bottom, mangrove, trawling ground and pelagic) where they are most common, but it should be recognised that this was not definitive, and was only intended to provide an indication of where the species was most likely to be found. Reef fish were most diverse

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(476 species), with moderate numbers of soft bottom inhabitants (117) and mangrove fishes (121) (Appendix A). Table 3-2 shows that the majority (69) of the 121 species listed for mangroves were also listed for other habitats, primarily pelagic (25 species) or reefs (24); eight species occurred in both habitats. This shows that most of the fish species in mangroves are not restricted to the mangroves; even species listed as commonly found only in mangroves are likely to also occur in other habitats. In particular, pelagic species can move into and out of mangroves with the tides.

Table 3-2 Habitats of fish present in Dampier mangroves and related habitats (from Hutchins 2003)

Habitat	Number of species
Mangrove only	52
Mangrove – Reef	24
Mangrove – Sand	7
Mangrove - Trawling	3
Mangrove – Pelagic	25
Mangrove - Reef and Sand	2
Mangrove - Reef and Pelagic	8
Total	121

As many of these species were found only on one or a few occasions, Hutchins (2003) considered analysis of the most abundant species to provide a better method of characterising the fish fauna of the archipelago. This method included 24 species from hard bottoms, 14 from soft bottoms, and nine from mangroves. Characteristic mangrove species are shown in Table 3-3.

The nine species are from eight different families; there are two species of Mugilidae (mullets). Seven of the nine species are recorded as being common in two or more habitats. Mangrove species are shared with reef and pelagic habitats.

The mullet *Liza alata* is listed by Hutchins (2003) only as a mangrove species. It was recorded from a single rotenone station on Dolphin Island. The description of the station is “Reef flat lined with igneous boulders fronting mangal; 21.10.98 stunted corals, sponges and ascidians; flowing creek exiting mangroves, with several pools in muddy bottom” (Hutchins 2004). This is a common Indo-West Pacific species that occurs in sheltered coastal waters, and even ventures into freshwater; it is not restricted to mangroves. *Liza alata* is a commercially fished species in Taiwan (Shao 2010).

The second species listed only for mangroves by Hutchins (2003) is the blue spotted mangrove goby *Acentrogobius gracilis*. It is one of 11 species of gobies listed for mangroves out of a total of 69 goby species in the Dampier Archipelago. While *A. gracilis* is native to northern Western Australia, the related *A. pflaumi* has been introduced to WA (Wells et al. 2009).

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Table 3-3 Habitats of common fish in Dampier mangroves (from Hutchins 2003) potentially introduced marine pests

Species	Family	Common name	Habitat
Herklotsichthys koningsbergeri	Clupeidae	Herring, sardine	Mangroves and pelagic
Zenarchopterus rasori	Hemiramphidae	Halfbeak	Mangroves and pelagic
Craterocephalus pauciradiatus	Atherinidae	Silverside	Mangroves and reef
Ambassis vachellii	Chandidae	Glassfish	Mangroves and reef
Acanthopagrus latus	Sparidae	Bream	Mangroves and reef
Abudefduf bengalensis	Pomacentridae	Damselfish	Mangroves and reef
Liza alata	Mugilidae	Mullet	Mangroves
Valamugil buchanani	Mugilidae	Mullet	Mangroves, reef and pelagic
Acentrogobius gracilis	Gobiidae	Goby, mudskipper	Mangroves

LDM (1998) provided a summary of knowledge of fish in Pilbara mangroves until that time, pointing out that Pilbara mangrove creeks differ in a number of important characteristics from mangroves further north on the continent, including being shorter in length, being in an area of greater tidal range, the water is clearer, annual rainfall is lower and episodic, and salinities are consistently high. Many of the side branches of the creeks dry entirely at low tide, and even in major creeks the water is very shallow or restricted to tidal pools. LDM (1998) concluded that many of the fish in mangrove creeks are occasional and sporadic visitors to the system that enter opportunistically during high tides. This includes fish groups such as sharks, longtoms, trevallies, queenfish, mackerel, pike and flatheads. A minority of species contribute the majority of the catch by numbers. Eighty-six species were listed as occurring in Pilbara mangrove creeks, none of which could be considered to be obligate mangrove species, though some were consistent mangrove residents. Twenty-nine species comprised 91% of the catch in Dampier mangrove creeks. The most abundant fish species was the perchlet *Ambassis gymnocephalus*; six species of mullet comprised 26.1% of total fish numbers.

Robertson and Duke (1990) found that 20 fish species accounted for >96% of the catch by numbers in mangrove habitats in Alligator Creek, Queensland. Five species were permanent residents, completing their life-cycles in mangrove swamps; eight were 'long-term' temporary residents, thought to be present for one year as juveniles before moving to nearshore habitats; and seven were 'short-term' residents or sporadic users of the mangroves. Temporary residents dominated the fish community in the wet season (December to April), but resident species comprised more than 90% of total fish numbers in the mid dry season (August). Several species had more than one peak of recruitment during the wet season. Nine of the 20 species examined were strictly dependent on mangrove-lined estuaries, the remaining 11 were captured in significant numbers in other nearshore habitats. Four species were commercially important, but most were major prey for several valuable, commercial species harvested both within mangrove habitats and in adjacent shallow shelf habitats.

3.2 Other Vertebrates

URS (2009c) analysed protected vertebrate species in the marine environment of the Project area. Ninety-six species are possibly present in the Pilbara; 11 of these were examined in detail.

3.2.1 Crocodiles

The saltwater, or estuarine, crocodile (*Crocodylus porosus*) was extensively hunted from the 1940s until the early 1970s, when the species became protected both nationally and in Western Australia. By the time the species became protected, it is estimated that the population had decreased to 5% of its original level. By 1984, the Northern Territory population had increased to 30-40% of the pre-harvest level, and by 2000 it was considered to be fully recovered.

In northern Australia saltwater crocodiles live primarily in tidal rivers, coastal floodplains and channels, billabongs and swamps. However, they can be now be found up to 150 km inland from the coast, as well as far out to sea. DEWHA (2009b) provides a range based on published literature from the 1990s from King Sound, WA to Rockhampton, Queensland. However, as the population has recovered, saltwater crocodiles are being found in areas where they have not occurred in living memory, progressively farther inland and down the east and west coasts.

In Western Australia saltwater crocodiles were rare south of Cape Leveque in the 1970s. The range has progressively extended southwards, with animals occasionally being found in the Pilbara in recent years. A limited number, thought to be about six individuals, is now present in the Ashburton Delta (URS 2009a) and one was recently seen south of Coral Bay near North West Cape.

3.2.2 Turtles

Six species of turtles occur in Australia, five of which are found in the Wheatstone area (URS 2009a). The green turtle *Chelonia mydas* is the most common species, followed by the flatback turtle *Natator depressus*. Both species have major nesting areas on Barrow Island, where the population of green turtles is estimated at 100,000 and there are thought to be 10,000 flatback turtles. There are very few nesting turtles along the shoreline at Ashburton North (Pendoley 2009). Aerial surveys of the west Pilbara could not distinguish between turtle species, but no aggregations were seen along the Ashburton North shoreline. It is possible that some turtles enter the mangrove systems at high tide and move back out to sea on the falling tide. This would be more likely to occur in the large lagoon inside the entrances to the Ashburton Delta. None have been reported in Hooley Creek.

3.2.3 Sea snakes

Fifteen species of sea snakes are known from the Pilbara (URS 2009a). Two of these are found in Pilbara mangroves (Biota 2005). The mangrove mud snake *Ephalophis grayae* is the more common, and enters the mangroves to hunt in crab burrows for mudskippers. The banded mangrove snake *Hydrelaps darwiniensis* is less common.

3.2.4 Marine mammals

Marine mammals are thought to be rare in both the Ashburton Delta and Hooley Creek. WAM survey scientific study teams occasionally saw individual dugong (*Dugong dugon*) in the Bay of Rest in Exmouth Gulf in the 1980s, but URS survey teams have not seen them in either the Ashburton Delta or Hooley Creek. One unidentified dolphin was seen at Hooley Creek by a URS survey team in January 2010. The animal entered the lower creek on a rising tide and remained in Hooley Creek for about 15 minutes before exiting the creek.

Invertebrates

4.1 Benthic Invertebrates

The muddy or sandy sediments of the mangroves may be home to a variety of epibenthic, infaunal, and meiofaunal invertebrates. The composition and importance of these communities varies enormously from habitat to habitat depending on the sediment characteristics of the individual mangrove community (Kathiresan & Bingham 2001). However, most of these studies refer to the intertidal areas where mangroves occur (Section 2.2), and there has been little study of subtidal areas within the mangroves, such as tidal creeks.

Daniel and Robertson (1990a, 1990b) examined the relationship between the epibenthic species inhabiting mangrove creeks and open embayments in a large bay in north Queensland. Twelve sites were sampled in and near Missionary Bay using a beam trawl:

- three mangrove creeks
- one accreting bank adjacent to the mangrove forest
- three in the inner bay
- two in the outer bay
- two in the Murray River estuary
- one site near the mouth of the river.

Four hundred and ten taxa were identified to major groups, and included a wide range of organisms. Catches in the mangrove creek habitat were dominated by crustaceans (caridean shrimp, mysids, tanaids and penaeid prawns), polychaetes and fish.

There have been no known studies of the benthic invertebrates of subtidal habitats of Pilbara mangroves. However, banana prawns (*Penaeus merguiensis*) are a small (8.8%), but important, component of the catch of the ONPMF. The Ashburton Delta is the key area for this fishery as it is the nursery area for the banana prawn (URS 2009c). This species can benefit from storm events and the associated high rainfall. There is typically a lag of a year when high rainfall during one summer is reflected in high catches of banana prawns the following year (Sporer & Kangas 2005; URS 2009c). As rainfall in the Onslow region is typically very low, the banana prawn catches tend to be low, but an outstanding catch of 90 tonnes was obtained in 1997 following good rains. Nagelkerken et al. (2008) reported that banana prawns are common in the channels of mangroves at low tide but extend into mangroves at high tide, up to 200 m from the channel, returning to the channels as tide falls.

The pattern of juvenile prawns occurring in mangroves then migrating into adjacent coastal ecosystems as they mature is shared by a number of other prawn species, but is not uniform to all species (Kathiresan & Bingham 2001).

4.2 Planktonic Invertebrates

Little information is available on planktonic species in Australian mangroves. The most comprehensive study was undertaken by Robertson et al. (1988) in Alligator Creek near Townsville, Queensland. They reported that juvenile fish in small creeks in the mangrove forests of northern Australia were four to 10 times more abundant than over seagrass and sandflats in the same area. Most of the juvenile fish in the mangroves were zooplankton feeders. Two hypotheses were advanced for the abundance of these fish: that the structural diversity of mangroves provides refuge for the small fish; or that increased zooplankton populations in the mangroves provide more food for the fish. To examine this, zooplankton were sampled in four habitats in and near the Alligator Creek mangrove system:

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- mangrove drainage creek
- mainstream of a mangrove dominated estuary
- adjacent seagrass flat
- station 10 km offshore.

The low tide water depth in the drainage creek was only about 0.5 m, but the depth in the major drainage creek was 5 m in an area where the maximum tidal range is 3.5 m.

Zooplankton can be divided into two components: holoplanktonic species that undergo their entire life cycle in the plankton, and meroplanktonic species that undergo their larval stages in the plankton but then settle to the bottom for the juvenile and adult portions of their life cycle. Robertson et al. (1988) recorded both components in the mangrove zooplankton. Overall, species collected were diverse, with 170 taxa recorded, 110 of which were copepod crustaceans. In addition to copepods, holoplanktonic groups included tintinnids, larvaceans, chaetognaths and foraminiferans, all of which are common in zooplankton studies. As is usually the case in zooplankton studies, copepod crustaceans were numerically dominant, particularly *Parvocalanus crassirostris, Paracalanus* spp., several species of *Oithona* and *Euterpina acutifrons*. While the zooplankton community structure often differed between the two mangrove sites, the mangrove sites consistently separated from the other habitats. This was due to the abundance of meroplanktonic larvae in the mangroves. The larvae belonged to a wide range of groups, including brachyuran (crab) zoea, and the larvae of gastropods, bivalves, polychaete worms and echinoderms. The meroplankton in mangrove sites was dominated by seasonally abundant invertebrate eggs and crab larvae in the zoea stage of the life cycle. Total zooplankton density in mangrove and seagrass habitats (11,300 to 19,700.m^{-3}) was always higher than in the offshore bay habitat. Zooplankton densities were strongly seasonal, being an order of magnitude greater in the wet season than during the dry season.

Robertson et al. (1988) found that the dominant groups in the area they studied were similar to the results of other studies conducted in northern Australia and South East Asia. They concluded the crab larvae were dominated by species of the families Grapsidae and Ocypodidae which are diverse in mangrove environments, including the Ashburton and Hooley Creek systems (URS 2009b). When seasonally present, these crab larvae were a major dietary component of zooplanktivorous fish.

Interestingly, Robertson et al. (1988) reported that there was a close similarity between zooplankton community structure during high tide in the creek habitat and low tide community structure in the mainstream, suggesting that many taxa are flushed from the creek with the ebbing tide and are returned by the subsequent flood tide. This is supported by the fact that, when the tidal amplitude was smallest, there were no differences in community structure between high and low tides. However, simple flushing is not the complete answer as zooplankton densities were significantly higher in the mangrove creek at high tide than at low tide. A previous study has shown that, by migrating to near the bottom of creeks, copepods accumulated in the uppermost reaches of saltmarsh creeks rather than dispersing over the marsh with the flood. As the tide ebbed the copepods moved downstream. Thus copepod densities in the upper region of the creek were significantly lower at low tide.

Benthic Primary Producers

Recent work in Port Hedland harbour has demonstrated that there are small areas of benthic primary producer habitats (BPPH), particularly small coral assemblages, at the mouths of some of the channels through the mangroves. Because of this, the tidal creeks and lagoons adjacent to the Wheatstone Project area have been surveyed for subtidal BPPH.

5.1 North-eastern Lagoon of the Ashburton Delta

A common user corridor is required for trunkline shore crossings for the Project and planned future developments at Ashburton North. The proposed site for the shore crossings is through a recently developed tidal lagoon at the north-eastern corner of the Ashburton Delta. URS (2010) recently assessed the potential environmental impacts of two methods for constructing the trunkline shore crossing: micro tunnelling and trenching.

A sandy barrier spit extended eastward for 3.2 km from Entrance Point until it joined the coastline beyond the eastern extremity of the Ashburton Delta (Damara 2009) (Plate 5-1). The spit was built of sediments transported eastward from the Ashburton River delta. The ocean beach at the western end of the spit had a moderate beach slope (1:8) with a berm at about the highest astronomic tide level [in the order of 3 m chart datum (CD)]. The profile gradually fell away towards the estuary where there was a steep silty bank that dropped into the estuary mouth. Whilst the ocean beach was relatively straight, the estuary beach was sinuous with intermittent shoals. The western extremity of the spit had a thick assemblage of the mangrove *Avicennia marina* and smaller numbers of *Rhizophora stylosa*.

Plate 5-1 Aerial view of the north-eastern lagoon of the Ashburton Delta facing east. The proposed pipeline route is in the upper lagoon in the photo.

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The north-eastern lagoon is at the top of Plate 5-1; the bottom substrate is similar to the lagoon in the foreground. The area between the barrier spit and the shoreline tapered from a width of approximately 250 m on a spring tide at the lagoon entrance over its 3.2 km length to the eastern end. The upper intertidal at the western end of the lagoon had mangroves on both the barrier spit and on the shoreline. At low tide the lagoon entrance was less than 100 m wide, and was very shallow.

Mangroves along the shoreline were sampled in detail from 4 to 8 December 2009 during a spring tide period. The mangroves themselves were predominately in a narrow fringe in the mid to upper intertidal area near the mouth of the lagoon. Mangroves rapidly decreased in size and density towards the lagoon. There were no mangroves in the eastern half of the lagoon (URS 2010).

Aside from a small area of limestone outcrop near the eastern end of the lagoon shoreline, the lower intertidal region of the shoreline and spit were composed entirely of muddy sand. The entire length of the lagoon was walked at low tide but no areas of subtidal BPPH were found. The subtidal areas were mobile, shallow sand (Plates 5-2 to 5-5).

Plate 5-2 Ashburton lagoon at Transect 6 facing east showing the absence of benthic primary producer habitats in the lower intertidal region.

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Plate 5-3 Ashburton lagoon at Transect 6 facing the shore showing the absence of benthic primary producer habitats in the lower intertidal region.

Plate 5-4 Ashburton lagoon at Transect 6 facing west showing the lack of benthic primary producer habitats in the lower intertidal region.

Plate 5-5 Ashburton lagoon at Transect 9 showing the lack of benthic primary producer habitats in the lower intertidal region.

5.2 Hooley Creek

During a spring tide series in January 2010 the entire margin of Hooley Creek from the seaward entrance to the upper reaches of West Hooley Creek was surveyed for BPPH at low tide. Plates 5-6 to 5-12 show a series of photographs taken from the entrance up the creek. As can be seen on the photos, no BPPH were found. Other observations in East Hooley Creek also found no BPPH.

The entrance to Hooley Creek was a sandbar approximately 1.2 km long that had developed in recent decades (since 1980) (Damara 2009). The entrance was mobile sand, with no hard bottom (Plate 5-7). There was some low, broken limestone at the junction of Hooley Creek and Middle Creek (Plate 5-8), but there were no attached plants. Similar low rock occurred on the west side of the junction of East and West Hooley Creek (Plate 5-9), but again lacked plants. During the 1980s, Hooley Creek exited directly to the sea from this point (F. Wells, pers. obs.).

The bottom of the lower reaches of Hooley Creek was sand which became muddier up the creek (Plates 5-10 to 5-12).

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Plate 5-6 **Aerial photograph of Hooley Creek showing East Hooley Creek on the left and West Hooley Creek on the right. The following photographs start at the creek mouth and progress up West Hooley Creek.**

Plate 5-7 **Mouth of Hooley Creek facing the open sea.**

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Plate 5-8 Mouth of Hooley Creek with entrance to Middle Creek in the background.

Plate 5-9 Area just seaward of the entrance to West Hooley Creek.

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Plate 5-10 Junction of West Hooley Creek (upper) and East Hooley Creek (right).

Plate 5-11 Representative area of the lower part of West Hooley Creek.

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Plate 5-12 Upper reaches of West Hooley Creek.

Conclusions

The key results of this survey are:

- While there are gaps in scientific knowledge, the species composition and broad distribution patterns of intertidal species in mangroves is relatively well known. There is little information available on the fish and invertebrates that inhabit creek channels that retain water at low tide (i.e. subtidal habitats in creeks within the mangroves).
- Three protected species of the sawfish genus *Pristis* occur in Western Australian waters, but the narrow sawfish (*Anoxypristis cuspidata*) is more common and is not protected. Several sawfish have recently been seen in the north-eastern lagoon of the Ashburton Delta and in Hooley Creek. The specific identity of these fish is unknown.
- Other protected vertebrate species that occasionally occur in Pilbara mangroves are the saltwater crocodile (*Crocodylus porosus*), marine turtles and the dugong (*Dugon dugong*).
- Over 120 species of fish are known to occur in Pilbara mangroves. Most enter the system with the incoming tide and depart as the tide falls. Some remain in the lower parts of channels and tide pools which retain water at low tide. While some species, such as mudskippers, are characteristic of mangroves, there are no species restricted to mangroves.
- The relatively clear water in mangroves at high tide allows a relatively high proportion of piscivorous fish to occur in Pilbara mangroves. This, and other features of mangroves in the region, reduces the nursery value of mangroves. However, the Ashburton system is regarded as a nursery area for the commercially valuable banana prawn, *Penaeus merguiensis*.
- There is a small, but important, group of restricted range invertebrates inhabiting intertidal habitats in Pilbara mangroves. Most of these species occur widely in both the Pilbara and Kimberley. While there is less information available on subtidal invertebrates and zooplankton, no such restricted range species are known to occur.
- No BPPH habitats occur in the subtidal areas of west Hooley Creek or the north-eastern lagoon of the Ashburton Delta, the areas potentially impacted by the Wheatstone Project.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the CTR dated 20 November 2009.

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

This report was prepared between November 2009 and March 2010, and finalised in May 2010, and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

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Appendix A Species of fish found in mangroves in the Dampier Archipelago (from Hutchins 2003)

CARCHARHINIDAE

Carcharhinus brevipinna (Müller and Henle, 1839)

Carcharhinus cautus (Whitley, 1945)

Carcharhinus leucas (Valenciennes, 1839)

Carcharhinus limbatus (Valenciennes, 1839)

Carcharhinus melanopterus (Quoy and Gaimard, 1824)

Carcharhinus sorrah (Valenciennes, 1839)

HEMIGALEIDAE

Hemipristis elongata (Klunzinger, 1871)

DASYATIDIDAE

Himantura granulata (Macleay, 1883)

Himantura uarnak (Forsskål, 1775)

Taeniura lymma (Forsskål, 1775)

ELOPIDAE

Elops hawaiensis Regan, 1909

MEGALOPIDAE

Megalops cyprinoides (Broussonet, 1782)

OPHICHTHIDAE

Muraenichthys macropterus Bleeker, 1857

CONGRIDAE

Conger cinereus Rüppell, 1830

Appendix A

CLUPEIDAE

Herklotsichthys koningsbergeri (Weber and De Beaufort, 1912)

Nematalosa vlaminghi (Munro, 1957)

ENGRAULIDIDAE

Stolephorus commersonii Lacepède, 1803

Thryssa hamiltonii (Gray, 1835)

CHIROCENTRIDAE

Chirocentrus dorab (Forsskål, 1775)

CHANIDAE

Chanos chanos (Forsskål, 1775)

ARIIDAE

Arius argyropleuron Valenciennes, 1840

Arius graeffei Kner and Steindachner, 1866

Arius leptaspis (Bleeker, 1862)

Arius mastersi Ogilby, 1898

Arius proximus Ogilby, 1898

Arius species

HEMIRAMPHIDAE

Arrhamphus sclerolepis Günther, 1866

Hemiramphus robustus Günther, 1866

Hyporhamphus affinis (Günther, 1866)

Hyporhamphus quoyi (Valenciennes, 1847)

Zenarchopterus rasori (Popta, 1912)

Appendix A

BELONIDAE

Strongylura strongylura (van Hasselt, 1823)

Tylosurus crocodilus (Péron and Lesueur, 1821)

Tylosurus gavialoides (Castelnau, 1873)

ATHERINIDAE

Atherinomorus endrachtensis (Quoy and Gaimard, 1824)

Craterocephalus capreoli Rendahl, 1922

Craterocephalus mugiloides (McCulloch, 1912)

Craterocephalus pauciradiatus (Günther, 1861)

Hypoatherina temminckii (Bleeker, 1853)

SYNGNATHIDAE

Choeroichthys brachysoma (Bleeker, 1855)

Corythoichthys haematopterus (Bleeker, 1851)

SCORPAENIDAE

Synanceia horrida (Linnaeus, 1766)

PLATYCEPHALIDAE

Cymbacephalus nematophthalmus (Günther, 1860)

Platycephalus endrachtensis Quoy and Gaimard, 1825

Platycephalus indicus (Linnaeus, 1758)

CENTROPOMIDAE

Psammoperca waigiensis (Cuvier, 1828)

CHANDIDAE

Ambassis vachellii Richardson, 1846

Appendix A

SERRANIDAE

Epinephelus coioides (Hamilton, 1822)

Epinephelus quoyanus (Valenciennes, 1830)

TERAPONTIDAE

Amniataba caudavittata (Richardson, 1845)

Terapon jarbua (Forsskål, 1775)

SILLAGINIDAE

Sillago analis Whitley, 1943

Sillago burrus Richardson, 1842

Sillago lutea McKay, 1985

Sillago sihama (Forsskål, 1775)

ECHENEIDAE

Echeneis naucrates Linnaeus, 1758

RACHYCENTRIDAE

Rachycentron canadum (Linnaeus, 1766)

CARANGIDAE

Carangoides hedlandensis (Whitley, 1934)

Carangoides malabaricus (Bloch and Schneider, 1801)

Caranx ignobilis (Forsskal, 1775)

Caranx sexfasciatus Quoy and Gaimard, 1825

Gnathanodon speciosus (Forsskål, 1775)

Pantolabus radiatus (Macleay, 1881)

Scomberoides commersonnianus Lacepède, 1801

Scomberoides lysan (Forsskål, 1775)

Trachinotus blochii (Lacepède, 1801)

Appendix A

LEIOGNATHIDAE

Gazza minuta (Bloch, 1797)

Leiognathus decorus (De Vis, 1884)

Leiognathus elongatus (Günther, 1874)

Leiognathus equulus (Forsskål, 1775)

LUTJANIDAE

Lutjanus argentimaculatus (Forsskål, 1775)

Lutjanus russelli (Bleeker, 1849)

GERREIDAE

Gerres abbreviatus Bleeker, 1850

Gerres filamentosus Cuvier, 1829

Gerres oyena (Forsskål, 1775)

Gerres subfasciatus Cuvier, 1830

HAEMULIDAE

Diagramma labiosum Macleay, 1883

Plectorhinchus flavomaculatus (Ehrenberg, 1830)

Plectorhinchus gibbosus (Lacepède, 1802)

Pomadasys kaakan (Cuvier, 1830)

Pomadasys maculatus (Bloch, 1797)

SPARIDAE

Acanthopagrus latus (Houttuyn, 1782)

Acanthopagrus palmaris (Whitley, 1935)

MULLIDAE

Parupeneus indicus (Shaw, 1803)

MONODACTYLIDAE

Monodactylus argenteus (Linnaeus, 1758)

Appendix A

SCATOPHAGIDAE

Scatophagus argus (Linnaeus, 1766)

Scatophagus multifasciatus Richardson, 1846

POMACANTHIDAE

Chaetodontoplus duboulayi (Günther, 1867)

MUGILIDAE

Liza alata (Steindachner, 1892)

Liza subviridis (Valenciennes, 1836)

Liza vaigiensis (Quoy and Gaimard, 1824)

Mugil cephalus Linnaeus, 1758

Rhinomugil nasutus (De Vis, 1883)

Valamugil buchanani (Bleeker, 1853)

Valamugil seheli (Forsskål, 1775)

SPHYRAENIDAE

Sphyraena barracuda (Walbaum, 1792)

Sphyraena flavicauda Rüppell, 1835

POLYNEMIDAE

Eleutheronema tetradactylum (Shaw, 1804)

Polydactylus sheridani (Macleay, 1884)

LABRIDAE

Choerodon cyanodus (Richardson, 1843)

Choerodon schoenleinii (Valenciennes, 1839)

SCARIDAE

Scarus chameleon Choat and Randall, 1986

Appendix A

GOBIIDAE

Acentrogobius caninus (Valenciennes, 1837)

Acentrogobius gracilis (Bleeker, 1875)

Acentrogobius janthinopterus (Bleeker, 1852)

Acentrogobius viridipunctatus (Valenciennes, 1837)

Apocryptodon madurensis Bleeker, 1849

Drombus triangularis (Weber, 1911)

Drombus species

Glossogobius circumspectus (Macleay, 1883)

Mugilogobius littoralis Larson, 2001

Periophthalmus argentilineatus Valenciennes, 1837

Yongeichthys nebulosus (Forsskål, 1775)

ELEOTRIDIDAE

Bostrychus sinensis Lacepède, 1801

Butis butis (Hamilton-Buchanan, 1822)

SIGANIDAE

Siganus lineatus (Valenciennes, 1835)

SCOMBRIDAE

Scomberomorus commerson (Lacepède, 1800)

Scomberomorus semifasciatus (Macleay, 1884)

BOTHIDAE

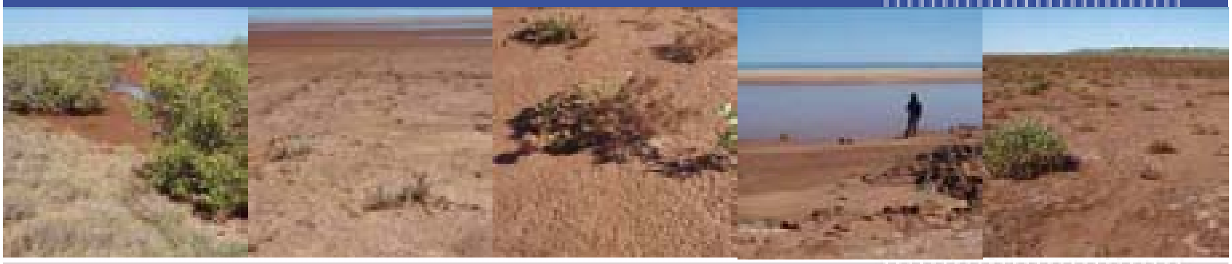
Pseudorhombus arsius (Hamilton, 1822)

Pseudorhombus elevatus Ogilby, 1912

Pseudorhombus quinquocellatus Weber and de Beaufort, 1929

TETRAODONTIDAE

Chelonodon patoca (Hamilton-Buchanan, 1822)



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Appendix N14

Assessment of the Potential Impacts of the Proposed Pipeline Route Through the Northern-Eastern Lagoon of the Ashburton Delta

Tables

Figures

Abbreviations

Abbreviation	Description
BPPH	Benthic Primary Producer Habitat
CD	Chart Datum
DEWHA	Department Of The Environment, Water, Heritage And The Arts
EPA	Environmental Protection Authority
ERMP	Environmental Review And Management Programme
GPS	Global Positioning System
PLF	Product Loadout Facility
HDD	Horizontal Directional Drilling
LNG	Liquefied Natural Gas
MTPA	Million Tonnes Per Annum
PASS	Potential acid sulphate soil

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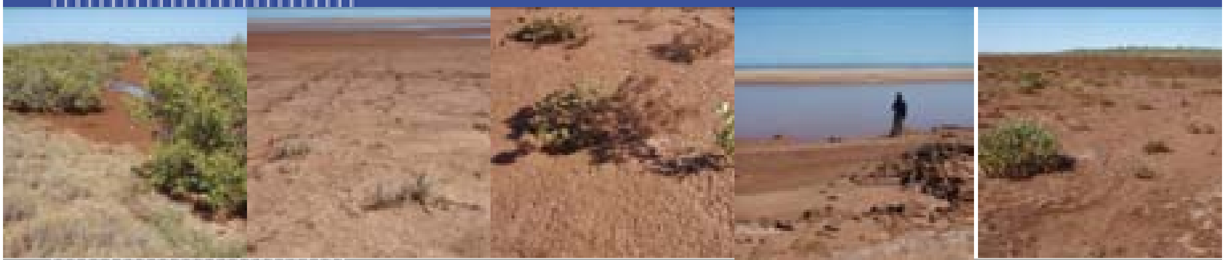

Report

Assessment of the Potential Impacts of the Proposed Pipeline Route through the North-eastern Lagoon of the Ashburton Delta

26 JUNE 2010

Prepared for

Chevron Australia Pty Ltd

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Executive Summary

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

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The assessment of the potential impacts of the proposed pipeline shore crossing route presented in this report has been conducted to support the environmental impact assessment process.

A common user corridor is planned for pipeline shore crossings for the Wheatstone Project and planned future developments at Ashburton North Strategic Industrial Area (SIA). The proposed corridor crosses a small lagoon at the north-eastern corner of the Ashburton Delta, an area considered to have significant environmental value by the EPA.

The Ashburton delta is highly dynamic. The entrance has moved in historical times from Entrance Point to the present day river mouth. The Ashburton East entrance closed between 2001 and 2004. The Entrance Point eastern spit migrated eastwards by about 2.2 km between 1973 and 2009, welding to the coastline after 2004, creating a narrow lagoon with an opening to the west. The pipeline shore crossing will be near the centre of the barrier spit, cross a shallow lagoon (subtidal), and intertidal sand flat.

The barrier spit is unvegetated in the area of the pipeline crossing and there are no benthic primary producer habitats (BPPH) on the subtidal lagoon habitat. On the mainland shoreline, a narrow band of mangroves, primarily *Avicennia marina*, occurs near the western end of the lagoon. Mangroves are sparse near the proposed shore crossing (a few scattered seedlings) and are absent further eastwards.

Chevron initially considered four options for bringing the pipelines to shore:

1. Horizontal Directional Drilling (HDD) from onshore out beneath the lagoon and barrier spit to a location seaward of the spit.
2. Bringing the pipeline to the Product Load out Facility (PLF) jetty head and then across the beach via the PLF jetty.
3. Micro tunnelling beneath the lagoon from an onshore site to a location seaward of the barrier spit.
4. Excavating a trench through the lagoon and barrier spit, then pulling the pipeline through the trench and backfilling the trench after the pipeline has been buried.

Options 1 and 2 were rejected by Chevron for engineering reasons (Option 1) and technical reasons (Option 2). Micro tunnelling is the preferred option for Chevron. Trenching is also being investigated as a fallback option if detailed studies show micro tunnelling is not possible.

Micro tunnelling would commence in the dune system landward of the lagoon, extend under the lagoon and emerge in the nearshore zone approximately 100-200 m seaward of the barrier spit. There would be no direct impacts on the lagoon and Ashburton Delta arising from this option.

Trenching would require construction of two parallel rock berms across the lagoon and barrier spit to a location 200 m seaward of the spit. The berms may be 40-50 m apart and would be joined at the seaward end. Inside this work area, a coffer dam would be constructed to produce an excavated trench about 6 m wide with a floor level of -6 m chart datum (CD). Once the pipelay trench is constructed, the seaward end of the dam would be opened and the pipeline pulled through the trench from onshore. Once the pull is completed the trench would be backfilled to as close to the original bathymetry as possible, and the sheet piling for the coffer dam and the two rock groynes removed. This work would take approximately 30 months to complete.

Pre-installing 2.5 m diameter casing pipe or culverts for possible future campaigns would require considerable initial expense but, once installed, there would be no need for further excavations through the lagoon. Alternatively, future projects could construct their own pipeline shore crossings, serially impacting the lagoon.

There are three areas of potential environmental effects of the shore crossing:

- terrestrial
- lagoon
- offshore

Terrestrial effects caused by micro tunnelling would be construction of an access road through the sand dune and disturbance of an area seaward of the dunes for the tunnelling.

As micro tunnelling would commence in the dune system landward of the lagoon, extend under the lagoon and emerge seaward of the barrier spit, there would be no direct impacts on the lagoon.

A small channel would be constructed to allow a pipelay vessel into shallow water to join the shore pipe with the offshore pipeline. Channel dredging would have only minor environmental effects which will be assessed separately.

The environmental effects of trenching would be much larger. Onshore there would be quarrying in the source area for the trenching rock. The access road to Ashburton North, laydown areas on the southern side of the sand dunes, the excavation through the sand dune and the terrestrial area affected on the shoreward side of the dune would all be much larger than for micro tunnelling. There may also be alteration of coastal processes responsible for terrestrial dune formation. There would also be a need to store the material excavated from the trench in ponds on shore, some of which may be potential acid sulphate soil (PASS) and require neutralisation.

There would be very limited destruction of mangrove seedlings and samphires during construction of the trench, as most of the intertidal habitat is unvegetated sand. The EPA is likely to view this area as potential BPPH. Water flows east of the causeway would be interrupted while the trench is in place. This can be ameliorated by constructing a channel through the barrier spit to allow water to flow into and out of the lagoon to the east of the causeway.

Except for the small patch of stunted shrubs on the mainland side near the proposed causeway, there are currently no mangroves east of the trenching area. If the lagoon retains its present form, the eastern area may also be considered as potential BPPH. Tidal circulation would be modified to the west of the causeways, with some modification of the present sand flats on the landward and seaward sides of the lagoon. This might modify the potential for mangrove colonisation in the area.

Sediment deposition in mangrove areas might bury the aerial root system. Trenching could potentially release sediment during construction and is also more vulnerable to cyclones affecting sediment containment measures.

There would also be effects on the present lagoon system during removal of the groynes, and it is probable there would be some rocks remaining after the groyne is decommissioned.

As with micro tunnelling, trenching would require the development of an offshore channel to allow the pipeline to be joined. Trenching would require a larger channel, increasing the potential environmental impacts.

In addition, the groynes would extend beyond the beach into the open sea, causing changes to nearshore circulation patterns. It is likely that some sediment accretion would occur on the western side of the groynes and erosion on the eastern side while they are in place.

The environmental effects of the trenching option are significantly larger than for micro tunnelling in all three areas: terrestrial, lagoon, and offshore.

From an environmental perspective, micro tunnelling is the preferred option. It avoids construction in a difficult engineering environment. Micro tunnelling impacts are largely confined to the terrestrial environment and there would be no impact to the intertidal lagoon area or adjacent mangroves. In addition, micro tunnelling demonstrates to the EPA that Chevron has endeavoured to avoid impacts to the Ashburton Delta mangrove system by using best practice technology.

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Introduction

1.1 Wheatstone Project

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

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). The assessment of the potential impacts of the proposed pipeline shore crossing route presented in this report has been conducted to support the environmental impact assessment process.

1.2 Need for the Pipeline Route

The Wheatstone Project is planned for an area identified for major infrastructure development projects at Ashburton North, 12 km east of Onslow. Wheatstone is planned to be the first LNG project to be developed. The original concept was to have all of the Wheatstone facilities in the Ashburton North Strategic Industrial Area (SIA) at Hooley Creek.

The Wheatstone Project is being planned to incorporate requirements from other potential plants to be built on the site. This includes development of a common user corridor for pipelines from the sea to the various plants (Figure 1-1). To ensure there is sufficient space, the proposed pipeline corridor has been moved slightly to the west, where it will cross a small lagoon that has developed in recent years at the north-eastern corner of the Ashburton Delta.

1 Introduction

Figure 1-1 Map showing the location of the proposed pipeline corridor

1.3 Objectives

The present study evaluates the potential environmental impacts of the pipeline shore crossing through the lagoon on the Ashburton Delta. This study includes consideration of a range of options for completion of the pipeline shore crossing that are being assessed by Chevron from both engineering and environmental perspectives.

Ashburton System

2.1 Environmental Values

The Western Australian EPA and other agencies have long recognised the importance of mangroves to benthic primary production processes and in the provision of habitat for a variety of other organisms. As part of the studies for the Wheatstone project, URS is currently developing an ecological model of the Ashburton Delta and Hooley Creek systems.

Over a number of years, Dr Vic Semeniuk produced a seminal body of work (e.g. Semeniuk 1983; 1985; 1986; 1993a; 1993b; 1996; 1997; Semeniuk et al. 1978) that has considerably enhanced scientific understanding of mangroves in Western Australia, particularly in the Pilbara region. These studies demonstrated that the Pilbara contains the largest single area of relatively undisturbed tropical arid zone mangroves in the world, making the Pilbara mangroves of global significance. Like other arid zone mangrove assemblages, Pilbara mangroves are characterised by a number of features, as follows:

- they are open woodlands and shrublands with relatively low biological productivity;
- they are subject to extreme stress due to the absence of freshwater and presence of high salinity;
- trees are small and species diversity is low; and
- associated flora and fauna communities are not complex.

The EPA (2001) produced guidelines for the protection of Pilbara mangroves, largely based on the Semeniuk (1997) discussion of the regional significance of Pilbara mangrove areas. Semeniuk (1997) used the following characteristics to assess the significance of individual areas:

- ecological reasons pertaining to productivity, feeding grounds, and fish nurseries
- scientific reasons of heritage, research and education
- preservation of biodiversity.

Specific criteria used were:

- extent or rarity of the habitat
- internal diversity of the habitat
- ecological significance of a given stand
- nationally to internationally significant features of a given site

A series of four categories was developed with Category A: Extremely Special Areas being the most significant mangroves.

The EPA (2004) later developed a strategy for the protection of Benthic Primary Producer Habitats (BPPH), which was recently updated (EPA 2009). The basis for this strategy is that most of the primary (plant) production which provides the energy sources used by the animal secondary consumers in the Western Australian marine environment is provided by benthic rather than planktonic plants. Conservation of benthic primary production is critical to maintenance of marine ecosystems.

Mangroves are considered by the EPA to be one of the key BPPH. Category A habitats are afforded the highest degree of protection. The EPA considers that “No development activities should take place in these areas, nor should there be any development elsewhere, that would cause direct or indirect damage/loss of benthic primary producer habitat or ecological integrity of these areas”. There should be no cumulative loss of BPPH in these areas (EPA 2009). The document continues “The EPA will give benthic primary producer habitat in these areas the highest degree of protection and as such proponents should be aware that, where development related activity in these areas would cause the damage/loss of benthic primary producer habitat or pose a substantial risk to ecological integrity, the EPA will adopt a presumption against finding the proposals environmentally acceptable.

The Ashburton Delta is one of the Category A areas afforded the highest protection levels by the EPA.

2.2 Ashburton Delta

Damara (2009) recently described the Recent geological history of the Ashburton River delta (Figures 2-1 and 2-2), concluding that the delta was produced by interactions between low to intermediate wave energy, strong littoral drift, the micro- to mesotidal regime and low to moderate fluvial discharge. All of these factors can be overwhelmed by extreme conditions which occur during tropical cyclones. The key feature is that the active Ashburton deltaic plain is highly dynamic. There is substantial evidence of historical change in the location of the river entrance from Entrance Point to the present day river mouth. Damara (2009) considers this to be essentially a transition from deposition covering and flanking a lithified chenier plain to development of a wholly unconsolidated landform, and suggests that this "raises questions about the stability of the modern delta and the potential movement of sediment along the coast towards Beadon Creek as the form and position of the delta changes".

The Pilbara coastline has been divided into a series of sediment cells. Each sediment cell is a section of the coast, including both the nearshore terrestrial and marine environments, within which movement of sediment is readily identifiable if not largely self-contained (Damara 2009). The net sediment movement in the Ashburton compartment is from west to east, but this can be reversed by prevailing winds.

2.3 Dynamic System

Damara (2009) reported that at least since the Quaternary, the Ashburton River has been shifting its course, resulting in the development of a suite of coalescing deltas. The deltaic plain consists of overlapping and inter-fingering delta lobes set against a north-west trending rocky shore. At any period there have been few channels, with a single channel conveying most of the river outflow and sediment. The location of the main outflow changed periodically as the delta developed. The delta is asymmetrical as sediment has accumulated on a series of chenier spits on the eastern side of its mouth in the last 600 years. As the successive cheniers have developed they have been in filled by sediment. Mangroves have established and developed into a series of mangal communities.

2 Ashburton System

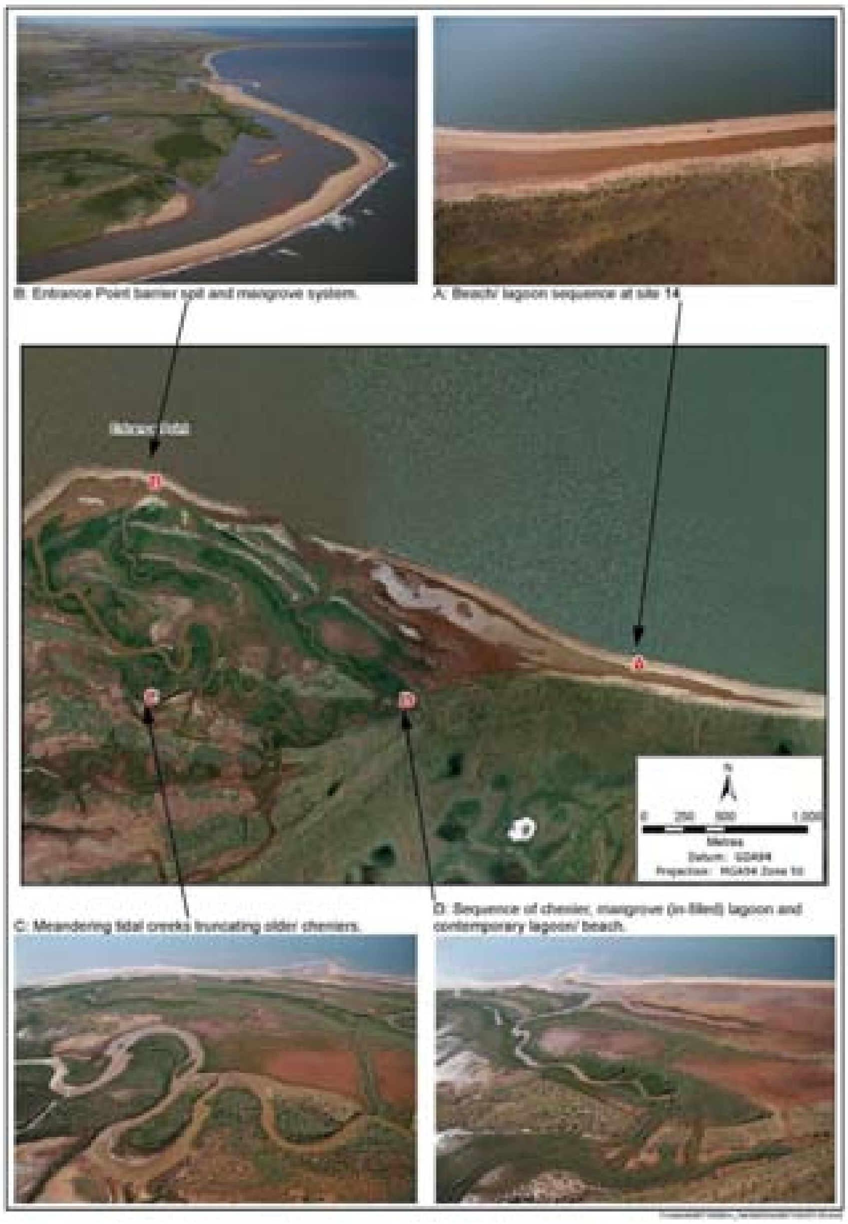

Figure 2-1 Ashburton Delta from the air showing the location of the north-eastern lagoon (from URS 2009)

2 Ashburton System

2.3.1 Old Onslow

Damara (2009) provides a sequence of development of man-made structures in the Ashburton system that demonstrates the considerable mobility of the Ashburton delta. The town of Onslow was originally located on the margins of a deep pool approximately 6 km from the mouth of the Ashburton River. It was built to service the developing pastoral industry in the western Pilbara. The town was proclaimed in 1883. There was originally a small lighter landing that was supplemented by a riverside wharf constructed in 1885; the landing was expanded in 1893, though not without incident. Navigating the river entrance through the bar could be treacherous, a situation exacerbated by floods in 1894. The Ashburton entrance at the time was at Entrance Point (21°41'S; 114°57E), east of the current entrance. It could be used only by boats with a draught of less than 1.2 m.

To overcome the shallow, treacherous entrance to the facilities on the river, a 2,760 foot (841 m) timber jetty was constructed from the coastline out beyond the sandbar to deeper water east of the entrance, in the vicinity of the proposed pipeline crossing. The jetty was nearly complete in December 1897 when a severe Boxing Day storm removed most of the decking on the top of the jetty and loosened many of the support piles. The jetty was reconstructed 15 feet (4.6 m) above high water. The new jetty, completed in 1900, was 960 feet (293 m) and 14 feet (4.3 m) wide. The berthing head at the seaward end was 124 feet (38 m) long and 30 foot (9 m) wide. There was a platform at the shore end of the jetty with a rail line to Onslow. Silt from the Ashburton River eventually reduced the water depth at the head of the jetty, reducing its utility. To overcome this, a timber jetty was constructed at Beadon Point in the 1920s. The location of the new jetty and persistent flooding caused Onslow to be relocated to its present location.

2.3.2 Development of sand spit

Damara (2009) used several methods, including analysis of historical aerial photography, to trace the development of the Ashburton delta in recent decades (Table 2-1). There has been a series of changes during which the various channels have opened and closed in the five time periods which could be examined since 1973. The consistent feature has been that at all times there has been either one or two channels open; all three have not been open at the same time.

Table 2-1 Locations of openings through the sandbar of the Ashburton lagoon since 1973 (from Damara 2009)

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

In particular, the Ashburton East entrance closed between 2001 and 2004. As there were no significant flow events in the river during this period, Damara (2009) concluded that littoral drift overwhelmed the tidal flow. The Entrance Point eastern spit migrated eastwards by about 2.2 km between 1973 and 2009. Since 1993, the eastward migration has continued at a rate of about 100 m/yr. This spit welded to the coastline after 2004, at about the same time as the current western entrance opened. The entrance spit is welded to the shore about 500 m west of the proposed Wheatstone Plant Site. The present rates of eastward migration are uncertain, but historic rates have been very high. The barrier spit is a transitory feature; it could survive for years or could be removed by one or more cyclones approaching from the correct direction (Damara 2009; Dr Ian Elliot, pers. comm.).

Hence the lagoon, or parts of it, which has formed due to the protection provided by the spit, may also be considered as a transitory feature. The sand spit and lagoon system in the vicinity of the pipeline crossing is a recent formation (approximately 10-15 years) that is likely to have experienced considerable change due to the dynamic nature of coastal landform development in this section of the delta.

The intertidal habitats around the lagoon reflect the above in terms of their age and structure as evidenced by:

- soft, spongy sediment (i.e. of recent origin with little time for consolidation by sedimentological and biological processes)
- typically sparse coverage by mangroves and intertidal fauna.

2.3.3 Hooley Creek

In 1973 the entrance to Hooley Creek was located near the centre of the three tidal creeks (Damara 2009). There were two sand spits, each about 1.0 km long on the two sides of the entrance, with the western spit further offshore. The entrance bar configuration in 1993 was similar to the 2009 configuration, but the bar had deflated and progressively rebuilt during this period, most likely due to Tropical Cyclone Vance in 1999. The 2001 photography shows deflation of the entrance bar with isolated, disconnected subaerial bars in the entrance. By 2004 the western spit of Hooley Creek had re-established. It elongated by about 700 m between 2004 and 2009. The eastward migration of sand is expected under typical conditions.

The historic photography of Hooley Creek suggests the entrance spit is highly dynamic and has been deflated and rebuilt a number of times during the last 30 years, influencing tidal exchange to the creek system.

2.4 North-eastern Lagoon

A sandy barrier spit extends eastward for 3.2 km from Entrance Point until it joins the coastline beyond the eastern extremity of the Ashburton Delta (Damara 2009) (Figure 2-2). The spit is built of sediments transported eastward from the Ashburton River delta. The ocean beach at the western end of the spit has a moderate beach slope (1:8) with a berm at about the highest astronomic tide level (in the order of 3 m chart datum (CD). The profile gradually falls away towards the estuary where there is a steep silty bank that drops into the estuary mouth. Whilst the ocean beach is relatively straight, the estuary beach is sinuous with intermittent shoals. The western extremity of the spit has a thick assemblage of mangroves, primarily *Avicennia marina*.

A beach profile was also made by Damara (2009) midway along the Entrance Point eastern spit. The beach slope in this area is flatter (1:11) and the spit marginally wider. The spit impounds a shallow lagoon which is approximately 50 m wide at this site, with a narrow beach, low rocky cliff and high vegetated dunes evident on the landward side of the lagoon. The lagoon was surveyed at one location by URS in November 2008 and found to have a depth in the order of minus 3 m CD.

2 Ashburton System

Figure 2-2 Aerial view of the Entrance Point area with the lagoon extending eastwards (photo taken during high tide)

The eastern spit of Entrance Point welds to the beach approximately 500 m west of a prominent salient. The coastline faces due north at this location and the beach is more than 100 m wide. Beach slope west of the salient is about 1:13 with a berm level in the order of 3 m CD and a wide, overwashed beach in the order of 100 m wide. There is a sparsely vegetated low spinifex foredune backed by high primary dunes. A low rock cliff evident landward of the spit extends along the lagoon shore and the back of the beach at this location. Isolated rock levels surveyed along this shore are in the order of 2.5 m CD and appear to fall away between the spit weld and the salient, resurfacing in isolated areas at the salient (Damara 2009).

The lagoon is connected to tidal creek systems in the eastern delta, and forms part of the tidal network, with the entrance at its western end held open by tidal flows. The spit impounds a shallow lagoon. Connection of the lagoon to the ocean reduces the hydraulic resistance of the flow pathway from the Ashburton River, which is presently only a breakout from the river to the coastal lagoon. These lagoons are an interface between the oceanic and delta tidal ecosystems.

The approximate location of the pipeline shore crossing is shown in Figure 2-2 and the habitats that the pipeline corridor traverses are shown in Figures 2-3 and 2-4. Habitats within the pipeline corridor consists of which a narrow unvegetated beach, a shallow muddy lagoon (subtidal) and a broad intertidal sand flat witch currently supports a very low density of mangrove seedlings (Figure 2-4).

2 Ashburton System

Figure 2-3 Habitats in Vicinity of Pipeline Corridor (photo taken during low tide)

Figure 2-4 Intertidal sand flat within the pipeline corridor. Supporting a very low density of seedlings

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Ashburton Lagoon Survey

3.1 Purpose

URS (2009) undertook a broad examination of intertidal habitats along the Onslow coastline to place the Ashburton North site into a regional context. Particular emphasis was placed on the Ashburton North SIA and the Ashburton River delta. Three sites were examined on the north-eastern lagoon of the Ashburton Delta. However, the URS (2009) study was made before the proposed pipeline shore crossing was moved to the present site. Accordingly, URS conducted a survey of the north-eastern lagoon in December 2009 to provide more detail on the lagoon.

3.2 Methods

3.2.1 Fieldwork schedule

The fieldwork was undertaken as follows:

- Monday, 7 December. Fly Perth to Karratha, obtain last minute supplies in Karratha, drive to Onslow and prepare for field work on the following days.
- Tuesday, 8 December. Preliminary visual reconnaissance of the eastern corner of the lagoon. Transect work commenced at the western end of the survey area. The westernmost transect was surveyed first, then transects were established every 300 m proceeding east. A total of three transects and 22 stations were made during the day. A preliminary examination was also made of the intertidal portions of the area to be used for geological investigations by Chevron. Field notes on the day's work were written up during the late afternoon and evening.
- Wednesday, 9 December. Transects were continued every 300 m to the east across the intertidal mudflat until the easternmost corner of the lagoon was sampled. A total of eight transects and 28 stations were made during the day. Field notes on the day's work were written up during the late afternoon and evening.
- Thursday, 10 December. A single transect was surveyed 150 m to the east of the proposed pipeline route. The intertidal areas of the proposed boreholes and the corridors to be used by the mud buggy were surveyed to provide data for the Vegetation Clearing Permit application. Field notes on the day's work were written up during the late afternoon and evening.
- Friday, 11 December. The Onslow accommodation was vacated and the group drove to Karratha Airport for the flight to Perth.

3.2.2 Survey methods

To collect information on the intertidal flora and fauna, a series of transects was surveyed (Figure 3-1). The transects typically started at the landward edge of the lagoon flat and extended to the lagoon shoreline.

Following the preliminary survey of the lagoon, the first transect was established at 7601388N; 241693E, the furthest point west of the survey. Further progress west was blocked by an intertidal creek (Figure 3-1). In this area, mangroves are dominated by *Avicennia marina* in an open shrubland near the creek channels. The habitat closer to the lagoon is a sandflat with scattered seedlings. The following procedures were employed:

- Transects started in the seaward tree zone of the mangroves and ran directly to the lagoon.
- A 10 x 10 m quadrat was marked with surveyors tape; quadrats were spaced every 20 m. All mangroves within the quadrat were identified and their height measured to the nearest 5 cm.


Onslow
Ashburton North
Transect 1
Transect 2
Transect 3
Transect 4
Transect 5
Transect 6
Transect 7
Transect 8
Transect 9
Transect 10
Transect 11
Transect 12
Legend
Mangrove survey area site
Transect
Indicative Terrestrial Project Area
Datum: GDA94
Projection: MGA94 Zone 50
Client
CHEVRON AUSTRALIA PTY LTD
URS
Project
Wheatstone Project
Title
Mangrove Field Survey- Transect Locations
Drawn: MR
Approved: LS
Date: 23/12/2009
Job No.: 42907100
Figure: 3-1
Rev. A
A3

- A Global Positioning System (GPS) reading was made at the north-east corner of each quadrat. One or more digital photographs were also taken of each quadrat.
- After Transect 3, samphire plants were also counted. The percentage cover of mangroves and samphires was estimated independently by the three surveyors and a consensus estimate obtained.
- Some quadrats with dense seedlings were sub-sampled using a 5 x 5 m corner of the larger quadrat and the data adjusted to the full quadrat size.
- Three 1 x 1 m quadrats were established outside the mangrove quadrat to measure crab density. The number of fresh holes in each quadrat was counted. Crabs that emerged were identified to the lowest practical level in the field.
- Transect 6 occurred at approximately the site of the proposed pipeline route. Additional transects (5 and 7) were surveyed 150 m to the east and west of Transect 6 to provide more detailed coverage of this area.

3.3 Mangroves along the Lagoon Shoreline

Mangroves along the lagoon shoreline consisted of a narrow band near the western end of the lagoon, and sparse coverage of low (seedling size) plants near the proposed pipeline crossing area. Further east they were largely absent (i.e. very occasional single seedlings). This distribution reflects:

- the relatively young periods of time that the lagoon and associated intertidal sandflat have existed (i.e. habitat suitable for mangrove colonisation is only recent for most parts of the lagoon)
- the dynamic nature of coastal landform development.

Mangroves were best developed on Transect 1 (the westernmost transect), near the junctions of the tidal creeks (Figures 3-2 and 3-3; Table 3-1) where they formed a low shrubland. Two of the three key characteristics measured [mean height of mangroves (50 ± 4 cm) and mean coverage (30 ± 15%)] were greatest on Transect 1 (Table 3-1), and the mean number of mangroves/100m^2 (77 ± 30) was also high.

The mean number of mangroves/100m^2 was highest (124 ± 100) at Transect 2, but was also high at Transect 3 (77 ± 30). Mean height of mangroves was similar (29 ± 1 cm at Transect 2 and 28 ± 1 at Transect 3), but the percentage cover decreased on both transects (16 ± 9 % at Transect 2 and 10 ± 6 % at Transect 3). This reflects the fact that both transects had large numbers of small seedlings (Figure 3-4), though some large shrubs were present on Transect 3.

There was also a pattern at Transects 1 to 3 of mangroves being larger and more abundant in a narrow zone next to the small tidal creek and the density of mangroves (mangroves/100m^2) dropped sharply further seaward of the tidal creek. The relatively few mangroves in the lower (more seaward) quadrats of each transect were all small, with a high proportion being seedlings.

Transects 4-6 were characterised by much lower densities of mangroves (7-13 mangroves/100m^2) that were generally seedlings, providing very low percentage cover (1% and 2% on Transects 4 and 5 respectively and 9% on Transect 6). Transect 5 is the proposed location for the pipeline route (see Figure 2-4).

There was a low number (7 ± 3/100m^2) of mangroves at Transect 7 (Figure 3-4). They were generally low shrubs (mean height 61 ± 5 cm), though none were large; the maximum height was about 125 cm (Figure 3-3). These shrubs can be seen on Figure 3-1, which showed that the area was physically

3 Ashburton Lagoon Survey

different from the adjoining transects. It was a remnant shoreline from the time that the bar was formed in the 1980s, and the area had firmer sand than the adjoining transects. Mangroves on Transect 7 appeared to be older than the seedlings in the surrounding area, probably dating back to the early 1980s. They had developed a broad structure but were stunted. They appeared to be surviving under adverse conditions and were not thriving, as is shown by the very low number of small mangroves (<25 cm) found on the transect (Figure 3-4). Those small mangroves present had several branches, suggesting they were several years old.

East of Transect 7 the lagoon narrowed considerably. There were two quadrats on Transect 7, but Transects 8 to 12 had only one quadrat each due to the lack of available habitat. A single seedling about 10 cm high was found on Transect 9; the remaining transects had no mangroves. Visual examination demonstrated that the absence of mangroves in the transects was representative of the eastern half of the lagoon; there was a very limited number of small seedlings in this section of the lagoon that were likely to be 1-2 years old. Figures 3-5 and 3-6 show a largely bare sand flat fringing a narrow lagoon at transects 8 and 11 respectively.

Table 3-1 Mangrove data from 12 transects sampled in the north-eastern lagoon of the Ashburton Delta in December 2009

Transect Number	Number of Quadrats	Total Number of Trees	Mangrove Height (cm) Mean ± 1SE	No. Mangroves /100m² Mean ± 1 SE	Mangrove Percentage cover (%) Mean ± 1 SE
1	6	464	50 ± 4	77 ± 30	30 ± 15
2	5	619	29 ± 1	124 ± 100	16 ± 9
3	13	1000	28 ± 1	77 ± 31	10 ± 6
4	11	65	21 ± 1	6 ± 2	1 ± 0
5	11	71	20 ± 1	7 ± 2	2 ± 1
6	8	103	33 ± 2	13 ± 7	9 ± 3
7	3	20	61 ± 5	7 ± 3	10 ± 7
8	2	0	None	0	0
9	1	1	10	1	0
10	1	0	None	0	0
11	1	0	None	0	0
12	1	0	None	0	0

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Figure 3-2 Mangroves fringing the tidal creek at Transect 1

Figure 3-3 Lower mangroves further seaward, than Figure 3-2 (on Transect 1)

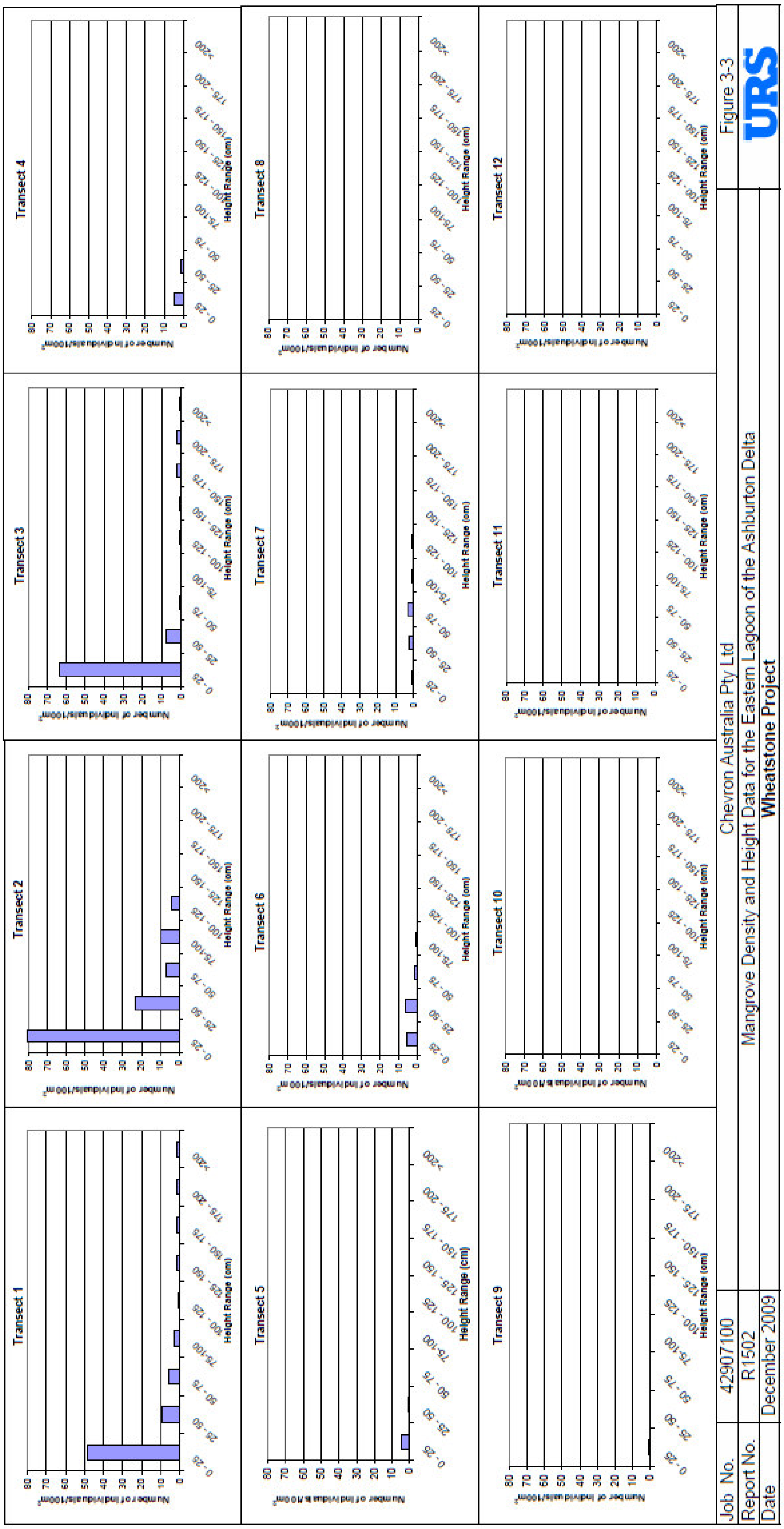

Figure 3-4 Height of mangroves on 12 transects in the north-eastern lagoon of the Ashburton Delta sampled in December 2009

3 Ashburton Lagoon Survey

Figure 3-5 Largely bare sand flat fringing the lagoon at Transect 8

Figure 3-6 Narrow lagoon at Transect 11

3.4 Crustaceans along the Lagoon Shoreline

Crabs dominated the invertebrate biota of the transects and there were some gastropod molluscs, as described below.

The quadrats on Transect 1 had a mean abundance of crabs of 8.0 m^{-2}, split between fiddler crabs (*Uca*), which dominated and sesarmids. The upper quadrat of Transect 2, in the mangrove zone, had a mean crab density of 17.0 m^{-2}. The sediment was wet when these samples were taken, and many of the crabs were up and actively moving about.

The lower quadrats on Transect 2 had a mean crab density of 2.4 m^{-2}, dominated by the sand crab *Scopimera*, with a small proportion (10%) being *Ocypode*. In contrast, by the time these transects were sampled the sand had dried out and the crabs had retreated to their burrows. Crabs were identified using fresh burrows. *Ocypode* has a much larger burrow than *Scopimera*, which has a characteristic pattern of sand pellets in front of the burrows. Subsequent transects were all sampled when the shore was dry, and counts were based on fresh burrows. *Scopimera* had a total density of 4.4 m^{-2} on Transect 4, but this dropped to 0.9 m^{-2} on Transect 6. Crabs were rare or absent on all subsequent transects.

Although the tide had dried the sand out, small tracks of the potamidid snail *Cerithidea cingulata* were present in some areas. The snails had burrowed into the sand as it dried. These were most abundant on the first few transects, up to about Transect 4. The few individuals that could be seen on the sand surface were all juveniles, 6 mm or less in total length.

Pipeline Construction

4.1 Initial Options Considered

Chevron initially considered four options for bringing the pipelines to shore:

1. Horizontal Directional Drilling (HDD) from onshore out beneath the lagoon and barrier spit to a location seaward of the spit where minor excavation would be required to link the pipeline to the well.
2. Bringing the pipeline to the PLF jetty head and then across the beach via the PLF Jetty.
3. Micro tunnelling beneath the lagoon from a site onshore to a location on the seaward side of the barrier spit, also requiring minor offshore excavation to link the tunnel to the pipeline.
4. Excavating a trench through the lagoon and barrier spit, then pulling the pipeline through the trench and backfilling the trench after the pipeline has been buried and lagoon and spit bathymetry re-instated.

Option 1 is not considered to be feasible for the size of pipeline required, but HDD could be considered in future for smaller pipelines that are technically feasible. However, the environmental considerations of the high potential for release of drilling fluids into the ocean must be carefully evaluated. Option 2 is not considered feasible for safety reasons.

Construction of the pipeline shore crossing using Options 3 or 4 is considered technically feasible and is being further investigated by Chevron. On an engineering basis, micro tunnelling is currently the preferred option and is actively being investigated. Trenching is also being investigated as a fallback option if detailed engineering studies show that micro tunnelling is not possible.

4.2 Preferred Option: Micro Tunnelling

Micro tunnelling as required by each of the potential projects in the Ashburton North development area reduces the environmental impact and requires less up front pre-investment. It is also more flexible should requirements for future projects change. Micro tunnelling enables Chevron, or other future users, to install a casing pipe approximately 2.5 m diameter with a tunnel boring machine that has little impact on environmentally sensitive areas. Space is required for a tunnel shaft and laydown area, but these can be placed in suitable areas from environmental and heritage perspectives. There would be no need for special equipment or any onshore equipment apart from the tunnel boring machine for construction of the shaft and tunnelling laydown areas.

Current estimates of micro tunnelling are:

- approximate location of the micro tunnel pit: 292476E; 7600656N
- micro tunnelling overall site area: 5,980 m^2 (this however does not include tunnel spoil areas)
- micro tunnel pit area: 15 m x 20 m x 3 m
- excavation (per tunnel): 2.5 m diameter x 1350 m long (6,630 m^3)
- cuttings pit: 5 m x 6 m (30 m^2)
- bentonite storage: 6 m x 3 m (18 m^2)
- water storage: 12 m x 8 m (96 m^2)
- intermediate pipe storage: 30 m x 30 m (900 m^2).

(The intermediate pipe storage area is a temporary holding area for pipe being immediately used in the tunnel. An additional area is required for the total tunnel pipe.)

The total construction duration for a single pipeline using micro tunnelling is approximately nine months.

It is considered likely that, should Chevron require a second tunnel, construction would utilise a second tunnel boring. Seasonal effects would be limited because tunnelling operations are not affected by the weather.

4.3 Alternate Option: Trenching

A trench approximately 50 m wide would be dug and 2.5 m diameter casing pipe or culverts that could be used for the possible future campaigns would be pre-installed. This involves a large pre-investment in materials, but there would be no requirement for further work in the lagoon. The initial impact on the mangrove region could be quite high considering the corridor width required to pre-install potentially six to eight culverts/casings. Expensive offshore installation equipment and dive spreads would also need to be mobilised in order to install the offshore section of the culverts into water depths that could be accessed by dredging equipment for installing future pipelines.

Trenching would require constructing two parallel rock berms across the lagoon and barrier spit to a location 200 m seaward of the spit to provide support for excavating, earthmoving and pile driving plant and equipment. These berms may be 40-50 m apart and joined at the seaward end. A coffer dam would be constructed inside this work area to produce an excavated trench approximately 6 m wide with a floor level of -6 m chart datum (CD). It is anticipated that the coffer dam could be dewatered so excavation could be conducted in the dry and that excavated material would be stored onshore.

Once the pipelay trench is constructed, the seaward end of the dam would be opened and the pipeline pulled through the trench from onshore. On completion, the trench would be backfilled to restore the original bathymetry. The sheet piling for the coffer dam would be removed and the two rock would be removed by excavators working from seaward back to shore. It is anticipated this work would take approximately 30 months to complete.

If culverts are not pre-installed, trenching could be repeated another two or three times over the next 25 years as additional pipelines are brought ashore for other developments.

The land take requirements and specific locations for the trenching operation are listed below. All figures are approximations:

- winch pad location: 292472E; 7600666N
- open cut overall site area: 420,000 m^2
- winch pad area: 50 m x 100 m (5,000 m^2)
- trench width: 25 m
- equipment and material storage: 60 m x 90 m (5,400m^2)
- general materials storage: 175 m x 115 m (20,25m^2)
- trench material stockpile: 200 m x 325 m (65,000 m^2)
- rock berm stockpile: 160 m x 120 m (19,200 m^2)
- offices / mess / etc.: 30 m x 45 m (1,350 m^2).

The trenching operation would take approximately 22 months. It would require the use of offshore dredging equipment working in tandem with onshore equipment in order to construct a trench wide enough to accommodate up to potentially eight culverts. This method will have a very high exposure to seasonal weather patterns.

Potential Environmental Impacts of the Pipeline Route

A workshop to consider the environmental risks posed by the two options for the pipeline shore crossing was held at URS on 15 December 2009. The meeting comprised representatives from Chevron, URS and Damara WA. The following section is based on the risks assessed by the workshop. Two options were considered:

- micro tunnelling
- trenching.

5.1 Micro Tunnelling

There are three areas of potential environmental effects of micro tunnelling:

- terrestrial
- marine lagoon
- offshore

5.1.1 Terrestrial

Terrestrial effects caused by micro tunnelling would be construction of an access road through the sand dune, storage of material excavated from the tunnel and disturbance of an area seaward of the dunes for the actual micro tunnelling. Broad-scale vegetation mapping of the dune has already been undertaken, but further specific vegetation survey may be required and heritage issues would also need to be addressed. Note that these requirements are common to both micro tunnelling and trenching.

5.1.2 Marine lagoon

As micro tunnelling would commence in the dune system landward of the lagoon, extend under the lagoon and emerge in the nearshore zone approximately 100-200 m seaward of the barrier spit, there would be no direct impacts on the lagoon and Ashburton Delta arising from this option.

5.1.3 Offshore

Micro tunnelling would require construction of a small channel to allow a pipelay vessel into shallow water to join the shore pipe with the offshore pipeline. This work would probably be undertaken by backhoe dredge and would involve only a small volume of excavation. Channel dredging would be assessed separately with the other components of the marine construction of the pipeline. Note that these requirements are common to both micro tunnelling and trenching. Habitat mapping surveys have not detected any BPPH (e.g. seagrasses, corals) in this area, the seafloor comprising barren and bioturbated silty sands.

5.1.4 Summary

From both engineering and environmental perspectives, micro tunnelling is the preferred option because it avoids direct impacts to the eastern lagoon.

5.2 Trenching

As with micro tunnelling, the potential environmental effects of trenching can be divided into three areas:

- terrestrial
- marine lagoon
- offshore.

5.2.1 Terrestrial

Onshore there would be environmental effects arising from quarrying in the source area for the rock for the trenching. The laydown areas on the southern side of the sand dunes, the excavation through the sand dune and the terrestrial area affected on the shoreward side of the dune would all be much larger than for micro tunnelling. There may also be a need to store the material excavated from the trench in ponds on shore, some of which may be potential acid sulphate soil (PASS) and require neutralisation.

5.2.2 Marine lagoon

There would be very limited destruction of mangrove seedlings and samphires during construction of the trench, as most of the habitat is at present unvegetated sand. While this area is not mapped as existing mangrove habitat due to low seedling density, the EPA is likely to view this area as potential BPPH in accordance with guidance provided in Environmental Assessment Guidance No. 3 (EPA 2009). Water flows east of the causeway would be interrupted while the trench is in place. This can be ameliorated by constructing a channel through the barrier spit/beach to allow water to flow into and out of the lagoon to the east of the causeway.

Except for the small patch of stunted shrubs on the mainland side near the proposed causeway (Transect 6, Figure 3.1), there are currently no mangroves east of the trenching area. If the lagoon retains its present form, the area to the east of the proposed pipeline route may also be considered as potential BPPH.

Tidal circulation would be modified to the west of the causeways, with some modification of the present sand flats on the landward and seaward sides of the lagoon. This may modify the potential for mangrove colonisation in the area.

An additional potential indirect impact to adjacent mangrove stands exists from the release of sediment during construction activities (e.g. excavation and other earthworks) and the deposition of that sediment amongst mangroves.

The deposition of sediment within mangrove areas has the potential to cause impacts to mangroves if the depositing material accumulates in excess of natural sedimentation rates and to sufficient depths to bury the aerial root system. Sediment containment measures within the breakwater and trench would also be vulnerable to cyclones.

There would also be effects on the present lagoon system during removal of the groynes, and it is probable there would be some rocks remaining after the groyne is decommissioned.

5.2.3 Offshore

As with micro tunnelling option, trenching would require the development of an offshore channel to allow the pipeline to be joined. Trenching would require a longer channel, increasing the potential environmental impacts.

In addition, the groynes would extend beyond the beach into the open sea, causing changes to nearshore circulation patterns. It is likely that some sediment accretion would occur on the western side of the groynes and erosion on the eastern side.

5.2.4 Summary

The environmental effects of the trenching option are significantly larger than for micro tunnelling in all three areas: terrestrial, lagoon, and offshore.

5.3 Conclusions

Environmentally, micro tunnelling is clearly the preferred option. It has limited impacts generally and has no impact to the intertidal lagoon area or adjacent mangroves. In addition, micro tunnelling demonstrates to the EPA that Chevron has endeavoured to avoid impacts to the Ashburton Delta mangrove system by using best practice technology.

The potential environmental effects of trenching are much greater. Environmental impacts would be temporary in an area that is subject to considerable modification by cyclones and other storm events. The potential indirect effects to adjacent mangroves and the lagoon system are more significant and would require considerably more management measures to ensure protection of nearby mangroves and the maintenance of tidal flows to the eastern section of the lagoon. In addition there is more uncertainty in the potential effects of trenching when compared to micro tunnelling.

Additional pipeline shore crossings may be required in future for other developments at the Ashburton North SIA. If so, the potential environmental effects of future micro tunnelling projects would be similarly small. However, repeated trenching would magnify the potential environmental effects of a single trenching operation and present increased longer term risk to the lagoon environment. The lagoon environment may recover from a single trenching operation, yet be degraded by several trenches being built at intervals of a few years.

It should be noted that on the basis of recent EPA assessments of other pipeline shore crossings through mangrove areas in the Pilbara, it is expected that the EPA would strongly favour micro tunnelling.

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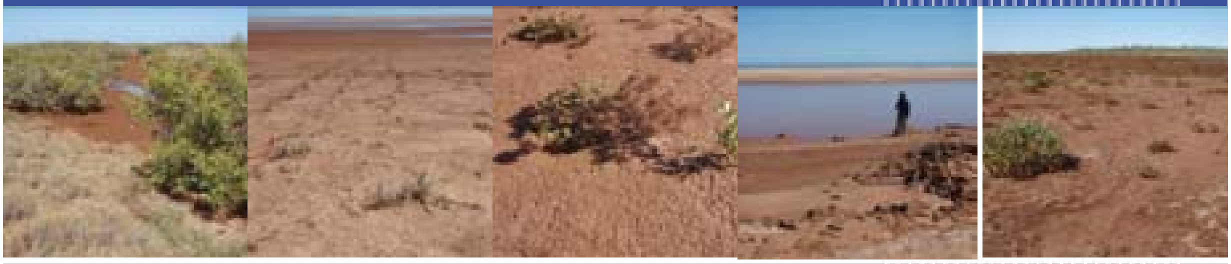

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Appendix N15

Benthic Primary Producer (Seagrass and Macroalgae)
Habitats of the Wheatstone Project Area

Tables

Figures

Photographs

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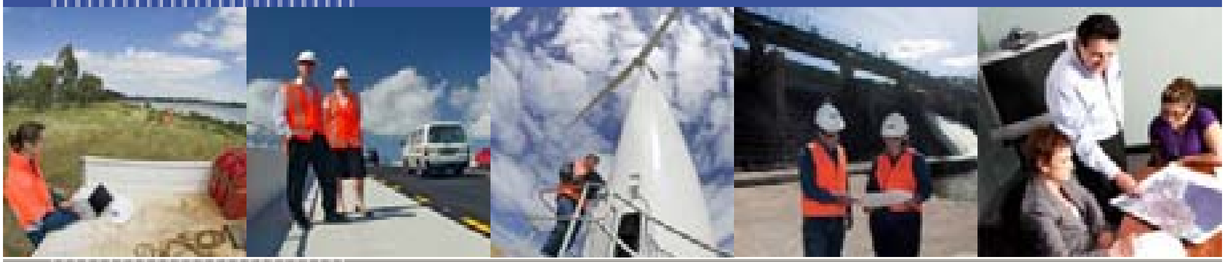

Report

Benthic Primary Producer (Seagrass and Macroalgae) Habitats of the Wheatstone Project Area.

5 MAY 2010

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Executive Summary

To support an Environmental Assessment and approvals for a proposed LNG facility on the Pilbara coast, Chevron Australia Pty Ltd (Chevron) is currently undertaking the background environmental studies needed to develop the documents required for the Commonwealth and Western Australian government approval processes. The present report details the potential loss of seagrasses and macroalgae when the Project is constructed.

Seagrasses are marine flowering plants that can occur in a variety of habitats, but flourish in shallow, protected, nearshore waters. Nearly half of the 60 known species in the world occur in Western Australia, and there are extensive, highly productive, seagrass meadows (large areas of extensive seagrasses that are hundreds of square metres or larger in area) south of Shark Bay. In contrast to the southern areas, the twelve species of seagrasses known to occur in the Pilbara form only local areas of small, transitory seagrasses with 10% or less of the biomass of their southern counterparts. However, tropical seagrass areas constitute important feeding grounds for dugongs and green turtles.

Macroalgae in North-Western Australia (Kimberley and Pilbara) are poorly known, but there may be as many as 500 species. Macroalgae perform a variety of ecological roles including being a food source and providing habitat and shelter for animals (including fish). As decomposing organisms they provide source materials for detritivores.

Seagrasses and macroalgae in the Pilbara are all species that have wide geographical distributions. There are no known areas of high density or diversity of seagrasses or macroalgae in the Wheatstone Project Area.

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Introduction

1.1 Background

To support an Environmental Assessment and approvals for a proposed LNG facility on the Pilbara Coast, Chevron Australia Pty Ltd (Chevron) is currently undertaking the background environmental studies needed to develop the documents required for the Commonwealth and Western Australian government approval processes. As part of this work, Chevron contracted URS Australia to provide a description of seagrasses and macroalgae in Western Australia, specifically in the Pilbara region.

Primary production by plants forms the basis of most ecosystems in the oceans. As the ocean off Western Australia is oligotrophic, with low nutrient availability, there is a relatively low level of primary production by phytoplankton in the water column. Most of the primary production that provides the energy used by animals is generated by benthic primary producers. In recognition of the importance of benthic primary producer habitats (BPPH), the Environmental Protection Authority (EPA) developed a policy for protecting Benthic Primary Producer Habitats (EPA 2004). One of the criteria for the EPA assessment of the Wheatstone Project will be the potential effects of the project on BPPH. Several major types of primary producers are recognised:

- mangroves;
- cyanobacterial mats;
- corals (although animals, corals have symbiotic plant cells, or zooxanthellae, in their tissues that are important primary producers);
- seagrasses; and
- macroalgae.

The ecological importance of three of the BBPH in the Wheatstone Area (mangroves, cyanobacterial mats and corals) is already being examined by other studies (URS 2009; MScience 2009). The present project describes the ecological importance of the remaining two plant components of BPPH: seagrasses and macroalgae.

It should be noted that a recent Environmental Assessment Guideline developed by the EPA (2009) replaces the BPPH statement (EPA 2004), and includes filter feeders such as sponges. These are not included in the present study.

1.2 Objective

The objective of this study is to provide information to Chevron about benthic primary producer (seagrass and macroalgae) habitats as background information for use in the environmental assessment process for the Wheatstone development.

1.3 Scope of Work

Specifically the project will:

a) provide a desktop summary of benthic primary producer (seagrass and macroalgae) communities in the Wheatstone Project area, including any available information on their taxonomic composition, ecological role, areal extent and seasonality; and
b) assess the regional significance of seagrass and macroalgae in the Project Area.

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Seagrass

2.1 Seagrasses in Western Australia

2.1.1 Taxonomic composition

Seagrasses are marine flowering plants that can occur in a variety of habitats, but flourish in shallow, protected, nearshore waters. Worldwide seagrass diversity is relatively small, with approximately 60 species known. Half of the known species occur in Australia, including 16 endemic to the continent. Eleven of the 12 genera of seagrasses occur in Australian waters. Twenty-seven species of seagrasses occur in Western Australia (Kuo & McComb 1989). Thus Western Australia supports almost half the known species of seagrasses and it is likely that additional taxa from the State will be described (J. Kuo, cited in DEWHA 1994).

Records of seagrasses from southern WA are numerous and only major works will be listed here. Floristic treatments include Robertson (1984); overviews are provided by Kirkman & Walker (1989), Kirkman & Kuo (1996); and taxonomic revisions are included in Cambridge & Kuo (1979), Kuo & Cambridge (1984), Campey et al. (2000; 2002) plus others. Progressing northward, species lists for various regions are included in Kirkman (1997; WA generally), Huisman & Walker (1992, Rottnest I.), Cambridge (1999, Rottnest I.), Huisman & Borowitzka (2003, Dampier Archipelago), Walker & Prince (1987, NW Australia), Wells et al. (1995, Kimberley), and Huisman et al. (2009, Rowley Shoals, Scott Reef, Seringapatam Reef).

Walker & Prince (1987) suggested that the WA seagrasses did not fall into precise biogeographic provinces, but there is certainly a general north-south gradient of temperate to tropical species. Shark Bay is the limit of several species but has a greater southern component than might be expected from its latitude, which Walker & Prince (1987) suggest may be due to its relatively low water temperatures in winter. The southern, colder water taxa such as *Posidonia* spp. and *Amphibolis* spp. are very common in Shark Bay.

Huisman et al. (2009) reported on the seagrasses of the offshore atolls of the North West Shelf (Rowley Shoals, Scott Reef, and Seringapatam Reef). Only four species were included, *Halophila ovalis*, *H. decipiens*, *Thalassodendron ciliatum*, and *Thalassia hemprichii*, with the latter the only species forming meadows of any significance.

Wells et al. (1995) investigated the marine flora and fauna of 21 sites in the southern Kimberley, WA, between Cape Leveque and Montgomery Reef. They reported extensive seagrass meadows in shallow water near Sunday and Tallon Islands. These are the largest meadows of large species of seagrass known on the north coast of Western Australia, and included eight species. *Thalassia hemprichii* was the most widely encountered species, being found at 15 sites, often with 30-50% coverage of the substratum. *Enhalus acoroides* was found at 10 stations and *Halophila ovalis* at eight stations. The remaining species were patchily distributed: *Cymodocea serrulata*, *Halodule uninervis*, *H. decipiens*, *H. ovalis*, *H. minor* and *Thalassodendron ciliatum*.

2.1.2 Ecological role

Seagrasses are found in many Australian coastal waters, from the tropics to the Tasmanian coasts. They usually grow on mud, sand or coral sand, from the intertidal zone to not more than 50 m in depth, but mostly at 2 m to 10 m. Their distribution is mostly dependent on light, but also upon temperature and exposure to wave action.

2 Seagrass

The general ecological roles and importance of seagrasses have been summarised in many publications (e.g. Walker 1991/92; Kirkman 1997). Although seagrasses are photosynthetic organisms of moderate size, they are not usually grazed upon by herbivores. The two important exceptions are the dugong (*Dugong dugon*), which ingests leaves and rhizomes, and the green turtle (*Chelonia mydas*), which eats leaves (Kirkman 1997). In warm temperate regions, seagrasses are fed on by a few fish, but grazing is more typically only on the epiphytes and by molluscs and amphipods (Klumpp et al. 1989).

Seagrass meadows also have a role in nutrient cycling. The leaves and stems can support numerous and abundant epiphytes, which, when discarded, are broken up by wave action and bacteria, to be consumed eventually by detritivores. Drift leaves from seagrass communities together with seaweeds accumulate on the beach to heights of 2 m along parts of the south Western Australian coastline during winter. These accumulations form the basis of a community of microbes, detritivores such as small crustaceans, and carnivores.

Seagrass meadows act as nursery grounds for numerous fish and crustacean species. Juveniles use the seagrass for protection against predators, to feed on the epiphytic algae, and to feed on associated organic detritus. In parts of northern Australia, juvenile prawns (*Penaeus esculentus*, *P. semiscatus*, *Metapenaeus ensis* and *M. endeavouri*) use seagrass meadows as their nursery grounds (Staples et al. 1985; Poiner et al. 1987; Coles et al. 1993). Post-larvae settle into the shallow inshore seagrass meadows and, as they mature, move into and through the deeper meadows. In Western Australia, the juveniles of the western rock lobster forage in seagrass meadows close to the reefs in which they shelter (Joll & Phillips 1984).

Seagrasses also significantly modify the environment. Their leaves act as a filter by slowing the movement of the overlying water, thus allowing settlement of suspended sediments (Bulthuis et al. 1984). In addition, the extensive rhizome systems of seagrass meadows stabilise the underlying sediment and prevent erosion (Kirkman 1997). Seagrasses are also an important substratum for other organisms, the epiphytic algae and animals that are often a conspicuous component of seagrass meadows. Sixty-six species of algal and 40 species of animal epiphytes have been found on the seagrasses of Shark Bay (Walker 1989) and it has been estimated that on *Amphibolis* seagrasses around Australia there are more than 100 epiphytic species (Ducker et al. 1977).

2.1.3 Areal extent

In addition to the high species diversity, Western Australia is also renowned for the areal extent of its seagrasses. Seagrasses cover an estimated 2,200 km^2 of inshore seabed, representing 43% of the Australian total, and clearly make up an important component of the coastal ecosystem in Western Australia (Kirkman & Walker 1989; Kirkman 1997). Those authors provided a figure of seagrass distribution in WA that indicated seagrass occurring virtually State-wide, with the exception of a section of coast just south of Shark Bay and portions of the south coast. The northernmost Kimberley was regarded as unknown, but since that time (1994) several expeditions to the region have contributed further distribution records. It has been estimated that seagrass meadows in Western Australia cover the same area as rainforest in the whole of Australia (Kirkman 1997). Major areas of seagrass growth are sheltered embayments and estuaries, although extensive meadows also occur in more exposed locations. The large, calm, shallow expanse of Shark Bay (13,000 km^2) contains 12 species of seagrasses, which cover an estimated 4,500 km^2 of seabed, the largest reported seagrass meadows in the world (Walker 1989). The majority of extensive meadow-forming taxa (*Amphibolis*

2 Seagrass

spp. and *Posidonia* spp.) occur in the cool-temperate to sub-tropical regions, essentially from the south coast northward to Shark Bay. In tropical areas genera such as *Thalassia*, *Halodule* and *Cymodocea* can be abundant and form significant areas of seagrass. Examples of large meadows are given by Walker & Prince (1987), who reported areas of *Cymodocea angustata* at Mary Anne Reef (Pilbara) of “several hundred hectares of ca. 30-50% cover”, and a “continuous canopy” of *Cymodocea serrulata* at Sunday Island. Huisman et al. (2009) observed extensive areas of *Thalassia hemprichii* at the Rowley Shoals, but the actual extent was not given.

2.1.4 Seasonality

According to Kirkman (1997), little is known about the population biology of seagrasses in Australia or the rest of the world. Reproduction is typically seasonal, with fruiting usually occurring in spring/summer. Walker (1991/92) reported *Posidonia* in Shark Bay fruiting from December to January, and *Amphibolis* flowering around October.

2.2 Seagrasses in the Pilbara

2.2.1 Taxonomic composition

The north-western Australian seagrasses (including the Pilbara) were documented by Walker & Prince (1987), who reported 14 species from the region, ten of which were recorded from the Pilbara (Table 2-1; Walker & Prince 1987: Huisman & Borowitzka 2003; WA Herbarium). Subsequent collections in the WA Herbarium (see FloraBase, the online WA flora produced by the Department of Environment and Conservation) have added records of *Cymodocea serrulata* from Onslow, Thevenard Island and Barrow Island, and *Enhalus acoroides* from the Dampier Archipelago (Huisman & Borowitzka 2003). Walker & Prince (1987) described the northwest seagrass species as “generally those that might be expected from biogeographic considerations” and indicated floristic similarities with other areas such as Papua New Guinea, Torres Strait, and the Gulf of Carpentaria. The Pilbara species were mainly Indo-Pacific in affinity, but with differences in their latitudinal limits. The only endemic species is *Cymodocea angustata*, which Walker & Prince (1987) demonstrated to have a more extensive occurrence within its previously known range. Pilbara specimens of *C. angustata* in the WA Herbarium are from Varanus Island, Abutilon Island (in the Lowendal Islands) and the Montebello Islands.

With 14 species, north-western Australia has the highest seagrass diversity in the Indo-Pacific. Walker & Prince (1987) suggested this may be due to the general suitability of the environment, a high degree of habitat partitioning, and the range of species from north and south available for colonisation.

2 Seagrass

Table 2-1 Seagrass species in the Pilbara.

Species
Cymodocea angustata
Cymodocea serrulata
Enhalus acoroides
Halodule pinifolia
*Halodule uninervis**
Halophila decipiens
Halophila minor (as H. ovata in Walker & Prince 1987)
Halophila ovalis
Halophila spinulosa
Syringodium isoetifolium
Thalassia hemprichii
Thalassodendron ciliatum

**Waycott et al. (2004) used genetic evidence to suggest that Halodule uninervis and H. pinifolia may in fact be the same species. As with all taxonomic judgements, it will take time to see if this suggestion is accepted.*

2.2.2 Ecological role

Seagrasses in the Pilbara perform the same ecological roles as seagrasses in other areas (Section 2.1.2). However, there is a basic difference in that seagrasses in temperate areas of WA are large plants that develop large biomass and have a large biomass of associated macroalgae and invertebrates. Aside from extensive meadows of large seagrasses near Sunday Island in the Kimberley, tropical species of seagrasses in Western Australia have 10% or less of the biomass of their southern counterparts (Fletcher *et al*. 2006).

Walker & Prince (1987) surveyed seagrass distribution patterns along the entire north coast of Western Australia. McCook *et al*. (1995) examined the ecological importance of seagrasses in Exmouth Gulf. Exmouth Gulf is well known as the home of approximately 1,000 dugongs (Preen *et al*. 1995), green turtles are abundant, and the gulf area is home to a prawn fishery that catches an average of 1,000 tonnes of prawns, largely king prawns, per year. McCook *et al*. (1995) expressed surprise that not only had the apparently important seagrasses in Exmouth Gulf not been studied, but their work was only the second study of seagrasses along the entire north coast of Western Australia.

McCook *et al*. (1995) examined seagrasses at 64 sites in Exmouth Gulf, concentrated primarily in the south-eastern corner of the gulf and in areas where seagrasses were most likely to be abundant. They found one small patch of thick *Thalassodendron ciliatum* on a rocky pavement. The patch had 100% cover, but was limited in area to <100 m^2). Most of the intertidal zone at the site was bare sand beach.

