



Technical Appendices 08 to 012 and P1 to P2

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

July 2010



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Technical Appendices O8 to O12 and P1 to P2

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Marine Turtle Beach Survey
Onslow Mainland Area and Nearby Islands
25 January – 6 February 2009



Report to
URS – Chevron Wheatstone Project Team
By
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Executive Summary

This report presents the results of a marine turtle survey conducted in the Onslow region from 24th January to 7th February, 2009 for Chevron Wheatstone. Ground surveys were conducted at all mainland and island beaches within a 30 km radius of the project site. This encompassed mainland beaches from Locker Point to Coolgara, as well as Ashburton, Bessieres, Direction, Flat, Locker, Round, Serrurier, Table, Thevenard, Tortoise, NE Twin and SW Twin Islands.

Data were collected regarding identification of species present at each site, level of nesting activity, identification of emerged nests, hatching success and hatching orientation, site specific physical characteristics and additional observations of relevant flora and fauna.

There was no evidence of any nesting for any species of marine turtle at the proposed development site. Knowledge of characteristics of preferred marine turtle nesting habitat precludes this area from exhibiting notable levels of nesting activity. Based on the findings of this survey the Onslow mainland area supports very low levels of nesting that are unlikely to be of regional significance.

It is unlikely that survey results were substantially impacted by the passing of Tropical Cyclone Dominic, although it did result in a lower than expected count at some of the sites. Cyclonic activity erased evidence of nesting prior to the survey period. The path of the cyclone impacted more heavily upon islands within the eastern sector of the survey area. The passing of the cyclone delayed the survey period by five days which consequently fell just outside peak nesting for flatback turtles but still within peak nesting for green turtles.

Nesting on the mainland was found at Census beach four. Activity documented at this site comprised one newly laid and one emerged flatback turtle nest and evidence of 18 nests laid prior to the survey period, five of which were confirmed as flatback nests. This level of flatback turtle nesting along mainland beaches is not regionally or even locally significant based on current knowledge of marine turtle nesting within the region.

Twelve islands were assessed during the survey. Level of nesting during the survey period varied from island to island. Ashburton, Bessieres, Locker, Serrurier and Thevenard showed the highest level of marine turtle activity. Nesting at Serrurier and Bessieres Islands was predominantly by green turtles with small numbers of flatback turtles documented. Thevenard Island recorded mostly flatback turtle nesting on the south-western coast and green turtle nesting along the north-western coast. Nesting at Ashburton and Locker Islands was dominated by flatback turtles.

Small areas of suitable nesting habitat and low to moderate density nesting were identified at Direction, Flat, NE Twin, Table, Tortoise, Round and SE Twin Islands.

For the most part, the highest nesting density beaches occurred on the eastern and southern coasts of surveyed islands. This pattern is dictated by available nesting habitat in these areas.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Within the survey region and study period, flatback turtles nested on islands closer to the mainland while green turtles nested on islands further offshore. No green turtle nesting was found on the mainland. There was one record of hawksbill turtle nesting documented on Bessieres Island. No records were made of loggerhead turtle nesting during this survey. More extensive surveys would be needed to establish the significance of hawksbill or loggerhead nesting within the Onslow region.

A total of nine flatback and three green turtle nests were excavated after hatchlings had emerged to determine the hatch success of each nest. Mean hatch success and clutch size for green and flatback turtles were within the known range for these species (Miller 1997).

Hatchling orientation was measured for five green and 13 flatback turtle nests. Levels of misorientation were found to be low for both species; one flatback and one green turtle nest showed signs of disrupted sea-finding behaviour.

Importantly, 58 sightings of juvenile green turtles were documented in the shallow near shore waters of surveyed islands. Two adult green turtles were recorded off the northern coast of Serrurier Island. One large juvenile/sub-adult loggerhead turtle was seen off the coast of SW Twin Island and one unidentified small juvenile turtle was seen at Tortoise Island. There were no sightings of turtles in the water along the mainland coast although turbid waters may limit visibility in this area. There were no sightings of flatback or hawksbill turtles in the water.

Other marine fauna, notably dolphins, sharks, rays and dugongs were observed during the survey.

Although abundance of nesting at the project site was limited, nesting by three marine turtle species was documented within the survey area. Assessment of indices of reproductive success show values within the typical range for these species. Hatchling emergence patterns indicate little disruption to sea-finding behaviour. Temporal constraints of survey execution preclude meaningful assessment of nesting by hawksbill turtles and it is recommended that this be assessed. Near-shore waters of several offshore islands support foraging habitat for juvenile green turtles. It would be of value to further characterise these foraging assemblages where they occur within the project impact area.

I Objective and Scope

This report presents the results of a marine turtle survey conducted on all mainland and island beaches within a 30 km radius of the project site. This comprised the Ashburton River Delta mainland beaches near Onslow and the Ashburton River Delta and on Ashburton, Bessieres, Direction, Thevenard, Tortoise, Serrurier, Table, Flat, Round, SW Twin, NE Twin and Locker Islands (Figure 1). The survey was conducted from 24th January to 7th February, 2009.

There were two primary objectives of this survey:

1. To gather evidence of marine turtle nesting activity on regional beaches, to identify the species using the nesting habitat and to obtain an estimate of the size of the nesting population. These beach surveys used track census techniques on selected 'census' and 'snapshot' beaches to document the distribution of the four most common marine turtle species that nest locally, as well as the relative density of adult nesting.
2. To collect data on the number of nests emerging successfully and the orientation of hatchlings as they make their way to the ocean following emergence from the nest. Counts of successful nest emergences provide an indication of the productivity of the survey beaches. Monitoring hatchling emergence fan indices provides indication of how successful the hatchlings are in sea-finding after emerging from the nest. These indices document occurrences of potential misorientation hatchlings may display as a result of artificial light sources nearby.
3. The beach surveys also documented physical characteristics of the beaches, actual and potential nest predation, near shore observations of turtles (principally foraging juveniles), in addition to opportunistic observations of avian and marine fauna in the area.

Benthic habitat (including coral reef, seagrass/algae and soft bottom) in the potential zone of impact and influence will be identified during baseline subtidal surveys as part of the environmental approvals process but are outside of the scope of this survey.

2 Biology & Ecology of Marine Turtles on the North-west Shelf of Australia

Marine turtle activity within the survey area has not been systematically studied; little has been published in the scientific literature on marine turtles in this area. Consequently, the bulk of background information within comes from grey literature including government reports, previous surveys conducted by Pendoley Environmental staff and anecdotal sources.

Six species of marine turtles from two families (*Cheloniidae*, *Dermochelyidae*) inhabit West Australian waters (Table I). All six species are considered endangered or vulnerable and are protected by state and federal legislation and international organisations (Table I).

Of these six species, only four are known to be reproductively active in the North-Western Shelf region of Australia. Among these populations, Prince (1994a, 1994b) and Pendoley (2005) have identified the following as being of regional significance:

- Green turtle rookeries at Northwest Cape, Muiron Islands, Barrow Island, Varanus Island, Rosemary Island and the Lacepede Islands;
- Hawksbill turtle rookeries at Northwest Cape, Rosemary and Varanus Islands. Additional nesting occurs at Delambre Island in the Dampier Archipelago, North and South Muiron Islands, Airlie, Barrow, Beacon, Bridled, Hermite, Parakeelya, Trimouille and Varanus Islands in the Lowendal group.
- Flatback turtle rookeries at Barrow Island, within the Montebello Island complex, on Varanus Island within the Lowendal Island complex, on Cowrie Beach on Mundabullangana Station, at Eighty Mile Beach in the southern Kimberley region and at Cape Domett in the Northern Kimberly (Whiting et al. 2008)
- Loggerhead turtle rookery at Dirk Hartog Island, Northwest Cape and the Muiron Islands (Baldwin et al. 2003).

Knowledge of loggerhead turtle populations within the study region is sparse. No large olive ridley turtle rookeries have been recorded in Western Australia. There has been one nesting event recorded at Darcy Island though this record remains unconfirmed and exists only as anecdotal evidence. Leatherback turtles are occasional visitors to Western Australian waters and have not been documented nesting.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Table 1: The conservation status of marine turtle species occurring in Western Australian waters

Species	Wildlife Conservation Act 1950	Environment Protection and Biodiversity Conservation (EPBC) Act 1999	Convention on Migratory Species (CMS) Appendix (as at May 2009)	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix (as at May 2009)	International Union for Conservation of Nature (IUCN) Status (as at May 2009)
Loggerhead Turtle <i>Caretta caretta</i>	Schedule I*	Endangered	I & II	I	Endangered
Green Turtle <i>Chelonia mydas</i>	Schedule I	Vulnerable	I & II	I	Endangered
Hawksbill Turtle <i>Eretmochelys imbricata</i>	Schedule I	Vulnerable	I & II	I	Critically Endangered
Olive Ridley Turtle <i>Lepidochelys olivacea</i>	Schedule I	Endangered	I & II	I	Vulnerable
Flatback Turtle <i>Natator depressus</i>	Schedule I	Vulnerable	Not listed	I	Data Deficient
Leatherback Turtle <i>Dermochelys coriacea</i>	Schedule I	Vulnerable	I & II	I	Critically Endangered

* Schedule I. Fauna that is rare or likely to become extinct

2.1 Nesting Habitat and Reproductive Periods

Nesting beaches used by female turtles for egg laying are generally sandy. Eggs incubate within nesting beaches over a 6-8 week period, following which, hatchlings emerge and head into the water.

Nesting beach habitat most commonly associated with the three turtle species typically found in the Pilbara region has been described by Pendoley (2005) as follows:

- Hawksbill turtles are found associated with beaches located close to nearshore coral reefs and the beach sediment typically comprises a shallow bed of coarse sand and coral rubble (e.g. Beacon Island and Rosemary Island).
- Green turtles nest on high energy, steeply sloped beaches comprising deep well sorted medium grain sized sand, with a deep water approach to the beach independent of tide state (i.e. the intertidal zone is narrow or absent, e.g. west coast of Barrow Island and exposed beaches of North West and Trimouille Islands in the Montebello group).
- Flatback turtles favour low energy beaches that are typically narrow with moderate grain size and a low to moderate beach slope. The beach bed is often shallow (underlain by rock platform or clay) and the beach approach obstructed by broad

intertidal mud or limestone intertidal platforms (e.g. east coast of Barrow Island, south coast of Thevenard Island and Mundabullangana).

It is worth noting that this description represents currently known preferred habitat only and is not exclusive of others types of unknown, less preferable or potentially less suitable habitat types.

Within the Onslow region marine turtle nesting is well documented within the Barrow-Montebello-Lowendal Island complex. Three species of marine turtle nest in significant numbers in this region, a distance of approximately 100-150 km north east from the survey area. These are the green turtle, the hawksbill turtle and the flatback turtle. Loggerhead turtles are very occasionally observed nesting in the area (Pendoley 2005).

Four species of marine turtle are likely to utilize the Onslow region for nesting. These are: green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), flatback turtle (*Natator depressus*) and loggerhead turtle (*Caretta caretta*). The magnitude of nesting for each species is not well documented in the area.

There have been no records of leatherback (*Dermochelys coriacea*) or olive ridley (*Lepidochelys olivacea*) nesting in the Onslow region.

The locations of mating aggregations for marine turtles have not been formally documented for the survey area. Mating aggregations for green (Limpus 1993) and hawksbill turtles (Witzell 1983) typically occur in close proximity to the nesting beaches. The location of mating aggregations for flatback turtles is not known. At the large nesting rookeries on Barrow Island green turtles mating aggregations are seen within several metres of shore, while flatback turtles are not regularly seen in near-shore waters and sightings of male flatback turtles are virtually unknown (Pendoley 2005). It is possible that flatback mating aggregations occur at some greater distance from their nesting rookery habitat than for other species of marine turtles.

Precise breeding periodicity for marine turtles within the Onslow region has yet to be comprehensively defined. Temporal duration of this survey was based on findings from the Barrow-Montebello-Lowendal Island complex (Pendoley 2005). Within this complex, flatback turtle nesting occurs from November to March with peak nesting during December and January and green turtle nesting takes places from November to April with peak nesting from December to February (Pendoley 2005). Hawksbill nesting takes place from August to April and peaks earlier during October and November. Nesting in hawksbill turtles is more temporally diffuse and has been known to occur year round in other locations (Beggs et al. 2007).

Migratory pathways for marine turtles nesting in the Pilbara and Gascoyne regions include the coastal waters of the Onslow region. Green, hawksbill and flatback turtles nesting on Barrow Island and Varanus Island have been tracked via satellite telemetry and are known to move through these coastal waters (Barrow Island flatback turtle tracking, Barrow Island green turtle tracking, Varanus Island hawksbill turtle tracking; Pendoley, *unpublished data*).

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Interesting movements and habitats for marine turtles nesting in the Onslow region are not known. However, it is likely that green (Carr 1974) and hawksbill (Starbird et al 2001) turtles remain within the general vicinity of their nesting beaches during their internesting period. Flatback turtles nesting at Barrow Island have been tracked via satellite telemetry and are known to routinely use the near shore habitats of the mainland coast 50-60 km to the south-east of Barrow Island during their inter-nesting period (Barrow Island flatback turtle tracking project). Flatback turtles nesting at Mundabullangana and Cemetery Beach however, remain within ~20 km of their mainland nesting rookeries (Cemetery Beach, Port Hedland turtle tracking project, Mundabullangana Station turtle tracking project). Information regarding inter-nesting areas, migratory pathways or foraging grounds has not yet been elucidated for marine turtles in the Onslow region. It is not known if flatback turtles nesting in the Onslow region travel similar distances during their inter-nesting period and where they may be moving to.

Foraging habitat for green, hawksbill or flatback turtles has not been specifically identified in the survey area; however, it is reasonable to expect green turtles to occur in the vicinity of sea grass or algae beds, hawksbill turtles on or near coral reef habitat and flatback turtles over soft bottom habitat supporting sea pens or other infauna (Pendoley 2005). Recent flatback turtle satellite tracking studies indicate potential foraging in a wide variety of habitats and in water depths of 10–50 m off the Western Australian coast (Pendoley Environmental, *unpublished data*). Aerial surveys conducted outside the typical marine turtle nesting season to focus on spatial distribution and abundance of resident turtles, indicate aggregations of turtles around Locker, Serrurier, Bessieres, Ashburton and Thevenard islands (Prince 2000). Although positive identification of species was not always possible due to survey design constraints, it is probable that most animals observed were juvenile green turtles.

3 Methods

3.1 Survey Site

Beaches were assessed either via 'census' where beaches were visited daily over a period of four days to assess overnight nesting during the survey period or by 'snapshot' where beaches were visited once during the survey period.

Census locations were selected based on their proximity to proposed project infrastructure and potential (Table 2) for or knowledge of marine turtle rookeries in these areas. Census beaches were identified on the north and south coasts of Thevenard Island, east coast of Ashburton and Bessieres Islands and seven selected mainland beaches within a 10 km radius of the Ashburton River Delta.

'Snapshot' surveys were conducted on Tortoise, Serrurier, Flat, Round, Table, SW Twin, NE Twin and Locker Islands and selected mainland beaches within a 30 km radius of the Ashburton River Delta. Snapshot beaches were generally located further away from proposed project infrastructure or contained limited or poorer quality nesting habitat.