The dominant seagrasses in other areas were species of *Halodule* in the intertidal region and *Cymodocea* at depths of 0 to 5 m. Cover was generally less than 5%, mean shoot densities were always less than 1,000 m^{-2} and often less than 100 m^{-2}, and biomass was generally less than 60 to 100 grams wet weight m^{-2}. McCook *et al*. (1995) contrasted the low abundance of seagrasses in Exmouth Gulf with Shark Bay, 450 km south of Exmouth. There the most common species of seagrasses are the temperate *Posidonia australis* and the more abundant *Amphibolis antarctica*, which forms extensive and dense meadows (Walker 1989). In Shark Bay *A. antarctica* reaches

2 Seagrass

biomasses of 2 kg dry weight m^{-2} and densities of 300-500 shoots m^{-2}, each up to 2 m long (Walker *et al*. 1988). Walker *et al*. (1988) also recorded 600 leaves m^{-2} and 60 to 100 grams dry weight m^{-2} of *Halodule uninervis*, and 30% cover of *Cymodocea angustata* as understorey beneath the larger seagrasses. Assuming a wet weight to dry weight conversion factor of 10, the biomass of *Halodule* in Shark Bay as an understorey species is ten times greater than reported by McCook *et al*. (1995) in Exmouth Gulf.

McCook *et al*. (1995) discussed in detail the apparent conflict between the low seagrass density and biomass they recorded and the large numbers of dugongs and turtles and the high productivity of the prawn fishery in Exmouth Gulf. They presented a rationale for extrapolating their results, based largely on samples taken in the south-eastern portion of the gulf, to the entire gulf. They hypothesised that macroalgae living in the seagrass meadows and on hard surfaces in the gulf presented an alternative food source for both green turtles and dugongs. Green turtles are known to eat both seagrass and seaweeds. While dugongs prefer seagrass, they will feed on macroalgae when seagrass are scarce (Lanyon *et al*. 1989). Thus an alternative food source for dugongs is available in Shark Bay. McCook *et al*. (1995) also speculated that macroalgae could provide an alternative habitat for prawns, and detrital products of the macroalgae could provide food for the prawns.

2.2.3 Areal extent

The largest known meadow of large seagrasses in the Pilbara is a patch of *Cymodocea angustata* at Mary Anne Reef, east of Onslow, that has several hundred hectares of 30 to 50% cover. The meadow occurs primarily at a depth of 2 to 3 m (Walker & Prince 1987).

2.2.4 Seasonality

Little is known of seasonality of tropical seagrasses in the Indo-West Pacific. The few studies that have been done demonstrate factors such as changes in seasonal tidal patterns, rainfall, nutrient availability and seasonal or sporadic changes in seagrass populations caused by cyclones. Seagrasses in northern Australia are sparser and less stable than species in temperate Australia (Erftemeijer & Herman 1994; Lanyon & Marsh 1995; Mellors 2003; Mellors et al. 1993). Straits (2006) reported that there is a clear seasonal pattern in seagrass populations in Exmouth Gulf, with the minimum biomass being reached in August and September. A rapid increase in biomass occurs during the spring (October to December), with the greatest biomass being in late spring and summer.

2.2.5 Taxonomic composition

Previous reports and collections of seagrasses from the Project Area are limited. There are several specimens collected from Onslow, Direction Island and nearby Thevenard Island in the WA Herbarium. These are listed in Table 2-2. Judging from these records, the composition of the seagrass flora in the Project Area is likely to be typical for the Pilbara (as described above).

2 Seagrass

Table 2-2 Seagrasses of the Wheatstone Project area, housed at the Western Australian Herbarium.

Seagrass Species	Location
Halophila ovalis	Thevenard I. & Direction I.
Halophila spinulosa	Direction I.
Halodule uninervis	Thevenard I.
Thalassia hemprichii	Thevenard I.
Cymodocea serrulata	Thevenard I., Onslow

2.2.6 Areal extent

There are no known areas of seagrass meadows in the Wheatstone Project Area, similar to those found in areas of southern Western Australia. Instead the distribution of seagrasses is patchy, with the plants usually occupying areas of a few square metres. There are areas of seagrass immediately west of Ashburton Island, north-west of Onslow and at West Reef. It should be emphasised that these are generalised areas interspersed with patches of seagrasses of a few square metres or tens of square metres; they are not continuous patches.

URS (2009a) undertook a survey of the intertidal fauna on the eight islands in the project area (Direction, western end of Thevenard, Table, Serrurier, Bessieres, Ashburton, Tortoise and Northeast Twin). There were no major seagrass areas reported in the intertidal region, but there were isolated small patches of a few square metres of seagrass in intertidal tidepools (Figure 2-2).

URS (2009b) surveyed 352 sites in the Project Area using a Remotely Operated Video (ROV). The greatest concentration of seagrasses (12% percent cover) occurred in the area of shoreline extending north-east along Beadon Bay towards Coolgra Point, with lower percentage cover (5-10%) extending from this shoreline towards Direction and Twin Islands. Low percentage cover of seagrass (5%) was also present around Glennie Patches extending in a north-east direction towards Brewis Reef (Figure 2-2). *Halophila* species typically found on the NWS generally propagate by means of seasonal seed production with high fecundity and wide dispersal (Rasheed, 2004). *Halophila ovalis/decipiens* was observed to be growing on the Onslow Salt channel dredge placement area at similar density to adjacent areas during the ROV survey (URS 2009b). This suggests that recruitment of *Halophila* sp. over impacted areas readily occurs in this region.

UWA (2009) used towed video and drop camera to survey benthic assemblages at depths of 15 to 70 m along five transects from 6 to 17 km on the outer continental shelf off Onslow. Sand was the dominant substratum observed, comprising 75% of the substrata observed in the region, and over 90% of observed substrata in deep water (40+m). Sand typically formed large patches >200 m long. Biotic communities associated with sand habitats were typically sparse and dominated by a red microalgal mat. Low profile reef and sand inundated reef were the other substrata observed in the study area. Areas of reef were most commonly observed in shallow waters (<19.9 m) on the shallow inshore shelf and on the offshore slope to 40 m depth. Seagrasses were found in low density (0.06% cover or less) on two transects; no seagrasses were found on Transect C, the proposed trunkline route.

URS (2009c) used ROV to survey the trunkline in deep water, out to the petroleum titles in approximately 200 m depth, but no seagrass were found.

2 Seagrass

To the east of the Wheatstone project Area, URS (2009d) mapped benthic primary producer habitats along the proposed Domgas pipeline route from Barrow Island to the existing pipeline shore crossing east of Onslow. Small, isolated patches of several square metres of the seagrass *Halophila* occurred in some areas, but no seagrass beds were observed.

To the east of the Wheatstone project Area, URS (2009d) mapped benthic primary producer habitats along the proposed Domgas pipeline route from Barrow Island to the existing pipeline shore crossing east of Onslow. Small, isolated patches of several square metres of the seagrass *Halophila* occurred in some areas, but no seagrass beds were observed.

2.3 Regional significance

As indicated in Section 2.2.1 seagrasses in the Pilbara are all species that have wide geographical distributions. Habitats present in the Project Area are a subset of a broader range of marine habitats that occur in the Pilbara. There are no known areas of high density or diversity of seagrasses in the Wheatstone Project Area.

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2 Seagrass

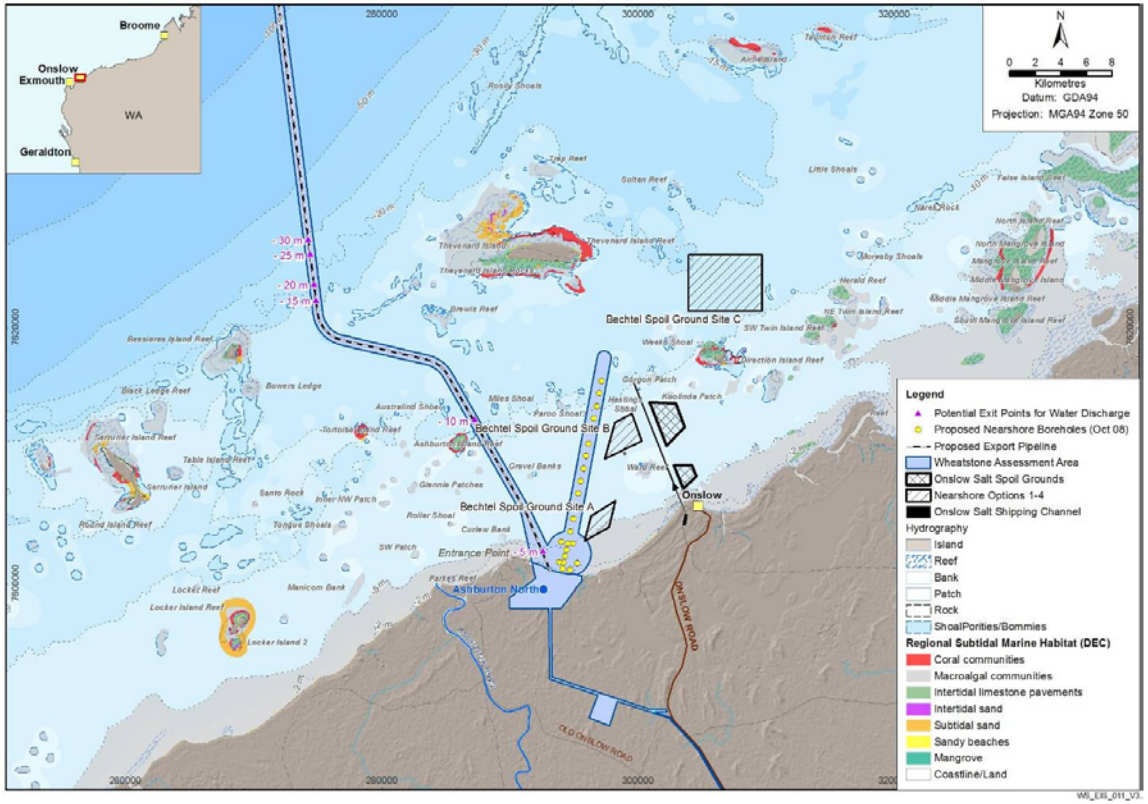

Figure 2-1 Map of the nearshore region of the Wheatstone Project Area.

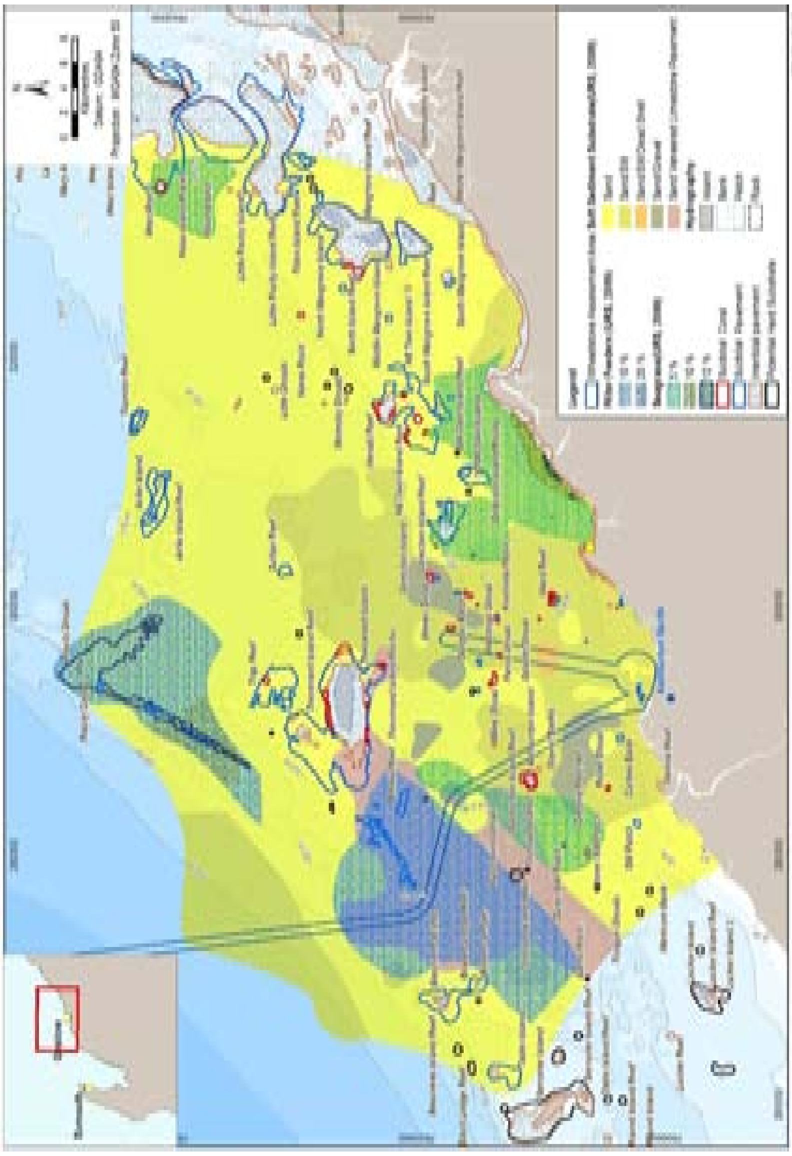

Figure 2-2 Map of the study area showing the percent coverage of seagrasses.

2 Seagrass

Photograph 2-1 The seagrass *Halophila* sp. at a depth of 8 m off Bessieres Island.

Photograph 2-2 The seagrass *Halodule* sp. at a depth of 24 m south of Thevenard Island.

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Macroalgae

3.1 Macroalgae in Western Australia

Macroalgae include the large algae that can be readily observed without a microscope. In the marine environment these are mostly benthic (attached to the substratum), and will grow on virtually all substrata, including rocky reefs, sand and mud, artificial structures, and other organisms. The only habitats that do not generally support macroalgal growth are high-energy, sandy beaches, where the mobile sands do not allow settlement of spores. Within these environments, however, any semi-stable surface can be colonized by macroalgae.

While most macroalgae are attached, floating rafts of the brown alga *Sargassum* are also occasionally common. Unlike in other areas such as the Sargasso Sea, however, where the distribution of floating *Sargassum* is limited by currents, in WA the genus does not form relatively stationary floating beds. While their movement with currents has not been studied, these floating rafts presumably contribute to dispersal of both the *Sargassum* and associated flora and fauna, as they tend to act as mobile reefs.

3.1.1 Taxonomic composition

Entwisle & Huisman (1998) and Huisman et al. (1998) summarised what was then known about the Western Australian (and Australian) marine macroalgal flora. While its documentation had its beginnings in seventeenth century with the famous buccaneer turned explorer William Dampier, who provided the first of Western Australia's (and Australia's) marine plants to be recorded in print (Ducker 1990), subsequent progress has been erratic. The macroalgal flora of WA's south and south-west is relatively well-known due to the work of Bryan Womersley, who published a series of books describing the southern Australian macroalgae (Womersley 1984; 1987; 1994; 1996; 1998; 2003). These books cover most of the species likely to be encountered in WA localities from the south coast to approximately the Perth region, becoming less comprehensive further north to Geraldton and the Houtman Abrolhos, and including only a handful of (supposedly) widespread species in the State's north. More recently, Huisman et al. (1990) documented the marine flora of Shark Bay, Goldberg & Kendrick (2005) the Esperance area, Huisman & Walker (1992) Rottnest Island and Huisman (1997) at the Houtman Abrolhos. On the north coast, the major publications are on the Dampier Archipelago (Huisman & Borowitzka 2003), and the Rowley Shoals, Scott Reef and Seringapatam Reef (Huisman et al. 2009).

All published records of Australian macroalgae are documented in the 'Australian Marine Algal Name Index' (AMANI, Cowan 2009), a website devoted to algal nomenclature and distribution. AMANI is a nomenclatural database and therefore contains no specimen data; all records are based on published reports. That site lists 2,478 species (and varieties) of macroalgae in Australia, with 927 of those from Western Australia. The latter is composed of 144 green algae (Chlorophyta), 156 brown algae (Heterokontophyta), 607 red algae (Rhodophyta) and 20 blue-green algae (Cyanobacteria).

The Australian coastline has been subdivided into broad-scale 'Biogeographical Provinces' (see Huisman 2007) and more fine-scale 'Marine and Coastal Regions' (Commonwealth of Australia, 2006). In WA, two provinces are recognized, the tropical Dampierian in the north and the temperate Flindersian in the south, with an overlap zone along the mid-west coast from the Houtman Abrolhos to Cape Leeuwin; this terminology parallels that of Wilson & Allen (1987), who refer to the tropical Northern Australian and temperate Southern Australian Region (Figure 3-1). The Dampierian Biogeographical Province encompasses much of northern and north-western Australia, from the tip of Cape York Peninsula westward to approximately the Houtman Abrolhos and Geraldton on the coast of Western Australia (Womersley 1981b; Huisman, 2007). The boundaries of this province are somewhat

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vague - the eastern boundary is given by some authors as the tip of Cape York, but recent studies indicate there is a single tropical Australian marine flora (Huisman 2007).

The extent of the west coast overlap zone can vary tremendously, presumably as a result of the varying strength of the Leeuwin Current. Occasionally tropical species are recorded in unexpected locations, but their occurrence is clearly sporadic. For example, Harvey (1855) recorded the green alga *Penicillus nodulosus* as common on the reef flats at Rottnest Island. This species is common in tropical north-west Australia but modern records do not extend any further south than the Jurien Bay to Geraldton region (Huisman & Walker 1992).

The tropical Dampierian Province, which includes the Pilbara, is the least known of the Australian provinces (Huisman et al. 1998). Its relative inaccessibility and remoteness from population centres, plus the difficulties in dealing with large tidal amplitudes, turbid water and life-threatening fauna, such as crocodiles and sharks, have relegated the region to the 'least appealing' in terms of algal collecting. Our knowledge of the algal flora of the region is relatively poor, with large regions almost totally unexplored. Huisman et al. (1998) reviewed the published records of marine macroalgae to that time and noted only 28 species in the region extending from North West Cape to the Western Australian/Northern Territory Border (a distance of well over 2,000 km). Over half of those species were mangrove-associated epiphytes, indicating obvious biases in collecting and clearly not an accurate assessment of the flora of the region. Huisman et al. (1998) indicated that the region would support over 300 species. More recent publications on the flora of the Dampierian region include Huisman & Borowitzka (2003), Huisman (2004) and Huisman et al. (2009).

Telford (1998) assessed the richness and affinities of the Dampierian Province using all available data and concluded that 440 species of macroalgae are known from the Dampierian Province. Given Telford's results and the geographic and taxonomic gaps in our knowledge of the tropical Australian flora, the number of species occurring in the area is likely to be in the vicinity of 500.

Figure 3-1 Marine distribution patterns in Western Australia (after Wilson & Allen 1987).

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3.1.2 Ecological role

In general, macroalgae perform a similar role to most plants; as primary producers they are a food source; as moderately large three dimensional structures they provide habitat and shelter for a variety of other organisms (including fish); as decomposing organisms they provide source materials for detritivores (Ince et al. 2007). This is true all along the WA coastline. Particular species or groups of species have more specialized roles: the large kelps and other fucalean algae are clearly a major component of the habitat structure in southern Australia and they significantly influence the local diversity through competition for light (Toohey 2006). While a few kelp-associated species are consistently present over broad ranges, there is not a general assemblage and the spatial variation in community structure is considerable, suggesting that local and small-scale processes contribute considerably to heterogeneity in macroalgal assemblages (Wernberg et al. 2003; Wernberg & Goldberg 2008; Toohey & Kendrick 2008). Within site variation is also a result of disturbance (e.g. cyclones) and subsequent assemblage recovery, creating a mosaic of different patch types (Toohey 2006). Thus, even within seemingly uniform assemblages (the ‘kelp beds’), there is much variation.

Progressing northward, in tropical areas the macroalgae also play an important ecological role. Crustose coralline algae (CCA) are red macroalgae that lay down calcium carbonate as calcite, forming pink to red crusts on a variety of surfaces. In coral reef habitats the CCA are crucial to the formation and maintenance of reefs (Littler 1972), as they serve to cement and bind the reef materials together into a solid and sturdy structure, thereby protecting them from the full brunt of ocean swells (Bak 1976). This function is particularly important on the windward reef crests. They also significantly affect the settlement and subsequent establishment of coral (and other organisms), with some species of CCA preferentially settled on (Adey 1998). CCA can also modify the environment in other ways. The Faure Sill in Shark Bay is comprised primarily of the remnants of coralline algae that have grown on the area’s extensive seagrass meadows, thus the existence of the high salinity Hamelin Pool can be seen as a result of CCA.

While seemingly robust, crustose coralline algae are nevertheless dependent on the presence of sufficient light, as calcium carbonate dissolution can occur in the dark (Chisholm 2000). Their existence in shallow areas is apparently enhanced by grazing activity and wave action serving to reduce turf algal biomass, and in deeper or cryptic environments by light levels being too low to support vigorous growth of competitor species (Chisholm 2000). Increased carbon dioxide concentrations can also have a direct effect on CCA, as the resultant acidification of the seawater inhibits CCA growth and promotes that of other species (Kuffner et al. 2007).

A further example of specific ecological roles played by macroalgae is the calcified green alga *Halimeda*. When plants of *Halimeda* become reproductive all of the cytoplasm is converted to gametes and subsequently only the calcium carbonate skeleton remains. This eventually becomes part of the sediment. In the Great Barrier Reef, Maxwell (1968) demonstrated that 10-30% of the reef surface was composed of *Halimeda* rubble, 5-65% of inter-reef sediments were *Halimeda* derived and that, in the Swains region, *Halimeda* frequently created over 65% of the sediment. Drew (1983) showed that *Halimeda* contributes to 2,234-3,000 g of calcium carbonate m-1 year-1 on the GBR, suggesting that *Halimeda* can be a major contributor to reefal structures. Species of this genus are extremely common in some North-West regions and no doubt makes a significant contribution to local sediments. Large stands of *Halimeda distorta* were recorded at Scott Reef (Huisman et al. 2009). Similarly dense

Halimeda banks were reported for the Big Bank Shoals in the Timor Sea (Smith et al. 2001). While the species was not identified, the images suggest it is likely to be *H. distorta*. Coverages of up to 35% were reported and the *Halimeda* was regarded as one of the dominant carbonate structures.

3.1.3 Areal extent

As photosynthetic organisms, macroalgae are dependent on light and are therefore restricted to a band in the intertidal and shallow subtidal region along the coast; in the Wheatstone Project Area the 20 m depth contour is approximately 30 km off the coast. In clear off-shore waters macroalgae can exist at depths up to 200m, but in most coastal waters the light is absorbed by suspended matter and very little algal growth occurs below 50m. Much of the near-shore Western Australian subtidal environment is relatively shallow, and therefore provides suitable habitat for macroalgal growth. The WA coast also occupies a broad latitudinal range, from the temperate waters of the south coast to the tropical Kimberley. As is typical for such cold to warm transitions, the colder waters are more nutrient-rich and support dense macroalgal growth, the dominant species being the kelp *Ecklonia radiata* and a variety of fucalean species in the genera *Cystophora*, *Sargassum*, and *Platythalia* (amongst others). Progressing northwards, the majority of these genera reach their distributional limits around the Perth region, with *Ecklonia* occurring no further north than Kalbarri and the Houtman Abrolhos (Huisman 2000), essentially the limits of the Flindersian Province. Tropical macroalgae are more sporadic and rarely form conspicuous beds akin to their southern counterparts. One exception is the genus *Sargassum*, which has been observed to dominate intertidal platforms at places such as Barrow Island and the Maret Islands (and presumably similar habitats at other locations). Curiously, *Sargassum* is absent from the more offshore islands and atolls, including the Rowley Shoals, Scott Reef, and Browse Island (Huisman et al. 2009).

3.1.4 Seasonality

For the most part, macroalgae in Western Australia do not exhibit a pronounced seasonality, though Borowitzka & Mercer (2007) reported clear seasonality in the productivity of turf algae communities in the Dampier Archipelago, with maximum productivity in winter. In some brown and red algal species with heteromorphic life histories (i.e. with alternate phases in the life history that are inconspicuous and differ from the other phase), the larger, conspicuous phase can appear at different seasons. Several of the red algae appear in spring and summer, eventually disappearing in winter (e.g. *Helminthora*). Some of the brown algae in the Perth region appear in winter (e.g. *Petalonia*). Whether these apparent seasonal appearances are truly seasonal or simply distributional shifts due to colder or warmer conditions has not been assessed. The brown algal genus *Sargassum*, which is common along much of WA's coastline, is reported to undergo annual growth and reproductive cycles that involve production of fertile branches. Reproduction generally coincides with peak growth, although Gillespie & Critchley (1999) recorded reproduction following peak growth in South African species. The productive season for *Sargassum* apparently varies depending on locality, in warmer area it is during colder seasons, and vice-versa in colder areas (Rao & Rao 2002). *Sargassum* phenology has been examined in detail for species at Rottnest Island by Kendrick & Walker (1994), who found growth of annuals was initiated in April, thalli became reproductive by late August–early September, and senescence occurred in December–January, indicating the peak period was winter. There are no comparable studies for any species occurring further north. At Magnetic Island, on Australia's east coast, the maximum growth and reproductive period for *Sargassum* was during summer (December-February; Martin-Smith 1993).

3.2 Macroalgae in the Pilbara

Macroalgae of the Pilbara have been recorded in numerous publications, the most comprehensive being the annotated checklists for the Dampier Archipelago (Huisman & Borowitzka 2003; Huisman 2004) and the reports generated by Bowman Bishaw Gorham (1995; 1996; 1997) dealing with Thevenard I. and Barrow I., based on collections and/or identifications by J. Huisman. Collections have been made by Huisman from Direction I., the Montebello Is., and Little Turtle I. and North Turtle I. off Port Hedland. While those collections remain unpublished, they have been incorporated into the WA Herbarium and have been databased, as such they are for the most part able to be interrogated via FloraBase, the Department of Environment and Conservation's online Western Australian Flora. They will eventually form part of the NW Flora book currently being prepared by J. Huisman.

Telford (1998) compiled a list of species collected from Direction Island during a field trip in 1998. Several lists of species found at Thevenard Island and Barrow Island have appeared in reports (e.g. Bowman Bishaw Gorham 1995; 1996; 1997; Wells & Huisman 2004a; 2004b). Recent collections by the author and others (e.g. that from the Montebello Islands mentioned in Huisman 1992) have relieved the situation somewhat, but as yet the majority of these remain unpublished.

Based on these reports and collections, the macroalgae of the Pilbara are clearly tropical in composition and form a subset of the Indo-West Pacific flora.

3.2.1 Taxonomic composition

The most extensive list of macroalgae for the Pilbara was presented by Huisman & Borowitzka (2003), who recorded a total of 201 species, including 114 rhodophytes (red algae), 50 chlorophytes (green algae), 30 phaeophytes (brown algae), and 5 cyanophytes (cyanobacteria) from a survey in the Dampier Archipelago. The chlorophyte genus *Caulerpa* was most diverse, with 15 species and varieties. Other diverse genera were the rhodophyte genus *Polysiphonia* (8 species) and the chlorophyte genus *Halimeda* (6 species).

3.2.2 Ecological role

There is limited information directly addressing the ecological role of macroalgae within the Pilbara. It is expected that they fill similar roles to macroalgae from other regions and described above.

3.2.3 Areal extent

There have been no studies describing the areal extent of macroalgae in the Pilbara. With the high diversity of species, it is likely that most suitable habitats in the photic zone will contain macroalgae.

3.2.4 Seasonality

No detailed information is available regarding seasonality of macroalgae in the Pilbara. Based on observations of intertidal algae on Barrow Island, it is likely that *Sargassum* spp. undergo a seasonal succession, blooming and becoming fertile over summer (Huisman, *pers. comm.*). It is likely that other taxa follow similar patterns, but detailed study is required to confirm this.

3.3 Macroalgae in the Wheatstone Project area

3.3.1 Taxonomic composition

In the immediate region, macroalgae have been collected from Thevenard Island by Bowman Bishaw Gorham and identified by J. Huisman. These specimens are now housed in the WA Herbarium. Huisman also participated in a field survey of Direction Island, the results of which were collated by Telford (1998). The latter survey was restricted to intertidal and drift algae and the specimens are also housed in the WA Herbarium. Other than these limited collections, information regarding the taxonomic composition of the Wheatstone Project Area is exceedingly scant. Extrapolating from what is known, the macroalgae form part of the broader Pilbara flora, itself a subset of the Indo-West Pacific flora. As would be expected, all known species have tropical affinities.

3.3.2 Ecological role

Again there is limited information directly addressing the ecological role of macroalgae within the project area. It is expected that they fill similar roles to macroalgae from other regions and is described above.

3.3.3 Areal extent

Based on remote footage, existing collections in the WA Herbarium, and personal observations, macroalgae can be dominant components of intertidal and shallow reef systems, but become significantly less so at depth, possibly due to light attenuation as a result of the elevated turbidity that is common in the area. Alternatively, low densities of macroalgae can also be due to a lack of hard substrate and high levels of consumption by herbivores.

As described in Section 2.3.2, URS (2009) mapped benthic primary producer habitats along the proposed Gorgon Domgas pipeline route from Barrow Island to the existing Apache pipeline shore crossing east of Onslow. The only area of extensive macroalgal abundance was Transect 5, where the macroalga *Caulerpa* carpeted the bottom; Transects 4 and 6 on either side lacked the macroalgae. Aside from Transect 5, *Caulerpa* was found only in isolated small patches of a few square metres on some transects. The seabed near South Passage Island appeared to be a thin veneer of sand overlying a flat limestone platform. There were small, low patches of algae attached to slight lumps in the substrate. Depths in this area ranged from 13.7 to 8.5 m, with crinoids and sea urchins dominating the fauna. The seabed inshore of South Passage Island was all bare sand, again dominated by crinoids and sea urchins. No biota was observed on Transects 24 to 27, closest to shore. The extensive intertidal sandflat seaward of the mangroves was surveyed at low tide, but no seagrasses or macroalgae were found.

URS (2009a) surveyed intertidal fauna on eight islands in the Onslow area (Section 2.3.2). Most of the rocky intertidal shores had extensive, low growths of macroalgae (Figures 3-2, Photograph 3-1, Photograph 3-3), though this was absent at some sites (Photograph 3-2). One shallow sandy area with macroalgae was found at the western end of Thevenard island (Photograph 3-4) and limited amounts of beachwrack were found on some sandy beaches (Photograph 3-5), though this was very limited compared to the 2 m or more that can accumulate in the southwest corner of the State.

As described in Section 2.3.2, URS (2009b) examined 352 sites in the shallow waters of the Wheatstone Project Area using an ROV. The sites generally were sandy substrates with low densities of seagrasses of the genera *Halophila* and *Halodule* in some areas; in other areas the there was little flora, or patches of *Caulerpa* (Photograph 3-6). In areas with a hard seafloor, there was a mixture of fauna such as corals, sponges and sea whips mixed with macroalgae (Photograph 3-7). The greatest macroalgae coverage was near Thevenard Island and Mangrove Islands (Photograph 3-8), typically on subtidal limestone platforms, with localised lower abundances present at a number of shoals and islands.

The percent of algal cover on the five deepwater transects of the shelf break (20-70 m CD) studied by UWA (2009) ranged from 0.95% on Transect E to 12.32% on Transect A; the average was 4.99% cover. Transect C, along the proposed pipeline route, had an average of 3.83% algal cover. Further offshore, no macroalgae were found on the outer shelf or in the area of the gas fields (URS 2009c)

3.3.4 Seasonality

No information is available regarding seasonality of macroalgae in the Wheatstone Project Area. Based on observations of intertidal algae in nearby Pilbara locations, it is likely that intertidal and shallow subtidal *Sargassum* species undergo a seasonal succession, with peak growth and becoming fertile over summer (Huisman. *pers. comm.*). It is unknown whether other taxa follow similar patterns and detailed study is required to confirm this.

3.4 Regional significance

As indicated in Section 3.1.1, the known macroalgae in the Pilbara are all species that have wide geographical distributions. Habitats present in the Project Area are a subset of a broader range of marine habitats that occur in the Pilbara. There are no known areas of high density or diversity of macroalgae in the Wheatstone Project Area.

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Photograph 3-1 An intertidal rock platform on Tortoise Island covered with low macroalgae.

Photograph 3-2 Intertidal rock platform with macroalgae on North East Twin Island.

3 Macroalgae

Photograph 3-3 Some of the rocky intertidal shores had very little macroalgae.

Photograph 3-4 Macroalgae in an intertidal pool on Ashburton Island.

3 Macroalgae

Photograph 3-5 Abundant algae in a shallow sandy environment on the west end of Thevenard Island.

Photograph 3-6 Macroalgal wrack washed up on the beach.

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Photograph 3-7 The macroalga *Caulerpa* at a depth of 24 m south of Thevenard Island.

Photograph 3-8 A mixed bottom of macroalgae and corals at Gravel Banks.

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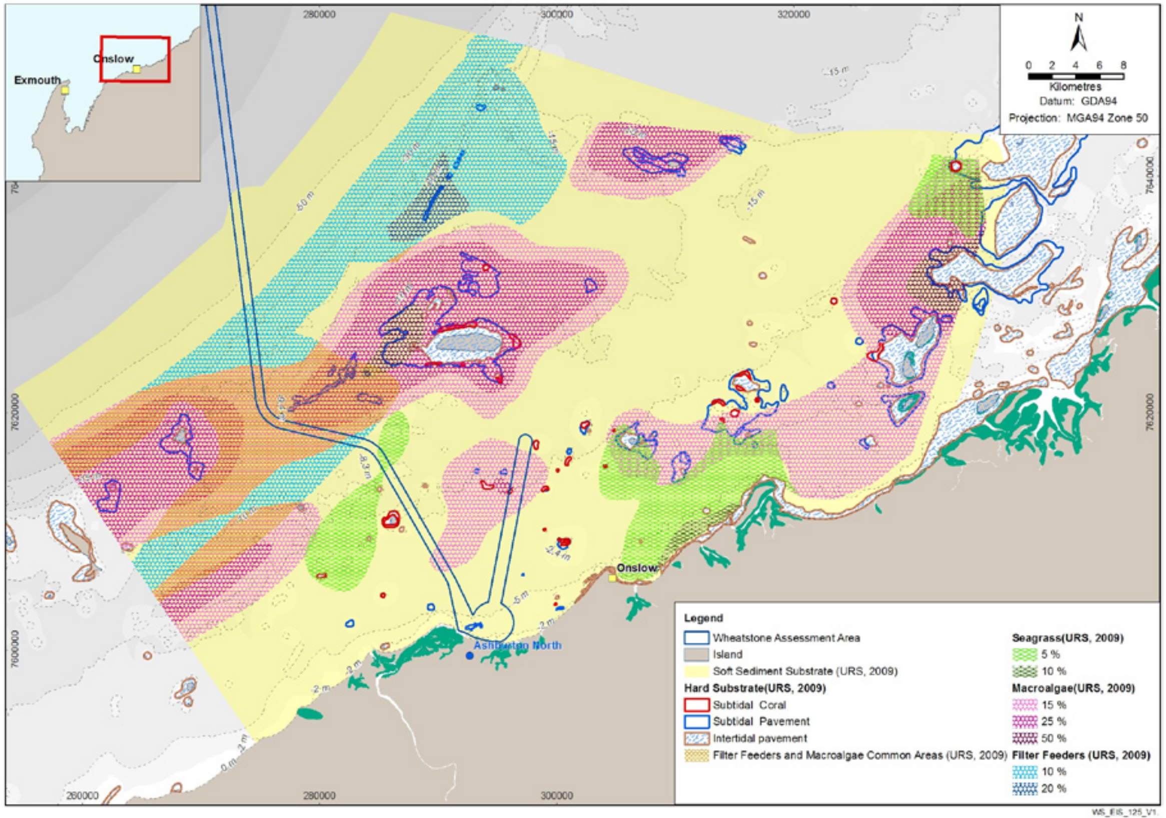

Figure 3-2 Map of the study area showing the percent cover of macroalgae.

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Limitations

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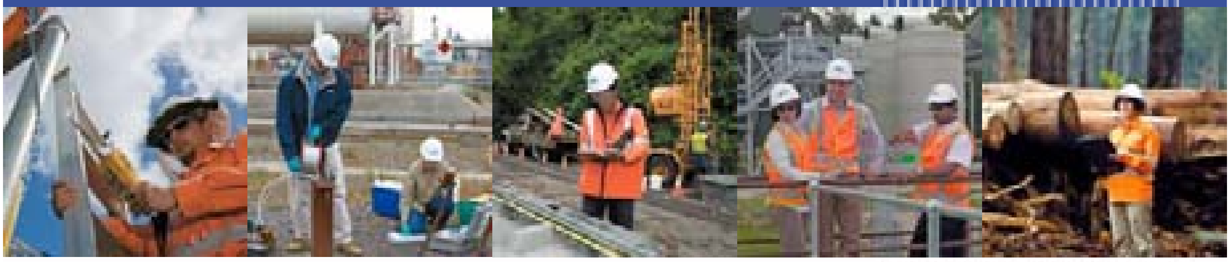

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Appendix 01

An Assessment of Light Emissions in Relation to Sea Turtle Nesting Beaches in the Wheatstone Project Area

Tables

Figures

Photograph

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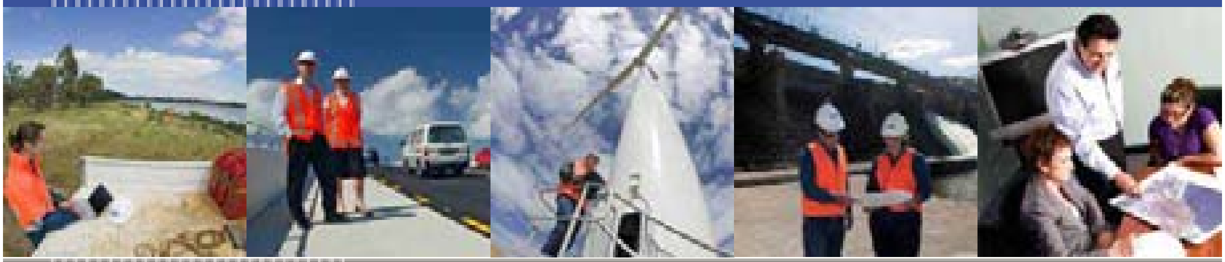

Report

Wheatstone Project

An Assessment of Light Emissions in Relation to Sea Turtle Nesting Beaches in the Wheatstone Project Area.

10 MAY 2010

Prepared for

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Introduction

1.1 Wheatstone Project Background

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate the Wheatstone Project (the Project), a multi-train LNG and Domgas plant 12 km south-west of Onslow on the Pilbara coast. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State waters and on land. The LNG processing plant will initially process gas from two Petroleum Titles, located approximately 225 km offshore from Onslow in the West Carnarvon Basin (Figure 1-1). The Ashburton North Strategic Industrial Area (Ashburton North SIA) is the proposed site for the onshore and nearshore plant (Figure 1-1). The LNG plant will have a maximum capacity of 25 MTPA of LNG with the Domgas plant capacity being equal to 15% of LNG sales. The Wheatstone Platform will provide initial treatment of LNG and condensate, which will then be transported via a sub-sea trunkline (Figure 1-1) to the Ashburton North SIA.

1.2 Aim & Objectives

The aim of this report is to characterise light emission sources from the Ashburton North SIA, and their intensity in relation to known sea turtle nesting habitat (sensitive receptors) in the Project area.

The specific objectives are:

- To model lighting emissions from the Ashburton North SIA to determine their extent and intensity; and
- To model the intensity of the light emissions at identified sensitive receptor locations

The Western Australia Environmental Protection Authority (EPA) has recently published Draft Environmental Assessment Guideline #5: Environmental Assessment Guideline for Protecting Marine Turtles from Light Impacts (EAG #5; EPA 2010), which provides non-statutory recommendations on minimising the impacts of artificial lighting on marine turtles, particularly through Project design.

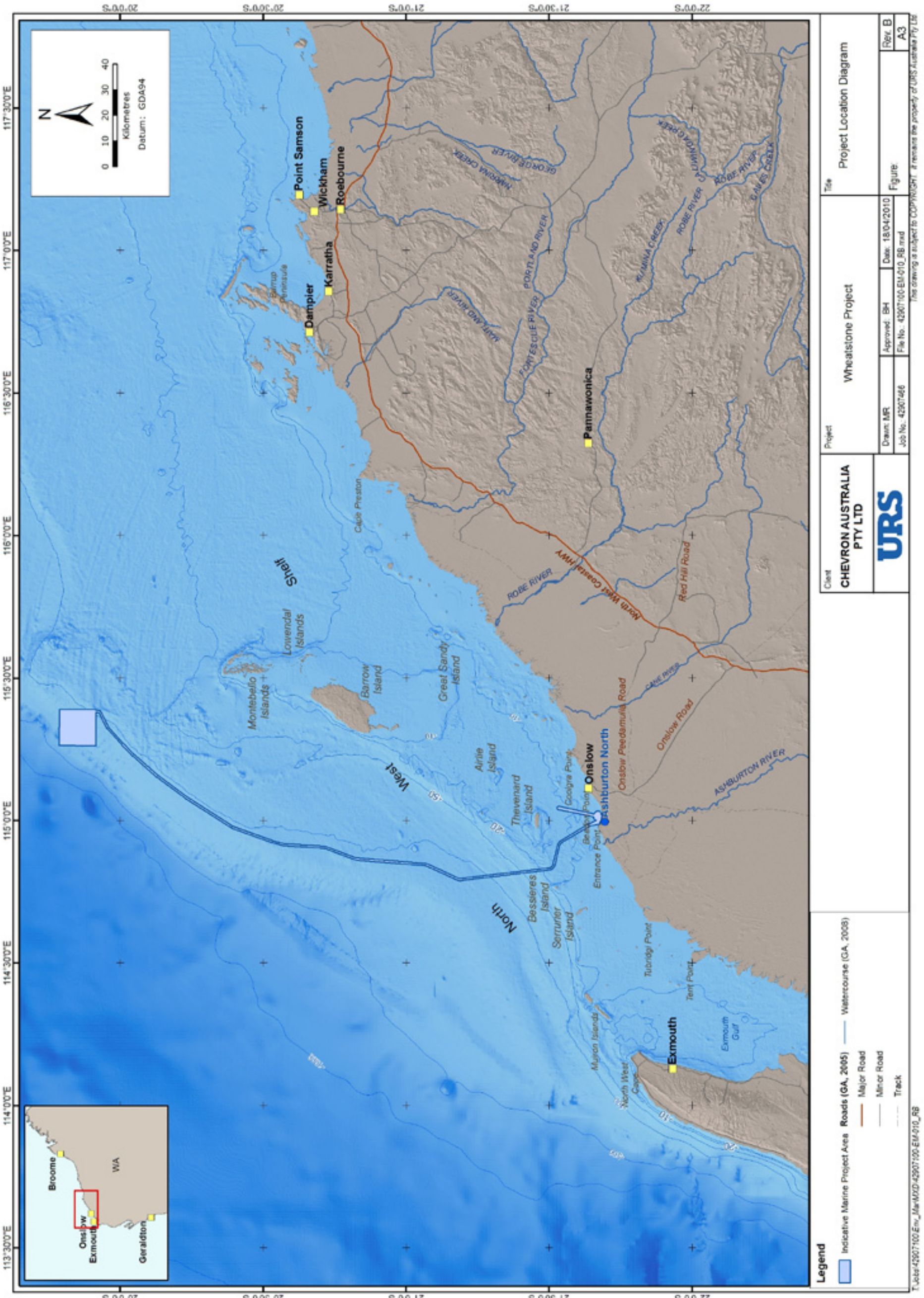

Figure 1-1 Location of the Wheatstone Project.

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2 Sea Turtle Biology

2.1 Vision & Behaviour

Artificial light, where it occurs at higher intensities than natural ambient sources such as moonlight and starlight, is known to have a range of effects on both adult and hatchling sea turtle behaviour. Artificial light can deter adult turtles from coming ashore to nest, disrupt adult female egg-laying behaviour, misorient both hatchlings and adults in their ability to locate the sea and increase the probability of predation (Witherington and Martin 1996).

The sea finding ability of sea turtle hatchlings makes use of a mechanism called phototropotaxis, which refers to an animal carrying out a directed movement toward a source of light along a path which permits the animal's paired eyes to receive equal intensities of light throughout the movement (Witherington and Martin 1996; Mrosovsky and Kingsmill 1985). Emerging hatchlings orient themselves in a seaward direction by moving towards the brightest part of their field of view. Under normal circumstances (i.e. in the absence of artificial light) this is towards the seaward horizon, as opposed to the darker and silhouetted inland areas.

Sea turtles respond to all wavelengths of visible light but have increased sensitivity to shorter wavelengths such as ultraviolet and blue (Witherington 1992), since it is these wavelengths that penetrate the water column and dominate the underwater environment. Additionally, they are the predominant wavelengths of moonlight and starlight, which attract both nesting adults and hatchling turtles and help them differentiate between the lighter sea and darker inland areas. This is prevalent in most common species found in the vicinity of the Project (Pendoley Environmental 2009a), the flatback turtle (*Natator depressus*). Flatback hatchlings have been shown to exhibit attraction towards blue-green light (500 nanometres (nm)), even at low intensities (Pendoley Environmental 2007). Flatback hatchlings appear to be either disoriented or repelled by orange light (650 nm). A strong response has also been observed from flatback hatchlings to fluorescent and metal halide light sources when compared to high-pressure sodium (HPS) light sources (Pendoley Environmental 2004).

2.2 Sea Turtles in the Project Area

2.2.1 Mainland Beaches

A beach survey conducted along the mainland coast in the vicinity of the Ashburton North SIA in early 2009 (Pendoley Environmental 2009a) found no evidence of sea turtles nesting in this area. High tide waters regularly inundate the sand bar on sections of the beach within the Ashburton North SIA, making it unlikely that marine turtles would utilise those areas. Other studies (e.g. Pendoley Environmental 2009b; RPS 2010) support the notion that sea turtles do not nest on the mainland beaches immediately adjacent to the Ashburton North SIA.

The closest reported turtle nesting area to the Ashburton North SIA occurs between the two existing entrances to the Ashburton River, approximately 4.5 km to the west of the Ashburton North SIA. This area will be referred to as the Ashburton River delta beach (RPS 2010) (Figure 2-1; Photograph 2-1). Low-density flatback turtle nesting has been observed on the Ashburton River delta beach (Pendoley Environmental 2009a). This is further supported by additional turtle nesting surveys of the area indicating that between 21 and 34 tracks were created per night in 2009, during the peak December period (RPS 2010).

2 Sea Turtle Biology

Turtle surveys have also observed flatback turtle nesting at Sunset Beach, located more than 8 km east of the Ashburton North SIA, between Four Mile Creek and the Onslow town site (Pendoley Environmental 2009b). However, during the January 2009 survey, only two nests were recorded from Sunset Beach (Pendoley Environmental 2009b). Flatback turtle nesting activity recorded between Beadon Creek and Coolgra Point, more than 10 km away from the Ashburton North SIA (Pendoley Environmental 2009b), has also been documented. All nesting activity observed on mainland beaches was recorded as being of low-density, with large sections of beach described as having no nesting activity at all. Overall, none of the mainland beaches surveyed within the Ashburton North SIA were considered to support locally or regionally significant breeding colonies (Pendoley Environmental 2009a).

Photograph 2-1 Ashburton River delta beach.

2.2.2 Island Beaches

Ashburton Island is the closest island to the Ashburton North SIA with confirmed turtle nesting habitat. It is approximately 10 km northwest of the Ashburton North SIA (Figure 2-1). Ashburton Island is considered to be part of a locally significant nesting area for flatback turtles that includes Direction, Locker and Thevenard islands (Pendoley Environmental 2009b). Surveys of Ashburton Island recorded evidence of low-density nesting on the northern, western and southern beaches, with medium-density nesting on the eastern beach of the island (Figure 2-1). Both green (*Chelonia mydas*) and flatback turtle nesting has been recorded on Ashburton Island (Pendoley Environmental 2009a).

Nesting activity of green and flatback turtles has been recorded on both large (Serrurier and Thevenard) and medium size (Bessieres, Locker and Ashburton) islands in the vicinity of the

2 Sea Turtle Biology

Ashburton North SIA (Pendoley Environmental 2009a). Other smaller islands, such as Flat, Table, Direction and the Twin islands, have limited areas of suitable habitat and only moderate to low levels of turtle nesting activity (Pendoley Environmental 2009a).

Green turtles nest predominately on the outer islands (Bessieres, Serrurier, north and west coasts of Thevenard). These islands are believed to support regionally significant nesting rookeries for this species. However none of these rookeries approach the size of the green turtle rookeries on Barrow Island and in the Dampier Archipelago (60 km north northeast and 200 km northeast of the Ashburton North SIA respectively) (Pendoley Environmental 2009a).

2 Sea Turtle Biology

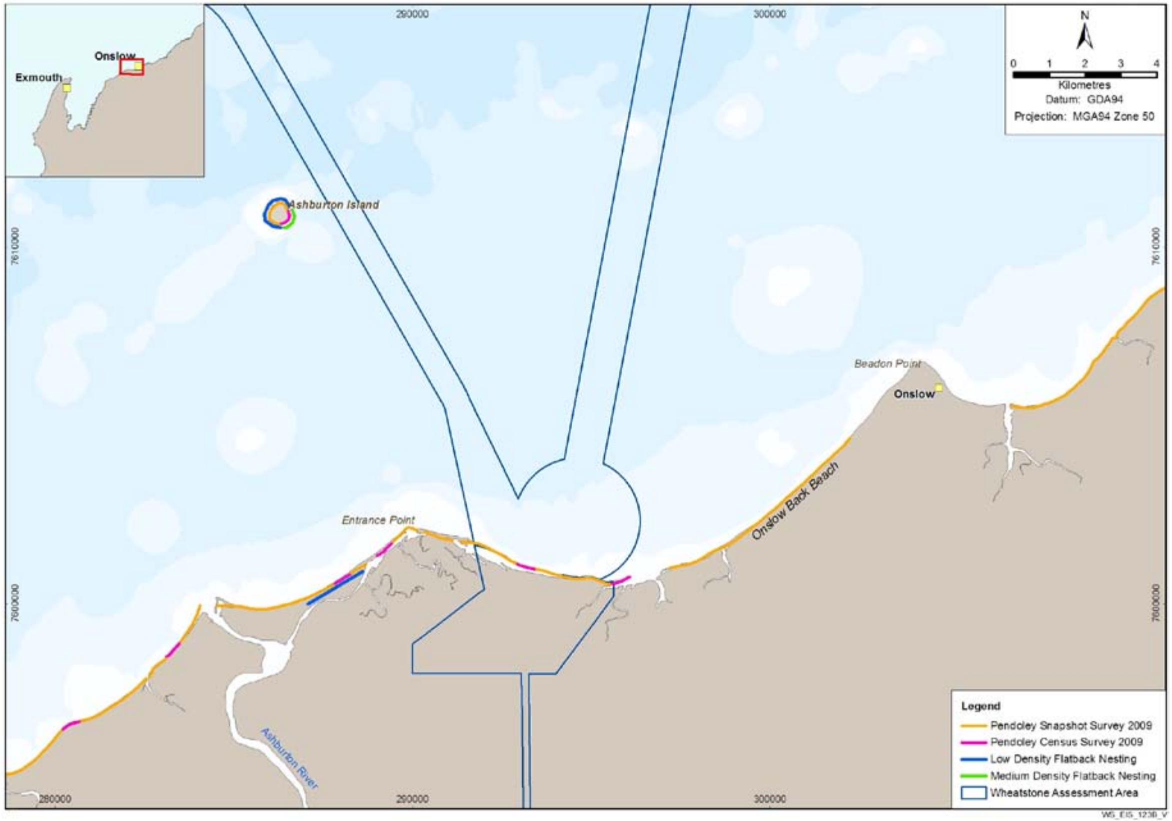

Figure 2-1 Location of Ashburton River delta beach and Ashburton Island nesting surveys, in relation to the proposed Ashburton North SIA.

Light Modelling

3.1 Lighting Model Methodology

Light predicted to emanate from routine lighting infrastructure used throughout the Ashburton North SIA (i.e. not including flares) was modelled in accordance with minimum light levels outlined in Australian/New Zealand Standard 1680.1:2006 Interior and workplace lighting (Standards Australia/Standards New Zealand 2006). For modelling purposes, two basic luminaires with 250-Watts (W) and 400-W HPS globes were considered as the light sources. These were used to estimate intensity levels at various locations within the Ashburton North SIA and to generate a contour map of expected lighting distribution. For the purpose of the estimation, the following assumptions were made:

- lamp posts for perimeter lighting, jetty and roadways were 30 m apart
- 250W and 400W HPS globes were to be used throughout the plant
- the air mass ratio was 1 (i.e. does not account for skyglow)
- no topographic features, such as dunes and tall vegetation, occurred in the area (i.e. the entire site was treated as a flat plane)
- no other lighting contribution (from temporary construction activity, offshore shipping or flaring) occurred in the area.

3.2 Natural & Artificial Ambient Light

To provide context to the modelled light emissions from the Ashburton North SIA, a comparison of light levels emanating from common lighting situations and natural ambient lighting phenomena is presented below (Table 3-1).

Table 3-1 Examples of relative illuminance.

Illuminance (Lux)	Source
0.0001	Light from Sirius, the brightest star in the night sky
0.001	Total starlight, overcast night sky
0.002	Moonless clear night sky with airglow
0.01	Quarter moon
0.27	Full moon on a clear night
1	Full moon overhead at tropical latitudes
3.4	Dark limit of civil twilight under a clear sky
50	Family living room
80	Hallway/bathroom
100	Very dark overcast day
320–500	Office lighting
400	Sunrise or sunset on a clear day.
1,000	Overcast day; typical TV studio lighting
10,000–25,000	Full daylight (not direct sun)
32,000–130,000	Direct sunlight

3 Light Modelling

Spectral distribution of various artificial light sources are presented in the following illustration (Figure 3-1). HPS lamps predominately transmit light in the longer wavelengths of the visible spectrum (e.g. red light), while low-pressure sodium (LPS) lamps are essentially monochromatic and transmit light largely in the yellow and orange spectral bands. Metal halide lamps predominately transmit light in the shorter wavelengths of the visible spectrum (e.g. blue, violet).

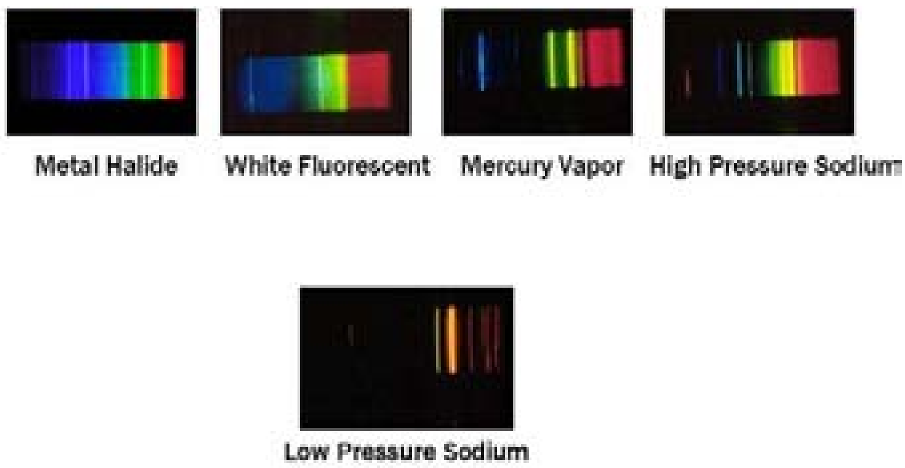

Figure 3-1 Spectral distribution from artificial light sources.

3.3 Lighting Model Results – Routine Emissions

The estimated impact of the Ashburton North SIA illumination, when viewed directly from above, is illustrated below (Figure 3-2). This estimate accounts for the height of major infrastructure within the onshore development area (e.g. buildings, tanks) and shows the intensity of light surrounding the different parts of the Ashburton North SIA. Light is shown as being the most intense at its source (shown in red) and gradually decreasing in intensity as it travels further away from the source (shown in blue).

3 Light Modelling

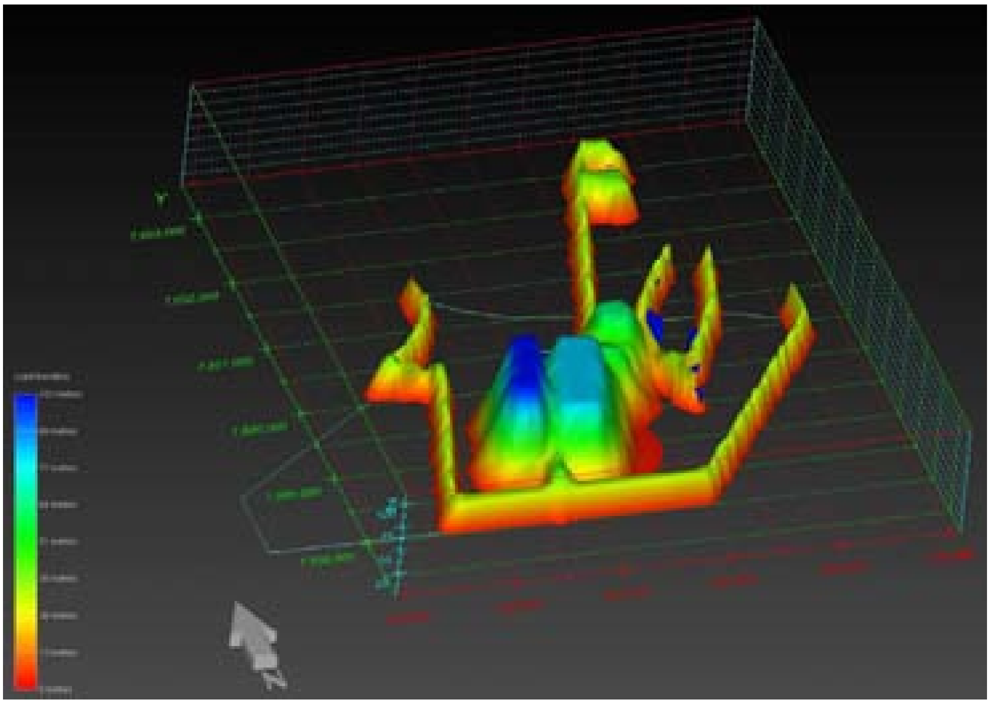

Figure 3-2 Lighting model for light emissions at the Ashburton North SIA.

The following diagram (Figure 3-3) is a rendering of the lighting model with a domain of predicted contour lines out to a cut-off level of 0.001 Lux. A Lux value of 0.001 is comparable with total starlight or an overcast night sky and is therefore considered to be a very low light intensity level. The model predicts the intensity of artificial illumination on the foreshore and beaches within the boundaries of the Ashburton North SIA. Levels of between 0.001 Lux and 20 Lux are shown on sections of beach, primarily where the nearshore structures are constructed perpendicular to the shore. Beyond the contour domain presented below (Figure 3-3), the light levels decrease to below 0.001 Lux.

3 Light Modelling

Figure 3-3 Lux contours of the Ashburton North SIA lighting model.

Light levels emanating from the Ashburton North SIA decrease with increasing distance from the source (Figure 3-4). Light levels generated by LNG plant infrastructure are presented on a logarithmic scale in Lux against the linear scale of distance in metres. The amount of illumination received by a sensor (or the eye) varies inversely with the square of the distance from the point source, thus the intensity of light that can be detected decreases exponentially as the distance from the source increases (i.e. if the distance from a point source is doubled the intensity falls by a factor of four). Light dissipates both laterally (over distance) and longitudinally (increasing height), depending on the viewing location (Figure 3-2).

Routine lighting emanating from the Ashburton North SIA is not predicted to cause illumination at ground level above 0.001 Lux, beyond 3 km from the Ashburton North SIA.

3 Light Modelling

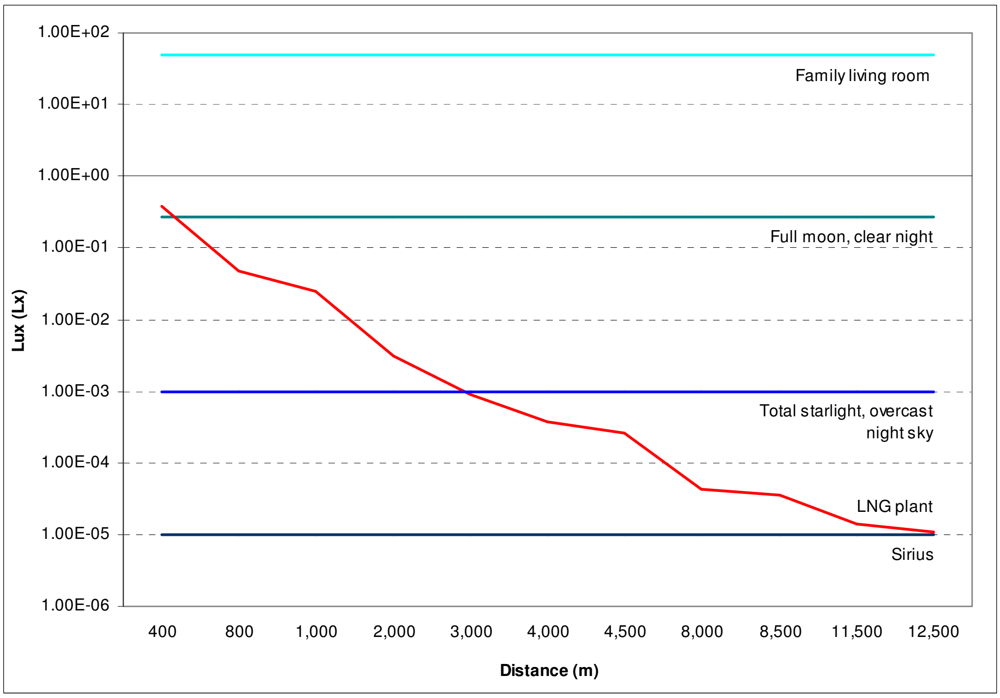

Figure 3-4 Light spill versus distance from the Ashburton North SIA during routine operation. The 'y' axis is shown as an exponent of 1, with 1.00E-05 equalling 0.00001 Lx and 1.00E+02 equalling 100 Lx, and so on.

3.4 Lighting Model Results – Dry/Wet, Marine & Pilot Flaring

Commissioning of the LNG plant will be undertaken after the completion of construction and installation works. This commissioning will be undertaken to ensure that the facility is operating correctly. During this period, residual gas will be flared. It is anticipated that commissioning will be undertaken for each train, in isolation, therefore it may be necessary to conduct commissioning flaring between four and six times during the life of the Project. It is anticipated that commissioning flaring will be several days in duration. During routine LNG plant operation, it is anticipated that total flaring (dry/wet, marine) will occur for approximately 174 hours per year, non-continuous. It is anticipated that a non-routine flare event will last for approximately 15 mins (but not more than for 1 hr). It is important to note that regardless of the duration or amount of gas flow being flared, the light intensity, and therefore light spill, will be the same. A flaring event is considered to have equal probability of occurring during the day or during the night. It is likely that dry/wet flares will emit light between the wavelengths of 360 nm (blue-green spectrum) and 860 nm (red spectrum), dependant on the distance from the flare as blue-green light diminishes more rapidly than red light with increasing distance.

The current Ashburton North SIA flare system design indicates that dry/wet flares will be 138 m in height above mean sea level (AMSL) (assuming that the site is raised to 7.5 m AMSL). In calm conditions, the flame will stand at approximately 6 m above this level. Marine flares will be 37 m in height AMSL (assuming the site is raised to 7.5 m AMSL). In calm conditions, the flame will stand at

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4 m above this level (URS 2010). A pilot light will also operate consistently during LNG plant construction and operation, however it is not expected that the resultant light will be of an intensity to cause light spill, outside of the Ashburton North SIA.

The topography of the area between Entrance Point and the mouth of the Ashburton River through to the Ashburton North SIA is intersected by a series of coastal dunes running parallel to the beach. Beach width ranges from 1 m to 60 m, while beach dune heights range from 1.4 m to 16 m (Damara 2010). Parallel dunes that will influence the amount and spread of light spill from marine flares are approximately 1100 m to 1600 m apart, and range between 10 m and 16 m in height. Parallel dunes influencing light spill from the dry/wet flares are 2600 m to 5800 m apart, and range from 10 m to 12 m in height. The significance of the height of the dunes and the distances between dune systems is that the light emitting structures may be hidden from an observer on the beach, and nearshore, by the dunes. In this circumstance, the observer would see reflected and diffused light (skyglow), rather than direct light.

Light spill, as a result of intermittent flaring from dry/wet flares (Figure 3-5) and marine flares (Figure 3-6), has been modelled conservatively in relation to the only known flatback turtle nesting beach in the vicinity of the Ashburton North SIA (Ashburton River delta beach; Pendoley, 2009a). The modelled domain is presented as coloured points and grey contour shading in the sector of interest. Both presentations predict ground level Lux levels, but on different scales. As the first dune crest is of sufficient height to protect the central section of Ashburton River delta beach from direct light spill, the predicted Lux value in the model is reduced at the central section of the beach but higher slightly out to sea. The results assume that only one flare operates at any one time. This is not necessarily what will occur in routine Project functioning. However, Lux levels from combined flaring would be not significantly different from one dry/wet flare operating alone.

Light spill intensity from the dry/wet flares (Figure 3-5) is most significant at the eastern end of Ashburton River delta beach, which receives up to 0.13 Lux. At the western end of Ashburton River delta beach, lower levels of 0.03 Lux to 0.05 Lux are received, due to both the distance from the light source and to the impact of beach dune heights. Beach dune heights are generally lower at the eastern end of Ashburton River delta beach and highest close to the western entrance of the Ashburton River delta (URS 2010). Nesting activity is restricted to the central and western sides of the beach (RPS 2010) and most nesting is predicted to occur at the base of the dunes, an area largely shielded from direct light by the dune crest.

The modelling contour presentations do not characterise the spectrum shift in wavelength intensity as a function of distance from the light source. Dry/wet and marine flare spectra verses wavelength data are presented below (Figure 3-7; Figure 3-8). As the distance from the flare increases, the received light source shifts towards the red end of the spectrum due to attenuation by refraction and absorbance. At the median distance of the dry/wet flares from the beach which is approximately 4,400 m, the blue end of the spectrum (< 540 nm) will have diminished by 13 per cent, whereas the red end of the spectrum (> 540 nm) will have diminished by 2 per cent (Figure 3-7). This red shift changes the perceived light intensity for humans, although the illuminance (Lux) is the same.

3 Light Modelling

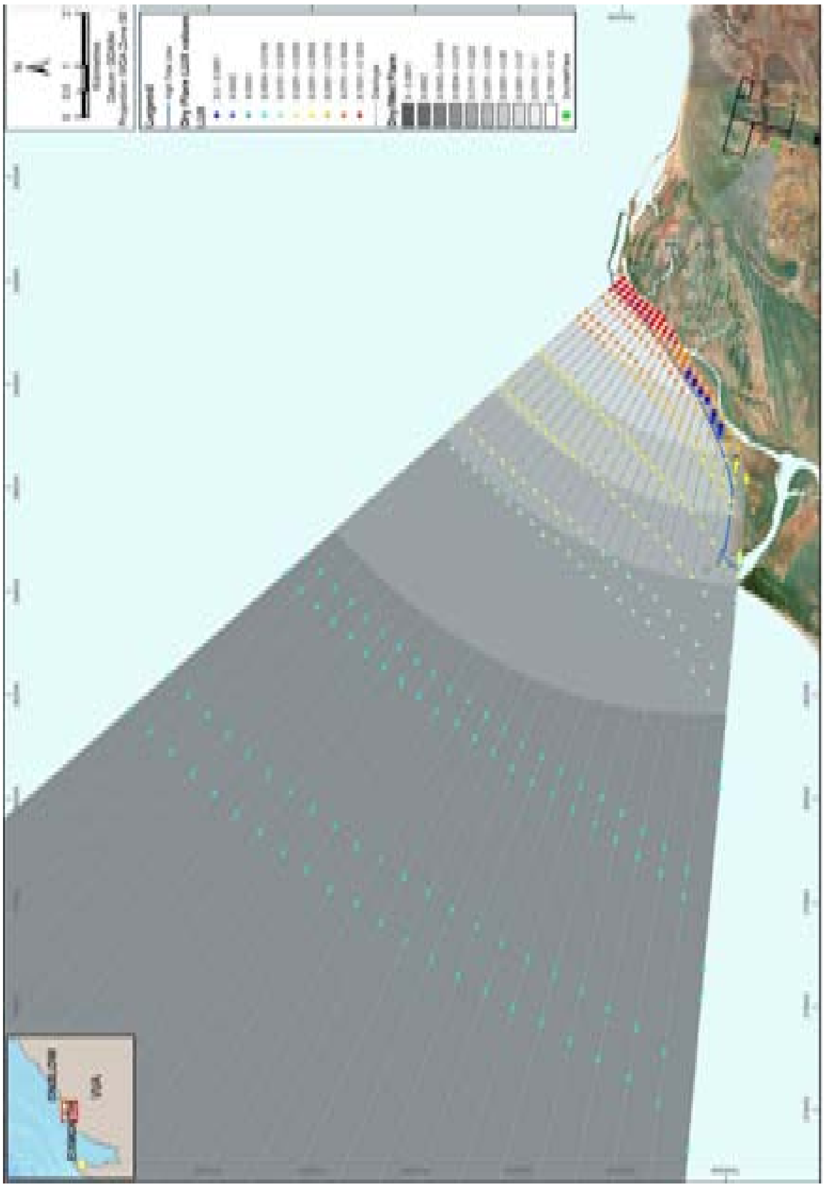

Figure 3-5 Light spill from dry/wet flares.

3 Light Modelling

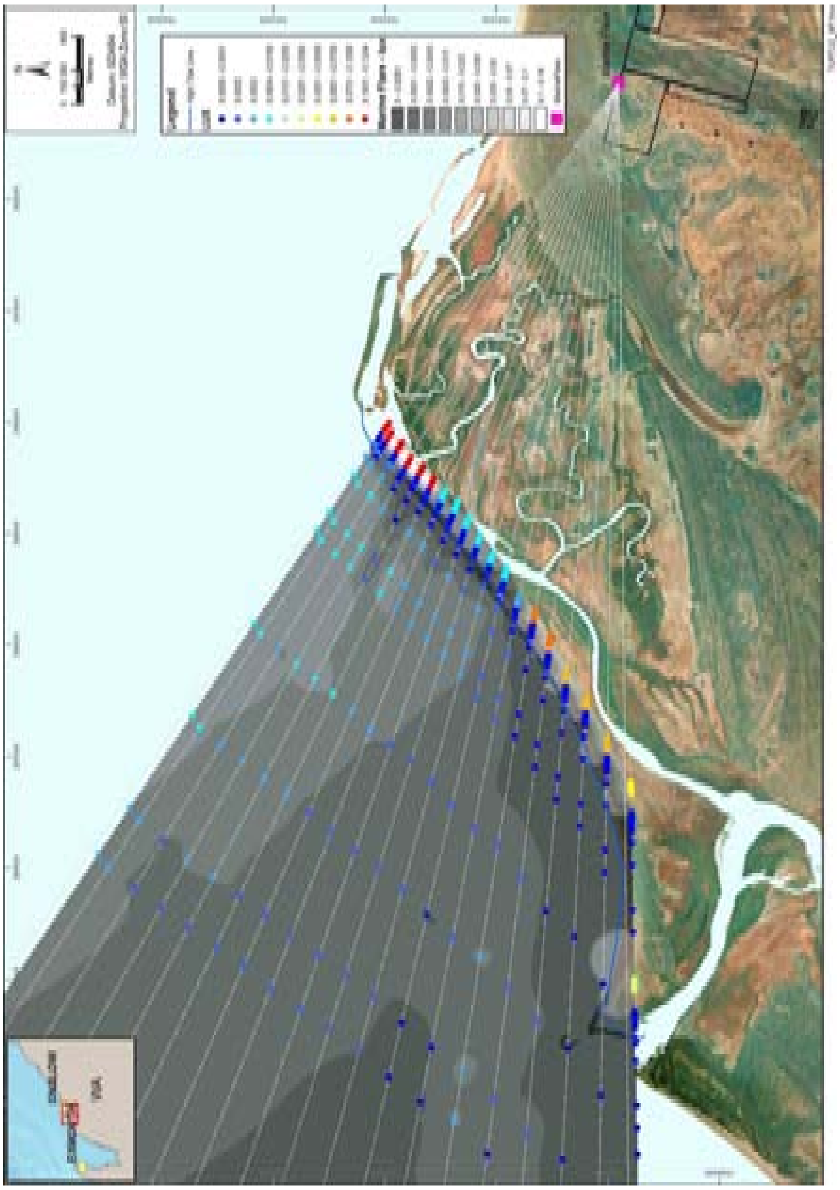

Figure 3-6 Light spill from marine flares.

3 Light Modelling

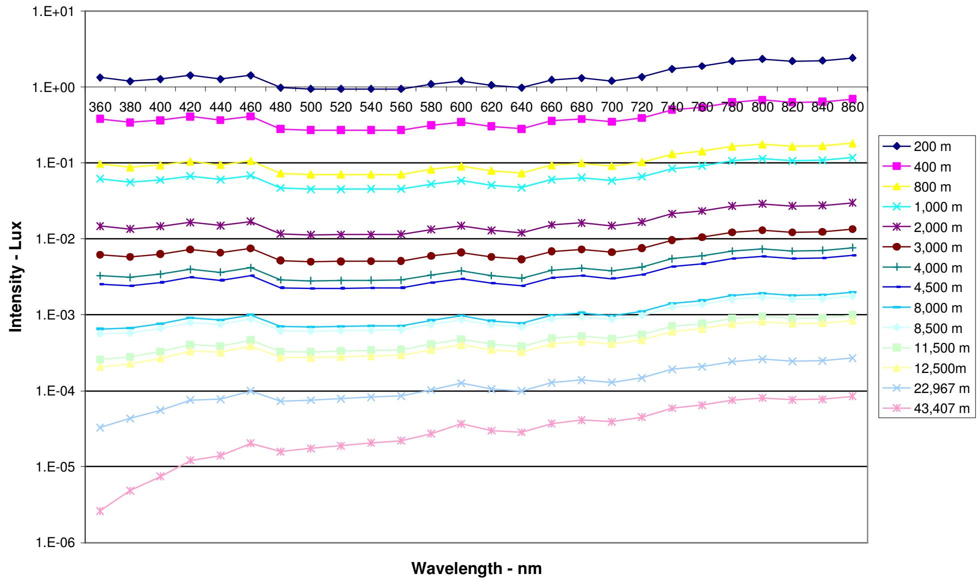

Figure 3-7 Dry/Wet flare spectra versus wavelength

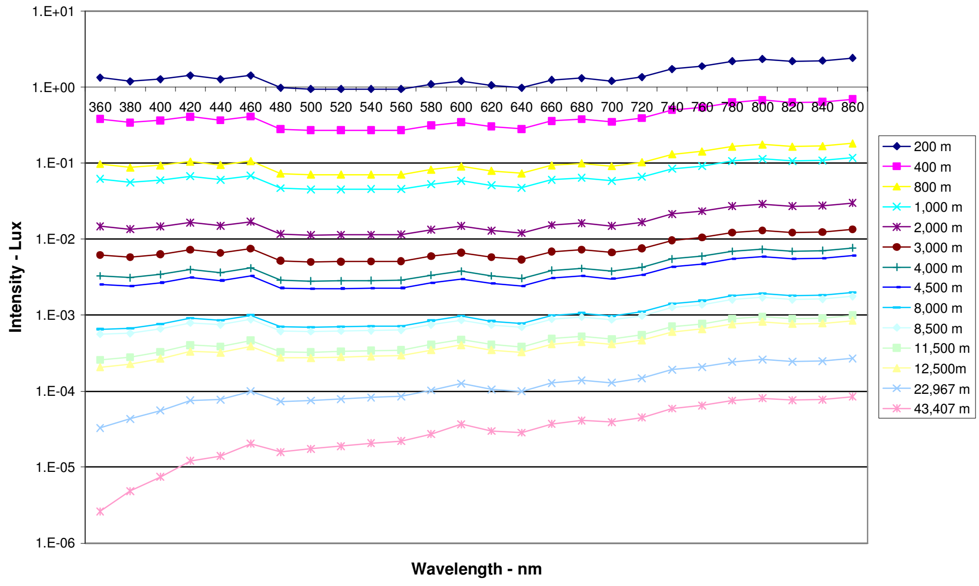

Figure 3-8 Marine flare spectra versus wavelength.

3.5 Lighting Model Results – Skyglow

Skyglow occurs when artificial light reflects off clouds and atmospheric particles such as dust and water vapour, causing a 'scattering' effect. Different light sources will produce different amounts of skyglow from the same amount of light being sent into the atmosphere. A simple metric for this phenomenon is known as the Rayleigh Scatter Index, which indicates that HPS lamps produce roughly one-third to one-half of the skyglow than typical metal halide lamps, based on the same amount of light entering the atmosphere. Airborne particles, cloud elevation, and sea conditions will all considerably effect the level at which skyglow is perceived from an observer, located some distance from the Ashburton North SIA.

Conservative modelling assumptions for deriving "worst-case" skyglow estimates from the Ashburton North SIA are summarised below:

- Maximum light intensity derived from the additive effects of routine light emissions from the Ashburton North SIA plus an operational marine flare.
- Assumed that the cloud cover is total and for cumulonimbus (thunderstorm clouds) with an albedo of 80%.
- Cloud height is 150 m Australian Height Datum.
- Assumed Lambertian reflection.
- Ashburton North SIA boundary assumed to be 650 metres from the flares.
- Sensitive receptor shoreline is assumed to start approximately 3000 m from the flares.

Maximum Lux perceived as a result of skyglow by a turtle hatchling in the modelled domain occurs at a point approximately 3,400 metres from the flare. This would reach the nearshore area of the Ashburton River delta beach. The maximum intensity of the skyglow is computed as being approximately 0.00001 Lux. This is one order of magnitude less than the light produced by Sirius (Table 3-1).

Discussion

Known turtle nesting beaches and islands in the vicinity of the Ashburton North SIA will not experience direct illumination from routine lighting at levels above that of natural phenomena.

Under routine operational conditions, including routine pilot lighting, light levels between 0.001 Lux and 20 Lux occur where nearshore structures are constructed perpendicular to the shore. Outside of these areas, light levels decrease below 0.001 Lux. The intensity of light emissions under routine operations beyond 1 km from the Ashburton North SIA are below 0.01 Lux. Mainland beaches within an 8 km radius of the Ashburton North SIA will likely be subjected to light emissions of an intensity that may compete with natural light sources (i.e. light from Sirius (0.0001 Lx) or a full moon on a clear night (0.27 Lx); Table 3-1). This is dependant on atmospheric conditions and moon phase.

Conversely, modelling predicts that flare events will have the potential to be comparable with moonlight at Ashburton River delta beach, approximately 4.5 km west of the Ashburton North SIA. However, this type of event is expected to be infrequent during the operational lifetime of the Ashburton North SIA with each release of a flare lasting for only a brief period. The probability that flaring would coincide with nesting events or hatchling emergence is considered to be low.

In a worst case scenario, assuming ideal atmospheric conditions and not accounting for shielding by natural terrain and vegetation, a flare event could be perceived by sea turtles in the vicinity of Ashburton River delta beach as an object half as bright as a full moon.

Offshore islands appear to support greater numbers of nesting sites and higher use of the beaches, however most of these islands are at a sufficient distance from the Ashburton North SIA not to be effected by routine operational lighting or flare events. Under flare conditions, light spill will exist in the form of direct light as the flares will be visible from most locations along Ashburton River delta beach. This light intensity will be most significant at the eastern end, which receives between 0.1 Lux and 0.12 Lux. This has limited potential to deter female turtles from selecting this area as a nesting site, or to misorient hatchlings.

Skyglow arising from the Project is not considered to present a significant source of light. Maximum calculated skyglow under “worst case” conditions with a marine flare operational and low cloud cover, is calculated to be an order of magnitude less than the light produced by Sirius at the nearest probable sensitive receptor site.

In Ashburton North SIA design terms, LPS light sources present the least disruptive artificial light source to sea turtle behaviour, while HPS light sources are the next most preferred source. Fluorescent and metal halide light sources emit nearly a full spectrum of light characteristics and are the least preferred light sources to use near potential nesting sites.

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Glossary

Term	**Definition**
Attenuation	The gradual loss in intensity of any kind of flux through a medium.
High-Pressure Sodium Lamp	A high intensity discharge (HID) lamp whose light is produced by radiation from sodium vapour (and mercury).
Illuminance	A photometric term that quantifies light incident on a surface or plane. Illuminance is commonly called light level. It is expressed as lumens per square foot (footcandles), or lumens per square meter (Lux).
Lambertian Reflection	Assumes that all light rays will reflect off of a flat surface equally.
Low-Pressure Sodium Lamp	A low-pressure discharge lamp in which light is produced by radiation from sodium vapour. Considered a monochromatic light source (most colours are rendered as gray).
Luminaire	A complete lighting unit consisting of a lamp or lamps, along with the parts designed to distribute the light, hold the lamps, and connect the lamps to a power source. Also called a fixture.
Luminance	A photometric term that quantifies brightness of a light source or of an illuminated surface that reflects light. It is expressed as foot lamberts (English units) or candelas per square meter (Metric units).
Lux (Lx)	The metric unit of measure for illuminance of a surface. It is a measure of the density of light that falls on a surface and is what light meters measure. One Lux is equal to one lumen per square meter. One Lux equals 0.093 footcandles.
Metal Halide Lamp	A type of high intensity discharge (HID) lamp in which most of the light is produced by radiation of metal halide and mercury vapours in the arc tube. Available in clear and phosphor coated lamps.
Rayleigh Scatter Index	A type of light scattering that occurs when light bounces off of molecules (i.e. nitrogen or oxygen).

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Limitations

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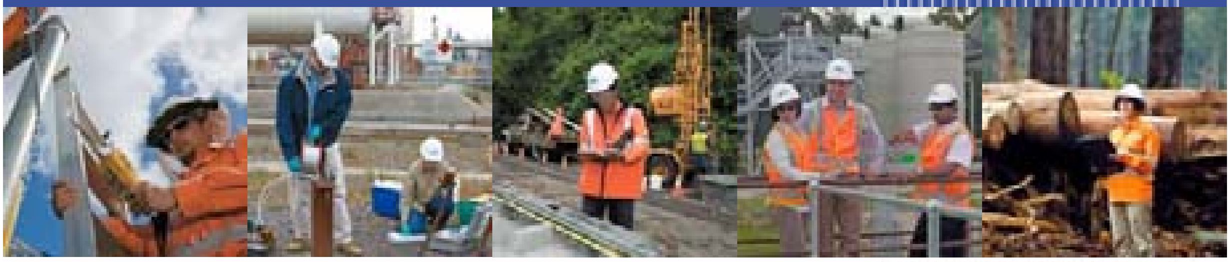

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Appendix 02

Sea Noise Logger Deployment: Wheatstone and Onslow - April to July 2009 Preliminary Analysis

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Centre for Marine Science and Technology
Curtin University

SEA NOISE LOGGER DEPLOYMENT WHEATSTONE AND ONSLOW, APRIL TO JULY 2009
PRELIMINARY ANALYSIS

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04-Dec-2009

For - URS / Chevron

PROJECT CMST 829
REPORT R2010-09

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Abstract

A series of five sea noise loggers were deployed, two near shore west of Onslow over April to July 2009, and three in a 2 km triangle on the shelf break north of the Monte Bello Islands over May to July 2009 (Wheatstone or offshore site). A preliminary analysis of noise logger data has been presented here. The noise logger program is to carry over a full season into 2010 after which a thorough analysis will take place. The noise loggers detected various whale species including: pygmy blue, dwarf minke; Brydes; and humpback whales. The recording period is currently too short to correctly delineate seasonal patterns in whale trends. The offshore noise loggers were dominated their entire recording period by seismic survey and vessel noise. At times three seismic survey sources could be detected at the offshore location, these believed associated with two surveys running in deep waters adjacent the continental shelf to the south. Vessel noise was prominent at the offshore location, presumably from vessels involved in site works at the proposed Wheatstone and Pluto gas fields. Pygmy blue whales were present offshore over most of the May to July period. These where believed to be north bound pygmy blue whales returning to low latitudes after spending summers feeding in temperate waters. The time integrated count of individual calling pygmy blue whales from the Wheatstone site from a nearby data set made in 2006 was compared with the similar count made in 2009 over the matching time period in Julian days. Six times fewer whales were recorded in 2009 compared with 2006. Dwarf minke whales were detected inshore and offshore. Offshore, dwarf minke whales were recorded persistently across the April to July period with a slight tendency for more whales in June-July. The time integrated counts of individual calling dwarf minke whales offshore in 2009 were compared with the same calculation for the nearby site made in 2006 and seven times fewer dwarf minke whale detections were made in 2009. It is currently not clear why counts of pygmy blue and dwarf minke whales were lower in 2009 than in 2006 at the offshore site. The listening area of the offshore site was calculated and under quiet ambient noise conditions found to be approximately 61 km and 48 km for humpback and pygmy blue whales respectively. Under the ambient noise regime experienced from vessel and seismic noise this detection range dropped by more than a factor of three. Brydes whales were detected on one day only in April at a site in 43 m of water west of Onslow. Humpback whales were present at the 43 m depth inshore site and at the offshore site. The first detection of humpbacks at the 43 m inshore site, on the known migratory route was on the 30-May-2009 with numbers of singers steadily increasing to be persistent across July. It was estimated that by July on average 27 humpbacks were within the listening range of the noise logger (112 km^2 under quiet sea conditions) for a density of 0.24 whales / km^2, but at times this could reach from 0.5-0.6 whales / km^2. Periodicity in humpback calling at 1, 3, 6 and 14 days was observed related to a daily cycle (one day period) and possibly residency times and movements of pulses or groups of whales through the area. Regular evening fish choruses were heard at the 43 m depth inshore site but not at the 10 m depth site. Expected fish choruses from the offshore site were not detected. This work is ongoing with further data collection and analysis planned.

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1. Introduction

In April 2009 URS contracted the Centre for Marine Science and Technology to deploy sea noise loggers at the proposed Wheatstone offshore gas facility and off the coast west of Onslow. The noise loggers were deployed in order to gain information on ambient sea noise sources and the presence and movements of great whales. The sea noise logger records were to be analysed for great whale signal types and these used to describe the passage of whales near the offshore facility location and at the two inshore sites near a proposed harbour channel and pipeline route.

Data was intended to be collected in two phases, the first being a preliminary set of measurements with analysis made over a very short time period. The second phase allowed for data capture over a full season and a thorough analysis. The noise loggers were deployed as shown on Figure 1 in two stages, with the two southern loggers set on the 16-Apr-2009 and the northern grid of three, set on the 5-May-2009. All data was recovered over the 22nd and 23-July-2009. Data was bought back to Curtin on the 27-July and a preliminary analysis carried out so that a lead in report could be produced by the 06-Aug-2009 (ie. two weeks were allowed for analysis and reporting). This report builds on the initial data recovered set to include analysis of humpback patterns at one of the inshore sites. No discussion is presented here.

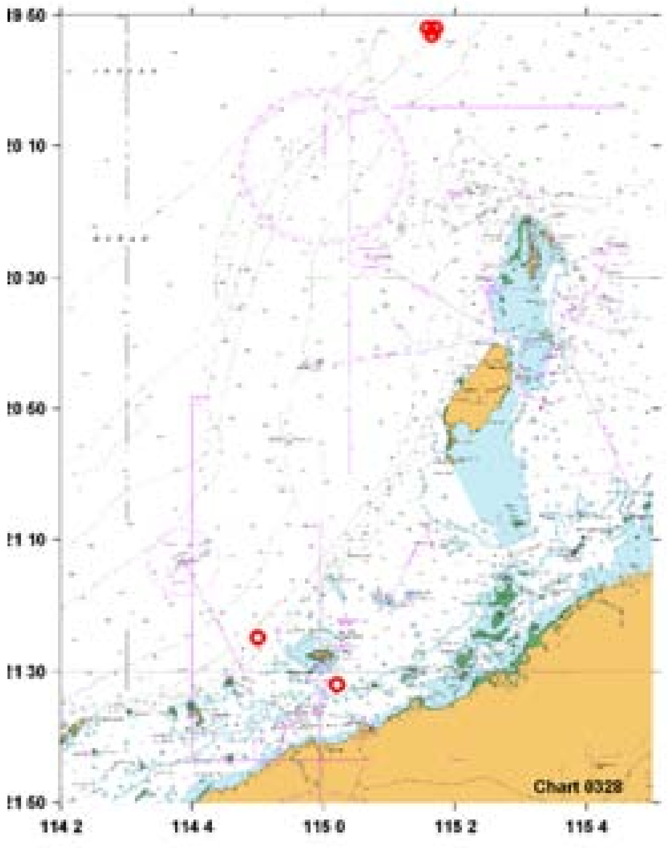

Figure 1: Location of noise loggers set in Phase I. All noise loggers were redeployed at similar locations. The Phase I locations have been given the numbers: 2808 – logger closest to shore; 2809 logger in 43 m water nearshore; set 2810, southern-most logger of offshore grid; 2811, western-most logger of offshore grid; and 2812 the eastern-most logger of the offshore grid.

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The sea noise loggers capture samples of ocean noise and so a record of all the noise sources detectable in the bandwidth of the noise logger. The offshore noise loggers were set with a useable bandwidth of 1 Hz to 3 kHz, the inshore loggers from 1 Hz to 8 kHz (sample rates of 6 and 16 kHz respectively). The offshore loggers will thus detect: most vessel noise; marine petroleum seismic survey signals; marine construction activities; great whale signals – expected to be here humpback, pygmy blue, fin, minke and Bryde's at least; fish choruses; and natural physical sea noise sources such as wind and rain. The inshore noise loggers were set with a higher sampling frequency in order to additionally capture any dolphin signals from nearby animals. The bandwidth selected for sampling is a trade-off against the deployment length and the available battery and hard disk capacity. By using a larger bandwidth the hard disks fill up quicker and the gear needs servicing more frequently.

All of the phenomena collected by the noise loggers can be quantified to some degree. For example we can define the received levels of seismic signals, vessel movements or natural ambient noise, or we can count the number of singing whales of a given species to give a time series of their passage, or relative abundance measures. This report describes some of the signal types recorded and presents a preliminary analysis of whale abundance and ambient noise.

2. Methods

2.1 Deployment locations and sampling

Five noise loggers were deployed, three in a triangular tracking configuration set offshore on the 200 m contour near the proposed Wheatstone gas facility and two inshore. The location of all loggers was shown on Figure 1 with a larger scale chart of the inshore loggers shown on Figure 2 and the offshore loggers on Figure 3.

Noise loggers were recovered during a field trip over the 20-23 Jul-2009. The same noise loggers were reconfigured with new hard disks, the flash cards copied over and re-formatted, the clock drift checked against GPS transmitted time and the loggers redeployed. The offshore loggers were also re-programmed to get their respective start times set for 10:15 UTC.

The CMST-DSTO sea noise loggers deployed were designed and built at Curtin. The logger design has evolved since the work was initially funded in the late 1990's to take advantage of digital technology in collecting sea noise data. In all deployments described here noise loggers were set on the seabed with the hydrophone external to the housing lying on the seafloor and entering the housing via a bulkhead connector. The hydrophone signal was amplified using an impedance matching pre-amplifier (20 dB gain), filtered with a low frequency roll-off starting at 8 Hz and the loss increasing with decreasing frequency so as to flatten the naturally high levels of low frequency ocean noise and increase the system dynamic range. An anti-aliasing filter was applied and the signal then fed to a 16 bit analogue to digital converter. The digital signal then had further gain applied (20 dB) and was sampled according to a pre-programmed sampling schedule. Samples were written to flash card (power cheap) then when the flash card was near full transferred to a hard disk (power hungry).

The sea noise logger sets, their recording numbers (a Curtin number is assigned to each deployment), locations, water depth at hydrophone (all loggers set on the seabed) and good samples collected are listed on Table 1. All loggers collected 200 s samples of sea noise every 15 minutes. All sets except the shallowest logger, 2808 in 10 m of water north of Onslow, collected good data for their deployment duration. There were a few mooring artefacts observed on some loggers (mooring lines tugging on loggers due to tidal flow) but these have been removed in analysis. The shallow water set 2808 suffered a cable fault approximately three weeks into the deployment. The hydrophone cable was found to be pinched, this probably occurring during deployment as it was thoroughly tested before being flown on site. The cable subsequently failed due to water ingress. The cable was completely wrapped in a protective shield, thus must have received a sharp knock or was cut accidentally somewhere during set up or deployment.

All noise loggers were calibrated before deployment by inputting white noise of known level through the bulkhead connector with the hydrophone in-series. This gave the system gain with frequency, with the system response for all loggers shown on Figure 4. The logger electronics deliberately apply a low frequency rolloff, nominally below 8 Hz, to flatten the naturally high sea noise levels and so increase the loggers input dynamic range (ie. low frequencies are less likely to saturate). This rolloff was corrected in post-processing. The loggers were calibrated from 1 Hz to the anti-aliasing filter setting using the system gain curves and the hydrophone sensitivity.

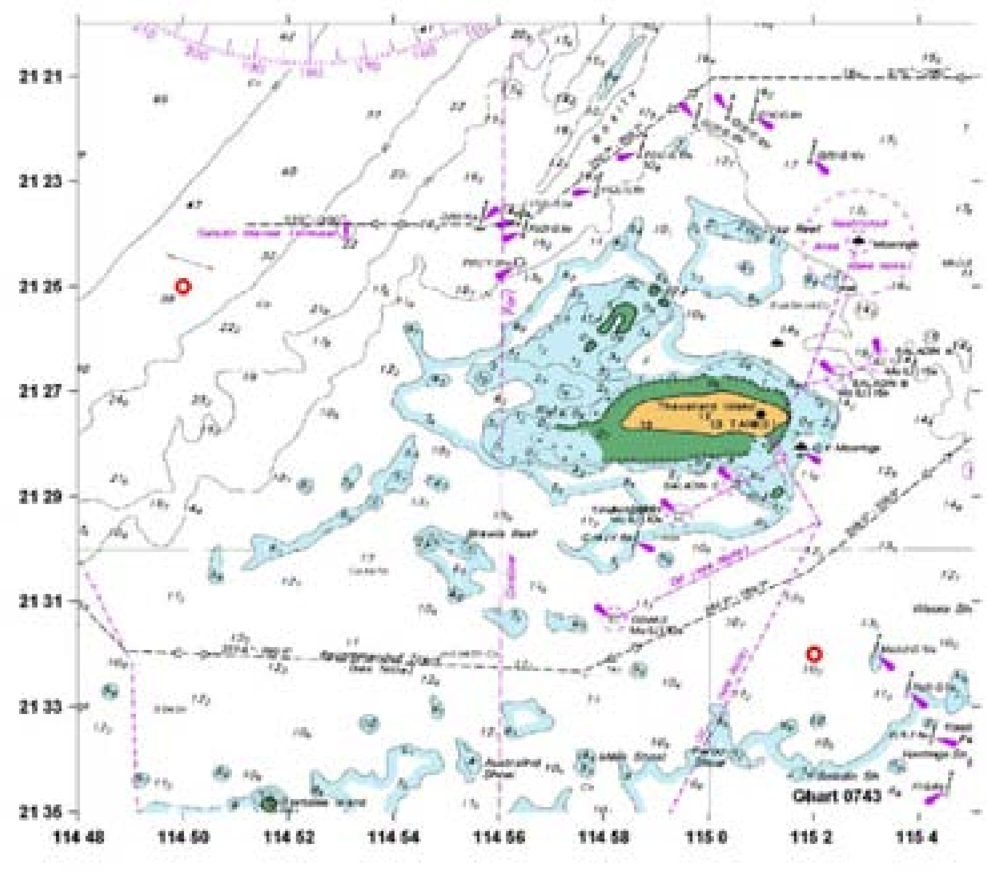

Figure 2: Location of the two Phase I inshore loggers (red circles). Set 2808 is the eastern one, set 2809 the western one.

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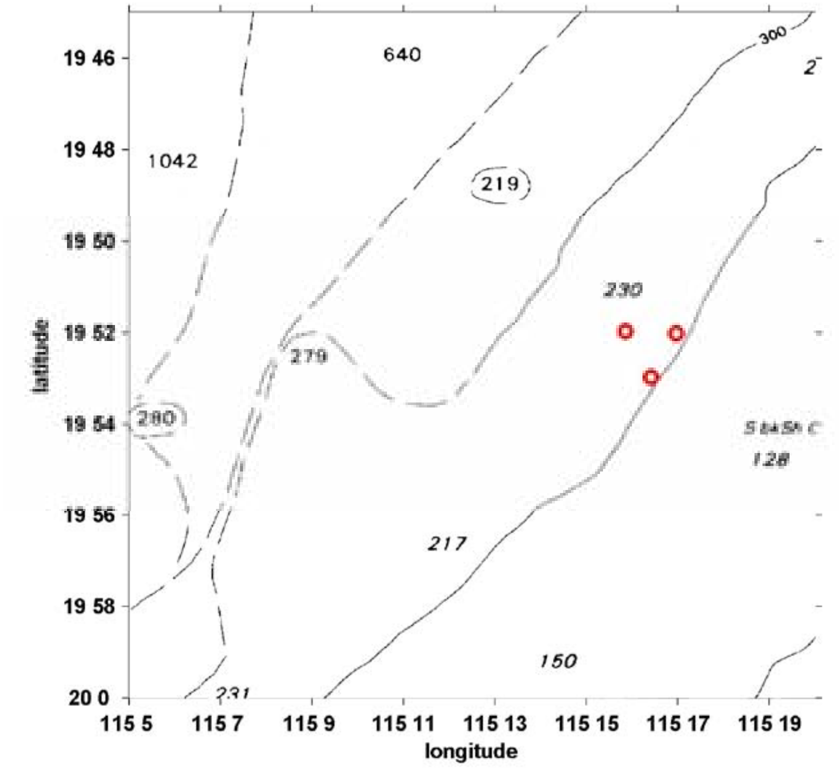

Figure 3: Location of offshore noise loggers (red circles) with bathymetry contours shown (from the east, 200, 300, 500 and 1000 m). Set 2810 is the southern location, 2811 the western location and set 2812 the eastern location.

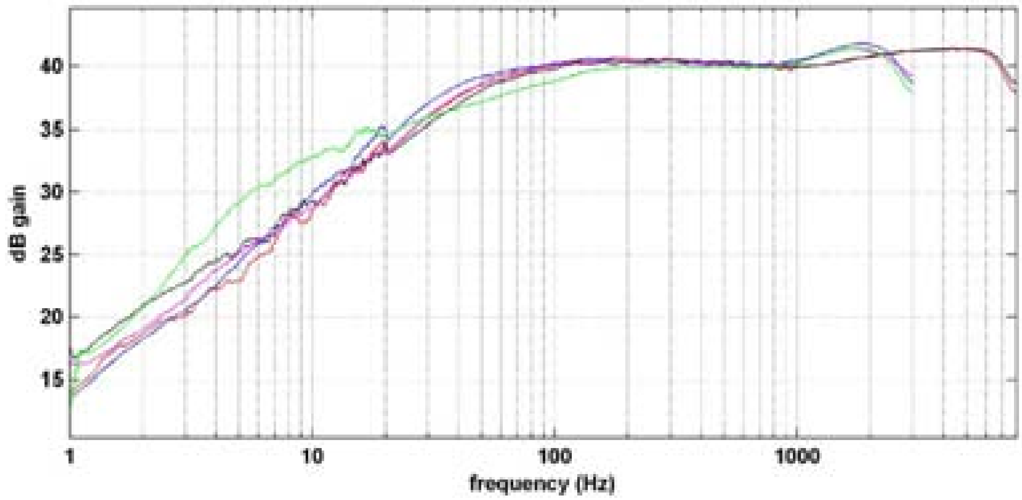

Figure 4: Calibration curves for the Wheatstone Phase I sea noise loggers.

All loggers were time synchronised to GPS time before deployment and clock drift read after deployment, with estimated clock accuracies at any point in time of the order of ± 250 ms. The

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logger clocks jump when going in and out the water due to the temperature change thus the drift determined from the GPS synchronisations is not completely linear between the GPS time synchronisations. The time drift of all except one of the offshore noise loggers was read during the redeployment field trip. For one logger (set 2810) the GPS unit used to synchronise the loggers could not get satellites during the time available to re-set the unit whilst at sea, thus its clock drift could not be read.

In order to synchronise the clocks of the three offshore loggers one mooring used a modified acoustic release, which produced a 7.5 kHz ping every 20 s for 30 minutes, once per day. Each of the noise loggers was programmed to sample the ping once per day using a 22 kHz, 200 s sample (sets 2813, 2814, 2815 Table 1). By knowing the geometry of the pinger source and receiver locations and an estimated sound speed, the arrival time of the ping can be used to set two of the logger clocks to the third logger. This analysis then gives the relative clock times of the three loggers allowing the grid to have a tracking capability by using arrival time differences for any signal coherent on the three loggers. The analysis of the tracking grid has not been carried out for this report.

Table 1: Summary of sea noise recordings made during phase I of the Wheatstone noise logger deployments. Locations use WGS84 datum. Times are WST. Abbreviations are: WO_1_1_6 = Wheatstone Offshore logger 1 (of grid of 3), set 1, 6 kHz sample rate, WO_2_2_22 is Wheatstone Offshore logger 2 (of grid of 3), set 2, 22 kHz sample rate etc.

Set	Location	Elect.	Hyd.	sample rate (Hz), length/incr. (s)	Latitude (S)	Longitude (E)	Depth (m)	Good samples, (days recorded), sample dates
2808	Onslow_10_1	Silicon	HTI 033	16, 200/900	21° 32.005’	115° 02.001’	10	95-1873 (18.5), 16-Apr-2009 15:30 to 1 05-May-2009 04:00
	Onslow_10_2							
	Onslow_10_3				21 32.030	115 01.907		12-Sep-2009 07:00
2809	Onslow_45_1	Reef	HTI 014	16, 200/900	21° 25.006’	114° 49.995’	43	87-9190 (94.5), 16-Apr-2009 13:30 to 20-Jul-2009 09:15
2842	Onslow_45_2				21 24.994	114 49.960		22-Jul-2009 12:45 to 04-Nov-2009 00:15
	Onslow_45_3							
2810	WO_1_1_6	Redo	HTI 011	6, 200/900	19° 52.011’	115° 16.966’	211	1-7445 (77.5), 06-May-2009 18:15 to 23-Jul-2009 07:15
2813	WO_1_1_22	Redo	HTO 011	22, 200/86,400	19° 52.011’	115° 16.966’	211	
2811	WO_1_2_6	Perceval	Massa 495	6, 200/900	19° 52.973’	115° 16.419’	202	1-7482 (78.0), 06-May-2009 18:15 to 23-Jul-2009 16:30
2814	WO_1_2_22	Perceval	Massa 495	22, 200/86,400	19° 52.973’	115° 16.419’	202	
2812	WO_1_3_6	Revenge	HTI 032	6, 200/900	19° 51.972’	115° 15.858’	238	1-7358 (77.6), 06-May-2009 18:15 to 23-Jul-2009 09:30
2815	WO_1_3_22	Revenge	HTI 032	22, 200/86,400	19° 51.972’	115° 15.858’	238	
	WO_2_1_6				19 52.960	115 16.459		
	WO_2_1_22				19 52.960	115 16.459		
	WO_2_2_6				19 51.958	115 15.843		
	WO_2_2_22				19 51.958	115 15.843		
	WO_2_3_6				19 51.921	115 17.013		
	WO_2_3_22				19 51.921	115 17.013		

2.2 Units and analysis

All times given in this document are WST unless otherwise indicated.

Much of the analysis of noise used here resolves around time averaged power spectra taken across each sea noise logger sample. Noise is typically variable, with at short time scales (s) often large fluctuations around a mean noise level. To remove this variability it is standard practice in noise studies to do time averaging and so present a ‘mean’ noise level established across some time period long enough to enable an unchanging noise average to be derived (ie. averaging over longer periods will not largely alter the average derived). There is a trade off here in that one may be interested in time variations in the mean noise field so the averaging time must be selected to suit the time frames required - the averaging time must be long enough to give a constant ‘noise’ level but not long enough to mask any time period over which one is interested in looking at changes in the noise level. In this document the power spectral averages used in analysis of long term trends in noise levels have been mostly averaged across each noise logger sample of 200 s and the minimum unit for a change of noise level with time taken as the increment between samples (15 minutes).

Collecting sea noise recordings is not easy as there are a multitude of artefacts which turn up in the noise records. We attempt to reduce noise artefacts by setting the hydrophones on the seabed with as best as possible the noise logger isolated from the mooring lines. Artefacts still occur though, from a variety of sources such as the mooring line tugging on the logger despite our efforts to de-couple the two, the hydrophone rolling on the seabed, animals bumping or chewing on the hydrophone, housing or cable, and turbulent flow across the seabed in the hydrophone vicinity. We have had noise artefacts from shark bites on cables, shark teeth embedded in hydrophones on recovery, fish which set up home under the logger and continually bump it, squid laying eggs on the cable and logger, in areas of high tidal streams rocks rolling along the seabed and bumping into the housing, and molluscs grazing on algae which grows on the housings.

A technique has been applied to remove large noise spike artefacts from records during spectral averaging across the sample. This involved calculating an ensemble of consecutive power spectra within a 200 s sample, with each of these power spectra taken across equal time frames, at resolutions of 0.18 Hz (1 average), 1.46 Hz (8 averages) and 23.44 Hz (128 averages). Using the 1.4 Hz resolution spectra, the median spectral value at a reference frequency of 10 Hz (or the nearest frequency to this) was found along with the standard deviation of the mean. Any of the ensemble of power spectra which exceeded the median plus 1.1 times the standard deviation at the reference frequency, was rejected as a noise spike since these typically show high energy down to near DC. The average spectral value (in the linear domain) at each frequency from the accepted ensemble of spectra was then used for this sample and frequency resolution to give the ‘de-spiked’ power spectra, or the power spectra with noise artefacts removed.

The units and their definitions used in this report are:

- **dB re 1µPa^2/Hz –** these are termed spectral level units. The value has been normalised so that the intensity is presented in the equivalent of a one Hz bandwidth, even if the actual bandwidth the measurement was calculated in was not one Hz. These units are used widely in underwater acoustics and are useful for comparing the energy content of different sources, as the units can be directly overlain, even if for example the power spectral frequency resolution differs.
- **dB re 1µPa –** this is the intensity across the measurement bandwidth, with the bandwidth potentially differing. The bandwidth may be across the power spectra frequency resolution or it may be across the source effective frequency (typically assumed as the default if a bandwidth is not stated), as discussed below

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- **dB re 1µPa Broadband –** this is the integrated energy across the full frequency bandwidth of the source. Usually exact frequency bandwidths are not stated so it is assumed that the measurement encompasses the frequency range of dominant energy in the source (ie the signal energy outside of this frequency range does not contribute to the overall source energy received).
- **dB re 1µPa across a 1/3 octave band –** 1/3 octaves are recognised logarithmically increasing frequency bands used in airborne acoustic studies. Each band has a defined lower frequency, centre frequency and upper frequency. The dB re 1µPa within a 1/3 octave band is the intensity summed across the band. The 1/3 octave bands are normally referenced by their centre frequency. The 1/3 octave scale was designed to mimic the frequency resolution of the human ear, which integrates energy in logarithmic frequency bands. It turns out that this is a trait common to all vertebrates, hence has wide application in studies into animal response to noise and hearing.
- **dB re 1µPa @ 1 m –** or source level – this is the intensity of a measured source at some range, which has been assumed to be a point source and which has had the transmission loss correction for that range and frequency applied. The source level is then the intensity at one m range the source would radiate if it were an infinitesimal point. Most real sources are not infinitesimal points so for large sources such as vessels and air gun arrays, where the radiated noise is actually the sum of many spatially separated sub-sources, source levels are never reached.
- **dB re 1µPa^2.s SEL & dB re 1µPa *msp* –** The first measure, SEL is widely termed as *sound exposure level*. It is a measurement which is approximately proportional to a signal's energy. This measurement is used to describe impulsive signals, such as air guns, which are short and sharp. For measuring long term noise the *mean squared pressure* (**MSP**) units are commonly used. As the name suggests, *mean squared pressure* levels are simply the mean value of the squared pressure converted to appropriate dB values. To take a mean value implies an averaging time, which if the noise in question is stationary (ie changes little over the time frame of averaging) is not of major consequence. Impulse signals are short, usually less than one second, thus the *mean squared pressure* level of an impulse measure may be critically dependant (or vary) according to the way the averaging time is defined. Since SEL measures are calculated in a way that accounts for time, they are independent of an averaging time. Given that SEL is also a closer match to the energy delivered by an impulse signal (noting that it is not a correct energy measure itself) then the SEL value is now widely accepted as the best unit to define the approximate energy of an impulse signal

3. Preliminary results

3.1 General patterns

To visually display the majority of data collected by each noise logger summary stacked sea noise spectra have been calculated in 20 or 36 day periods starting from 16-Apr-2009 10:15. These plots were made by taking the de-spiked time averaged power spectra of each 200 s sample at three frequency resolutions, averaging these across four or seven samples (20 or 36 day plots respectively) and stacking a combination of the averaged spectra through time on a colour plot. The figures are displayed with a logarithmic frequency scale from 10 Hz to the upper calibrated limit of the recording system using a fixed colour scale with bounds from 55 to 110 dB re 1 µPa^2/Hz. The colour scale bounds are fixed to standardise the plots and optimise the colour dynamic range. Extreme values are set to the colour bounds. These plots are shown on Figure 5 to Figure 7. These figures show broad scale temporal patterns only and because of the averaging involved (within a 200 s sample and across the consecutive averaged samples) can miss or not display well, signals which are short in relation to the sample length (200 s), such as humpback signals. The plots tend to highlight signal types which are either intense or which persist across the 200 s sample length either through a long signal duration or multiple signals within a sample.

The long time stacked sea noise plots highlight various noise sources. Significant features observed include:

- Very little biological noise source activity in the 10 m site west of Onslow (2808), apart from snapping shrimp (energy > 1.5 kHz) and fish noise (energy between 20-500 Hz).
- Regular evening fish choruses at the 43 m site (2809) centred near 1 kHz (ie. as highlighted on Figure 5, lower panel).
- Bryde's whales from at least the 43 m site, as characterised by a specific low frequency signal type (highlighted on the lower panel of Figure 5 for site 2809)
- Seismic survey noise – this dominated the offshore site the entire duration of the recording period and involved periods where at least three seismic vessels were operating simultaneously. A typical survey line, where the signal starts low, increases as the vessel passes and then decreases as it departs, is shown on Figure 6 and Figure 7.
- Vessel noise, particularly at the offshore site, this can be seen as either periods of sustained noise across a broad frequency band or consists of continual tonal type signals for a vessel holding station nearby (ie. highlighted on Figure 6, lower panel or Figure 7, upper panel).
- Humpback signals, with these largely obscured at the offshore site by seismic survey or vessel noise and partly obscured at the inshore 43 m site by seismic noise. An example of close humpback singing is highlighted on Figure 7 (upper panel, site 2809). Humpback singing tends to have most energy between 100-400 Hz.

These sources have been elaborated below. The large amount of vessel and seismic survey noise at the offshore Wheatstone site made identifying and classifying biological signals difficult and problematic. All of the detection algorithms suffer in the presence of vessel tones and seismic survey noise, causing many false detections and masking of signals of interest. Thus at the stage of writing, except for pygmy blue calls, the counts of biological sources are preliminary and need manual cross checking. The cross checking process involves:

- Using the detection algorithm output to display the presence of a whale source within each 200 s sample as a spectrogram (time-frequency-intensity plot) with the source's presence (humpback and Brydes) or number of individual callers (pygmy blue and dwarf minke) listed in a data base field attached to the spectrogram and located in the spectrogram.
- Visually checking each detection in the spectrogram and if required altering the data base field;
- Once the full set of detection outputs have been checked for a source type then each verified detection or series of detections is bracketed by five samples which have not been previously checked and these displayed and perused for the presence of the source.
- This bracketing procedure is continued until all samples with source detections have been bracketed by five samples without the source present.

The result is a full check of the detection algorithm output and bracketing of the verified output to account for calls missed by the detection algorithm. The cross checking process can take considerable time.

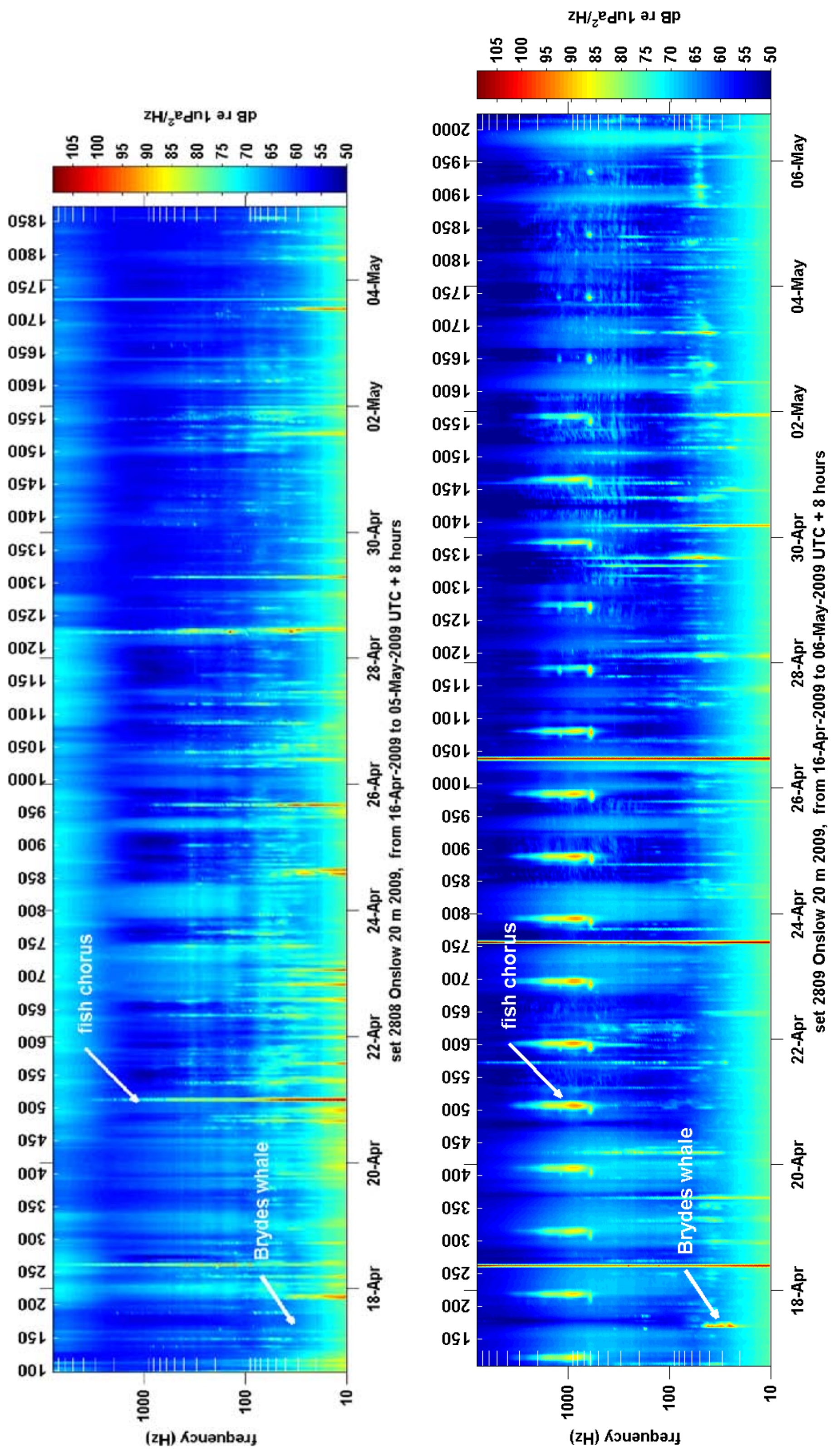

Figure 5: Stacked sea noise spectra (18.5 and 20 day period) for the 10 m site (set 2808, top) and the 43 m site (2809, bottom) over 16-Apr-2009 15:30 to 06-May-2009 18:15. The frequency scale is logarithmic from 10-8000 Hz.

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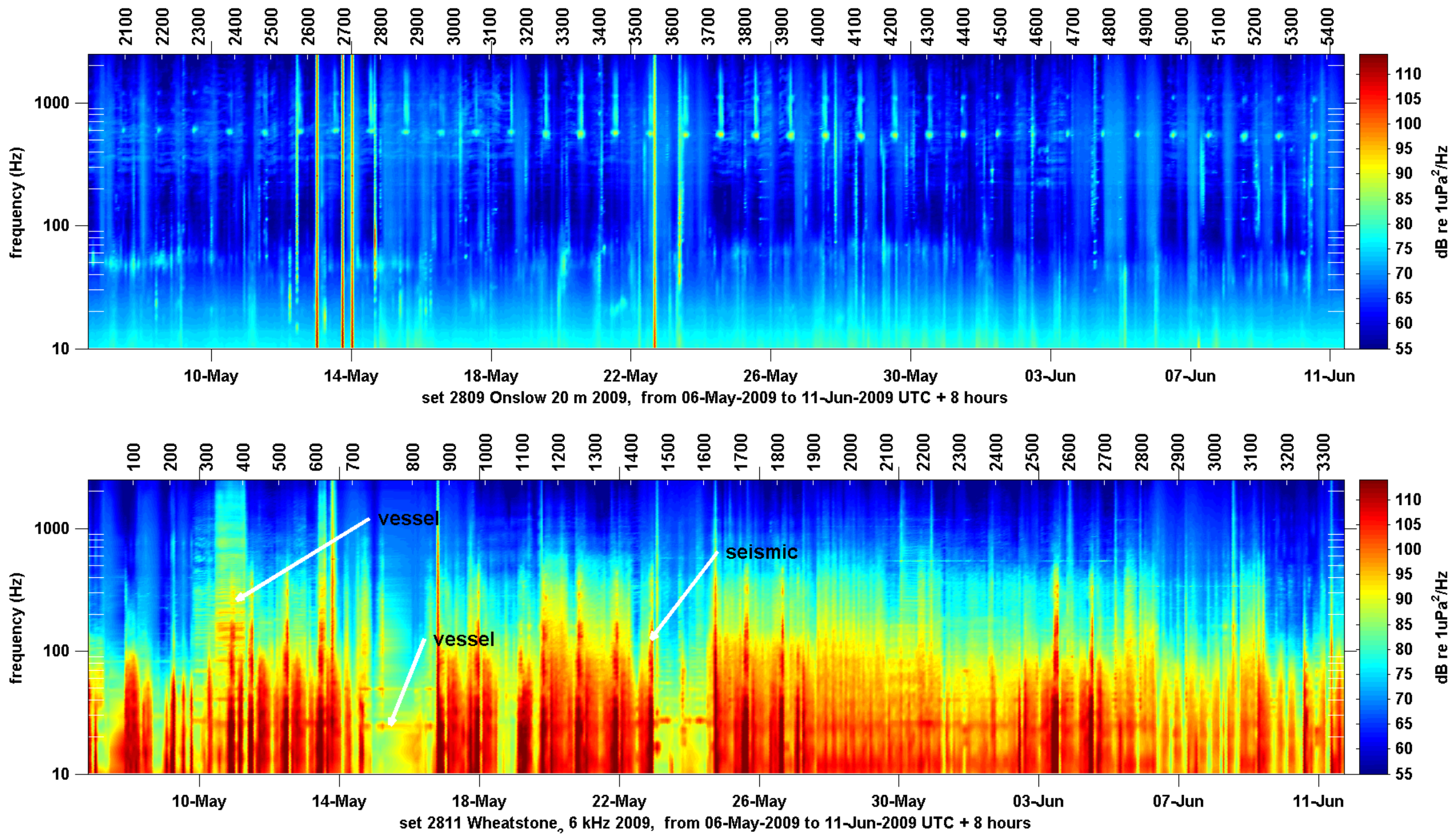

Figure 6: Stacked sea noise spectra (36 day period) for the 43 m site (set 2809, top) and the westernmost logger (2811, bottom) of the offshore site (see Figure 1 for locations) over 06-May-2009 18:15 to 11-Jun-2009 18:15. The frequency scale is logarithmic from 10-2500 Hz.

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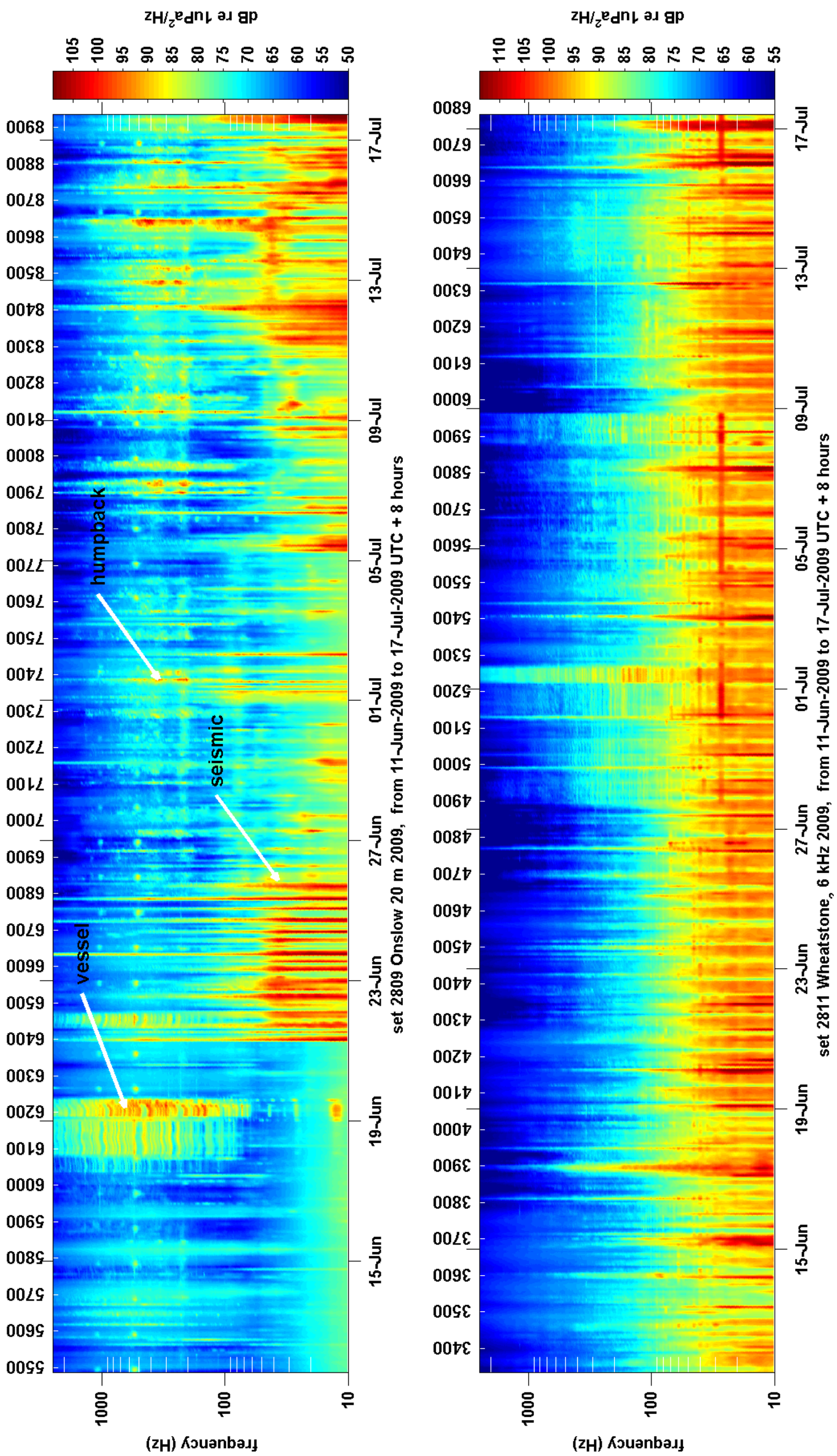

Figure 7: Stacked sea noise spectra (36 day period) for the 43 m site (set 2809) and the westernmost logger (2811) of the offshore site (see Figure 1 for locations) over 11-Jun-2009 18:15 to 17-Jul-2009 18:15. The frequency scale is logarithmic from 10-2500 Hz.

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3.2 Estimating noise logger listening areas

Estimates of the listening ranges of the noise loggers for humpback whale song and pygmy blue whales calls were made. To do this: 1) sound transmission models were run at each site for frequencies of the respective call; 2) a call source level and calling depth range was assumed; 3) the sound transmission modelling was used to predict the signal decay with range and this curve used to give a probability of detection within a certain range; and 4) the call received level was run down to a chosen background noise level to find a range at which some probability of outside call detection was reached (with call level and background noise level in the same units). By using the same units in the final step (run call level to background noise level) one is approximating for an animals critical hearing ratio. The critical ratio is the ratio (in dB) for the animal to detect a signal in broadband units above background noise which is averaged over a critical frequency band centred on the frequency of maximum call energy and presented in spectral level units.

The sound transmission models which can deal with varying bathymetries along a travel path (range dependant) and cope with shear waves in the underlying limestone substrate are extremely tedious and difficult to run. Limestone substrates with varying depths of overlying sand are prevalent along the Western Australian coast and play a major role in sound transmission losses, thus must be included in all modelling. The depth of sand is critical for sound transmission (it changes the reflectance) down to 5 m sand thickness after which the depth of sand makes little difference in transmission loss. To expedite the estimations of listening ranges then for all transmission loss runs except at the site 2809 run for humpbacks, a single seabed type with a constant water depth profile was used. While all sites do not have constant depth bathymetry profiles running away from the receiver an all headings, this technique was used to give a first approximation of listening ranges. At site 2809 for the humpback calculations the bathymetry profiles were interpolated along eight headings at 45^o spacing out to 25 km, from the GeoScience Australia 0.0025^o Australian bathymetry grid (270 m resolution). These bathymetry profiles are shown on Figure 8 along the lines shown on Figure 9.

The seabed types used in the modelling assumed two m of sand over limestone at the shallowest site (2808), one m of sand over limestone at the 43 m depth site (2809) and five m of sand over limestone at the offshore, Wheatstone site (2810-2812). The seabed geo-acoustic parameters used in modelling are listed in Table 2. Constant depth profiles of 10 m, 40 m and 200 m were assumed for pygmy blue and humpback whales in sets 2808, 2809 and 2810-2812 with the exception of the modelling at site 2809 for humpbacks using the bathymetry profiles shown on Figure 8. The sound transmission model Scooter was used for the constant depth profiles and RAMS for the variable bathymetry paths.

Table 2: Seabed layering used in the sound transmission modelling. Given are: the layer type; layer thickness; compressional sound speed (C_p); shear wave sound speed (C_s); compressional wave absorption; shear wave absorption; and density.

layer	**thickness**	**C_p (ms^{-1})**	**C_s (ms^{-1})**	**α_p (dB / λ)**	**α_s (dB / λ)**	**ρ (kg / m^3)**
Water column	10 / 40 / 200 m constant	1533 at surface to 1528 at 200 m	0	0	0	1024
sand	2 m site 2808, 1 m site 2809 5 m offshore (2810-2812)	1600	50	0.5	0.2	1600
Limestone	400 m	2700 – 3000	1420 - 1578	0.5	0.2	2400 2450
basement		3000	1578	0.5	0.2	2450

An estimate of the source level of the type II pygmy blue whale song component (ie. 18-26 Hz sweep over 55-85 s on Figure 13 below) of 183 dB re 1µPa (rms) has been given in McCauley et al (2001) based on received levels of signals recorded in the Perth Canyon. Cummings and Thompson (1971) estimated blue whale signals recorded off the Californian coast as having source levels of 188 dB re 1µPa. The higher order estimate of the source level was used in estimating detection ranges (188 dB re 1µPa). McCauley et al (2001) showed that the highest level component of the pygmy blue whale call was the type II component and that for this component the bandwidth of most energy was across 20-26 Hz, hence the average transmission loss across the frequency steps 20-26 Hz as returned by the modelling was used to give the signal transmission loss for the full source level of the type II component. The pygmy blue whale signal is tonal in nature so the source level does not need to be reduced to account for bandwidth about the spectral maximum (ie. making sure the source and background noise level units are similar).

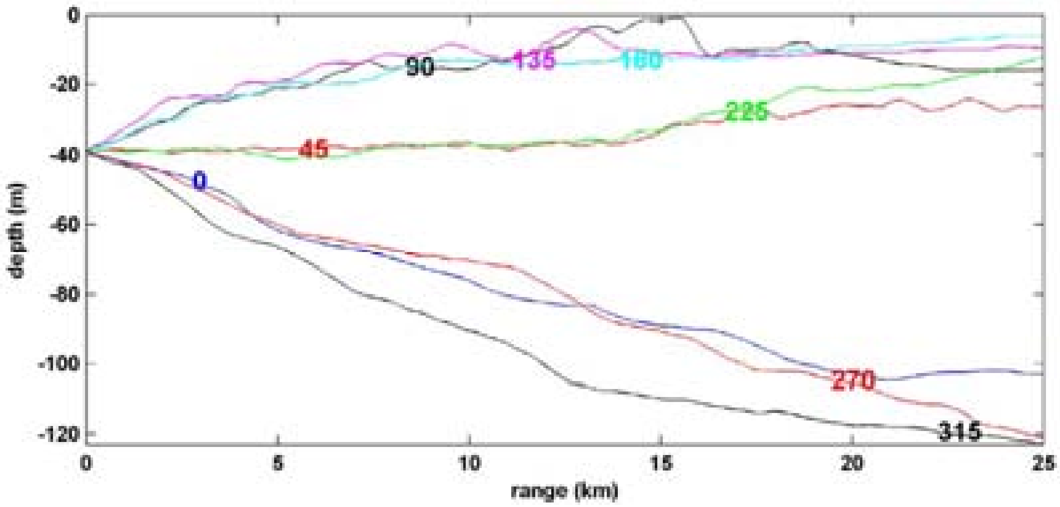

Figure 8: Bathymetry profiles along eight headings at 45° increments, from site 2809 (see Figure 2).

McCauley et al (2001) noted that for many received pygmy blue whale signals in the Perth Canyon it was the 70-75 Hz up-sweep of the type II component which tended to be that most dominant in signals received at long range. This was due to sound transmission phenomena on the shelf or along the shelf break which stripped away lower frequency energy and favoured the higher frequencies. An analysis of close calls revealed that the received level of the 70-75 Hz portion of this component was 9.8 dB below the total received level. Thus to account for sound transmission phenomena which may favour propagation of the 70-75 Hz up-sweep, sound transmission modelling over 68-76 Hz in one Hz steps was averaged and used with the blue whale source level minus 9.8 dB to estimate transmission of this higher frequency part of the call.

A source level of humpback song of 174 dB re 1µPa (rms) was used, as defined in McCauley and Jenner, (2001). Humpback whale song components may vary considerably in frequency bandwidth and source level values. Typically the song has most energy between 100-400 Hz which can be seen on the power spectra of samples with nearby song, shown on Figure 10 taken from site 2809. Since the humpback song at moderate to long range which reaches a receiver typically spans 100-400 Hz then the average transmission of the song across the frequencies of 100, 200, 300 and 400 Hz was used. The source depth was averaged over 20-30 m where the water was deep enough. For site 2808 in shallow water a source depth averaged over 5-8 m was used. At site 2809 the average source depth of 20-30 m was used or the source tracked just above the seabed if in water shallower than 30

m. A bandwidth correction of 12 dB was applied to reduce the source level of the humpback song to spectral level units, since typically humpbacks components are not tonal like pygmy blue whale signals but rather span some frequency range. By using several received close range calls the bandwidth of the more powerful lower frequency signals was ascertained to be around 12 dB (16 Hz). Thus the source level of the humpback call was dropped by 12 dB to bring the units (source level in dB re 1µPa) to the same units as the ambient noise (dB re 1µPa^2/Hz). The range at which the song fell to ambient level was then returned using the 95% probability of detection at the appropriate ambient noise level.

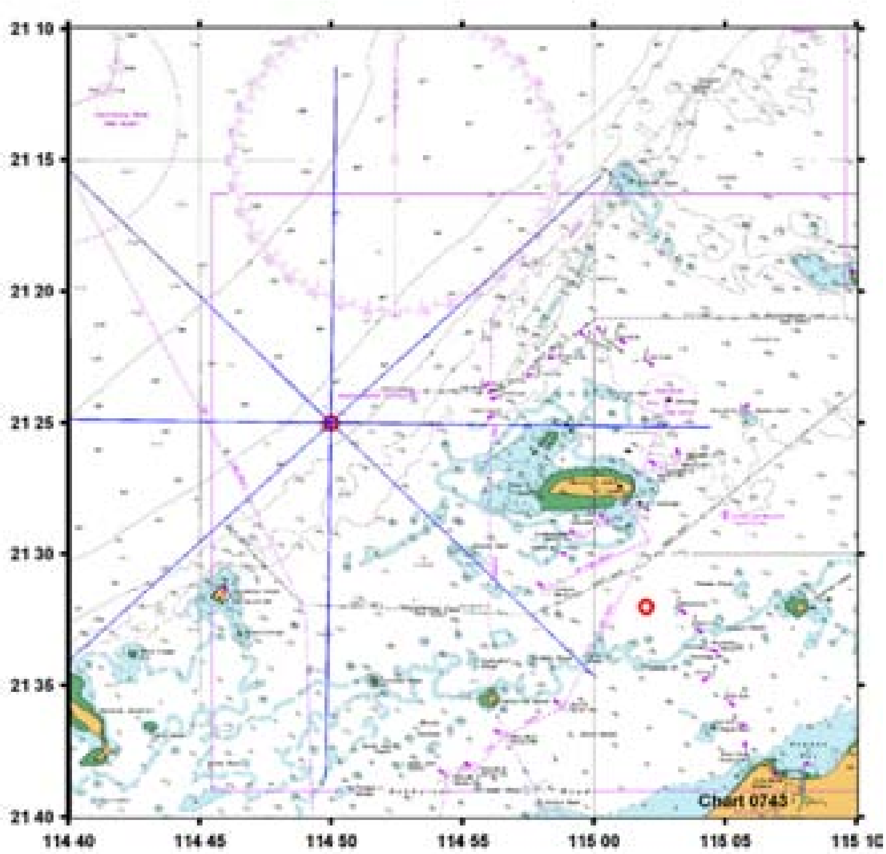

Figure 9: Bathymetry lines along which sound transmission was calculated for humpbacks at site 2809 (see Figure 8 for actual bathymetry profiles).

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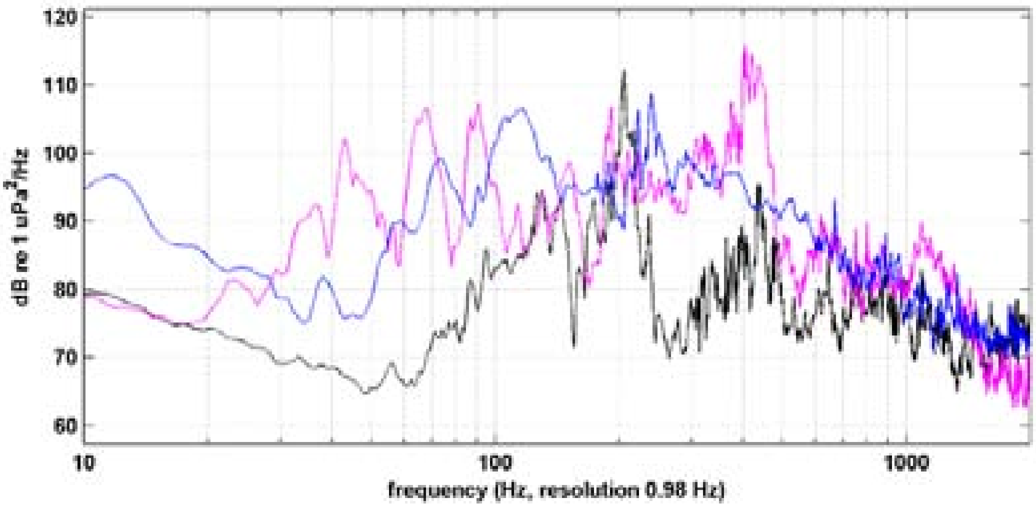

Figure 10: Power spectral averages made across four 200 s samples, each with close nearby humpback calling present across the 200 s sample.

The median ambient noise level across the frequency band 100-400 Hz 1/3 octaves during the time of humpback whale passage from the set 2809 was 63 dB re 1µPa^2/Hz. This agreed with 10 kn wind noise data from algorithms supplied by Doug Cato. This ambient noise level has been used for humpback and pygmy blue calling and is indicative of low wind natural sea noise conditions. At the offshore site the ambient noise field was dominated by man made noise. The mean spectral level ambient noise across the 1/3 octaves spanning centre frequencies of 100 – 400 Hz was 80 dB re 1µPa^2/Hz, thus for humpbacks ambient noise of 63 and 80 dB re 1µPa^2/Hz have been used in estimating song detection range to compare the detection range under quiet conditions with those actually experienced.

The estimated listening ranges and area for pygmy blue and humpback whales are given in Table 3 using the lowest estimate of ambient noise of 63 dB re 1µPa^2/Hz for all sources and sites, plus the average ambient noise of 80 dB re 1µPa^2/Hz for humpbacks at the offshore site. At site 2809 the humpback listening range varied according to the heading around the receiver. While the sound transmission modelling did not account for the different bathymetry paths around each noise loggers except at site 2809, it gives an initial approximation of listening ranges. For all sites the humpback song listening range was clear of blocking bathymetry (ie. any reefs or islands falling within the range). The humpback listening area for the inshore sites under low noise conditions are shown on Figure 11, where the decrease in detection range around the site 2809 towards shallow water are apparent. At the offshore site the humpback listening area suggests that under low wind conditions and in the absence of continual man made noise, song produced just north of the Monte Bello Islands may be detectable at the receiver site. But, the offshore site was dominated by various forms of man made noise which elevated the background levels, reducing the detection range by more than three times thus rendering any singing humpbacks near the northern end of the Monte Bello Islands not detectable.

To show the differences in the ambient noise regimes at the sites the distribution of broadband noise levels from the inshore 43 m site 2809, and the offshore site 2811 (westernmost logger of the grid) are shown on Figure 12. The broadband noise levels were derived by averaging within a sample across 10 Hz to the upper frequency limit of the respective recording system. The offshore ambient noise regime is markedly higher than the inshore one due to the presence of seismic surveys, underwater hammering near the receivers and vessels, particularly frequent instances of vessels operating in dynamic positioning mode. This acted to reduce the listening range of the receiver system as well as making the automatic detection of signals difficult.

Table 3: Estimated listening range and area (km^2) for pygmy blue and humpback whales at the three sites. Transmission of pygmy blue whale calls was carried out across two frequency bands using two source levels, the combination which returned the greatest range is listed below.

	Setup (source level, noise level, frequency band, source depth)	**Listening range (km) / listening area (km^2)**
10 m depth humpback (2808)	SL=163 dB re $1uPa^2$/Hz noise=63 dB re $1uPa^2$/Hz Freq 100-400 Hz, z=5-8 m	2.4 / 18
43 m depth humpback (2809)	SL=163 dB re $1uPa^2$/Hz noise=63 dB re $1uPa^2$/Hz Freq 100-400 Hz, z=20-30 m	3.3 – 9.1 / 112
200 m depth humpback (2810-2812)	SL=163 dB re $1uPa^2$/Hz noise=63 dB re $1uPa^2$/Hz Freq 100-400 Hz, z=20-40 m	61 / 11,690
200 m depth humpback (2810-2812)	SL=163 dB re $1uPa^2$/Hz noise=80 dB re $1uPa^2$/Hz Freq 100-400 Hz, z=20-40 m	18 / 1,018
40 m depth pygmy blue whales	SL=188 dB re 1uPa noise=63 dB re $1uPa^2$/Hz Freq 20-26 Hz, z=20-30 m	19 / 1,134
200 m depth pygmy blue whales	SL=178 dB re 1uPa noise=63 dB re $1uPa^2$/Hz Freq 68-76 Hz, z=20-40 m	48 / 7,238

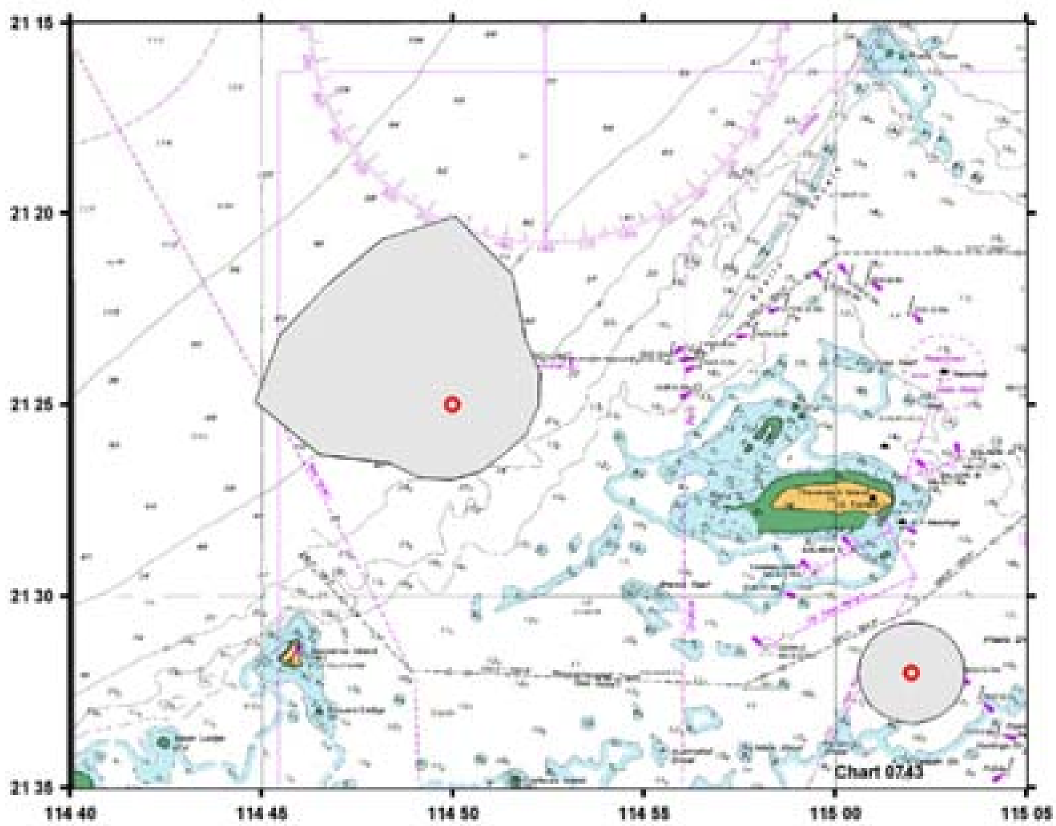

Figure 11: Estimated listening area of inshore loggers for humpback whales (grey shaded regions) based on sound transmission modelling, humpback call source level estimates and low ambient noise conditions.

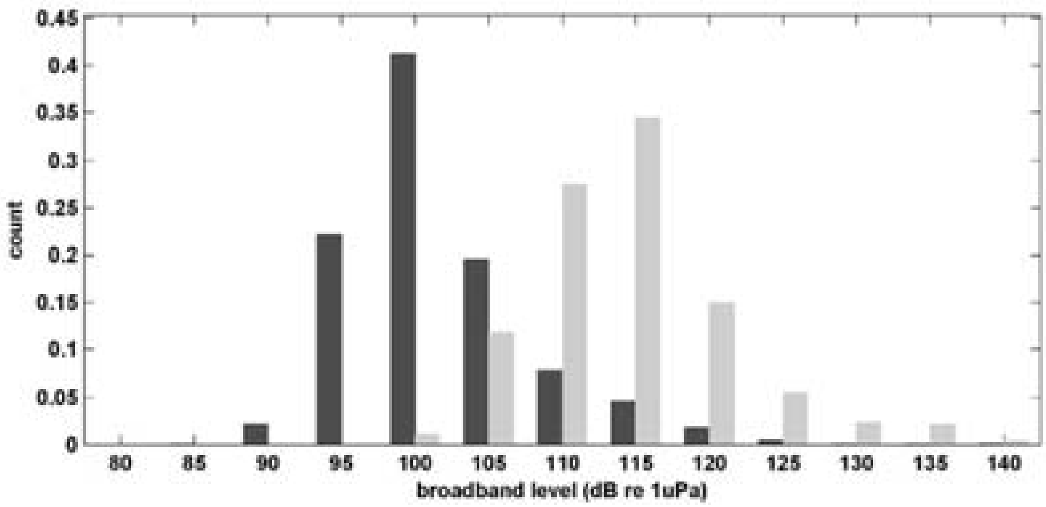

Figure 12: Distribution of broadband ambient noise levels averaged across each sample, for the full recording periods of the site 2809 (dark bars) and the offshore site 2811 (light bars). The count (y-axis) is normalised.

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3.3 Pygmy blue whales

Pygmy blue whales produce a series of three powerful, low-frequency, long tonal signals as well as a separate call type of a downsweep (McCauley et al 2001). Each of these call types were recorded at the Wheatstone offshore site. The gross signal structure of the three part call recorded at the offshore site is identical to signals recorded from the Perth Canyon by the author and attributed to pygmy blue whales, many of which feed in the Perth Canyon. This signal type is comprised of three complex long tonal signals (components) which have most energy over 18-26 Hz but harmonics and a secondary source with energy up to 75 Hz. An example of the three part call recorded from the Wheatstone site, with air gun signals in the background is shown on Figure 13. The series of tones are stereotypical showing little variation and are repeated at a minimum call separation of around 200 s but usually longer. Thus counts of the numbers of the calls recorded nominally within a 200 s sample, give counts of calling individual whales.

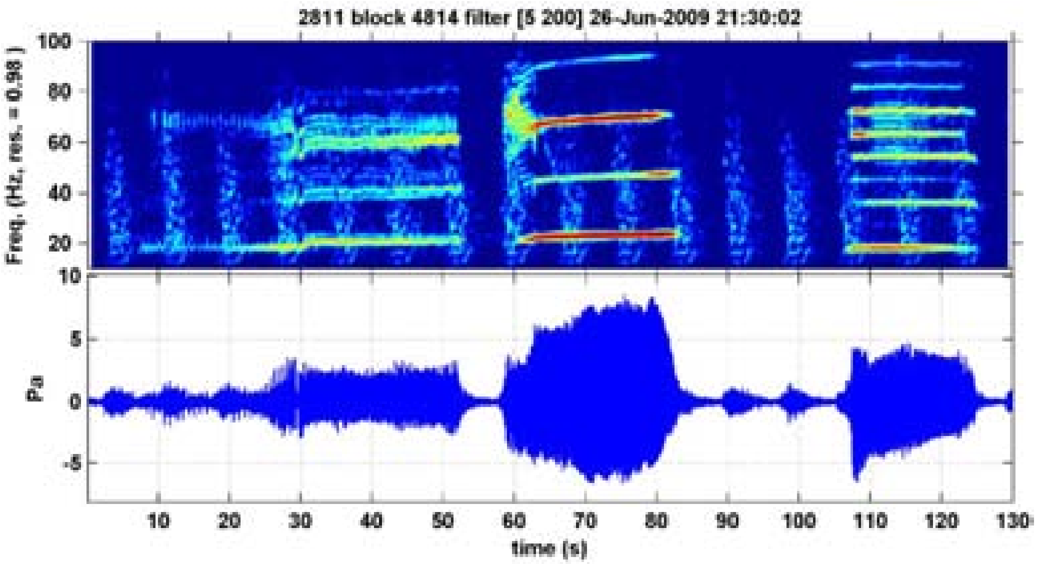

Figure 13: Example of pygmy blue whale call spectrogram (top) and waveform recorded from the offshore site. The call is stereotypical composed of three long tones. The vertical bursts of energy in the background are distant air gun signals.

As an introduction, the blue whale species complex has multiple sub-populations, which have been split into sub-species. In the Australian context there are believed to be two sub-species (Branch et al 2007), these being:

- The 'true' or Antarctic blue whale which is the best known sub-species and which mostly over-winters in southern hemisphere mid latitude waters (as far north as perhaps 30^o S), although some animals are known to remain in Antarctic waters, and which then spends summers feeding in Antarctic waters on the krill, *Euphausia superba*;
- The eastern Indian Ocean and western Pacific pygmy blue whale, which resides from the central to eastern Indian Ocean, or off the east Australian coast possibly as far north as Papua New Guinea. The pygmy blue whale, which reaches lengths of only a few m less than the Antarctic blue whale form, over winters in northern waters possibly as far north as the equator and over summers in southern Australian waters as far south as the Antarctic convergence zone

or potentially further south for some animals. The eastern Indian Ocean sub-species, which was that encountered by the Wheatstone noise loggers, has a distinct call type from the other sub species. The Western Australian pygmy blue is known to feed opportunistically on comparatively small, ephemeral swarms of several krill species.

The pygmy blue whale signals detected by the Wheatstone logger have been recorded along the Western Australian coast from the shelf break to the west of Scott Reef, south to Cape Naturaliste, then east across to Bass Strait and as far south as the Antarctic convergence zone (45^{o} to 55^{o} S). Currently it appears that a flux of animals passes south of Exmouth in October – December each year peaking there in late November. On passing Cape Naturaliste these and possibly other pygmy blue whales from the Indian Ocean fan out across southern Australian waters to feed on krill patches over summer to early Autumn. The pygmy blue whales aggregate in certain areas such as the Perth Canyon, along the Bonney coast (western Victoria) or along the Antarctic convergence zone, if the particular area can sustain a suitably high abundance of krill. The Perth Canyon acts as a stopover during the return, north bound migration for animals moving up the west coast. In April to May some proportion of the population head north along the Western Australian coast, with a north bound pulse of animals observed off Exmouth in June - July. This pulse is believed to split north of the Monte Bello Islands with approximately 16-45% of the animals which pass Exmouth, following the North West Shelf north and the remainder fanning out west and north-west across the northern Indian Ocean (McCauley and Salgado Kent, 2008). We have evidence that some portion of northbound animals head into northern Indonesian waters (Banda Sea) to over-winter based on sightings by Indonesian whale scientists.

The noise logger data from the western Wheatstone site has been systematically searched for pygmy blue whale signals by running an algorithm across each sample which looked for the characteristic up-sweep of the second call component (ie. up-sweep centred near 70 Hz over 58-83 s on Figure 13). The spectrograms of each of the search algorithm detections were manually checked as described in the methods to check for false and missed detections.

All counts of the number of individual whales calling were converted to the number of calling individual whales per 200 s as a standardised relative abundance measure. Pygmy blue whales are known to have daily and lunar cycles in their calling behaviour. For example McCauley et al. (2004) showed an average 2.2 times greater call rate during darkness than daylight, with crepuscular peaks in call rates. Thus to remove time of day bias from the relative abundance estimate when comparing different sites the values are averaged over a 24 hour period running from 12:00 one day to 12:00 the next, to give the mean number of instantaneous individual calling whales, averaged over a one day period.

Pygmy blue whales were detected at the offshore site from 19-May-2009 12:15:02 to 17-Jul-2009 22:45:01.

The crude numbers of individual pygmy blue whales calling at the western logger (2811) site are shown on Figure 14 along with a smoothed curve showing the trend (± three hour running average). Blue whale detections came in pulses, averaging at 4.2 ± 2.6 (95% confidence limits) days apart with up to six whales calling at any point in time. Each of the individual calling bouts had instances of multiple whales calling, indicating that pygmy blue whales must travel at least as loose herds if not as tight pods of several whales in close proximity.

Several time series data sets of calling pygmy blue whale counts are available from the Exmouth to Monte Bello Island region for comparison with the Wheatstone data set. All of these sites have been fully checked for the search algorithm accuracy. The locations of sites available are shown on Figure 15. One site sampled in 2005-2006 (set 2720) was only 2.4 km NE of the westernmost logger of the Wheatstone offshore deployment location. The sets inshore of the 150 m depth contour did not have pygmy blue whale detections, despite being in the water over one of the known migratory pulse periods. This indicates that few if any pygmy blue whales venture up onto the shelf in this area. This was reinforced by the set 2809 here in 43 m depth not detecting any pygmy blue whales during its deployment.

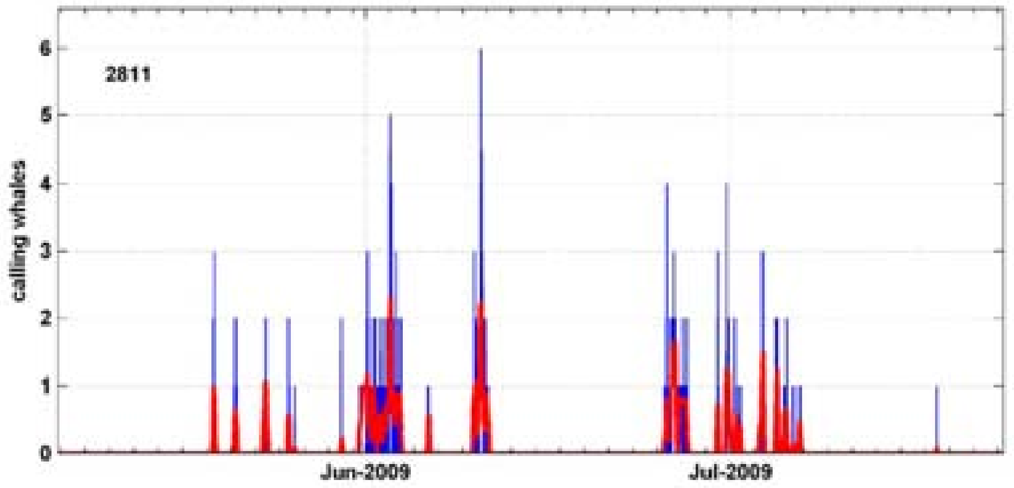

Figure 14: Counts of calling pygmy blue whales from the western logger of the Wheatstone offshore site (2811). The red curve is a three hour running average. The minor tick increments are two days apart.

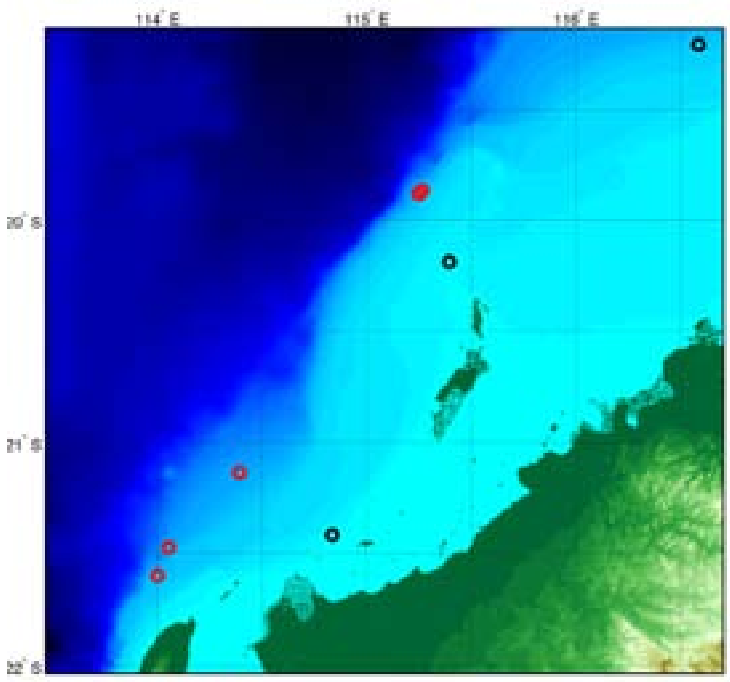

Figure 15: Locations of sites sampled in region over periods where pygmy blue whales have been expected to pass. The red circles represent places where pygmy blue whales have been detected and the black circles places where they have not been detected despite sampling over expected migratory periods.

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The 24 hour averaged counts of individual pygmy blue whales passing through the area for four of the shelf edge sites (shown on Figure 15) including the Wheatstone site, are shown on Figure 16. The two 'Exmouth' data sets are the southernmost sites shown on Figure 15 (from McCauley and Jenner 2001 and McCauley 2006), the lower two panels of Figure 16 are within a few miles of the centre of the Wheatstone tracking grid including data from this set of deployments. The seasonal trend of blue whales through the region is clear on Figure 16, a sharp southerly pulse of steadily swimming animals over Oct-Dec each year and a more protracted northerly pulse over Mar-Aug. The pygmy blue whale swimming directions have been ascertained by acoustic studies along the WA coast (tracking capability and comparing widely spaced loggers) combined with various visual observations.

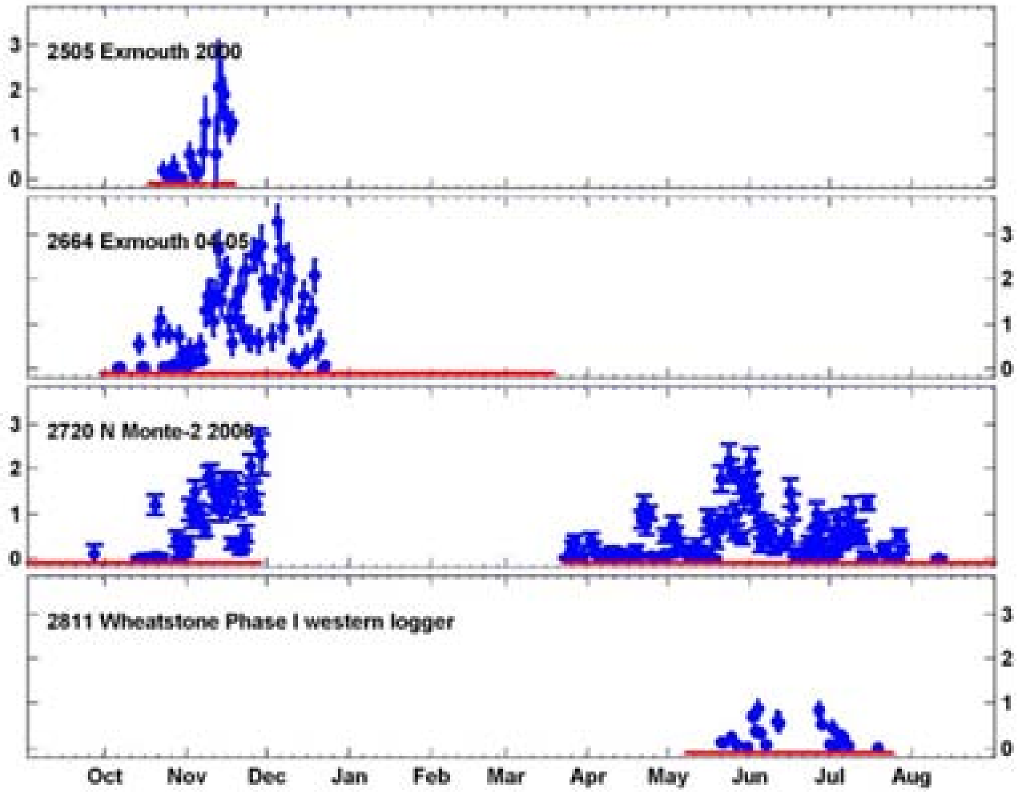

Figure 16: Numbers of individual pygmy blue whale callers averaged over 24 hour periods from sites off Exmouth and in the Wheatstone area (set 2720 and 2811).

A notable difference evident in Figure 16 in the two sites near the Wheatstone tracking grid (lower two panels of Figure 16) is the much lower number of pygmy blue whale detections between the two seasons sampled (2006 and 2009). To quantitatively check this, the curves given by the number of individuals calling per sample (15 minute sampling separation) were integrated to give whale.days over the overlapping period between years, using the Julian day time base. The resulting calculations for the period 16-Apr 13:13 to 20-Jul 09:20 (74.6 days) in 2006 and 2009 gave:

2006	42.453	whale.days
2009	06.989	whale.days

where whale.days is the integrated value of the curve of individual-calling-whales, with time. Thus there where six times as many whales detected in 2006 as 2009 at essentially the same location over the same time frame (in Julian days).

Reasons for the difference in whale counts between seasons are currently not clear. There was considerable seismic survey activity in 2009 south of the Wheatstone location (see below section 3.6) with seismic signals dominating the Wheatstone recordings and three seismic sources operating at times. But, on perusal of the data set 2720 made in 2006 during the overlapping time frame with the Wheatstone set, there was also considerable seismic survey activity occurring, albeit with only one vessel. At a first glance it seems the ambient noise environment of the two recording sets, made within a few km of each other, are similar. Thus without further work it is not clear why six times fewer pygmy blue whales were detected in 2009 compared with the same period in 2006.

3.4 Dwarf minke whales

Dwarf minke whale signals were present in the recording sets from the offshore site, with an example call shown on Figure 17 as the set of harmonics centred near 225 Hz but extending into higher frequencies. The calls were not detected at the inshore sites. These calls are similar to those reported by Gedamke et al (2001) from dwarf minke whales in the northern Great Barrier Reef. Little is known of the calling habits of dwarf minke whales in Western Australia. We know little of call repetition rates, call increments, variability in calling, which animals in the population call and in what context. For the east Australian minke whales Gedamke et al (2001) gave call repetition intervals of 32 s with low variability (± 2.2 sd maximum from three 8-10 minute sequences analysed). McCauley (2009) has calculated call increments for dwarf minke whale calls at either near 6 s (6.1 s) or in the range 32 to 36 s based on a series of Western Australian recordings from Exmouth to Scott Reef.

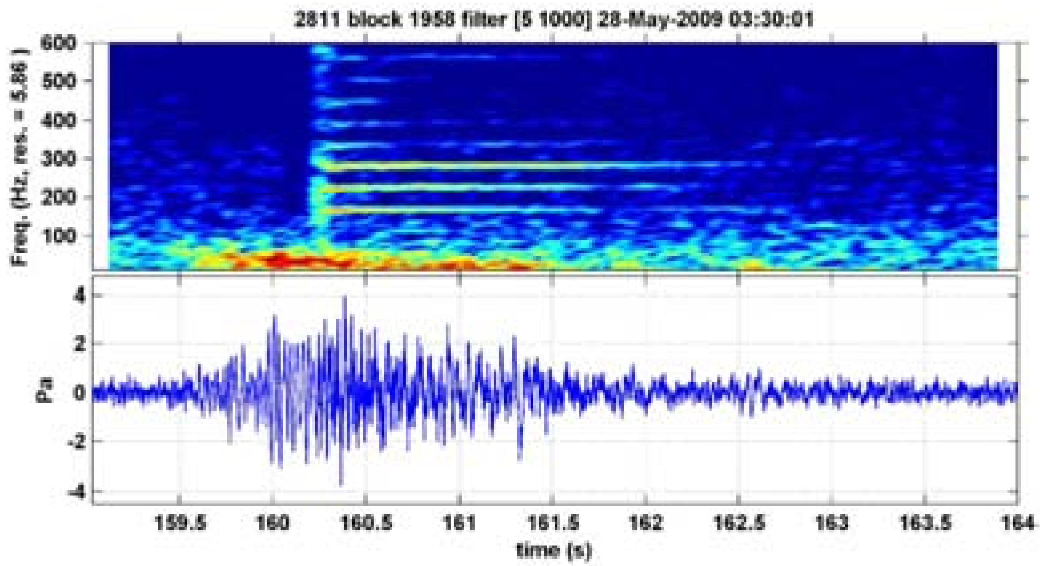

Figure 17: Example of a dwarf minke whale call (set of harmonics over 160.2 to 162.5 s with energy above 100 Hz) overlying a long range air gun signal (energy below 100 Hz).

The biological habits of dwarf minke whales in Western Australia have not been reported to date.

A reliable algorithm has been built which locates the harmonic structure of dwarf minke whale calls even in the presence of vessel and air gun noise. The algorithm has been found to give some false hits from humpback whale signals but otherwise seems robust in the presence of various noise sources provided the sound transmission environment allows the 225 Hz energy (the most powerful part of the call) to transmit well. The search algorithm detections return the time spacing between consecutive calls and various parameters of call level. The minimum time spacing between calls (6.1 s when multiple animals are calling) has been used to determine the number of calling dwarf minke whales. The resulting counts of calling dwarf minke whales, averaged over 24 hour periods to remove any day-night calling patterns, is shown on Figure 18. The search algorithm data has not been manually cross checked as the pygmy blue whale data has. From Figure 18 it appears that at the offshore site dwarf minke whales were present at low levels throughout the full recording period of the Phase 1 deployment, but tended to increase in numbers in late June.

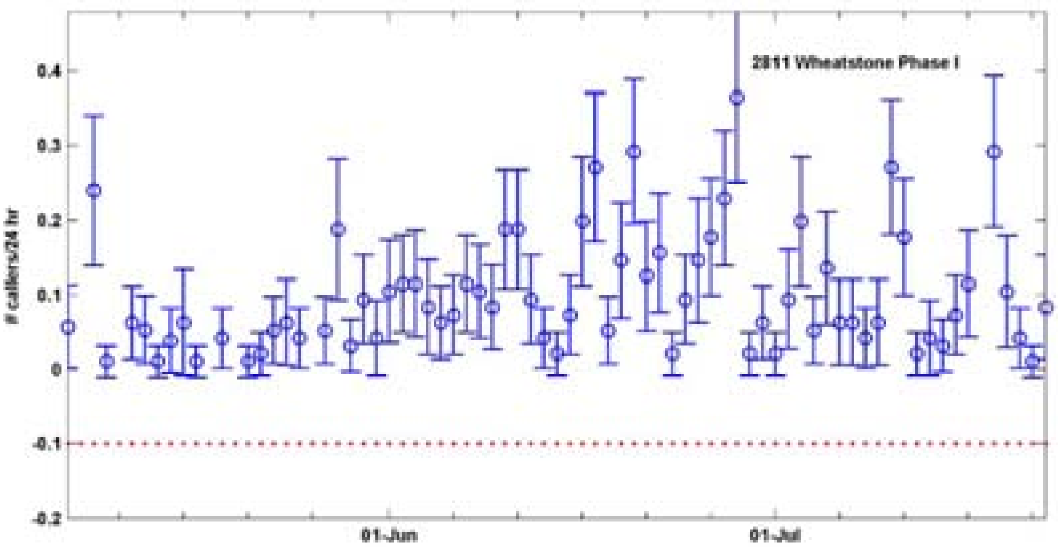

Figure 18: Dwarf minke whale detections from the offshore site 2811 (westernmost logger) over the Phase I recording period. The values shown are 24 hour means (12:00 one day to 12:00 the next) of the number of individual calling dwarf minke whales. The red points indicate days sampled. The error bars are 95% confidence limits for each 24 hour period.

Several other data sets in the region were similarly searched for dwarf minke whale calls. A comparison of the Wheatstone site dwarf minke detections with the recording set 2720, which was collected over 2006 a few km away, is shown on Figure 19. A peak of animals calling in late June to early July is evident in the two data sets. Like the pygmy blue whale counts, the 2006 dwarf minke whale counts have greater numbers of calling whales detected than the 2009 data set. The integrated counts over the correlating 74.6 days gave:

2720 50.6139 whale.days
2811 6.9064 whale .days

or 7.33 times greater numbers in 2006 than 2009. Like the pygmy blue whale counts it is not clear why this discrepancy exists between dwarf minke whale counts between the seasons.

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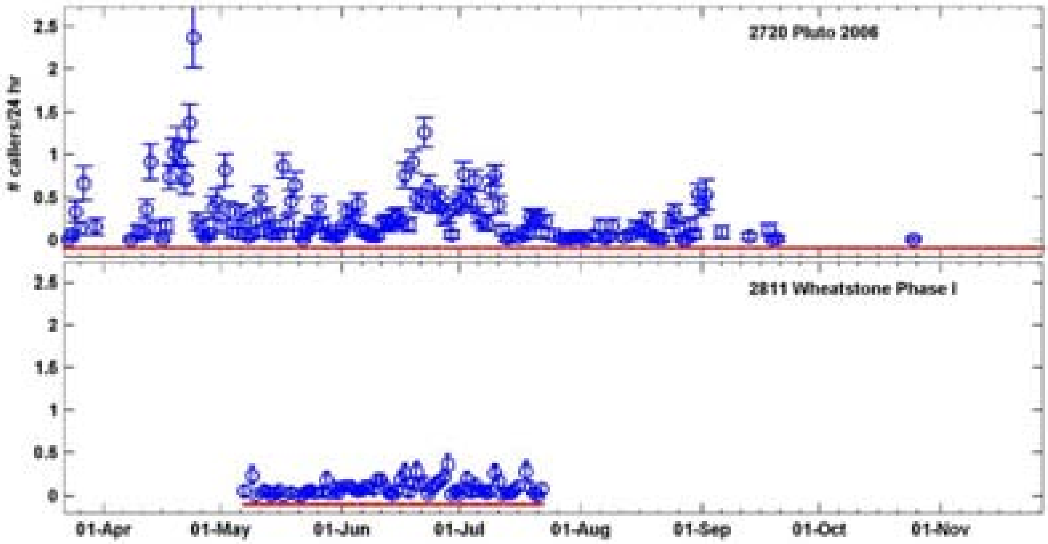

Figure 19: Dwarf minke whale individual callers averaged in 24 hour periods with 95% error bars shown, from the Wheatstone site in 2006 and 2009.

3.5 Brydes whales

A call which has characteristics of a Bryde's whale signal was recorded on a few occasions at the 43 m depth inshore site (2809). An example of this call is shown on Figure 20. This call has been commonly reported in northern Australia shelf waters by the author. The call has strong similarities to a sequence as reported by Heimlich et al (2005) in the eastern tropical Pacific and attributed to Bryde's whales (especially their calls c & d). The calls recorded here and by Heimlich et al (2005) are distinctly unique in that they are low frequency and dispersed across a comparatively wide frequency band with a poor harmonic structure. This poor harmonic structure (although the intensity is not weak) is not present in any fish calls, which typically have strong and distinct harmonics due to the fish sound generation mechanism (pulsing a gas bubble or their swimbladder). To the authors knowledge the Bryde's calls displayed by Heimlich et al (2005) are the most similar published great whale calls, to the distinct call type heard here and at other northern Australian sites. Thus given no other great whale candidates, the strong similarities between the calls detected in northern Australia and those of Heimlich et al (2005) and the uniqueness of the call, then we are attributing this call to Bryde's whales.

Currently there is no information available on Bryde's whale habits, including calling behaviour, in northern Australia. In order to begin an investigation of their presence and habits in the noise logger data sets a search algorithm has been built to locate the signal type shown on Figure 20. The detection algorithm matched the envelope of a high signal to noise ratio call against sequentially taken sections from each sample, then looked at the energy content at frequencies above and below the energy of the call to remove any broad band signals, such as air guns. To date the Bryde's whale detection algorithm has only been run across a small selection of data sets available. The algorithm was run across set 2809 at the 43 m inshore site (ie. Figure 2). Only a handful of Bryde's whales calls were detected, these on 17-Apr-2009 over 10:00 to 16:00 hours.

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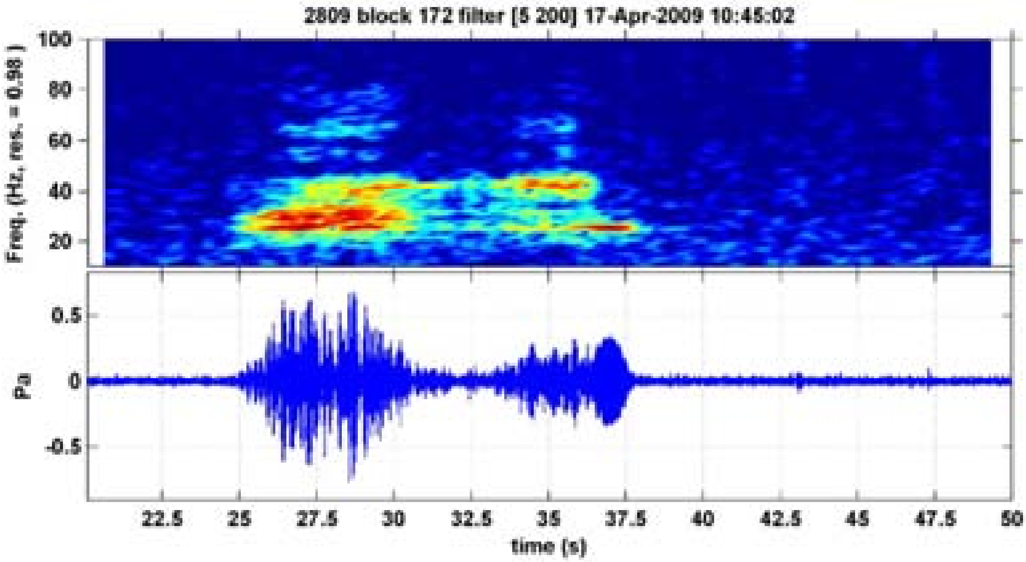

Figure 20: Example of a call type heard at the 43 m depth inshore site (2809) and believed produced by a Brydes whale.

3.6 Humpback whales

Humpback whale song featured prominently in the inshore set 2809 (43 m) and later, at the offshore tracking site. An example of a noise logger sample with two humpbacks singing from the 43 m depth inshore site is shown on Figure 21. The complexity of the song is evident. The individual components which make up the song vary slightly amongst individuals, making counting the numbers of animals calling using automated techniques difficult. The aim of analysis with humpback song is to obtain counts of the numbers of calling animals at any point in time, or a 200 s sample here. While difficult, this analysis was carried out for the inshore 43 m depth site, by manually viewing the sea noise record spectrograms from the time of first humpback detection to the recording end and counting the number of calling whales in each sample. Where required the data was listened to. Beyond three calling whales it was extremely difficult to accurately count the number of callers, although usually one to two calling humpbacks where only heard.

Quantifying humpback singing at the offshore site transpired to be extremely difficult due to the continual levels of moderate to high levels of multiple seismic survey signals (as many as three surveys detectable at any given time), underwater hammering or vessel noise over the entire recording time frame. The difference in the averaged ambient noise regime was shown on Figure 12 highlighting the increased noise at the offshore site (around 15 dB greater on average). This noise either masked humpback song (reduced the detection range as shown in Table 3) or caused the search algorithms to give large numbers of false detections (the algorithm triggers on man-made noise) or miss calls (due to noise rejection techniques applied to reduce the false detections). The humpback singing which has been detected at the offshore site was mostly weak and indicative of animals singing at long range. This may either be due to a natural tendency of humpbacks to keep inshore of the offshore hydrophone location, towards the top of the Monte Bello Islands (expected), or the high levels of noise offshore keeping animals inshore. At this stage a full analysis of humpback singing at the offshore site has not been undertaken.

No humpback song was detected from the shallow water site (10 m depth, set 2808). This was believed due to it stopping recording some weeks before humpbacks were expected to begin arriving. This logger was replaced in mid 2009 so will collect humpback singing for the majority of the 2009 season.

At the inshore 43 m site (set 2809, Figure 2) humpbacks were first detected on 30-May-2009 at 18:15 and remained present throughout the rest of the recording period, although persistent calling did not begin until 13-Jun-2009. Persistent calling was calculated by obtaining the cumulative number of individual callers across the recording period and locating the time window which encompassed 5% and 95% of this curve. The time at which 5% of the cumulative number of callers was reached was considered the beginning of persistent calling. Humpbacks were present at times within less than a km of the receiver based on the high received signal level. In total 2987 samples of 4861 (from first humpback detection at sample 4330, until last valid sample 9190) had humpback calling detected, with 52% comprised of one singer, 44% of two, 4% of three and only two samples scored as four singers (0.07%).

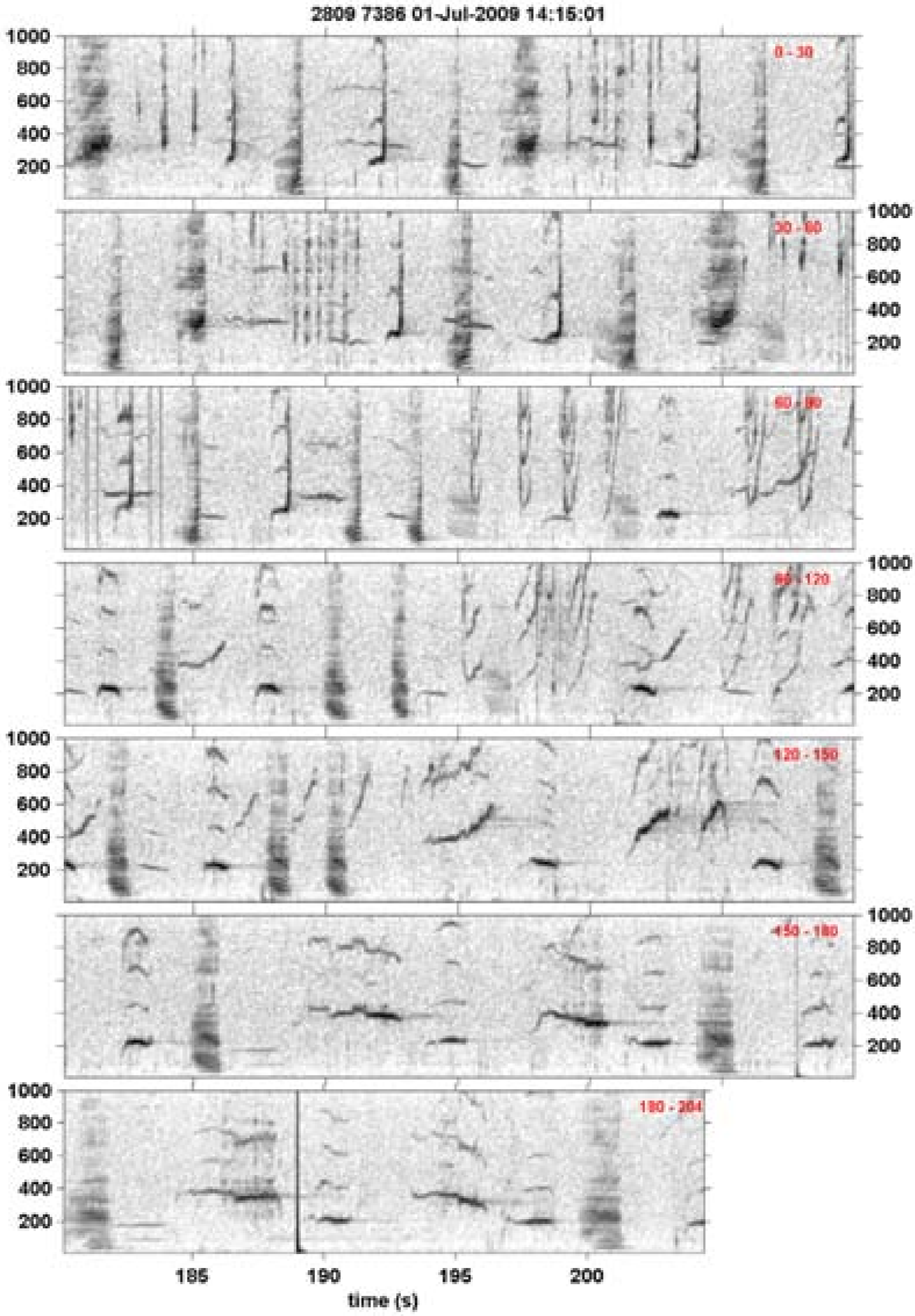

Figure 21: Spectrograms of 204 s of section with two humpback singers from the 43 m site in July.

The time series of the number of individual calling whales at the 43 m inshore site is shown on Figure 22, where the counts every 15 minutes have been averaged over a four hour period and a smoothed curve fitted (running linear fit). Calling can be seen to become almost continual from late June. Cato et al (2001) have measured the singing rate for northbound humpback whales off the Eastern Australian coast as 5.5% of whales in the area singing. Assuming this singing rate to apply here up until late July implies that during July on average 27 humpbacks where in the listening area of the noise logger using a mean in July of 1.51 whales singing at any point in time, and that at times this may have reached as many as 55-72 whales in the area (maximum of three to four whales singing detected). The listening area of the noise logger at location 2809 has been calculated above for low wind conditions as 112 km^2. Assuming low wind conditions across the full recording period then average densities of 0.24 whales / km^2 were found in July this possibly reaching as high as 0.5 – 0.6 whales / km^2.

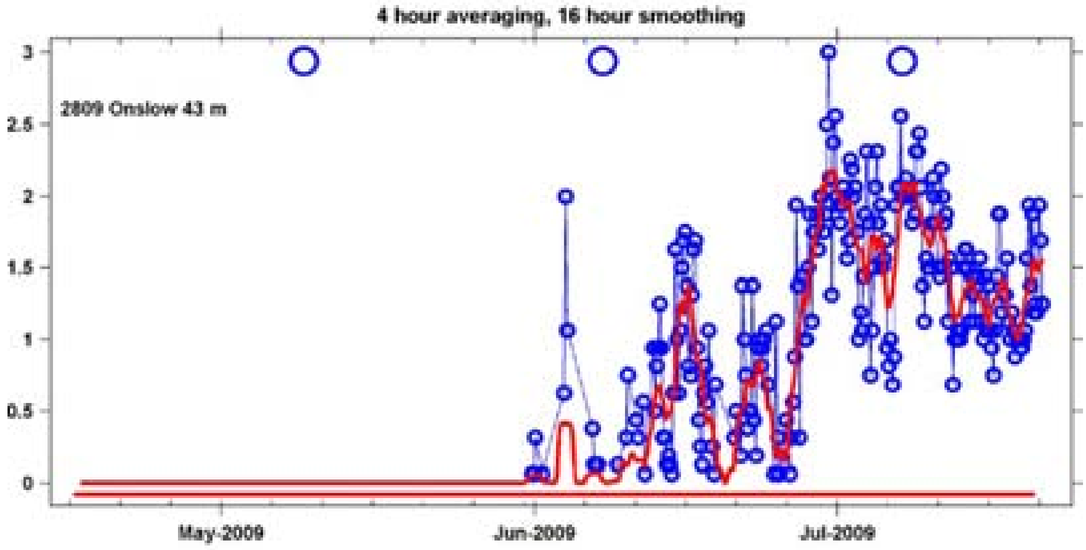

Figure 22: Time series trend of the number of individual calling humpbacks recorded form the 43 m inshore site. The counts per 15 minutes have been averaged in 4 hour bins (circles and thin blue line) and a smoothed curve fitted (heavy red line). The sampling period is shown by the red line below the axis. The minor ticks are five day increments. The circles represent times of full moon.

A periodicity can be seen in the numbers of whales calling as shown on Figure 22, which does not appear to be related to lunar cycle (the full moons are shown on Figure 22). This type of periodicity is common in these humpback acoustic data sets. The periodicity in numbers of calling whales from set 2809 was calculated from the power spectral density of the curve given by subtracting the longer term trend in calling individual whales (derived using an eight day averaging process) from the four hour average trend of calling individual whales. The two curves, the four hour and eight day averages, are shown on Figure 23, along with the spectral distribution of periodicity in the de-trended curve.

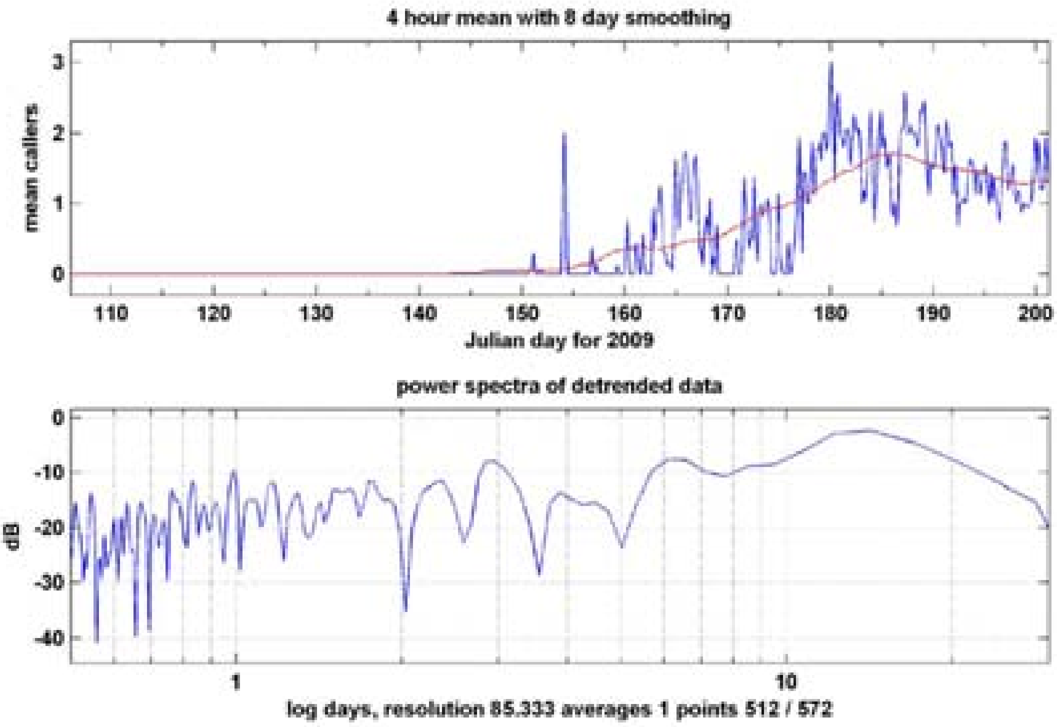

Figure 23: (top) Four hour averaged number of individual humpback whales detected at site 2809 (blue curve) with the eight day average trend shown (red curve). The eight day long term trend was subtracted form the four hour average curve to give the de-trended data, and the power spectra of this taken, and is shown (below) using days as the logarithmic x-axis.

The set 2809 data set has several peaks of periodicity in the numbers of individual whales calling, notably at one, 2.8-2.9, 6.1 and 14 days. The one day periodicity is a diurnal effect and can be accounted for in the statistics of whale numbers from the acoustic counts by averaging across a 24 hour period of 12:00 one day up to 12:00 the next. The larger periods (~ 3, 6 and 14 days) in the numbers of individual whales calling probably relate to the residency times of whales in an area and the fact that humpbacks are known to move through an area in 'pulses' of whales rather than as a steady stream of individual animals. The residency time of singing whales in this region is unknown. It is expected that the average residency times will differ depending on the stage of the season. It is likely that humpbacks have shorter residency times during the northbound migration when most animals purposefully head north as far as the Kimberley, and greater residency times during the southbound migration when animals meander their way south. Once the full data set becomes available we will attempt to see if the periodicity in the number of calling whales varies across the season (with the restriction that for this analysis the season needs to be split into large sections, to enable the periodicity to be determined). The whale residency time is an important factor in calculations of density using visual or acoustic surveys.

A comparison of the whale counts made for site 2809 and other similar data sets from this region is shown on Figure 24. Based on the set 2809 described here and the 2000 and 2004 data the humpback season in the area appears to probably range from June to mid November. The full data set to be recovered will elaborate the trend in greater detail by giving counts at three locations in the region. There also appears to be a lag of approximately one month between humpbacks arriving in substantial numbers between the location 2809 and at the northern end of the Monte Bello Islands (set 2680) and to the west of this (set 2710).