An overview of the region is shown in Figure 1. A summary of the survey dates and locations is shown in Table 3.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Table 2: Distance of surveyed area from Proposed LNG facility

Location	Distance from Proposed LNG Facility (km)
Ashburton Island	12.4
Bessieres Island	30.1
Thevenard Island	25.7
Tortoise Island	18.3
Direction Island	22.4
NE Twin Island	30.8
SW Twin Island	28.9
Locker Island	23.3
Serrurier Island	33.6
Flat Island	39.6
Round Island	35.4
Table Island	29.8
Mainland Beach One	15.8
Mainland Beach Two	12.4
Mainland Beach Three	9.2
Mainland Beach Four	4.4
Mainland Beach Five	3.5
Mainland Beach Six	1.2
Mainland Beach Seven	3.5

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 1: Overview of the area surveyed in January and February 2009

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Table 3: Summary of dates and locations of marine turtle surveys conducted in the Onslow area and nearby islands, 24th January-7th February, 2009

Date	Task	Survey Locations			
24-Jan-09	Mobilization to field				
25-Jan-09	Census Line-in Snapshot	Ashburton Is Thevenard Is (west)	Bessieres Is	Thevenard Is.	
26-Jan-09	Demobilize for Cyclone				
27-Jan-09	Demobilize for Cyclone				
28-Jan-09	Demobilize for Cyclone				
29-Jan-09	Remobilize to field				
30-Jan-09	Census Line-in		Bessieres Is	Thevenard Is.	
31-Jan-09	Census Line-in Census Day One Snapshot	Ashburton Is Direction Is	Bessieres Is	Thevenard Is.	
1-Feb-09	Census Day One Census Day Two Snapshot	Ashburton Is Tortoise Is	Bessieres Is	Thevenard Is.	
2-Feb-09	Census Day Two Census Day Three	Ashburton Is	Bessieres Is	Thevenard Is.	
3-Feb-09	Census Day Three Census Line-in Snapshot	Ashburton Is Mainland Beach 1-7 NE Twin Is			
4-Feb-09	Census Day One Snapshot	Mainland Beach 1-7 Serrurier Is	Table Is	Round Is	Flat Is
5-Feb-09	Census Day Two Snapshot	Mainland Beach 1-7 Locker Is	Urala/Locker Pt	Onslow Back Beach	Coolgara/ Beadon Ck
6-Feb-09	Census Day Three Snapshot	Mainland Beach 1-7 SW Twin Is			
7-Feb-09	Demobilize				

3.2 Data Collection

The primary data collected from each survey beach are listed below.

Track census and nest counts

The track census survey methodology used for this program was based on techniques developed for beach surveys within the Barrow/Montebello/Lowendal Island complex (Pendoley 2005) and is consistent with IUCN SSC Marine Turtle Specialist Group methodology (Schroeder and Murphy, 1999).

Observation and documentation was made as follows:

- Marine turtle tracks below high tide mark (BHT). These tracks indicate the number of animals attempting to nest since the overnight high tide. This is therefore an underestimation of the number of turtles traversing the beach overnight as it does not account for animals crawling up and down the beach before the high tide had come and gone, thereby sweeping the beach clean of all tracks.
- Marine turtle tracks above high tide level (AHT). This information provides an indication of marine turtle activity on the beach in the recent past. This could be days to months dependent upon metocean conditions (e.g. Cyclones, storms, wind, rain and tidal surge will wipe the beach clean), along with the size, orientation and sediment characteristics of the beach. Secondary visual cues were also used to determine past nesting attempts, such as crab burrow holes through less-recent tracks, overlay of hermit crab, perentie or bird tracks and erosion level of crawls.
- Observations of marine turtles on the beach and in the water. Behaviour of animals in the water provides an indication of habitat usage and may include mating aggregations, developmental habitat or foraging grounds.
- Number of nests. Indicators used to assess whether eggs have been laid included the size, shape and compaction of sand in disturbed areas at the potential nest site, and track characteristics (where observable).
- All surveys were undertaken during the day and nesting female turtles were therefore unlikely to be encountered on the beaches. Track and nest characteristics e.g.: track width, shape and orientation of flipper marks, tail drag marks, morphology and depth of nest pit and associated mound were used to determine the species of the nesting turtle. Where the species could not be reliably identified from track or nest characteristics the tracks were recorded as unidentified.
- Nest predation. Nest predation was recorded for nests that clearly show evidence of animal foot prints and digging to egg/hatchling depth. Eggs, egg shell or hatchling remains may be visible. Where possible the predator was identified from tracks, dig marks etc.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Quantification of nesting effort during snapshot surveys was assessed using the following density scale:

- Low density = 1 track or crater per 10m+, very widely spaced tracks or craters with large areas of fresh sand visible.
 - Medium density = 1 track or crater per 5m – 10m.
 - High density = 1 track or crater per 1m, tracks and craters may be overlapping each other and little fresh sand is visible on the beach.
- Quantification of nesting effort during census surveys is calculated by the number of turtles arriving over the census line per night, averaged over three nights, per kilometre of beach. Density values are based on nesting levels at what are regarded as regionally and nationally significant nesting rookeries at Barrow Island and Mundabullangana.
 - Low density = <2 turtles per km/night.
 - Medium density = >2 and <20 turtles per km/night.
 - High density = >20 turtles per km/night.
 - Stranded turtles or carcasses and skeletons. The presence of dead turtles or turtle remains in the nesting habitat can be used to verify the species utilizing the beach to nest. Stranded turtles around the high-water mark indicate the presence of the species in near-by waters.
 - White-bellied sea-eagle (*Haliaeetus leucogaster*) nests were checked for the presence of any turtle remains.

Hatchling Emergence Fan monitoring methods

- The total number of emerged nests were counted and a GPS location taken for each. Nests are seen as expanding 'fans' of hatchling tracks from a distinct source point. Nests were recorded as a successful emergence when 5 or more tracks are sighted.
- Fan data were collected from suitable nests. Nests that displayed a clear fan not obscured by other nest fans, bird or other animal tracks were deemed suitable.
- The methods used to document hatchling emergence fan indices follow those developed by Pendoley (2005). Typically the angle of spread of the fan will increase under the influence of light (both natural and artificial) while lights behind, or at the end of the beach will cause the fan orientation to shift away from a direct line to the ocean.
- The spread of the fan was measured using a sighting compass to record the bearing along the outside arms of each fan. The bearing was taken at the point where the tracks cross the high tide line, or from the nest for fans that are orientated parallel to the ocean.

- An angle of spread was then calculated from these bearings. The orientation of the fan relative to the most direct line to the ocean is termed the fan offset angle and is determined by calculating the angle between the most direct line to the ocean (X) and the bearing bisecting the fan spread angle (C).
- As with the nesting track count, fans may not be visible for survey due to wind, rain, or animal tracks erasing them. Furthermore heavy cyclonic rain can prevent hatchlings emerging from the sand in the days following.

3.3 Survey limitations

- The timing of the survey was dictated by 3rd party logistical and operational constraints and meeting client safety requirements.
- The passage of Tropical Cyclone Dominic through the region on 26th-27th January interrupted the surveys. No surveys were carried out between 26th and 29th January. This interruption forced the survey to take place 5 days later than planned. This was within the known peak nesting period for green turtles but outside the known peak period for flatback turtles.
- Strong winds and heavy rain associated with the cyclone obscured evidence of prior turtle nesting on some beaches. This was most evident on mainland beaches near Onslow and Ashburton and Direction Islands.
- The movement of a storm system through a marine turtle nesting region may also lower the magnitude of turtle nesting activity in the short term. It is therefore likely that the surveys undertaken have resulted in a minimum estimate of marine turtle nesting activity in these locations.
- Nesting marine turtle populations often exhibit large fluctuations in the number of turtles nesting per night on a beach. Flatback turtle nesting numbers have fluctuated from under 5 per night to over 250 per night during the peak nesting season at Barrow Island (Pendoley 2005 and unpublished data). In some cases nesting numbers can be influenced by the timing and magnitude of tides while there are also many unknown variables. Counts made over the course of just one or a few nights are not necessarily indicative of the mean level of nesting throughout a season.
- While this survey takes place during the peak nesting seasons for green and flatback turtles, it is recognized that hawksbill nesting occurring outside of the project period may not be accurately represented by these findings; an additional survey during this period is recommended to capture these data.
- High density turtle nesting may obscure previous turtle tracks from being counted or identified.

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- Hatch success rates are over estimated when only successfully emerged nests are excavated. Nests with little or no hatchling emergence cannot be visibly identified as such (there are no hatchling tracks) and therefore are not excavated and are thereby excluded from hatching success data.

3.4 Acknowledgements

The field survey was designed by Dr Kellie Pendoley and implemented by Mr Barry Krueger, Mr Nicholas Sillem, Dr Kellie Pendoley and Ms Anna Vitenbergs (Pendoley Environmental Pty Ltd), experienced marine turtle ecologists/biologists. Marine support for accommodation and transportation was provided by Broadsword Marine. Photographs were taken by B. Krueger. Plate 2, photograph by K. Pendoley. Figures were produced using Google Earth Pro Ref ID# 1839881.