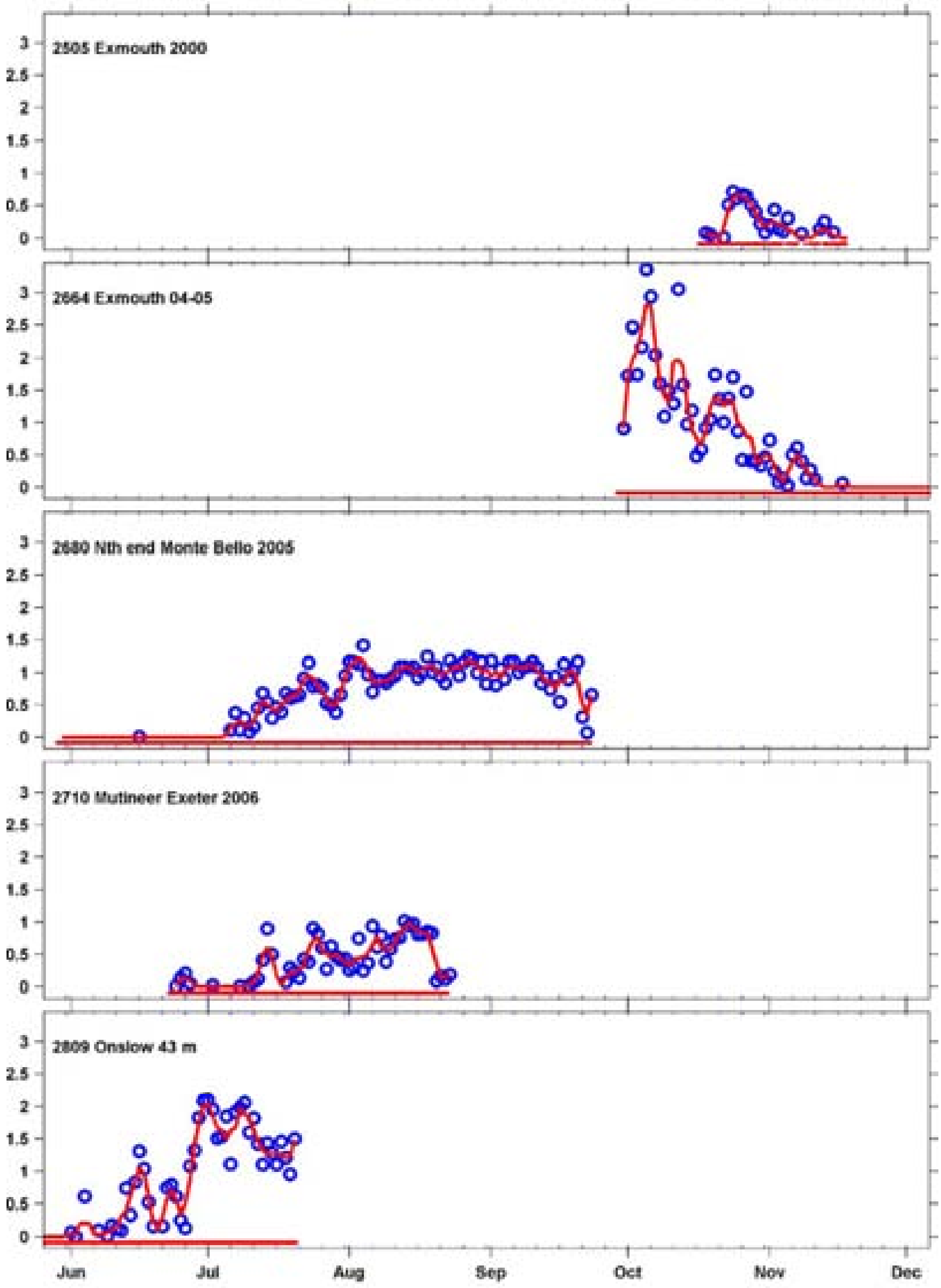

Figure 24: Acoustic counts of the mean number of singing humpbacks per 24 hour period form sites off Exmouth (see Figure 15 for locations, 2710 is the easternmost site, 2680 is at the northern end of the Monte Bello Islands, 2505 and 2664 are north of NW Cape, and 2809 is as shown on the westernmost site of Figure 2)

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3.7 Seismic survey signals

The offshore site was dominated by seismic survey noise. Two seismic surveys were known to be operating to the south of the Wheatstone site, with the polygons defining the survey regions shown on Figure 25 (co-ordinates as given by EPBC referrals). The northern survey is being run by Fugro Survey and involves two seismic vessels operating consecutively. The southern survey involves a single vessel and was being run by Gardline. The three seismic vessels straddle the known northern migratory route of pygmy blue whales which is adjacent the shelf break out to water depths of several thousand m, and which partly straddle the northern migratory route of humpback whales, which is partly on and partly off the continental shelf. The movements of dwarf minke and Brydes whales in Western Australia are currently not known. Algorithms have been built which pick out air gun signals from data sets and analyse these for various characteristics. These have yet to be run across these data sets but will be, in order to better characterise the ambient noise field at the inshore and offshore sites.

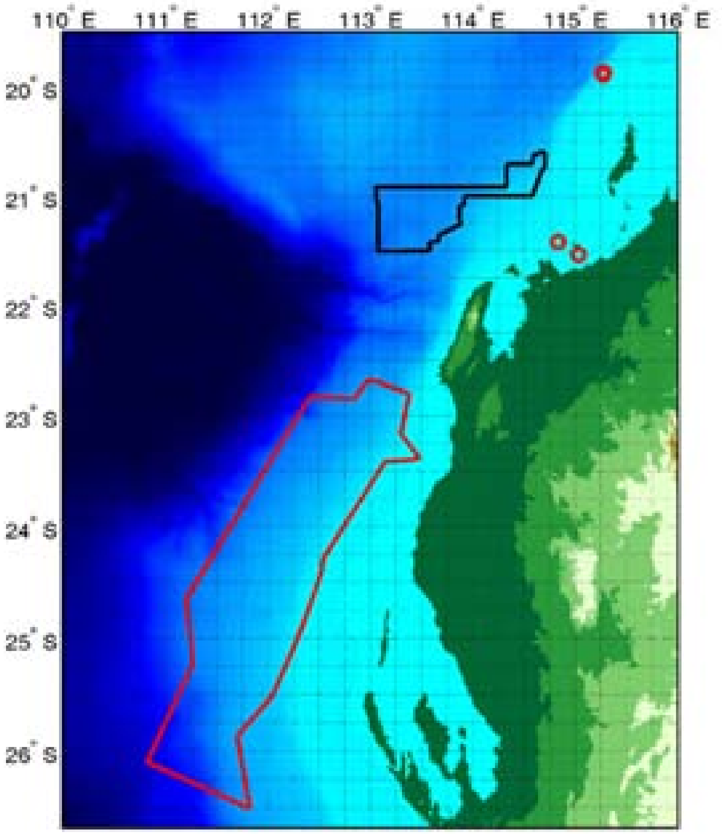

Figure 25: Location of seismic survey regions where vessels were known to be operating over the Wheatstone Phase I period. The red survey area had one vessel run by Gardline, the black survey area had two vessels operated by Fugro Surveys.

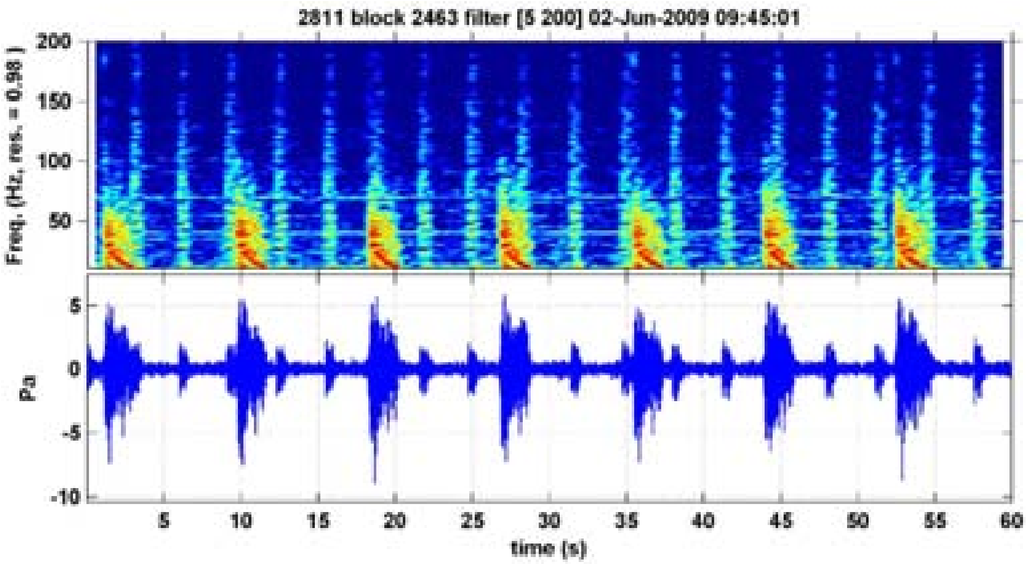

Figure 26: Example of period from the Wheatstone site with three seismic vessels operating.

3.8 Fish choruses

Daily sporadic fish calling was present at the inshore sites, with regular evening fish choruses present at the deeper of the two sites (43 m, set 2809). These choruses were indicative of nocturnal evening fish planktivorous fish, as recorded by the author at multiple locations across northern Australia. The evening fish chorus pattern is shown on Figure 27 where the evenings 800 Hz 1/3 octave level has been used to indicate the fish chorus pattern each evening. The time each evening was zeroed to time of local sunset (time of lower limb hitting the horizon) since the fish respond to light, not our clock. Lunar and seasonal patterns are evident and agree with previous observed trends. These trends are not elaborated here but will be when further data is in hand.

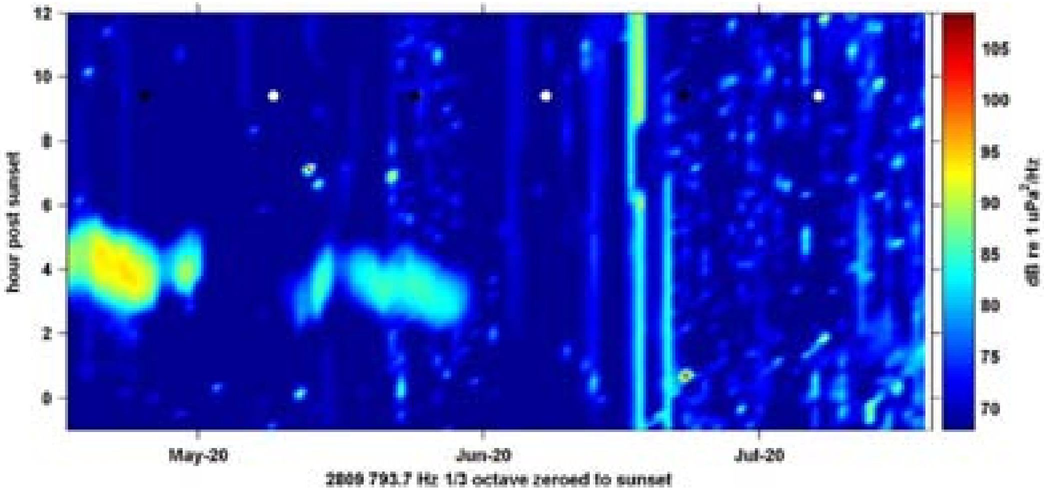

Figure 27: The 800 Hz 1/3 octave levels across each evening from the inshore 43 m site, as indicative of the nocturnal planktivorous fish choruses. The evening time scale was zeroed to time of local sunset. The fish choruses are evident as the energy over 2-6 hours into late May. The small circles are moon phase.

An expected fish chorus at the offshore site, which is indicative of local secondary productivity via Myctophidae fishes of the deep scattering layer, was not detected.

3.9 Dolphin presence

The two inshore noise loggers (2808 and 2809) were set with sampling rates sufficient to collect dolphin whistles. The sample rate used in the two loggers of 16 kHz allowed analysis up to a frequency of 7.5 kHz, with dolphin whistles expected to span 1-15 kHz (summary tables in Richardson et al, 1995) with the most common dolphins likely to be present having whistle energy below 7.5 kHz. Dolphin sonar click frequencies vary from the low kHz range up to 30-50 kHz and higher in some species. Dolphins communicate with each other via the whistles and search their environment with the sonar. The data sets were searched for dolphin whistles by looking for energy increases in the 1-8 kHz range on the summary five day plots produced (ie. as shown in Figure 5 to Figure 7 but on a five day time frame). To date no dolphin whistles have been located in the data sets. Noise sources found in the > 1 kHz frequency band from the inshore sites include: snapping shrimp (most common at the shallow site with diurnal patterns evident); the upper frequency end of humpback calls (energy goes up to 4 kHz for some song components); several unknown, probable fish sources; and vessel noise. While not calculated, the listening range of the noise loggers for dolphin whistles is expected to be around one km.

Reasons for not yet detecting dolphin whistles in the data set include: they simply have not yet been located in the data - although the data sets have been searched this is not yet systematic or conclusive; the small listening range (~ 3 km^2) for dolphin whistles combined with low dolphin densities implies a low probability of detecting dolphins at the sites; or the noise logger sites are not in preferred dolphin habitats or along dolphin migratory routes (for example inshore-offshore).

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Appendix 03

A Description of Mega Fauna Distribution and Abundance in the SW Pilbara Using Aerial and Acoustic Surveys – Mid-Study Field Report August 2009

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Field Report

A Description of Mega Fauna Distribution and Abundance in the SW Pilbara Using Aerial and Acoustic Surveys – Mid-Study August 2009

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October 22, 2009

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1. Abstract

A series of aerial and acoustic surveys have been initiated near to the proposed Wheatstone pipeline in order to determine mega fauna distribution and abundance in this area and to relate encountered species populations to the broader regional context. A total of 228 humpback whales were sighted in 6 aerial surveys over the SW Pilbara off-shore region during May to August, 2008. Near shore waters have lower densities of humpback whales than off-shore waters (deeper than 50m) perhaps due to annual water temperature profiles. Sperm whales and pilot whales were also sighted during the aerial surveys. Acoustic survey conducted over the same time period identified the presence of humpback whales, pygmy blue whales, Brydes' whales and dwarf minke whales in the study area. Pygmy blue whales and dwarf minke whales are present in deeper waters of the off-shore study area from mid May onwards, although in the 2009 season apparently in lesser numbers (based on call rates) than in previous seasons. Inshore legs of the aerial surveys(depths less than 50m) reported regular sightings of dugongs, dolphins, manta rays and turtles throughout the period of the survey. No high density concentrations of mega fauna have been identified during the May to August time period near the onshore terminus of a proposed pipeline.

2. Scope of Work

The primary purpose of this study is to determine the seasonal distribution and relative abundance of great whales and other mega fauna along the south western Pilbara coast, and off-shore over the proposed Wheatstone subsea pipeline route, during a twelve month period. The Centre for Whale Research (CWR) and Curtin University were commissioned by URS Pty. Ltd. in April 2009 to design, conduct and analyse a series of aerial and acoustic surveys that would best compliment existing datasets and fill knowledge gaps in great whale and other mega fauna distribution and abundance along the inshore and off-shore SW Pilbara coastline and in particular near to Chevron's proposed Wheatstone pipeline (Figure 1).

The combination of aerial and passive acoustic surveys were considered the most effective means of detecting spatial and temporal species clusters in the time window assigned, and which could be used for preliminary environmental assessment purposes for consideration in planning the placement of infrastructure for a gas pipeline and a port facility. Using a combination of acoustic and aerial survey techniques results in a reduction of knowledge gaps that typically arise using just one or the other technique. Aerial surveys alone generally suffer from lack of temporal detail and are unable to sample at night, while acoustic surveys generally suffer from lack of spatial (in shallow water) and species (for none vocalising species) detail. Documenting the existing levels of vessel activity and coastal infrastructure was also considered to be an important part of baseline data collection so that "before and after" style analyses of mega-fauna patterns accurately reflects change.

This report is an initial examination of the data collected between May and August, 2009, and will be followed by a final report which includes analyses of the complete twelve month aerial and acoustic datasets.

Aerial surveys were to be conducted in two phases such that a preliminary analysis of a three month (approx.) subset of the data could be used to inform an environmental approvals process to be lodged in late 2009. A final report to be presented in mid 2010 will document the complete twelve month monitoring program (total 26 aerial surveys) and provide contextual interpretation of the results for future management purposes.

This report focuses on the first 3 months of acoustic and aerial survey data. Acoustic surveys began in mid-April, 2009 and spanned 78 days at an offshore site and 94 days at an inshore site. Aerial surveys consisted of six flights beginning in mid-May and extending through to July, 2009 (approximately the same time period as the acoustic surveys). This report should be considered preliminary as the data collection period spanned only a fraction of a season for all species discussed below, and data analysis was not completed for all species acoustically detected due to limited analysis time from the time of the logger recovery. Acoustic data sets are large and time consuming to analyse and validate and a comprehensive assessment is planned for the final report.

3. Background

Humpback whales are expected to be the most frequently encountered protected species in this study area. As such, the species receives much attention in this report. Furthermore, there is a relatively large wealth of knowledge on humpback whale ecology and behaviour. CWR has been conducting independent studies into the population dynamics and migratory habits of humpback whales in Western Australia since 1990. Through this work, CWR has confirmed Chittleborough's (1953) theory that Exmouth Gulf, immediately to the southwest of the study area is a nursery area for humpback whales (Jenner *et. al*. 2001). Hence, a variety of boat and aerial based survey studies have been conducted in Exmouth Gulf since 1995.

Chittleborough (1953) first described Exmouth Gulf as a possible "nursery" for humpback whales based on aerial surveys over the area in 1951 and 1952. These flights were a regular part of an exploratory process designed to maximise returns for the commercial whaling industry. A whaling station operated at Norwegian Bay near Pt. Cloates (Lat S 22° 36') from 1912 to 1916 and then from 1922 – 1928, and finally from 1949-1955. By 1963, when a moratorium on humpback whaling was passed, there was thought to be less than 800 whales left in Breeding Population "D", or Western Australian population (Chittleborough, 1965).

Now, over forty years since the cessation of whaling, this population of whales is thought to have been recovering at an annual rate of between 7 and 12% (Bannister and Hedley, 2001). By extrapolating this recovery rate forward to 2010, the population could reach 20 - 30,000 individuals. If, as suggested, approximately 10% of this population is represented by cow/calf pairs(Bannister and Hedley, 2001), then as many as 3,000 pairs could use nursing areas like Exmouth Gulf by 2010. How this population increase is progressing and how it relates to the use and significance of areas adjacent to nursing or resting areas (such as the location of the proposed Wheatstone pipeline just north of Exmouth Gulf) is of great interest to managers.

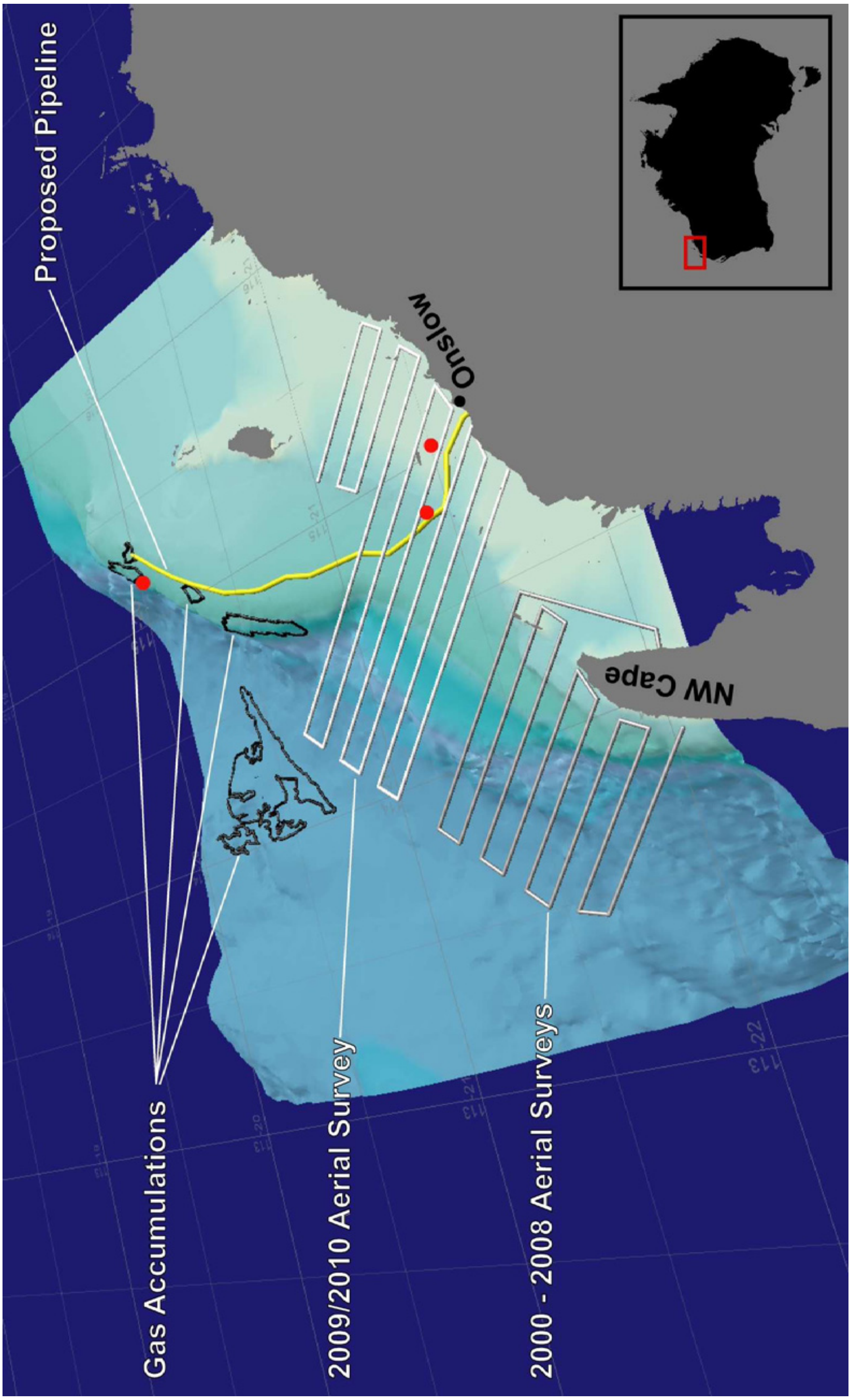

Figure 1. Aerial survey flight paths for the 2009/2010 study period showing proximity to the 2000 – 2008 CWR aerial survey flight path near NW Cape and 2009 acoustic logger position s (red dots). Continental Shelf and Continental Slope depth contours (>500m) are shades of green.

3.1 Humpback Whales at Exmouth Gulf/NW Cape

The migration of humpback whales both north and south past Exmouth Gulf follows predictable but complicated progression of age and sex classes north and south along the coast each season. The northern migration of this species near Albany, Western Australia, has been described by Chittleborough (1965) as being segregated by age and sex class. It is likely that this same pattern where subadults and mature females terminating lactation are in the vanguard of the northern migration, followed by mature males and females and then later pregnant females (carrying near term foetuses), is present off North West Cape and the broader SW Pilbara off-shore region.

The southern migration follows a similar order, with cows with their newly born calves appearing at the tail end of the migration. It's the cow/calf portion of the migration that congregate in greatest numbers inside Exmouth Gulf and that may have an overlap of spatial /temporal distribution near inshore portions of the study area.

Spatially, the northern migratory path appears to be consistent (CWR unpubl. data) for all age and sex classes off North West Cape and centres on about the 250m line (Figure 2). Whales rarely enter Exmouth Gulf during the northern migration (June to early August), perhaps due to the 3°C or more temperature difference between the open ocean and the shallow Gulf during June to early August. A transition phase between the northern and southern migrations occurs from early August to early September (Figure 3). This time period is consistent with peak numbers of whales each season (Figure 5) and results in the migratory path spreading to include a much wider depth range than is observed during the northern or southern migration. Sightings of whales inside the warmer northern part of the Gulf increase during early September and by mid-late September the main southbound migratory peak passes west of North West Cape with some animals entering the Gulf (Figure 4).

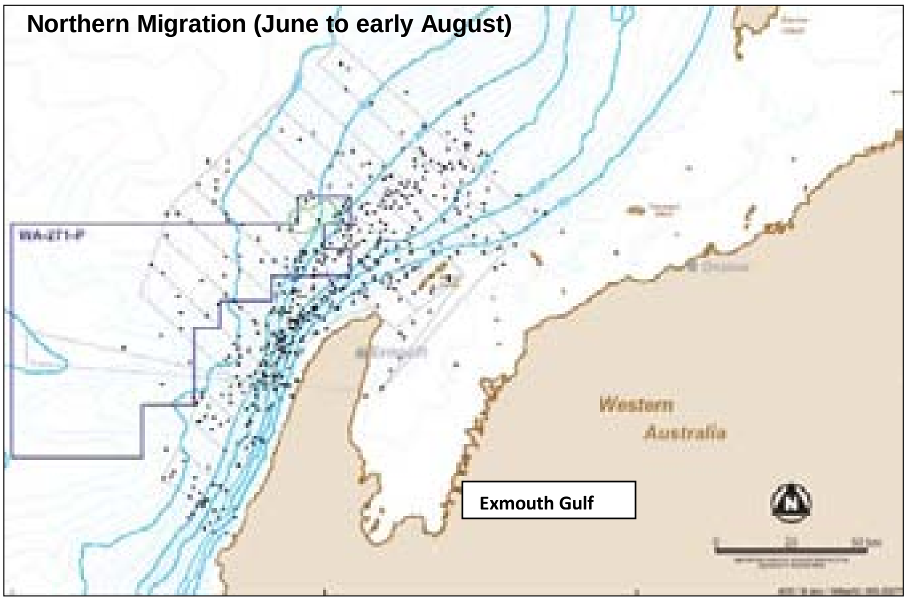

Figure 2. Aerial survey sightings of humpback whales during the northern migratory period (June to early August)in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

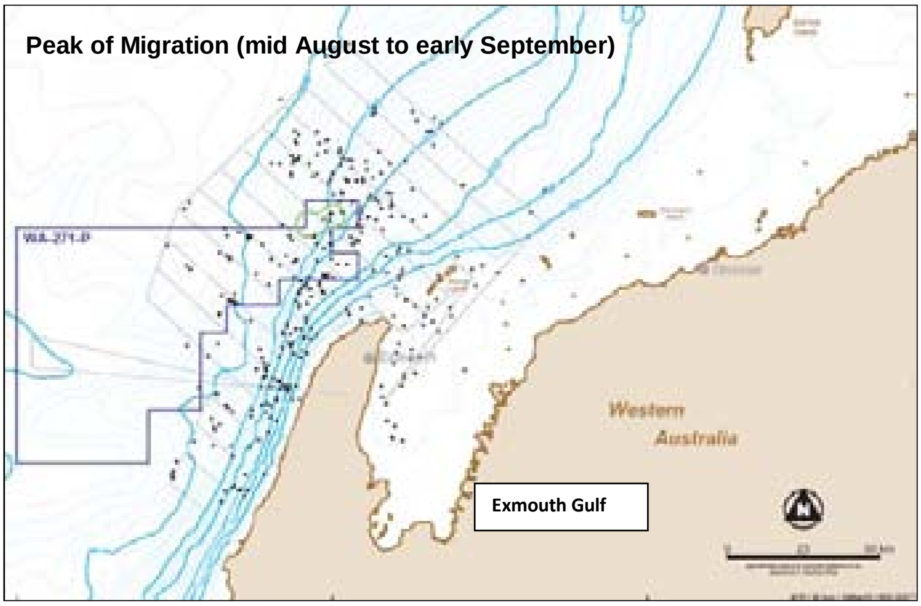

Figure 3. Aerial survey sightings of humpback whales during the Transition Phase (mid Audust to early September) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

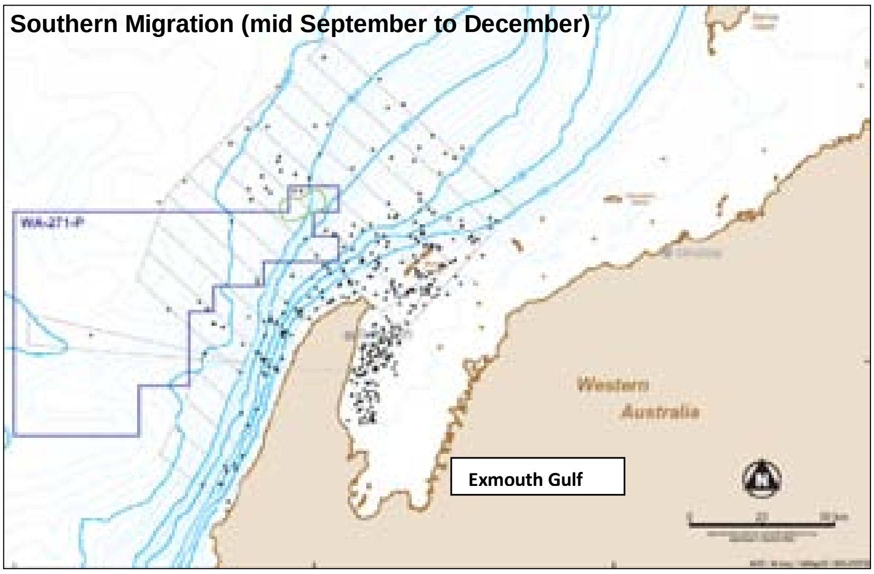

Figure 4. Aerial survey sightings of humpback whales during the southern migratory period (mid September to December) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

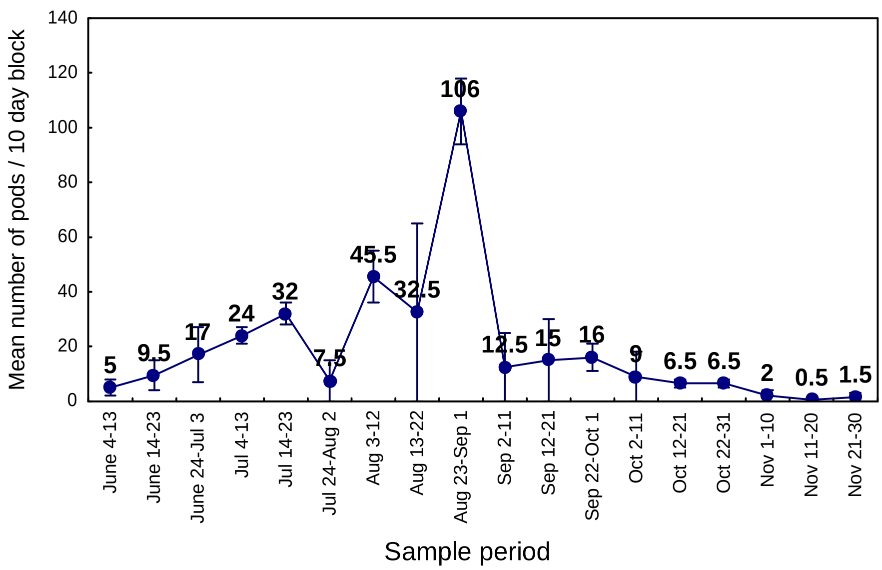

Figure 5. Mean number of humpback whale pods recorded during aerial surveys in 10 day sample blocks during the months of June to October during 2000 and 2001 ($\bar{x}$ ± 1 SE). Data from CWR aerial surveys west of, and not including, Exmouth Gulf for Woodside Energy 2000/2001, EIS document.

It is likely that water temperature plays a role in determining when whales, particularly cow/calf pairs trying to minimise metabolic expenditures, enter Exmouth Gulf. Cow/calf numbers inside the Gulf peak during the first 2 weeks of October, at a similar time annually as the sea surface temperature inside the Gulf becomes equal to that found off-shore at the same latitude (Figures 6 & 7).

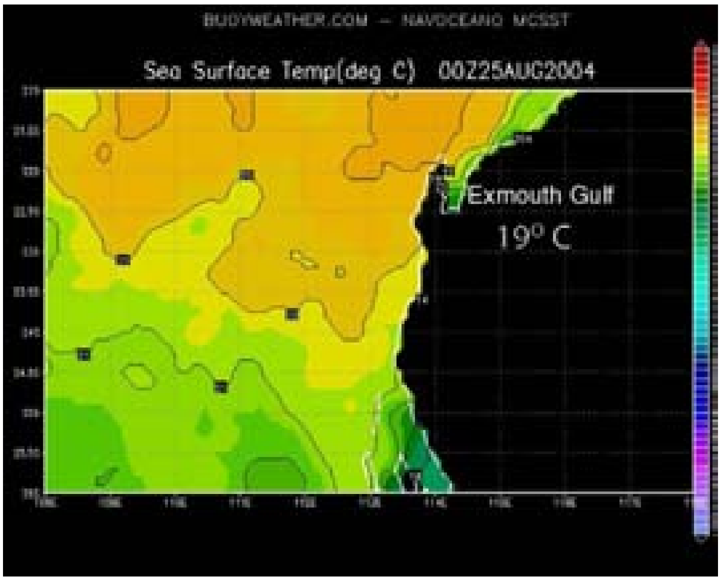

Figure 6. Sea surface temperature map for late August 2004 (during the transition phase with peak numbers of whales off-shore) showing the cooler water inside Exmouth Gulf and the inshore SW Pilbara region.

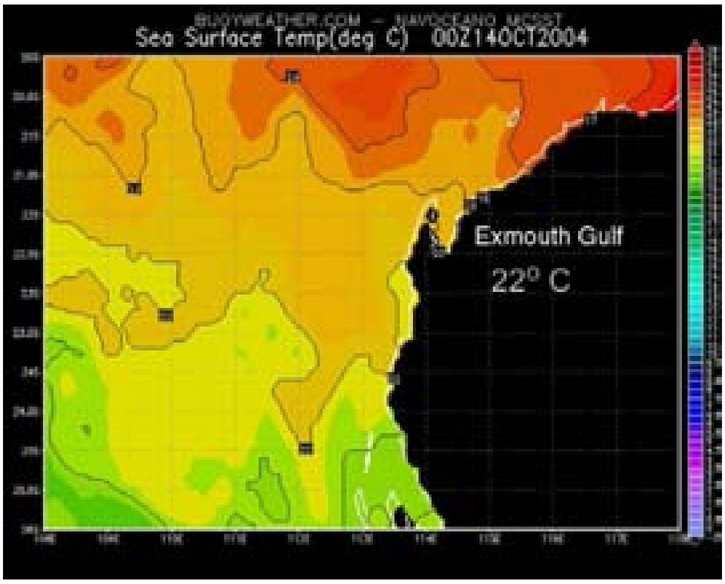

Figure 7. Sea surface temperature map for mid-October 2004 showing the increase in temperature inside Exmouth Gulf during the period when peak numbers of cow/calf pods rest in the Gulf and in-shore SW Pilbara Region.

Expansion of the existing knowledge base for humpback whale spatial and temporal distribution from the NW Cape area and Exmouth Gulf is a logical and necessary first step for this current study program.

4. Methods

4.1 Acoustic Surveys

A series of five sea noise loggers were deployed two near shore west of Onslow over April to July 2009, and three in a 2 km triangle on the shelf break north of the Monte Bello Islands over May to July 2009 (Wheatstone or offshore site). Details of the passive acoustic survey methodology are presented in a separate report (McCauley and Kent, 2009).

4.2 Aerial Surveys

The off-shore area between Exmouth Gulf and Barrow Island was systematically examined using aerial surveys for mega fauna from mid-May to late-July. Transects were designed to be consistent, comparable and a logical extension to transects described in Jenner and Jenner (2008). The transects covered an area which included the main humpback whale migratory body,(Jenner *et al.*, 2001). A total of six samples of all transects were collected at 14 day intervals with the precise dates within these time blocks (intervals) dependant on “good” weather conditions (winds less than 18 knots) for detecting humpback whales (the primary target species). It is recognised that these conditions may not be optimal for spotting other smaller species however this study program is focused particularly at great whales. Designing surveys which are ideal for smaller species sightings

The design of the survey followed protocols defined in the Distance ver. 5.1 software program (Buckland *et al.,* 2001, Buckland *et al.*, 2004). This program specifically allows users to design line transect surveys and analyse data resulting from these surveys for the purpose of estimating density and abundance. Using the principles of this system, transects were drawn over the study area in order to maximise coverage probability during a single flight. Although parallel line transect designs are disadvantaged because the time spent in between transects is “off survey”, this technique results in a more even probability of coverage for non-rectangular survey areas such as the current study site (Buckland *et al.* 2001). Furthermore, this system is consistent with previous CWR aerial surveys from both off-shore near NW Cape (20 km southwest of the study area) and Exmouth Gulf (40 km southwest of the study area) (Figure 1).

The timing of the first six surveys was planned to coincide with the bulk of the northern migration of humpback whales through this region (see Figure 8 for the trend in humpback swim direction) although confirmation of this timing will not be available until the full migratory cycle has been examined.

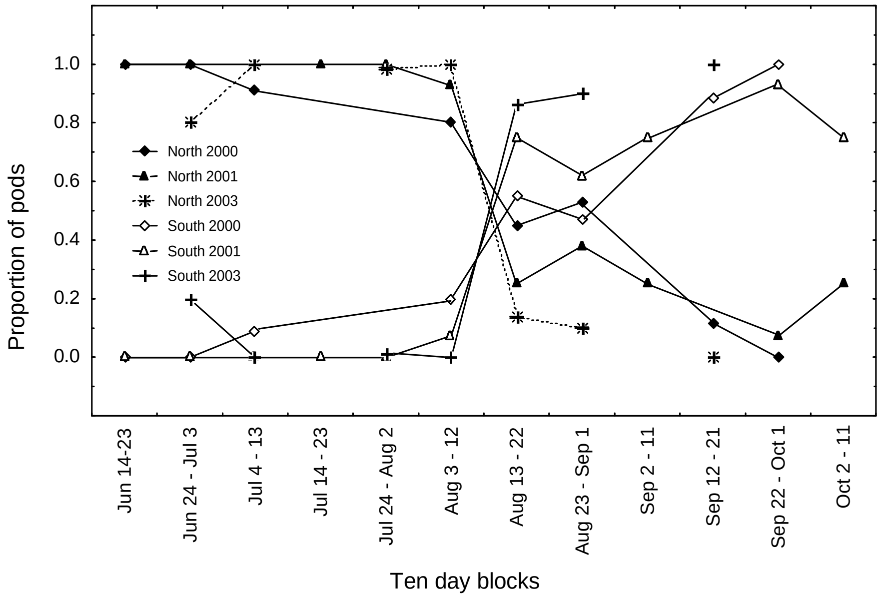

Figure 8. Migratory direction of humpback whale pods recorded during aerial surveys at NW Cape, showing June and July as a northern migration period (from Jenner *et al.*, in prep.). Non- migrating whales (i.e. resting or milling) are not plotted.

4.2.1 Aerial Survey Detail

Aerial surveys were conducted at an altitude of 305 m (1000 ft) and a speed of 222 km/hr (120 knots) using a twin-engine, over-head wing aircraft (Cessna 337). The plane followed line transects which were surveyed in passing mode (e.g. the plane did not deviate from the flight path). Surveys were only initiated in wind speed less than 33 km h^{-1} (18 knots) which has been shown to be adequate for spotting whales (Jenner *et al.* in prep). Each flight was of approximately 5.5 to 6 hours duration and take-off times varied between 8:40 and 10:55 so that the mid-day period was consistently sampled and glare would be a consistent factor for all flights. Flights during the expected northern migration period where flown from north to south to minimize the possibility of double counting pods of whales on successive transects. Similarly, the flights during the southern migratory period will be flown from south to north.

Personnel for each survey included four people; two pilots and two observers. The observer team consisted of 4 trained personnel. One person (Lyn Irvine) flew all six flights, one person (Jane Kennedy) flew four flights and one person (Emily Wilson) flew two flights. The fourth observer did not fly any of the first six flights. The pilots were not responsible for spotting, and were separated acoustically from the two observers. The pilots were responsible for recording the planes' angle of drift on each transect, so that angles reported from the compass boards could be corrected relative to the flight path. The observers were linked via a separate intercom system which was logged to a Sony Mini Disk Recorder NH900 which allowed the observers to search continuously and voice record all sightings to a time code which was synchronized to the Global Positioning System (GPS) before each flight. A Garmin III Pilot aeronautical GPS was used to log sightings (as waypoints) and coordinates of the flight path, including altitude, for every second of the flight.

Observers sighted and recorded positions of whales by measured vertical and horizontal angles from the aircraft to the whales (using Suunto PM-5/360PC clinometers, and a compass board). The location (latitude and longitude) of each sighted whale was later plotted by projecting a new GPS waypoint from the waypoint recorded at the time of sighting (using Oziexplorer ver 3.95 GPS software) from the calculated angle and distance of the aircraft to the whale. The angle was calculated with the following formulae: Angle to starboard = *AC* + (*MHA* + *DA*), and Angle to port = *AC* + (*MHA* - *DA*), where *AC* was the aircraft course, *MHA* was the measured horizontal angle and *DA* was the angle of drift of the aircraft. Distances were calculated using formulae in Lerczak and Hobbs (1998).

No vertical or horizontal angles were recorded for any other species (i.e. dolphins, dugongs, rays sharks or turtles) and it was assumed for plotting purposes that sighting positions were the same as the waypoint marked (i.e. directly under the plane). However vertical and horizontal angles were measured for vessels and other man-made objects, and, where possible, direction of travel was also recorded.

The sighting information that was recorded for whales included the direction of migration (north, south, resting/milling, or undetermined) of each pod observed. Northbound pods were those sighted steadily swimming parallel to the coast in a northerly direction. Likewise, southbound whales were those sighted swimming parallel to the coast in a southerly direction. Pods reported as "milling" were swimming perpendicular to the coast (not northbound or southbound) or surface lying at the time of sighting with no obvious signs of swimming (i.e. resting whales). Pods recorded as "undetermined" were sighted too far from the aircraft, or for too short a time period, to assess swim direction.

The level and direction of glare (scale 1-3) for each observer was recorded for each transect as well as environmental variables such as Beaufort sea-state (scale 0 -12), associated wind speed (estimated in knots) and direction (from wave patterns), cloud cover below 1000 feet (percentage) and overall visibility (scale 1-3).

4.2.2 Analysis

The GIS program Arcview 3.2, with extensions Spatial Analyst and Animal Movement (Hooge and Eichenlaub, 1997), was used to analyze the distribution of cetaceans and all other encountered wildlife. Complete spatial randomness (CSR) of cetacean sightings was tested to determine if sightings data were spatially structured (i.e. whether sightings were clustered, random or uniformly distributed) within the flight path study area. Other smaller species (dugongs, dolphins, turtles etc.) were not tested for CSR since they could not be reliably sighted away from the track line. Nearest neighbor routines were run in Arcview to test for CSR and a Kernel "home range" estimator was used to compute locations of clusters (indicating higher relative densities and possible a migratory corridor or resting area) for cetaceans within the study area. Apparent clustering of humpback whales around the track line has been assumed, for the purposes of this report, to have minimal effect on the results given an effective half strip width of 5 km (Bannister and Hedley, 2001).

The mean distance of whale pods on each flight from the nearest section of coastline was measured using a GIS "Spider Distance" tool to establish spatial and temporal patterns in clustered data. Probability contour maps were generated for each flight that display relative density contours on the day of the survey and across all surveys reporting humpback whales.

A smoothing factor ("*h*" statistic) controls the size of the home range reported and has been shown to be inconsistent for different sample sizes (Hooge and Eichenlaub, 1997). For this reason a second technique, the minimum convex polygon (MCP) method was used to first confirm sightings range extent. The MCP was considered to be the minimum extent of the sightings range and the smoothing factor was adjusted until the area of an unbroken 95% kernel contour for the entire dataset completely included the area of the MCP. This provides an objective method for selecting the smoothing factor (Hooge and Eichenlaub, 1997) and creates a baseline for relative density comparisons between flights.

The "h" statistic was used to calculate 50%, 75% and 95% probability density contours for each flight day where the 50% contour represents the highest density of whale pods (not whales) and the 95% contour represents the likely extent of all pods. However, at this stage of analysis where only part of the migratory season is available for calculations, the "h'" statistic is preliminary and will need to be recalculated based on maximum density in the entire study area over the entire study period.

5. Results

5.1 General Description – Acoustic Loggers

A general description of preliminary results from the passive acoustic surveys is presented here, however a detailed description of these results is presented in McCauley and Kent, 2009. The work presented is ongoing with further data collection and analysis planned.

The noise loggers detected various whale species including: pygmy blue, dwarf minke, Brydes, and humpback whales. The recording period is currently too short to correctly delineate seasonal patterns in whale trends. The offshore noise loggers were dominated by seismic survey noise and vessel noise during the entire recording period. At times three seismic survey sources could be detected at the offshore location. These are believed to be associated with two surveys running in deep waters adjacent to the shelf to the south. Vessel noise was prominent at the offshore location, presumably from vessels involved in site works at the proposed Wheatstone and Pluto gas fields.

Pygmy blue whales were present offshore over most of the May to July period. These are believed north bound pygmy blue whales returning to low latitudes after spending summers feeding in temperate waters (Branch et al. 2007). The time integrated count of individual calling pygmy blue whales from the Wheatstone site from a nearby data set made in 2006 was compared with the similar count made in 2009 over the matching time period in Julian days. Six times fewer whales passed in 2009 compared with 2006.

Dwarf minke whales were detected and counted at the offshore site. Dwarf minke whales were present persistently across the April to July period with a slight tendency for more whales in June-July. The time integrated counts of individual calling dwarf minke whales in 2009 were compared with the same calculation for the nearby site made in 2006 and seven times fewer dwarf minke whale detections were made in 2009(McCauley, unpubl. data). It is currently not clear why counts of pygmy blue and dwarf minke whales are lower in 2009 than in 2006 at the offshore site.

Brydes whales were detected on one day only in April at a site in 43 m of water west of Onslow.

Humpback whales were present at the 43 m depth inshore site and at the offshore site but the counts have not yet been analysed for trends or timing.

Regular evening fish choruses were heard at the 43 m depth inshore site (expected regular demersal species) but not at a 10 m depth site. Expected fish choruses from the offshore site (ie. globally dispersed deep water myctophid species) were not detected.

5.2 General Description – Aerial Surveys

A total of 6 flights at approximately two week intervals from May 17, 2009, to July 23, 2009 totalling 42.1 survey hours over the south western Pilbara off-shore region resulted in 1052 mega fauna sightings and 280 vessel sightings (Table 1). A single whaleshark was sighted on May 17, 2009, and a sighting of 10 sperm whales on July 11, 2009. No blue whales were sighted during the first six flights. Humpback whales were the most commonly sighted large cetacean.

Table 1. Mega fauna and vessel sightings during the first 6 flights of a 26 flight series.

SIGHTING	Survey 1 - May 17, 2009	Survey 2- May 31, 2009	Survey 3- June 12, 2009	Survey 4- June 26, 2009	Survey 5 - July 11, 2009	Survey 6 - July 23, 2009	Cumulative TOTAL:
Humpback whale:	0	0	6	50	75	97	228
Blue whale:	0	0	0	0	0	0	0
Minke whale:	0	0	0	1	0	0	1
Pilot whale	0	0	25	0	0	0	25
Sperm whale:	0	0	0	0	10	0	10
Other whales (unidentified):	0	0	0	0	2	0	2
Dolphin spp.:	40	203	8	68	47	78	444
Dugong:	13	3	12	31	2	25	86
Whale Sharks:	1	0	0	0	0	0	1
Manta rays:	2	4	0	12	1	3	22
Turtles:	2	101	4	12	14	100	233
Vessels:	51	42	36	48	48	55	280
Aquaculture Net	NA	1	1	1	1	1	5

5.3 Humpback Whales

A total of 144 humpback whale pods containing 228 individual whales were sighted during the mid-May to late July time period (Table 1). A total of 3 cows with calves were sighted (all during the July 23 flight). No humpback whales were sighted during the first two flights in May.

Table 2. Humpback whale sightings during the first 6 flights of a 26 flight series.

Flight Date	Number of Pods	Number of Whales	Number of Calves	Number Whales Swimming	Number Whales Resting	Number Undetermined
17/05/09	0	0	0	0	0	0
31/05/09	0	0	0	0	0	0
12/06/09	4	6	0	6	0	0
26/06/09	28	50	0	43	0	7
11/07/09	46	75	0	42	1	32
23/07/09	66	97	3	68	11	19
Totals	144	228	3	159	12	58

Humpback whale sightings increased steadily after flight 3 (June 12, 2009) and peaked during flight 6 (Figure 9).

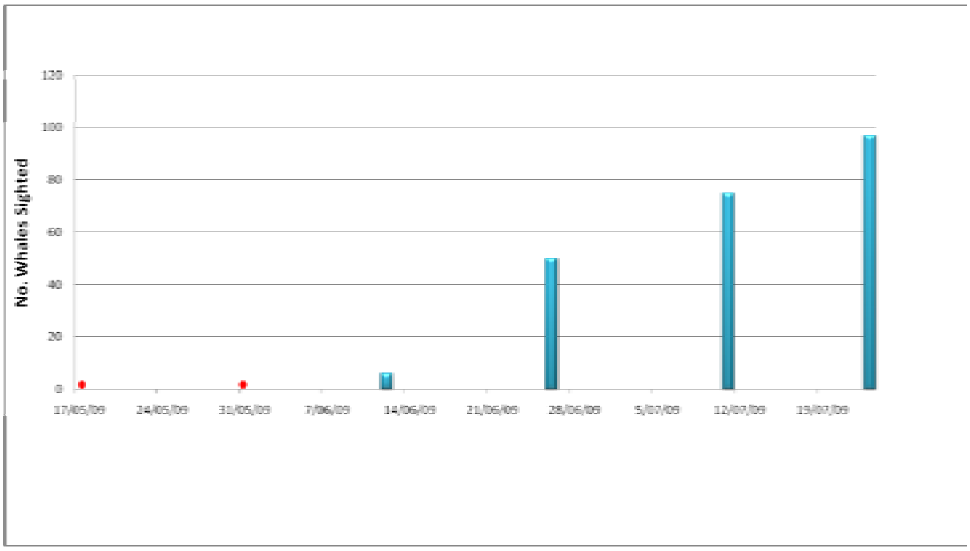

Figure 9. Numbers of humpback whales sighted per flight for the first six flights (red dot indicates a flight but no sightings).

As a means of initially exploring the spatial datasets, tests for Complete Spatial Randomness (CSR) of humpback whale pod distribution were conducted to test the hypothesis that distribution within the study area was random. The nearest neighbour analysis in Animal Movement (v.2.0) was used to test for CSR using a polygon encompassing the flight path area as a boundary.

Assumptions for the test are as follows;

1) If the resulting value of *R* from the nearest neighbour analysis equals 1 for an observed data set then the data is randomly distributed, since the observed distribution does not deviate from the expected random model.
2) If $R < 1$, the data is clustered where the observed mean nearest neighbour distance is less than what is expected with the random model, thereby resulting in clusters.
3) If $R > 1$, the data is uniformly distributed because the mean observed nearest neighbour distance is greater on average than the expected.

Complete Spatial Randomness analysis using the nearest neighbour technique resulted in the data points on flights during June 26, July 7 and July 23 being designated "clustered" (*R* values all less than 1, Table 3). There were too few sightings on June 12 to run the test effectively.

Table 3. Values of *R* indicating clustered distribution of humpback whale pods during each flight

Flight	"R" Value
12/06/2009	-
26/06/2009	4.734 x 10e-006
11/07/2009	5.88 x 10e-006
23/07/2009	6.702 x 10e-006

Having established that there is clustering of the data points, the next step in spatial analysis was to determine if there is any evidence of site fidelity among flights, bearing in mind variables such as migratory direction which may influence distribution. We assume here, and confirm below, that all pods sighted in surveys to July 23rd are likely to be part of the northern migratory phase.

The GIS tool Animal Movement 2.0 (Hooge et al., 1997) was used to calculate probabilistic contours of equal utilization distributions. This is also know as a kernel home range calculator. The kernel home range is considered one of the most robust of the probabilistic techniques for spatial analysis of point data (Worton 1989). The kernel is essentially a grid of equal utilisation areas that has smoothed edges. The smoothing can be done automatically by the GIS program or adjusted manually, using an "h" statistic, which is fit to the dataset with a Minimum Convex Polygon (MCP). For the current dataset, points from all flights were combined to define the maximum boundary for the MCP (Figure 10). An "h" value of 0.045 was selected based on the visual fit of the 95% probability contour which results in a maximum envelope around a single point equal to the half strip width of the line transects (5km).

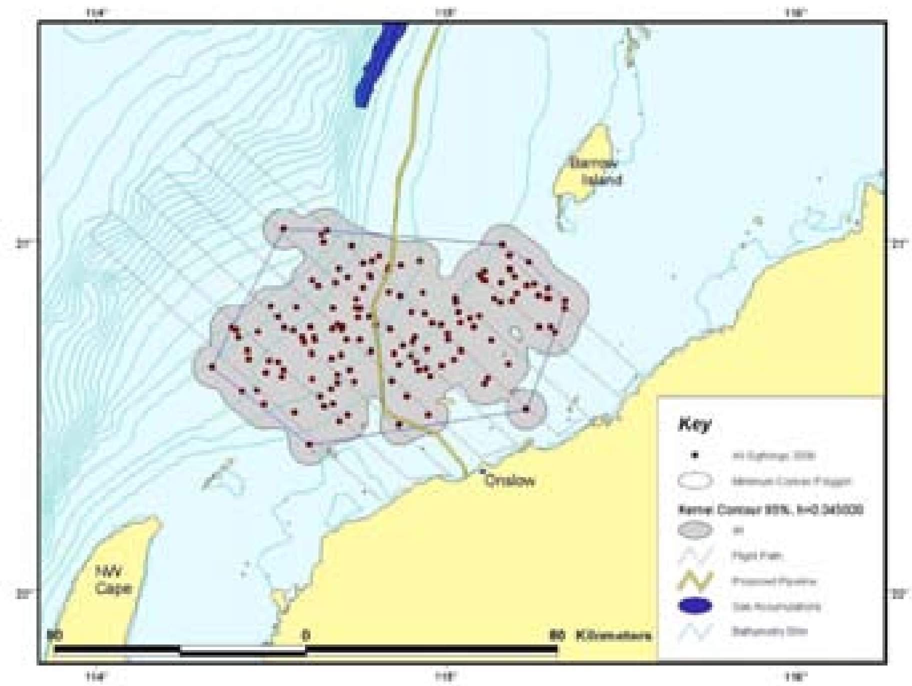

Figure 10. The Minimum Convex Polygon used to select the smoothing factor for the June/July humpback whale dataset (h=0.045) and the resulting 95% kernel contour for all sightings. Positions of all pods (n=144) are shown.

Maps showing ranked kernel density polygons (highest to lowest) for flights 4 to 6 (June 26, July 11 and July 23) using the same “h” value (0.045) are presented in Figures 11 to 14, and show a comparative relative density and range of migrating humpback whales in the June and July flights. A similar plot for flight 3 (June 12) was not constructed as there were too few data points (n=4) to perform the calculations (Figure 11).

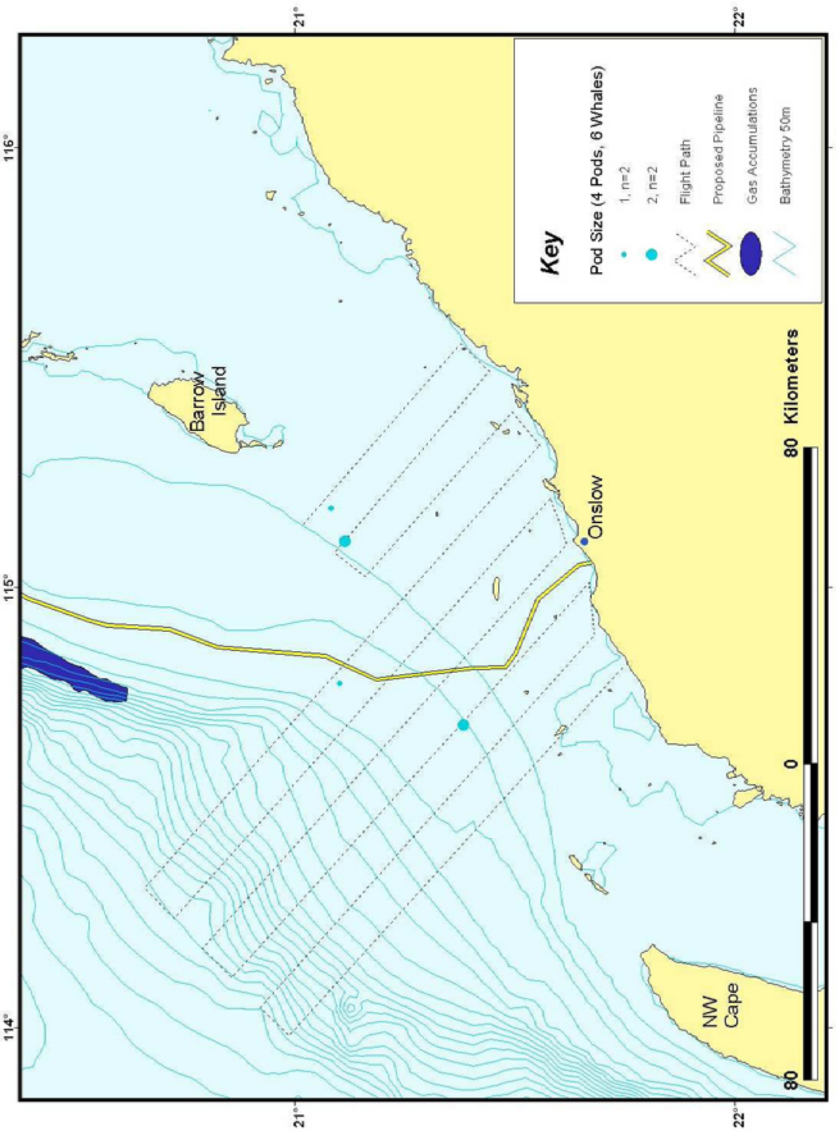

Figure 11. Positions of humpback whale pods sighted on June 12, 2009.

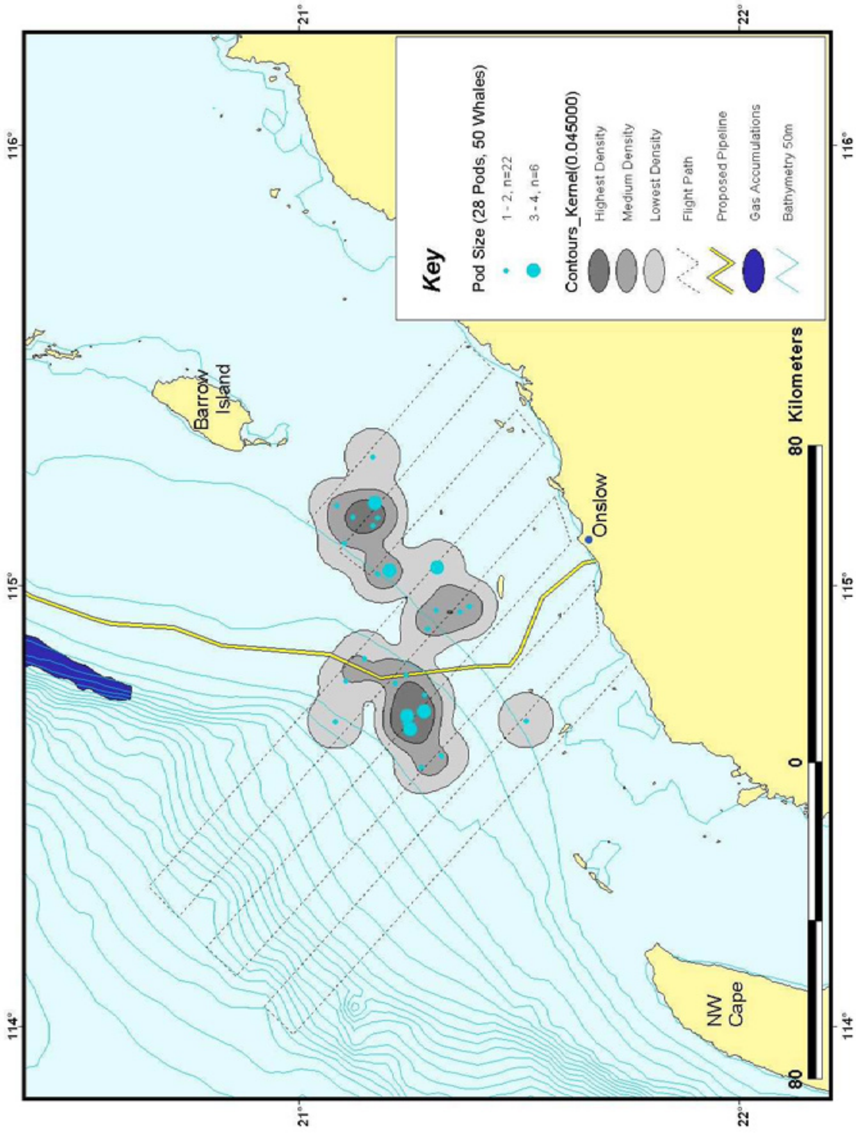

Figure 12. Positions of humpback whale pods sighted on June 26, 2009, with relative density distribution polygons.

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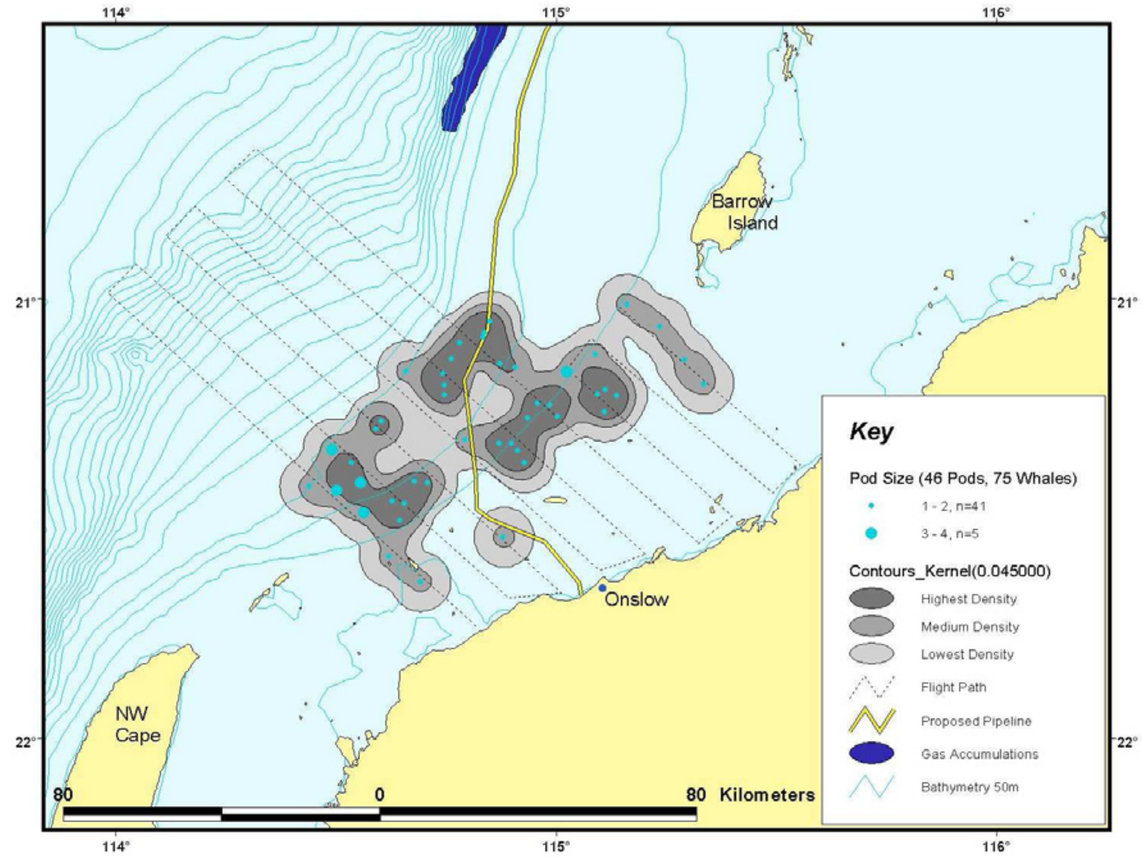

Figure 13. Positions of humpback whale pods sighted on July 11, 2009, with relative density distribution polygons.

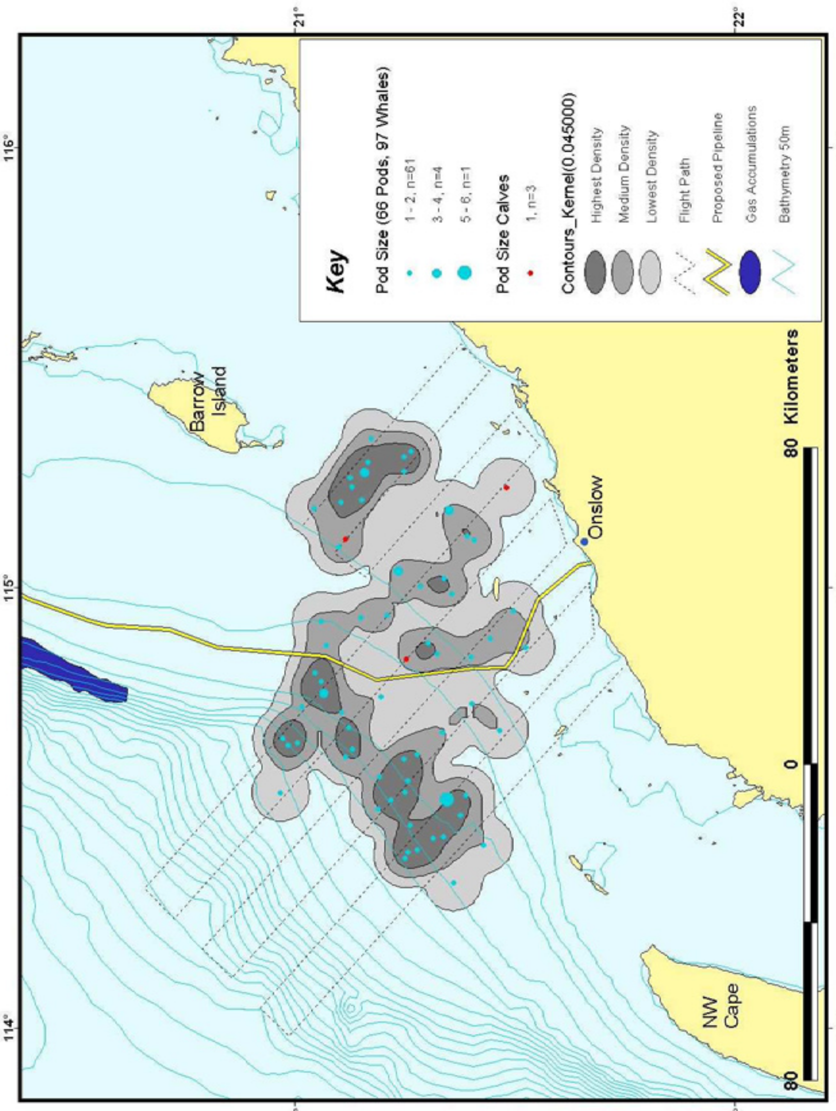

Figure 14. Positions of humpback whale pods sighted on July 23, 2009, with relative density distribution polygons.

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Mean distance from shore of humpback whale pods remained consistent for all four flights, ranging from 34 km to 70 km off-shore (Figure 15 and 16).

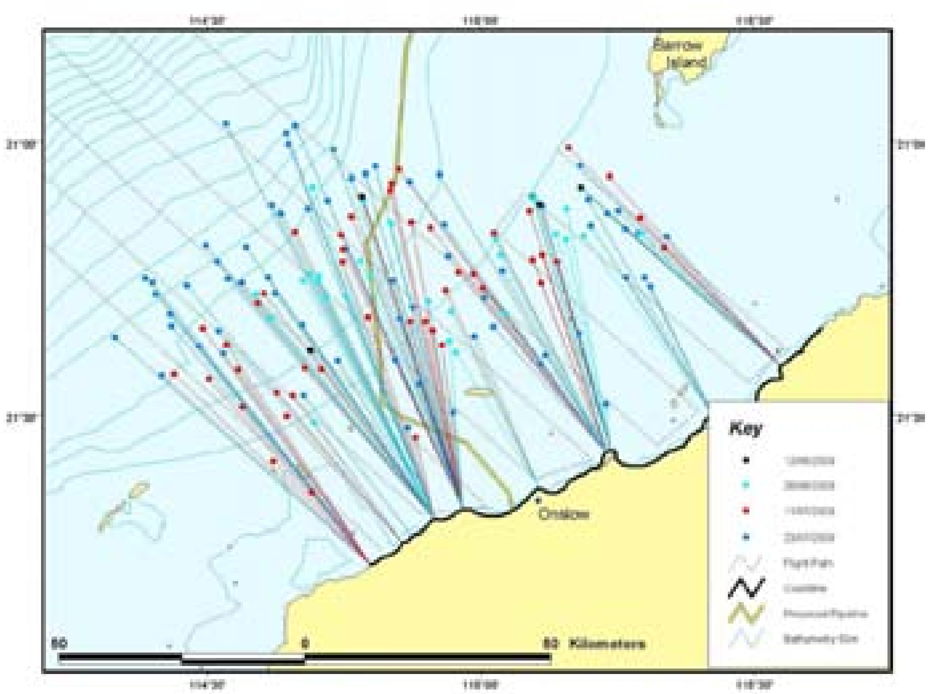

Figure 15. "Spider distance" measurements from each pod to the nearest section of coastline.

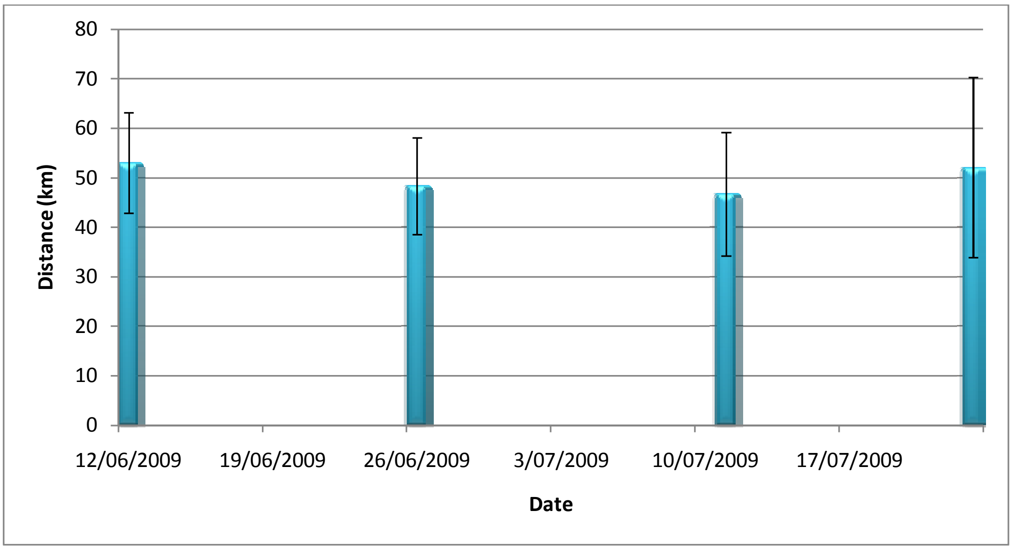

Figure 16. Mean distance from shore of humpback whale pods sighted during each flight from Spider distance data. Error bars are ± 1SD.

Migratory direction was not clearly defined during the June 12th flight although only four pods of whales were sighted (Figure 17). During the June 26th flight the majority (96%, n=28) of pods sighted were northbound. A decline in the proportion of northbound pods was observed during the two July flights with a noticeable increase in the proportion of pods identified as Resting and/or Milling

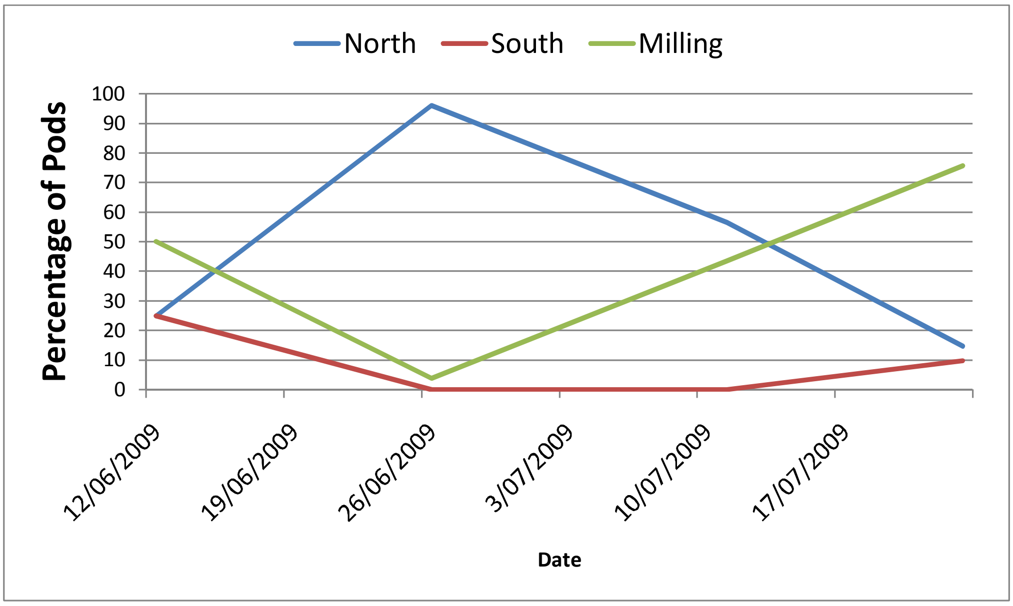

Figure 17. Migratory direction reported for humpback whale pods sighted during flights on June 12, June 26, July 7 and July 23, 2009 ("undetermined" pods have been proportionately allocated[1]).

There was no apparent spatial pattern to swim direction across the June/July flights with Northbound, Resting/Milling and Southbound whales sighted at similar ranges off-shore (Figure18). The proportion of pods sighted with "Unknown" swim direction were allocated, in proportion, to North, South and Milling categories to produce Figure 17 but have been plotted separately in Figure 18 to show distribution of this direction category (unknown swim direction is assigned to whales sighted only as breaching or too few times to observe a swim direction)

[1] Proportional allocation is the process of assigning "undetermined" data points to determined bins (such as "North", "South" or "Milling") based on an assumption of equal proportional representation within those points. This allows the entire dataset to be included in the analysis.

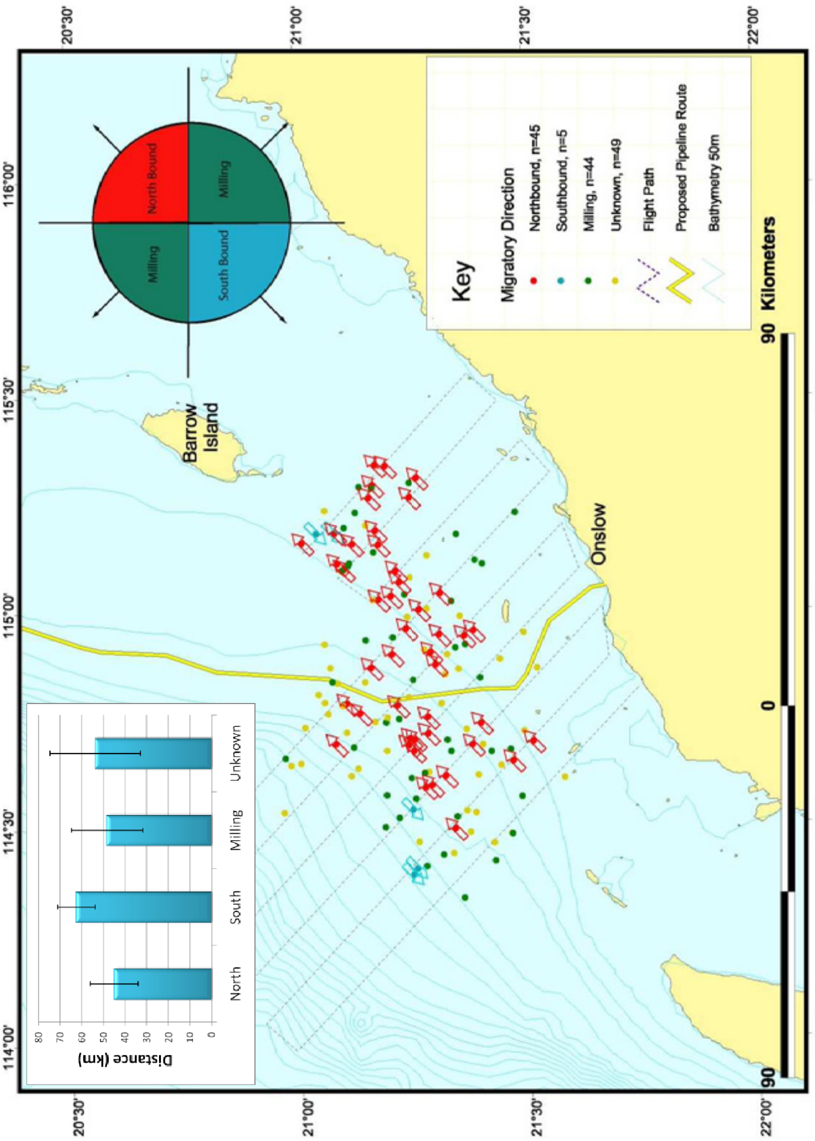

Figure 18. Migratory direction for all pods during June/July with accompanying graph showing mean distances off-shore (with standard deviations) of each directional group. Note: migratory direction is assumed based on actual swim direction and is assigned based on sections of the compass rose in the upper right corner of the figure.

23 | P a g e

5.4 Other Mega Fauna

5.4.1 Dugongs

Dugongs were sighted during each of the six flights throughout the study period. A total of 86 dugongs were sighted over the six flights, with peak numbers observed during the June 26 flight (Figure 19). Herds containing cow/calf pairs accounted for 11% (5/44) of all sightings (Table 4). Dugongs were predominantly sighted in the south western portion of the study area in water depths less than 10m (Figure 20).

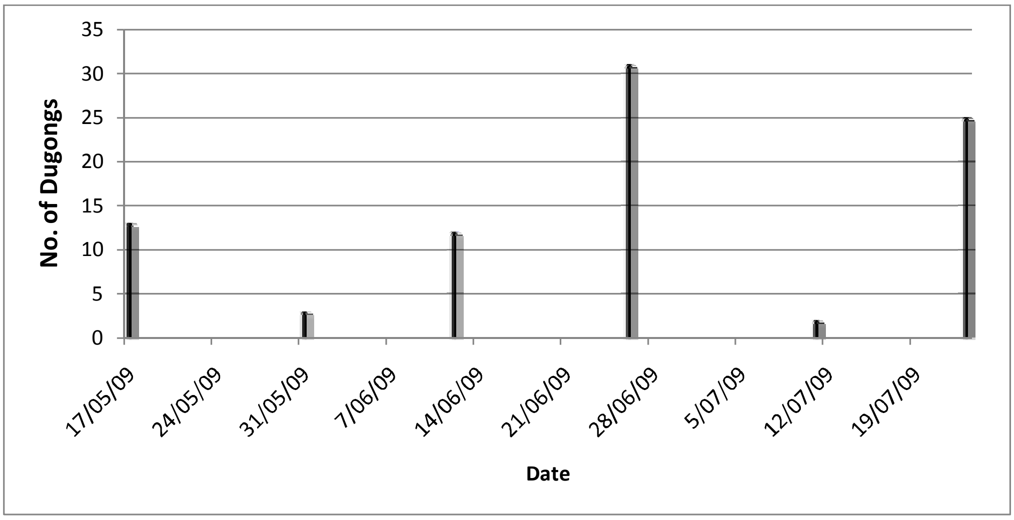

Figure 19. Numbers of Dugongs sighted during each flight from May 17 to July 23, 2009.

Table 4. Numbers of Dugongs sighted per flight

Flight Date	Dugong Herds	No. Dugongs	Dugong Calves
17/05/09	3	13	0
31/05/09	2	3	0
12/06/09	7	12	2
26/06/09	19	31	3
11/07/09	2	2	0
23/07/09	11	25	0
TOTAL	**44**	**86**	**5**

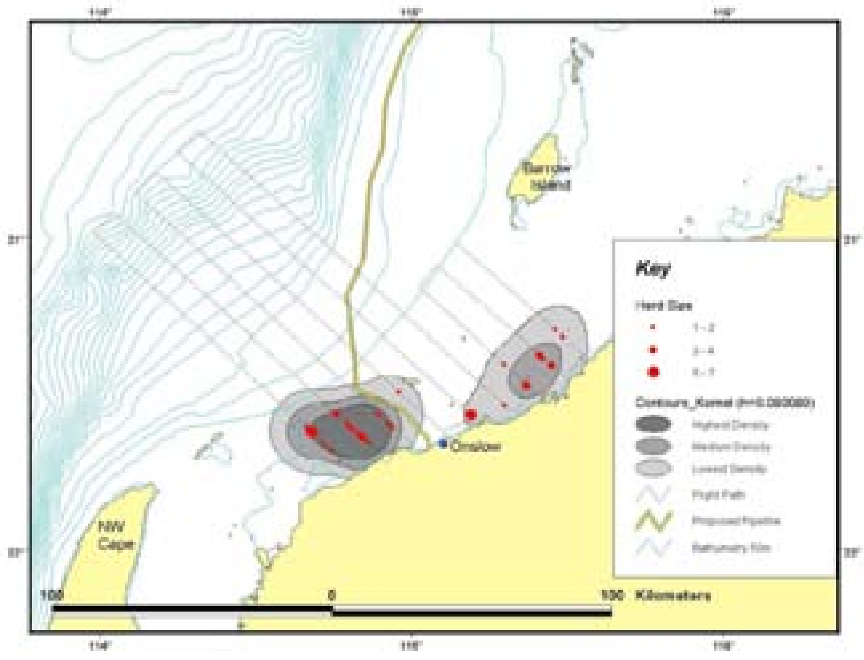

Figure 20. Distribution and relative density of Dugong herds sighted from May 17 to July 23, 2009.

5.4.2 Dolphins

Dolphins are likely to either be inshore (< 50m) species including *Tursiops spp.*, *Sousa chinensis or Orcaella spp.* and the off-shore species may include *Tursiops spp.* and *Stenella spp,(* Jenner and Jenner, unpublished data from vessel surveys), however sightings were not identified to species level due to difficulty in identification. Dolphins were sighted during each of the six flights throughout the study period. A total of 444 dolphins were sighted with a peak number of 203 animals observed during the May 31 flight (Figure 21). Only two calves were sighted throughout the survey period (Table 5). Dolphins were predominantly sighted in the south western portion of the study area in water depths less than 10 m, although some large pods (>100 individuals) were sighted off-shore (Figure 22).

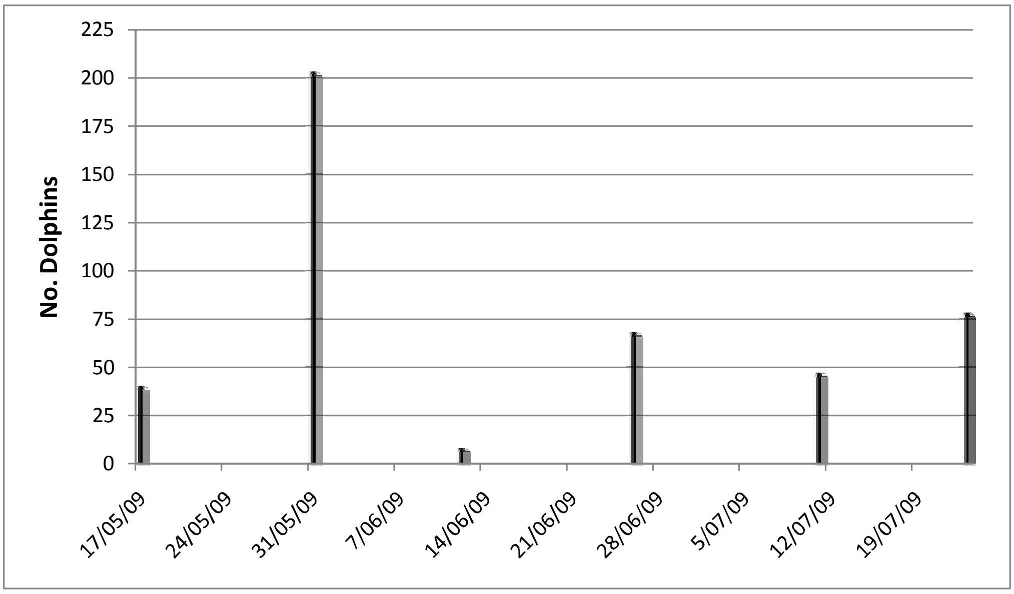

Figure 21. Numbers of dolphins sighted during each flight from May 17 to July 23, 2009.

Table 5. Numbers of dolphins sighted per flight.

Flight Date	Dolphin Pods	No. Dolphins	Dolphin Calves
17/05/09	10	40	0
31/05/09	18	203	0
12/06/09	4	8	0
26/06/09	28	68	0
11/07/09	10	47	1
23/07/09	29	78	1
TOTAL	**99**	**444**	**2**

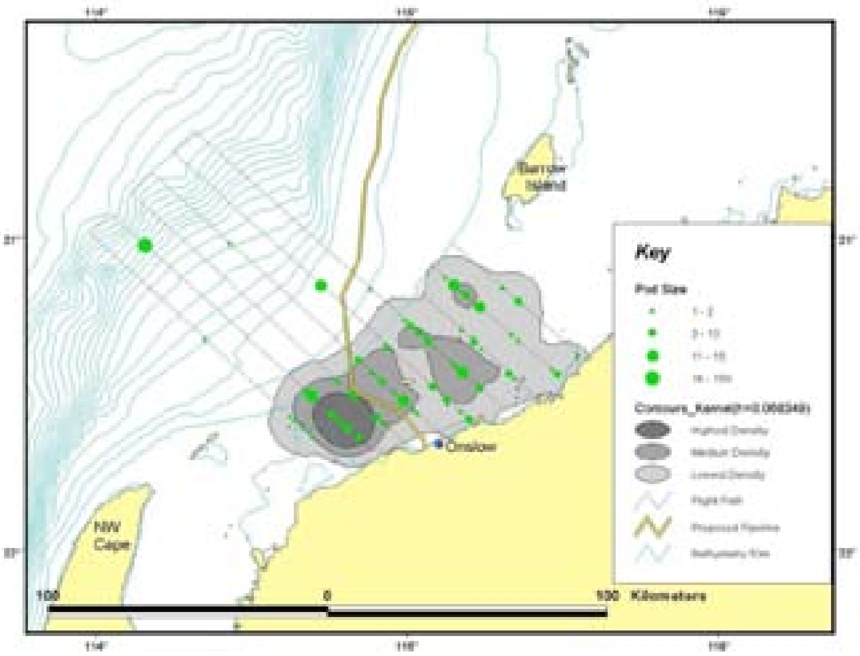

Figure 22. Distribution and relative density of dolphin pods sighted from May 17 to July 23, 2009.

5.4.3 Other Cetaceans

Other cetacean species sighted included sperm whales, pilot whales and a single minke whale (Figure 23). A pair of fast swimming unidentified whales, possibly Brydes' whales or minke whales, were sighted on July 11, 2009. The sperm whales (n=10) were logging at the surface when sighted over the continental slope, as were the pilot whales (n=25). A dwarf minke whale sighted on June 26, 2009, was swimming steadily northeast.

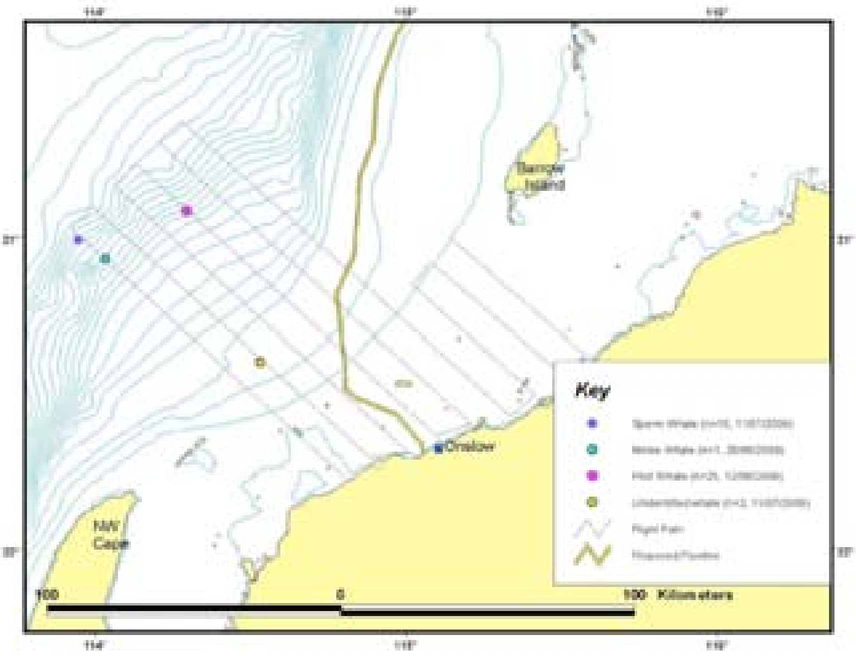

Figure 23. Distribution of other cetacean species sighted during the May 17 to July 23, 2009, period.

5.4.4 Turtles, Rays and Whalesharks

Turtles were not able to be identified to species level at the time of sighting. Boat based sightings by CWR from previous surveys suggest that the principle turtle species in the near shore Exmouth Gulf region during the May to November period is the green turtle (*Chelonia mydas)*. However, hawksbill turtles (*Eretmochelys imbricata*) are frequently sighted in mangrove creeks and loggerhead (Caretta caretta) and flatback (Natator depressus) have also been sighted in CWR surveys between 2000 and 2009. Manta rays (*Manta birostris*) were distinguished from other rays by their distinctive shape although it is possible that other species of bottom dwelling rays were mistaken for Mantas along the mangrove creek areas. Whalesharks (*Rhincodon typus*) are unique in shape and size and are commonly sighted and identified using aerial surveys (i.e. Ningaloo whaleshark tourist industry) so misidentification is considered unlikely.

Turtles were sighted during each of the six flights while manta rays were sighted during all flights except May 31, 2009 (Table 6). A single whaleshark was sighted during the May 17, 2009, flight. Turtles were predominantly located inside the 50m bathymetry line (Figure 24) while manta rays were more broadly and sparsely distributed (Figure 25).

Table 6. Numbers of turtles, manta rays and whalesharks sighted per flight.

Flight Date	Turtle spp.	Manta Ray	Whaleshark
17/05/09	53	2	1
31/05/09	101	0	0
12/06/09	32	4	0
26/06/09	122	12	0
11/07/09	14	1	0
23/07/09	100	3	0
TOTAL	**422**	**22**	**1**

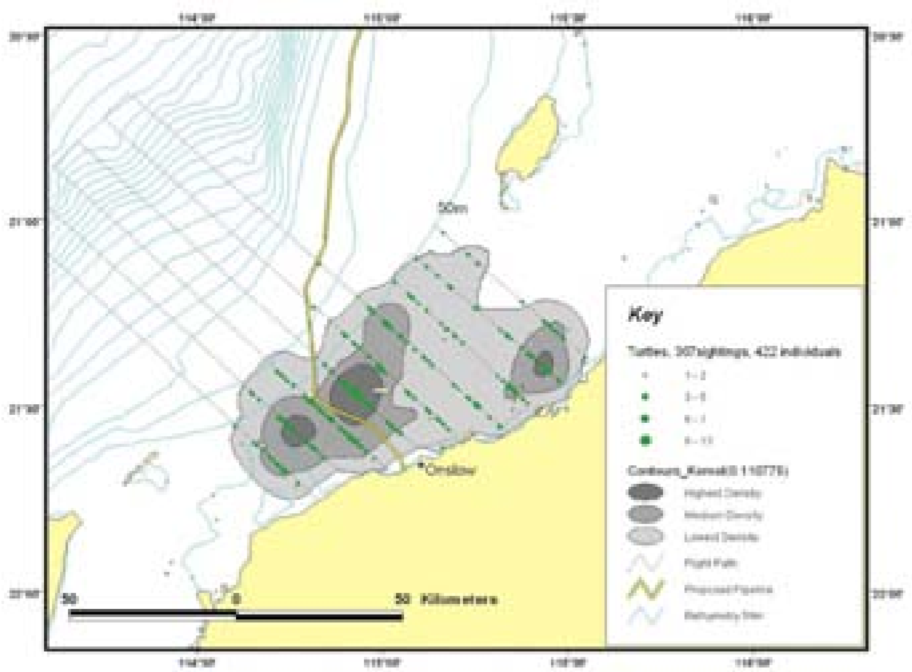

Figure 24. Distribution and relative abundance of turtle species sighted during the May 17 to July 23, 2009, period.

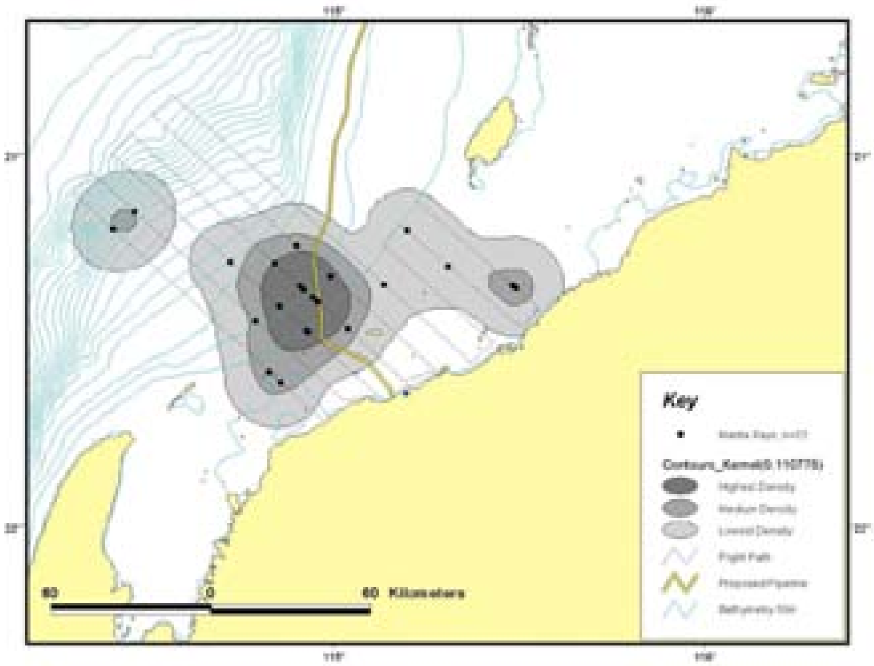

Figure 25. Distribution and relative abundance of manta rays sighted during the May 17 to July 23, 2009, period.

5.4.5 Vessels

A total of 285 vessels and other man-made structures (drill rigs, storage platforms, ships, small vessels, aqua-culture, etc.) were sighted during the mid May to late July period (Table 7). Although "home range" calculations for vessels are not biologically meaningful, the application of consistent density distribution mapping techniques to demonstrate high usage areas justifies its use here. The majority of vessels were sighted in water depths less than 50m and focussed around the Thevenard Island area where a large number of oil and gas production and storage facilities are located (Figure 26). Of note was a seismic survey that was ongoing from mid-June until late July.

Table 7. Numbers of vessels and man-made structures sighted per flight.

Flight Date	Vessels
17/05/09	51
31/05/09	43
12/06/09	37
26/06/09	49
11/07/09	49
23/07/09	56
TOTAL	**285**

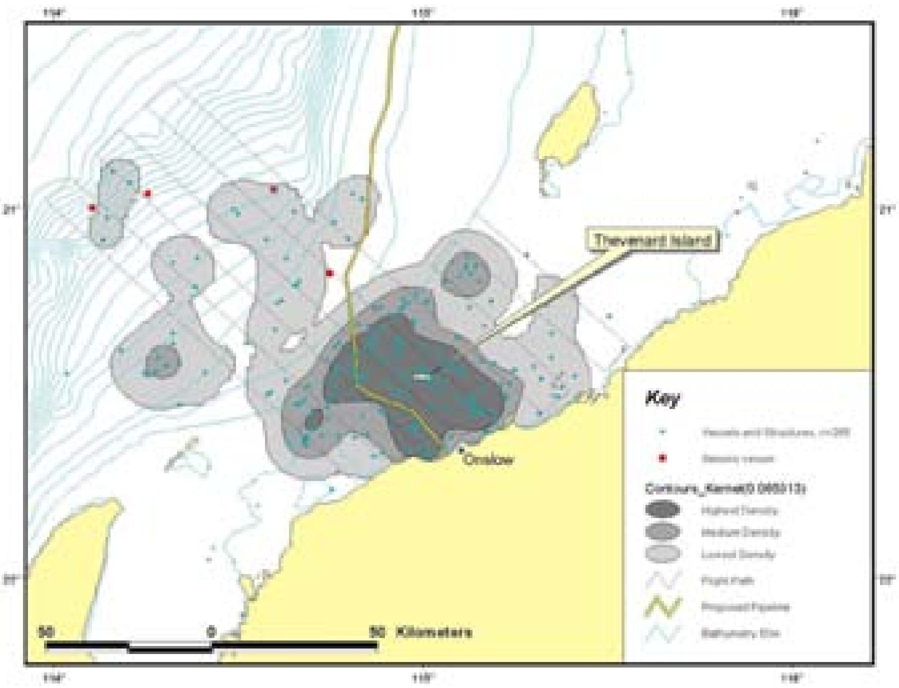

Figure 26. Distribution and relative abundance of vessels and man-made structures during the May 17 to July 23, 2009, period.

6. Discussion

This report summarises a study program carried out in the austral winter of 2009, in the off-shore southwest Pilbara region using aerial surveys at approximately 14 day intervals and acoustic surveys (McCauley and Kent, 2009) from bottom mounted sea noise loggers. The results presented in this document and McCauley and Kent (2009) are preliminary and represent the first quarter of a one year study period. Temporal and spatial pattern analysis for both survey types will benefit from comparisons of the complete 12 month dataset, however some useful comments can be made regarding the data collected thus far.

Detection of cetacean species using a combination of acoustic and aerial survey techniques has resulted in a reduction of knowledge gaps that typically arise using just one or the other technique. Aerial surveys alone generally suffer from lack of temporal detail and are unable to sample at night, while acoustic surveys generally suffer from lack of spatial (in shallow water) and species (for none vocalising species) detail. Here we discuss the survey area during the May to August period with the benefit of both datasets which substantially mitigate the short fallings of each other.

A total of six cetacean species were identified from the study area over the three month study period, five by the aerial surveys and four by the acoustic surveys. Importantly, from a management perspective, pygmy blue whales and Brydes' whales, which were not sighted in the aerial surveys, were detected in the acoustic surveys. It is useful confirmation to have positive identification of

Brydes' whales from the acoustic dataset as an "unidentified cetacean" sighting on July 11 during the aerial survey was reported as either "minke or Brydes", making the classification of Brydes' more plausible. Both species are tropical baleen whale species that do not migrate to polar waters and have been identified in previous surveys in the area (Jenner and Jenner, 2005 and CWR unpubl. data). Conversely, sperm whales and pilot whales were sighted in the aerial surveys but not detected in the acoustic surveys, either due to proximity or because the loggers are designed to receive predominantly low frequency sounds (higher frequency sounds such as those made by toothed whales do not propagate long distances).

Both the acoustic surveys and the aerial surveys detected at least one (but possibly three) seismic operations over the three month period. Seismic survey noise dominated the offshore acoustic dataset making species detection and identification more difficult. Previous studies have shown behavioural reactions of individual baleen whales to seismic survey (air gun) sounds (summarised in Richardson *et al.* 1995 and McCauley *et al.*, 2003) however there is no information available regarding the impacts of seismic surveys on migratory herds of these animals.

During the current aerial surveys, 22% and 48% of sightings in July were reported to be resting and without migratory direction (milling), while only 28% to 9% were migrating northwards as expected. This is an unexpected high proportion of resting and milling whales during the July time period. CWR aerial survey data from2000 to 2005 from the NW Cape area (immediately to the southwest of the study site) indicate that 80 to 100% of sightings are typically northbound at this time of year (Jenner *et al.*, in prep). Furthermore, swim speeds are expected to be relatively high (5.1 to 7.9 km/hr for June/July, versus 4.1 to 4.5km/hr in Aug/Sept/Oct, Jenner *et al.*, in prep) at this time of year. Hence few whales are expected to be resting at this time of the year as has been observed.

Possible causes for this change in migratory behaviour during the 2009 season are currently being investigated and will include environmental and anthropogenic possibilities. Initial investigation of the acoustic dataset indicate that at the shelf edge air gun signals were clear and at the 100-200m bathymetry contours where the majority of humpback whale pods were sighted, air gun signals would have been audible. Near the inshore logger positions (45 m and 10 m depth) there were no air gun signals detected. However, slightly stronger wind conditions on July 11. 2009, may have contributed to the higher number of "unknown" migratory direction pods reported (50% of sightings) and therefore contributed to the lower sightings of northbound humpback whales. Further investigation shows that approximately 65% (15 of 23) of pods sighted and reported with unknown swim direction were breaching or exhibiting other splash behaviours, an association (wind and splashing behaviours) supported by Dunlop *et al.*(2008), while only a small number of pods (8 of 23) were sighted for too short a time to determine swim direction, indicating that perhaps sea conditions were not the most important factor in the reported swim directions. Also of interest is what appears to be comparatively low numbers of acoustic detections of pygmy blue and dwarf minke whales compared with a similar data set collected in 2006 (McCauley and Kent, 2009).

Other aspects of the humpback whale migration appear more similar to anticipated patterns such as the steady increase in numbers (density) per flight from June onwards, and the general spatial distribution of the migratory herd (Figure 27, see also Figure 2 for comparison). In a previous CWR survey (2004/2005) in which the entire Exmouth Gulf area was surveyed at three week intervals over 12 months, no humpback whales were sighted inside the Gulf during the June/July period (Jenner and Jenner, 2005). It was suggested by Jenner and Jenner (2005) that this was largely due to cooler water temperatures in the near shore waters at this time of year.

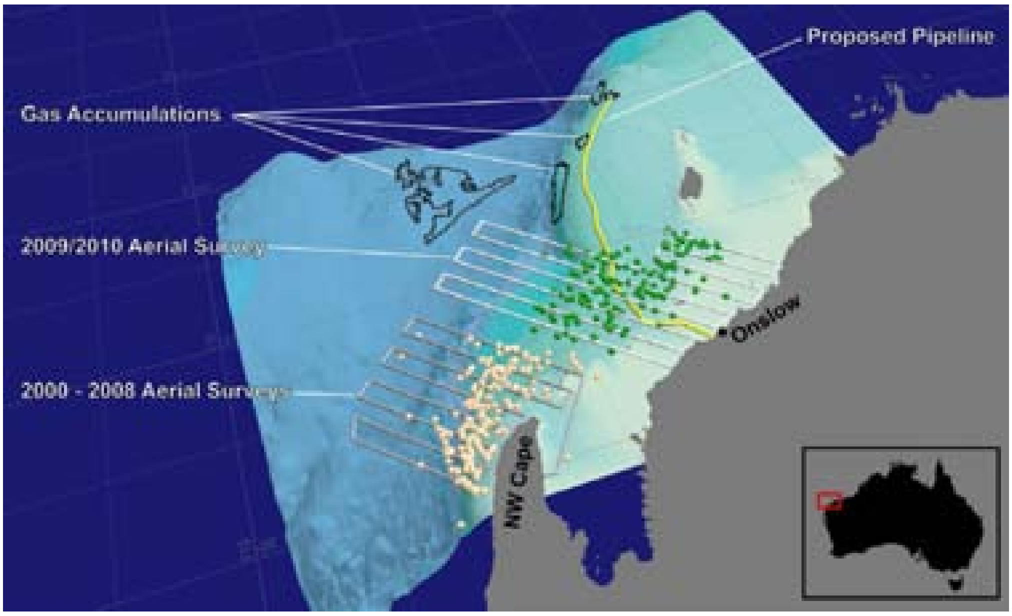

Figure 27. The 2009 humpback whale dataset (green) compared to the 2006 northern migration near NW Cape (CWR, unpubl. data).

Similarly, during the 2009 surveys, the near shore waters were significantly cooler than the off-shore waters (Figure 28) and a similar paucity of whales in this region was reported in this study.

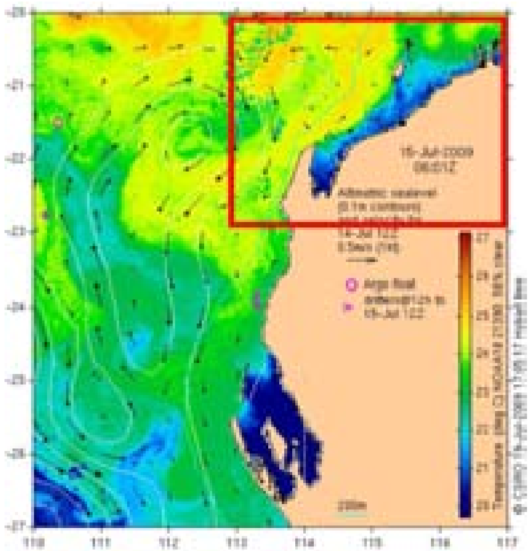

Figure 28. Sea surface temperature map from July 15, 2009, showing the cools near shore waters extending from Exmouth Gulf, northeast along the SW Pilbara Off-shore region (red box).

The inshore legs of the aerial survey area (within the 50m bathymetry) had the highest densities of dugongs, dolphins, turtles and vessels. Dugong and dolphin densities were highest near the Exmouth Gulf side of the sample area, suggesting a link to known populations, and possibly food sources, in that area (Jenner and Jenner, 2005). Variation in numbers of dugongs, manta rays, dolphins and turtles and less visible species is likely attributable to weather conditions (see Appendix 2). As such sightings of other mega fauna reported here are of limited use in determining actual densities of these species and should rather be used to infer presence (not absence, nor density) during a particular temporal period. However it is interesting to note that at this stage of the study program, there were no high density contours for any mega fauna species that overlapped the onshore position of the proposed Wheatstone pipeline.

The area inshore of the 50m contour, in the vicinity of the proposed pipeline, is already a relatively high density vessel traffic area. Monitoring increases in vessel traffic and the resulting effects on mega fauna distribution will be an important component of ongoing development and production in theregion.

7. Conclusions

- Humpback whales are present in the study area in increasing numbers from early to mid-June onwards.
- Spatial distribution of humpback whales is clustered indicating a likely northern migratory corridor between 34 and 70 km off-shore.
- Near shore waters have lower densities of humpback whales than off-shore waters (deeper than 50m) in June and July perhaps due to annual water temperature profiles.
- Pygmy blue whales and dwarf minke whales are present in deeper waters of the off-shore study area from mid May onwards, although in the 2009 season apparently in lesser numbers (based on call rates) than in previous seasons (McCauley and Kent, 2009).
- Brydes' whales, sperm whales and pilot whales are present in the study area in deeper water areas at as yet undetermined frequencies and densities.
- Dugongs, dolphins and turtles are found predominantly inside the 50m depth contour with detection rates likely linked to sea state (and other visibility conditions).
- Manta rays are found predominantly in depths of 50-150m and sightings rates are also likely linked to sea state conditions.
- No mega fauna species have high densities in the immediate area near the proposed Wheatstone pipeline landfall during the June to August period.

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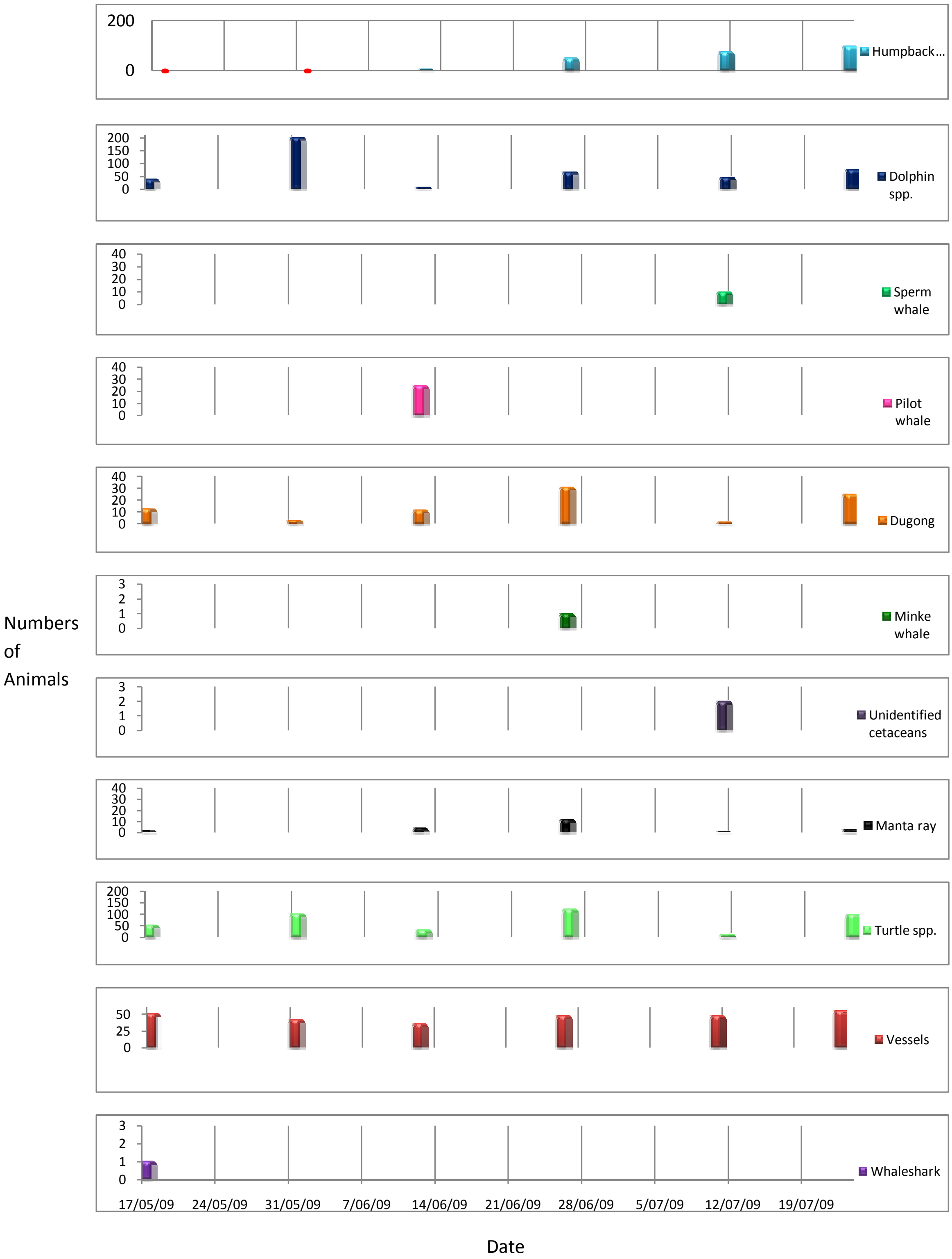
Appendix 1 – Sea State for all transects during each flight – darker shades indicate stronger wind.

Flight Date	17/05/2009	31/05/2009	12/06/2009	26/06/2009	11/07/2009	23/07/2009
TRANSECT1	3	3	4	3	3	2
TRANSECT2	3	2/ 3	3	3	3	2
TRANSECT3	3	2	3	3	4	2
TRANSECT4	3	3	3	1	3	2
TRANSECT5	2	2	2	2	3	3
TRANSECT6	2	2	3	1	3	2
TRANSECT7	2	2	3	1	3	2/ 3
TRANSECT8	2	2	2	1	2	2
TRANSECT9	2	2	2	1	3	2
Daily average	2.4	2.3	2.8	1.8	3.0	2.2

Apendix 2 – Sea State as a sighting variable. Peak values per species/object in yellow.

Flight Date	Vessels	Aquacullture Net	Sperm whale	Minke whale	Pilot whale	Unidentified cetaceans	Dolphin spp.	Dugong	Manta ray	Turtle spp.	Whaleshark	Mean Sea State
17/05/09	51	0	0	0	0	0	10 (40)	13	2	53	1	2.4
31/05/09	42	1	0	0	0	0	18 (203)	3	0	101	0	2.3
12/06/09	36	1	0	0	25	0	4 (8)	12	4	32	0	2.8
26/06/09	48	1	0	1	0	0	28 (68)	31	12	122	0	1.8
11/07/09	48	1	10	0	0	2	10 (47)	2	1	14	0	3
23/07/09	55	1	0	0	0	0	29 (79)	25	3	100	0	2.2
TOTAL	280	5	10	0	25	2	0	86	22	422	1	

Appendix 3 – Mega Fauna Counts per Survey


Numbers of Animals
Humpback...
Dolphin spp.
Sperm whale
Pilot whale
Dugong
Minke whale
Unidentified cetaceans
Manta ray
Turtle spp.
Vessels
Whaleshark
17/05/09
24/05/09
31/05/09
7/06/09
14/06/09
21/06/09
28/06/09
5/07/09
12/07/09
19/07/09
Date

Appendix 04

A Description of Mega Fauna Distribution and Abundance in the SW Pilbara Using Aerial Surveys - Mid-Study Report December 2009

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A Description of Megafauna Distribution and Abundance in the SW Pilbara Using Aerial and Acoustic Surveys - Mid-Study December 2009

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1. Abstract

A series of aerial and acoustic surveys have been initiated near to the proposed Wheatstone trunkline in order to determine megafauna distribution and abundance in this area and to relate encountered species populations to the broader regional context. A total of 1221 humpback whales were sighted in 17 aerial surveys over the South West Pilbara offshore region during May to December 2009. Nearshore waters (5-50m depths) have lower densities of humpback whales than offshore waters (50-950m depths) perhaps due to annual water temperature profiles. Sperm whales and pilot whales were also sighted during the aerial surveys. Acoustic surveys conducted over the same time period identified the presence of humpback whales, pygmy blue whales, Brydes' whales and dwarf minke whales in the study area. Pygmy blue whales and dwarf minke whales are present in deeper waters of the offshore study area from mid May onwards, although in the 2009 season apparently in lesser numbers (based on call rates) than in previous seasons. Nearshore legs of the aerial surveys (depths less than 50m) reported regular sightings of dugongs, dolphins, manta rays and turtles throughout the period of the survey. No high-density concentrations of megafauna have been identified during the May to December time period near the Ashburton North Strategic Industrial Area, where an onshore LNG Plant and Product Loading Facility (PLF) are proposed to be developed.

2. Scope of Work

The primary purpose of this study is to determine the seasonal distribution and relative abundance of great whales and other megafauna along the Southwestern Pilbara coast, and offshore over the proposed Wheatstone subsea trunkline route, during a twelve-month period. The Centre for Whale Research (CWR) and Curtin University were commissioned by URS Pty. Ltd. in April 2009 to design, conduct and analyse a series of aerial and acoustic surveys that would best compliment existing datasets and fill knowledge gaps in great whale and other megafauna distribution and abundance along the nearshore and offshore South West Pilbara coastline and in particular near to Chevron's proposed trunkline. The new aerial survey program was to be consistent with existing CWR survey data collected near NW Cape between 2000 and 2008 (Figure 1).

The combination of aerial and passive acoustic surveys were considered the most effective means of detecting spatial and temporal species clusters in the time window assigned, and which could be used for preliminary environmental assessment for the Project. Using a combination of acoustic and aerial survey techniques results in a reduction of knowledge gaps that typically arise using just one or the other technique. Aerial surveys alone generally suffer from lack of temporal detail and are unable to sample at night, while acoustic surveys generally suffer from lack of spatial (in shallow water) and species (for non-vocalising species) detail. Documenting the existing levels of vessel activity and coastal infrastructure was also considered to be an important part of baseline data collection so that "before and after" style analyses of megafauna patterns accurately reflects change.

This report is an initial examination of the data collected between May and December 2009, and will be followed by a final report which includes analyses of the complete twelve-month aerial and acoustic datasets.

Aerial surveys were to be conducted in two phases such that a preliminary analysis of a three-month (approx.) subset of the data could be used to inform an environmental approvals process for the Project. A second interim report (this document) was requested to be delivered in January 2010 that included all flights in 2009 and presumably the complete humpback whale migratory cycle. A final report to be presented in mid 2010 will document the complete twelve-month monitoring program (total 26 aerial surveys) and provide contextual interpretation of the results for future management purposes.

This report focuses on the first 3 months of acoustic and 8 months of aerial survey data. Acoustic surveys began in mid-April, 2009 and spanned 78 days at an offshore site and 94 days at a nearshore site. Aerial surveys consisted of 17 flights beginning in mid-May and extending through to 24 December 2009. This report should be considered preliminary as the data collection period spanned only part of a season for some species discussed below, and data analysis was not completed for all species acoustically detected due to limited analysis time from the time of the logger recovery. Acoustic data sets are large and time consuming to analyse and validate and a comprehensive assessment is planned for the final report.

3. Background - Humpback whales at Exmouth Gulf and North West Cape

Humpback whales are expected to be the most frequently encountered protected species in this study area. As such, this species receives much attention in this report. Furthermore, there is a relatively large wealth of knowledge on humpback whale ecology and behaviour. CWR has been conducting independent studies into the population dynamics and migratory habits of humpback whales in Western Australia since 1990. Through this work, CWR has confirmed Chittleborough's (1953) theory that Exmouth Gulf, immediately to the southwest of the study area, is a nursery area for humpback whales (Jenner *et. al.* 2001). Hence, a variety of boat and aerial-based survey studies have been conducted in Exmouth Gulf since 1995.

Chittleborough (1953) first described Exmouth Gulf as a possible "nursery" for humpback whales based on aerial surveys over the area in 1951 and 1952. These flights were a regular part of an exploratory process designed to maximise returns for the commercial whaling industry. A whaling station operated at Norwegian Bay near Pt. Cloates (Lat S 22• •36') from 1912 to 1916 and then from 1922 – 1928, and finally from 1949-1955. By 1963, when a moratorium on humpback whaling was passed, there was thought to be less than 800 whales left in Breeding Population "D", or Western Australian population (Chittleborough, 1965).

Now, over forty years since the cessation of whaling, this population of whales is thought to have been recovering at an annual rate of between 7 and 12% (Bannister and Hedley, 2001). By extrapolating this recovery rate forward to 2010, the population could reach 20 - 30,000 individuals. If, as suggested, approximately 10% of this population is represented by cow/calf pairs (Bannister and Hedley, 2001), then as many as 3,000 pairs could use nursing areas like Exmouth Gulf by 2010. How this population increase is progressing and how it relates to the use and significance of areas adjacent to nursing or resting areas (such as the location of the proposed Wheatstone Project just north of Exmouth Gulf) is of great interest to managers.

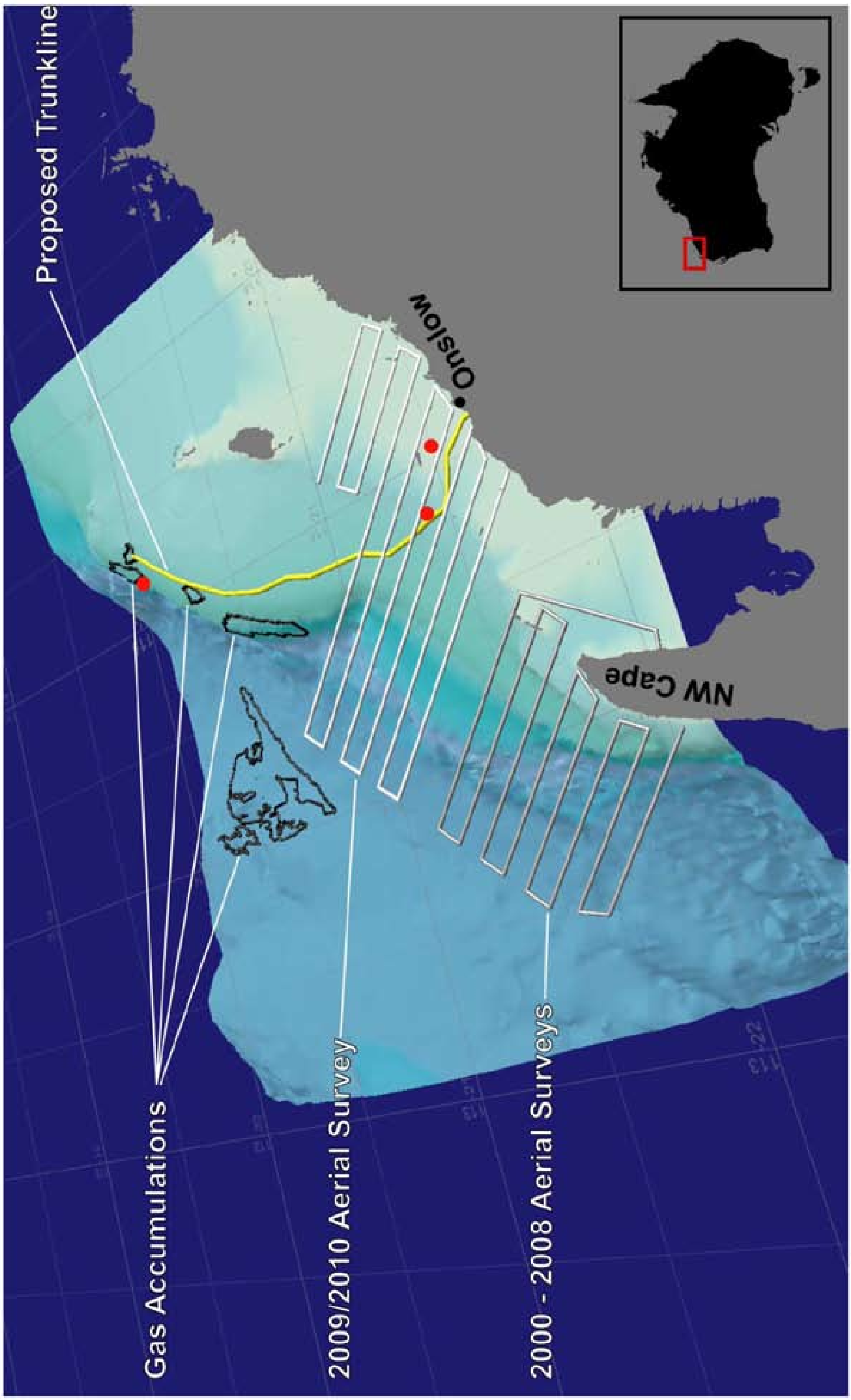

Figure 1. Aerial survey flight paths for the 2009/2010 study period showing proximity to the 2000 – 2008 CWR aerial survey flight path near North West Cape and 2009 acoustic logger positions (red dots). Continental Slope and Continental Shelf depth contours (>500m) are shades of green.

The migration of humpback whales both north and south past Exmouth Gulf follows a predictable but complicated progression of age and sex classes north and south along the coast each season. The northern migration of this species near Albany, Western Australia, has been described by Chittleborough (1965) as being segregated by age and sex class. It is likely that this same pattern where subadults and mature females terminating lactation are in the vanguard of the northern migration, followed by mature males and females and then later pregnant females (carrying near term foetuses), is present off North West Cape and the broader South West Pilbara offshore region.

The southern migration follows a similar order, with cows with their newly born calves appearing at the tail end of the migration. It is the cow/calf portion of the migration that congregate in greatest numbers inside Exmouth Gulf and that may have an overlap of spatial /temporal distribution in nearshore portions of the study area.

Spatially, the northern migratory path appears to be consistent in its location (CWR unpubl. data) for all age and sex classes off North West Cape, and centres on between the 150m and 350 lines (Figure 2). Whales rarely enter Exmouth Gulf during the northern migration (June to early August), perhaps due to the 3•€ or more temperature difference between the open ocean and the shallow Gulf during June to early August. A transition phase between the northern and southern migrations occurs from early August to early September (Figure 3). This time period is consistent with peak numbers of whales each season (Figure 5) and results in the migratory path spreading to include a much wider depth range than is observed during the northern or southern migration. Sightings of whales inside the warmer northern part of the Gulf increase during early September and by mid-late September the main southbound migratory peak passes west of North West Cape with some animals entering the Gulf (Figure 4).

It is likely that water temperature plays a role in determining when whales, particularly cow/calf pairs trying to minimise metabolic expenditures, enter Exmouth Gulf. Cow/calf numbers inside the Gulf peak during the first 2 weeks of October, at a similar time annually as the sea surface temperature inside the Gulf becomes equal to that found offshore at the same latitude (Figures 6 & 7).

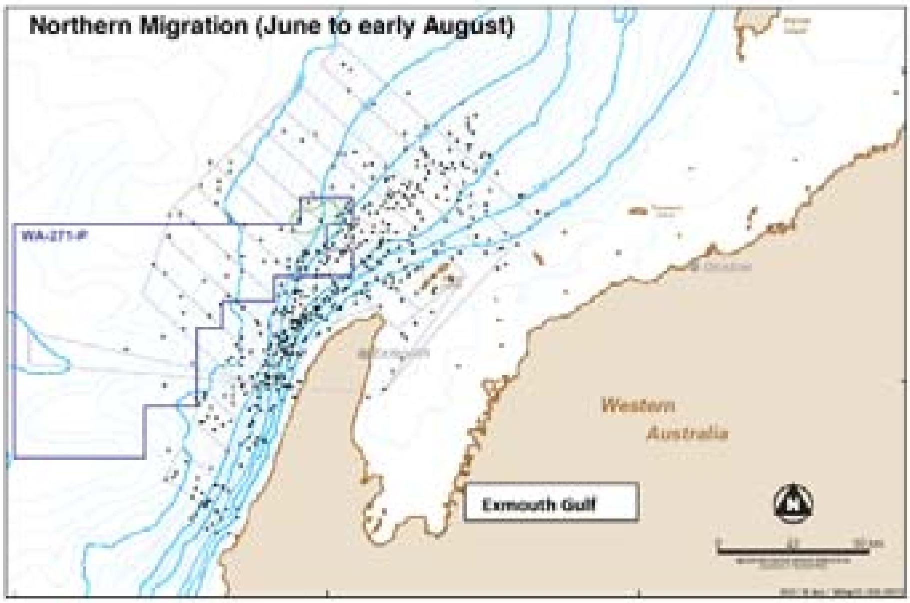

Figure 2. Aerial survey sightings of humpback whales during the northern migratory period (June to early August) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

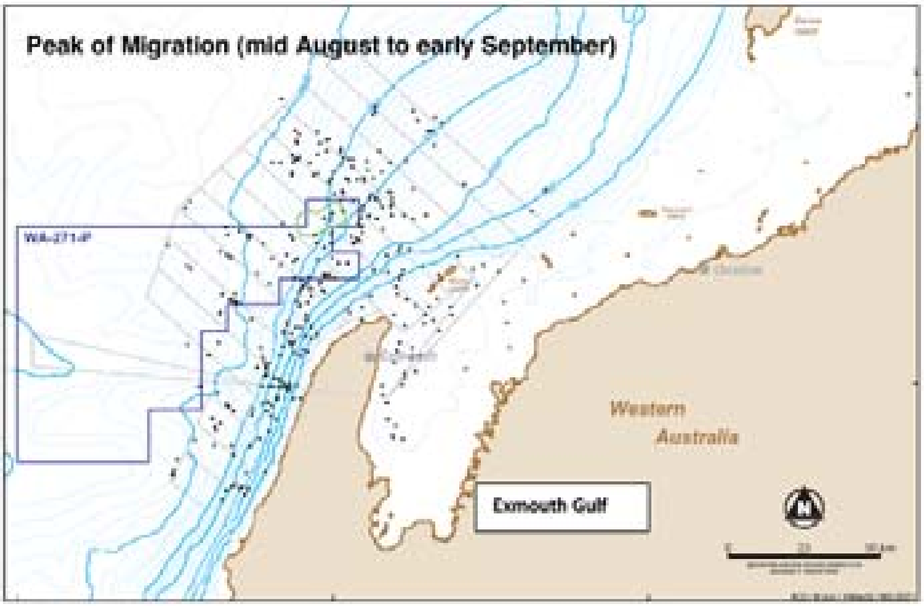

Figure 3. Aerial survey sightings of humpback whales during the Transition Phase (mid Audust to early September) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

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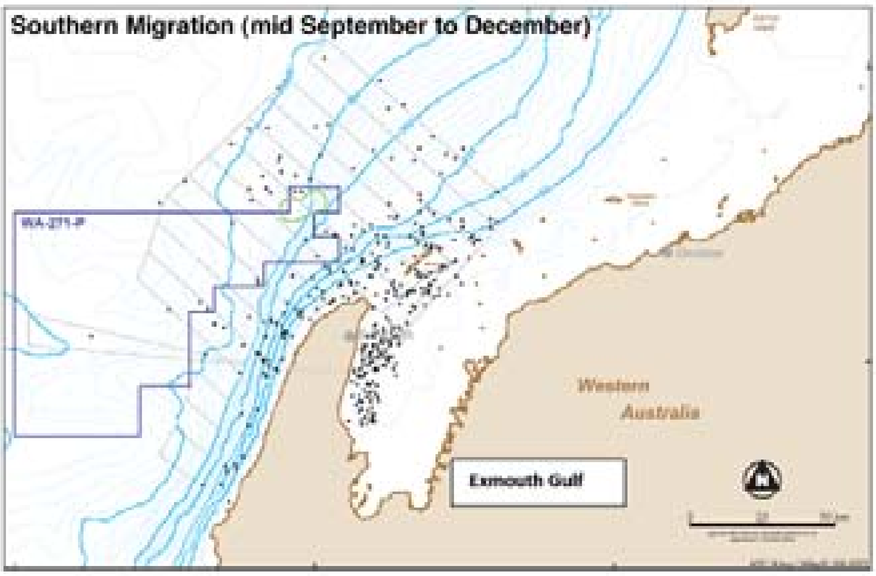

Figure 4. Aerial survey sightings of humpback whales during the southern migratory period (mid September to December) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

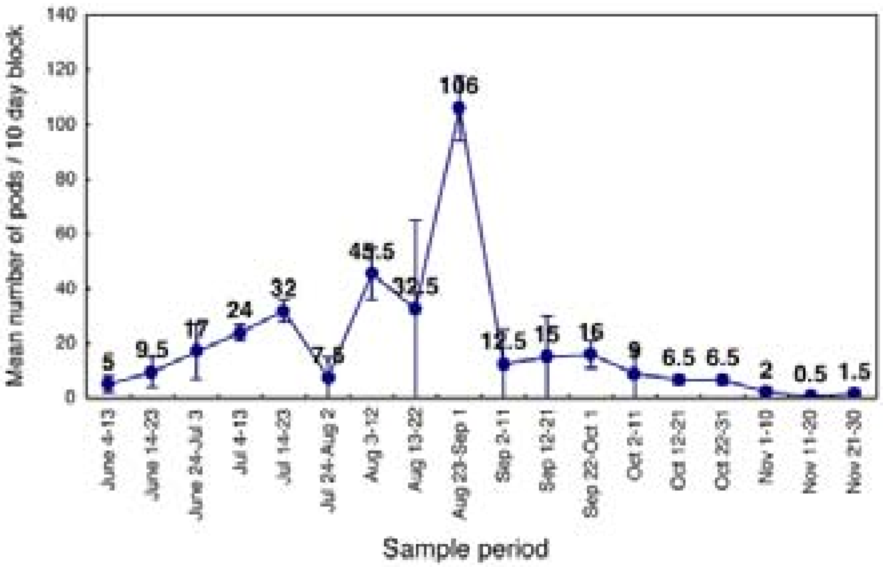

Figure 5. Mean number of humpback whale pods recorded during aerial surveys in 10-day sample blocks during the months of June to October during 2000 and 2001 ($\bar{x}$ ± 1 SE). Data from CWR aerial surveys west of, and not including, Exmouth Gulf for Woodside Energy 2000/2001, EIS document.

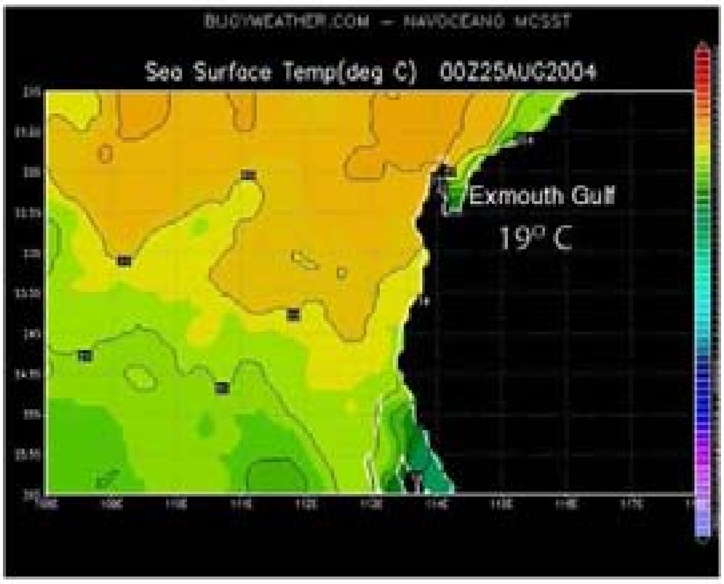

Figure 6. Sea surface temperature map for late August 2004 showing the cooler water inside Exmouth Gulf and the nearshore South West Pilbara region.

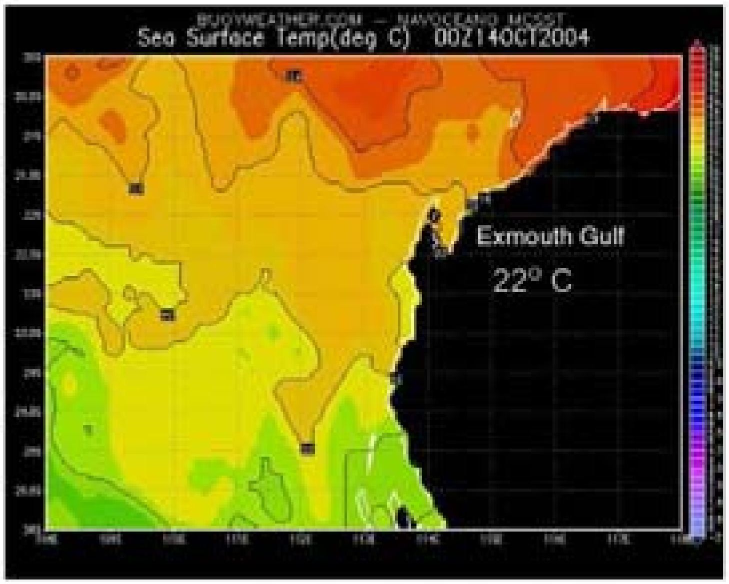

Figure 7. Sea surface temperature map for mid-October 2004 showing the increase in temperature inside Exmouth Gulf.

4. Methods

4.1 Acoustic Surveys

A series of five sea noise loggers were deployed near shore west of Onslow over April to July 2009, and three in a 2 km triangle on the shelf break north of the Monte Bello Islands over May to July 2009 (offshore site) (see Figure 1). Near shore logger depths ranged from 10m to 43m while offshore logger depths were 200 to 225m. The offshore logger positions were within 20km of a similar system deployed by the author (McCauley) in 2006. Details of the passive acoustic survey methodology are presented in a separate report (McCauley and Kent, 2009).

4.2 Aerial Surveys

4.2.1 Design

The offshore area between Exmouth Gulf and Barrow Island was systematically examined using aerial surveys for megafauna from mid-May to late-December. Transects were designed to be consistent, comparable and a logical extension to transects described in Jenner and Jenner (2008). The transects covered an area which included the main humpback whale migratory body (Jenner *et al.*, 2001). A total of seventeen samples of all transects were collected at 14 day intervals with the precise dates within these time blocks (intervals) dependant on “good” weather conditions (winds less than 18 knots) for detecting humpback whales (the primary target species). It is recognised that these conditions may not be optimal for spotting other smaller species however this study program is focused particularly at great whales. Designing surveys which are ideal for smaller species sightings

The design of the survey followed protocols defined in the Distance ver. 5.1 software program (Buckland *et al.*, 2001, Buckland *et al.*, 2004). This program specifically allows users to design line transect surveys and analyse data resulting from these surveys for the purpose of estimating density and abundance. Using the principles of this system, transects were drawn over the study area in order to maximise coverage probability during a single flight. Although parallel line transect designs are disadvantaged because the time spent in between transects is “off survey”, this technique results in a more even probability of coverage for non-rectangular survey areas such as the current study site (Buckland *et al.*, 2001). Furthermore, this system is consistent with previous CWR aerial surveys from both offshore near North West Cape (20 km southwest of the study area) and Exmouth Gulf (40 km southwest of the study area) (Figure 1).

The timing of the first six surveys was planned to coincide with the bulk of the northern migration of humpback whales through this region (see Figure 8 for the trend in humpback swim direction).

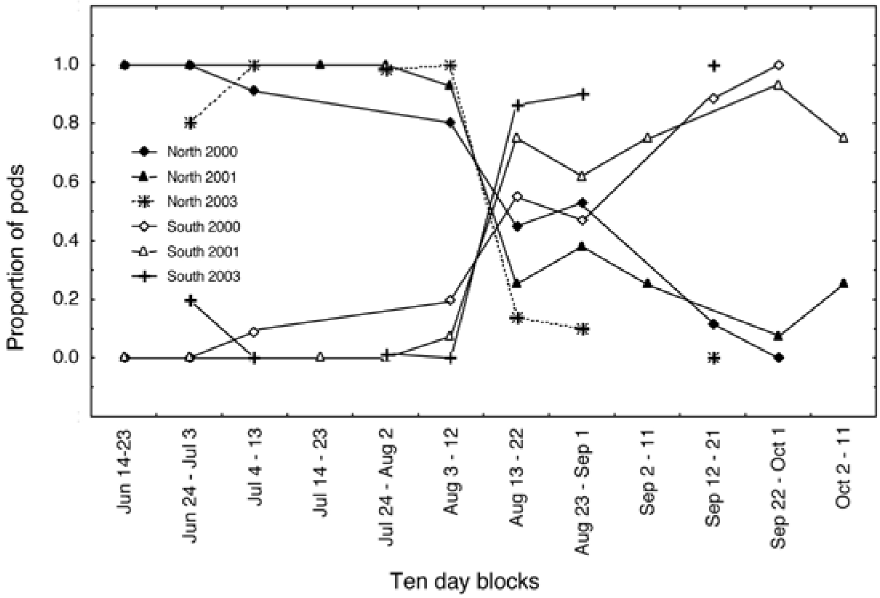

Figure 8. Migratory direction of humpback whale pods recorded during aerial surveys at North West Cape, showing June and July as a northern migration period (from Jenner *et al.*, in prep.). Non-migrating whales (i.e. resting or milling) are not plotted.

4.2.2 Methodology

Aerial surveys were conducted at an altitude of 305 m (1000 ft) and a speed of 222 km/hr (120 knots) using a twin-engine, over-head wing aircraft (Cessna 337). The plane followed line transects which were surveyed in passing mode (e.g. the plane did not deviate from the flight path). Surveys were only initiated in wind speed less than 33 km h^{-1} (18 knots or Beaufort Sea State lees than 5, see Appendix 1), which has been shown to be adequate for spotting whales (Jenner *et al.* in prep). Each flight was of approximately 5.5 to 6 hours duration and take-off times varied between 8:40 and 10:55 so that the mid-day period was consistently sampled and glare would be a consistent factor for all flights. Flights during the expected northern migration period where flown from north to south to minimize the possibility of double counting pods of whales on successive transects. Similarly, the flights during the southern migratory period will be flown from south to north.

Personnel for each of the seventeen surveys included four people; two pilots and two observers. The observer team consisted of 4 trained personnel. One person (Lyn Irvine) flew all sixteen flights, one person (Jane Kennedy) flew eleven flights, one person (Jennifer Thompson) flew 4 flights and one person (Emily Wilson) flew three flights. The pilots were not responsible for spotting, and were separated acoustically from the two observers. The pilots were responsible for recording the planes' angle of drift on each transect, so that angles reported from the compass boards could be corrected relative to the flight path. The observers were linked via a separate intercom system which was logged to a Sony Mini Disk Recorder NH900 and allowed the observers to search continuously and voice record all sightings to a time code which was synchronized to the Global Positioning System (GPS) before each flight. A Garmin III Pilot aeronautical GPS was used to log sightings (as waypoints) and coordinates of the flight path, including altitude, for every second of the flight.

Observers sighted and recorded positions of whales by measured vertical and horizontal angles from the aircraft to the whales (using Suunto PM-5/360PC clinometers, and a compass board). The location (latitude and longitude) of each sighted whale was later plotted by projecting a new GPS waypoint from the waypoint recorded at the time of sighting (using Oziexplorer ver. 3.95 GPS software) from the calculated angle and distance of the aircraft to the whale. The angle was calculated with the following formulae: Angle to starboard = $AC + (MHA + DA)$, and Angle to port = $AC + (MHA - DA)$, where AC was the aircraft course, MHA was the measured horizontal angle and DA was the angle of drift of the aircraft. Distances were calculated using formulae in Lerczak and Hobbs (1998).

No vertical or horizontal angles were recorded for any other species (i.e. dolphins, dugongs, rays sharks or turtles) and it was assumed for plotting purposes that sighting positions were the same as the waypoint marked (i.e. directly under the plane). However vertical and horizontal angles were measured for vessels and other man-made objects, and, where possible, direction of travel was also recorded.

The sighting information that was recorded for whales included the direction of migration (north, south, resting/milling, or undetermined) of each pod observed. Northbound pods were those sighted steadily swimming parallel to the coast in a northerly direction. Likewise, southbound whales were those sighted swimming parallel to the coast in a southerly direction. Pods reported as "milling" were swimming perpendicular to the coast (not northbound or southbound) or surface lying at the time of sighting with no obvious signs of swimming (i.e. resting whales). Pods recorded as "undetermined" were sighted too far from the aircraft, or for too short a time period, to assess swim direction.

The level and direction of glare (scale 1-3) for each observer was recorded for each transect as well as environmental variables such as Beaufort sea-state (scale 0 -12), associated wind speed (estimated in knots) and direction (from wave patterns), cloud cover below 1000 feet (percentage) and overall visibility (scale 1-3).

4.2.3 Analysis

The GIS program Arcview 3.2, with extensions Spatial Analyst and Animal Movement (Hooge and Eichenlaub, 1997), was used to analyze the distribution of cetaceans and all other encountered wildlife. Complete spatial randomness (CSR) of cetacean sightings was tested to determine if sightings data were spatially structured (i.e. whether sightings were clustered, random or uniformly distributed) within the flight path study area. Other smaller species (dugongs, dolphins, turtles etc.) were not tested for CSR since they could not be reliably sighted away from the track line. Nearest neighbor routines were run in Arcview to test for CSR and a Kernel "home range" estimator was used to compute locations of clusters (indicating higher relative densities and possible a migratory corridor or resting area) for cetaceans within the study area. Apparent clustering of humpback whales around the track line has been assumed, for the purposes of this report, to have minimal effect on the results given an effective half strip width of 5 km (Bannister and Hedley, 2001).

The mean distance of whale pods on each flight from the nearest section of coastline was measured using a GIS "Spider Distance" tool to establish spatial and temporal patterns in clustered data. Probability contour maps were generated for each flight that display relative density contours on the day of the survey and across all surveys reporting humpback whales.

A smoothing factor ("*h*" statistic) controls the size of the home range reported and has been shown to be inconsistent for different sample sizes (Hooge and Eichenlaub, 1997). For this reason a second technique, the minimum convex polygon (MCP) method was used to first confirm sightings range extent. The MCP was considered to be the minimum extent of the sightings range and the smoothing factor was adjusted until the area of an unbroken 95% kernel contour for the entire dataset completely included the area of the MCP. This provides an objective method for selecting the smoothing factor (Hooge and Eichenlaub, 1997) and creates a baseline for relative density comparisons between flights.

The "*h*" statistic was used to calculate 50%, 75% and 95% probability density contours for each flight day where the 50% contour represents the highest density of whale pods (not whales) and the 95% contour represents the likely extent of all pods. However, at this stage of analysis where only part of the migratory season is available for calculations, the "*h*" statistic is preliminary and will need to be recalculated based on maximum density in the entire study area over the entire study period.

5. Results

5.1 General Description – Acoustic Loggers

A general description of preliminary results from the passive acoustic surveys is presented here, however a detailed description of these results is presented in McCauley and Kent(2009). The work presented is ongoing with further data collection and analysis planned.

The noise loggers detected various whale species including: pygmy blue, dwarf minke, Brydes, and humpback whales. The recording period is currently too short to correctly delineate seasonal patterns in whale trends. The offshore noise loggers were dominated by seismic survey noise and vessel noise during the entire recording period. At times three seismic survey sources could be detected at the offshore location. These are believed to be associated with two surveys running in deep waters adjacent to the shelf to the south. Vessel noise was prominent at the offshore location, presumably from vessels involved in site works at the proposed Wheatstone and Pluto gas fields.

Pygmy blue whales were present offshore over most of the May to July period. These are believed northbound pygmy blue whales returning to low latitudes after spending summers feeding in temperate waters (Branch *et al.*, 2007). The time integrated count of individual calling pygmy blue whales from the offshore site from a nearby, but unrelated, data set made in 2006 was compared with the similar count made in 2009 over the matching time period in Julian days. Six times fewer whales passed in 2009 compared with 2006.

Dwarf minke whales were detected and counted at the offshore site. Dwarf minke whales were present persistently across the April to July period with a slight tendency for more whales in June-July. The time integrated counts of individual calling dwarf minke whales in 2009 were compared with the same calculation for the nearby site made in 2006 and seven times fewer dwarf minke whale detections were made in 2009(McCauley, unpubl. data). It is currently not clear why counts of pygmy blue and dwarf minke whales are lower in 2009 than in 2006 at the offshore site.

Brydes whales were detected on one day only in April at a site in 43 m of water west of Onslow.

Humpback whales were present at the 43 m depth nearshore site and at the offshore site but the counts have not yet been analysed for trends or timing.

Regular evening fish choruses were heard at the 43 m depth nearshore site (expected regular demersal species) but not at a 10 m depth site. Expected fish choruses from the offshore site (i.e. globally dispersed deep water myctophid species) were not detected.

5.2 General Description – Aerial Surveys

A total of seventeen flights at approximately two week intervals from 17 May 2009, to 24 December 2009, totalling 119.2 survey hours over the south western Pilbara offshore region resulted in 4491 megafauna sightings and 554 vessel/manmade object sightings (Table 1). A total of five species of great whale (humpback, blue, killer, minke and sperm whales) were sighted. Humpback whales were the most commonly sighted large cetaceans while small cetacean sightings of pilot whales and dolphin species were also reported.

Table 1. Megafauna and vessel sightings during the first seventeen flights of a 26 flight series

SIGHTING	1 - May 17, 2009	2- May 31, 2009	3- Jun 12, 2009	4- Jun 26, 2009	5 - Jul 11, 2009	6 - Jul 23, 2009	7 – Aug 5, 2009	8 - Aug 20, 2009	9 - Sep 3, 2009	10 - Sep 17, 2009	11 - Oct 2, 2009	12 - Oct 15, 2009	13 - Nov 2, 2009	14 - Nov 12, 2009	15 - Nov 28, 2009	16 - Dec 13, 2009	17 - Dec 24, 2009	TOTAL
Humpback whale	0	0	6	50	75	97	169	231	145	218	119	87	16	4	2	0	2	1221
Blue whale	0	0	0	0	0	0	0	0	0	0	0	0	2	0	6	3	0	11
Killer whale	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	5
Minke whale	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
Pilot whale	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
Sperm whale	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	10
Other whales (unidentified)	0	0	0	0	2	0	2	0	0	2	0	0	0	5	1	1	0	13
Dolphin spp.	40	203	8	68	47	78	71	31	36	171	84	99	7	102	150	174	0	1369
Dugong	13	3	12	31	2	25	18	13	14	6	2	2	0	2	5	0	0	148
Whale Shark	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	4
Manta ray	2	0	4	12	1	3	21	3	9	4	4	3	4	5	11	5	1	92
Turtle	53	101	32	122	14	100	261	31	159	112	14	174	61	134	140	50	33	1591
Vessel	50	46	36	50	48	55	32	27	37	22	33	15	9	16	25	20	5	526
Aquaculture Net	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	15
Krill Ball	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	2
Warning Beacon	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	5
Buoy	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	1	0	6

5.3 Humpback Whales

A total of 801 humpback whale pods containing 1221 individual whales were sighted during the mid-May to late December time period (Table 2). A total of 95 cows with calves were sighted. No humpback whales were sighted during the first two flights in May, nor on the December 13, 2009, flight.

Table 2. Humpback whale sightings series of 17 flights.

Flight Date	Number of Pods	Number of Whales	Number of Calves	Number Whales Migrating	Number Whales Resting/Milling	Number Undetermined
17/05/2009	0	0	0	0	0	0
31/05/2009	0	0	0	0	0	0
12/06/2009	4	6	0	6	0	0
26/06/2009	28	50	0	41	6	3
11/07/2009	46	75	0	23	24	28
23/07/2009	66	97	**3**	61	17	19
05/08/2009	113	169	10	87	46	36
20/08/2009	152	231	10	103	70	58
03/09/2009	100	145	10	52	79	14
17/09/2009	138	218	22	41	155	22
02/10/2009	87	119	11	35	61	23
15/10/2009	52	87	19	20	66	1
02/11/2009	11	16	6	10	5	1
12/11/2009	2	4	2	0	4	0
28/11/2009	1	2	1	2	0	0
13/12/2009	0	0	0	0	0	0
24/12/2009	1	2	1	0	2	0
TOTAL	**801**	**1221**	**95**	**481**	**535**	**205**

Humpback whale sightings increased steadily after flight 3 (June 12, 2009) and peaked during flight 8 (Figure 9).

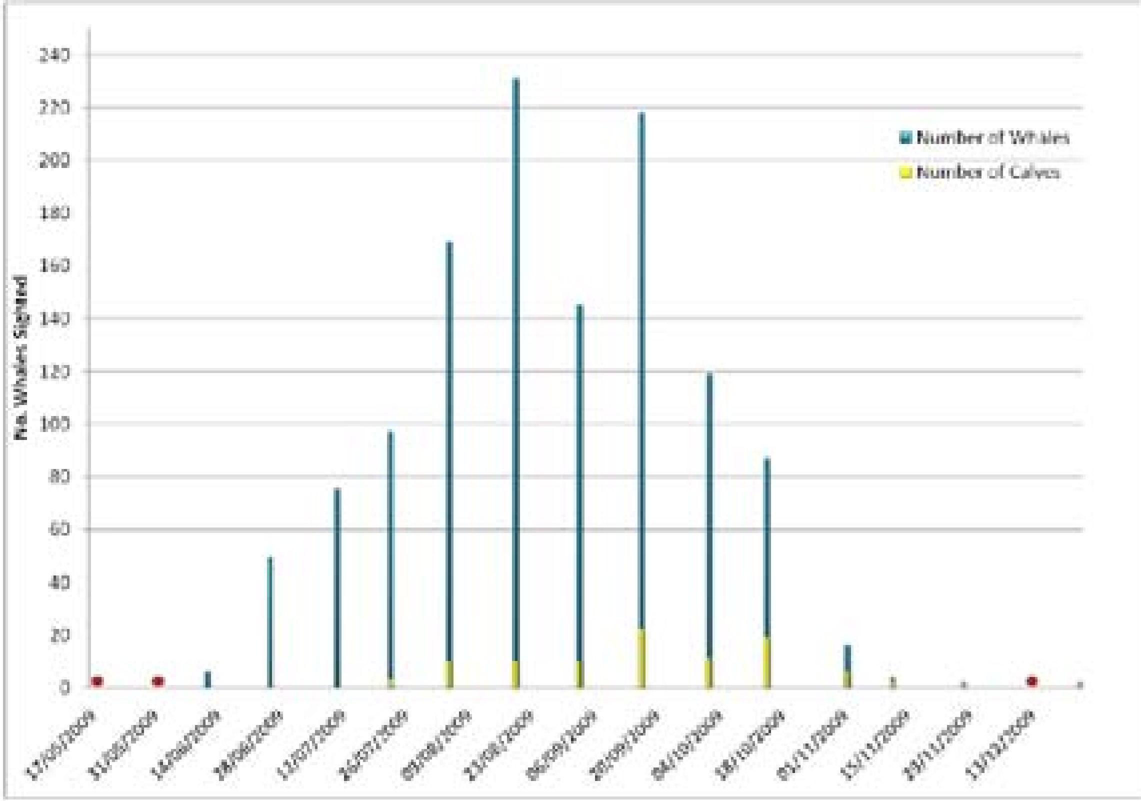

Figure 9. Numbers of humpback whales and numbers of calves sighted per flight for the first seventeen flights (red dot indicates a flight but no sightings).

As a means of initially exploring the spatial datasets, tests for Complete Spatial Randomness (CSR) of humpback whale pod distribution for each flight were conducted to test the hypothesis that distribution within the study area was random. The nearest neighbour analysis in Animal Movement (v.2.0) was used to test for CSR using a polygon encompassing the flight path area as a boundary.

Assumptions for the test are as follows:

1) If the resulting value of *R* from the nearest neighbour analysis equals 1 for an observed data set then the data is randomly distributed, since the observed distribution does not deviate from the expected random model.
2) If $R < 1$, the data is clustered where the observed mean nearest neighbour distance is less than what is expected with the random model, thereby resulting in clusters.
3) If $R > 1$, the data is uniformly distributed because the mean observed nearest neighbour distance is greater on average than the expected.

Complete Spatial Randomness analysis using the nearest neighbour technique resulted in the data points on all flights during June 26 to November 2 being designated "clustered" (*R* values all less than 1, Table 3). There were too few sightings on June 12, November 12, November 28, December 13 and December 24 to run the test effectively.

Table 3. Values of *R* indicating clustered distribution of humpback whale pods during each flight. Meaningful values could not be calculated for flights with low sightings numbers (*) or for the 13/12/2009 flight when no whales were sighted.

Flight	"R" Value
12/06/2009	*
26/06/2009	4.73E-06
11/07/2009	5.88E-06
23/07/2009	6.70E-06
5/08/2009	7.12E-06
20/08/2009	7.11E-06
3/09/2009	7.72E-06
17/09/2009	6.56E-06
2/10/2009	8.14E-06
15/10/2009	7.60E-06
2/11/2009	8.91E-06
12/11/2009	*
28/11/2009	*
13/12/2009	-
24/12/2009	*

Having established that there is clustering of the data points, the next step in spatial analysis was to determine if there is any evidence of site fidelity among flights, bearing in mind variables such as migratory direction which may influence distribution. We assume here, and confirm below, that the majority of pods sighted in surveys in June, July and early August are likely to be part of the northern migratory phase and those sighted after later August are likely to be part of the southern migration.

The GIS tool Animal Movement 2.0 (Hooge *et al.*, 1997) was used to calculate probabilistic contours of equal utilization distributions. This is also known as a kernel home range calculator. The kernel home range is considered one of the most robust of the probabilistic techniques for spatial analysis of point data (Worton 1989). The kernel is essentially a grid of equal utilisation areas that has smoothed edges. The smoothing can be done automatically by the GIS program or adjusted manually, using an "*h*" statistic, which is fit to the dataset with a Minimum Convex Polygon (MCP). For the current dataset, points from all flights were combined to define the maximum boundary for the MCP (Figure 10). An "*h*" value of 0.056538 was selected based on the visual fit of the 95% probability contour which results in a maximum envelope around a single point equal to the half strip width of the line transects (5km).

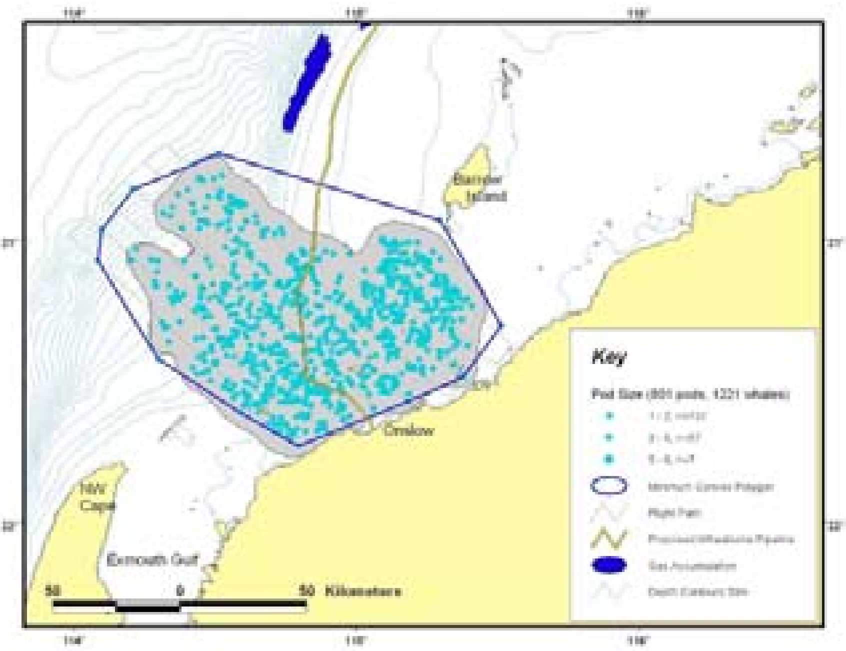

Figure 10. The Minimum Convex Polygon used to select the smoothing factor for the June to December humpback whale dataset (h=0.056538) and the resulting 95% kernel contour for all sightings. Positions of all pods (n=1221) are shown.

Maps showing ranked kernel density polygons (highest to lowest) for flights 4 to 21 (June 26 to November 2) using the same "*h*" value (0. 0.056538) are presented in Figures 12 to 21, and show a comparative relative density and range of migrating humpback whales across all flights. Similar kernel plots for flights on June 12, November 12, November 28, December 13 and December 24 were not constructed as there were too few data points (all less than 5) to perform the calculations (Figures 11, 22, 23, and 24).

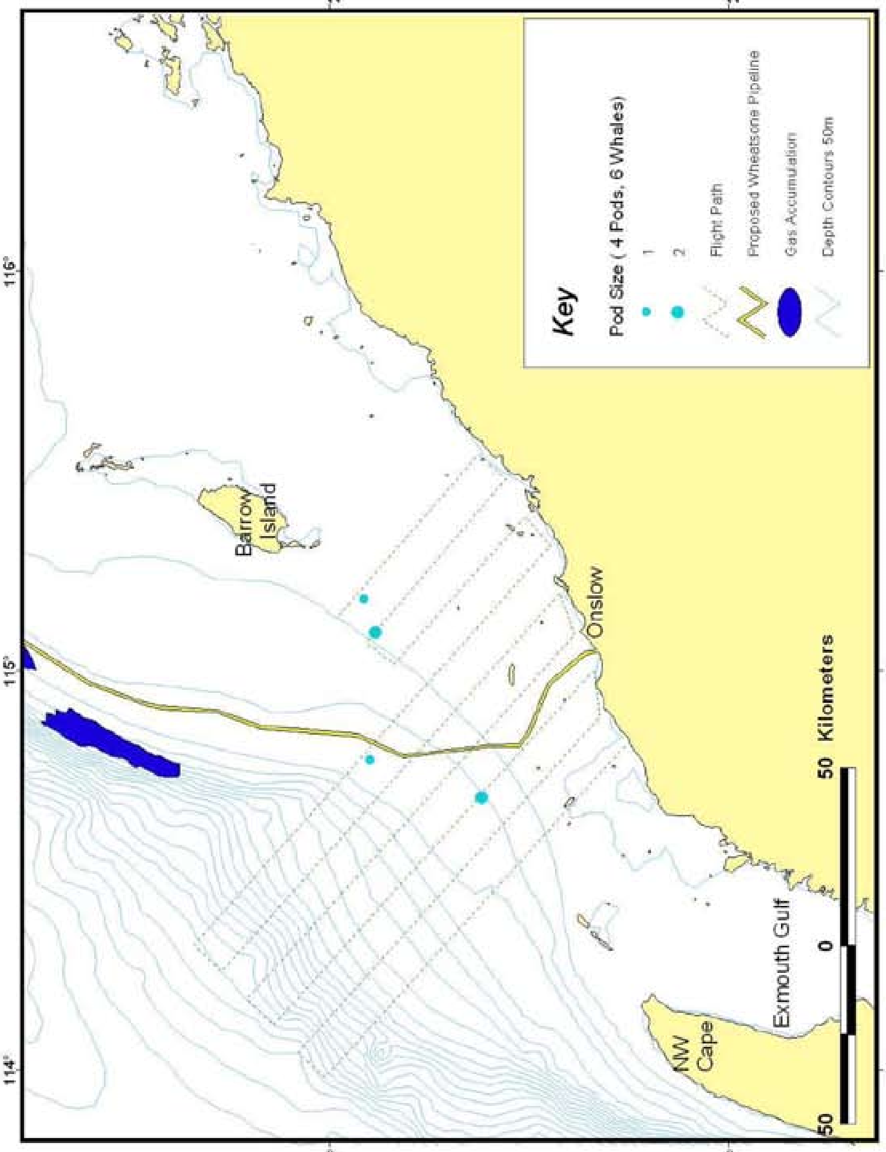

Figure 11. Positions of humpback whale pods sighted on June 12, 2009.

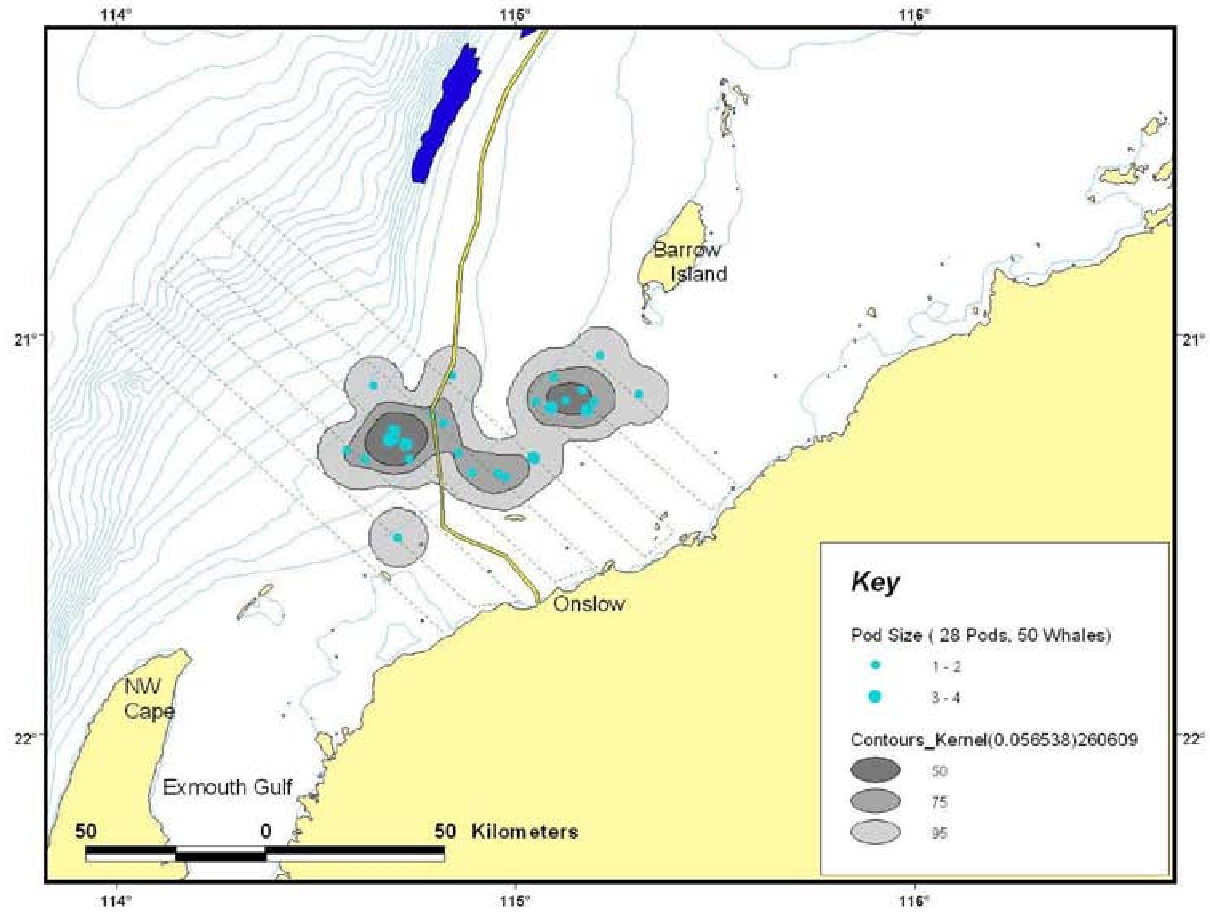

Figure 12. Positions of humpback whale pods sighted on June 26, 2009, with relative density distribution polygons.

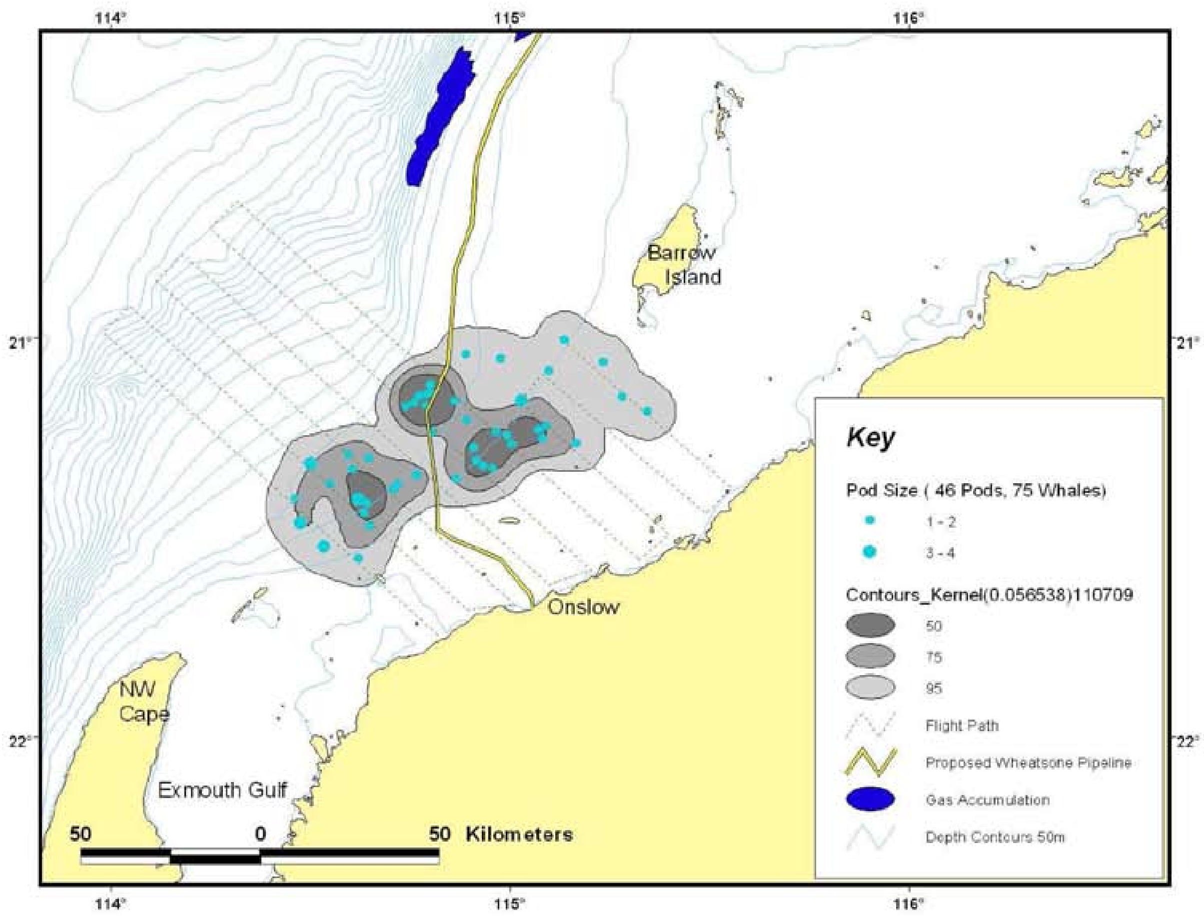

Figure 13. Positions of humpback whale pods sighted on July 11, 2009, with relative density distribution polygons.

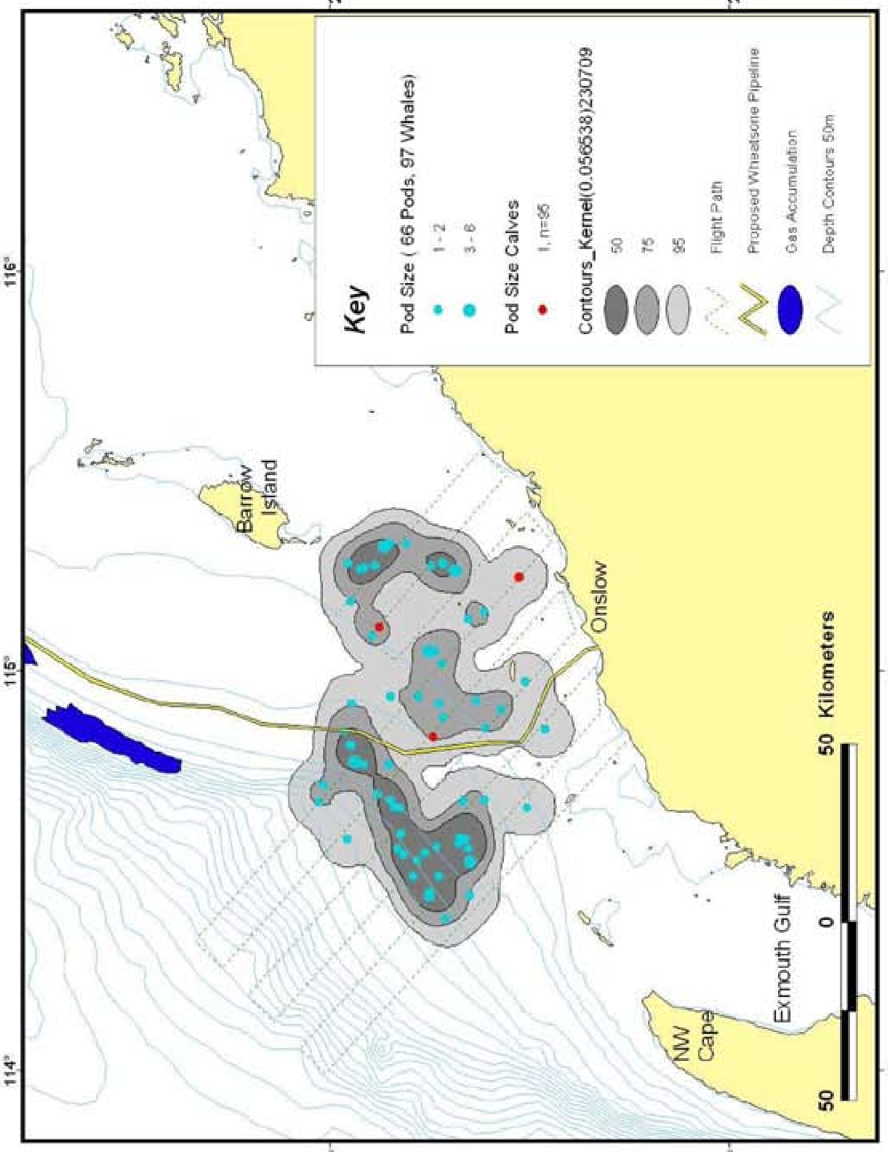

Figure 14. Positions of humpback whale pods sighted on July 23, 2009, with relative density distribution polygons.

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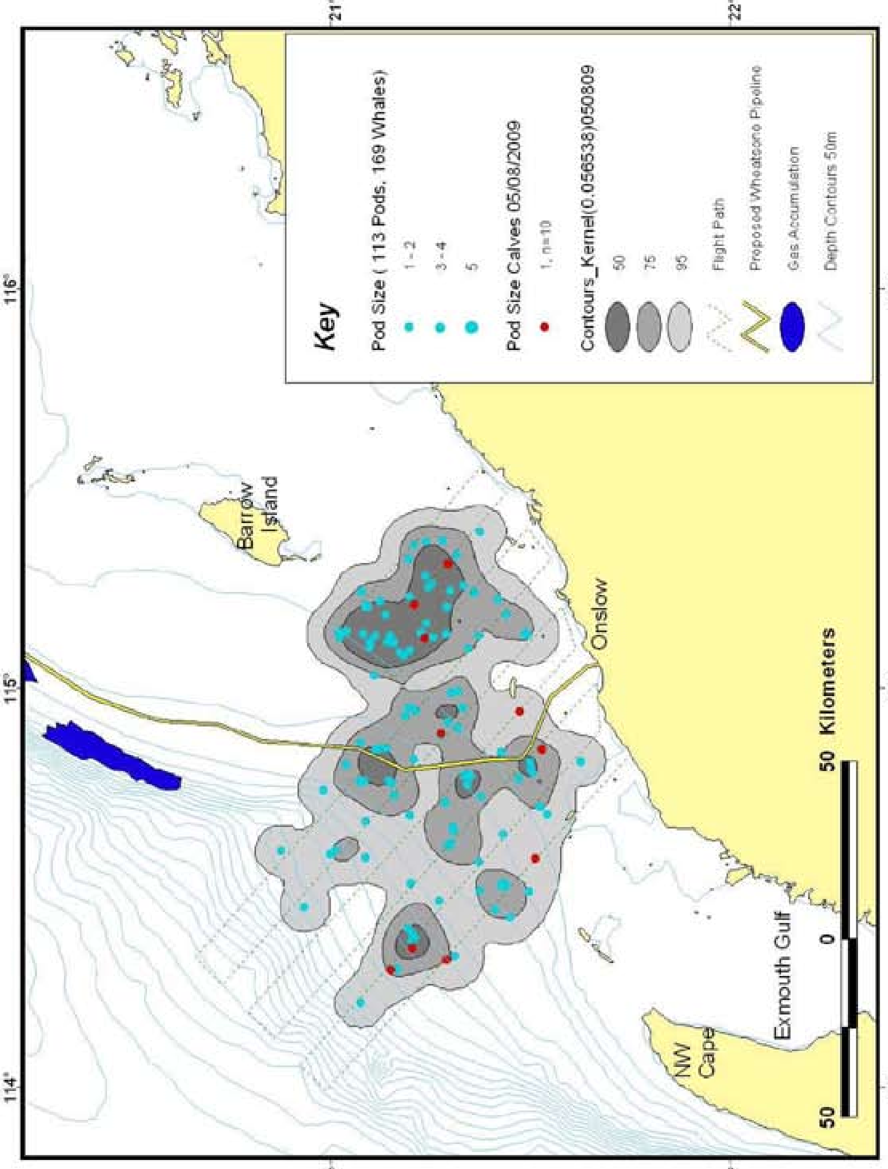

Figure 15. Positions of humpback whale pods sighted on August 5, 2009, with relative density distribution polygons.

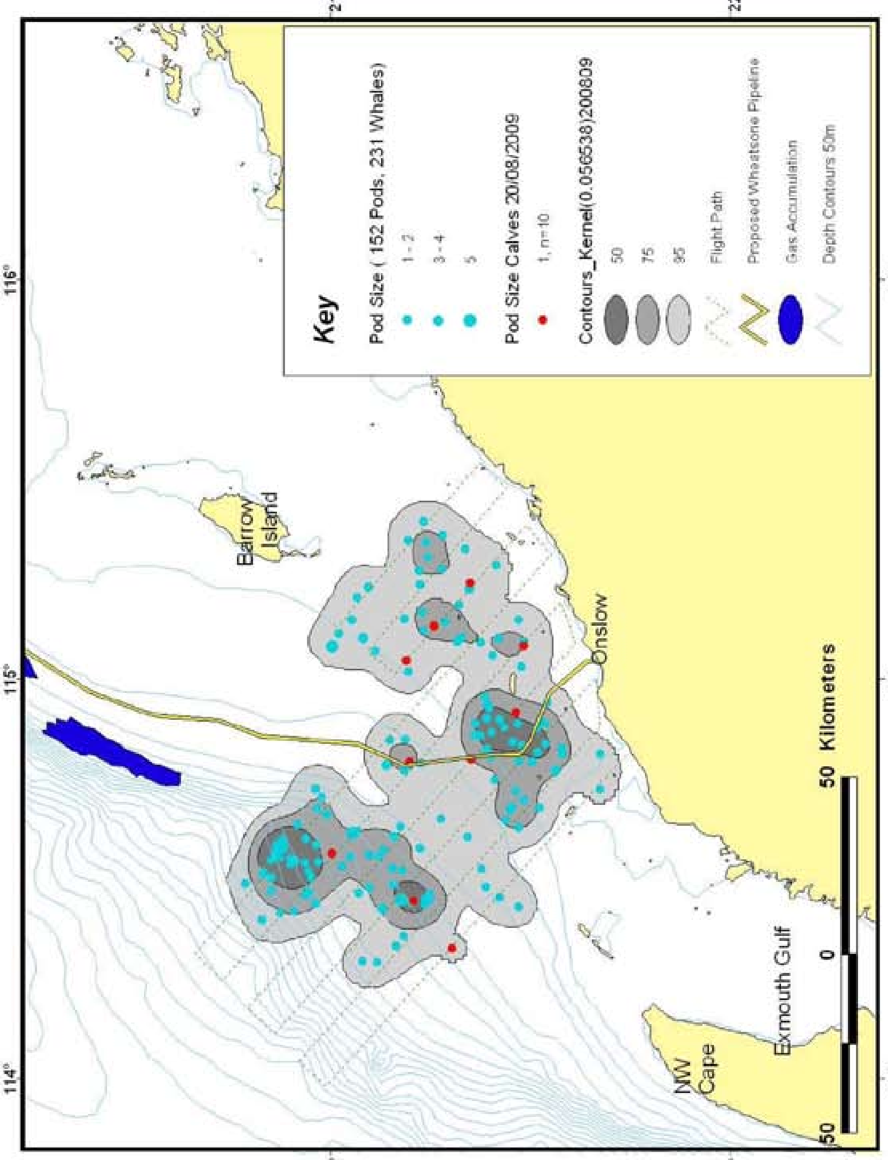

Figure 16. Positions of humpback whale pods sighted on August 20, 2009, with relative density distribution polygons.

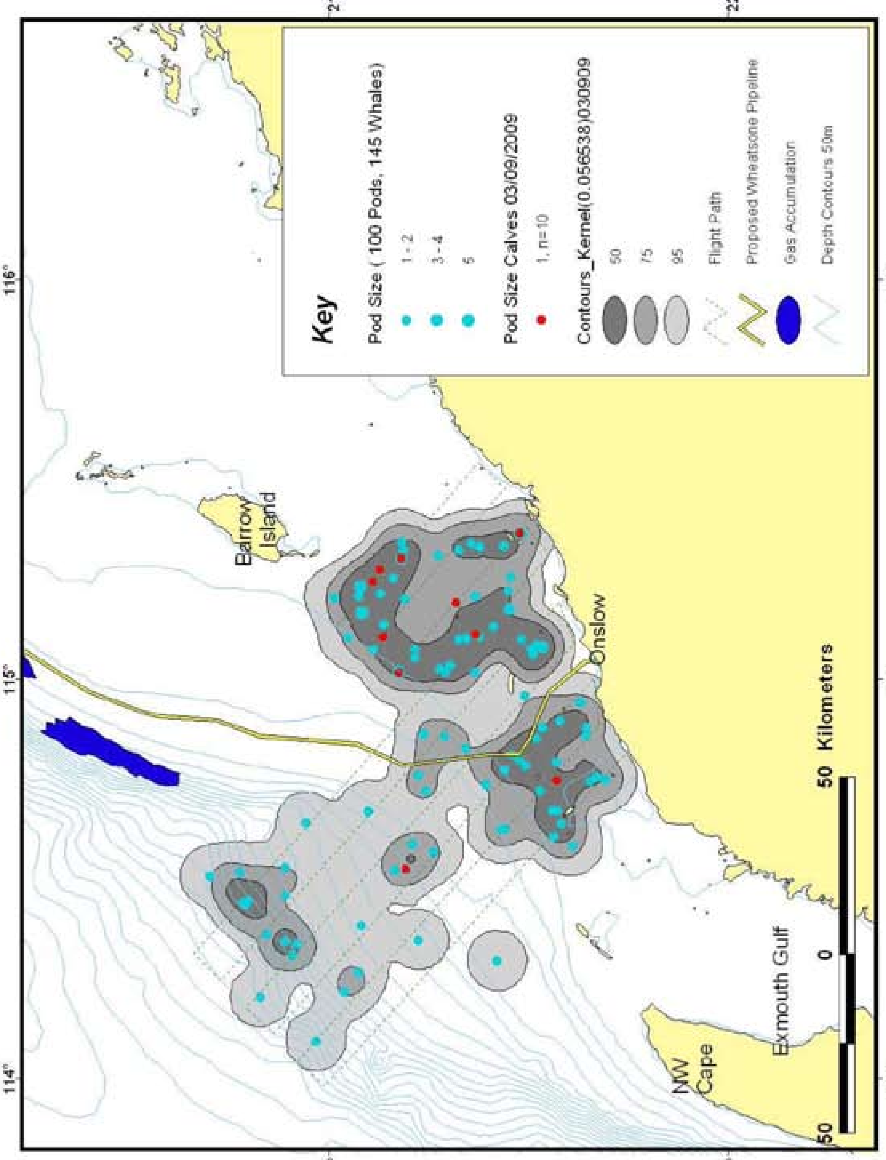

Figure 17. Positions of humpback whale pods sighted on September 3, 2009, with relative density distribution polygons.

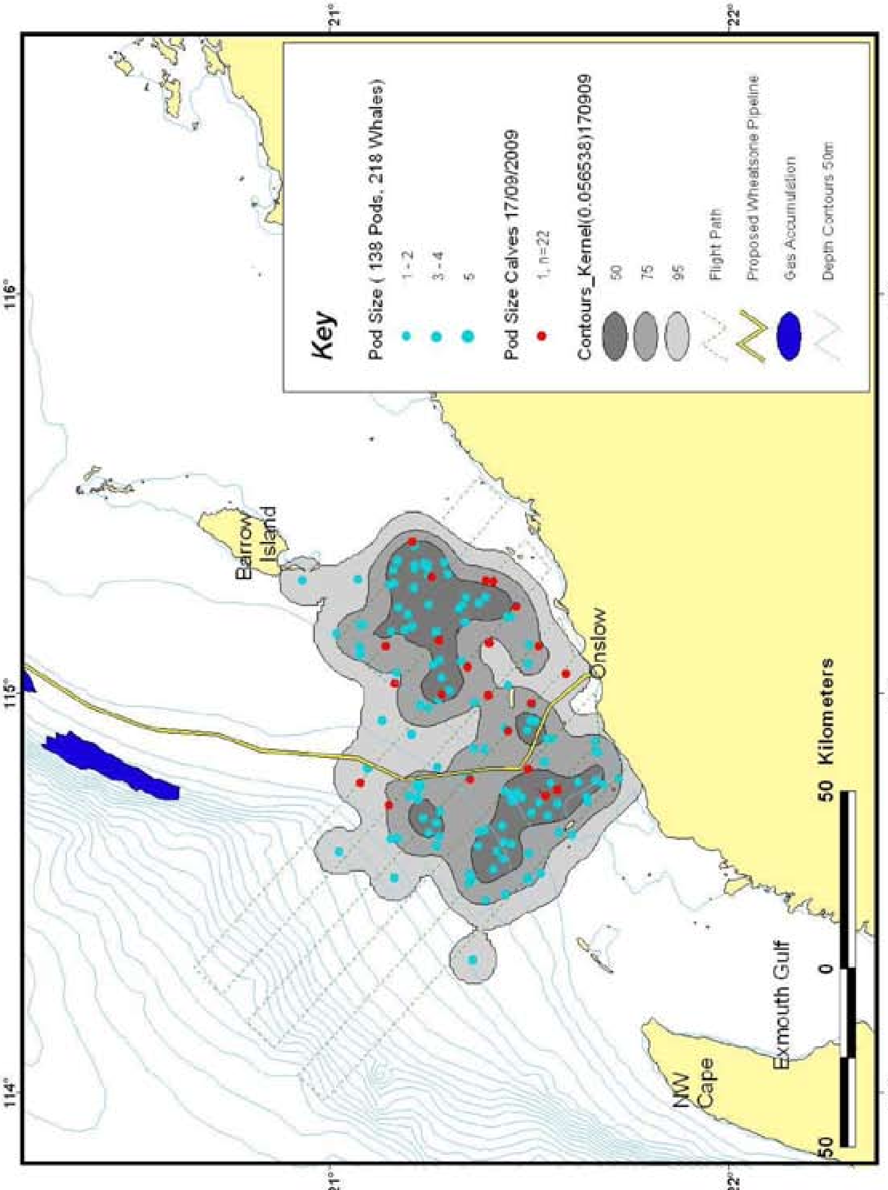

Figure 18. Positions of humpback whale pods sighted on September 17, 2009, with relative density distribution polygons.

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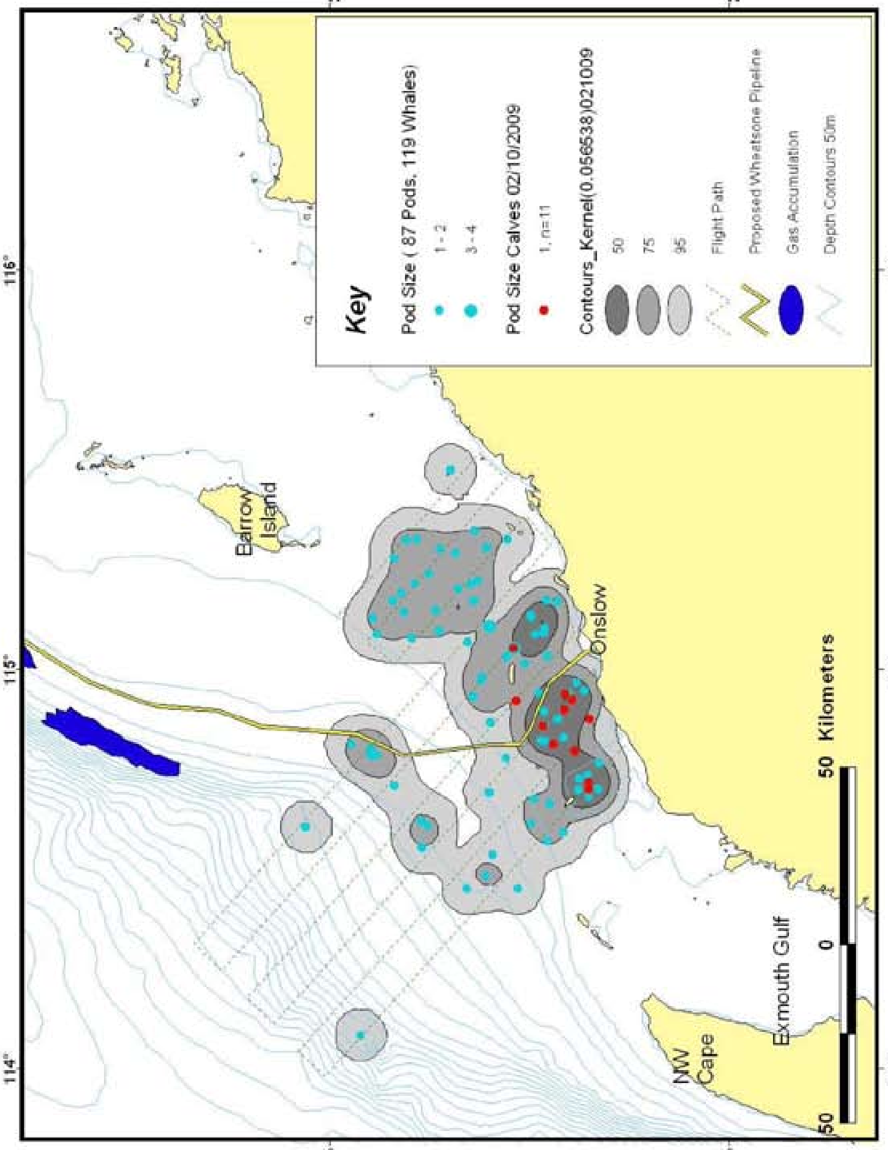

Figure 19. Positions of humpback whale pods sighted on October 2, 2009, with relative density distribution polygons.