4 Results

Marine turtle nesting activity was found to be very low in the mainland survey area. Large sections of coastline exhibit no signs of marine turtle nesting activity. Low density flatback nesting was identified at one site to the west of the Ashburton River (Figure 41).

There is no evidence from this survey of marine turtle nesting for any species in the immediate vicinity of the proposed site for the Wheatstone LNG facility. The beach in this area has also been observed to be inundated by high spring tides (A. Vitenbergs, pers.com) making it unsuitable for marine turtle nesting (Figure 2).

Marine turtle nesting densities on the nearby islands varied significantly from island to island. The highest density nesting took place on Serrurier, Bessieres, Thevenard, Locker and Ashburton Islands. Nesting at Serrurier and Bessieres Islands was largely by green turtles with small numbers of flatback turtles. Thevenard Island had mainly flatback turtle nesting on the south-western coast and mainly green turtle nesting along the north-western coast. Nesting at Ashburton and Locker Islands was dominated by flatback turtles.

Smaller islands such as Tortoise, Round, Table, SE Twin and Direction Islands had small areas of suitable nesting habitat and very low density nesting activity. Other smaller islands such as Flat and NE Twin Islands, while also having smaller areas of suitable nesting habitat, have moderate levels of nesting within that habitat.

The highest nesting density beaches generally occurred on the east and southern coasts of the majority of islands surveyed.

Flatback turtles were found to be predominately nesting on the islands closer to the mainland and mainland beaches. Green turtles were found to be nesting on the islands further offshore. No green turtle nesting was found on the mainland. There was only one record of hawksbill turtle nesting, which occurred on Bessieres Island. There were no indications of loggerhead turtle nesting during this survey.

Survey results are presented in detail by island/area and the full data are tabulated in Appendices A-G.



Figure 2: Tidal inundation of project site.

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

4.1 Census Beaches

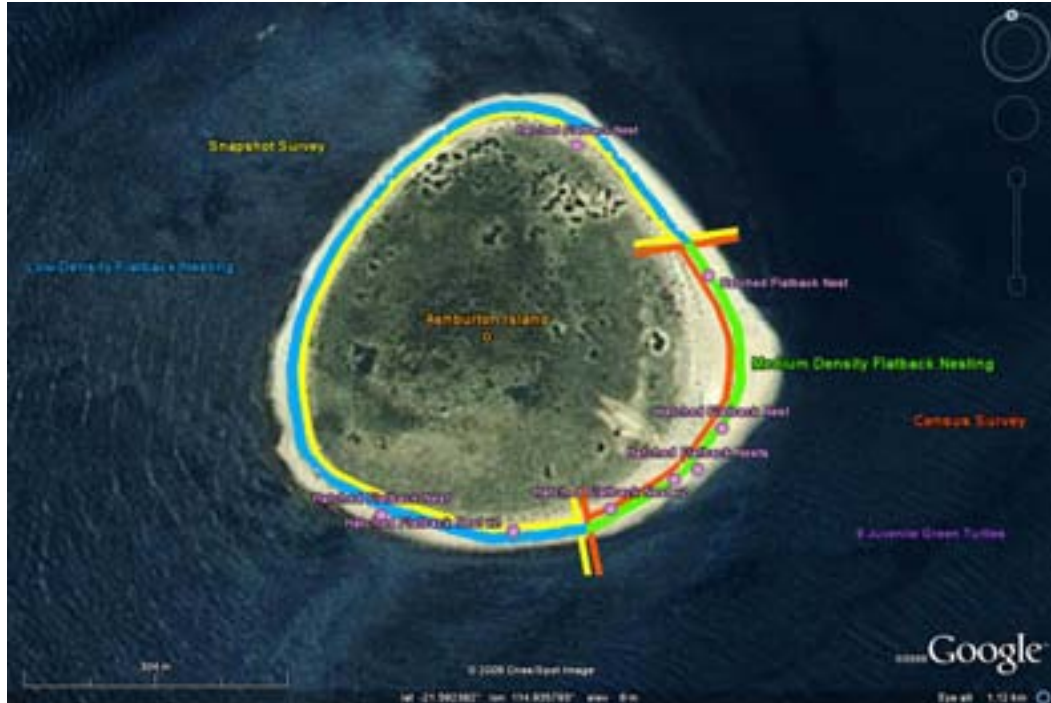


Figure 3: Ashburton Island - survey sites and results



Ashburton Island

The results of a line-census and snapshot survey on Ashburton Island (Figures 3 & 4) are presented below.

East Coast: Survey Date: 25th January, 2009. There were seventy eight flatback turtle tracks (up and down tracks, representing 39 turtles) observed above high tide (AHT), on the first survey. There were an additional three flatback tracks since the last high tide. Five emerged flatback turtle nests were found. No turtles were seen in the water although the water conditions were turbid.

Line census: line-in survey date: 31st January, 2009. There were twenty two flatback tracks AHT since the passage of cyclone Dominic on the 27th of January, 2009. There were an additional three green turtle tracks since the last high tide. Two emerged flatback turtle nests were observed. No turtles were seen in the water although the water conditions were turbid.

Line Census Surveys:

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1st February, 2009. No turtle tracks or emerged nests were observed. One juvenile green turtle was seen in the near shore waters.

2nd February: No turtle tracks or emerged nests were observed. Two juvenile green turtles were seen in the near shore waters.

3rd February, 2009. No turtle tracks or emerged nests were observed. Four juvenile green turtles were seen in the near shore waters.

Snapshot survey was carried out on 25th January, 2009. There was less than one track per 10 metres; and therefore, low density flatback turtle nesting along the north, west and south coasts of the island outside the east coast census area. Four emerged flatback nests were seen. There were no sightings of turtles offshore although the water conditions were turbid.

The south and east coasts have suitable nesting habitat for turtles with broad gently sloping beaches. The northern and western coasts are less suitable, being largely rocky with difficult access to the beach.



Figure 4: South coast of Ashburton Island with wind-blown turtle tracks in the foreground

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Figure 5: Bessieres Island - survey sites and results

Bessieres Island

The results of a line-census and snapshot survey on Bessieres Island (Figures 5 & 6) are presented below.

East Coast: Survey Date: 25th January, 2009. There were four flatback and one hundred and eighty-one green turtle tracks observed AHT on the first survey. One emerged green turtle nest was found. No turtles were seen in the water although the water conditions were turbid.

Census line in survey date: 30th January, 2009. There were twenty two flatback and two hawksbill tracks AHT since the passage of cyclone Dominic on the 27th of January, 2009. There were an additional three green turtle tracks since the last high tide. Two emerged green turtle nests were observed. No turtles were seen in the water although the water conditions were rough and turbid.

Line Census Surveys:

31st January, 2009. Four green turtle tracks were observed (i.e. two overnight nesting attempts). One green turtle nest emerged. No turtles were seen in the water.

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1st February. Two flatback and four green turtle tracks were observed. One green turtle nest emerged. One juvenile green turtle was seen in the water.

2nd February, 2009. No fresh tracks were observed. One flatback and one green turtle nest emerged. No turtles were seen in the water.

Snapshot survey was carried out on 25th January, 2009. Low density green turtle nesting was observed along the north, west and south coasts of the island outside the east coast census area. There were no sightings of turtles in the water.



Figure 6: Green turtle nesting on the east coast of Bessieres Island

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Figure 7: Western Thevenard Island - survey sites and results

Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Light blue area
Medium density nesting	Green area
High density nesting	Red area
In-water sightings	Purple area
Hatched nests	Pink circle

Thevenard Island

The results of a line-census and snapshot survey on Thevenard Island (Figure. 7) are presented below. An initial snapshot survey was conducted on the north-west, west and south-west coasts of the island. Two 500m census lines were then put in on the north-west and south-west coasts.

South Coast: AHT survey date: 25th January, 2009. There were sixty three flatback and four green turtle tracks observed on the first survey. No turtles were seen in the water.

Census line in survey date: 30th January, 2009. There were no turtle tracks since the passage of cyclone Dominic on the 27th of January, 2009. No turtles were seen in the water.

Line Census Surveys:

31st January, 2009. No turtle tracks were observed. Fourteen juvenile green turtles were seen in the water. Numerous sharks and rays were seen in near shore waters.