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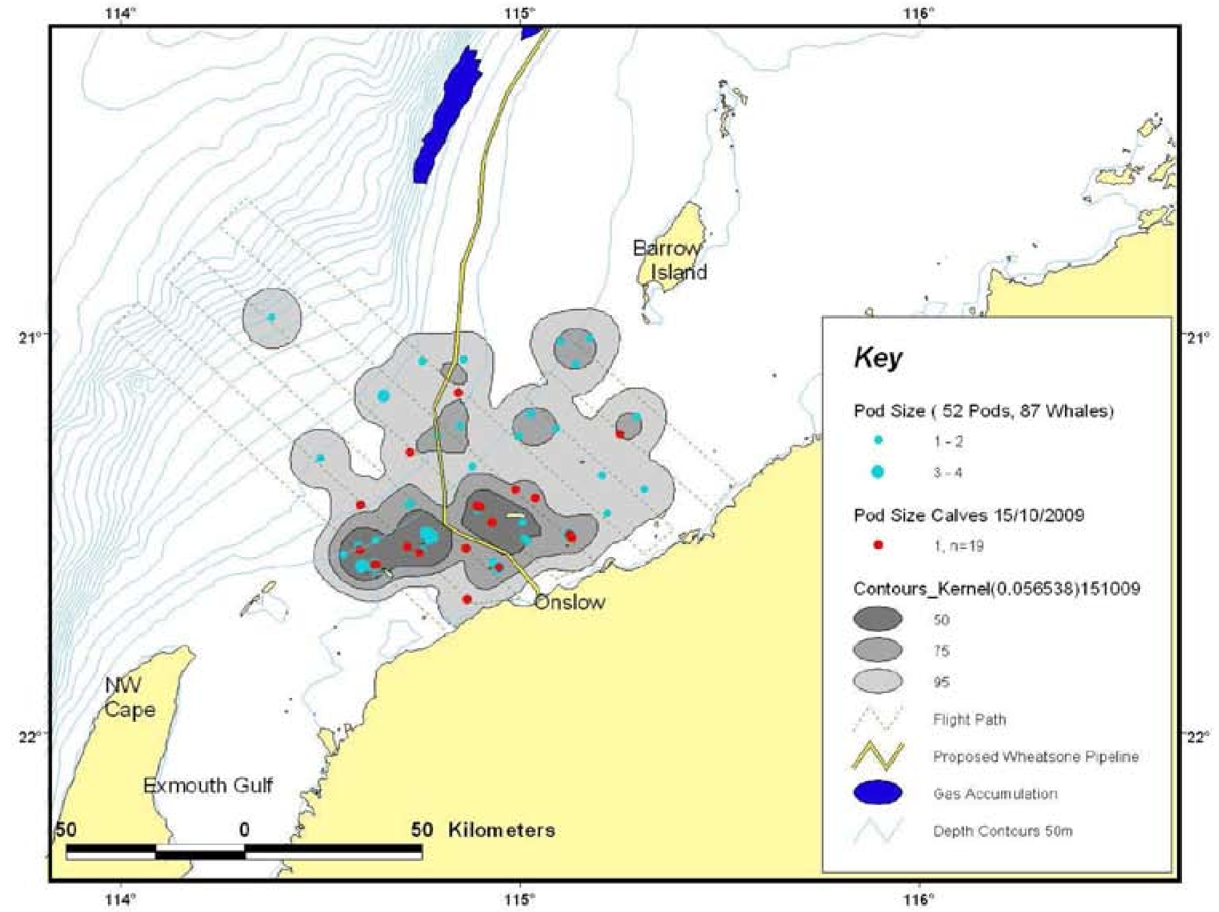

Figure 20. Positions of humpback whale pods sighted on October 15, 2009, with relative density distribution polygons.

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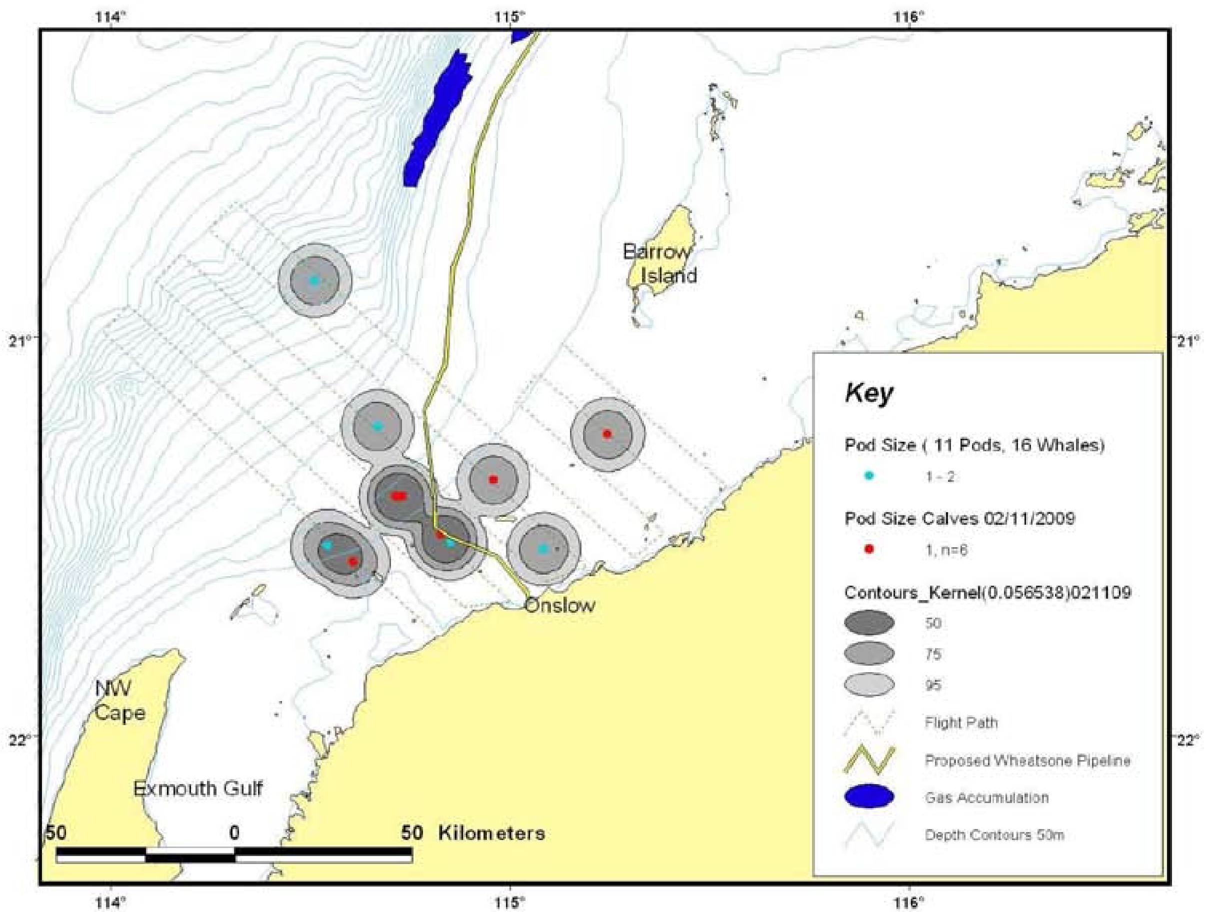

Figure 21. Positions of humpback whale pods sighted on November 2, 2009, with relative density distribution polygons.

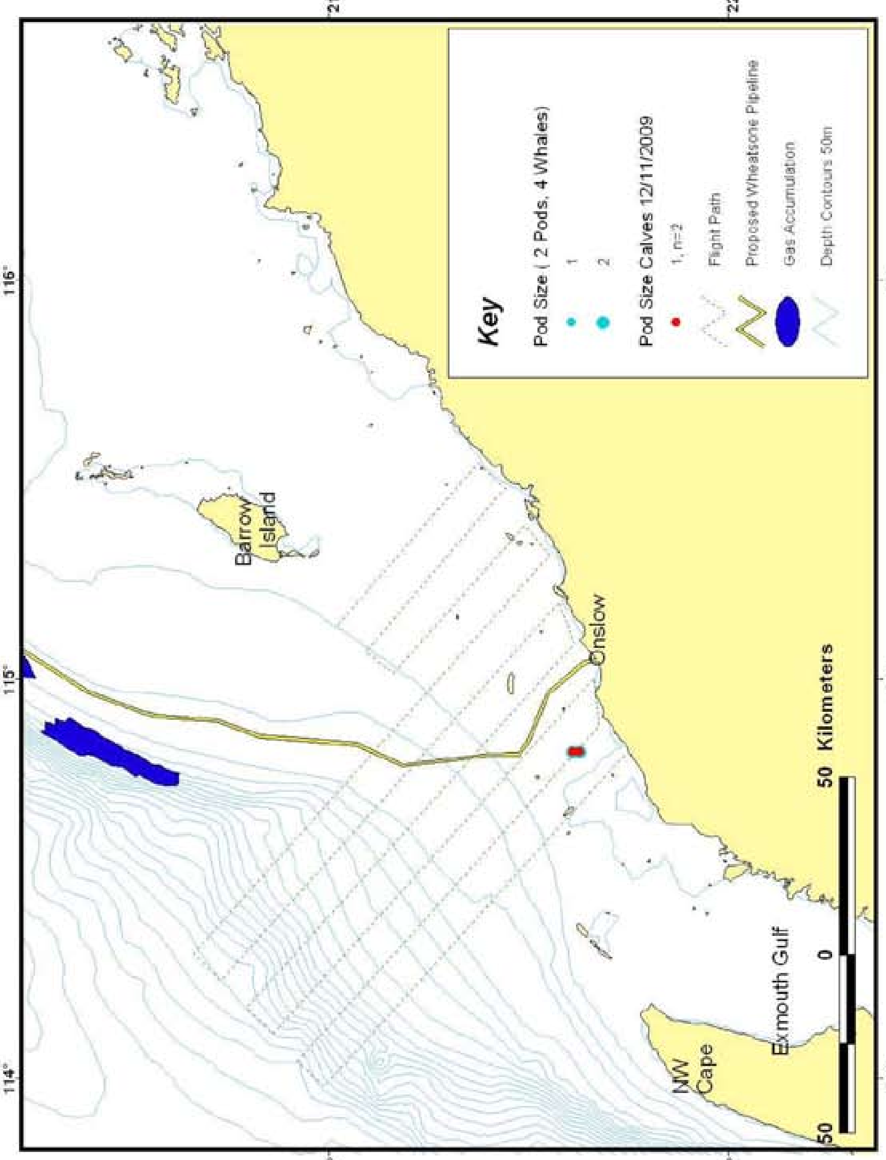

Figure 22. Positions of humpback whale pods sighted on November 12, 2009.

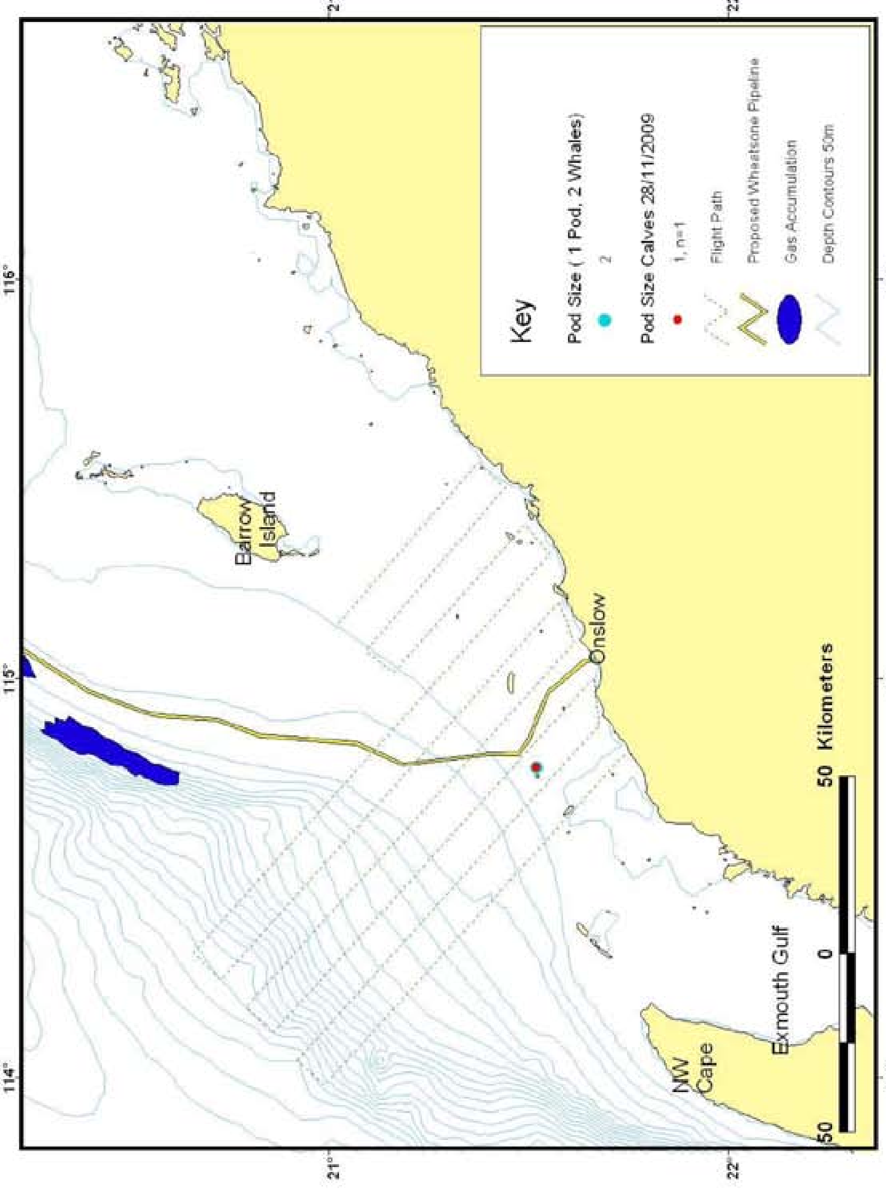

Figure 23. Positions of humpback whale pods sighted on November 28, 2009.

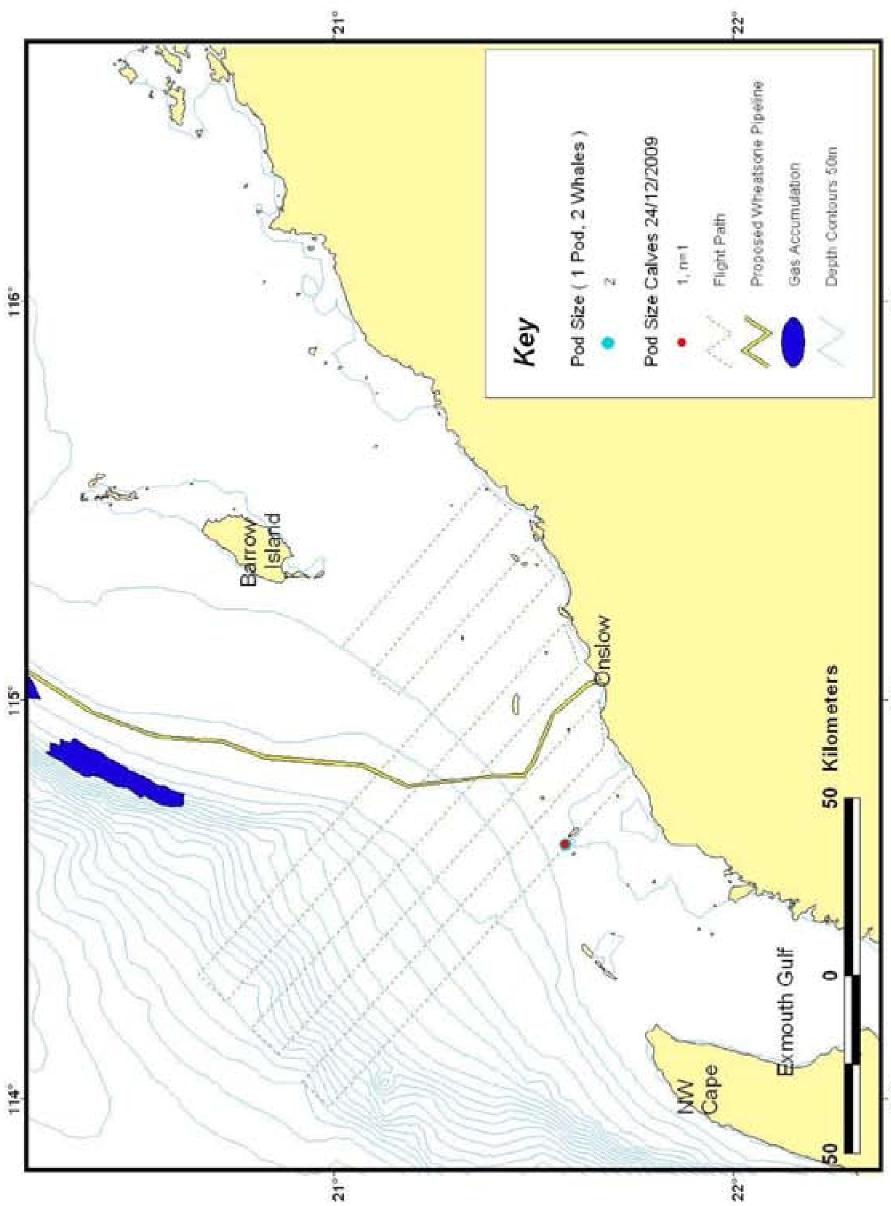

Figure 24. Positions of humpback whale pods sighted on December 24, 2009.

Migratory direction changed from being predominantly northbound in the study area, to predominantly southbound, in mid August between flights on the 5th and 20th of August 2009 (Figure 25). Higher proportions of resting/milling pods were sighted during the southern migratory phase than during the northern phase.

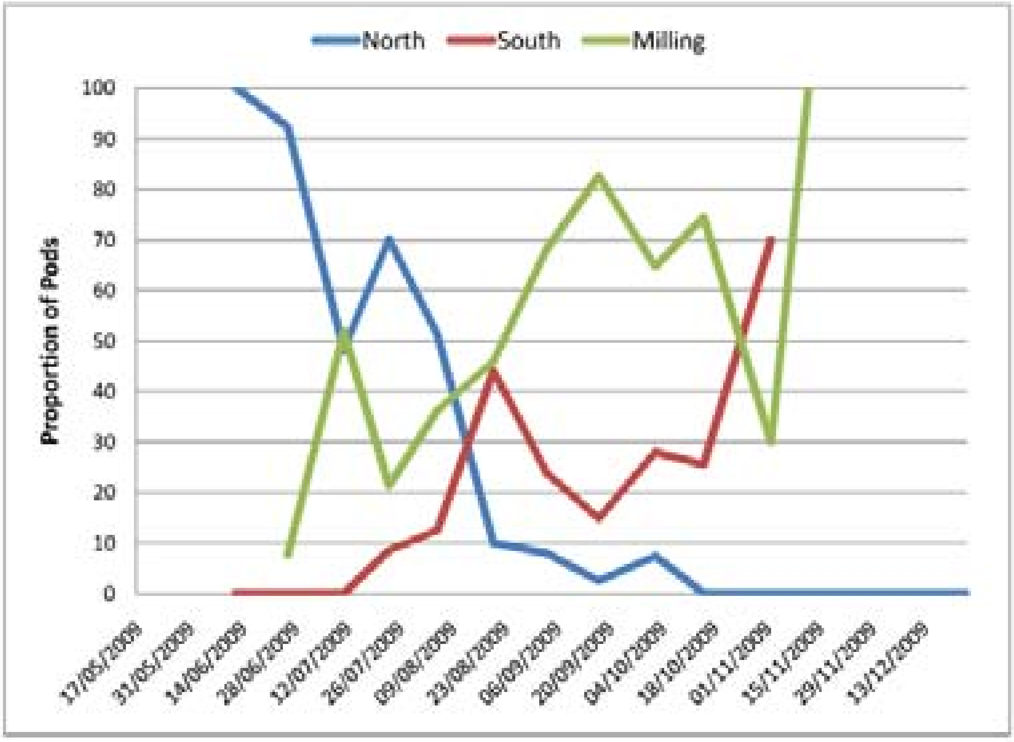

Figure 25. Proportion of humpback whale pods sighted swimming northbound, southbound or milling during the June 12 to December 24, 2009, study period.

Whales sighted during the northern migration period (prior to August 20, 2009) were sighted an average of 49.1 km (±1.0 SE, n=257) offshore while during the southern migration (after August 20, 2009) whales were an average of 35.9 km (±1.2, n=392) offshore. Whales sighted on August 20, the peak of season in terms of sightings numbers, were significantly further offshore than during the northern or southern phases (mean = 55.6 km ±2.4 SE, n=152).

Swim direction during the northern migratory phase was consistently northbound while peak of season contained approximately equal proportions of southbound and milling whales (Figures 26 and 27). The southern migration was mostly made up of milling/resting pods (Figure 28). Cow/calf pods were also mostly resting and in less than 50m water depth (Figure 29).

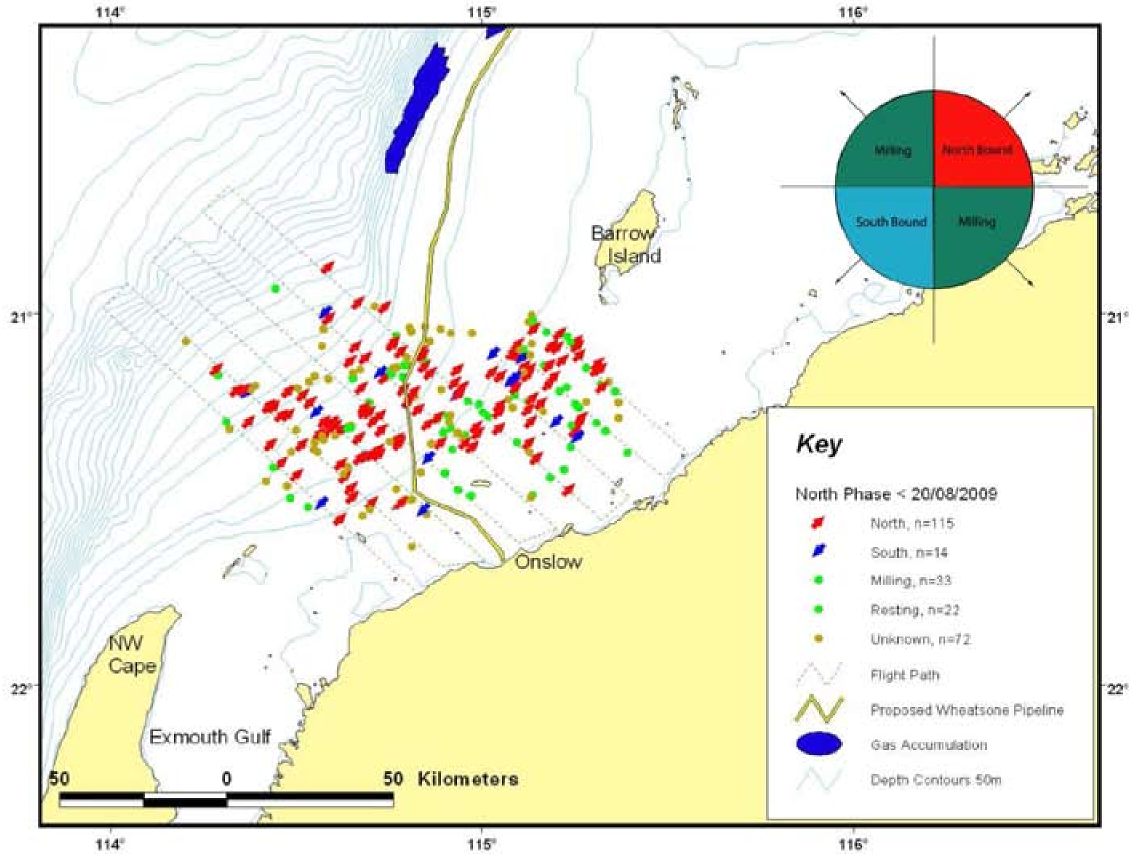

Figure 26. Swim direction with proportions reported for humpback whale pods sighted during the northern migratory phase (June 12 – August 5, 2009)

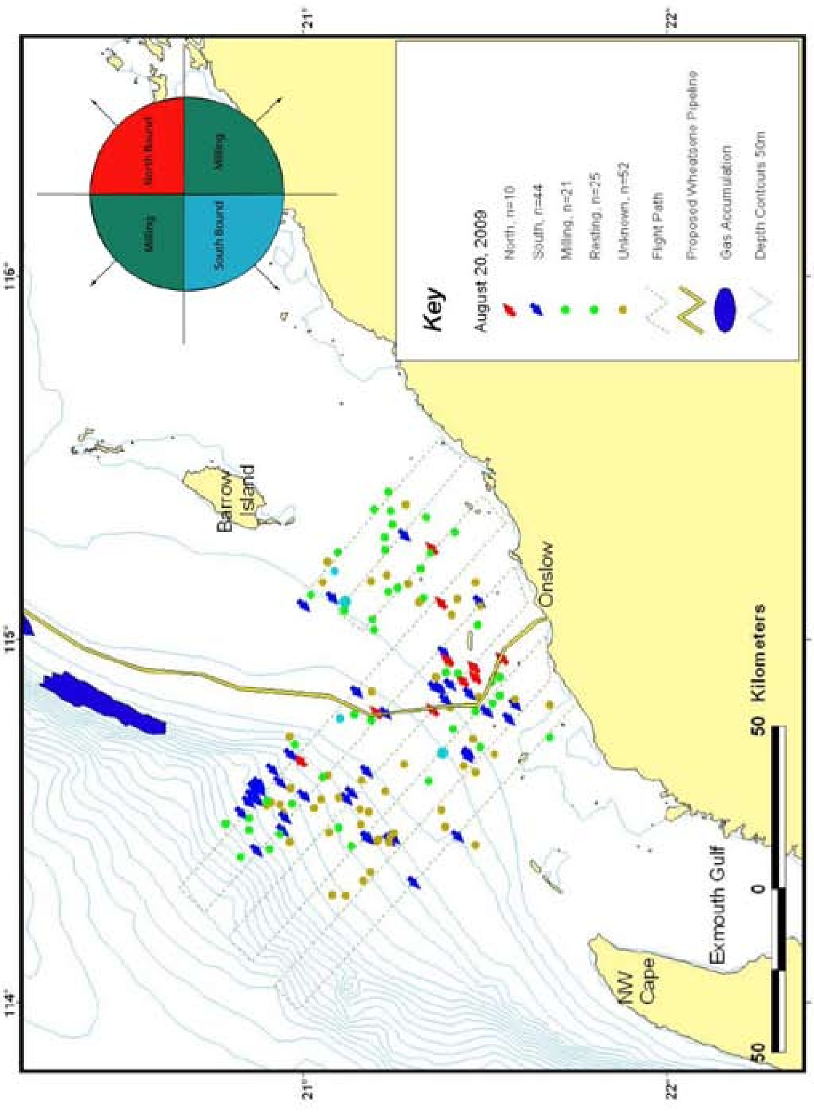

Figure 27. Swim direction reported for humpback whale pods sighted during the peak of migration (August 20, 2009)

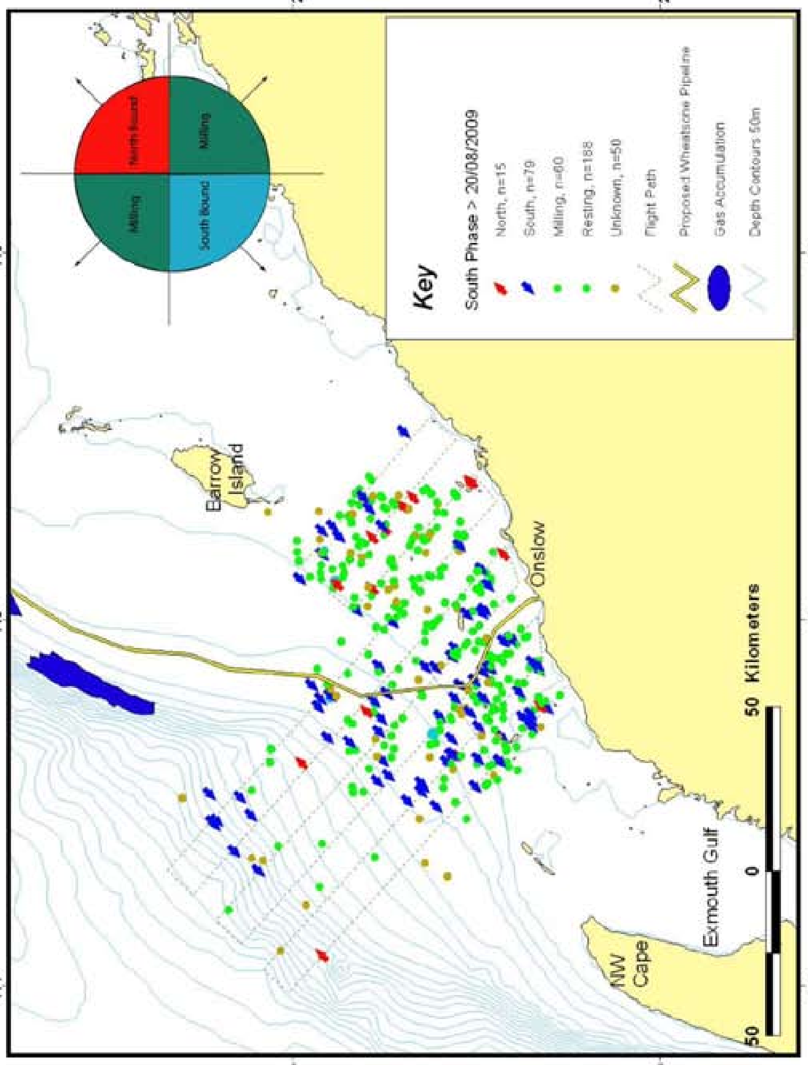

Figure 28. Swim direction reported for humpback whale pods sighted during the southern migratory phase (September 3 to December 24, 2009)

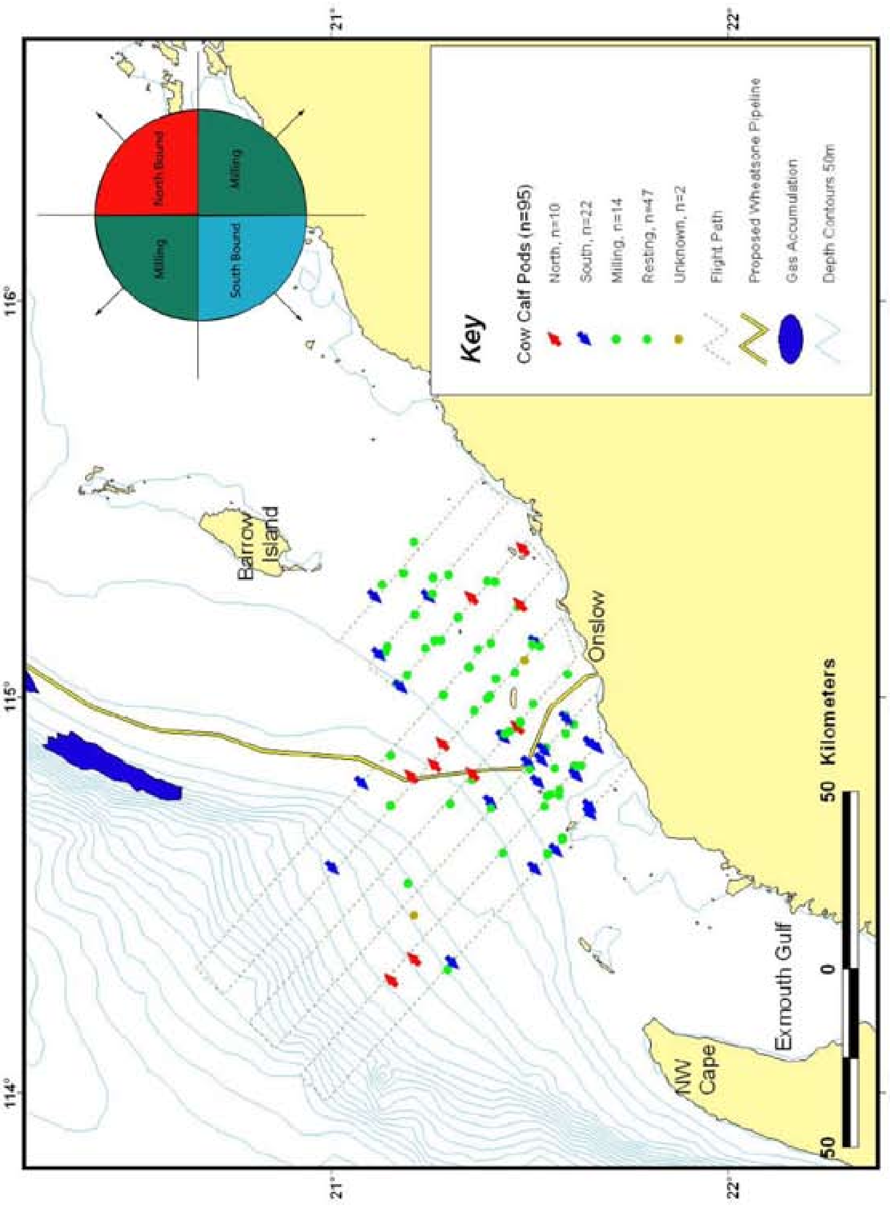

Figure 29. Swim direction reported for humpback whale pods with calves sighted during all flights from June 12 to December 24, 2009

5.4 Other Megafauna

5.4.1 Dugongs

Dugongs were sighted throughout the study period and peaked in late June (Figure 30). A total of 148 dugongs were sighted over the May 17 to December 24, 2009, time period. Herds containing cow/calf pairs accounted for approximately 10% (9/86) of all sightings (Table 4). Dugongs were predominantly sighted in the southwestern portion of the study area in water depths less than 10m (Figure 31).

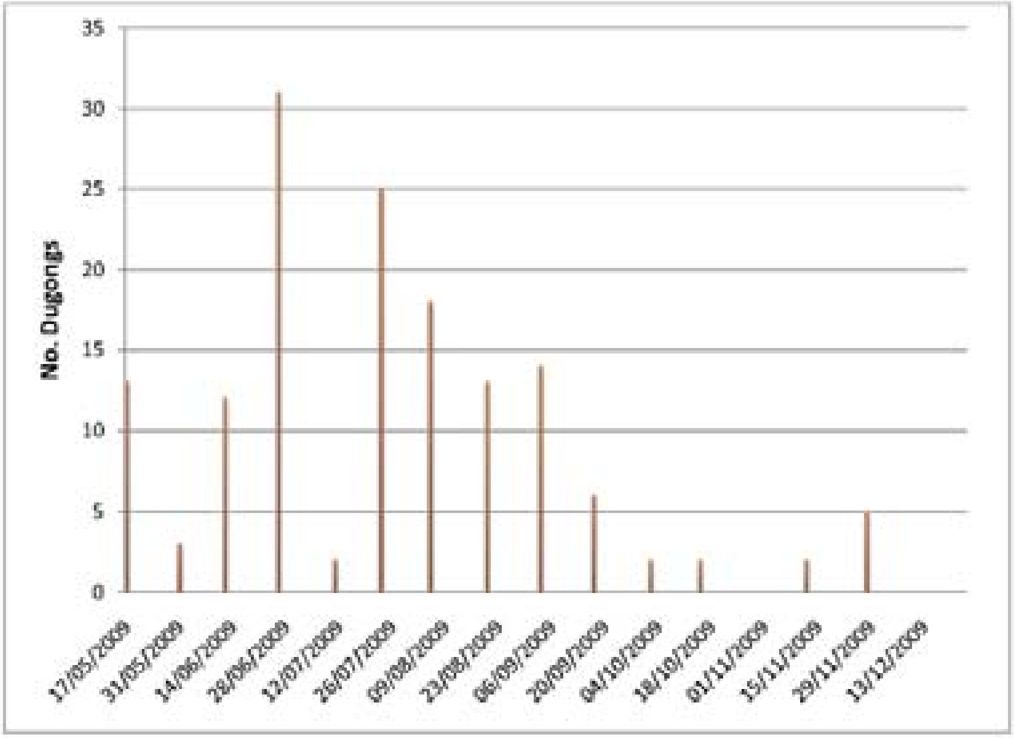

Figure 30. Numbers of Dugongs sighted during each flight from May 17 to July 23, 2009.

Table 4. Numbers of Dugongs sighted per flight

Flight Date	Dugong Herds	No. Dugongs	Dugong Calves
17/05/2009	3	13	0
31/05/2009	2	3	0
12/06/2009	7	12	2
26/06/2009	19	31	3
11/07/2009	2	2	0
23/07/2009	11	25	0
05/08/2009	12	18	1
20/08/2009	8	13	1
03/09/2009	10	14	0
17/09/2009	5	6	1
02/10/2009	2	2	0
15/10/2009	1	2	0
02/11/2009	0	0	0
12/11/2009	1	2	1
28/11/2009	3	5	0
13/12/2009	0	0	0
24/12/2009	0	0	0
TOTAL	**86**	**148**	**9**

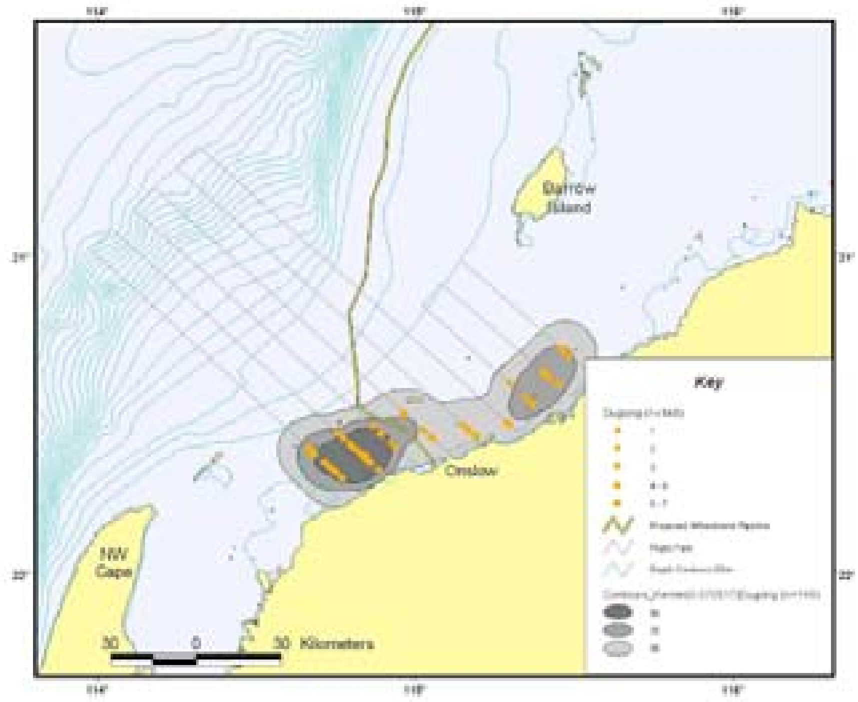

Figure 31. Distribution and relative density of Dugong herds sighted from May 17 to December 24, 2009.

5.4.2 Dolphins

Dolphins are likely to either be nearshore (< 50m) species including *Tursiops spp.*, *Sousa chinensis or Orcaella spp.* and the offshore species may include *Tursiops spp.* and *Stenella spp.* (Jenner and Jenner, unpublished data from vessel surveys), however sightings were not identified to species level due to difficulty in identification. Dolphins were sighted during each flight during the May to December period. A total of 1369 dolphins were sighted with a peak number of 203 animals observed during the May 31 flight (Figure 32). Only nine calves were sighted throughout the survey period (Table 5). Dolphins were predominantly sighted in the southwestern portion of the study area in water depths less than 50 m, although some large pods (>100 individuals) were sighted offshore (Figure 33).

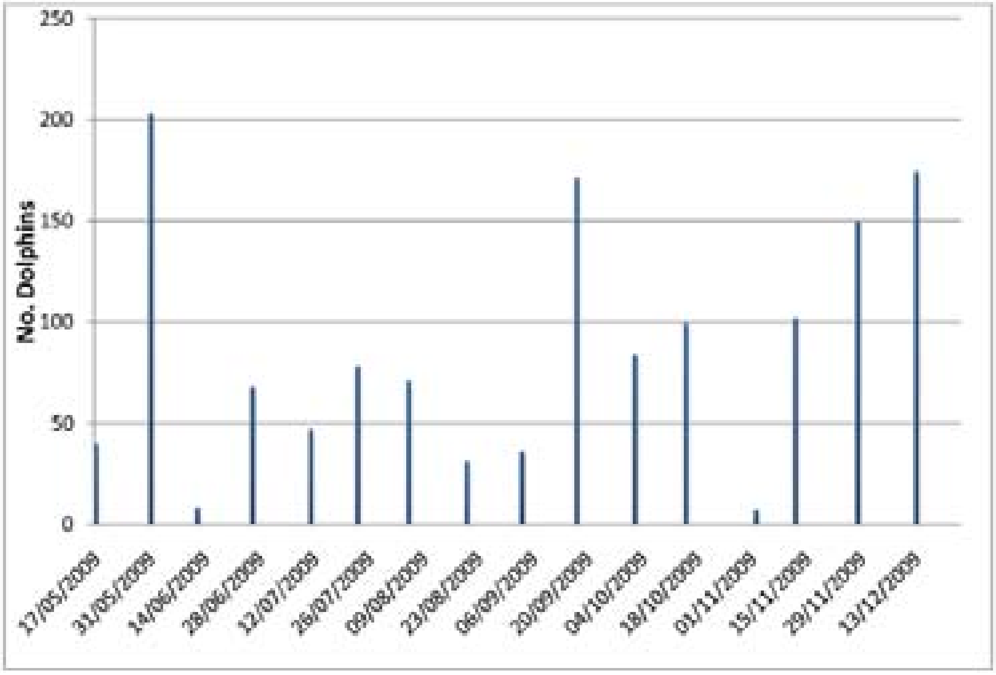

Figure 32. Numbers of dolphins sighted during each flight from May 17 to July 23, 2009.

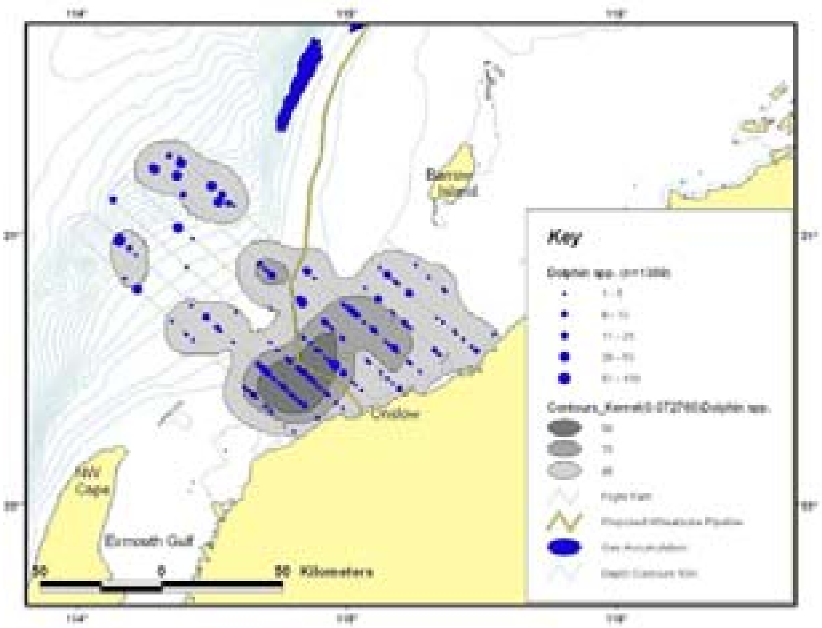

Figure 33. Distribution and relative density of dolphin species sighted from May 17 to December 24, 2009.

Table 5. Numbers of dolphins sighted per flight.

Flight Date	Dolphin Pods	No. Dolphins	Dolphin Calves
17/05/2009	10	40	0
31/05/2009	18	203	0
12/06/2009	4	8	0
26/06/2009	28	68	0
11/07/2009	10	47	1
23/07/2009	0	78	1
05/08/2009	19	71	1
20/08/2009	4	31	1
03/09/2009	17	36	0
17/09/2009	34	171	0
02/10/2009	4	84	0
15/10/2009	14	99	0
02/11/2009	1	7	0
12/11/2009	12	102	1
28/11/2009	17	150	2
13/12/2009	10	174	2
24/12/2009	0	0	0
TOTAL	**202**	**1369**	**9**

5.4.3 Other Cetaceans

Other cetacean species sighted included blue whales, killer whales, sperm whales, pilot whales and minke whales (Figure 34, Table 1). A pair of fast swimming unidentified whales, possibly Brydes' whales or minke whales, were sighted on July 11, 2009. The sperm whales (n=10) were logging at the surface when sighted over the continental slope, as were the pilot whales (n=25). A dwarf minke whale sighted on June 26, 2009, was swimming steadily northeast. The blue whales were all migrating southbound.

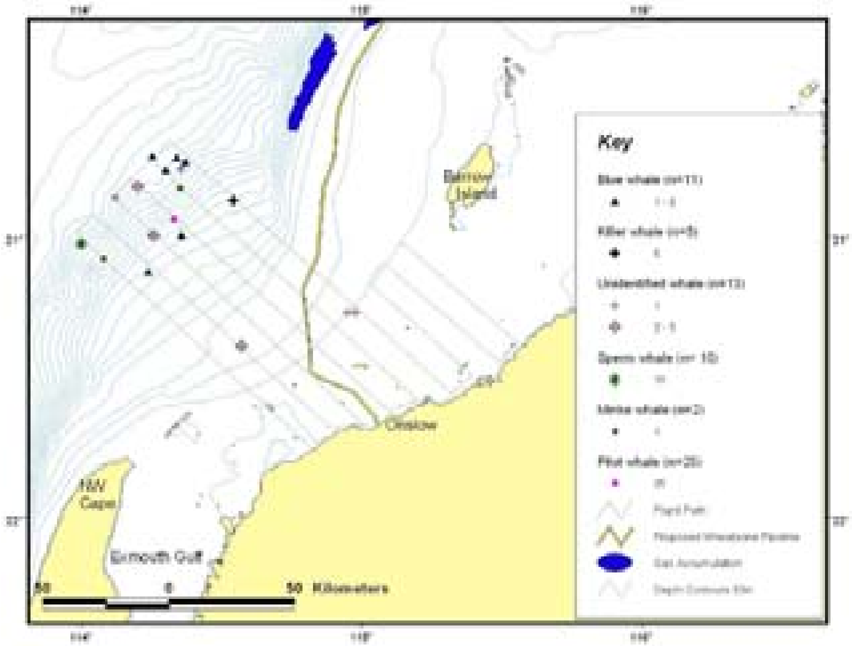

Figure 34. Distribution of other cetacean species sighted during the May 17 to December 24, 2009, period.

5.4.4 Turtles, Rays and Whale sharks

Turtles could not be identified to species level at the time of sighting. Boat based sightings by CWR from previous surveys suggest that the principle turtle species in the near shore Exmouth Gulf region during the May to November period is the green turtle (*Chelonia mydas)*. However, hawksbill turtles (*Eretmochelys imbricata*) are frequently sighted in mangrove creeks and loggerhead (*Caretta caretta*) and flatback (*Natator depressus*) have also been sighted in CWR surveys between 2000 and 2009. Manta rays (*Manta birostris*) were distinguished from other rays by their distinctive shape although it is possible that other species of bottom dwelling rays were mistaken for Mantas along the mangrove creek areas. Whale sharks (*Rhincodon typus*) are unique in shape and size and are commonly sighted and identified using aerial surveys (i.e. Ningaloo whale shark tourist industry) so misidentification is considered unlikely.

Turtles were sighted during each of the six flights while manta rays were sighted during all flights except May 31, 2009 (Table 1). A single whale shark was sighted during the May 17, 2009, flight and no further whale sharks were sighted until mid November when 2 animals were sighted, followed by another single animal in mid December. Turtles were predominantly located inside the 50m bathymetry line (Figure 35). Manta rays were more broadly and sparsely distributed and were sighted near the 50m depth contour as well as nearshore near a mangrove area known as the Passage Islands (Figure 36).

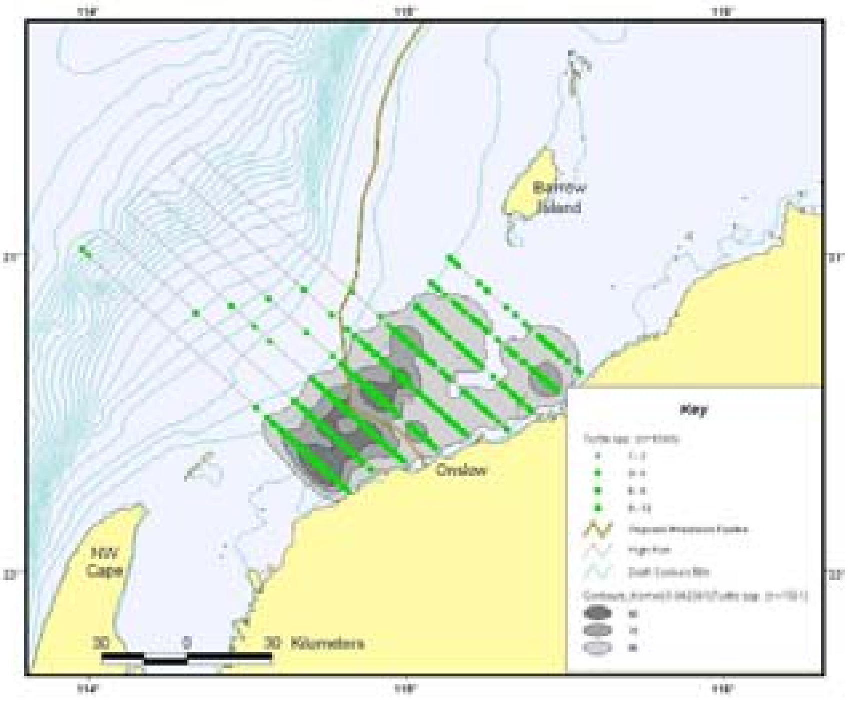

Figure 35. Distribution and relative abundance of turtle species sighted during the May 17 to December 24, 2009, period.

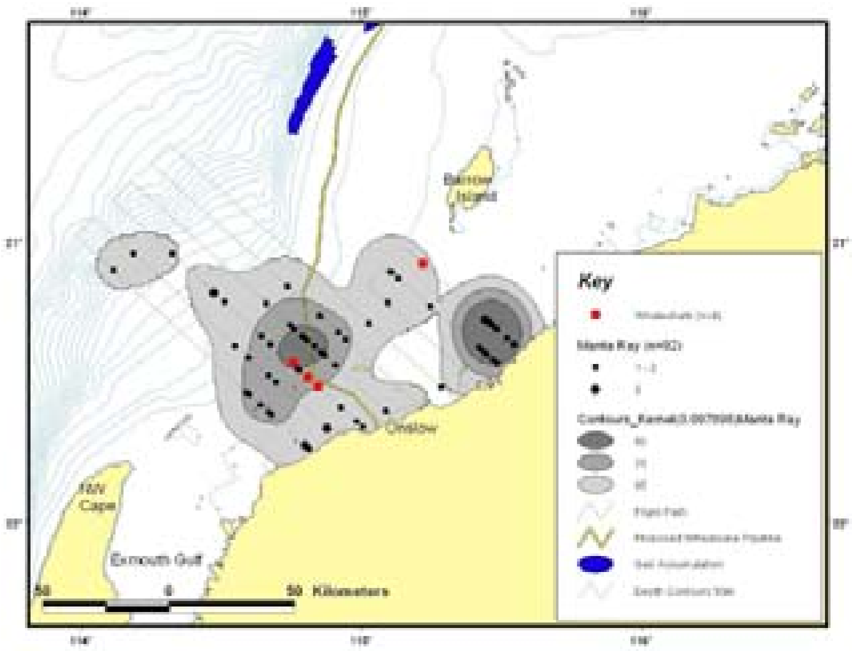

Figure 36. Distribution and relative abundance of manta rays and distribution of whale sharks sighted during the May 17 to December 24, 2009, period.

5.4.5 Vessels

A total of 526 vessels and other man-made structures (drill rigs, storage platforms, ships, small vessels, aqua-culture, etc.) were sighted during the mid May to late July period (Table 1). Although "home range" calculations for vessels are not biologically meaningful, the application of consistent density distribution mapping techniques to demonstrate high usage areas justifies its use here. The majority of vessels were sighted in water depths less than 50m and focussed around the Thevenard Island area where a large number of oil and gas production and storage facilities are located (Figure 37). Of note was a seismic survey that was ongoing from mid-June until late July.

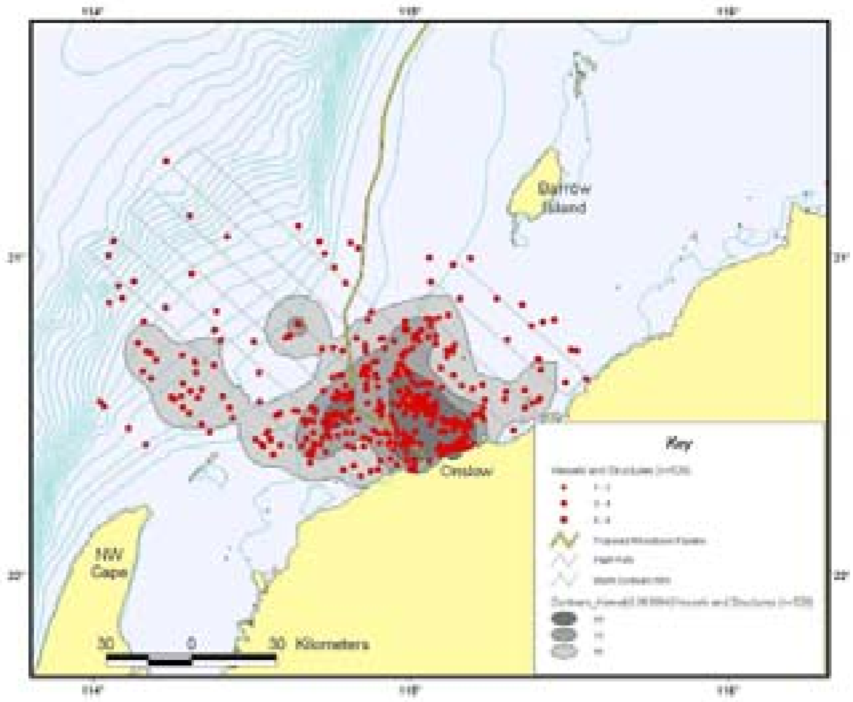

Figure 37. Distribution and relative abundance of vessels and man-made structures during the May 17 to December 24, 2009 period.

6. Discussion

This report summarises a study program carried out in the austral winter of 2009, in the offshore southwest Pilbara region using aerial surveys at approximately 14-day intervals and acoustic surveys (McCauley and Kent, 2009) from bottom mounted sea noise loggers. The results presented in this document and McCauley and Kent (2009) are preliminary and represent eight months of a 12-month study period. Temporal and spatial pattern analysis for both survey types will benefit from comparisons of the complete 12-month dataset, however some useful comments can be made regarding the data collected thus far.

Detection of cetacean species using a combination of acoustic and aerial survey techniques has resulted in a reduction of knowledge gaps that typically arise using just one or the other technique. Aerial surveys alone generally suffer from lack of temporal detail and are unable to sample at night, while acoustic surveys generally suffer from lack of spatial (in shallow water) and species (for none vocalising species) detail. Here we discuss the survey area during the May to December period with the benefit of both datasets, which substantially mitigate the short fallings of each other.

A total of six cetacean species were identified from the study area over the eight-month study period, six by the aerial surveys and four by the acoustic surveys. Importantly, from a management perspective, pygmy blue whales and Brydes' whales, which were not sighted in the aerial surveys in May to July, were detected in the acoustic surveys. It is useful confirmation to have positive identification of Brydes' whales from the acoustic dataset as an "unidentified cetacean" sighting on

July 11 during the aerial survey was reported as either "minke or Brydes", making the classification of Brydes' more plausible. Both species are tropical baleen whale species that do not migrate to polar waters and have been identified in previous surveys in the area (Jenner and Jenner, 2005 and CWR unpubl. data). Conversely, sperm whales and pilot whales were sighted in the aerial surveys but not detected in the acoustic surveys, either due to proximity or because the loggers are designed to receive predominantly low frequency sounds (higher frequency sounds such as those made by toothed whales do not propagate long distances).

Both the acoustic surveys and the aerial surveys detected at least one (but possibly three) seismic operations over the three-month period. Seismic survey noise dominated the offshore acoustic dataset making species detection and identification more difficult. Previous studies have shown behavioural reactions of individual baleen whales to seismic survey (air gun) sounds (summarised in Richardson *et al.* 1995 and McCauley *et al.*, 2003) however there is no information available regarding the impacts of seismic surveys on migratory herds of these animals.

The aerial survey program between May and December has captured the complete northern and southern migratory cycle of humpback whales in this area. A northern migration changing in mid-August to a southern migration was consistent with historical datasets. The peak of season was observed during the cross-over between northern and southern migrations as has been previously described by Jenner *et al.* (in prep).

During the aerial surveys, 22% and 48% of sightings in July were reported to be resting and without migratory direction (milling), while only 28% to 9% were migrating northwards. This is an unexpected high proportion of resting and milling whales during the July time period. CWR aerial survey data from 2000 to 2005 from the North West Cape area (immediately to the southwest of the study site) indicate that 80 to 100% of sightings are typically northbound at this time of year (Jenner *et al.*, in prep). Furthermore, swim speeds are expected to be relatively high (5.1 to 7.9 km/hr for June/July, versus 4.1 to 4.5km/hr in Aug/Sept/Oct, Jenner *et al.*, in prep) at this time of year. Hence few whales are expected to be resting at this time of the year contrary to what has been observed.

Possible causes for this change in migratory behaviour during the 2009 season are currently being investigated and will include environmental and anthropogenic possibilities. Initial investigation of the acoustic dataset indicate that at the shelf edge air gun signals were clear and at the 100-200m bathymetry contours where the majority of humpback whale pods were sighted, air gun signals would have been audible. Near the nearshore logger positions (45 m and 10 m depth) there were no air gun signals detected. However, slightly stronger wind conditions on 11 July 2009 may have contributed to the higher number of "unknown" migratory direction pods reported (50% of sightings) and therefore contributed to the lower sightings of northbound humpback whales. Further investigation shows that approximately 65% (15 of 23) of pods sighted and reported with unknown swim direction were breaching or exhibiting other splash behaviours, an association (wind and splashing behaviours) supported by Dunlop *et al.* (2008), while only a small number of pods (8 of 23) were sighted for too short a time to determine swim direction, indicating that perhaps sea conditions were not the most important factor in the reported swim directions. Also of interest is what appears to be comparatively low numbers of acoustic detections of pygmy blue and dwarf minke whales compared with a similar data set collected in 2006 (see McCauley and Kent, 2009).

Other aspects of the humpback whale migration appear more similar to anticipated patterns such as the general spatial distribution of the migratory herd (Figure 38). The mean distance from shore of pods sighted during the peak of migration was greater than those observed for the northern and southern migration, perhaps indicating a social need for spacing during the migration. Higher numbers of whale migrating through the same migratory area may spread out to minimise mating competition.

Increasing numbers of resting and milling whales were sighted after the cross-over period and this observation class dominated the period of the southern migration. This behaviour pattern appears to be typical of this species and results in a slower southern migration and possibly greater opportunities for mating. Also influencing the rate of travel of the southern migratory body are cows moving south from the Kimberley Calving Grounds with newborn calves. Feeding intervals may be regular en route and it is unclear whether this species migrates steadily between resting areas or, instead, rests at regular intervals along the migratory path. The high densities of resting whales inside the 50m depth contour between Barrow Island and Exmouth Gulf could be due to either of these possibilities, or others and will form the basis for ongoing studies.

In a previous CWR survey (2004/2005) in which the entire Exmouth Gulf area was surveyed at three week intervals over 12 months, no humpback whales were sighted inside the Gulf during the June/July period (Jenner and Jenner, 2005). It was suggested by Jenner and Jenner (2006) that this was largely due to cooler water temperatures in the nearshore waters at this time of year.

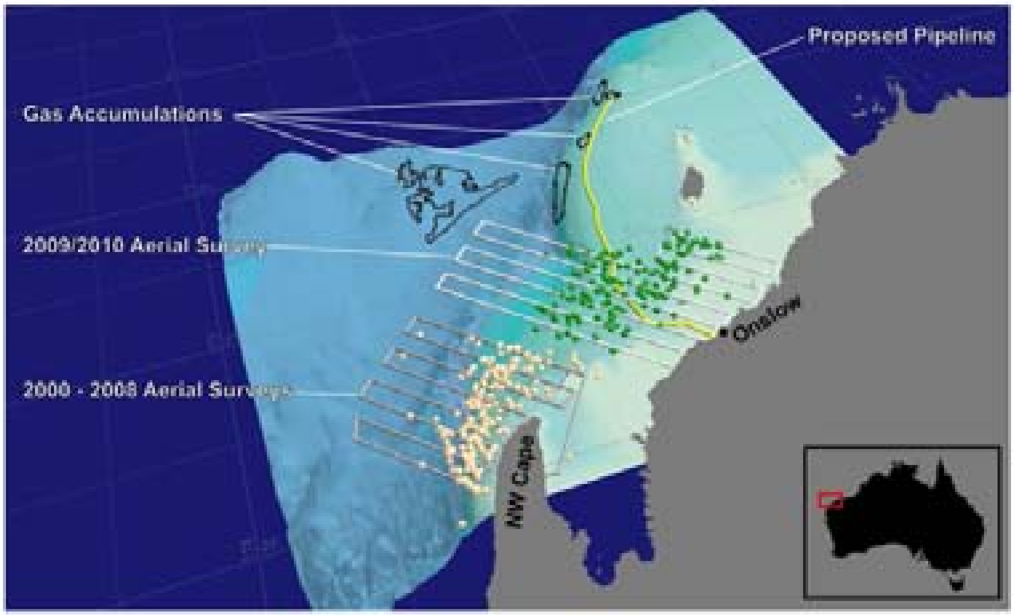

Figure 38. The 2009 humpback whale dataset (green) compared to the 2006 northern migration near North West Cape (CWR, unpubl. data).

Similarly, during the 2009 surveys, the nearshore waters were significantly cooler than the offshore waters (Figure 39) and a similar paucity of whales in this region was reported in this study. Water temperatures nearshore of the 50m depth contour increase during August and September, coinciding with the arrival of the southern migratory body.

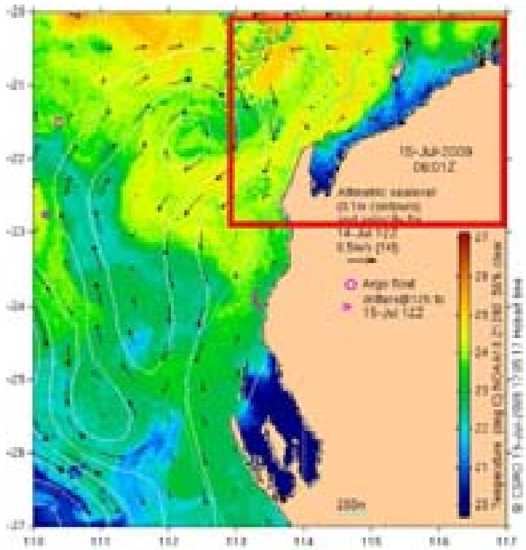

Figure 39. Sea surface temperature map from July 15, 2009, showing the cools near shore waters extending from Exmouth Gulf, northeast along the South West Pilbara offshore region (red box).

The nearshore legs of the aerial survey area (within the 50m bathymetry) had the highest densities of dugongs, dolphins, turtles and vessels. Dugong and dolphin densities were highest near the Exmouth Gulf side of the sample area, suggesting a link to known populations, and possibly food sources, in that area (Jenner and Jenner, 2005). Variation in numbers of dugongs, manta rays, dolphins and turtles and less visible species is likely attributable to weather conditions (see Appendix 2). Such sightings of other megafauna reported here are of limited use in determining actual densities of these species and should rather be used to infer presence (not absence, nor density) during a particular temporal period. However it is interesting to note that at this stage of the study program, there were no high-density contours for any megafauna species that overlapped the nearshore position of the Wheatstone trunkline, and the proposed coastal location of the Ashburton North Strategic Industrial Area.

The area nearshore of the 50m contour, in the vicinity of the proposed trunkline, is already a relatively high-density vessel traffic area. Monitoring increases in vessel traffic and the resulting effects on megafauna distribution will be an important component of ongoing development and production in the region.

7. Conclusions

- Humpback whales are present in the study area in increasing numbers from early to mid-June onwards to mid August when a peak occurs, after which numbers steadily decrease to end of December
- Spatial distribution of humpback whales is clustered indicating a likely northern migratory corridor centred 50 km offshore and a southern corridor 35 km offshore.

- Cow/calf humpback whale pods are found in highest numbers inside the 50m depth contour in the study area.
- Cow/calf pods are predominantly resting in the area nearshore of the 50m bathymetry, although for unknown lengths of time.
- Near shore waters have lower densities of humpback whales than offshore waters (deeper than 50m) in June and July perhaps due to annual water temperature profiles.
- Pygmy blue whales and dwarf minke whales are present in deeper waters of the offshore study area from mid May onwards, possibly as part of an annual north/south migration, although in the 2009 season apparently in lesser numbers (based on call rates) than in previous seasons (McCauley and Kent, 2009).
- Brydes' whales, sperm whales and pilot whales are present in the study area in deeper water areas at as yet undetermined frequencies and densities.
- Dugongs, dolphins and turtles are found predominantly inside the 50m depth contour with detection rates likely linked to sea state (and other visibility conditions).
- Manta rays are found predominantly in depths of 50-150m and sightings rates are also likely linked to sea state conditions.
- No megafauna species occurred in high densities in the immediate area adjacent to the proposed Wheatstone trunkline and coastal infrastructure during the June-December 2009 study period.

8. References

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Appendix 1 – Beaufort Sea State for all transects during each flight – darker shades indicate stronger wind.

Flight Number	Flight 1	Flight 2	Flight 3	Flight 4	Flight 5	Flight 6	Flight 7	Flight 8	Flight 9	Flight 10	Flight 11	Flight 12	Flight 13	Flight 14	Flight 15	Flight 16	Flight 17
Flight Date	17/05/2009	31/05/2009	12/06/2009	26/06/2009	11/07/2009	23/07/2009	05/08/2009	20/08/2009	03/09/2009	17/09/2009	02/10/2009	15/10/2009	02/11/2009	12/11/2009	28/11/2009	13/12/2009	24/12/2009
TRANSECT 1	3	3	4	1/ 2	3	2	1	1/ 2	3	2	2	1	2	2	2	2	2
TRANSECT 2	3	2/ 3	3	1	2	2	1	1	2/ 3	2	2	1	2	1	1	2	2
TRANSECT 3	3	2	3	1	3	2	1	1	2	2	3	1	2	2	1	2	2
TRANSECT 4	3	3	3	2	3	2	1	2	2	2	3	2	3	2	1	1	2
TRANSECT 5	2	2	2	2	3	2	1	2	2	2	3	1	3	3	3	2	2
TRANSECT 6	2	2	3	1/ 3	3	2	1	1/ 3	1/ 2	2	3	3	3	1	3	2	2
TRANSECT 7	2	2	3	3	3	2	1	3	0	2	3	3	3/ 4	3	3	3	2
TRANSECT 8	2	2	2	3	3	2	1/ 2	3	0	2	3	3	4	2	3	3	2
TRANSECT 9	2	2	2	2	3	2	1	2	0	2	3	2	3	3	3	3	2

Appendix 2 – Sea State as a sighting variable. Peak values per species/object in yellow for May to July.

Flight Date	Vessels	Aquaculture Net	Sperm whale	Minke whale	Pilot whale	Unidentified cetaceans	Dolphin spp.	Dugong	Manta ray	Turtle spp.	Whaleshark	Mean Sea State
17/05/09	51	0	0	0	0	0	10 (40)	13	2	53	1	2.4
31/05/09	42	1	0	0	0	0	18 (203)	3	0	101	0	2.3
12/06/09	36	1	0	0	25	0	4 (8)	12	4	32	0	2.8
26/06/09	48	1	0	1	0	0	28 (68)	31	12	122	0	1.8
11/07/09	48	1	10	0	0	2	10 (47)	2	1	14	0	3
23/07/09	55	1	0	0	0	0	29 (79)	25	3	100	0	2.2
TOTAL	280	5	10	0	25	2	0	86	22	422	1	

Appendix 05

Survey of Fish in Hooley Creek and the North-eastern Lagoon of the Ashburton Delta

Tables

Figure

Plates

Appendices

Abbreviations

Abbreviation	Description
ºC	Degrees Celsius
Chevron	Chevron Australia Pty Ltd
CITES	Convention of International Trade in Endangered Species of Wild Fauna and Flora 2009
DEWHA	Commonwealth Department of Environment, Water, Heritage and the Arts
DO	Dissolved oxygen
EPA	Western Australian Environmental Protection Authority
EPBC	Environment Protection and Biodiversity Conservation Act 1999;
ERMP	Environmental Review and Management Programme
FRMA	Western Australian Fish Resources Management Act 1994
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature and Natural Resources
km	kilometre/s
LNG	Liquefied natural gas
m	metre/s
mm	millimetre/s
MTPA	Million tonnes per annum
NTU	nephelometric turbidity unit
pH	phosphorus
ppt	parts per thousand
WAM	Western Australian Museum

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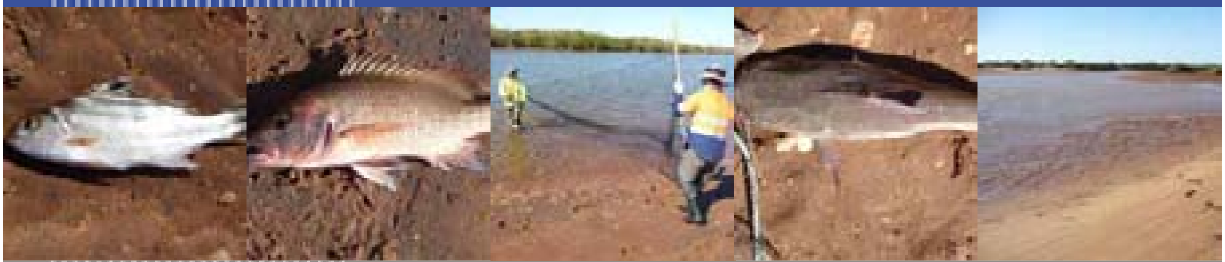

Report

Wheatstone Project

Survey of Fish in Hooley Creek and the North-eastern Lagoon of the Ashburton Delta

14 MAY 2010

Prepared for

Chevron Australia Pty Ltd

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Executive Summary

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

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). An Environmental Scoping Document was prepared by Chevron (2009), setting out the relevant factors and scope of work required for the Environmental Review and Management Programme (ERMP). This document was subsequently approved by the EPA and forms the basis of the forthcoming environmental assessment.

URS has developed a number of studies of the marine habitats of the Ashburton North site to provide the knowledge basis for the environmental assessment of the project. These studies concentrated on intertidal areas, which constitute the majority of the area at Ashburton North. The present study complements earlier work by examining subtidal fish and crustaceans caught in seine and prawn nets in late April 2010. Measurements of physical water parameters were also made using a multi-parameter instrument.

Three days of sampling at stations in West Hooley Creek and the north-eastern Ashburton lagoon revealed a moderate degree of fish diversity in the systems; 344 individuals of 34 species were recorded; only one individual each of the mudcrab *Scylla serrata* and the swimmer crab *Portunus* sp. were collected. Twenty fish species were recorded in West Hooley Creek and 28 in the Ashburton lagoon; 14 common species were recorded in both systems. In general, species that were found in only one creek were uncommon. Part of the differences can be attributed to physical differences in the areas sampled in the two systems.

Most of the fish enter the tidal channels on rising tides and depart on the subsequent falling tides. There are relatively few species that are restricted to the areas near the mangroves, such as the mudskipper genus *Periophthalmus*. The species recorded are broadly in agreement with the much more extensive work undertaken in Dampier by Hutchins (2003).

Protected species of sawfish have been sighted in both West Hooley Creek and the north-eastern Ashburton lagoon, but were not seen during the present study. As the sightings were made in November 2009, a similar survey is planned for November 2010 to maximise the opportunities for providing further information on these species.

A number of the species collected are potentially recreationally and commercially important. Both the Ashburton system and, to a lesser extent, Hooley Creek are recreational fishing areas. Scalefish species caught in the nets were generally too small to attract the attention of anglers, but there may be larger individuals present. The presence of small Sea Mullet (*Mugil cephalus*) in the Ashburton lagoon suggests the region is a nursery area, at least for this species.

While the present survey provides only a snapshot of the fish present, combined with the November 2010 survey, it will provide important information on the fish present in both Hooley Creek and the Ashburton system.

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Introduction

1.1 Background

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

The Wheatstone Project has been referred to the State Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA). An Environmental Scoping Document was prepared by Chevron (2009), setting out the relevant factors and scope of work required for the Environmental Review and Management Programme (ERMP). This document was subsequently approved by the EPA and forms the basis of the forthcoming environmental assessment.

URS has developed a number of studies of the marine habitats of the Ashburton North site to provide the knowledge basis for the environmental assessment of the Project. In particular, URS (2009a) examined the biotic communities inhabiting the intertidal environment along the Onslow coastline and provided considerable information on the plants and invertebrate animals inhabiting the Ashburton River delta and the Hooley Creek systems. Following the decision to move the proposed pipeline route into the north-eastern lagoon of the Ashburton River delta, URS (2010) provided more detail on the north-eastern lagoon. Bamford (2009) surveyed migratory birds in the area. Changes to the development footprint have increased the potential impact of the LNG plant site on West Hooley Creek, requiring the development of further information on the biota living in the creek itself, particularly the fish. These studies concentrated on the intertidal regions that constitute the great majority of the area of both the Ashburton and Hooley Creek systems. In recognition of this, URS (2010a) undertook a desktop study of available information on species, particularly fish, living in the subtidal parts of the systems. The report highlighted how little is known of the fish that live in Pilbara mangroves.

1.2 Significance of the Study

Fish are an iconic group to many people, including commercial and recreational fishers and environmental groups. All of these groups can be expected to closely scrutinise the Wheatstone ERMP for the effect of the Project on coastal fisheries. In addition to Project impacts directly in Hooley Creek and the north-eastern Ashburton lagoon, these habitats are regarded as important nursery areas for commercially-important species of fish (including banana prawns) and thus have a broader importance.

The present report will also provide information on sawfish present in the two areas. It is critical to determine what species are present in these systems.

The present report presents the results of surveys of fish and important crab species in the north-eastern lagoon of the Ashburton Delta and in Hooley Creek. It also contributes to the broader scientific knowledge of fish in Pilbara mangrove ecosystems.

1.3 Objectives

The key objective of this study is to supplement URS (2010a) by:

- Undertaking seasonal sampling of fish and recreationally- and commercially-important species of crabs in April/May and November 2010.
- Sampling in West Hooley Creek and the north-eastern lagoon of the Ashburton Delta. Both areas will potentially be impacted by the Wheatstone Project.
- Providing reports on species caught in each survey.
- Assessing implications of findings, particularly for protected species, for the Wheatstone Project.

Fish in Pilbara Mangrove Systems

2.1 Protected species

Sawfish (family Pristidae) are highly modified rays with a shark-like appearance but the head is flattened, with an elongated rostrum, known as the saw, which gives rise to the common name of sawfish. The saw has a number of pairs of rostral teeth that extend laterally. Four species occur in Western Australian waters, and all are protected under various legislation (Table 2-1). All four occur in nearshore coastal waters and estuaries, with the narrow and green sawfishes also extending to deeper waters of 40 to 70 m. As its name implies, the range of the freshwater sawfish (*Pristis microdon*) extends past estuaries well into freshwater habitats, but this is mainly in the juvenile stage. The dwarf sawfish (*P. clavata*) was originally considered to be a small species, <140 cm in total length, but specimens have been recorded with total lengths up to 310 cm. In contrast, the third species of the genus, the green sawfish *P. zijsron* can grow to 730 cm in Australian waters (Stevens et al. 2008; Last & Stevens 2009; DEWHA 2009). Both the dwarf and green sawfish tend to occur in shallow water near mangroves (Thorburn et al. 2004; 2007; DEWHA 2009). A fourth species, the narrow sawfish (*Anoxypristis cuspidata*) is protected under the Western Australian Fish Resources Management Act 1994 (FRMA). The exact range of all four species in Western Australia is unclear; all four occur in the Kimberley and possibly the Pilbara. The green sawfish extends to Coral Bay in WA and occasionally further south. A vagrant freshwater sawfish was recorded on the west coast as far south as Cape Naturaliste (Last & Stevens 2009). URS (2010a) provides more details of the reasons why sawfish are protected.

Table 2-1 Species of sawfish in northern Australia (data from DEWHA 2009)

Species	Common name(s)	Conservation status
Pristis clavata	Dwarf sawfish Queensland sawfish	EPBC: Vulnerable FRMA: Totally Protected CITES: Appendix I IUCN: Critically endangered
Pristis microdon	Freshwater sawfish	EPBC: Vulnerable FRMA: Totally Protected CITES Appendix II
Pristis zijsron	Green sawfish Narrowsnout sawfish Dindagubba	EPBC: Vulnerable FRMA: Totally Protected CITES: Appendix I IUCN: Critically endangered
Anoxypristis cuspidata	Narrow sawfish	FRMA: Totally Protected IUCN: Critically endangered

EPBC = Environment Protection and Biodiversity Conservation Act 1999; FRMA = Western Australian Fish Resources Management Act 1994. IUCN = International Union for Conservation of Nature and Natural Resources (IUCN) Red List 2008. CITES = Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) 2009.

No bony fish are regarded as endangered in northern Western Australia (DEWHA 2008). Four endangered species of sharks occur in the state (DoF 2008a): whale shark (*Rhincodon typus*), great white shark (*Carcharodon carcharias*), grey nurse shark (*Carcharias taurus*) and northern river shark (*Glyphis* sp. C). The first three are known to occur in Pilbara waters, but are large sharks that occur farther offshore and are very unlikely to enter mangrove systems. The northern river shark occurs in

Papua New Guinea and northern Australia. The only reference to Western Australian localities in DoF (2008a) is for the Kimberley region, not the Pilbara.

2.2 Sawfish species present at Ashburton North

In late 2009, survey teams sighted three small (<1.2 m) sawfish in the north-eastern lagoon of the Ashburton Delta and one in Hooley Creek. The most substantial sighting was made in a small intertidal pool at Hooley Creek in November 2009, when a school of 12-15 small sawfish was seen feeding on minnows in the shallows (URS 2010a). As all of the sawfish sighted were small, they are probably juveniles. There is scant information on the use of mangrove systems by sawfish, though they may move closer to inshore waters in the later months of the year, as evidenced by the sightings at Ashburton North in November and December 2009. Further north, Thorburn et al. (2007) reported that Dwarf Sawfish use estuarine habitats as nursery areas. Juveniles remain in these areas until they are three years old.

Without a specimen, the identification of these sawfish cannot be confirmed. There is little information available on the distribution of sawfish in the Pilbara. An analysis of the bycatch of the Pilbara Fish Trawl Fishery found that 89 narrow sawfish (*Anoxypristis cuspidata*) and 25 green sawfish (*Pristis zijsron*) were caught in the fishery in 2003 (DoF 2004), confirming the presence of the two species in the Pilbara. A similar analysis of the Onslow Nickol Bay Prawn Fishery did not record sawfish as bycatch. All four species are thought to occur in the Pilbara (DoF 2008b). As its common name implies, the green sawfish (*P. zijsron*) has a green colouration, as has the dwarf sawfish (*P. clavata*). Neither the freshwater sawfish (*P. microdon*) nor the narrow sawfish (*A. cuspidata*) are green. As the green sawfish is trawled in the Pilbara (DoF 2004), it is likely that this was the green species sighted by URS in the Ashburton lagoon. A second, less likely, possibility is that the species was the dwarf sawfish. Both the green and dwarf sawfish are classified as vulnerable under the EPBC and are totally protected under the FRMA. It is also possible that other species may occasionally be present in Hooley Creek and the Ashburton system.

2.3 Other species of fish

The fish biota of Pilbara mangroves is poorly known. The Western Australian Museum (WAM) has records of only nine species in the Ashburton system and none in Hooley Creek (Sue Morrison, WAM, pers. comm.). The nine species from the Ashburton system were collected during the early 1970s during a freshwater fish survey in the river, not the delta (Dr Jerry Allen, WAM, pers. comm.).

As part of a survey of the fishes of the Dampier Archipelago, Hutchins (2003) compiled a list of species found in mangroves in the Dampier region. The records were obtained by a combination of fieldwork, the scientific literature and specimen records in WAM collected over a period of decades. A total 121 species were listed for mangrove systems. Table 2-2 shows that the majority (69) of the 121 species listed for mangroves, were also listed for other habitats, primarily pelagic (25 species) or reefs (24); eight species occurred in both habitats. This shows that most of the fish species in mangroves are not restricted to the mangroves; even species listed as commonly found only in mangroves are likely to also occur in other habitats. In particular, pelagic species move into and out of mangroves with the tides.

2 Fish in Pilbara Mangrove Systems

Table 2-2 Habitats of fish present in Dampier mangroves (from Hutchins 2003)

Habitat	Number of species
Mangrove only	52
Mangrove – Reef	24
Mangrove – Sand	7
Mangrove - Trawling	3
Mangrove – Pelagic	25
Mangrove - Reef & Sand	2
Mangrove - Reef & Pelagic	8
Total	121

As many of these species were found only on one or a few occasions, Hutchins (2003) considered analysis of the most abundant species to provide a better method of characterising the fish fauna of the archipelago. This method included 24 species from hard bottoms, 14 from soft bottoms, and nine from mangroves. Characteristic mangrove species are shown in Table 2-3.

Table 2-3 Habitats of common fish in Dampier mangroves (from Hutchins 2003)

Species	Family	Common name	Habitat
Herklotsichthys koningsbergeri	Clupeidae	Herring, sardine	Mangroves and pelagic
Zenarchopterus rasori	Hemiramphidae	Halfbeak	Mangroves and pelagic
Craterocephalus pauciradiatus	Atherinidae	Silverside	Mangroves and reef
Ambassis vachellii	Chandidae	Glassfish	Mangroves and reef
Acanthopagrus latus	Sparidae	Bream	Mangroves and reef
Abudefduf bengalensis	Pomacentridae	Damselfish	Mangroves and reef
Liza alata	Mugilidae	Mullet	Mangroves
Valamugil buchanani	Mugilidae	Mullet	Mangroves, reef and pelagic
Acentrogobius gracilis	Gobiidae	Goby, mudskipper	Mangroves

The nine species are from eight different families; there are two species of Mugilidae (mullets). Seven of the nine species are recorded as being common in two or more habitats. Mangrove species are shared with reef and pelagic habitats.

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Methodology

The fish survey was undertaken from 17 to 21 April 2010. The areas surveyed were the lower portion of West Hooley Creek (one net was set on East Hooley Creek) and the north-eastern lagoon of the Ashburton delta (Figure 3-1). Two net types were used for most of the survey: a 30 x 1.5 m net with a 50 mm mesh (Figures 3-2 and 3-3) was used as a seine or a set net, and a small prawn net (4 x 1.5 m with a 10 mm mesh) was used to sample smaller areas (Figure 3-4). The last two hauls at the Ashburton site were made with the large net. As it neared shore, the prawn net was deployed within the larger net to prevent small fish from escaping through the mesh. In addition, several casts were made with a small (4 m diameter) throw net at Hooley Creek on 19 April. Physical measurements were made of the GPS location, water temperature, salinity, pH, dissolved oxygen concentration and turbidity. Water characteristics were measured with a YSI 6600EDS multi-parameter water quality sonde inserted to near the bottom in shallow areas and about 1 m depth at deeper stations.

The predicted low tide on 18 April was 1.05 m at 0616. As some of the field staff underwent inductions prior to entering the Ashburton north site, fishing commenced on arrival at West Hooley Creek at about 1000 on 18 April, at about half tide. Fishing was initially from shore using both nets. Dinghies from *King Diver* were prevented from entering the creek until the tide was sufficiently high at 1030. Following their arrival, the 30 m net was used as a seine or a set net from the dinghies and the prawn net was used from shore. Fishing continued until approximately 1600.

The same area was fished on 19 April. The combination of a later low tide (1.10 m at 0644) and earlier arrival (0730) meant water levels in West Hooley Creek were initially very low (Figures 3-5 and 3-6). The creek was about 50 m wide in the area fished. As it was <60 cm deep at the shallowest point, the entire width of the creek could be fished. However, there were relatively few fish in the shallow water, so a deeper area of 90 cm was fished. Catches in this area were higher. As the tide returned, fish entering the upper areas of West Hooley Creek passed through the area being fished. At high tide the deepest areas fished with the set net were approximately 3 m deep.

The eastern end of the north-eastern lagoon of the Ashburton delta was surveyed on 20 April, when the predicted low tide was 1.18 m at 0707. On arrival at 0730, there was a small tidal lagoon approximately 60 m long and 30 m wide at the eastern end (Figure 3-7). The large net was used as a seine to sweep the entire area of this tide pool; the prawn net was then used in the eastern half. Both nets produced excellent results. The lagoon was continuous to the west. The survey proceeded westward in the southern half of the lagoon until the westernmost area of the survey was reached. As the entrance to the Ashburton Delta is very shallow, the *King Diver* dinghies were unable to enter until 1200. Fishing continued in the area using a combination of shore sweeps and dinghy sets with the large net and shoreline surveys with the prawn trawl. As small fish were escaping through the large mesh, the prawn net was inserted into the middle of the large net during the final stages of the last two hauls to retain the smaller species.

Fish were immediately placed in a nally bin containing seawater when the net arrived on shore. Each fish was provisionally identified, counted and measured (standard length). One or more individuals of all species were photographed with a digital camera. Representatives of most species were retained for the permanent collections of WAM. This process required only a few minutes. All species of fish remaining alive, the majority of individuals, were returned to the water.

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Survey of the Fishes in the Wheatstone Area (URS, 2010)
Indicative Terrestrial Project Area
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CHEVRON AUSTRALIA PTY LTD
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Wheatstone Project
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3 Methodology

Plate 3-1 Fish being removed from the large net on West Hooley Creek.

Plate 3-2 Removing a fish from the large net.

3 Methodology

Plate 3-3 The prawn net being used at West Hooley Creek.

Plate 3-4 The main area sampled on West Hooley Creek, shown on an incoming tide.

3 Methodology

Plate 3-5 The area sampled slightly further up West Hooley Creek.

Plate 3-6 The tidepool in the eastern corner of the north-eastern Ashburton lagoon.

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Survey Results

4.1 Physical data

4.1.1 West Hooley Creek

Table 4-1 shows the physical data collected with the samples at Hooley Creek. In general the data fluctuated within moderate ranges. Water temperatures in the morning were as low as (19.5ºC) and increased in the afternoon to as much as 27.5ºC. Salinities were consistently higher than seawater, ranging from 41.7 ppt to 47.2 ppt. pH was almost constant, ranging only from 8.1 to 8.3. Dissolved oxygen was always high, from 90 to 100% of saturation. Turbidity was in general low, from 1 to 16.9 NTU.

Table 4-1 Physical data collected in Hooley Creek

Sample	Northing	Easting	Temperature (°C)	Salinity (ppt)	pH	DO (%)	NTU
HC-1	295364	7700475	25.08	42.26	8.23	99	4.5
HC-2	295392	7600487	25.38	42.15	8.29	95.9	1
HC-3	295358	7600478	25.25	41.96	8.30	94.7	3
HC-4	295329	7600462	25.29	41.89	8.30	97.1	6
HC-5	295452	7600497	26.04	41.69	8.24	97	11.7
HC-6	295461	7600497	26.58	41.72	8.25	93.5	12.1
HC-7	295498	7600513	26.38	41.66	8.22	97.8	2.8
HC-8	295375	7600490	26.90	42.03	8.10	98.1	2.7
HC-10	295364	7600475	27.47	41.85	8.12	100	3.2
HC-11	295392	7600487	24.65	47.18	8.33	99.6	1.3
HC-12	295358	7600478	24.76	46.92	8.29	99.4	4
HC-13	295329	7600462	24.79	46.57	8.26	99.4	4
HC-14	295452	7600497	24.85	46.25	8.31	89.7	4.6
HC-15	295461	7600497	25.09	46.09	8.29	94	6.6
HC-16	295498	7600513	25.09	46.09	8.29	94	6.6
HC-17	295375	7600490	25.70	45.21	8.18	96.5	8.2
HC-18	295364	7600475	25.60	45.26	8.35	95.7	16.9
HC-19	295392	7600487	25.40	45.75	8.27	90.9	2
HC-23	295973	7599809	26.68	41.88	8.23	99	3.7
HC-24	295347	7600441	26.60	41.90	8.21	100	3.7
HC-25	295208	7600279	27.06	41.93	8.33	96.8	4.5

4.1.2 North-eastern lagoon of the Ashburton River

Physical data collected in the north-eastern lagoon of the Ashburton lagoon were similar to those obtained in Hooley Creek (Table 4-2). Despite the early morning arrival, temperatures were higher in the Ashburton lagoon, ranging from 23.2ºC to 32.0ºC. Salinity varied over a small range from 42.0 to 44.9 ppt. pH ranged from 8.2 to 8.3. Dissolved oxygen (84 to 116% saturation) and turbidity (3 to 128 NTU) were both more variable than in Hooley Creek. The measurements of samples ASH-3 and ASH-4 were made after the nets were hauled, which artificially increased the turbidity.

Table 4-2 Physical data collected in the north-eastern lagoon of the Ashburton Delta

Sample	Northing	Easting	Temperature (ºC)	Salinity (ppt)	pH	DO (%)	NTU
ASH-1	294049	7600741	23.17	44.85	8.16	100.6	3
ASH-2	294049	7600741	23.17	44.85	8.16	100.6	3
ASH-3	293867	7600769	28.84	43.94	8.19	84.5	128
ASH-4	293867	7600769	28.84	43.94	8.19	84.5	128
ASH-5	293090	7600888	26.17	43.25	8.16	90.7	44.9
ASH-6	293090	7600888	26.17	43.25	8.16	90.7	44.9
ASH-7	292672	7600978	31.16	44.63	8.25	116.3	31.7
ASH-8	292672	7600978	31.16	44.63	8.25	116.3	31.7
ASH-9	292672	7600978	31.16	44.63	8.25	116.3	31.7
ASH-10	292628	7600975	28.20	44.13	8.23	105.5	8.6
ASH-11	292509	7601102	26.84	42.03	8.26	99.6	9.2
ASH-12	292787	7600918	30.47	42.67	8.25	109.8	18.5
ASH-13	292787	7600918	30.47	42.67	8.25	109.8	18.5
ASH-14	292787	7600918	32.07	42.83	8.32	109.0	9

4.2 Fish caught

4.2.1 West Hooley Creek

A total of 115 fish of 20 species were caught (or seen) in the samples made at Hooley Creek (Tables 4-3 and 4-5). There was a considerable size range of individual fish, ranging from 26 mm standard length for a small Hardyhead (*Craterocephalus* sp.) to 510 mm for a Giant Sea Catfish (*Netuma thalassina*). The Common Hardyhead (*Atherinomorus vaigiensis*) was the most abundant fish caught, with 44% of the total. This figure was high because part of a small school was caught in a single cast by a throw net. Catches in the large net were dominated by Sea Mullet (*Mugil cephalus*)

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and Western Yellowfin Bream (*Acanthopagrus latus*). Both are important recreational and commercial species, but the individuals were small. The largest mullet was 230 mm and the largest bream was 160 mm.

Table 4-3 Fish caught in Hooley Creek

Sample	Scientific name	Common name	Standard Length (mm)
HC-1	*Craterocephalus* sp.? *Ambassis gymnocephalus*	Hardyhead Barehead Glassfish	30,30,30 40
HC-2	None		
HC-3	None		
HC-4	*Periophthalmus argentilineatus*	Silverlined Mudskipper	30,50
HC-5	*Acanthopagrus latus* *Aptychotrema vincentiana?*	Western Yellowfin Bream Western Shovelnose Ray	? Visual record
HC-6	*Valamugil buchanani* *Sillago ingenuua?* Hemiramphidae	Bluetail Mullet Bay Whiting Garfish	165,170,170 37 Visual record
HC-7	*Atherinomorus vaigiensis* *Sillago* sp.	Common Hardyhead Whiting	80 50
HC-8	*Sillago ingenuua?* *Acanthopagrus latus*	Bay Whiting Western Yellowfin Bream	120 100
HC-9	*Atherinomorus vaigiensis*	Common Hardyhead	42 individuals
HC-10	None		
HC-11	None		
HC-12	*Amniataba caudavittata* *Lutjanus argentimaculatus* *Acanthopagrus palmaris* *Mugil cephalus*	Yellowtail Grunter Mangrove Jack Northwest Black Bream Sea Mullet	150 250 220 200, 215
HC-13	*Acanthopagrus latus* *Acanthopagrus palmaris* *Lutjanus argentimaculatus* *Atherinomorus vaigiensis* *Mugil cephalus*	Western Yellowfin Bream Northwest Black Bream Mangrove Jack Common Hardyhead Sea Mullet	135, 140, 160,160 280 230 53 115,205
HC-14	*Acanthopagrus latus* *Mugil cephalus*	Western Yellowfin Bream Sea Mullet	33 195,205,225,230
HC-15	*Scomberoides commersonnianus* *Acanthopagrus latus*	Giant Queenfish Western Yellowfin Bream	210 118,125,150
HC-16	*Valamugil buchanani*	Bluetail Mullet	205,225

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Sample	Scientific name	Common name	Standard Length (mm)
HC-17	*Acanthopagrus latus* *Mugil cephalus* *Valamugil buchanani*	Western Yellowfin Bream Sea Mullet Bluetail Mullet	138 195,198,202 265
HC-18	*Acanthopagrus latus* *Mugil cephalus*	Western Yellowfin Bream Sea Mullet	104 180
HC-19	*Netuma thalassina* *Terapon theraps*	Giant Sea Catfish Largescale Grunter	180,185,190,195,205, 456,510 1 partially eaten 155
HC-20	*Atherinomorus vaigiensis*	Common Hardyhead	80
HC-21	*Atherinomorus vaigiensis* *Craterocephalus* sp.	Common Hardyhead Hardyhead	73,74,75,80,81,84,88, 26
HC-22	*Valamugil buchanani* *Mugil cephalus*	Bluetail Mullet Sea Mullet	240 155,165,195,210
HC-23	*Valamugil buchanani*	Bluetail Mullet	280
HC-24	None		
HC-25	*Nematalosa come* *Scylla* sp.	Hairback Herring Brown mud crab	155

4.2.2 North-eastern lagoon of the Ashburton River

A greater diversity of fish (28 species) and abundance (229 individuals) was caught or seen in the north-eastern Ashburton lagoon (Table 4-4). A grey shark approximately 1.2 m in length was caught briefly in the net and escaped. A small Black Tipped Shark (*Carcharhinus* sp.) was also seen but not caught. The largest individual caught was a Cowtail Stingray (*Pastinachus sephen*), 950 mm in total length. Other large individuals were a Blue Threadfin (*Eleutheronema tetradactylum*) of 530 mm and Western Shovelnose Rays (*Aptychotrema vincentiana*) of 440 and 460 mm

Numerous small individuals were caught with the prawn net. These was a combination of small juveniles of larger species such as mullet, and adults or near adults of small species. The Ornate Ponyfish (*Leiognathus decorus*) dominated catches in the prawn nets, with 46 individuals ranging in size from 15 to 55 mm, with a mean of 38.9 ± 4.9 (SE) mm. The Blacktip Silverbiddy (*Gerres oyena*) was also common. Twenty-one individuals were caught, ranging from 19 to 58 mm in standard length, with a mean of 40.0 ± 3.0 mm.