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1st February, 2009. Two flatback turtle tracks were observed. No turtles were seen in the water.

2nd February, 2009. No turtle tracks were observed. Eight juvenile green turtles were seen in the water. Numerous sharks and rays were seen in near shore waters.

North Coast: AHT survey date: 25th January, 2009. There were ninety three green turtle tracks observed on the first survey. Previous nesting density was high. No turtles were seen in the water.

Census line in survey date: 30th January, 2009. There were twenty six green tracks AHT since the passage of cyclone Dominic on the 27th of January, 2009. No turtles were seen in the water.

Line Census Surveys:

31st January, 2009. No turtle tracks were observed. Two juvenile green turtles were seen in the water.

1st February, 2009. Two flatback turtle tracks were observed. No turtles were seen in the water.

2nd February, 2009. Four flatback turtle tracks were observed. No turtles were seen in the water.

West Coast: A snapshot survey was carried out on 25th January, 2009. Medium density green turtle nesting was observed on the west coast of the island between the north and south coast census areas. Additional survey carried out 30th January, 2009. Seven green turtles had come ashore in the three days since the passage of cyclone Dominic on 27th January, 2009. One emerged green turtle nest was found. Fourteen juvenile green turtles were seen in the near shore waters.

The south-western coastline consists of a narrow gently sloping beach backed by low grass covered dunes. Turtle nesting occurs mostly within this dune area. The northern half of the west coast and northern coast consists of a slighting wider gently sloping beach backed by significantly higher dunes. The southern half of the west coast segment is actively eroding the face of the sand dunes that lie along the long axis of Thevenard Island. The dunes drop straight into the sea and dominate the supratidal zone.

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands



Figure 8: The mainland coast west of Onslow - survey sites

Mainland west of Onslow

The results of a line-census and snapshot survey for the mainland coast between Urala and Onslow Back Beach (Figures 8 to 13) are presented below.

A snapshot survey was carried out on 3rd February, 2009 between Urala and Onslow Back Beach area. No evidence of current or prior turtle nesting was seen although the beaches were heavily windblown. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

Onslow mainland: Beach One

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad (~10 m to high water mark) and flat with fine grain light brown coloured sand. Low grassy dunes were backed by higher shrub covered dunes (Figure 9). There was no evidence of reef structures off shore.



Figure 9: Census line in place on mainland beach one

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Onslow mainland: Beach Two

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad and gently sloping with fine grain medium brown coloured sand interspersed with pebbles. There was a fine layer of black sand ~5 m wide around the high water mark. Large un-vegetated dunes backed the beach (Figure 10).



Figure 10: Looking towards the east on mainland beach two

Onslow mainland: Beach Three

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. Two rib bones from an unidentified but adult sized turtle were found ~2 m above the high water mark. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad and flat with fine grained medium brown coloured sand. A ~5 m wide strip of fine grained black sand was found around the high water mark. The beach was backed by low grassy dunes with slightly higher shrub covered dunes further inland (Figure 11).



Figure 11: Mainland beach three looking towards the north-east

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Onslow mainland: Beach Four

There was evidence of thirteen previous turtle nesting activities on the first visit to this beach, although all activities were difficult to observe due to earlier high winds and heavy rain from Cyclone Dominic. A further five nests were only visible due to them having been partially or completely predated by foxes (Figure. 13). No additional nesting was recorded during the three day census survey period. The nests were too wind-blown to determine the species that laid them although all five predated nests had the remains of flatback turtle shells present. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad and gently sloping with fine grained dark brown coloured sand. A ~5 m wide strip of fine grained black sand was found around the high water mark. Low grassy dunes backed the beach with no dunes further inland. There was an extensive stand of tree trunks below the high water mark and immediately to the east of the census line (Figure 12).



Figure 12: Looking eastwards from mainland beach four

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 13: Fox predation of a flatback turtle nest at mainland beach four

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Onslow mainland: Beach Five

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. A section of carapace from an unidentified but probably adult sized turtle was found on the beach. This section of beach was very heavily wind-blown. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The census line started 50 m north of the mouth of a creek. The beach consisted of a 0.5 m vertical eroded drop at the western end which gradually decreased to a gently sloping broad flat beach at the eastern end. The beach was backed by low grassy dunes ~50 m from the high water mark. A large amount of natural wooden debris was found on the beach (Figure 14).



Figure 14: Mainland beach five looking towards the east

Onslow mainland: Beach Six

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach is broad and gently sloping and consists of fine grained medium brown coloured sand. There is a ~5 m wide strip of fine grained, black coloured sand around the high water mark (Figure 15).



Figure 15: Mainland beach six looking towards the east

Wheatstone Marine Turtle Survey
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Onslow mainland: Beach Seven

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach is broad, flat and gently sloping and consists of medium coloured, fine grained sand. There is a ~5 m wide strip of fine grained black coloured sand around the high water mark. The beach above the high water mark is heavily littered with mussel shells (Figure 16).



Figure 16: Mainland beach seven looking towards the east

4.2 Snapshot Beaches

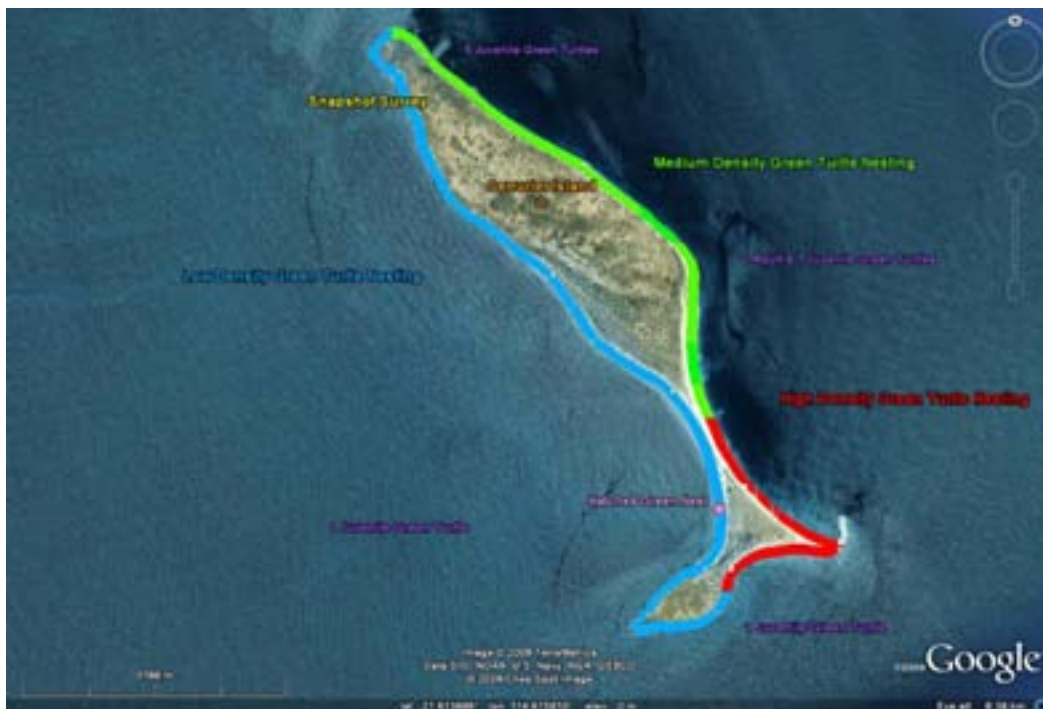


Figure 17: Serrurier Island – a snapshot survey encompassed the entire island

Serrurier Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Serrurier Island (Figure 17 to 20) are presented below.

South East Coast: Based on presence of old body pits and associated nest mounds, there was evidence of high density green turtle nesting in the southern bay, along the south-eastern sand spit and the lower eastern coast. The majority of the nesting activity was by green turtles with lower levels of flatback nesting activity also present. One dead nesting green turtle was found on the beach. This animal had a curved carapace length of 96 cm. One juvenile and two adult green turtles were seen in near shore waters off the south eastern coast and one juvenile green turtle was seen off the southern bay.

Wheatstone Marine Turtle Survey
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Figure 18: Serrurier Island east coast with recent green turtle tracks

East coast: There was evidence of medium density green turtle nesting along the remainder of the eastern coastline. Lower levels of flatback turtle nesting were also seen. Five Juvenile green turtles were seen in near shore waters.

The sand dune height behind the east coast beaches increased in height towards the northern end of the island. In some cases turtles were nesting considerable distances up steeply sloping sand dunes (Figures 18 & 19).

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 19: Recent green turtle nesting on the north-east coast of Serrurier Island



Figure 20: Serrurier Island west coast

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West coast: Low density green turtle nesting was observed along the entire west coast (Figure 20). There was no evidence of flatback nesting along the west coast. One juvenile green turtle was seen in near shore waters.

The east coast beaches are generally broad and gently sloping and consist of fine grained, light brown coloured sand. There are several rocky areas on the east coast which become more common and pronounced towards the north. The beach narrows at the northern point of the island and the dunes become higher. The west coast beaches are generally narrower. There are also more rocky areas. The south western point is mostly rocky and generally not suitable for marine turtle nesting. The bay on the south coast has a gently sloping beach backed by low grass covered dunes.

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple dots
Hatched nests	Pink circle

Figure 21: Tortoise Island - a snapshot survey encompassed the entire island

Tortoise Island

The results of a snapshot survey, carried out on 1st February, 2009, around the entire coast of Tortoise Island (Figure 21) are presented below.

There was no evidence of current turtle nesting seen, although the beaches were heavily windblown. There were several old nesting pits in the AHT zone that could be discerned, indicating a very low level of prior nesting on the east coast. There was no evidence of any nesting around the remainder of the island. Eight sea-eagle nests were checked for marine turtle remains. No remains were found. One unidentified juvenile turtle was seen in the water. Eight dark coloured, unidentified dolphins were seen to the north west of Tortoise Island. Three lighter coloured unidentified dolphins were seen west of Tortoise Island.

The only suitable nesting habitat was on the small east coast beach and sand-spit (Figure 23). The sand on the east coast was light brown in colour and fine grained. The north, west and south coasts of the island were rocky (Figure 22).

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 22: South coast of Tortoise Island



Figure 23: Small east coast beach and sand spit on Tortoise Island

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 24: Direction Island - a snapshot survey encompassed the entire island

Direction Island

The results of a snapshot survey, carried out on 31st January, 2009, around the entire coast of Direction Island (Figure 24) are presented below.

No evidence of current turtle nesting was seen, although the beaches were heavily windblown and eroded. There were several older nesting pits from unidentified species on the eastern side of the island in the AHT zone. There was no evidence of recent hatching. No turtles were seen in the water.

There was a broad gently sloping beach and sand-spit on the eastern side of the island. The northern, western and southern coastlines were largely rocky and exhibited signs of recent erosion. A tourist shack is located on the south-west coast of the island.

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink dot

Figure 25: SW Twin Island - a snapshot survey encompassed the entire island

SW Twin Island

The results of a snapshot survey, carried out on 6th February, 2009, around the entire coast of SW Twin Island (Figure 25) are presented below.

The beaches were heavily windblown and eroded and there was evidence of seven previous nest pits in the AHT zone, from unidentified turtle species. There was no recent nesting activity. There was no evidence of hatchling tracks. Three sea-eagle nests were examined for turtle remains although none were found. One large, probably sub-adult, loggerhead turtle was seen in the water, on the surface, approximately 200 m south-east of the island in water approximately 10 m deep.

The east coast has a small gently sloping beach on the east coast which consists of moderately coarse grained and medium brown coloured sand (Figure 26). The beach is backed by small grassy dunes and the interior of the island is mostly covered in low shrubs of up to 0.5 m high. The north-west, west and south west coasts are rocky with shrubs to the high water line.

Wheatstone Marine Turtle Survey
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Figure 26: Small east coast beach on SW Twin Island, looking towards NE twin Island

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink dot

Figure 27: NE Twin Island – a snapshot survey encompassed the entire island

NE Twin Island

The results of a snapshot survey, carried out on 3rd February, 2009, around the entire coast of NE Twin Island (Figure 27) are presented below.

Although the beaches were heavily windblown and eroded there was evidence of thirty old nest pits from unidentified turtle species. There were an additional seven activities observed that could be identified as being flatback turtle nests and tracks. Two of these had occurred since the passage of Cyclone Dominic on 27th January, 2009. There was no evidence of any hatchling tracks. Four sea-eagle nests were examined and the remains of one ~15 cm long post-hatchling flatback turtle were discovered in a nest on the eastern side of the island (Figure 28). No turtles were seen in the water.

The main suitable nesting habitat was on the east coast beach and sand-spit. The sand is a medium brown colour and course grained. There was a large amount of seaweed washed up on the beach. There were low grass covered dunes behind the east coast beaches. The centre of the island was mostly covered in shrubs, some reaching to a height of ~2 m. The north east

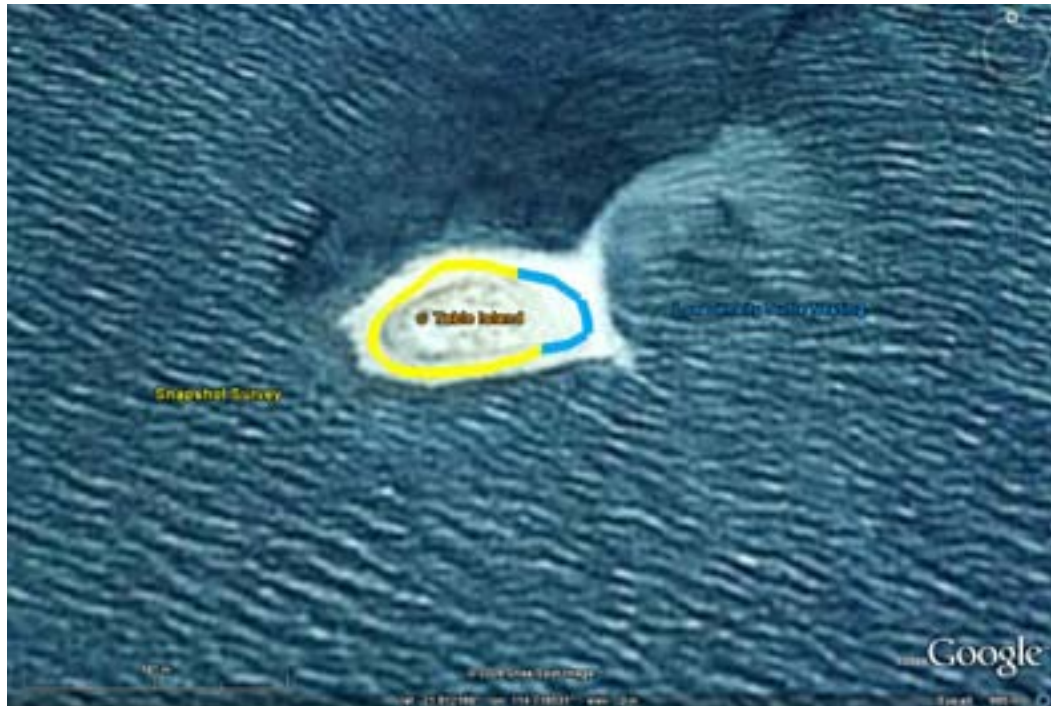
Wheatstone Marine Turtle Survey
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coast has a narrow beach area suitable for nesting. The remainder of the north coast is rocky. The west coast and south west coast is rocky.



Figure 28: Juvenile flatback turtle remains (turtle carapace next to nest in the lower right corner) at a white-bellied sea eagle nest on the east coast of NE Twin Island

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 29: Table Island - a snapshot survey encompassed the entire island

Table Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Table Island (Figure 29) are presented below.

One flatback turtle had come ashore since the passage of cyclone Dominic on 27th January, 2009. There was evidence of low density nesting by unidentified turtle species on the small east coast beach. No hatchling tracks were seen. The skeletal remains of an unidentified adult turtle were found on the east coast in the dune nesting habitat. No turtles were seen in the water.