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Table 4-4 Fish caught in the north-eastern Ashburton lagoon

Sample	Scientific name	Common name	Standard Length (mm)
ASH-1	*Sillago ingenuua*	Bay Whiting	40,80
	Terapon theraps	Largescale Grunter	45
	Amniataba caudavittata	Yellowtail Grunter	115,148,155,158
	Mugil cephalus	Sea Mullet	48,50,50,50,52,60,60, 60,70,72,73,73,80,88, 167,180,190,195,210, 240
	Drepane punctata	Sicklefish	190
	Acanthopagrus latus	Western Yellowfin Bream	122,148
	Acanthopagrus palmaris	Northwest Black Bream	110
ASH-2	*Lutjanus argentimaculatus*	Mangrove Jack	195
	Lutjanus fulviflamma	Blackspot Snapper	69
	Amniataba caudavittata	Yellowtail Grunter	93
	Ambassis gymnocephalus	Barehead Glassfish	19,20,24,30
	Gerres oyena	Blacktip Silverbiddy	22,23,28,39,44,45,48, 48,49,52,55,55,58,59
	Leiognathus decorus	Ornate Ponyfish	28,30,30,31,31,32,33, 34,34,35,35,35,35,37, 38,38,40,40,41,41,42, 45,45,47,48,55
	Mugil cephalus	Sea Mullet	70
	Valamugil buchanani	Bluetail Mullet	65
	Yongeichthys nebulosus	Hairfin Goby	63
	Chelonodon patoca	Milkspot Toadfish	31,33,35,36,36,37,37, 38,38,38,39,39,39,40, 40,42,43
	Hemiramphus robustus	Three-by-two Garfish	39
ASH-3	*Leiognathus equulus*	Common Ponyfish	120,140,165
	Mugil cephalus	Sea Mullet	55,65,225,375
	Pomadasys kaakan	Barred Javelinfish	140,180
	Eleutheronema tetradactylum	Blue Threadfin	530
	Carcharhinus sp.	Black Tipped Shark	Visual record
ASH-4	*Pastinachus sephen*	Cowtail Stingray	950 (total length)
	Leiognathus decorus	Ornate Ponyfish	35,36,38,38,42,55
ASH-5	*Drepane punctata*	Sicklefish	115
	Lutjanus argentimaculatus	Mangrove jack	240,240
	Leiognathus decorus	Ornate Ponyfish	15,18,20,20,20,20,22, 25,40,
	Aptychotrema vincentiana	Western Shovelnose Ray	440
	Netuma thalassina	Giant Sea Catfish	230,250,270

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Sample	Scientific name	Common name	Standard Length (mm)
ASH-6	*Leiognathus decorus* *Nematalosa come*	Ornate Ponyfish Hairback Herring	22,23,24,42,48 65,70,72
ASH-7	*Gerres oyena*	Blacktip Silverbiddy	28
ASH-8	*Mugil cephalus*	Sea Mullet	65,70,158
ASH-9	*Caranx papuensis* *Amniataba caudavittata* *Chelonodon patoca* *Valamugil buchanani* *Mugil cephalus* *Acanthopagrus latus*	Brassy Trevally Yellowtail Grunter Milkspot Toadfish Bluetail Mullet Sea Mullet Western Yellowfin Bream	133 153 94 245 245 150
ASH-10	*Acanthopagrus latus*	Western Yellowfin Bream	95,125,132,135,138, 140,140,160
ASH-11	*Valamugil buchanani* *Netuma thalassina* *Mugil cephalus* *Scomberoides* sp. *Scomberoides commersonianus*	Bluetail Mullet Giant Sea Catfish Sea mullet Queenfish Giant Queenfish	290,290,230,285,370, 440 205,210,215,220,230 235,250,250,250, Bitten in half 230
ASH-12	*Chelonodon patoca* *Selenotoca multifasciata*	Milkspot Toadfish Striped Scat Grey shark	105 140,145 Visual record
ASH-13	*Aptychotrema vincentiana* *Valamugil buchanani* *Mugil cephalus* *Sillago ingenuua*	Western Shovelnose Ray Bluetail Mullet Sea Mullet Bay Whiting	460 94,95,99 52,55,55,65,68 30,38,42,65,80,88,90, 93,96
ASH-14	*Acanthopagrus latus* *Mugil cephalus* *Sillago ingenuua* *Gerres oyena*	Western Yellowfin Bream Sea Mullet Bay Whiting Blacktip Silverbiddy	155 38,55,58,58,58,60,65, 72,73,78 30,55,55,58, 58,68,68, 85,88,88,89 45,50

4.2.3 Comparison of fish caught in the two areas

Twenty species were caught or sighted in Hooley Creek and 28 in the north-eastern Ashburton Lagoon; overall 34 species were recorded. Fourteen species were recorded in both areas. These tended to be the more common larger species such as Sea Mullet (*Mugil cephalus*), Bluetail Mullet (*Valamugil buchanani*), Western Yellowfin Bream (*Acanthopagrus latus*) and Giant Sea Catfish (*Netuma thalassina*). Less abundant species were often found in only one area. Interestingly, the common smaller species tended to be present in only one system. For example, 51 individuals of the

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Common Hardyhead (*Atherinomorus vaigiensis*) were caught in West Hooley Creek and none in the Ashburton lagoon. Conversely, 51 Ornate Ponyfish (*Leiognathus decorus*) and 43 Blacktip Silverbiddy (*Gerres oyena*) were caught in the Ashburton lagoon and none in Hooley Creek. The individuals of all of these species were relatively small juveniles of species that grow to much larger sizes.

A greater number of fish (229) were caught in the north-eastern Ashburton lagoon than in Hooley Creek (115), despite there being two days of fishing in Hooley Creek and only one in the Ashburton lagoon. The differences were largely due to the small tidepool in the north-eastern Ashburton lagoon, where 99 fish were caught in a single haul with the large net (ASH-1) plus one haul with the prawn net (ASH-2). In addition, the most productive sampling occurred in the early morning in both systems when the tide was minimal.

Table 4-5 Comparison of fish caught in Hooley Creek and the north-eastern Ashburton lagoon

Scientific name	Common name	Hooley Creek	Ashburton lagoon	Combined
Mugil cephalus	Sea Mullet	16	42	58
Atherinomorus vaigiensis	Common Hardyhead	51		51
Leiognathus decorus	Ornate Ponyfish		46	46
Gerres oyena	Blacktip Silverbiddy		43	43
Acanthopagrus latus	Western Yellowfin Bream	12	12	24
Chelonodon patoca	Milkspot Toadfish		18	18
Valamugil buchanani	Bluetail Mullet	7	11	18
Sillago ingenuua?	Bay Whiting	2	13	15
Netuma thalassina	Giant Sea Catfish	8	4	12
Ambassis gymnocephalus	Barehead Glassfish	1	4	5
Nematalosa come	Hairback Herring	1	3	4
Craterocephalus sp.?	Hardyhead	4		4
Acanthopagrus palmaris	Northwest Black Bream	2	1	3
Lutjanus argentimaculatus	Mangrove Jack	2	1	3
Selenotoca multifasciata	Striped Scat		2	2
Periophthalmus argentilineatus	Silverlined Mudskipper	2		2
Aptychotrema vincentiana	Western Shovelnose Ray	Visual record	2	2
Amniataba caudavittata	Yellowtail Grunter	1	1	2
Scomberoides commersonnianus	Giant Queenfish	1	1	2
Terapon theraps	Largescale Grunter	1	1	2
Drepane punctata	Sicklefish	1	1	2
Sillago sp.	Whiting	1		1
Atherinomorus vaigiensis	Common Hardyhead	1		1

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Scientific name	Common name	Hooley Creek	Ashburton lagoon	Combined
Lutjanus fulviflamma	Blackspot Snapper		1	1
Yongeichthys nebulosus	Hairfin Goby		1	1
Hemiramphus robustus	Three-by-two Garfish		1	1
Eleutheronema tetradactylum	Blue Threadfin		1	1
Pastinachus sephen	Cowtail Stingray		1	1
Caranx papuensis	Brassy Trevally		1	1
Amniataba caudavittata	Yellowtail Grunter		1	1
Scomberoides sp.	Bitten in half - unidentifiable		1	1
Hemiramphidae	Garfish	Visual record		
	Grey shark		Visual Record	
Carcharinus sp.	Black Tipped Shark		Visual Record	
Total numbers		115	229	344
Total species		20	28	34

Plates 4-1 to 4-9 show some of the fish caught in the two areas.

Plate 4-1 The Largescale Grunter (*Terapon theraps*)

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Plate 4-2 A juvenile of the Giant Sea Catfish (*Netuma thalassina*)

Plate 4-3 A large (456 mm) individual of the Giant Sea Catfish (*Netuma thalassina*)

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Plate 4-4 The mangrove Mangrove Jack (*Lutjanus argentimaculatus*).

Plate 4-5 Several individuals of the Giant Queenfish (*Scomberoides commersonnianus*) were caught.

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Plate 4-6 The common hardyhead (*Atherinomorus vaigiensis*) was the most abundant small species of fish in West Hooley Creek, with schools being seen in shallow water

Plate 4-7 The Bluetail Mullet (*Valamugil buchanani*)

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Plate 4-8 The Western Yellowfin Bream (Acanthopagrus latus)

Plate 4-9 The Cowtail Stingray (*Pastinachus sephen*)

4.2.4 Recreationally- and commercially-important species

A number of species that are potentially recreationally- and commercially-important were caught. Mullet were most numerous amongst these: 58 Sea Mullet (*Mugil cephalus*) and 18 Bluetail Mullet (*Valamugil buchanani*). The size characteristics of the Sea Mullet differed in the two systems. There was one 115 mm long Sea Mullet in West Hooley Creek. The remaining 15 individuals were large, ranging in size from 155 to 230 mm, with a mean of 198.3 ± 5.2 mm. The sizes of large mullet in the Ashburton lagoon were similar. Again there was a single individual of 115 mm. Twenty-two large mullet ranged in length from 148 to 250 mm, with a mean of 200.6 ± 8.3 mm, very close to the mean in Hooley Creek. A single very large individual of 375 mm was caught. The Ashburton lagoon differed from Hooley Creek in the presence of 19 small mullet of 48 to 88 mm (mean 63.7 ± 2.6 mm).

Other common fish that are potentially recreationally- and commercially-important included 24 individuals of the Western Yellowfin Bream (*Acanthopagrus latus*) and 12 Giant Sea Catfish (*Netuma thalassina*). Less common were three Northwest Black Bream (*Acanthopagrus palmaris*), three Mangrove Jack (*Lutjanus argentimaculatus*), one Blackspot Snapper (*Lutjanus fulviflamma*), one Blue Threadfin (*Eleutheronema tetradactylum*) and one Brassy Trevally (*Caranx papuensis*). Aside from the 530 mm Blue Threadfin, these species were all too small to be taken for human food.

A single undersize individual of the mud crab *Scylla serrata* was recorded in West Hooley Creek and a single juvenile specimen of the swimmer crab *Portunus* sp. was found in the Ashburton lagoon.

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Discussion and Conclusions

The present report provides a snapshot of fish species present in West Hooley Creek and the north-eastern Ashburton lagoon in late April 2010. A second survey is planned for November 2010 to provide similar snapshot information late in the year. It must be recognised that the study was intended to present only a brief snapshot of the fish present. Sampling was limited temporally and spatially. Other methods would collect additional species. For example, use of the fish poison rotenone would collect more fish, but would be destructive.

The results suggest there is a moderate degree of fish diversity in the systems, with 34 species being recorded in only three days of sampling; 20 species were recorded in West Hooley Creek and 28 in the Ashburton lagoon. Fourteen species were found in both systems; most were common in both West Hooley Creek and the north-eastern Ashburton lagoon. Most of the species that were found in only one creek were uncommon: two species were represented by two individuals each, 10 species by one individual and three species were recorded only by sight. More extensive sampling would be expected to show a higher proportion of the species are to be found in the two systems.

Part of the differences, however, can be attributed to the areas sampled. There was a small (60 m long) tidepool at the eastern end of the north-eastern Ashburton lagoon, the margins of the system. Samples in the west in the lagoon were more similar to the part of West Hooley Creek sampled, and the fish present had a greater overlap.

As in previous studies, most of the fish enter the tidal channels on rising tides and depart on falling tides. There are relatively few species that are restricted to the areas near the mangroves, such as the mudskipper genus *Periophthalmus*. The species recorded are broadly in agreement with the much more extensive work undertaken in Dampier by Hutchins (2003). As many of the species were present on the high part of the tidal cycle, a trawl conducted by Kangas et al. (2007) off the entrance to the Ashburton system provides a broader list of species (Appendix A) that could potentially be found in the two creeks examined in the present study.

Protected species of sawfish have been sighted in both West Hooley Creek and the north-eastern Ashburton lagoon, but were not seen during the present study. As the sightings were made in November 2009, a similar survey is planned for November 2010 to maximise the opportunities for providing further information on these species.

A number of the species collected are potentially recreationally- and commercially-important. Both the Ashburton system and, to a lesser extent, Hooley Creek are recreational fishing areas. Neither is fished commercially, though both are included in the nursery area for the Onslow Prawn Managed Fishery (URS 2009). Scalefish species caught in the nets were generally too small to attract the attention of anglers, but there may be larger individuals present. The presence of small Sea Mullet (*Mugil cephalus*) in the Ashburton lagoon suggests the region is a nursery area, at least for this species.

While the present survey provides only a snapshot of the fish present, combined with the November 2010 survey, it will provide important information on the fish present in both Hooley Creek and the Ashburton system.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the CTR dated 17 March 2010.

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

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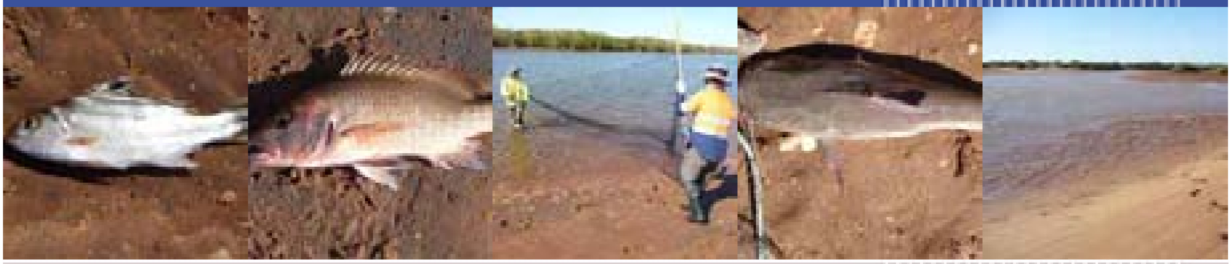
A

Appendix A Species caught in trawl conducted by Kangas et al. (2007) off the entrance to the Ashburton system

Exmouth Gulf Fishes - Onslow fishery				
Fam no:	**Sp no:**	**Family**	**Scientific name**	**Common name**
018.1	006	Carcharhinidae	*Rhizoprionodon acutus*	Shark, Milk
035	020	Dasyatididae	*Himantura toshi*	Ray, Black-spotted Whipray
039	000	Myliobatididae	*Aetomylaeus vespertilio*	Ray, Ornate Eagle Ray
085	022	Clupeidae	*Herklotsichthys blackburni*	Herring, Blackburn's
085	013	Clupeidae	*Sardinella gibbosa*	Sardine, Gold-striped
086	801	Engraulidae	*Stolephorus insularis*	Anchovy, Hardenberg's
086	005	Engraulidae	*Thryssa hamiltoni*	Anchovy, Hamilton's
087	001	Chirocentride	*Chirocentrus dorab*	Herring, Wolf
118.1	005	Bathysauridae	*Saurida argentea (was micropectoralis)*	Lizardfish, Short-finned
118.1	001	Bathysauridae	*Saurida undosquamis*	Lizardfish, Large-scaled
188	001	Ariidae	*Arius thalassinus*	Catfish, Giant Salmon
192	003	Plotosidae	*Euristhmus nudiceps*	Catfish, Naked-headed
192	801	Plotosidae	*Paraplotosus* sp.	Catfish, Eel-tailed
278	001	Fistulariidae	*Fistularia commersonii*	Flutemouth, Smooth
296	029	Platycephalidae	*Inegocia japonica*	Flathead, Rusty
296	020	Platycephalidae	*Platycephalus endrachtensis*	Flathead, Bar-tailed
296	033	Platycephalidae	*Platycephalus insularis*	Flathead, Indian
321	005	Terapontidae	*Pelates sexlineatus*	Trumpeter, 6-lined
321	006	Terapontidae	*Terapon puta*	Trumpeter, 3-lined
321	003	Terapontidae	*Terapon theraps*	Trumpeter, Banded
327	013	Apogonidae	*Apogon ellioti*	Cardinalfish, Flagfin
327	026	Apogonidae	*Apogon poecilopterus*	Cardinalfish, Pearly-Finned
330	004	Sillaginidae	*Sillago burrus*	Whiting, Trumpeter
330	007	Sillaginidae	*Sillago lutea*	Whiting, Mud
337	038	Carangidae	*Alectis indica*	Trevally, Diamond
337	072	Carangidae	*Parastromateus niger*	Pomfret
341	007	Leiognathidae	*Gazza minuta*	Ponyfish, Tooth Pony
341	009	Leiognathidae	*Leiognathus fasciatus*	Ponyfish, Striped
341	005	Leiognathidae	*Leiognathus leuciscus*	Ponyfish, Whipfin
341	004	Leiognathidae	*Leiognathus longispinis*	Ponyfish, Smithurst's
341	006	Leiognathidae	*Secutor insidiator*	Ponyfish, Pugnose
346	007	Lutjanidae	*Lutjanus malabaricus*	Seaperch, Saddle-tailed
349	005	Gerreidae	*Gerres subfasciatus*	Roach/Banded Silver-biddy
349	002	Gerreidae	*Pentaprion longimanus*	Silver Biddy, Long-Finned
350	011	Haemulidae	*Pomadasys kaakan*	Javelinfish, Spotted
350	002	Haemulidae	*Pomadasys maculatus*	Javelinfish, Blotched
354	000	Sciaenidae	*Johnius vogleri*	Croaker, Little Jewfish
355	010	Mullidae	*Upeneus asymmetricus*	Goatfish, Asymmetrical
355	014	Mullidae	*Upeneus tragula*	Goatfish, Bar-tailed
362	005	Ephippidae	*Drepane punctata*	Sicklefish
383	002	Polynemidae	*Polydactylus multiradiatus*	Threadfin, Gunther's
390	005	Pinguipedidae	*Parapercis nebulosa*	Grubfish, Red-Barred

Exmouth Gulf Fishes - Onslow fishery				
Fam no:	**Sp no:**	**Family**	**Scientific name**	**Common name**
427	007	Callionymidae	*Callionymus grossi*	Stinkfish, Gross's
427	010	Callionymidae	*Callionymis sublaevis*	Stinkfish, Multifilament
440	004	Trichiuridae	*Trichiurus lepturus*	Hairtail, Largehead
460.1	012	Bothidae	*Engyprosopon grandisquama*	Flounder, Spiny-headed
460.2	009	Paralichthyidae	*Pseudorhombus arsius*	Flounder, Large-toothed
463	001	Cynoglossidae	*Paraplagusia bilineata*	Sole, Patterned Tongue
464	007	Triacanthidae	*Tripodichthys angustifrons*	Tripodfish, Black Flag
465.2	010	Monacanthidae	*Anacanthus barbatus*	Leatherjacket, Bearded
465.2	009	Monacanthidae	*Monacanthus chinensis*	Leatherjacket, Fan-bellied
467	012	Tetraodontidae	*Lagocephalus lunaris*	Toadfish, Rough Golden
467	007	Tetraodontidae	*Lagocepahlus sceleratus*	Toadfish, Silver



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Appendix 06

Draft Protected Marine Fauna Management Plan

Acronyms and Abbreviations

ABU	Australasian Business Unit
ALARP	As Low as Reasonably Practicable
APPEA	Australian Petroleum Production and Exploration Association
AQIS	Australian Quarantine and Inspection Service
BPP	Benthic Primary Producers
BPPH	Benthic Primary Producer Habitat
CCIMPE	Coordinating Committee for Introduced Marine Pest Emergencies
Chevron ABU	Chevron Australasia Business Unit
Cwth	Commonwealth
DBNGP	Dampier Bunbury Natural Gas Pipeline
DEC	Department of Environment and Conservation (state)
DEWHA	Department for the Environment, Water, Heritage and the Arts (Commonwealth)
DoE	Department of Environment (state), now the DEC
DoF	Department of Fisheries (state)
DPI	Department for Planning and Infrastructure (State)
EA	Environment Australia (now DEWHA)
ECU	Ecological Unit
EIS/ERMP	Environmental Impact Statement/Environmental Review and Management Programme
EPA	Environmental Protection Authority (state)
EPBC Act (Cth)	*Environmental Protection and Biodiversity Conservation Act 1999*
EQO	Environmental Quality Objective
EQC	Environmental Quality Criteria
KPI	Key Performance Indicators
LAT	Lowest Astronomical Tide
LEP	Level of Environmental Protection
MCMP	Marine and Coastal Management Plan
MEB	Marine Ecosystem Branch
Mm3	Million cubic metres
MOF	Marine Offloading Facility
Mtpa	Million tonnes per annum
NIMPCG	National Introduced Marine Pests Coordination Group
NTU	Nephelometric Turbidity Units
OE	Operational Excellence
OEMS	Operational Excellence Management System
OSCP	Oil Spill Contingency Plan
PLF	Product Loading Facility
PMFMP	Protected Marine Fauna Management Plan
PWQMG	Pilbara Water Quality Management Guidelines
SDP	Sea Dumping Permit
SMFG	Size Management Fish Grads
SWQMG	State Water Quality Management Guidelines
WA	Western Australia

NOTE:
This section will summarise the commitments made within this plan in relation to the protected marine fauna species identified as key receptors. It will be completed on finalisation of Ministerial Conditions, objectives and management measures.

Commitments Register

No.	Reference	Commitment	Method	Timing
Humpback whales (Migratory)				
		Design: Nearshore infrastructure location selected to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpback Whales, Dugongs and turtles. Mitigate: Aerial, boat and land based surveys to identify and map critical habitat for marine mammals and turtles prior to construction.		
		Mitigate: Management of cetacean interactions will be in accordance with the requirements for cetacean interactions specified under Part 8 of the EPBC Regulations 2000 (Cth), the Australian National Guidelines for Whale and Dolphin Watching.		
		Monitor: Humpbacks and Dugong observations throughout the works as part of the marine mammal management procedures		
		Design: Selection of navigation channel, MOF and placement sites to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpbacks, Dugongs and turtles. Mitigate: Dredging and material placement will be conducted during favourable weather, tide and current		

		conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas		
		Prior to the commencement of dredging selected crew will receive training, which will include details on procedures in the event of sighting, injury and/or death of Protected Marine Fauna (e.g. Humpbacks, Dugong, turtles, dolphins). All sightings of Humpbacks and Dugong that result in management actions being implemented will be recorded. The vessel master will maintain a log of observed in-water incidents or injured/dead turtles and marine mammals. Humpbacks and Dugong observations and response procedures, including not commencing dredging or placement if whales or Dugongs are sighted within a 300m observation zone and ceasing dredging activities if whales or Dugongs enter a 100m exclusion zone. A trained crew member will maintain a lookout, during daylight hours, for Humpbacks and Dugongs while dredge are moving to and from the dredge area to dredge material placement sites. If sighted, direction/speed will be adjusted to reduce the likelihood of impact (within the safety constraints of the vessel).		
		Make existing mammal and turtle aerial sighting data available to DEC for planning purposes relating to recreational boating activity in the Onslow region.		

		Mitigate: To reduce impacts to marine fauna the following actions will be implemented: If a marine mammal or turtle enters the observation zone (500 m of an active pile hammer) the piling supervisor (or other individual) will be directed to monitor the movement of it in relation to the activity suspension zone Pile driving activities shall cease if a marine mammal or turtle is observed within the activity suspension zone (100 m of an active pile hammer). [see also mitigation below]		
		Where required, site specific noise modelling will be undertaken to validate or modify the adopted noise management zones for piling activity.		
		Use of marine fauna observers to confirm that no mammals and turtles are within the vicinity of designated fauna exclusion zones. Activities may be undertaken outside Humpback migration period.		
		Measures to mitigate against the risks of vertical seismic profiling (VSP) will be developed if required and will consider the seismic guidelines (DEWHA 2008) and be included in this Plan (which will be included with the Supplementary EIS).		
Indo-Pacific humpback dolphins / Spotted Bottlenose Dolphins (Migratory)				
		Mitigate: Aerial, boat and land based surveys to identify and map critical habitat for marine mammals and turtles prior to construction.		
		Mitigate: Management of cetacean interactions will be		

		in accordance with the requirements for cetacean interactions specified under Part 8 of the EPBC Regulations 2000 (Cth), the Australian National Guidelines for Whale and Dolphin Watching.		
		Mitigate: Dredging and material placement will be conducted during favourable weather, tide and current conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas		
		Prior to the commencement of dredging selected crew will receive training, which will include details on procedures in the event of sighting, injury and/or death of Protected Marine Fauna (e.g. Humpbacks, Dugong, turtles, dolphins).		
		Make existing mammal and turtle aerial sighting data available to DEC for planning purposes relating to recreational boating activity in the Onslow region.		
		Mitigate: To reduce impacts to marine fauna the following actions will be implemented: If a marine mammal or turtle enters the observation zone (500 m of an active pile hammer) the piling supervisor (or other individual) will be directed to monitor the movement of it in relation to the activity suspension zone Pile driving activities shall cease if a marine mammal or turtle is observed within the activity suspension zone (100 m of an active pile hammer). [see also mitigation below]		
		Where required, site specific noise modelling will be undertaken to validate or modify the adopted noise		

		management zones for piling activity.		
		Use of marine fauna observers to confirm that no mammals and turtles are within the vicinity of designated fauna exclusion zones.		
Dugongs (Migratory) and seagrass habitat				
		Design: Nearshore infrastructure location selected to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpback Whales, Dugongs and turtles. Mitigate: Aerial, boat and land based surveys to identify and map critical habitat for marine mammals and turtles prior to construction.		
		Monitor: Humpbacks and Dugong observations throughout the works as part of the marine mammal management procedures		
		Design: Selection of navigation channel, MOF and placement sites to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpbacks, Dugongs and turtles. Mitigate: Dredging and material placement will be conducted during favourable weather, tide and current conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas		
		Prior to the commencement of dredging selected crew will receive training, which will include details on procedures in the event of sighting, injury and/or death of Protected Marine Fauna (e.g. Humpbacks, Dugong,		

		turtles, dolphins). All sightings of Humpbacks and Dugong that result in management actions being implemented will be recorded. The vessel master will maintain a log of observed in-water incidents or injured/dead turtles and marine mammals. Humpbacks and Dugong observations and response procedures, including not commencing dredging or placement if whales or Dugongs are sighted within a 300m observation zone and ceasing dredging activities if whales or Dugongs enter a 100m exclusion zone. A trained crew member will maintain a lookout, during daylight hours, for Humpbacks and Dugongs while dredge are moving to and from the dredge area to dredge material placement sites. If sighted, direction/speed will be adjusted to reduce the likelihood of impact (within the safety constraints of the vessel).		
		Mitigate: To reduce the potential for increased vessel strikes of Dugongs and turtles from increased recreational pressure the following action may be implemented: Inform Project staff/contractors of DEC rules relating to the Wildlife Conservation Act e.g. distance to keep from animals Recreational boats and recreational vehicles will not be permitted within the boundaries of the Project area or to travel on the access road from Onslow Road.		

		Behaviour standards to be expected from all construction workers will be clearly articulated in a Recreation Code of Conduct. Construction workers will be asked to sign the Code of Conduct. A community feedback procedure will be established whereby any complaints from the community about unacceptable behaviour from construction workers will be investigated and, where necessary, action taken.		
		Make existing mammal and turtle aerial sighting data available to DEC for planning purposes relating to recreational boating activity in the Onslow region.		
		Mitigate: To reduce impacts to marine fauna the following actions will be implemented: If a marine mammal or turtle enters the observation zone (500 m of an active pile hammer) the piling supervisor (or other individual) will be directed to monitor the movement of it in relation to the activity suspension zone Pile driving activities shall cease if a marine mammal or turtle is observed within the activity suspension zone (100 m of an active pile hammer). [see also mitigation below]		
		Where required, site specific noise modelling will be undertaken to validate or modify the adopted noise management zones for piling activity.		
		Use of marine fauna observers to confirm that no mammals and turtles are within the vicinity of designated fauna exclusion zones.		

Marine turtles (Migratory and Threatened) and nesting beaches				
		Design: Nearshore infrastructure location selected to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpback Whales, Dugongs and turtles. Mitigate: Aerial, boat and land based surveys to identify and map critical habitat for marine mammals and turtles prior to construction.		
		Mitigate: Prior to commencement of dredging and dredge material management activities selected crew will receive training, which will include details on procedures in the event turtle sighting, injury and/or death.		
		Mitigate: When operating with less than five metres under keel clearance, the dredge will initially move slowly through the area before commencing dredging so that the noise and vibration disturb marine turtles in the vicinity and encourage them to leave. This will only be applied on dredging in new areas and not once the work area has been established. Mitigate: Dredge pumps will be stopped as soon as practicable after completion of dredging and where reasonably practicable the drag head will remain within four metres of the seabed until the dredge pump is stopped.		
		Mitigate: Release of healthy entrained turtles back to the marine environment and contact the DEC if an injured turtle is collected after being entrained. Mitigate: In the event of turtle mortality incident, as a		

		result of entrainment during dredging, revision of existing management measures will be investigated to ascertain whether additional measures may be put in place to reduce the potential for such incidents to occur in the future.		
		Report: Any incident involving the injury or mortality of turtles will be reported to the DEC and DEWHA within 48 hours of the incident occurring.		
		Design: Selection of navigation channel, MOF and placement sites to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpbacks, Dugongs and turtles. Mitigate: Dredging and material placement will be conducted during favourable weather, tide and current conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas		
		Mitigate: To reduce the potential for increased vessel strikes of Dugongs and turtles from increased recreational pressure the following action may be implemented: Inform Project staff/contractors of DEC rules relating to the Wildlife Conservation Act e.g. distance to keep from animals Recreational boats and recreational vehicles will not be permitted within the boundaries of the Project area or to travel on the access road from Onslow Road. Behaviour standards to be expected from all		

		construction workers will be clearly articulated in a Recreation Code of Conduct. Construction workers will be asked to sign the Code of Conduct. A community feedback procedure will be established whereby any complaints from the community about unacceptable behaviour from construction workers will be investigated and, where necessary, action taken.		
		Make existing mammal and turtle aerial sighting data available to DEC for planning purposes relating to recreational boating activity in the Onslow region.		
		Mitigate: To reduce impacts to marine fauna the following actions will be implemented: If a marine mammal or turtle enters the observation zone (500 m of an active pile hammer) the piling supervisor (or other individual) will be directed to monitor the movement of it in relation to the activity suspension zone Pile driving activities shall cease if a marine mammal or turtle is observed within the activity suspension zone (100 m of an active pile hammer). [see also mitigation below]		
		Where required, site specific noise modelling will be undertaken to validate or modify the adopted noise management zones for piling activity.		
		Mitigate: To reduce impacts to turtle hatchlings, light spill from construction and operation vessels operating nearby offshore islands and mainland beaches that support marine turtle nesting will be reduced, where reasonably practicable.		

		Monitor: The Proponent will monitor onshore infrastructure-attributable changes to the sea-finding success of marine turtle hatchlings at rookeries on Ashburton Island and at the Ashburton delta beach for a period to be determined based on the initial monitoring results. Monitor: Monitoring will be conducted during construction, to coincide with planned flaring events to assess the effects of this activity on hatchling behaviour, particularly in relation to their orientation to the beach and sea-finding success.		
		Use of marine fauna observers to confirm that no mammals and turtles are within the vicinity of designated fauna exclusion zones.		
Sawfish (Threatened)				
		Design: Selection of navigation channel, MOF and placement sites to reduce risks to habitat critical (nesting, feeding and calving areas) for marine fauna such as Humpbacks, Dugongs and turtles. Mitigate: Dredging and material placement will be conducted during favourable weather, tide and current conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas		
		Inform Project staff/contractors of recreational fishing Regulations [Sawfish are protected species]		
Sea birds (Migratory) and islands				
		Inform Project staff/contractors of DEC rules relating to		

		offshore nature reserves e.g. domesticated animals (such as dogs and cats) will be prohibited on offshore islands/reserves The Proponent will work with the DEC to reduce potential risks from excessive recreational use of the islands within a 25km radius of Onslow Recreational boats and recreational vehicles will not be permitted within the workforce accommodation village or to travel on the access road from Onslow Road. Behaviour standards to be expected from all construction workers will be clearly articulated in a Recreation Code of Conduct. Construction workers will be asked to sign the Code of Conduct A community feedback procedure will be established whereby any complaints from the community about unacceptable behaviour from construction workers will be investigated and, where necessary, action taken.		
Fishes other than sawfish				
		Inform Project staff/contractors of recreational fishing Regulations The Proponent will work with the DoF to reduce potential risks to the existing recreational fishery		

		Recreational boats and recreational vehicles will not be permitted within the workforce accommodation village or to travel on the access road from Onslow Road Behaviour standards to be expected from all construction workers will be clearly articulated in a Recreation Code of Conduct. Construction workers will be asked to sign the Code of Conduct A community feedback procedure will be established whereby any complaints from the community about unacceptable behaviour from construction workers will be investigated and, where necessary, action taken.		
		Conservation induction programs will be run for employees and contractors (e.g. to include education of better disposal of fishing line and use of biodegradable fishing line).		

1.0 INTRODUCTION

NOTE:
This document is a DRAFT FRAMEWORK, its purpose to inform interested stakeholders that a Protected Marine Fauna Management Plan is to be produced for the Wheatstone Project and to outline the plan's key components.

The reader is cautioned that this plan is as yet INCOMPLETE. Stakeholder engagement will be a key step in finalising this document.

1.1 Wheatstone Project

Chevron Australia Pty Limited (Chevron Australia) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) and domestic gas (Domgas) plant near Onslow on the Pilbara Coast, Western Australia.

The Wheatstone Project will process gas from various fields located offshore in the West Carnarvon Basin. The LNG and domgas plant will initially process gas from these fields, located approximately 200 km offshore from Onslow in the West Carnarvon Basin, as well as (ultimately) gas from other gas fields that are yet to be determined. The project is referred to as the Wheatstone Project, and Ashburton North is the proposed site for the LNG and domgas plant.

The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State waters and on land. The Wheatstone Project will produce gas from petroleum titles WA-356, WA-253-P & WA-17-R, WA-16-R, located 145km offshore from the mainland, approximately 100km north of Barrow Island and 225km north of Onslow. The LNG plant will have a maximum production capacity of 25 million tonnes per annum (MTPA) of LNG.

The Ashburton North site is located approximately 12km south-west of Onslow along the Pilbara coast within the Shire of Ashburton (Figure 1.1). The initial Project is expected to consist of two LNG processing trains, each with a capacity of between 4 and 7 million tonnes per annum (mtpa). Environmental approval is being sought for a 25Mtpa plant to allow for the expected further expansions. The Domgas plant will be a separate but co-located facility and will form part of the Wheatstone Project. The development of the Domgas plant also includes onshore pipeline installation to tie-in to the existing Dampier-to- Bunbury Natural Gas Pipeline (DBNGP) infrastructure.

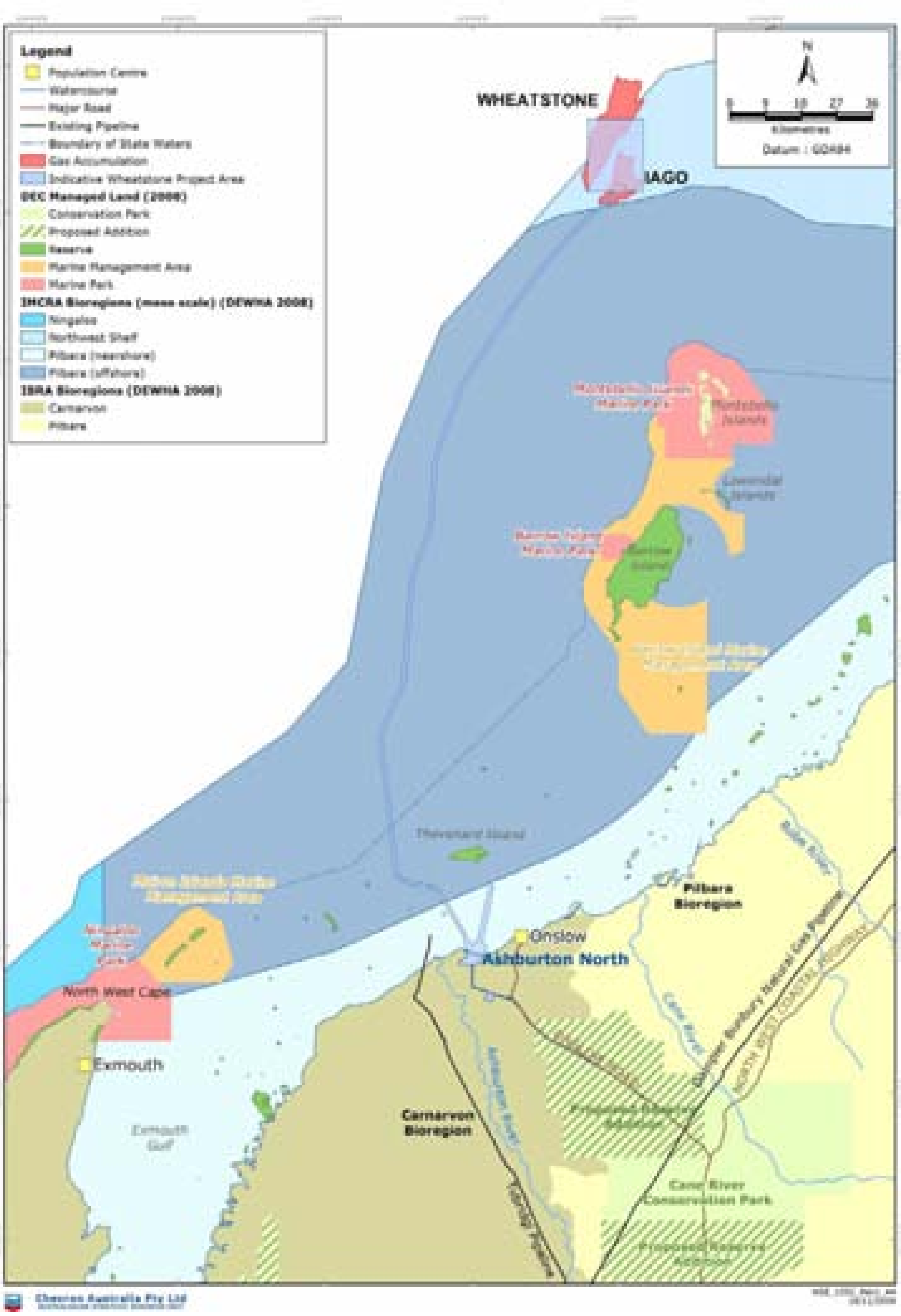

Figure 1.1: Location of the Project Area

1.2 Purpose of this Management Plan

Following the EPA's risk-based approach to EIA (EPA 2009), Statutory Environmental Management Plans (EMPs) were initially only to be developed for activities with a residual high risk ranking. However, as many marine fauna species are of high conservation significance and are very much valued by the community, it was determined that a dedicated management plan, to ensure their safeguard from potential Project impacts, was warranted.

The purpose of this plan is to clearly outline the Project's environmental objectives in relation to Protected Marine Fauna and to describe the associated management measures in achieving these, including responsibilities, training, timing, monitoring, auditing, adaptive management, review and contingency procedures.

1.3 Objectives of this Management Plan

NOTE:

This section will state specific objectives of the Protected Marine Fauna Management Plan which will be based on the Outcome Based Conditions and developed in consultation with Subject Matter Experts (SMEs), relevant government agencies and other relevant stakeholders. The objectives will be

- specific,
- measurable,
- achievable,
- realistic,
- timely and

will be guided by the following EPA Act (WA) and EPBC Act (Cth) management objectives:

- To maintain the abundance, diversity, geographic distribution and productivity of marine fauna in the region through the avoidance, or mitigation, of adverse impacts that could arise from construction and operational activities.
- To provide for the protection of the environment, especially matters of national environmental significance and to conserve Australian biodiversity.
- To be consistent with all relevant legislation and guidance.

1.4 Scope of this Management Plan

This plan aims to provide a performance-based and outcomes based management approach for the environmental management activities with a potential to affect protected marine fauna. It is inclusive of both construction phase (non-dredging aspects) and operational phase activities, associated with both downstream and upstream Project components. Mitigation to protect marine fauna associated with dredging activities is provided in the Dredging and Spoil Disposal Management Plan (DSDMP).

1.5 Aspects Addressed

A number of potential impacts to marine fauna and flora were identified during the initial scoping phase of the environmental impact assessment process (Chevron 2009). Using the EPA's risk methodology (EPA 2009), these were then revised to incorporate information obtained from baseline studies and the general management and mitigation measures formulated during FEED. This plan encompasses these and the management measures devised for the activities with the potential for impact, as identified in the EIS/ERMP (Chevron 2010) and presented in Table 1.

Table 1: Aspects Addressed in this PMFMP and their Residual Risk

Phase	Aspect	Residual Risk
Construction	Vessel movements	**Low**
Construction	Noise emissions	**Low**
Operation	Vessel movements	**Low**
Operation	Noise emissions	**Low**
Operation	Light emissions (nearshore and onshore facilities)	**Low**
Operation	Increased recreation (boating and island access)	**Medium**

Activities governed by their own dedicated management plan have been precluded from this plan (Table 2), but cross-reference will be made to the appropriate plan for Project risks.

Table 2: Activities and Associated Dedicated Plans

Activity	Dedicated Management Plan
Dredging and spoil disposal	Dredging and Spoil Disposal Management Plan
Coastal construction	Coastal Processes Management Plan
Unplanned leaks and spills	Oil Spill Contingency Plan
Installation of offshore infrastructure	Environment Plan in accordance with the OPGGS Act (Cth)
Increased recreational fishing	Specific strategies to be developed in consultation with Department of Fisheries

1.6 Receptors Addressed

This plan focuses on those marine fauna species identified as 'key receptors' in the Wheatstone ERMP (Table 3). The key receptors were selected from the inventory of marine fauna whose distributions overlap the Project area and have been assessed by their:

- spatial distribution within the Project footprint
- spatial distribution within the regional context
- temporal distribution within the Project footprint
- dependence on critical habitats or foraging areas within the Project footprint
- presence within the Project footprint during sensitive life history stages
- interaction with aspects of the Project.

In addition to the key receptors, species of lower conservation significance and significant species less likely to be affected by the Project are considered in the plan as other receptors, and have also been considered within this plan.

Table 3: Marine Fauna Addressed in this PMFMP

Key Receptor	Reason for selection as a 'key' receptor
Humpback Whale *Megaptera novaeangliae*	High conservation significance. Present in coastal waters during southward migration, cows and calves may rest within the Project area in spring.
Indo-Pacific Humpback Dolphin *Sousa chinensis*	High conservation significance. Likely to be present in coastal waters (< 20 m deep) throughout year.
Bottlenose Dolphin *Tursiops sp.*	High conservation significance. Likely to be present in coastal waters throughout year.
Dugong *Dugong dugon*	High conservation significance. Present in coastal waters adjacent the Project area.
Flatback Turtle *Natator depressus*	High conservation significance. Nests and forages in coastal waters of Project area.
Green Turtle *Chelonia mydas*	High conservation significance. Nests and forages in coastal waters of Project area.
Hawksbill Turtle *Eretmochelys imbricata*	High conservation significance. Nests in region encompassing Project area.
Loggerhead Turtle *Caretta caretta*	High conservation significance. Nests in region encompassing Project area.
Sawfish (*Pristis* sp.)	High conservation significance. Recorded in Hooley Creek and NE Ashburton lagoon (both within the Project area).
Other Receptors	**Reason for selection as 'other' receptor**
Baleen Whales (other than Humpback Whales)	High conservation significance. Present or migratory in low numbers in offshore waters, highly mobile.
Toothed Whales (e.g. killer whales)	High conservation significance. May be present or migratory in low numbers in offshore waters, highly mobile.
Southern Giant Petrel *Macronectes giganteus*	High conservation significance. Southern distribution means they are unlikely to be present in Project area.
Seabirds (various species)	Some species of high conservation significance. Nest and roost on islands (including Nature Reserves) in the Project area.
Sea Snakes (various species)	Conservation significance. However these species are generally widespread in the region and no critical habitats are known.
Whale Shark *Rhincodon typus*	High conservation significance. Migratory in offshore waters, unlikely to be present within the Project area.

Syngnathids (various species)	High conservation significance. Well represented within the regional context, no restricted habitats known within Project area, regional populations unlikely to be affected by the Project.
Demersal teleost fish (various species)	Well represented within the regional context, mobile, unlikely to be affected by the Project.

The plan also identifies island Nature Reserves as a factor, due to their importance for seabird and turtle nesting and their high conservation status.

1.7 Structure of this Plan

This plan is structured as follows

- **Section A** introduces the plan.
- **Section B** outlines the relevant framework.
- **Section C** provides an overview of the existing environment.
- **Section D** identifies the potential impacts to marine fauna from in-scope Project aspects and details the proposed management strategies.
- **Section E** details the implementation of the management plan including monitoring and inspection programs that will be implemented.

1.8 Stakeholder Engagement

NOTE: This section will provide a stakeholder map indicating when, who, what and how engagement will occur, in order to produce the final document. The finalised PMFMP will also be made publicly available during the EIS/ERMP public review period.

If changes occur to the design or operation of the Project after completion of the PMFMP the document will be reviewed and revised as appropriate. The review will include a reassessment of the environmental risks presented by the works and the corresponding management strategies being implemented. Any such changes will be communicated to DEC and DEWHA as required.

2.0 FRAMEWORK

2.1 Legislative Requirements

Guidelines and legislation relevant to the assessment and management of potential impacts to marine fauna are:

- Environmental Protection Act 1986 (EP Act (WA))
- Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act (Cth))
- EPBC Act (Cth) Policy Statement 1.1 Significant Impact Guidelines
- Wildlife Conservation Act 1950 (WC Act)

The EPBC Act (Cth) and the EP Act (WA) outlines the framework for assessment of marine fauna at Commonwealth and Western Australian (State) levels, respectively.

Most marine mammals are protected under the EPBC Act (Cth). The EPBC Act (Cth) also established the Australian Whale Sanctuary, which encompasses the area of the Exclusive Economic Zone outside state waters and which generally extends 200 nm from the coast, but further in some areas to cover the continental shelf and continental slope.

All native Australian marine fauna, including fauna that migrate periodically to Australia, are protected in Western Australia under the WC Act. Under this Act, it is an offence to kill, capture, disturb, molest or hunt any protected or threatened fauna. The level of protection for a given species depends on its conservation status.

Species requiring special protection are listed under one of the four following categories in the Wildlife Conservation (Specially Protected Fauna) Notice:

- Schedule 1 – fauna that are rare or likely to become extinct
- Schedule 2 – fauna presumed to be extinct
- Schedule 3 – birds that are subject to the agreement between the governments of Australia and Japan relating to the protection of migratory birds and birds in danger of extinction (i.e. Japan Australia Migratory Bird Agreement (JAMBA))
- Schedule 4 – other specially protected fauna.

2.2 International Conventions

International agreements applicable to this Draft PMFMP include, but are not limited to:

- The Convention on the Conservation of Migratory Species of Wild Animals (Secretariat of the Convention for the Conservation of Migratory Species of Wild Animals 1979)
- Japan-Australia Migratory Bird Agreement (JAMBA)
- China-Australia Migratory Bird Agreement (CAMBA)

2.3 Species Recovery Plans

The management strategies proposed for avoiding or mitigating impacts to marine fauna associated with the Project will be consistent with the objectives of the species recovery and action plans, as described in the following.

Commonwealth Fauna Recovery Plans and Action Plans used in the PMFMP include:

- Action Plan for Australian Cetaceans (Bannister et al. 1996)
- Blue, Fin and Sei Whale Recovery Plan 2005-2010 (DEH 2005a)
- Humpback Whale Recovery Plan 2005-2010 (DEH 2005b)
- Southern Right Whale Recovery Plan 2005-2010 (DEH 2005c)
- Recovery Plan for Marine Turtles in Australia (DEH 2003)
- Whale Shark (Rhincodon typus) Recovery Plan 2005-2010 (DEH 2005).
- DEC (2009a) Draft Marine Turtle Recovery Plan for Western Australia 2009-2016. Wildlife Management Program No. 45.

The Action Plan for Australian Cetaceans identifies a number of threatening processes that relate to the proposed Project which will require specific management strategies to be developed as follows (Bannister *et al.* 1996):

Immediate threats:
- Injury or mortality
- Entanglement
- Shipping strikes.

Intermediate threats:
- Oil spills
- Disturbance and harassment (i.e. acoustic disturbance)
- Degradation of cetacean habitat (i.e. physical or biological modification)
- Exposure to human wastes.

Long-term threats:
- Contamination of marine environments by chemical pollutants
- Contamination of marine environments by plastic debris.

Recovery plans for humpback whales; blue, fin and sei whales; and southern right whales (DEH 2005a, 2005b and 2005c) list identified and potential threats to these species, of which only habitat degradation is relevant to the proposed Project activities.

The WA State Draft Marine Turtle Recovery Plan (DEC 2009a) provides evidence for the higher relative importance of turtle rookeries on the Pilbara islands including:
- Productivity of WA mainland nesting beaches is under threat from egg predation by introduced animals, particularly foxes, while Pilbara islands are largely free from introduced predators.
- The area between the North West Cape and Port Hedland has the highest incidence of artificial lighting on turtle nesting beaches in WA, the cumulative impacts of which have not been assessed.
- Turtles that nest on the mainland may be disturbed by tourists, whereas limited tourism occurs on islands.

The overall objective of the Recovery Plan for Marine Turtles (DEH 2003) is:
'To reduce detrimental impacts on Australian populations of marine turtles and hence promote their recovery in the wild'.

A number of specific objectives have been further defined in the plan which will require specific management strategies to be applied throughout the duration of the Project as follows:
- Prevention of accidental death e.g. by boat strikes

- Identification of information gaps
- Management of factors that affect successful nesting
- Identification and protection of critical habitats (natal beaches, mating areas, inter-nesting habitat, feeding areas and pelagic waters).

The Whale Shark Recovery Plan (DEH 2005c) identifies potential future threats to this species relevant to the proposed Project activities as follows:

- Pollution and marine debris
- Direct disturbance from interference.

2.4 Chevron ABU Policy 530

The Chevron Australasia Business Unit (ABU) has stated its commitment to achieving Operational Excellence (OE) in ABU Policy 530. The Chevron ABU strives to achieve OE through the implementation of the ABU Operational Excellence Management System (OEMS). Further details regarding this policy can be found on Chevron's website at www.chevronaustralia.com. Chevron is committed to implementing the Project in accordance with ABU Policy 530.

2.5 Documentation Hierarchy

This plan will be implemented for the Wheatstone Project via the Chevron ABU OEMS. The OEMS is the standardised approach that applies across the ABU in order to continuously improve the management of safety, health, environment, reliability and efficiency to achieve world-class performance. Implementation of the OEMS enables the Chevron ABU to integrate its Operational Excellence (OE) objectives, processes, procedures, values and behaviours into the daily operations of Chevron Australia personnel and contractors working under Chevron Australia's operational control supervision. The OEMS is designed to be consistent with, and in some respects, go beyond ISO 14001-2004 (Environmental Management Systems – Requirements with Guidance for Use) (Standards Australia/Standards New Zealand 2004).

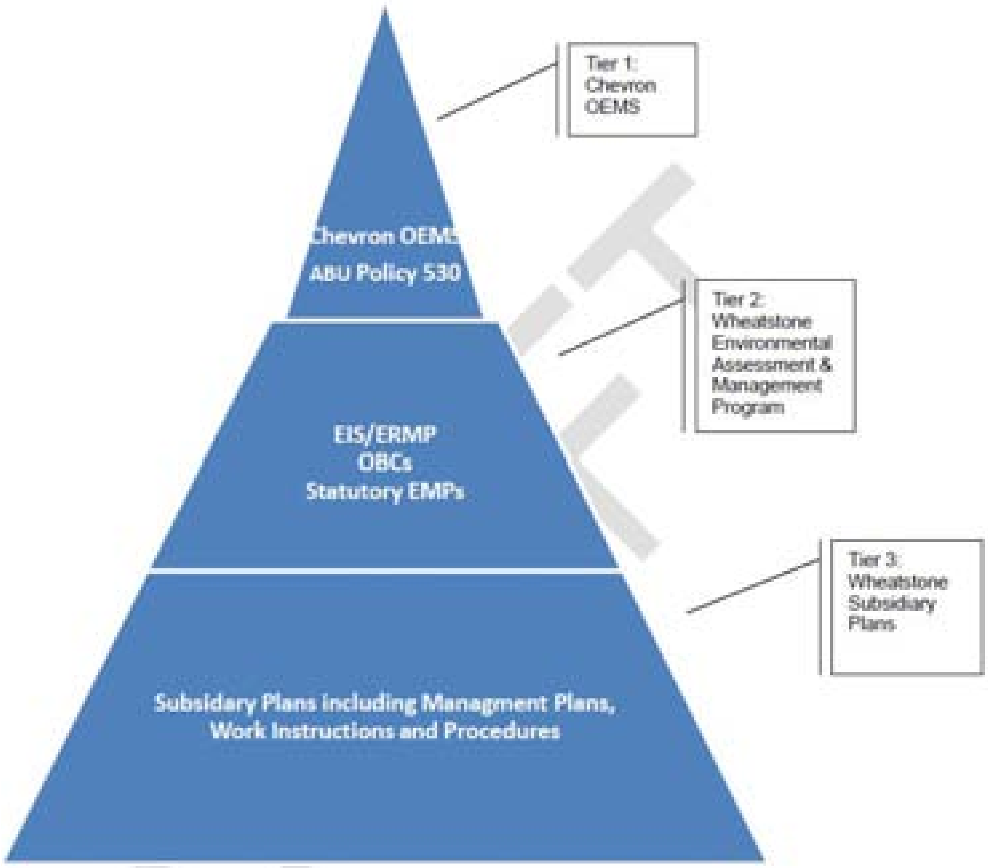

Figure 2: Wheatstone Environmental Management Framework

3.0 EXISTING ENVIRONMENT

3.1 Bioregional Overview

Through the grouping of marine areas based on ecological similarities and physical characteristics, the Commonwealth Government has created a series of marine bioregions to assist in planning and impact assessment (DEWHA 2008). The Integrated Coastal and Marine Regionalisation of Australia Version 4.0 (IMCRA) is an ecosystem based classification of Australia's marine and coastal environments that was developed by State, Territory and Commonwealth governments. Through IMCRA, Provincial Bioregions were classified based on physical structure, ecological communities and ecological processes. The upstream component of the Wheatstone Project is primarily situated in the Northwest Provincial Bioregion (IMCRA v4.0 2006). Situated entirely on the continental slope in depths ranging from 500 to 5000 m, this province consists of deep, open ocean (Figure 3). The seafloor is undulating, with the Exmouth Plateau a significant seafloor feature (DEWHA 2008). The terrain contributes to the upwelling of deeper, more nutrient rich waters from greater depths leading to areas of high biological productivity. (DEWHA 2008). Upwellings provide nutrients for phytoplankton blooms which in turn support zooplankton and demersal fish and squid communities that are on the upper and middle parts of the continental slope, therefore attracting predatory cetacean species, including oceanic dolphins and sperm whales (Jenner 2008; DEWHA 2008).

The offshore subsea pipeline will traverse both the continental slope and shelf, largely through the IMCRA Pilbara Offshore (PIO) bioregion. The bulk of the marine infrastructure (jetties, marine offloading facility (MOF), turning basin, shipping channel and pipeline shore crossing) will be located within the IMCRA Pilbara Nearshore (PIN) bioregion.

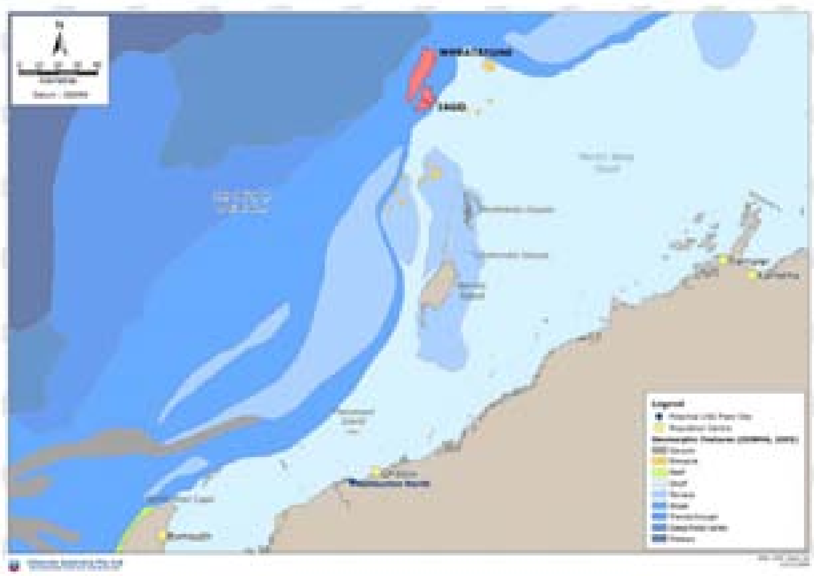

Figure 3: Major Seabed Features surrounding the Project Area (DEWHA 2008)

The Pilbara Offshore region has clear oceanic waters and contains many nearshore islands some surrounded by coral reef. The waters surrounding islands between Onslow and the Dampier Archipelago, including Serrurier and Thevenard, support resident populations of common bottlenose dolphins, Indo Pacific humpback dolphins and possibly dugong (DEWHA 2008). This bioregion also includes migratory routes for humpback whales. The 125 m isobath is thought to be an important migratory pathway for cetaceans and other pelagic species, such as whale sharks (DEWHA 2008).

The Pilbara Nearshore region is a coastal bioregion which extends from the coastline to the 10 m isobath and supports a range of habitats: sandy substrate, rocky coastline, mangroves and seagrasses and algal mats that support fish and dugongs (DEWHA 2008). Nearshore waters are characteristically turbid following cyclonic storms, large internal swells or heavy rainfall. Within the surrounding waters are the following important areas for cetaceans:

- Pilbara's largest known bed of large seagrasses, located at Mary Anne Reef, which supports several hundred hectares of 30-50% seagrass cover (URS 2009).
- Mangrove and Middle Islands, which provide seagrass and mangrove habitat for dugong, fish and turtles (DEWHA 2008).
- Exmouth Gulf, which supports aggregations of resting humpback whales and a large population of dugongs (DEWHA 2008).

3.2 Description of Marine Fauna Species

A detailed description of marine fauna species within the area can be found within the following documents:

- Wheatstone EIS/ERMP (Chevron 2010)
- Wheatstone EIS/ERMP Marine Fauna Technical Appendix O (RPS 2010; URS 2010)

3.3 Description of Island Nature Reserves

A number of island Nature Reserves also occur within the Pilbara Nearshore and Pilbara offshore bioregions. These include:

- Thevenard Island Nature Reserve
- Serrurier Island Nature Reserve
- Airlie Island Nature Reserve

By their isolated nature, islands provide refuge for indigenous flora and fauna. Weed and feral animal eradication programs have a greater chance of success compared to those on the mainland due to a lower risk of recolonisation by pest species.

Thevenard, Serrurier (Long) and Airlie islands within Onslow's nearshore environment are vested with the Conservation Commission of Western Australia and managed by the Department of Environment and Conservation (DEC). They are protected under the *Conservation and Land Management Act (1984)* as nature reserves. This legislation states that the management objective for nature reserves should be *"to maintain and restore the natural environment, and to protect, care for, and promote* *the study of, indigenous flora and fauna, and to preserve any feature of archaeological, historic or scientific interest".*

Categorised as 'offshore islands, Dampier to Onslow (as far west as Serrurier)' these islands are part of the 'Pilbara 4' subregion within the Roebourne Bioregion (CALM, 2002). They represent sandy soils and coastal vegetation, support a number of nesting sea bird and turtle species and dugongs may harbour in inshore waters (CALM, 2002). *Ctenotus angusticeps* (Airlie island skink) is a Priority fauna species that is endemic to Airlie and Thevenard Islands. The intertidal areas of these islands were found to be of low habitat diversity and moderate invertebrate fauna species diversity with no endemic, rare or endangered species present (URS 2009).

These islands are also listed on the Register of National Estate (RNE), place ID 10050, as 'small islands between Exmouth Gulf and the Mary Anne Group'. The listing includes all islands and associated rocks sand, mangroves and reefs. Nesting sea bird and turtle habitat importance is noted.

Onslow's proximity to the ocean and the Ashburton River attracts many visitors each year in pursuit of recreational coastal activities. Intercept surveys undertaken with visitors to the area highlighted visitors were predominantly from Western Australia (77 per cent compared to 21 per cent interstate visitors). More than a quarter stayed in the area for longer than three months, and 70 per cent of visitors engaged in recreational fishing.

The Shire of Ashburton acknowledges the importance of the islands for local recreation and their potential for increased use as tourist destinations. The Onslow Structure Plan (2003), states that these islands are important recreation areas for Onslow residents and tourists for activities such as swimming, fishing and diving. Visitation by mine workers from Onslow's hinterland (towns including Pannawonica, Tom Price and Paraburdoo) has increased in recent years (A. O'Halloran pers. com, 2009) as has camping on some islands.

3.4 Factor Sensitivities

The sensitivities of the factors described above are summarised in table 4 below. Also identified are their likely exposure to impacts from the Project and the potential for Project activities to adversely affect them. These are the main data used in the assessment of the consequences of impacts associated with the Project.

Table 4: Factor Sensitivities to Project Activities

Receptor	Potential Exposure	Potential Impact
Humpback Whale	♦ Migrate through the offshore waters of the Project area annually between June and November. ♦ Exmouth Gulf is a recognised resting area for cow/calf pairs. However, the southward migration pathway through the Project area is not well known. Cow/calf pairs expected to be present from late September to early November. ♦ Known to be present inshore of the 50 m isobath during southward migration, but only vagrants expected in nearshore areas	♦ Cow/calf pairs susceptible to acoustic impacts from piling activities. ♦ All whales susceptible to vessel strike when vessels are present in large numbers.
Indo-Pacific Humpback Dolphin / Bottlenose Dolphin	♦ Dolphins present throughout the Project area. ♦ Indo-Pacific humpback and bottlenose dolphins most common species in the Project area. ♦ The Indo-Pacific humpback dolphin is a nearshore species that generally inhabits shallow coastal waters, embayments and estuaries (< 20 m)	♦ Sensitive to habitat degradation and population fragmentation due to coastal developments. ♦ Susceptible to acoustic impacts from piling activities in nearshore areas during the construction phase. ♦ Susceptible to vessel strike when fast-moving vessels are present in nearshore areas in large numbers.
Dugong	♦ Present throughout the year in nearshore waters throughout the Project area. ♦ Cow/calf pairs have been recorded within herds during aerial surveys in the vicinity of the Project area.	♦ Susceptible to acoustic impacts from piling activities in nearshore areas during the construction phase. ♦ Susceptible to vessel strike when fast-moving vessels are present in nearshore areas in large numbers.

Receptor	Potential Exposure	Potential Impact
Marine turtles (green, flatback, hawksbill, loggerhead)	♦ Marine turtles likely to be resident in nearshore waters of the Project area throughout the year. ♦ Predominantly flatback nesting on islands near the Project area. Medium density nesting on Ashburton River Delta and Ashburton Island (approximately four km and 12 km from the Project area, respectively). ♦ Very low density nesting of flatback turtles on the mainland beaches and nest success expected to be low due to tidal inundation of nest sites. ♦ Peak periods of mating (October–December), nesting (October–February) and hatching (December–April). ♦ Reef habitats surrounding the islands offshore from Ashburton North appear to be important foraging habitat for juvenile and adult green turtles.	♦ Potentially sensitive to the effects of dredging (e.g. entrainment). ♦ Susceptible to acoustic impacts from piling activities in nearshore areas during the construction phase. ♦ Susceptible to vessel strike when vessels are present in nearshore areas in large numbers.
Sawfish	♦ Present in inshore lagoon near Ashburton River delta. ♦ Likely to occur in Hooley Creek in Project area.	♦ Susceptible to changes to hydrodynamics of lagoons and tidal creek systems.
NOTE: This table will be updated to encompass recreationally targeted fish and Island Nature Reserves.		

4.0 IMPACTS AND MANAGEMENT

In interest of the end user, this section has been separated into the two main Project phases. A brief description of each aspect is followed by a list of potential impacts to marine fauna and the management strategies. The management strategies provide the outcomes and performance objectives/indicators against which environmental performance will be measured.

4.1 Construction Phase

4.1.1 Vessel movements

NOTE:
This section will provide a list of each
a) vessel movements
b) potential impacts

Table x: Management Measures, Environmental Objectives and Performance Indicators for Construction Phase Vessel Movements

Management Measure	Environmental Objective	Performance Indicator
To be finalised	To be devised	To be devised
Management of cetacean interactions will be in accordance with the requirements for cetacean interactions specified under Part 8 of the EPBC Regulations 2000 (Cth), the Australian National Guidelines for Whale and Dolphin Watching.		
Monitor: Humpbacks and Dugong observations throughout the works as part of the marine mammal management procedures		
Mitigate: Dredging and material placement will be conducted during favourable weather, tide and current conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas		
Prior to the commencement of dredging selected crew will receive training, which will include details on procedures in the event of sighting, injury and/or death of Protected Marine Fauna (e.g. Humpbacks, Dugong, turtles, dolphins). All sightings of Humpbacks and Dugong that result in management actions being implemented will be recorded. The vessel master will maintain a log of observed in-water incidents or injured/dead turtles and marine mammals. Humpbacks and Dugong observations and response procedures, including not commencing dredging or placement if whales or Dugongs are sighted within a 300m observation zone and		

ceasing dredging activities if whales or Dugongs enter a 100m exclusion zone. A trained crew member will maintain a lookout, during daylight hours, for Humpbacks and Dugongs while dredge are moving to and from the dredge area to dredge material placement sites. If sighted, direction/speed will be adjusted to reduce the likelihood of impact (within the safety constraints of the vessel).		
Mitigate: Release of healthy entrained turtles back to the marine environment and contact the DEC if an injured turtle is collected after being entrained. Mitigate: In the event of turtle mortality incident, as a result of entrainment during dredging, revision of existing management measures will be investigated to ascertain whether additional measures may be put in place to reduce the potential for such incidents to occur in the future.		
Report: Any incident involving the injury or mortality of turtles will be reported to the DEC and DEWHA within 48 hours of the incident occurring.		

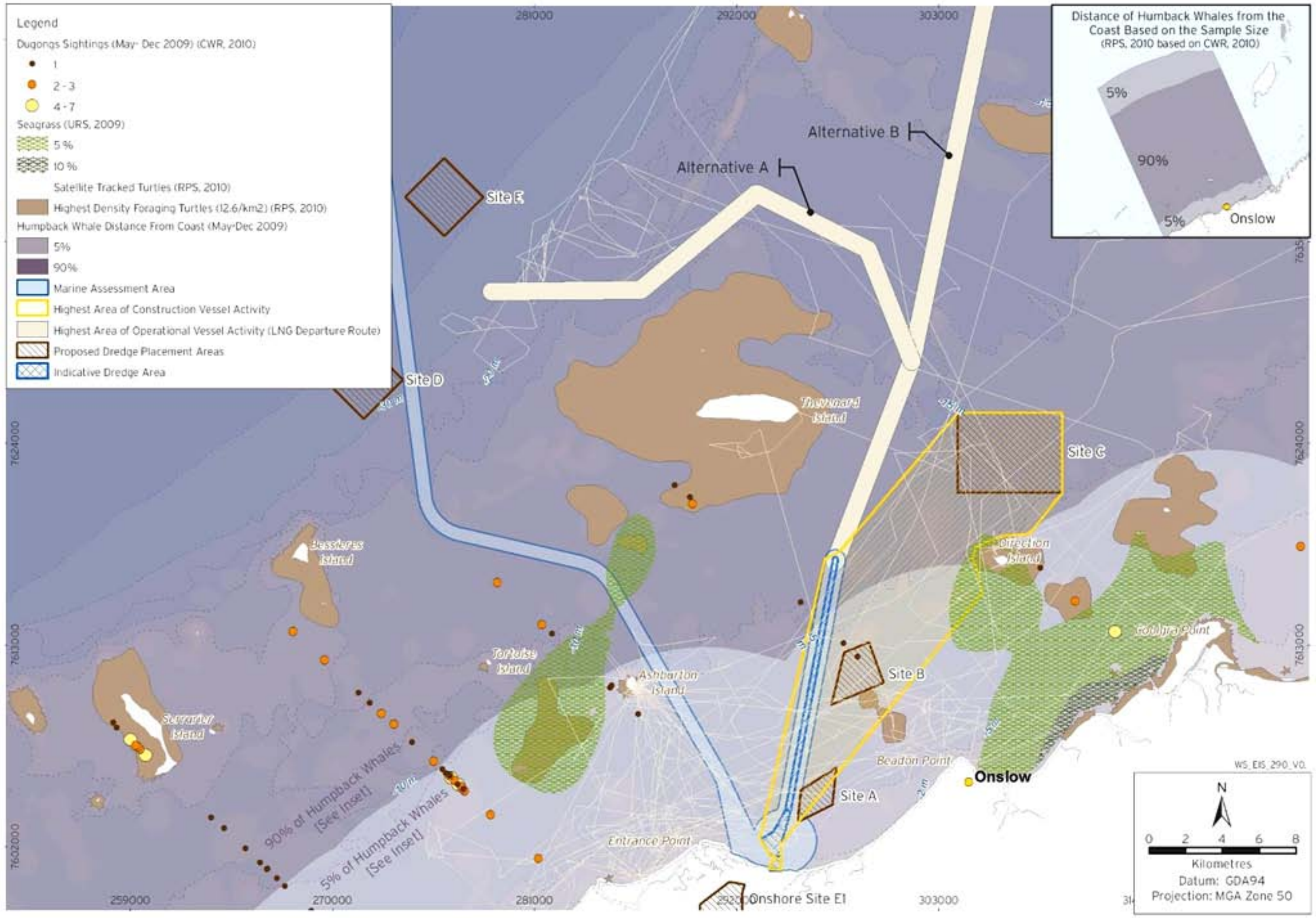

Figure X: Areas of Highest Project Vessel Movements in Relation to Important Areas for Turtles, Dugongs and Humpback Whales

4.1.2 Noise Emissions

NOTE:
This section will provide a list of each
a) sources of noise emission
b) potential impacts
c) further rationale behind proposed management measures

Table x: Management Measures, Environmental Objectives and Performance Indicators for Construction Phase Noise Emissions

Management Measure	Environmental Objective	Performance Indicator
To be finalised	To be devised	To be devised
Mitigate: To reduce impacts to marine fauna the following actions will be implemented: If a marine mammal or turtle enters the observation zone (500 m of an active pile hammer) the piling supervisor (or other individual) will be directed to monitor the movement of it in relation to the activity suspension zone Pile driving activities shall cease if a marine mammal or turtle is observed within the activity suspension zone (100 m of an active pile hammer).		
Use of marine fauna observers to confirm that no mammals and turtles are within the vicinity of designated fauna exclusion zones		
Activities may be undertaken outside Humpback migration period		

4.2 Operational Phase

4.2.1 Vessel movements

NOTE:
This section will provide a list of each
a) vessel movements
b) potential impacts

Table x: Management Measures, Environmental Objectives and Performance Indicators for Operational Phase Vessel Movements

Management Measure	Environmental	Performance

	Objective	**Indicator**
To be finalised	To be devised	To be devised
Mitigate: Management of cetacean interactions will be in accordance with the requirements for cetacean interactions specified under Part 8 of the EPBC Regulations 2000 (Cth), the Australian National Guidelines for Whale and Dolphin Watching.		
Monitor: Humpbacks and Dugong observations throughout the works as part of the marine mammal management procedures		
Mitigate: Dredging (maintenance) and material placement will be conducted during favourable weather, tide and current conditions, as far as reasonably practicable, to reduce the risk of impact to marine fauna while in close proximity to sensitive areas.		
Prior to the commencement of dredging [maintenance] selected crew will receive training, which will include details on procedures in the event of sighting, injury and/or death of Protected Marine Fauna (e.g. Humpbacks, Dugong, turtles, dolphins). All sightings of Humpbacks and Dugong that result in management actions being implemented will be recorded. The vessel master will maintain a log of observed in-water incidents or injured/dead turtles and marine mammals. Humpbacks and Dugong observations and response procedures, including not commencing dredging or placement if whales or Dugongs are sighted within a 300m observation zone and ceasing dredging activities if whales or Dugongs enter a 100m exclusion zone. A trained crew member will maintain a lookout, during daylight hours, for Humpbacks and Dugongs while dredge are moving to and from the dredge area to dredge material placement sites. If sighted, direction/speed will be adjusted to reduce the likelihood of impact (within the safety constraints of the vessel). Mitigate: Release of healthy entrained turtles back to the marine environment and contact the DEC if an injured turtle is collected after being entrained. Mitigate: In the event of turtle mortality incident, as a result of entrainment during dredging, revision of existing management measures will be investigated to ascertain whether additional measures may be put in place to reduce the potential for such incidents to occur in the future.		

Report: Any incident involving the injury or mortality of turtles will be reported to the DEC and DEWHA within 48 hours of the incident occurring.		

4.2.2 Noise Emissions

NOTE:
This section will provide a list of each
a) sources of noise emission
b) potential impacts
c) further rationale behind proposed management measures

Table x: Management Measures, Environmental Objectives and Performance Indicators for Operational Phase Noise Emissions

Management Measure	Environmental Objective	Performance Indicator
To be finalised	To be devised	To be devised

4.2.3 Light emissions (nearshore and onshore facilities)

NOTE:
This section will provide a list of each
a) sources of light emission
b) potential impacts

Table x: Management Measures, Environmental Objectives and Performance Indicators for Operational Phase Light Emissions

Management Measure	Environmental Objective	Performance Indicator
To be finalised	To be devised	To be devised
Mitigate: To reduce impacts to turtle hatchlings, light spill from construction and operation vessels operating nearby offshore islands and mainland beaches that support marine turtle nesting will be reduced, where reasonably practicable. Monitor: The Proponent will monitor onshore infrastructure-attributable changes to the sea-finding success of marine turtle hatchlings at rookeries on Ashburton Island and at the Ashburton delta beach for a period to be determined based on the initial monitoring results.		

Monitor: Monitoring will be conducted during construction, to coincide with planned flaring events to assess the effects of this activity on hatchling behaviour, particularly in relation to their orientation to the beach and sea-finding success.		

4.2.4 Increased recreational pressure associated with the project.

NOTE:
This section will provide a list of each
a) potential recreational activities associated with the Project
b) potential impacts

Table x: Management Measures, Environmental Objectives and Performance Indicators for Increased Recreational Pressure in the Marine Environment

Management Measure	Environmental Objective	Performance Indicator
To be finalised	To be devised	To be devised
Inform Project staff/contractors of DEC rules relating to offshore nature reserves e.g. domesticated animals (such as dogs and cats) will be prohibited on offshore islands/reserves The Proponent will work with the DEC to reduce potential risks from excessive recreational use of the islands within a 25km radius of Onslow Recreational boats and recreational vehicles will not be permitted within the workforce accommodation village or to travel on the access road from Onslow Road. Behaviour standards to be expected from all construction workers will be clearly articulated in a Recreation Code of Conduct. Construction workers will be asked to sign the Code of Conduct A community feedback procedure will be established whereby any complaints from the community about unacceptable behaviour from construction workers will be investigated and, where necessary, action taken.		
Inform Project staff/contractors of recreational fishing Regulations		

The Proponent will work with the DoF to reduce potential risks to the existing recreational fishery		
Inform Project staff/contractors of DEC rules relating to the Wildlife Conservation Act e.g. distance to keep from animals		
Conservation induction programs will be run for employees and contractors (e.g. to include education of better disposal of fishing line and use of biodegradable fishing line).		
Make existing mammal and turtle aerial sighting data available to DEC for planning purposes relating to recreational boating activity in the Onslow region.		

5.0 IMPLEMENTATION

5.1 Key Roles and Responsibilities

NOTE:
This section will define key roles and responsibilities for Project personnel, both Chevron-employed and contractor companies.

5.2 Induction and Training

All personnel (including contractors and subcontractors) are required to attend environmental inductions and training that are relevant to their roles on the Wheatstone Project. Training and induction programs will facilitate the understanding that personnel have of their environmental responsibilities, and increase the awareness of the management and protection measures required to reduce potential impacts on the environment.

Environmental training and competency requirements for personnel, including contractors and subcontractors, will be maintained in HES training matrices. These matrices will be reviewed and updated on an ongoing basis to ensure that the required competencies are met and the required training has been completed. Training will be provided to relevant personnel on the requirements of this Draft PMFMP.

5.3 Monitoring

NOTE:
This section will outline the monitoring program for checking environmental performance against specific performance indicators and will be based on adaptive management principles. It will include triggers for management response, establish reporting protocols and procedures, and nominate corrective and preventative action procedures.

5.4 Auditing

Inspections will be conducted by a Chevron representative against this plan and the relevant HES plans during the works. Any corrective actions will be documented and their timely implementation tracked through program team meetings. Any required remedial actions will be carried out as soon as practical. Items identified for urgent action, including amendments to procedures, will be dealt with immediately.

Chevron will undertake a review of environmental performance, including the results of the inspections following completion of the works.

5.5 Reporting

NOTE:
This section will include schedules for the following reporting:

- Compliance Reporting
- Environmental Performance Reporting
- Routine Internal Reporting

- Incident Reporting and Response Strategy (outline contingency procedures, including the timely reporting of incidents to DEC)
- Review of this Plan

6.0 REFERENCES

NOTE: To be updated.

Chevron, 2009. Wheatstone Project Environmental Scoping Document.

Chevron, 2010. Wheatstone Project EIS / ERMP.

DEWHA 2008. EPBC Act Policy Statement 2.1. Interaction between offshore seismic exploration and whales, Australian Government Department of the Environment, Water, Heritage and the Arts, September 2008.

EPA, 2009. Risk Assessment Methodology

7.0 APPENDIX A

Recreational Code of Conduct for Wheatstone workers

This will be developed in consultation with DEC, with involvement from their Parks and Visitor Services group and in line with their 'Leave no Trace' Policy.

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Appendix 07

Wheatstone Project: Literature Review of Listed Marine Fauna

Tables

Figures

Appendices

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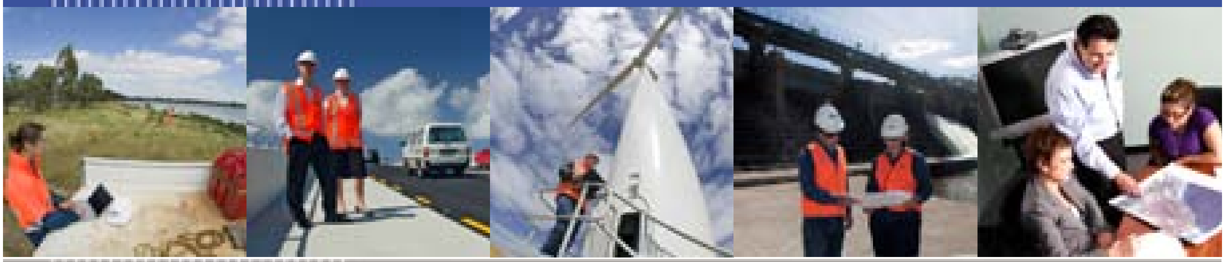

Report

Wheatstone Project: Literature Review of Listed Marine Fauna

11 MAY 2010

Prepared for

Chevron Australia Pty Ltd

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Executive Summary

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

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

The objectives of the project are to:

- develop a list of key species of marine wildlife (including fish) likely to live within the Pilbara region, particularly near the Wheatstone footprint area;
- document current knowledge of these species;
- determine whether there is a need for any targeted field surveys (which will have a seasonality consideration).

One critical feature of potential marine wildlife issues with respect to the Wheatstone LNG development is to understand shallow water (<200 m deep) marine distribution patterns in the north west of Western Australia. The issue of critical and endangered species becoming potentially extinct through human activity is well established in the public mind and in regulations. The 12,000 km coastline of Western Australia can readily be divided into three biogeographic zones. The tropical north coast extends northeast from North West Cape. It is part of the vast Indo-West Pacific region that extends from the east coast of Africa through the tropical parts of the Indian and Pacific oceans as far east as Hawaii, and well north and south of the equator. Many marine fauna species are distributed over this full range. In Australia, the tropical region extends from Shark Bay or North West Cape across the north coast of the continent to the southern extent of the Great Barrier Reef. There are no major distributional barriers along the north coast of WA. Essentially, if the proper habitat for a species occurs, most species occur over the entire north coast.

A search of the website of the Commonwealth Department of Environment, Water, Heritage and the Arts was conducted for Matters of National Environmental Significance (MNES) for listed protected species and migratory species that might occur in the Project Area. This is the key potential area where the Wheatstone Project may trigger an assessment under the Environmental Protection and Biodiversity Conservation Act (EPBC Act (Cth)). The websites of the Convention on International Trade in Endangered Species (CITES), the WA Department of Environment and Conservation (DEC) and the WA Department of Fisheries (DoF) were also searched for any additional species of potential concern. The search area was broad (the entire Pilbara region) as known distributions of many species are generalised, with few confirmed records of the species actually occurring in the area. The resulting list of 96 species included:

- 30 mammals (17 whales, 12 dolphins and the dugong);
- 22 reptiles (6 turtles, 15 sea snakes and 1 crocodile);
- 5 marine birds; and

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- 39 fish (whale shark, manta ray, grey nurse shark, great white shark, freshwater sawfish and 34 syngnathid species).

The following species were selected for further investigation because of their conservation significance, such as being listed as Endangered or Vulnerable and/or migratory under the EPBC Act (Cth) or having been raised as issues in previous environmental assessments of similar projects in the Pilbara:

- Three species of whales (humpback whale *Megaptera novaeangliae* (Vulnerable), blue whale (*Balaenoptera musculus*) (Endangered), and pygmy blue whale (*B. musculus brevicauda*) (Endangered) have a high level of conservation significance under the EPBC Act (Cth) and are migratory species. They are also on CITES Appendix I and II; all three were examined further. The southern right whale *Eubalaena australis* has similar conservation significance. However, while individuals may occasionally enter the project area, the vast majority of the population is located further south
- The dugong (*Dugong dugon*) has one of its largest populations in the world, some 10,000 individuals, in Shark Bay. As the DEC raised concerns about dugongs in a submission regarding the proposed Gorgon LNG development, the species was considered further as its distribution in the Pilbara region is poorly understood.
- Six species of turtles are found in the Pilbara, but only four are known to breed in the region; all four are considered to be endangered or vulnerable under the EPBC Act (Cth) as well as being listed under CITES. The loggerhead turtle (*Caretta caretta*) is both listed as being endangered and migratory. The remaining five species are all listed as vulnerable.
- The whale shark (*Rhincodon typus*) is the largest fish in the world. It is listed as both being vulnerable and migratory under the EPBC Act (Cth), and was also further considered.

The humpback whale (*Megaptera novaeangliae*) is known to migrate from polar feeding grounds to tropical waters to calf. The species occurs around the world. Six separate populations have been identified in the southern hemisphere, with the Group IV population being associated with Australia's North-west Marine Region. The Group IV population migrates approximately 3600 nautical miles from the southern feeding grounds to the northern calving grounds in the Kimberley. Temporal migration patterns for humpback whales have been consistent from the 1950's to the present. Northbound migration takes place in May to July on the continental slope at an average depth of 300 m. A transitional phase takes place in late August which is distributed from depths of 50 to 1200 m. During the migration south, from September to November, high densities of cow/calf pairs have been observed resting in Exmouth Gulf for periods of up to two weeks. During the southern migration most of the humpback whales are in waters shallower than 75 m. The southern migration takes place from September to November with most whales recorded at depths less than 75 m (Jenner 2008).

The blue whale (*Balaenoptera musculus*) is found in oceans throughout the globe. The pygmy blue whale (*Baelenoptera musculus brevicauda)* is a subspecies of the blue whale; it has a known summer feeding site at Perth Canyon, west of Fremantle and has been sighted making northern migrations in the Project Area. Blue whales are believed to occur around the entire continent of Australia. They are highly mobile, feeding in the Antarctic during summer, and are thought to feed also in the winter at tropical breeding grounds. Temperate feeding grounds off the Western Australian coast at Rottnest Island and in the Bonney Coast upwelling region (south-eastern Australia) are the only areas off the Australian coast where blue whales are known to aggregate.

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Shark Bay contains a large population of dugongs (*Dugong dugon*) that is of international significance, with an estimated 10 000 individuals. Exmouth Gulf and Ningaloo Reef are also important dugong habitats, each supporting in the order of 1000 dugongs. A second major population of about 11 000 individuals occurs along the east coast of Queensland, and there are estimates of at least 6000 dugongs in the Northern Territory and 1455 in Torres Strait. The Kimberley region is also a rich habitat for dugongs, but there are no data available on the population size in this area. Within these broad distributional patterns, there is a general lack of understanding regarding fine-scale movements and the importance of various habitats for resting, breeding or feeding. Major concentrations of dugongs tend to occur in wide shallow bays, mangrove channels and in the lee of large inshore islands. Shallow waters such as tidal banks and estuaries have also been reporting as sites for calving.

Green turtles (*Chelonia mydas*) are the most abundant sea turtles on the North West Shelf. There are four stocks of green turtles in Queensland: Gulf of Carpentaria, northern Great Barrier Reef, southern Great Barrier Reef, and Coral Sea. The northern Great Barrier Reef stock is the largest in the world. Its primary breeding areas are in the area of Raine Island and Moulter Cay where 41 000 turtles would nest during a typical year, increasing to 131 000 in the highest years. The Western Australian population of green turtles numbers in the tens of thousands. The principal rookeries are in the Lacepede Islands, some islands in the Dampier Archipelago, Barrow Island, Montebello Islands and at North West Cape. It has been estimated that there are 7000-9000 turtles in Shark Bay and a comparable number in Exmouth Gulf/Ningaloo Reef. The beaches of the west side of Barrow Island are internationally significant, with an estimated 100 000 animals. Adult green turtles and their eggs have been, and still are, harvested traditionally by Aboriginals and Indonesian fishermen. There have been several legal turtle harvesting fisheries in Western Australia that date back as early as 1870. The most recent was a fishery that operated between Coral Bay and the Montebello Islands from 1958 to 1973. It took at least 60 000 green turtles.

Flatback turtles *(Natator depressus)* are the second most common species in the North West. Flatbacks are one of the two species that are believed to lack a pelagic phase when they move about in open waters. Their range is restricted to shallow coastal and continental shelf waters of Northern Australia and adjacent parts of the southern Indonesian Archipelago and Papua New Guinea. There are two breeding units in the North West. Most individuals are part of the North West Shelf population, but those in the Bonaparte Gulf are probably part of the western Northern Territory group. The Barrow Island population is of international significance, with an estimated 10 000 animals.

The leatherback turtle (*Dermochelys coriacea*) is a widely distributed species that spends the majority of its lifetime in the open ocean. In Western Australia, large populations of leatherbacks feed on soft-bodied invertebrates, typically off coasts south of Geraldton.

Loggerhead turtles (*Caretta caretta*) are found throughout the world in both temperate and tropical waters. There are significant nesting areas in Western Australia, including the Muiron Islands and Shark Bay.

Hawksbill turtles *(Eretmochelys imbricata)* are found in tropical waters of the central Atlantic and the Indo-west Pacific. In Australia, they occur in tidal and subtidal coral and rocky reef habitats, extending into warm temperate areas as far south as northern New South Wales. Known feeding areas include the Great Barrier Reef, Torres Strait, the Northern Territory and Western Australia south to Shark Bay. There are two main breeding areas in Australia: i) the northern Great Barrier Reef, Torres Strait and north-eastern Arnhem Land, and ii) the North West Shelf. Several rookeries occur within each area.

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The North West Shelf rookeries include Rosemary Island in the Dampier Archipelago and Varanus Island near Onslow.

Olive ridley turtles *(Lepidochelys olivacea)* are found in tropical and subtropical shallow protected waters worldwide, including much of northern Australia, but not Western Australia.

The whale shark (*Rhincodon typus*) is the largest fish in the world, growing up to 12 m in length. They are broadly distributed in oceanic and coastal waters between latitudes 30°N and 35°S in tropical and warm temperate seas. Within Commonwealth waters, whale sharks are known to aggregate in the coastal waters at Christmas Island, in the Coral Sea and off Ningaloo Reef, the largest whale shark aggregation site in Australian waters. The whale shark migration in the Ningaloo region corresponds to the seasonal intensification of the Leeuwin Current and mass synchronous coral spawning events in March and April. It is estimated that 300-500 whale sharks aggregate at Ningaloo Reef with the majority of individuals being juvenile males.

There is a paucity of information regarding whale, turtle, dugong and whale shark presence in the Wheatstone Project Area. Therefore it is expected that Chevron will need to conduct some studies to provide greater information on these species.

As additional turtle studies have already been commissioned by Chevron, the recommendations below relate only to whales, dugongs and whale sharks:

- Acoustic studies. Whales in particular are known to be highly reliant on acoustic signals, and as such, some of their vocalisations can be recorded by hydrophones. This acoustic signal monitoring is conducted by using a data recorder and hydrophone array, which is lowered to a set depth in the water column. At the completion of the monitoring period, the hydrophones are recovered and the data are analysed. This method can be used to continuously determine whale presence and potentially movements both in the nearshore and offshore areas of the Wheatstone Project. In addition, the underwater noise monitoring can be used to determine ambient noise characteristics to provide a background noise baseline from which the potential impacts of the project can be assessed.
- Aerial surveys. Whales, dugongs and whale sharks are all large marine animals that have been commonly observed during aerial marine fauna surveys. These surveys use fixed wing aircraft or helicopters that can cover large areas and provide a snapshot of animal distributions within a short period of time. The information gathered from these surveys can also include summaries of species sighted, number of individuals and groups, swim direction and behaviour pattern (i.e. feeding, resting, migrating etc.). Strip transect survey methods are generally preferred as they have advantages such as less flight time and less cost than total coverage, ease of navigation, and reduced likelihood of double-counting. This standardised survey technique is also repeatable, and produces population estimates with known precision.

Introduction

1.1 Background

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

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

1.2 Scope of Work

The scope of work for the project was:

1) to conduct a desktop review of marine wildlife in the Pilbara region, concentrating on vertebrates listed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act (Cth)) or State legislation.

2) to place primary emphasis on dugongs, cetaceans, crocodiles and fish. Turtles were included to link with the studies being conducted by Pendoley Environmental Pty Ltd (Pendoley).

3) to convene a workshop to discuss and rank the risks of the Project to threatened fauna, assess issues likely to arise in the assessment/approvals process and make recommendations for any studies required to fill gaps.

1.3 Objectives

The objectives of the project were to:

1) develop a list of key species of marine wildlife (including fish) likely to live within the Pilbara region, particularly near the Wheatstone footprint area ;

2) document current knowledge of these species;

3) determine whether there was need for any targeted field surveys (which will have a seasonality consideration).

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Western Australia Marine Fauna Distributions

One critical feature of understanding potential marine wildlife issues with respect to the Wheatstone Project is to understand shallow water (<200 m deep) marine wildlife distribution patterns in Western Australia. The issue of critical and endangered species becoming potentially extinct through human activity is well established in the public mind and in regulations.

The 12,000 km coastline of Western Australia can readily be divided into three biogeographic zones (Figure 2-1). The tropical north coast extends northeast from North West Cape. It is part of the vast Indo-West Pacific region that extends from the east coast of Africa through the tropical parts of the Indian and Pacific oceans as far east as Hawaii, and well north and south of the equator. Many marine fauna species are distributed over this full range. Many of the species along the north coast are shared with countries such as Indonesia, Papua New Guinea, Thailand and southern Japan. In Australia, the tropical region extends from Shark Bay or North West Cape across the north coast of the continent to the southern extent of the Great Barrier Reef (Wells 1980; Wilson and Allen 1987). There are no major distributional barriers along the north coast of WA. Essentially, if the proper habitat for a species occurs, most species occur over the entire north coast (Wells 1980).