The small east coast beach was gently sloping and consisted of fine grained light brown sand. The north eastern coast was all rocky and coral rubble and unsuitable for turtle nesting (Figure 30). The south-west and western coasts consist of a mixture of fine grain sand with large amounts of coral rubble dispersed through it. The interior of the island has only about 50 % ground cover with the highest shrubs reaching 0.5 m.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 30: Sand spit and small east coast beach of Table Island

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in-census	Blue line
Low density nesting	Light blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 31: Round Island - a snapshot survey encompassed the entire island

Round Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Round Island (Figure 31) are presented below.

One flatback turtle had come ashore since the passage of Cyclone Dominic on 27th January, 2009. There was evidence of low density nesting by unidentified turtle species on the small east coast beach. One sea eagle nest was examined but no turtle remains were found (Figure 32). No hatchling tracks were seen. No turtles were seen in the water.

The small east coast beach consists of medium grain light brown coloured sand. The south, west and north coast are rocky with a narrow (~2 m) wide sandy beach beyond the rocks. There is coral debris mixed through the medium grained sand. The interior of the island has 70 % of covering with grass.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 32: Looking over a White-bellied sea-eagle nest to the small south-east coast beach on Round Island

Wheatstone Marine Turtle Survey
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Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 33: Flat Island - a snapshot survey encompassed the entire island

Flat Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Flat Island (Figure 33) are presented below.

Three flatback and three green turtles had come ashore since the passage of Cyclone Dominic on the 27th January, 2009. Medium density green and flatback turtle nesting was observed along the east coast of the island. Low density green turtle nesting was found along the west coast of the island. Two dead nesting green turtles were found on the east coast beach (Figure 34). One old sea eagle nest was examined but no turtle remains were found. Seven black-tipped reef sharks were seen within 10 m from shore in ~1 m deep water on the south coast. No hatchling tracks were seen. No turtles were seen in the water.

There is a large sand-spit on the south-eastern side of the island and a broad mildly sloping beach on the east coast which consists of light brown coloured, fine grained sand. There is a rocky shoreline on the north-east and south-west coasts. The west coast has coral rock to the waterline with a 3m wide line of rock to the high water mark (Figure 35). There is a mix of ~70 % sand and ~30 % rock to the base of the dunes.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

The interior of the island has a ~95 % covering of shrubs which reach a maximum height of ~1 m.



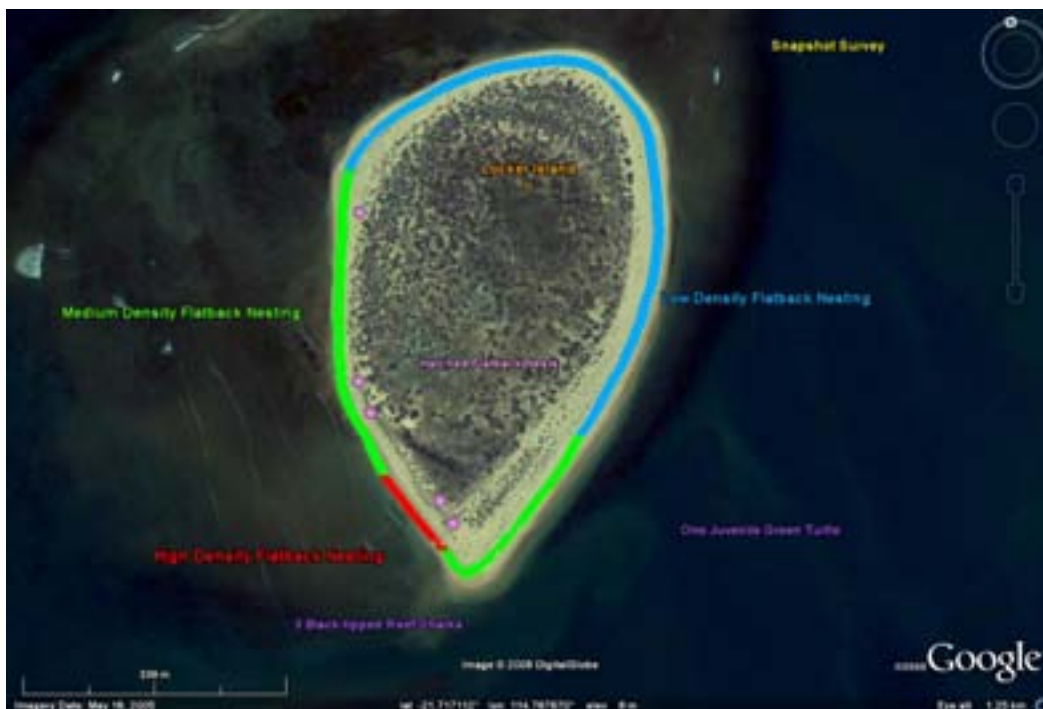
Figure 34: The remains of a nesting female green turtle on the east coast of Flat Island

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 35: Low density nesting on the exposed western coast of Flat Island

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple dot
Hatched nests	Pink dot

Figure 36: Locker Island - a snapshot survey encompassed the entire island

Locker Island

The results of a snapshot survey, carried out on 5th February, 2009, around the entire coast of Locker Island (Figure 36) are presented below.

Six flatback turtles had come ashore since the passage of cyclone Dominic on 27th January, 2009. Tracks from an additional seventeen flatback turtles could be identified AHT from prior to the passage of the cyclone. Flatback turtle nesting density was high on the south west coast (Figure 37) medium along the southeast and west coasts and low along the east and north coast. One juvenile green turtle was seen in near shore waters. Five flatback nest emergences were seen along the south western coast. One sea eagle nest was examined but no turtle remains were found. Three black-tipped reef sharks were seen within <10 m from shore in ~1 m deep water on the south coast.

There is a gently sloping beach surrounding the island. It is at its widest on the east and south east coasts. The sand is medium/coarse grained and light brown in colour and is mixed in with

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some coral debris. The beach is backed by low grassy dunes with higher shrub covered dunes in the interior. The west coast is rocky with a 5 m wide beach above the rocks.



Figure 37: High density flatback turtle nesting on the south west coast of Locker Island

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Figure 38: Urala to Locker Point - survey site

Urala to Locker Point

The results of a snapshot survey, carried out on 6th February, 2009, between Urala and Locker Point (Figure 38) are presented below.

No evidence of current or prior turtle nesting was seen although the beaches were heavily windblown. No turtles were seen in the water although the water conditions were turbid.

The beach survey was a total of 7 km in length. The beach was broad and gently sloping and consisted of medium brown coloured and medium grain sized sand. In some areas there was a ~5 m wide strip of fine grained black sand at the high water mark while in other areas this strip narrowed or disappeared completely. The beach was generally backed by low grass covered dunes. Water visibility was 2-3 m and a sandy bottom could be seen near-shore. A reef was found from ~700 m east of Locker Point until ~3 km east of Locker Point. There was exposed beach rock between 5.1 km and 5.7 km east of Locker Point. Several sections of beach, each 300-400 m long, had a 0.5 m vertical erosion line on the beach.

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Figure 39: Onslow back beach - survey site

Onslow Back Beach

The results of a snapshot survey, carried out on 6th February, 2009, on Onslow Back Beach (Figure 39) are presented below.

No evidence of current or prior turtle nesting activity was seen although the beaches were heavily windblown. No turtles were seen in the water although the water conditions were turbid.

This beach survey was a total of 6 km in length. The beach was wide with a gentle slope and consisted of medium brown coloured fine grain sand mixed with shells. The beach is backed by low grass covered dunes with slightly higher shrub covered dunes inland. There were significant numbers of vehicle tracks seen along the greater part of this beach.

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Figure 40: Coolgara to Beadon Creek - survey site

Coolgara to Beadon Creek

The results of a snapshot survey, carried out on 6th February, 2009, between Coolgara and Beadon Creek (Figure 40) are presented below.

No evidence of current or prior turtle nesting activity was seen although the beaches were heavily windblown. No turtles were seen in the water although the water conditions were turbid.

The beach survey was a total of 11 km in length. The beach is broad and gently sloping and backed by low grass covered dunes with higher shrub covered dunes inland. The beach is made up of fine grained, medium brown coloured sand. At 150 m, 1 km and 5 km from Coolgara Point there are 2.5 m high shrubs down to the water-line. At 5 km from Coolgara Point there is a ~100 m long rocky ledge. West of the rocky ledge the beach becomes narrower and the dunes higher. About 8 km from Coolgara Point the beach becomes wider and is backed by lower dunes until reaching Beadon Creek.