Figure 2-1 Map of Western Australia Showing the Three Major Biogeographic Zones (after Wilson & Allen 1987)

The south coast of WA, from Cape Leeuwin to the South Australian border is part of the southern Australian warm temperate region that continues across the entire south coast of the continent. Again, species are widely distributed in the region, but the temperate species are almost completely different from the tropical species that occur on the north coast. The east and west coasts of the continent are

2 Western Australia Marine Fauna Distributions

areas of biogeographic overlap where the tropical and temperate biotas mix. In WA, the west coast overlap zone extends from Cape Leeuwin to Shark Bay or North West Cape. Scientific opinion differs on the northern limit. The key features are that tropical species dominate in the north, temperate species in the south, and about 10% of the shallow water marine biota of Western Australia is endemic to the state. These species may occur on any of the coasts, but they tend to have at least part of their range in the west coast overlap zone (Wells 1980; Wilson and Allen 1987).

The above distribution patterns are true for marine invertebrates, fishes and plants. Distribution patterns of higher vertebrates tend to be even greater. For example, six species of turtles are found in the Pilbara. None of the six is restricted to the Pilbara; all are in fact worldwide in their distribution.

The Interim Marine and Coastal Regionalisation of Australia (IMCRA 1998) developed a classification of the Australian marine environment into 60 bioregions, which has recently been finalised. The Pilbara region is divided into the Pilbara Nearshore and Pilbara Offshore (Figure 2-2, 2-3). The Wheatstone project area occurs in both areas, with most of the facilities to be in the Pilbara Inshore.

2 Western Australia Marine Fauna Distributions

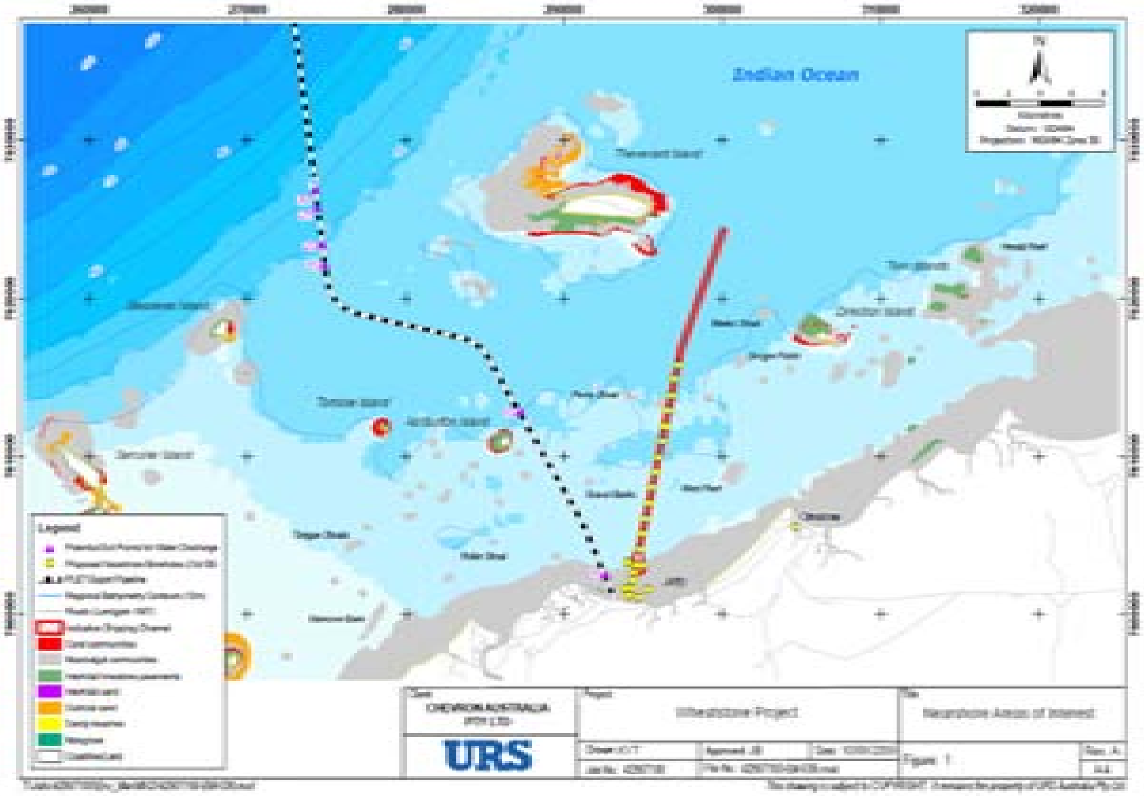

Figure 2-2 Wheatstone Project Area: Nearshore Areas of Interest

2 Western Australia Marine Fauna Distributions

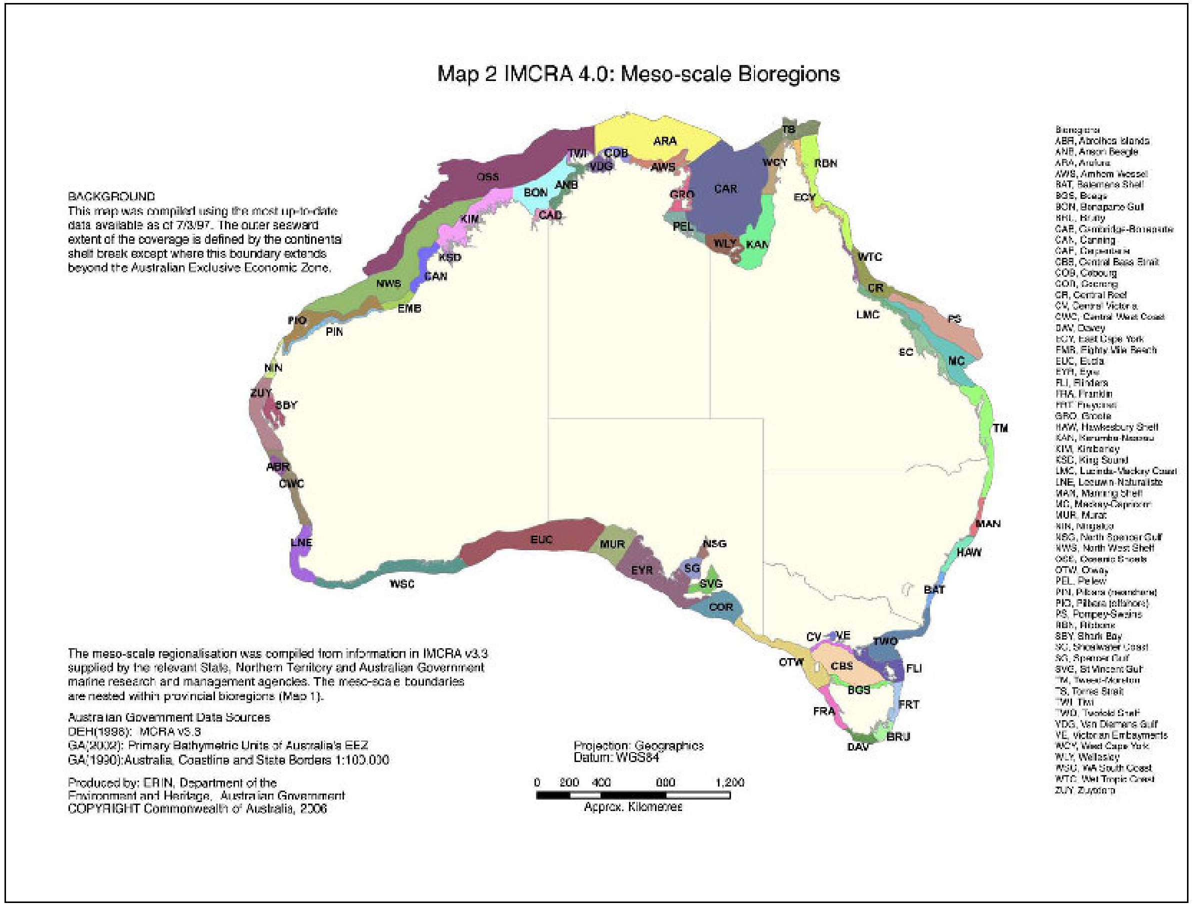

Figure 2-3 IMCRA Marine Bioregions in Australia (from IMCRA 1998)

3

Marine Fauna Legislation

There are several acts and conventions under which species in the Wheatstone areas may be protected.

3.1 Environmental Protection and Biodiversity Conservation Act 1999

Fauna listed as threatened or migratory under the EPBC Act (Cth) are protected under the act. Under the EPBC Act (Cth), Chevron is required to refer to the Commonwealth Minister for the Environment Water, Heritage and the Arts any action in the development of the Wheatstone LNG program that is likely to significantly affect any Matter of National Environmental Significance (MNES).

3.2 Wildlife Conservation Act 1950

Species listed under the Western Australian Wildlife Conservation Act 1950 are protected in Western Australian (WA) waters. The Act is administered by the WA Department of Environment and Conservation (DEC).

3.3 Fish Resources Management Act

The primary legislation under which the Western Australian Department of Fisheries is governed is the Fish Resources Management Act 1994 (FRM Act), and the accompanying Fish Resources Management Regulations 1995. Under this legislation, some species of fish are protected.

3.4 CITES (Conventional and International Trade in Endangered Species of Wild Fauna and Flora)

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international agreement between governments. It aims at eliminating threats from the international trade of wild animals and plants (UNEP-WCMC 2009). CITES works by listing species in three appendices: Appendix I comprises species threatened with extinction, Appendix II contains species not necessarily threatened with extinction, but in which trade must be controlled (threatened species) and Appendix III contains species that are protected in at least one country (UNEP-WCMC 2009).

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Methodology

A search of the DEWHA website was conducted on 15 December 2008 for MNES for listed protected species and migratory species, the key potential areas where the Wheatstone Project may trigger an EPBC assessment (Figure 4-1). The websites of DEWHA, CITES and DEC were searched for any threatened marine fauna which may potentially occur within the Wheatstone Project Area. The search contained species in Pilbara region (WA) from 19.2538°S; 112.8704°E to 22.9808°S; 118.2835°E (Appendix A). The area searched was very broad as the resulting distributions are very generalised, with few confirmed records of the species actually occurring in the area.

The list of species found to potentially occur within the Project Area were tabulated (Appendix A), and reviewed further to identify whether species listed may require additional study. Those species thought to have ecological significance in the study are presented in Section 5.

The website of the Western Australian Museum (WAM) was checked for confirmed records. The WAM website has links to the databases of the Museums and Art Galleries of the Northern Territory and the Queensland Museum, so the data obtained from the WAM website includes that of all three institutions (Appendix B).

The following sources were examined to obtain specific information on distributions in the Pilbara: management plans for Ningaloo (Commonwealth of Australia 2002); Dampier Archipelago (Department of Conservation and Land Management [CALM] 2005) and the Montebello/Barrow Islands (DEC 2007), and an unpublished report on cetaceans on the continental slope off Barrow Island (Jenner 2008). Additional areas were included with the search due to a gap in adequate information for the target area; those areas included Exmouth, Ningaloo, Barrow Island and the Montebello Islands.

In addition, the relevant proponent submissions and Environmental Protection Authority reports for development proposals in areas near the Wheatstone project were examined for relevant information. These included the Pluto (EPA 2007) and Gorgon (EPA 2003; RPS BBG 2005) LNG proposals and the Yannarie solar salt proposal for the eastern shore of Exmouth Gulf (EPA 2008).

In many cases, species were found to have significant gaps in information regarding distribution in the Wheatstone Project Area; these species were identified as requiring further investigations and are presented in Section 6.

4 Methodology

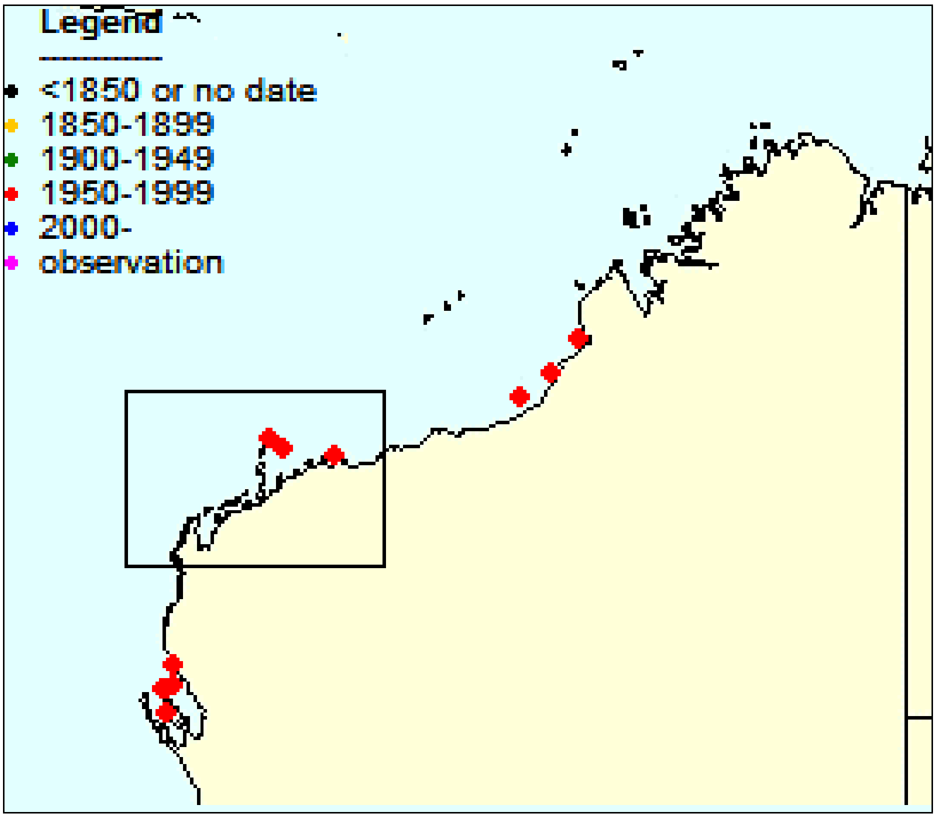

Figure 4-1 Wheatstone project listed Marine Wildlife MNES Search

Results

5.1 Potential Trigger Species

Searches of the appropriate databases revealed 95 EPBC listed vertebrate species (Table 5-1; Appendix A) as possibly occurring in the Wheatstone Marine Project area. An additional species was added to the list of species for consideration: the manta ray (*Manta birostris*). The manta ray has become an iconic species, attracting the attention of tourists, divers, etc. No species of concern for the project area were found to be listed under the FRM Act.

Table 5-1 Listed Species in the Pilbara Region.

Group	Taxa
Mammals	17 whales, 12 dolphins and 1 dugong
Reptiles	6 turtles, 15 sea snakes and 1 crocodile
Marine birds	5 species
Fish	1 whale shark, 1 manta ray, 1 grey nurse shark, 1 great white shark, 1 freshwater sawfish and 34 syngnathid species

5.2 Mammals

The humpback whale *Megaptera novaeangliae* (Vulnerable), blue whale (*Balaenoptera musculus*) (Endangered), the pygmy blue whale (*Baelenoptera musculus brevicauda*) and southern right whale (*Eubalaena australis*) (Endangered) have a high level of conservation significance under the EPBC Act (Cth) and CITES Appendix I and II; all three species are also listed as migratory. Individuals of the southern right whale may occasionally enter the project area, but the vast majority of the population is located further south and the species is regarded as being only occasional transients in the study area. The blue whale and humpback whales were considered further in this study as both species may utilise the area periodically.

Jenner (2008a) provided a summary of knowledge of cetaceans in the Pilbara Offshore Region (PIO), which included the Petroleum Titles. Three separate major habitats occur in the area: the deepwater offshore region, steep shelf slope and the broad, relatively shallow continental shelf. There is differing information available for each of the three habitats. Most of the information on cetacean activities in the Pilbara was gained through long-term examinations of humpback whale migrations in the area. More recently, Jenner (2008b) surveyed cetacean populations in the area north of Barrow Island, using transects across the outer continental shelf, past the slope and over the nearby offshore area.

As Jenner (2008a) discussed, there are still gaps in our knowledge of cetacean distributions, seasonality and activity patterns on the outer continental shelf and offshore. However, this is the area where studies have been concentrated. There is comparatively little information available on whales in the area of the inner continental shelf.

Thiele and Jenner (2008) examined available information on cetacean distributions and found that there was a clear positive relationship between habitat variability and cetacean density and diversity. Prey species of cetaceans tend to congregate in structurally complex areas such as undersea canyons, the shelf slope, deep holes, etc. where there are an increased number of habitats available, food is more plentiful and there are refuges from predators. Because of the availability of prey, cetaceans, including both whales and dolphins tend to congregate in the same areas.

Oceanographic processes in the PIO (Figure 2-2) are dynamic, with localised upwelling, oceanographic fronts, gyres, etc. These features may be permanent, seasonal or temporary and are areas where prey accumulate, further increasing the value of the region to cetaceans. The short duration of some of these features makes it difficult to reliably predict cetacean concentrations.

Jenner (2008a) concluded that while there are knowledge gaps, a number of species are known to be present. Humpback whales migrate through the area during winter. Other baleen whales, including blue whales, are present at this time, but the extent of their populations and whether the whales are present in other seasons is not clear. Some species, such as Brydes or minke whales, are year round residents. A peak in primary production in summer suggests some species may be concentrated in the area during summer. The large number of species present and the year round nature of cetacean presence make it difficult to design mitigation strategies, if required, for developments occurring in the area.

There were 12 species of dolphins on the original list of species possibly occurring in the Pilbara (Table 5-1), but little is known of actual population densities. Although dolphins are relatively common and not likely to be threatened, they are protected because they are cetaceans.

The newly identified snubfin dolphin (*Orcaella heinsohni*) is also expected to be present in the area, although very little is known about the ecology and distribution of the snubfin. Until 2005 (Parra et al. 2006), it was thought to be the Irrawaddy dolphin (*Orcaella brevirostris*). The snubfin Dolphin is believed to be endemic to Northern Australian and the Papua New Guinea regions (Parra et al. 2006). In Northern Queensland, Parra (2006) found snubfin dolphins were utilising shallow habitats (1-2m) close to river mouths, breakwaters and modified habitats such as dredged channels as well as areas with high seagrass coverage.

The dugong (*Dugong dugon*) has one of its largest populations in the world, some 10,000 individuals, in Shark Bay. The WA DEC raised concerns about dugongs in a submission regarding the proposed Gorgon LNG development, so the species was considered further as distribution in the Pilbara region is poorly understood.

5.3 Reptiles

Six species of turtles are found in the Pilbara, but only four are known to breed in the region, and all four are considered to be endangered or vulnerable under the EPBC Act (Cth) as well as being listed under CITES. The loggerhead turtle (*Caretta caretta*) is both listed as being endangered and migratory. The remaining five species are all listed as vulnerable.

The salt-water, or estuarine, crocodile (*Crocodylus porosus*) was heavily hunted for use in the leather industry. In Western Australia, such hunting was terminated in the early 1970s. Since then populations have recovered and the range of the animals has been extending south. The salt-water crocodile is the most widely distributed crocodilian species, occurring in Northern Australia, all throughout south-east Asia, Southern India and Palau (Kay 2004). The salt-water crocodile is considered common and locally abundant in Western Australia. Formerly rare south of Cape Leveque, salt-water crocodiles are now regularly reported in the Broome area by the media. In recent years there have been some individuals seen in the eastern Pilbara, and more recently there have been reliable sightings of an individual in the Ashburton River Mouth, a smaller one further up the river and a third at Three Mile

Creek. It is likely that as populations continue to increase the species will extend at least into Exmouth Gulf.

Sea snakes occur in tropical and subtropical waters of the Pacific and Indian oceans, encompassing the African Coast, Indo-Malayan Archipelago, China, Indonesia, and the Australian region. They are generally found in shallow waters along coast, islands and river mouths (Rasmussen 2001). Sea snakes are likely to be both species rich and abundant within the Project Area.

Because of their widespread distributions, neither salt-water crocodiles nor sea snakes are likely to be significantly affected by the Wheatstone LNG development, they are not be considered further in this report.

5.4 Marine Birds

The MNES search developed a list of 13 species of birds. Eight of these are terrestrial species that overfly the water occasionally, e.g. the rainbow bee-eater *Merops ornatus* and the barn swallow *Hirundo rustica.* These species are excluded from further consideration.

The five remaining species (silver gull *Larus novaehollandiae*, southern giant-petrel *Macronectes giganteus,* bridled tern *Sterna anaethetus,* Caspian tern *S. caspia* and white-bellied sea-eagle *Haliaeetus leucogaster*) are all listed species, but none has significant conservation status. All five species, except the silver gull, are considered to be migratory. Information on four of these species in the Wheatstone Project Area is presented by Bamford (2009).

The southern giant-petrel was the only species not found by Bamford (2009) in surveys of migratory birds in the Onslow area in November 2008 and March 2009. The species is widespread in the Southern Ocean, with 62 000 individuals. It breeds on six islands in the Australian region of the subantarctic and Antarctic. DEWHA (2009) showed an indicative distribution of the species across southern Australia and north as far as the Pilbara. If it occurs in the Pilbara at all, it would be only isolated individuals at sea that have been blown out of their normal range.

5.5 Fish

5.5.1 Syngnathidae

All species of the Family Syngnathidae, which includes seahorses and pipefish, are listed under the EPBC Act (Cth). For thousands of years, these species have been highly valued in Chinese medicine for their purported medicinal values. Any brief visit to a Chinese pharmacy in Asia will reveal considerable numbers of these fish dried and ready for use. Because of their heavy utilisation for this purpose, the species are widely considered to be at risk. However, in Australia the species are widespread and are not subject to such usage. Accordingly their status is not at risk. Small numbers of syngnathids are caught as incidental bycatch in the Onslow Prawn Managed Fishery (ONPMF) (DOF 2004). While the animals are returned to the sea after being caught, it is likely that many do not survive. In addition, the Marine Aquarium Managed Fishery is licensed to collect 750 syngnathids per year for sale in the aquarium trade. Data are not available on how many, if any, of these fish are collected in the Pilbara.

Sygnathids have an unusual biology in which the young fish are retained in a pouch on the male until they have developed to a stage where they can begin life on their own. The lack of a planktonic distributional phase in the life cycle means species ranges are smaller than in many families of fish, but the ranges are still extensive. There are few actual records of syngnathid species in the area off Onslow, but a study by Allen (2000) recorded eight species in the Montebello Islands: *Campichthys tricarinatus, Choeroichthys brachysoma, Doryhamphus janssi, D. pessuliferus, Festucalex scalaris, Halicampus brocki, H. nitidus* and *Phoxocampus belcheri*. The Montebello Islands have greater habitat diversity than the area off Onslow, so it is likely that only a few of these species will occur in the Wheatstone footprint area. RPS BBG (2005) discussed the common or weedy sea dragon *Phyllopteryx taeniolatus* and the leafy sea dragon *Phycodurus eques*, stating that there are unconfirmed reports of both species off Onslow. This is highly unlikely as both are temperate southern Australian species.

Phyllopteryx taeniolatus has been recorded from Geraldton down the West Australian coast and across the Great Australian Bight up to Newcastle, New South Wales, including Tasmania. *Phycodurus eques* has been recorded as far north as the Perth coastline and as far south as Kangaroo Island, South Australia (WAM 2008).

For all of the above reasons, syngnathids are not considered to be at risk through the Wheatstone LNG development, and are not considered further.

5.5.2 Sharks

The whale shark (*Rhincodon typus*) is the largest fish in the world. It is listed as both being vulnerable and migratory under the EPBC Act (Cth), and will be discussed further in the next section. The grey nurse shark (*Carcharias taurus*), great white shark (*Carcharodon carcharias*), and freshwater sawfish (*Pristis microdon*) all occur only rarely in the Project Area (McAuley & Gaughan 2004).

5.5.3 Manta ray

The manta ray (*Manta birostris*) is the largest species of ray in the world (Ari & Correia 2008). Disc widths have been reliably measured up to 6.7 m, but this species possibly grows up to 9.1 m disc width. Individuals of 4 m disc width are relatively common. The disc of the manta ray is wider than it is long. The manta ray lives in tropical marine waters worldwide, but is also found occasionally in temperate seas. In Australia it is recorded from south-western Western Australia, around the tropical north of the country and south to the southern coast of New South Wales. Manta rays congregate inside the reef as well as in deep water in the Ningaloo Reef (Commonwealth of Australia 2002) area and are also common in other localities such as Shark Bay and the Dampier Archipelago. The manta ray is not listed as being migratory or threatened under the EPBC Act, it is considered abundant in population and highly mobile, for these reasons the manta ray is not be discussed further.

Species Considered Further

There were 17 species of whales that were found to potentially occur within the Wheatstone Project Area (Table 5-1). Of the 17, the humpback whale, blue whale and the pygmy blue whale are identified as occurring within the area. Information gaps on the distribution and abundance of these species has prompted further consideration. In addition to the three whale species, the dugong, whale shark and six turtle species have been investigated further.

6.1 Humpback whale

The humpback whale (*Megaptera novaeangliae*) is a large (15-18m, 35-40 tonnes) whale, easily identified by its long flippers, tubercles on the lower jaw and head and black body with white/mottled underside. It is currently listed as both vulnerable and migratory under the EPBC Act (Cth) (DEHWA 2008). With the end of whaling, populations have increased substantially in recent decades. Recent estimates place the current population of humpback whales in Western Australia between 8 000 and 14 000 individuals (DEHWA 2008).

Humpback whales are known to migrate from polar feeding grounds to tropical waters to calf (Jenner, Jenner and McCabe 2001). The species occurs around the world; six separate populations have been identified in the southern hemisphere, with the Group IV population being associated with Australia's North-west Marine Region (DEHWA 2008). The Group IV population migrates across the North-West Shelf of Australia (Figure 6-1); their migratory path is approximately 3600 nautical miles from the southern feeding grounds to the northern calving grounds in the Kimberley (Jenner and Jenner 2001). The exact timing of the Group IV migration is variable, attributed to annual variations in food availability in the Antarctic (Jenner, Jenner and McCabe 2001). However, sufficient data are available to make informed statements on the seasonal variations of group IV migration in North-Western Australia.

Temporal migration patterns for humpback whales have been consistent from the 1950s to the present. Northbound migration takes place in May to July on the continental slope at an average depth of 300 m. A transitional phase takes place in late August which is distributed from depths of 50 to 1200 m. During the migration south, from September to November, high densities of cow/calf pairs have been observed resting in Exmouth Gulf for periods up to two weeks. During the southern migration most of the humpback whales are in waters shallower than 75 m (Jenner 2008). There are also reports that limited numbers of humpback whales may occur seasonally on the inner continental shelf in the Onslow area (Young, pers. comm.). The southern migration takes place from September to November with most whales recorded at depths less than 75 m (Jenner 2008). The migration route of humpback whales through the project area is unclear.

Figure 6-1 shows the locations of concentrations of humpback whales in Australia; Figure 6-2 illustrates both southern and northern migration routes of the humpback whales along the north-western coast of Australia

6 Species Considered Further

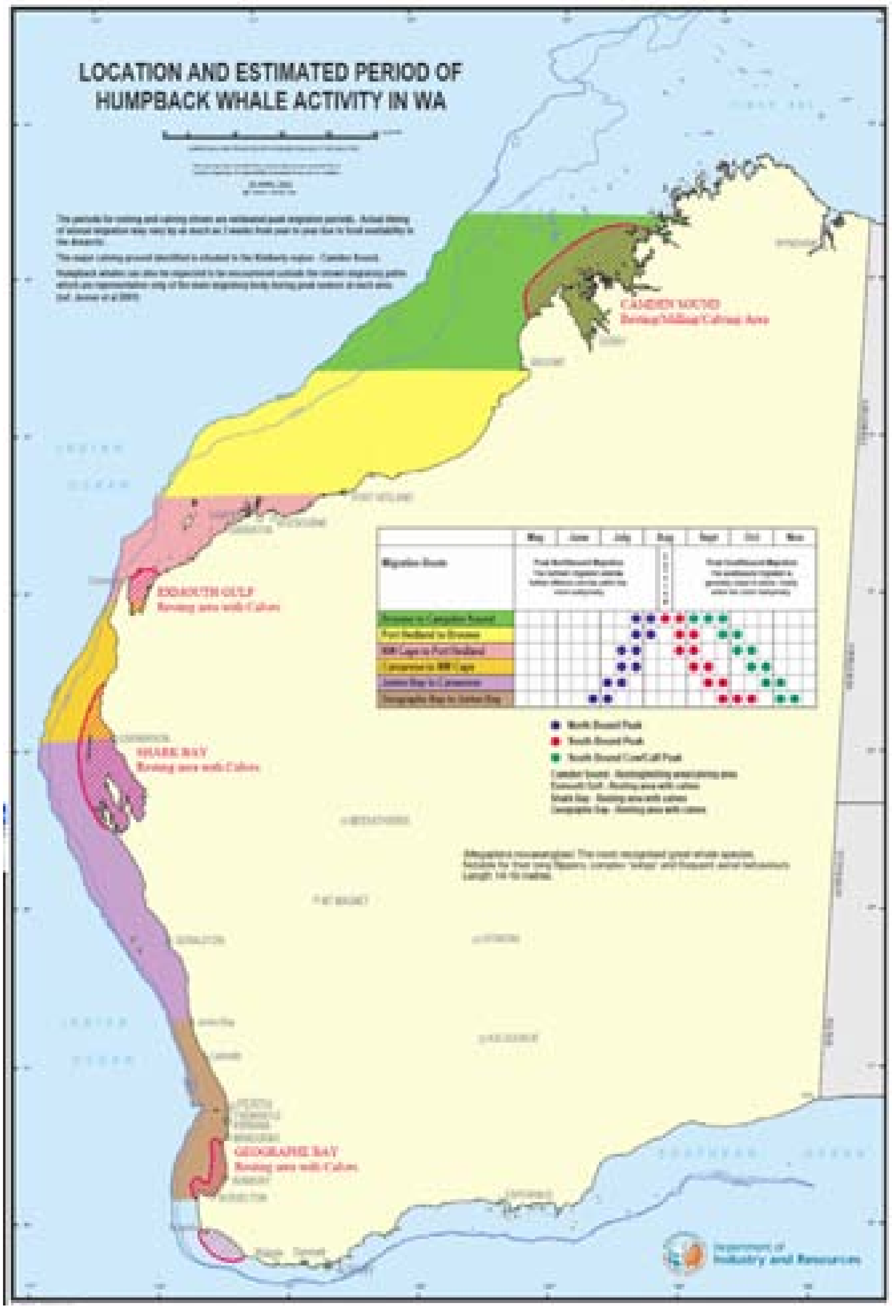

Figure 6-1 Location and Estimated Period of humpback whale Activity in WA

6 Species Considered Further

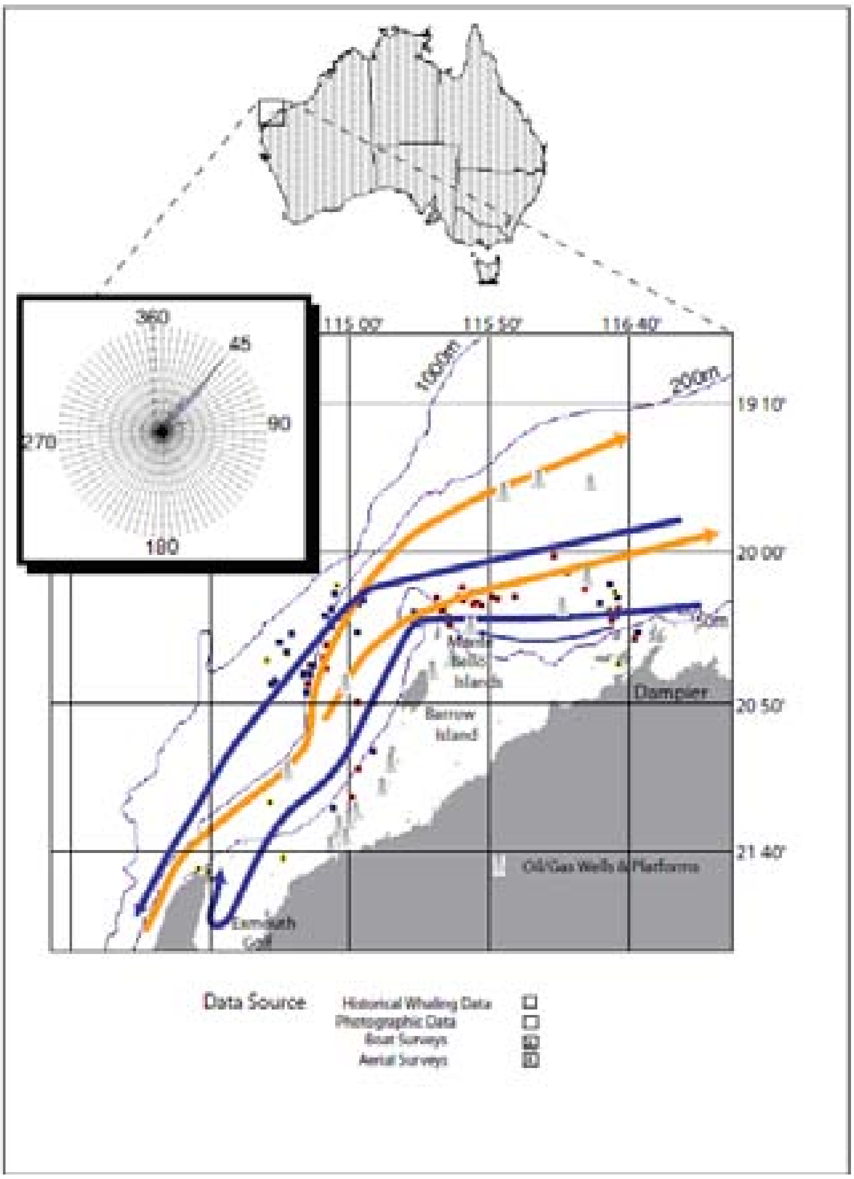

Figure 6-2 Assumed North and Southbound Migratory Path of humpback whales between Exmouth Gulf and the Dampier Archipelago. Inset charts are observed headings of northbound whales off the NW Montebello Islands in June/July 1992. Sightings reported from the oil and gas industry between 1991 and 1996 are shown as red (northbound), blue (southbound) or yellow (milling) squares. Source: Jenner et al. (2001).

6.2 Blue whales

The blue whale (*Balaenoptera musculus*) is the largest living animal, reaching lengths of over 30 m and weighing up to 180 tonnes. The blue whale is found in oceans throughout the globe (DEWHA 2008; 2009). Blue whales are a bluish grey with a lighter underside, however when fully submerged they appear a more luminous blue, mottled patterns on the sides and back are often used to identify individuals (DEWHA 2009).

The pygmy blue whale (*Baelenoptera musculus brevicauda*) is a subspecies of the blue whale; it has a known summer feeding site at Perth Canyon, West of Fremantle (Rennie et al. 2008) and has been sighted making northern migrations in the Project Area (Jenner, C pers. comm. 2008).

In Australian waters, blue whales are believed to occur around the entire continent, and have been sighted from the tip of Western Australia down to the Great Australian Bight and around Victoria, throughout Bass Strait and off the Tasmanian coasts as well as along the continental shelf of east Australia to southern Queensland, although they are predominately found in south-east and south-west Australia (DEWHA 2009).

Blue whales are a highly mobile species. Their enormous energy requirement creates the need for migration during the summer-autumn months. Blue whales feed in the Antarctic during summer, and are thought to feed also in the winter at tropical breeding grounds (DEWHA 2009). Temperate feeding grounds off the Western Australian coast at Rottnest Island and in the Bonney Coast upwelling region (south-eastern Australia) are the only areas off the Australian coast where blue whales are known to aggregate (DEWHA 2009).

6.3 Dugongs

Dugongs (*Dugong dugon*) are listed as a specially protected species of mammal under Schedule Four (‘fauna that need special protection’) of the WA Wildlife Conservation Act 1999 and threatened (Vulnerable) marine and migratory species under the EPBC Act (Cth).

The dugong is a shy marine mammal that inhabits shallow inshore waters within tropical and subtropical regions, from eastern Africa to Vanuatu (Figure 6-3). As its other name of ‘sea cow’ suggests, the dugong is a herbivore and spends most of its time grazing on seagrasses. Its reliance on large meadows of seagrass in waters close to land has resulted in a significant decline in numbers throughout much of its range, as a result of human activity and catastrophic natural events

Dugong feeding trails have been observed in dense seagrass meadows of *Halodule* and *Halophila*, between Middle and North Mangrove Islands (Pendoley and Fitzpatrick 1999). This region has extensive areas of shallow water, extending to the seaward side of Barrow Island and the Montebello Islands (Marsh et al. 2002). Dugongs have been well researched at Shark Bay; however there is an extensive gap in information in the Wheatstone project area.

Shark Bay contains a large population of dugongs that is of international significance. Estimates of approximately 10 000 dugongs resulted from aerial surveys conducted in both 1989 and 1994. Exmouth Gulf and Ningaloo Reef are also important dugong habitats, each supporting in the order of 1000 dugongs (Marsh et al. 1994; Preen et al. 1997). A second major population of about 11 000 individuals occurs along the east coast of Queensland. There are estimates of at least 6000 dugongs in the Northern Territory and 1455 in Torres Strait. The Kimberley is also a rich habitat area for dugongs (Gales et al. 2004), but there are no estimates of the Kimberley population. With their long lifespan and slow reproductive rates, it is difficult to know whether dugong populations are increasing or decreasing (Marsh 1988).

Shoreline surveys were undertaken in the 1980s between Exmouth Gulf and the De Grey River, 70 km north of Port Hedland. Most dugongs were observed in areas such as Mangrove and Passage Islands, Regnard Bay, Nickol Bay and within the Dampier Archipelago (Prince et al. 1981, Prince 1986). In April 2000, a quantitative aerial survey of this area recorded 2046 (± s.e. 376) dugongs at an average density of 0.10 dugongs per square kilometre. Most of the dugongs were in the locations identified from the earlier surveys and incidental reports of sightings or strandings (Prince 2001, Marsh et al. 2002).

Within these broad distributional patterns, there is a general lack of understanding regarding fine-scale movements and the importance of various habitats for resting, breeding or feeding. Major concentrations of dugongs tend to occur in wide shallow bays, mangrove channels and in the lee of large inshore islands. Shallow waters such as tidal banks and estuaries have also been reporting as sites for calving (Oceanwise 2005).

The acknowledged expert on dugongs, Professor Helene Marsh, made the following comments about dugong conservation:

> “The dugong's low rate of natural increase means that populations can sustain only a low level of man-induced mortality. The range of the dugong in Australia … extends over a huge area from which it will be both impossible and undesirable to prevent all causes of man-induced dugong mortality. A much more practical approach is to give a high level of protection to dugongs and their seagrass habitats in areas which still support large numbers of animals. In temperate areas such as Shark Bay, where dugongs use different core areas in different seasons (Anderson 1986), it will obviously be important to protect both their-summer and winter habitats. In tropical areas where animals appear relatively sedentary …, the banning of net-fishing and the regulation of Aboriginal hunting from key areas which are known to support large numbers of animals of animals should prove to be a significant conservation measure. Trawling has been banned from many inshore seagrass beds already in order to protect juvenile prawn nursery areas. This will protect dugong habitats as well. Such a policy of zonal management for dugongs is already operating in parts of the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority 1983, 1985).”
>
> As the only developed country whose waters harbour significant numbers of dugongs, Australia has a special responsibility to ensure that the dugong does not become extinct. I hope that the zonal management practices adopted to conserve dugongs in the Great Barrier Reef Marine Park will soon be extended to other areas.”

It should be noted that the major population of dugongs in WA is in Shark Bay, where a significant proportion (but not all) of the animals occur within the Shark Bay Marine Park. Preen et al. (1997) recommended expanding the marine park to match the boundaries of the Shark Bay World Heritage Area to include a larger proportion of the megafauna, including dugongs.

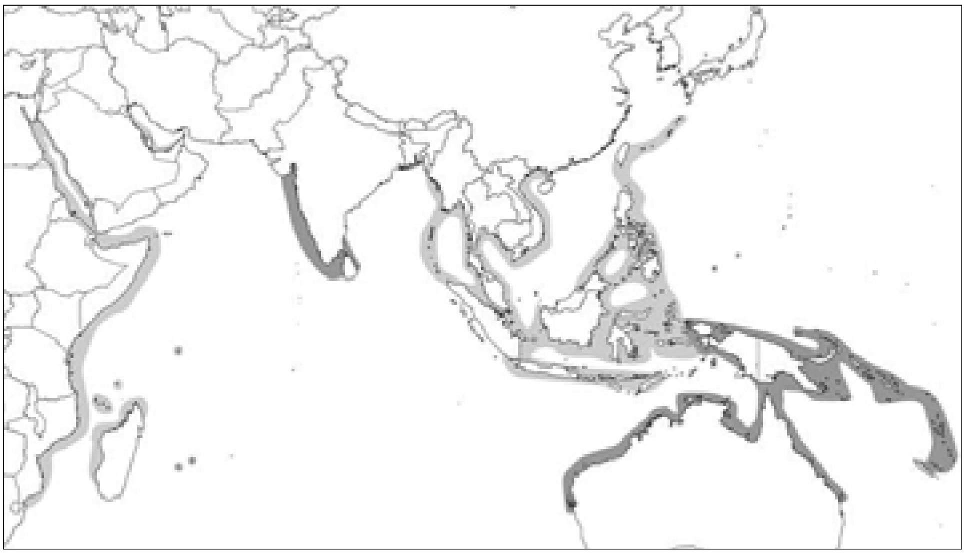

Figure 6-3 Known dugong Distributions (after Marsh et al. 2002)

6.4 Turtles

Two recent EPA assessments for proposaled LNG plants have discussed turtles in detail, demonstrating the high conservation significance of this group of animals. EPA (2006) examined the proposed Gorgon development at Barrow Island, by far the largest island in the Pilbara. The sea waters surrounding Barrow Island are an important year round habitat for five species of turtles. Nesting beaches on the west side of the island are world class for green turtles. Similarly, the east side of the island is important for flatback turtles. These beaches support a major part of Pilbara population, with about a third of the total number of animals nesting in the project area. The EPA concluded that because of the importance of Barrow Island and the limited knowledge about these species, the multiple threats to them raised by the project, expected losses due to boat strikes, and the high uncertainty about the consequences, the EPA did not consider that flatback turtles could be adequately managed for the development.

In contrast, the proposed Pluto LNG Plant on the Burrup Peninsula is situated in an area where there is little turtle nesting activity. The EPA (2007) believed the issues could be satisfactorily addressed through the development of a turtle management plan.

In recognition of the conservation importance of turtles, URS Australia commissioned Pendoley Environmental Pty Ltd to examine turtle nesting activity in the Onslow region during the summer of 2009. The survey was undertaken in January and February. Unfortunately, Cyclone Dominic passed through the area during the survey, disrupting the survey schedule. Preliminary results (Pendoley 2009) showed that there was very low density of turtle nesting at mainland sites east and west of Onslow. Substantial sections of this coastline had no visible activity. One site west of Ashburton River had low to moderate activity for flatback turtles, but there was no evidence of green turtles. There was

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no nesting activity in the proposed LNG Plant area. The report cautions that it was likely that storm activity reduced turtle nesting in the area.

Nesting activity varies substantially on offshore islands in the region. As would be expected, the larger islands (Serrurier, Besseires, Thevenard, Locker and Ashburton) have more activity, with a combination of flatback and green turtle nesting. Smaller islands, for example Tortoise, have very small areas of suitable nesting habitat and very low density nesting activity. Other smaller islands such as Flat, Table, Direction and the Twin Islands, have moderate levels of nesting activity the small areas of suitable habitat.

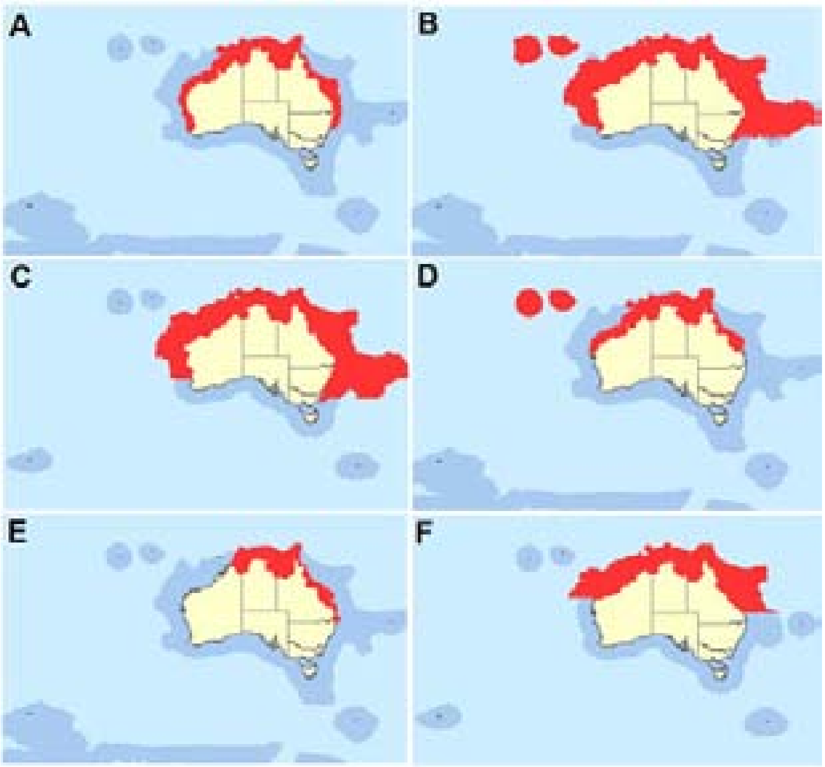

Figure 6-4 Distribution of Turtles around Australia; (A) Loggerhead turtle, (B) Green turtle, (C) Leathery Turtle or leatherback turtle, (D) Hawksbill turtle, (E) Olive ridley turtle and (F) Flatback turtle. (DEWHA 2009, species Profile and Threats Database)

6.4.1 Green turtles

Green turtles (*Chelonia mydas*) are the most abundant sea turtles on the North West Shelf (Prince 1993). They occur in inshore seagrass meadows and coral reefs rich in macroalgae in both tropical and subtropical areas of Western Australia and the Indo-Pacific (DEWHA 2008a). Adult green turtles feed on algae and seagrass while juveniles are carnivorous. Adults reach a size of approximately 1 m in length. Although they are often observed feeding in aggregations, green turtles are primarily a solitary species (DEWHA 2008a). As adults they average 150 to 300 kg with straight line carapace lengths of 65 to 90 cm (Paladino and Morreale 2001).

Obtaining information on turtle numbers is very difficult. Adults deposit eggs above the tide levels on sandy beaches. When the young turtles hatch they must escape the gauntlet of predators on the beach and in the shallows to begin their life at sea. It is many years before the adult female returns to the beach to deposit her eggs. A female may deposit eggs several times in a season, then not spawn again for three to five years. The most effective method of measuring nesting is to monitor the numbers of females coming ashore during the spawning season. On Barrow Island the nesting season starts in November, peaks in January-February and ends in April (Pendoley 2005), but it is impossible to monitor all of the beaches even on a single island throughout the season. There may be substantial inter-annual variations in nesting activity, which would give very different estimates of nesting numbers (Limpus et al. 2003), and such measurements would not include animals that did not nest.

Despite this, there are estimates of the numbers of green turtles in some areas. Limpus et al. (2003) reported that there are four stocks of green turtles in Queensland: Gulf of Carpentaria, northern Great Barrier Reef, southern Great Barrier Reef, and Coral Sea. The northern Great Barrier Route stock is the largest in the world. Its primary breeding areas are in the area of Raine Island and Moulter Cay. During a typical year about 41 000 turtles would nest. This would reach 131 000 in the highest years.

There are three genetic stocks of green turtles in the region: North West Shelf, Scott Reef and Ashmore Reef (Dethmers et al. 2006). The Pilbara green turtles are part of the North West Shelf stock that breeds in summer. This group effectively does not interbreed with the winter breeding stock in Bonaparte Gulf and Arnhem Land (Limpus 2006).

The Western Australian population of green turtles numbers in the tens of thousands (Figure 6-4B). The principal rookeries are in the Lacepede Islands, some islands in the Dampier Archipelago, Barrow Island, Montebello Islands and at North West Cape (DEWHA 2007; DEC 2009). Preen et al. (1997) estimated the number of turtles in Shark Bay at 7000-9000 with a comparable number in the area of Exmouth Gulf plus Ningaloo Reef. The beaches of the west side of Barrow Island comprise one of the few large scale breeding areas left for green turtles in the world (Hirth 1997). The Barrow Island population is a major part of the Pilbara genetic stock (Moritz et al. 2002) and is of international significance (EPA 2006). Pendoley (2005) estimated the Barrow Island green turtle population to be 100 000 animals.

Adult green turtles and their eggs have been, and still are, harvested traditionally by Aboriginals and Indonesian fishermen. There have been several legal turtle harvesting fisheries in Western Australia that date back as early as 1870. The most recent was a fishery that operated between Coral Bay and the Montebello Islands from 1958 to 1973. It took at least 60 000 green turtles.

6.4.2 Flatback turtles

Compared to green turtles, there is relatively little known of the distribution of flatback turtles (*Natator depressus*) in the north west, even though they are the second most common species. They are listed as vulnerable under the EPBC Act (Cth). Adults reach a maximum size of 1m; both the adult and juvenile diet is poorly understood although it is believed to include snails, soft corals, molluscs, bryozoans and sea pens (Paladino and Morreale 2001).

Flatbacks are one of the two species that are believed to lack a pelagic phase when they move about in open waters. Their range is restricted to shallow, soft bottom habitats of the coastal and continental shelf waters of Northern Australia (Figure 6-4F) and adjacent parts of the southern Indonesian Archipelago and Papua New Guinea typically in shallow soft bottom habitats (DEWHA 2008a). Hatchlings grow to maturity in shallow waters near their hatching beach, but may undertake long migrations from breeding grounds to feeding grounds. There are two breeding units in the north west. Most individuals are part of the North West Shelf population, but those in the Bonaparte Gulf are probably part of the western Northern Territory group (Limpus 2004).

The flatback turtle is a locally abundant breeding species, frequenting nesting beaches on the mainland and offshore islands, ranging from the east coast of Barrow Island to Torres Strait and the Great Barrier Reef (Prince 1993; DEWHA 2008a. Flatback turtles nest preferentially on the lower energy beaches of the eastern side of Barrow Island, and constitute a major portion of the Pilbara population. Approximately 700 nest on Barrow Island annually, one third of Pilbara total. The Barrow Island population is of international significance (EPA 2006). Monitoring of three key beaches (Terminal, Bivalve and Yacht Club North) on the east coast of the island in 2003-2004 averaged 26-49 nests/km/night (Chevron 2005a). Pendoley (2005) estimated the Barrow Island east coast flatback population at 10 000 animals.

6.4.3 Leatherback turtles

The leatherback turtle (*Dermochelys coriacea*) is the largest and most ancient sea turtle in the world. Its enormous body can reach lengths greater than 2m and weights of up to 600 kg as adults. It is a widely distributed species that spends the majority of its lifetime in the open ocean (Paladino and Morreale 2001). In Western Australia, large populations of leatherbacks are found feeding on soft-bodied invertebrates such as cnidarians and ctenophores, typically off coasts south of Geraldton (DEWHA 2008a, Paladino and Morreale 2001)(Figure 6-4C). A large proportion of the Australia leatherback population migrates to breed in neighbouring countries, particularly in Java, Indonesia. Leatherbacks have a nesting cycle of two to three years with females in general laying eggs four to five times per season. The clutch size varies from 46 to 160 eggs (DEWHA 2008a). The leatherback turtle is listed as vulnerable under the EPBC Act (Cth).

6.4.4 Loggerhead turtles

Loggerhead turtles (*Caretta caretta*) are found throughout the world in both temperate and tropical waters. In Western Australia they are found on coral reefs and in bays and estuaries. Loggerhead turtles are listed as endangered under the EPBC Act (Cth). Although they have been observed in the open ocean, they typically inhabit shelf and coastal waters to breed and feed (DEWHA 2008a). There are significant nesting areas in Western Australia, including the Muiron Islands and Shark Bay (Figure 6-4A).

Nesting probably occurs in Western Australia from late October; hatchlings emerge from nests from December until April with most hatching from February to early March. Loggerheads are primarily carnivorous but have a varied diet that includes crustaceans, molluscs, tube worms, sea pens, vegetation, sea pansies, whip corals, sea anemones, barnacles and shrimp (Paladino and Morreale 2001). Adults reach approximately 1 m in length (DEWHA 2008a).

6.4.5 Hawksbill turtles

Hawksbill turtles (*Eretmochelys imbricata*) are found in tropical waters of the central Atlantic and the Indo-west Pacific. In Australia, they occur in tidal and subtidal coral and rocky reef habitats, extending into warm temperate areas as far south as northern New South Wales (DEWHA 2008a). Known feeding areas include the Great Barrier Reef, Torres Strait, the Northern Territory and Western Australia south to Shark Bay (Figure 6-4D).

There are two main breeding areas in Australia: i) the northern Great Barrier Reef, Torres Strait and north-eastern Arnhem Land, and ii) the North West Shelf. Several rookeries occur within each area. On the North West Shelf, rookeries include Rosemary Island in the Dampier Archipelago and Varanus Island near Onslow. In Australia, hawksbill turtles mainly breed in spring or summer (DEWHA 2008a).

Hawksbill turtles forage among corals and consume sponges (adults consume about 90% sponges), algae, seagrasses, soft corals and shellfish (Paladino and Morreale 2001).

6.4.6 Olive ridley turtles

Olive ridley turtles (*Lepidochelys olivacea*) are found in tropical and subtropical shallow protected waters worldwide, including much of northern Australia, but not Western Australia (Figure 6-4E). The Olive ridley turtle’s diet mainly consists of shellfish and crustaceans. They are the smallest of the marine turtles, with maximum lengths less than 1 m but are typically around 55 to 70 cm (Paladino and Morreale 2001).

Olive ridley turtles are listed as endangered under the EPBC Act (Cth). Nesting typically occurs in summer and autumn, but may also occur in spring, depending on the region. They migrate in continental shelf waters and feed in shallow waters (DEWHA 2008a).

6.5 Whale shark

The whale shark (*Rhincodon typus*) is the largest fish in the world, growing up to 12 m in length (DEWHA 2008a). They are filter feeders, with diets consisting of phytoplankton, macroalgae, krill, crab larvae and small fish (DEWHA 2008a). Whale sharks occur in approximately 124 countries worldwide. They are broadly distributed in oceanic and coastal waters between latitudes 30°N and 35°S in tropical and warm temperate seas, preferring water temperatures of 21 to 25°C, although the average temperatures at Ningaloo during the whale shark migration is 27°C (DEWHA 2005).

The whale shark is currently listed under the EPBC Act (Cth) as vulnerable and migratory. Within Commonwealth waters, whale sharks are known to aggregate in the coastal waters at Christmas Island in the Coral Sea and off Ningaloo Reef, the largest whale shark aggregation site in Australian waters (Colomer 1999).

The whale shark migration in the Ningaloo region corresponds to the seasonal intensification of the Leeuwin Current and mass synchronous coral spawning events in March and April, although currently

6 Species Considered Further

there is no evidence to suggest whale sharks actually feed on the coral spawn (DEWHA 2008a). It is estimated that 300-500 whale sharks aggregate at Ningaloo Reef with the majority of individuals being juvenile males. The large number of whale sharks that consistently congregate at Ningaloo in April/May prompted the holding of an international symposium on the biology and conservation of whale sharks in Perth in May 2005 (Irvine and Keesing 2005; 2007).

Satellite tagging has shown that whale sharks departing Ningaloo make frequent dives in excess of 980 m and migrate generally toward the northeast, often into Indonesian waters (Meekan et al. 2008). This migration takes the whale sharks past the Wheatstone footprint area along the offshore continental slope.

The main cause of mortality in whale sharks is predation. In addition to being a target species of indigenous fishermen in certain areas, whale sharks are also taken as by-catch, notably in gillnet and purse seine fisheries (Stevens 2007). In the north west of Australia, whale sharks have been recorded as having sustained large injuries, suspected to be from large great white sharks (*Carcharodon carcharias*), with additional causes of mortality and injury being collisions with boat propellers (Stevens 2007).

The hearing capabilities of whale sharks has not yet received adequate study, however many shark species are well known to be highly sensitive to irregularly pulsed, low-frequency sounds, especially in the range of 20–400 Hz. The inner ear of whale sharks is the largest known in the animal kingdom. The large size of the inner ear mechanism may simply be an artefact of this species' enormity, but it suggests the other auditory structures may be proportional. Such large hearing structures would be expected to be most responsive to long wavelength, low-frequency sounds (Martin 2007). A large number of predatory sharks species are known to be extremely sensitive to irregularly pulsed, low-frequency sounds, although the hearing capabilities of whale sharks are largely unknown, whale sharks sometimes dive upon ignition of nearby inboard boat motors (Martin 2007). This may be a response to the low frequency sound signature of such motors. Like other elasmobranchs, the whale shark possesses an acoustico-lateralis system, modified anteriorly as ampullae of Lorenzini (Martin 2007). It is possible that inboard boat motors could potentially disrupt normal behaviours such as feeding, mating, or migrating from one place to another (DEWHA 2005).

Despite the whale shark being well studied in the North West of Australia, there is a large gap in information for distribution and abundance within the project area.

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Further Studies

There is a paucity of information regarding whale, turtle, dugong and whale shark presence in the Wheatstone Project Area. Therefore, it is expected that Chevron will need to conduct some studies to provide greater information on these species.

It is understood that additional turtle studies have already been commissioned by Chevron, therefore these recommendations relate only to whales, dugongs and whale sharks. The following survey methods are recommended (in consultation with the DEC) in order to gain greater information on these remaining species.

7.1 Acoustic Studies

Whales in particular are known to be highly reliant on acoustic signals, and as such, some of their vocalisations are able to be recorded by hydrophones. This acoustic signal monitoring is conducted by using a data recorder and hydrophone array which is lowered to a set depth in the water column. The depth at which the hydrophone is lowered can be derived using the Geoscience Australia bathymetry grid. Ideally, the hydrophones are deployed for a period of six months or more to gain a synopsis of the presence and movements of marine fauna (e.g. whales) in the region. At the completion of the monitoring period, the hydrophones are recovered and the data are analysed. This method can be used to continuously determine whale presence and potentially movements both in the nearshore and offshore areas of the Wheatstone Project.

In addition, the underwater noise monitoring can be used to determine ambient noise characteristics to provide a background noise baseline from which the potential impacts of the project can be assessed.

7.2 Aerial Survey

Whales, dugongs and whale sharks are all large marine animals that have been commonly observed during aerial marine fauna surveys. These surveys use fixed wing or helicopters and, as opposed to boat based observations, can cover large areas and provide a snapshot of animal distribution within a short period of time. The information gathered from these surveys can also include summaries of species sighted, number of individuals and groups, swim direction and behaviour pattern (i.e., feeding, resting, migrating etc.). Strip transect survey methods are generally preferred as they have advantages such as less flight time and less cost than total coverage, ease of navigation, and reduced likelihood of double-counting. This standardised survey technique is also repeatable, and produces population estimates with known precision.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Chevron Australia Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the CTR dated February 2009.

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

This report was prepared between February and May 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties.

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Appendix A Listed Species Recorded in the Pilbara Region, Western Australia

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Appendix A: Wheatstone Marine Fauna; Threatened Species in North-Western Australia

Figure 1: Location of Onslow, North Western Australia

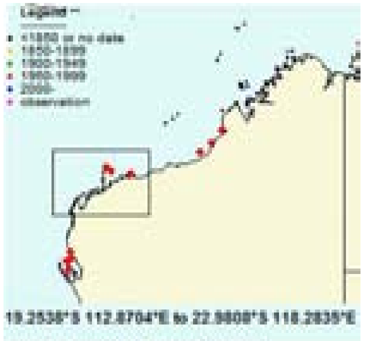

Figure 2: Search Area
www.museum.wa.gov.au

Key

Classification		Season	www.museum.wa.gov.au	Status		
Commonwealth	**State**	**(Source; SPRAT (iii))**	**Yes (Y) No (N)**	**Commonwealth**	**State**	**CITES**
TM: Threatened Mammals TR: Threatened Reptiles TS: Threatened Sharks MR: Migratory Reptiles MM: Migratory Marine Mammals MS: Migratory Shark LM: Listed Mammals LF: Listed Ray finned Fishes LR: Listed Reptiles WOC: Whales and Other Cetaceans MB: Migratory Birds LB: Listed Bird	Division 1: Mammals Division 3: Reptiles Division 5: Fish Division 9: Polychaetes	S: Summer- December to February A: Autumn- March to May W: Winter- June to August Sp: Spring- September to November U: Unknown or not specified seasons. Additional Literature review required N/A: Not Applicable	Y: Species has been sighted/recorded in area (figure 2) N: Species has no been sighted/ recorded in area (figure 2)	E: Endangered V: Vulnerable M: Migratory L: Listed EPBC Act C: Cetacean	S1: Schedule 1- Rare or likely to become extinct S4: Schedule 4- Other Specially Protected fauna	I: Appendix I (species threatened with extinction. Trade in specimens of these species is permitted only in exceptional circumstances) II: Appendix II (species not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival) III: Appendix III (protected in at least one country) NA: Not listed on CITES

Appendix A: Wheatstone Marine Fauna; Threatened Species in North-Western Australia

Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
Marine Mammals: Whales	*Balaenoptera borealis*	Sei Whale		Division 1	S	N		S1	I
	Balaenoptera musculus	Blue Whale	TM, MM	Division 1	U	N	E, M	S1	I
	Balaenoptera physalus	Fin Whale		Division 1	S, A	N		S1	I
	Eubalaena australis	Southern Right Whale	TM, MM	Division 1	A, S	N	E, M	S1	I
	Megaptera novaeangliae	Humpback Whale	TM, MM	Division 1	A, S	N	V, M	S1	I
	Balaenoptera bonaerensis	Antarctic Minke Whale, Dark-shoulder Minke Whale	MM		U	N	M		I
	Balaenoptera edeni	Bryde's Whale	MM		U	N	M		I
	Orcinus orca	Killer Whale	MM		U	N	M		II
	Physeter macrocephalus	Sperm Whale	MM		U	Y	M		II
	Balaenoptera acutorostrata	Minke Whale	WOC		N/A	N	C		I, II
	Feresa attenuata	Pygmy Killer Whale	WOC		N/A	N	C		II
	Globicephala macrorhynchus	Short-finned Pilot Whale	WOC		N/A	N	C		II
	Kogia breviceps	Pygmy Sperm Whale	WOC		N/A	N	C		II
	Kogia simus	Dwarf Sperm Whale	WOC		N/A	N	C		II
	Mesoplodon densirostris	Blainville's Beaked Whale, Dense-beaked Whale	WOC		N/A	Y	C		II
	Pseudorca	False Killer Whale	WOC		N/A	Y	C		II

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Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
	crassidens								
Marine Mammals: Whales	*Ziphius cavirostris*	Cuvier's Beaked Whale, Goose-beaked Whale	WOC		N/A	N	C		II
	Globicephala macrorhynchus	Short-Fined Pilot Whale	WOC		N/A	N	C		II
	Peponocephala electra	Melon-headed Whale	WOC		N/A	N	C		II
Dugong	*Dugong dugon*	Dugong	MM, LM	Division 1	S	Y	M, L	S4	II
Marine Mammals: Dolphins	*Sousa chinensis*	Indo-Pacific Humpback Dolphin	MM		U	Y	M		I
	Tursiops aduncus	Spotted Bottlenose Dolphin (Arafura/Timor Sea populations)	MM		U	N	M		II
	Delphinus delphis	Common Dolphin	WOC		N/A	Y	C		II
	Grampus griseus	Risso's Dolphin, Grampus	WOC		N/A	N	C		II
	Lagenodelphis hosei	Fraser's Dolphin, Sarawak Dolphin	WOC		N/A	N	C		II
	Stenella attenuata	Spotted Dolphin, Pantropical Spotted Dolphin	WOC		N/A	N	C		II
	Stenella coeruloalba	Striped Dolphin, Euphrosyne Dolphin	WOC		N/A	N	C		II
	Stenella longirostris	Long-snouted Spinner Dolphin	WOC		N/A	Y	C		II
	Steno bredanensis	Rough-toothed Dolphin	WOC		N/A	N	C		II

Appendix A: Wheatstone Marine Fauna; Threatened Species in North-Western Australia

Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
	Tursiops aduncus	Indian Ocean Bottlenose Dolphin, Spotted Bottlenose	WOC		N/A	N	C		II
	Tursiops truncatus s.str.	Bottlenose Dolphin	WOC		N/A	N	C		II
	Orcaella heinsohni	Snubfin Dolphin	WOC		N/A	N	C		NA
Marine Reptiles:	*Chelonia mydas*	Green Turtle	TR, MR, LR	Division 3	U	Y	V, L	S1	I
Marine Reptiles:	*Dermochelys coriacea*	Leathery Turtle or Luth	TR, MR, LR	Division 3	U	N	V, L	S1	I
Turtles	*Eretmochelys imbricata*	Hawksbill Turtle	TR, MR	Division 3	U	Y	V	S1	I
	Lepidochelys olivacea	Olive Ridley Turtle		Division 3	U	N		S1	I
	Natator depressus	Flatback Turtle	TR, MR	Division 3	U	Y	V	S1	I
Crocodile	*Crocodylus porosus*	Saltwater Crocodile		Division 3	N/A	N		S4	II
Marine Reptiles: Sea snakes	*Acalyptophis peronii*	Horned Seasnake	LR		N/A	Y	L		NA
	Aipysurus apraefrontalis	Short-nosed Seasnake	LR		N/A	Y	L		NA
	Aipysurus duboisii	Dubois Seasnake	LR		N/A	Y	L		NA
	Aipysurus eydouxii	Spine-tailed Seasnake	LR		N/A	Y	L		NA
	Aipysurus laevis	Olive Seasnake	LR		N/A	Y	L		NA
	Astrotia stokesii	Stokes Seasnake	LR		N/A	N	L		NA
	Disteira kingii	Spectacled Seasnake	LR		N/A	Y	L		NA
	Disteira major	Olive-headed Seasnake	LR		N/A	Y	L		NA
	Emydocephalus annulates	Turtle-headed Seasnake	LR		N/A	N	L		NA

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Appendix A: Wheatstone Marine Fauna; Threatened Species in North-Western Australia

Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
	Ephalophis greyi	North-western Mangrove Seasnake	LR		N/A	N	L		NA
	Eretmochelys imbricata	Hawksbill Turtle	LR		N/A	Y	L		NA
	Hydrophis czeblukovi	Fine-spined Seasnake	LR		N/A	N	L		NA
	Hydrophis elegans	Elegant Seasnake	LR		N/A	Y	L		NA
	Hydrophis ornatus	a Seasnake	LR		N/A	N	L		NA
	Pelamis platurus	Yellow-bellied Seasnake	LR		N/A	N	L		NA
Whale Shark	*Rhincodon typus*	Whale Shark	TS, MS		S,A,Sp	N	V, M		II
Manta ray	*Manta birostris*	Manta ray				N			NA
Fish	*Acentronura larsonae*	Helen's Pygmy Pipehorse	LF		N/A	N	L		NA
	Bulbonaricus brauni	Braun's Pughead Pipefish, Pug-headed Pipefish	LF		N/A	N	L		NA
	Campichthys tricarinatus	Three-keel Pipefish	LF		N/A	N	L		NA
	Choeroichthys brachysoma	Pacific Short-bodied Pipefish, Short bodied Pipefish	LF		N/A	Y	L		NA
Fish	*Choeroichthys larispinosus*	Muiron Island Pipefish	LF		N/A	N	L		NA
	Choeroichthys suillus	Pig-snouted Pipefish	LF		N/A	Y	L		NA
	Corythoichthys flavofasciatus	Yellow-banded Pipefish, Network Pipefish	LF		N/A	N	L		NA
	Cosmocampus	Roughridge	LF		N/A	N	L		NA

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Appendix A: Wheatstone Marine Fauna; Threatened Species in North-Western Australia

Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
Fish	*banneri*	Pipefish							
	Doryrhamphus dactyliophorus	Ringed Pipefish	LF		N/A	N	L		NA
	Doryrhamphus excisus	Indian Blue-stripe Pipefish, Blue-striped Pipefish	LF		N/A	N	L		NA
	Doryrhamphus janssi	Cleaner Pipefish, Janss' Pipefish	LF		N/A	Y	L		NA
	Doryrhamphus multiannulates	Many-banded Pipefish	LF		N/A	N	L		NA
	Doryrhamphus negrosensis	Flagtail Pipefish, Negros Pipefish	LF		N/A	N	L		NA
	Festucalex scalaris	Ladder Pipefish	LF		N/A	Y	L		NA
	Filicampus tigris	Tiger Pipefish	LF		N/A	N	L		NA
	Halicampus brocki	Brock's Pipefish	LF		N/A	Y	L		NA
	Halicampus grayi	Mud Pipefish, Gray's Pipefish	LF		N/A	Y	L		NA
	Halicampus nitidus	Glittering Pipefish	LF		N/A	Y	L		NA
	Halicampus spinirostris	Spiny-snout Pipefish	LF		N/A	Y	L		NA
	Haliichthys taeniophorus	Ribboned Seadragon, Ribboned Pipefish	LF		N/A	N	L		NA
	Hippichthys penicillus	Beady Pipefish, Steep-nosed Pipefish	LF		N/A	N	L		NA
	Hippocampus angustus	Western Spiny Seahorse, Narrow-bellied Seahorse	LF		N/A	Y	L		II
	Hippocampus histrix	Spiny Seahorse	LF		N/A	N	L		II

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Appendix A: Wheatstone Marine Fauna; Threatened Species in North-Western Australia

Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
Fish	*Hippocampus kuda*	Spotted Seahorse, Yellow Seahorse	LF		N/A	N	L		II
	Hippocampus planifrons	Flat-face Seahorse	LF		N/A	N	L		II
	Hippocampus spinosissimus	Hedgehog Seahorse	LF		N/A	N	L		II
	Micrognathus micronotopterus	Tidepool Pipefish	LF		N/A	Y	L		NA
	Phoxocampus belcheri	Rock Pipefish	LF		N/A	Y	L		NA
	Solegnathus hardwickii	Pipehorse	LF		N/A	N	L		NA
	Soleegnathus lettiensis	Indonesian Pipefish, Gunther's Pipehorse	LF		N/A	N	L		NA
	Solenostomus cyanopterus	Blue-finned Ghost Pipefish, Robust Ghost Pipefish	LF		N/A	Y	L		NA
	Syngnathoides biaculeatus	Double-ended Pipehorse, Alligator Pipefish	LF		N/A	N	L		NA
	Trachyrhamphus bicoarctatus	Bend Stick Pipefish, Short-tailed Pipefish	LF		N/A	Y	L		NA
	Trachyrhamphus longirostris	Long-nosed Pipefish, Straight Stick Pipefish	LF		N/A	Y	L		NA
Marine Birds	*Heliaeetus leucogaster*	White-bellied sea-eagle	MB		N/A	N	L		NA
	Larus novaehollandiae	Silver Gull	LB		N/A	N	L		NA
	Macronectes giganteus	Southern Giant-Petrel	LB		N/A	N	L		NA

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Groups	Species Name	Common Name	Classification		Season	www.museum.wa.gov.au	Status		
			Commonwealth	State		Yes (Y) No (N)	Commonwealth	State	CITES
Marine Birds	*Sterna anaethetus*	Bridled Tern	MB, LB		N/A	N	L		NA
	Sterna caspia	Caspian Tern	MB, LB		N/A	Y	L		NA

B

Appendix B Appendix B. Distribution of Listed Marine Fauna in the Pilbara Region, Western Australia

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Appendix B. Distribution of Threatened Marine Fauna in the Pilbara region, Western Australia

Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Mammals: Whales	*Balaenoptera borealis*	Sei Whale	Worldwide oceanic, QLD, WA, Great Australian Bight and Tasmania. Generally deep waters	
	Balaenoptera musculus	Blue Whale	Tip of W.A to the Great Australian Bight and around Vic, throughout Bass Strait and off Tasmanian Coasts as well as along the continental shelf of east Australia to Southern Qld, although are predominately found in south-east and south-west Australia (DEWHA, 2009).	
	Balaenoptera musculus brevicauda	Pygmy Blue Whale	Indian Ocean, along the African east coast, throughout the lower part of the Indian Ocean, along the Western Australian coast north to Indonesia, and along the Australian southern coast and east to NZ (McCauley et al, 2000)	
	Balaenoptera physalus	Fin Whale	Fin Whales migrate between Australian waters and the following external waters: Antarctic feeding areas (the Southern Ocean); subantarctic feeding areas (the Southern Subtropical Front); and tropical breeding areas (Indonesia, the northern Indian Ocean and south-west South Pacific Ocean waters) (DEWHA, 2008)	
	Eubalaena australis	Southern Right Whale	Principally found around the southern coastline off southern Western Australia and far west South Australia, Southern Right Whales occur anywhere between Sydney and Perth, including off Tasmania (DEWHA, 2009)	

Appendix B: Distribution of Threatened Marine Fauna in the Pilbara Region, Western Australia

Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Mammals: Whales	*Megaptera novaeangliae*	Humpback Whale	Humpback Whales migrate north from their Antarctic feeding grounds around May each year, reaching the waters of the North-west Marine Region in early June. (DEWHA, 2009)	
	Balaenoptera bonaerensis	Antarctic Minke Whale, Dark-shoulder Minke Whale	All States but not in the Northern Territory. The distribution up the west coast of Australia is currently unknown (DEWHA, 2009).	
	Balaenoptera edeni	Bryde's Whale	Temperate to tropical waters, both oceanic and inshore, bounded by latitudes 40° N and 40° S, or the 20 °C isotherm all Australian states except the Northern Territory (DEWHA, 2009).	
	Orcinus orca	Killer Whale	Found in every ocean, the orca is one of the most widely distributed animals.	
	Physeter macrocephalus	Sperm Whale	Sperm whales inhabit all oceans of the world. They can be seen close to the edge of pack ice in both hemispheres and are also common along the equator, especially in the Pacific. Sperm whales are found throughout the world's oceans in deep waters between about 60° N and 60° S latitudes.	
	Balaenoptera acutorostrata	Minke Whale	As far north as 11° S. The southern distribution extends down to approximately 41° S, but it is unlikely that this species normally migrates to such high latitudes of the Antarctic. Generally close inshore (DEWHA, 2009).	

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Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Mammals: Whales	*Feresa attenuata*	Pygmy Killer Whale	Tropical and subtropical inhabits oceanic waters around the globe, generally not ranging north of 40° N or south of 35° S. Western Australia and NSW coast (DEWHA, 2009).	
	Globicephala macrorhynchus	Short-finned Pilot Whale	Tropical (22–32 °C) to temperate (10–22 °C) oceanic waters, approaching coastal seas (DEWHA, 2009)	
	Kogia breviceps	Pygmy Sperm Whale	Mostly beyond the edge of the continental shelf in tropical and temperate waters around the world	
	Kogia simus	Dwarf Sperm Whale	It appears to be distributed widely in tropical to warm temperate zones, apparently largely offshore.	
	Mesoplodon densirostris	Blainville's Beaked Whale, Dense-beaked Whale	Low to mid-latitudes in both hemispheres prefers tropical and warm temperate waters around the world. North to Nova Scotia, Wales, Portugal, Western Mediterranean, Japan, Midway Islands, central California; and south Brazil, South Africa, Tasmania, central Chile (DEWHA, 2009).	
	Pseudorca crassidens	False Killer Whale	Mediterranean Sea and Red Sea as well as the Atlantic Ocean (from Scotland to Argentina), the Indian Ocean and the Pacific Ocean (from the Sea of Japan to New Zealand and the tropical area of the eastern side	

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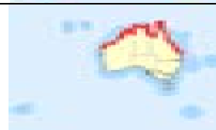
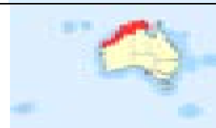
Group	Species Name	Common Name	Distribution	General Distribution Map
	Globicephala macrorhynchus	Short-Fined Pilot Whale	Tropical (22–32 °C) to temperate (10–22 °C) oceanic waters, approaching coastal seas in Australia. Occur in tropical and warm-temperate waters world-wide, between approximately 41°S and 45°N (DEWHA, 2009)	
	Peponocephala electra	Melon-headed Whale	Off-shore in all the world's tropical and sub-tropical oceans. found beyond the continental shelf between 20° S and 20° N.	
Marine Mammals: Dolphins	*Ziphius cavirostris*	Cuvier's Beaked Whale, Goose-beaked Whale	All temperate and tropical waters around the world	
	Sousa chinensis	Indo-Pacific Humpback Dolphin	coastal waters of the western Pacific. coast of southern China, Gulf of Thailand; northwestern coast of Borneo; the northwestern coast of Western Australia between North West Cape and Larrey Point; and the coast of eastern Australia from Cairns in Queenland to Wollonggong in New South Wales. Philippines	
	Tursiops aduncus	Spotted Bottlenose Dolphin (Arafura/Timor Sea populations)	coast of eastern Africa from Cape Province north to the Red Sea, thence eastward through the Persian Gulf, Arabian Sea, and Bay of Bengal, as far as Taiwan, thence south-east to northern Australia.	
	Delphinus delphis	Common Dolphin	Offshore waters, all Australian states & territories, but are rarely seen in northern Australian waters. Two main locations in Australia, with one in the southern south-eastern Indian Ocean and another in the Tasman Sea (DEWHA, 2009).	

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Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Mammals: Dolphins	*Grampus griseus*	Risso's Dolphin, Grampus	All states except Tasmania and the Northern Territory. range from about 23° S to 39° S.	
	Lagenodelphis hosei	Fraser's Dolphin, Sarawak Dolphin	most common near the equator in the eastern tropical Pacific. South Africa, Madagascar, Sri Lanka, and Indonesia. It also occurs away from equator as far north as Taiwan and Japan and, in small numbers, off Australia.	
	Orcaella brevirostris	Snubfin Dolphin	Northern East and West Coast Australia, Papua New Guinea	
	Stenella attenuata	Spotted Dolphin, Pantropical Spotted Dolphin	Northern Territory, Western Australia down south to Augusta, Queensland and NSW.	
	Stenella coeruleoalba	Striped Dolphin, Euphrosyne Dolphin	Deep oceanic waters, North; Atlantic to Newfoundland and south; Greenland and Iceland, in the Pacific to the Sea of Japan, Hokkaido (about 40° N) and across to British Columbia. Their southern limit is Buenos Aries, Argentina to Cape Province, Western Australia and New Zealand.	
	Stenella longirostris	Long-snouted Spinner Dolphin	Western Australia, as far south as Bunbury , the Northern Territory, along the east coast from Queensland to NSW (Bannister et al. 1996), including the Great Barrier Reef (DEWHA, 2009)	

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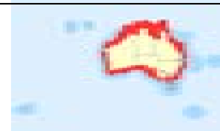
Group	Species Name	Common Name	Distribution	General Distribution Map
	Steno bredanensis	Rough-toothed Dolphin	tropical and warm temperate waters around the world.	
	Tursiops aduncus	Indian Ocean Bottlenose Dolphin, Spotted Bottlenose	Populations of unknown sizes exist in the Mediterranean and Caribbean Seas and the Atlantic, Indian and Pacific Oceans. Live sightings are almost universally made far off-shore beyond the continental shelf.	
Marine Mammals: Dolphins	*Tursiops truncatus s.str.*	Bottlenose Dolphin	Queensland, NSW, Tasmania, South Australia and south-western Western Australia. Usually found offshore in waters deeper than 30 m but also appear be found in some coastal waters (DEWHA, 2009)	
Marine Mammals: Dugong	*Dugong dugon*	Dugong	Inshore waters of northern Australia. Western Australia, Northern Territory and Queensland (DEWHA, 2009)	
Marine Reptile: Turtles	*Caretta caretta*	Loggerhead Turtle	Global distribution. In WA, low intensity nesting occurs on Murion I. and the beaches of NW Cape . There has been one reported loggerhead nesting at Ashmore Reef Also in the Indian Ocean, nesting populations occur in South Africa (DEWHA, 2009)	
	Chelonia mydas	Green Turtle	Green Turtles nest, forage and migrate across tropical northern Australia. They usually occur between the 20°C isotherms (DEWHA, 2009)	

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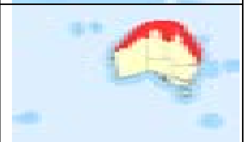
Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Reptile: Turtles	*Dermochelys coriacea*	Leathery Turtle or Leatherback Turtle	tropical, subtropical and temperate waters throughout the world. waters offshore from NSW, Vic.,Tas. and WA (DEWHA, 2009)	
	Eretmochelys imbricata	Hawksbill Turtle	Varanus Island and Rosemary Island in Western Australia, northern Great Barrier Reef and Torres Strait (DEWHA, 2009)	
	Lepidochelys olivacea	Olive Ridley Turtle	tropical and subtropical waters throughout the world. Large nesting aggregations are found in the eastern Pacific and in India (DEWHA, 2009)	
	Natator depressus	Flatback Turtle	only in the tropical waters of northern Australia, Papua New Guinea and Irian Jaya (DEWHA, 2009)	
Marine Reptile: Crocodiles	*Crocodylus porosus*	Saltwater Crocodile	In northern Australia (which includes the top ends of the Northern Territory, Western Australia and Queensland) the Saltwater Crocodile is thriving, particularly in the multiple river systems near Darwin	
Marine Reptile: Sea snakes	*Acalyptophis peronii*	Horned Seasnake	Seas of northern Australia (south in the west to Barrow I. and in the east to extreme north of New South Wales) and from southeast Asia to the seas west of New Caledonia (WAM, 2009)	

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Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Reptile: Sea snakes	*Aipysurus apraefrontalis*	Short-nosed Seasnake		
	Aipysurus duboisii	Dubois Seasnake	Recorded from Fraser Island in Queensland, Northern Territory and Western Australia to Exmouth Gulf (WAM, 2009)	
	Aipysurus eydouxii	Spine-tailed Seasnake	Northern seas, south to Exmouth Gulf. Also Northern Territory, Queensland and from south Vietnam to New Guinea. (WAM, 2009)	
	Aipysurus laevis	Olive Seasnake	Northern seas, south to Exmouth Gulf. Isolated records from Point Quobba and Bush Bay on the Carnarvon Coast. Also Northern Territory, southern New Guinea, Queensland and New Caledonia (WAM, 2009)	
	Astrotia stokesii	Stokes Seasnake	Northern Queensland, Northern Territory to Ashmore Reef (Northern WA) (WAM, 2009)	
	Disteira kingii	Spectacled Seasnake	Southern Queensland, Northern Teeritory and Western Australia as south as Barrow Islands (WAM, 2009)	

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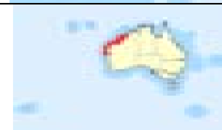
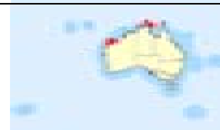
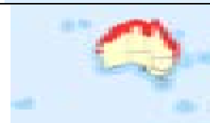
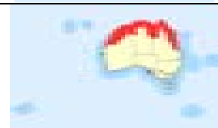
Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Reptile: Sea snakes	*Disteira major*	Olive-headed Seasnake	Seas of southern New Guinea and northern Australia, south in Western Australia to Shark Bay, occasionally straggling down lower west coast as far as Bunbury (WAM, 2009).	
	Emydocephalus annulatus	Turtle-headed Seasnake	Seas of northern Australia (south in the west to Shark Bay); in the east to Cato I., Queensland) and New Caledonia (WA, 2009).	
	Ephalophis greyi	North-western Mangrove Seasnake	North Western Australia, records in Broome (WAM, 2009)	
	Hydrophis czeblukovi	Fine-spined Seasnake	The species is known only from the Arafura Sea off northern Australia and in the eastern Indian Ocean off northwestern Australia	
	Hydrophis elegans	Elegant Seasnake	Found from Gold Coast QLD, along entire QLD coast, Torres Strait, Timor Sea and down West Australian Coast to Busselton (WAM, 2009).	
	Hydrophis ornatus	a Seasnake	Coastal waters of Northern Australia, has been found as south as Tasmania. Also found in China, Indonesia, Taiwan, Papua New Guinea	

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Group	Species Name	Common Name	Distribution	General Distribution Map
	Pelamis platurus	Yellow-bellied Seasnake	widespread in the tropical parts of the Pacific and Indian Oceans between the 18-20° C isotherms	
Fish: Sharks	*Rhincodon typus*	Whale Shark	In Australia, NSW, QLD, NT, WA and occasionally VIC and SA, most commonly seen in waters off northern Western Australia, Northern Territory and Queensland. Ningaloo Reef, is the main known aggregation site of Whale Sharks in Australian waters.	
Fish: Rays	*Manta birostris*	Manta ray	Manta ray distribution is circum-tropical, around the globe, generally between 35 degrees north and south latitude.	
Fish: Sygnathids	*Acentronura larsonae*	Helen's Pygmy Pipehorse	Tropical. Reef-associated; marine; depth range 3 - 9 m. Eastern Indian Ocean: known only off Alpha Island, Monte Bello Islands, Western Australia.	
	Bulbonaricus brauni	Braun's Pughead Pipefish, Pug-headed Pipefish	Reef-associated; depth range 1 - 10 m. tropical; 9°N - 23°S. Eastern Indian Ocean: off Sumatra, Indonesia and from Western Australia. Western Central Pacific: Palau.	
	Campichthys tricarinatus	Three-keel Pipefish	Reef-associated; marine; depth range 3 - 11 m. tropical. Western Central Pacific: northern Australia, including Baleine Bank and Montebello Island in Western Australia.	

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Appendix B: Distribution of Threatened Marine Fauna in the Pilbara Region, Western Australia

Group	Species Name	Common Name	Distribution	General Distribution Map
Fish: Sygnathids	*Choeroichthys brachysoma*	Pacific Short-bodied Pipefish, Short bodied Pipefish	Inhabits reefs and seagrass beds; Ningaloo Reef northwards; Indo-C. Pacific	
	Choeroichthys latispinosus	Muiron Island Pipefish	Inhabits coral reefs; known thus far only from South Munon Island. Found from North Western Australia, Exmouth and Port Denison	
	Choeroichthys suillus	Pig-snouted Pipefish	Tropical reef-associated; marine; depth range 0 - 14 m. Western Central Pacific: endemic to northern Australia, from Western Australia to Queensland and McCluer Island, Northern Territory.	
	Corythoichthys flavofasciatus	Yellow-banded Pipefish, Network Pipefish	Reef-associated; depth range ? - 25 m. tropical; 30°N - 28°S. Indo-Pacific: Red Sea and East Africa (Ref. 33390) to the Tuamoto Islands, north to Ryukyu Islands, south to northern Australia (Ref. 33390) and the Austral Islands.	
	Cosmocampus banneri	Roughridge Pipefish	Reef-associated; depth range 2 - 30 m. Tropical; 30°N - 23°S. Indo-West Pacific: Gulf of Aqaba and East Africa to Fiji, north to the Ryukyu and Marshall islands. Recently recorded from Tonga	
	Doryrhamphus dactyliophorus	Ringed Pipefish	Reef-associated; depth range 5 - 56 m. Tropical; 33°N - 26°S. Indo-Pacific: Red Sea and East Africa to Samoa, north to Japan (Ref. 559), south to Australia.	

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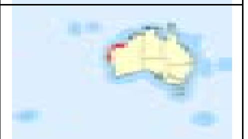
Group	Species Name	Common Name	Distribution	General Distribution Map
Fish: Sygnathids	*Doryrhamphus excisus*	Indian Blue-stripe Pipefish, Blue-striped Pipefish	Inhabits recesses of caves and crevices. Occurs on lagoon and seaward reefs in the depth range of 0 to at least 45 m. Northern Australia, Kenya, Mauritius, Seychelles, South Africa (country), Tanzania	
	Doryrhamphus janssi	Cleaner Pipefish, Janss' Pipefish	Inhabits coral reef crevices; Dampier Archipelago northwards; mainly W. Pacific (WAM, 2009)	
	Doryrhamphus multiannulatus	Many-banded Pipefish	Reef-associated; Tropical. Western Indian Ocean: Red Sea and Sodwana Bay, South Africa to the Chagos Islands and Maldives.	
	Doryrhamphus negrosensis	Flagtail Pipefish, Negros Pipefish	Reef-associated; tropical; 25°N - 18°S. Western Pacific: Borneo to Vanuatu, north to the Yaeyama Islands, south to Rowley Shoals; Belau and Yap in Micronesia.	
	Festucalex scalaris	Ladder Pipefish	Inhabits trawling grounds, amongst weeds; Kalbarri to Ningaloo Reef; W.A. only (WAM, 2009)	
	Filicampus tigris	Tiger Pipefish	Inhabits sand-weed areas; Shark Bay northwards; Australia only (WAM, 2009)	

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Group	Species Name	Common Name	Distribution	General Distribution Map
Fish: Sygnathids	*Halicampus brocki*	Brock's Pipefish	Inhabits coral and rocky reefs; Abrolhos northwards; mainly W. Pacific	
	Halicampus grayi	Mud Pipefish, Gray's Pipefish	Reef-associated; tropical. Indo-West Pacific: Gulf of Aden, off Sri Lanka, and from the Gulf of Thailand and Australia to Japan	
	Halicampus nitidus	Glittering Pipefish	Marine, tropical; 30°N - 23°S. Western Pacific: Viet Nam to Fiji, north to Ryukyu Islands, south to Rowley Shoals and New Caledonia; Belau in Micronesia.	
	Halicampus spinirostris	Spiny-snout Pipefish	Inhabits coral and rock reefs; Ningaloo Reef northwards; E. Indian Ocean and W. Pacific (WAM, 2009)	
	Haliichthys taeniophorus	Ribboned Seadragon, Ribboned Pipefish	Tropical; 2°S - 26°S. Indo-Pacific: Indonesian waters around Irian Jaya (northern coast and Tanamerah Bay) and Australian waters from Shark Bay, western Australia to the Torres Straits in northern Queensland	
	Hippichthys penicillus	Beady Pipefish, Steep-nosed Pipefish	Inhabits mangrove estuaries and lower reaches of freshwater streams; Onslow northwards; N. Indian Ocean and W. Pacific (WAM, 2009)	

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Group	Species Name	Common Name	Distribution	General Distribution Map
Fish: Sygnathids	*Hippocampus angustus*	Western Spiny Seahorse, Narrow-bellied Seahorse	Inhabits sheltered bays; Augusta to North West Cape; W.A. only (WAM, 2009)	
	Hippocampus histrix	Spiny Seahorse	Reef-associated; tropical; 32°N - 18°S. Indo-Pacific: Tanzania and South Africa to Hawaii and Tahiti, north to Japan, south to New Caledonia.	
	Hippocampus kuda	Spotted Seahorse, Yellow Seahorse	Reef-associated; marine; tropical; 31°N - 37°S; 22°e - 156°w. Indo-Pacific: Northern Australia, Pakistan and India to southern Japan, Hawaii,	
	Hippocampus planifrons	Flat-face Seahorse	Reef-associated; tropical. Indo-Pacific: southern India to Japan, Australia and Tahiti	
	Hippocampus spinosissimus	Hedgehog Seahorse	Reef-associated, subtropical. Indo-Pacific: Sri Lanka to Taiwan and Australia	
	Micrognathus micronotopterus	Tidepool Pipefish	Inhabits inshore reefs and tide pools; North West Cape northwards; Indo-Australian Archipelago (WAM, 2009)	

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Appendix B: Distribution of Threatened Marine Fauna in the Pilbara Region, Western Australia

Group	Species Name	Common Name	Distribution	General Distribution Map
Fish: Sygnathids	*Phoxocampus belcheri*	Rock Pipefish	Found in Tropical Reefs, Indo-West Pacific: Red Sea and East Africa, eastward to Japan and Fiji Islands.	
	Solegnathus hardwickii	Pipehorse	Inhabits trawling grounds; Onslow northwards; mainly W. Pacific (WAM, 2009).	
	Solegnathus lettiensis	Indonesian Pipefish, Gunther's Pipehorse	Tropical Marine. Occurs in Eastern Indian Ocean: Indonesia and Western Australia.	
Marine Birds	*Haliaeetus leucogaster*	White-bellied sea-eagle		
	Larus novaehollandiae	Silver Gull		
	Macronectes giganteus	Southern Giant-Petrel	breeds on six subantarctic and Antarctic islands in Australian territory; Macquarie Island, Heard Island and McDonald Island in the Southern Ocean, and Giganteus Island, Hawker Island, and Frazier Island in the Australian Antarctic Territories. It iswidespread throughout the Southern Ocean (DEWHA, 2009)	

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Group	Species Name	Common Name	Distribution	General Distribution Map
Marine Birds	*Sterna anaethetus*	Bridled Tern	widespread, breeding on offshore islands in western, northern and north-eastern Australia, extending from Cape Leeuwin in the south-west, around northern Australia to north-eastern and mid-eastern Queensland, extending through the Great Barrier Reef and Coral Sea as far south as Lady Elliott Island (DEWHA, 2009).	
	Sterna caspia	Caspian Tern		

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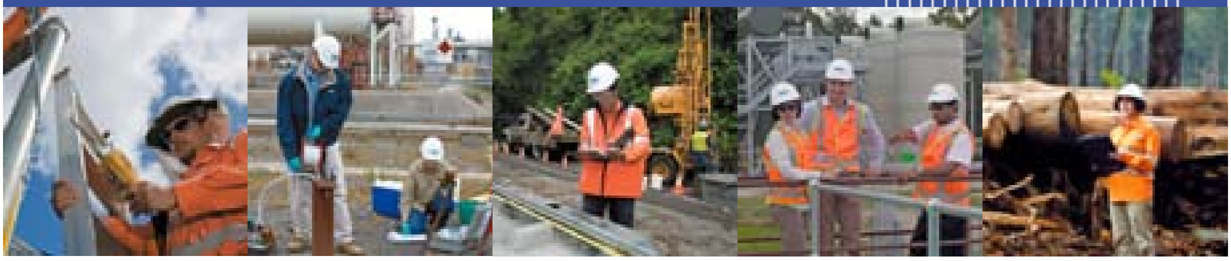

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