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4.3 Additional sightings

On 6th of February, three sets of recent flatback turtle tracks were seen en route to Census Beach four several hundred metres to the west of the survey area (Figure 41). One activity resulted in a potential nest while the others were unsuccessful nesting attempts. One emerged flatback nest was found in the same area. Two older fox predated nests were also seen. These nests had not been recognizable as marine turtle nests during the snapshot survey conducted on the 3rd February 2009 as the area was heavily wind-blown and the fox predation had occurred since that survey was undertaken.



Figure 41: Flatback turtle tracks and nest along the mainland coast west of census beach four

4.4 Hatchling Fan Indices

Hatchling fans were measured for five green and thirteen flatback turtle nests (Figure 42). The results are presented in Appendix E. There was no hatchling misorientation for 92.3 % of flatback nests monitored where the X value (direction of the sea) was within the fan spread (A & B) and offset angles were low. There was no misorientation in 80 % of green turtle nests monitored. There was significant hatchling misorientation in one flatback and one green turtle nest.



Figure 42: Flatback hatchling tracks lead away from an emerged nest west of mainland census beach four

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4.5 Hatching Success

A total of nine flatback and three green turtle nests were excavated after hatchlings had emerged to determine the hatch success of each nest. Results are presented in Appendix F. The mean hatch success for the green turtle nests was 91.3 %, with a range of 83.6-98.1 %. The mean hatch success for flatback turtles was 80.9 % with a range of 23.4-97.9 %. The mean number of eggs laid per clutch was 107.3 with a range of 104-114 for green turtles and 49.6 with a range of 35-64 for flatback turtles. All emergences apart from one flatback nest were found on the islands.



Figure 43: Hatchling flatback turtles at Bessieres Island

4.6 Inwater sightings

There were a total of sixty-two turtle sightings in the water. All sightings occurred within several hundred metres of shore around the islands. There were no sightings of turtles in the water along the mainland coast. Fifty-eight sightings were classified as juvenile green turtles, based on size, although size is not always a good indicator of maturity in marine turtles. The only two adult sized turtles seen in the water were green turtles off the northern coast of Serrurier Island. One large juvenile/sub-adult loggerhead was seen off the coast of SW Twin Island and one unidentified small juvenile turtle was seen at Tortoise Island. The remaining sixty in-water sightings were of green turtles. There were no sightings of flatback or hawksbill turtles in the water.

4.7 Other Observations

- **Dugong** (*Dugong dugon*)

There were two sightings of dugongs during the survey. One adult was seen in the shallow water off the north-western coast of Thevenard Island at ~10:00, 30-Jan-09. One adult was seen in Beadon Creek, Onslow, at 21:30, 5-Feb-09, while the survey vessel, 'Adrenaline Sprint', was at its mooring.

- **Cetaceans**

There were two sightings of unidentified dolphins during the survey. One pod of eight individuals west seen at ~11:15, 1-Feb-09, west of Tortoise Island while a second pod of three lighter coloured individuals was seen at ~11:30, 1-Feb-09 also to the west of Tortoise Islands.

- **Sharks and rays**

Seven black-tipped reef sharks (*Carcharhinus melanopterus*) (Figure 44) were seen off the southern coast of Flat island. Three black-tipped reef sharks were seen off the southern coast of Locker Island. Numerous sharks, rays and large fish were seen off the north western, western and south western coasts of Thevenard Island.

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Figure 44: Black-tipped reef sharks close to shore on the south coast of Flat Island

5 Discussion

There is no evidence of any nesting for any species of marine turtle along the mainland coast at the proposed development site. Subsequent observations made at this site documented high tide waters over topping the sand bar on sections of this beach (A. Vitenbergs, C. Bell pers. com.; Figure 2). It appears unlikely that marine turtles utilize this site for nesting in any significant numbers, if at all.

Apart from the low density nesting west of the Ashburton River at census beach four, there was no marine turtle nesting activity seen on mainland beaches during this survey. There is anecdotal evidence (B. Krueger pers. comm.) of low level flatback turtle nesting in the Onslow back beach area. There has also been a low level of nesting activity recorded between Beadon Creek and Coolgara (B. Krueger pers. comm.) All of the nesting activity observed on the mainland beaches has been very low density with large sections of beach apparently having no nesting activity at all.

The level of marine turtle nesting varies significantly from island to island. There is substantial nesting activity on the large (Serrurier and Thevenard) and moderate (Bessieres, Locker and Ashburton) sized islands, made of up a combination of flatback and green turtle nesting.

Smaller islands such as Tortoise Island have very small areas of suitable nesting habitat and very low density nesting activity (figure 45). Other smaller islands such as Flat, Table, Direction and the Twin Islands, while also having small areas of suitable habitat, have moderate levels of nesting activity within that habitat.

It is likely that the passage of Tropical Cyclone Dominic has resulted in a lower than expected count of marine turtle nesting activity for the survey period. The beaches were heavily wind-blown and nests laid prior to the passage of the cyclone were no longer visible and could therefore not be documented in many areas.

Census line track counts, indicating current levels of marine turtle nesting activity were low. The passing of Tropical Cyclone Dominic may have contributed to lower than expected counts as cyclonic activity erased evidence of nesting prior to the survey period and altered the timing of the survey which was conducted late in the turtle nesting season for all species.

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Figure 45: Wind-blown beach on Tortoise Island

5.1 Flatback Turtles

The results of this survey indicate that most marine turtle nesting that occurs on mainland beaches in the Onslow region is by flatback turtles. While most nest sites were too wind-blown to enable nest characteristics to be used to identify species, all fox predated nests had remains of flatback turtle egg shells in them. The only hatched nest observed in the area was also confirmed as a flatback nest after examination of the nest contents. Existing nesting records for the mainland region near Onslow are all of flatback turtle nesting (Pendoley *pers. comm.*).

The level of flatback turtle nesting along mainland beaches is not regionally or even locally, significant based on the current surveys. Other flatback rookeries in the region have been reported hosting much larger numbers of nesting females. For example, over 1700 flatback turtles nest annually at Mundabullangana (Pendoley *et al.* in press), and an estimated 1600 flatback turtles nest annually at Barrow Island (Pendoley 2005).

There is a marked division of flatback and green turtle nesting between locations. Flatback turtles are predominately found on the near shore islands with smaller aggregations on the mainland and the south coast of Thevenard Island.

5.2 Green Turtles

Green turtles were found to nest predominately on the outer islands such Bessieres, Serrurier and the north and west coasts of Thevenard Island. These islands appear to support regionally significant nesting rookeries for this species; however none of these rookeries approach the size of the green turtle rookeries at Barrow Island and in the Dampier Archipelago. The potential for negative impacts to green turtle nesting is expected to be lower than for flatback turtles, in part due to their major rookeries being at a greater distance to the proposed development site.

5.3 Hawksbill Turtles

Only one hawksbill nest was documented during the survey period. Many of the sites examined in this survey, particularly the mainland beaches, do not exhibit the preferred beach characteristics that hawksbill turtles normally utilize. It is therefore unlikely that any of the beaches in the region host large hawksbill nesting rookeries. However, it is difficult to assess with certainty which species have created older nesting pits. This is particularly significant for hawksbills as their preferred nesting season peaks earlier than that for green and flatback turtles. Hawksbills in the North-West shelf region tend to commence nesting in August, with peak nesting occurring between October and November (Pendoley 2005). Hawksbill turtles are the smallest of the marine turtles found in the region and their tracks and nests can be obscured by the larger and later season nesting green and flatback turtles. It is possible that significant levels of hawksbill nesting may take place on some of the island beaches during this earlier period.

5.4 Loggerhead Turtles

While no loggerhead turtle nesting was found in the Onslow region during this survey, occasional loggerhead turtle nesting has been reported in the Barrow/Montebello/Lowendal complex of islands (Pendoley 2005) and the closest known significant loggerhead turtle rookery is located at South Muiron Island, only about 65 km to the west of the Ashburton River delta. This island supports an annual nesting population of 150-350 females per year (Baldwin 2003). Previous surveys have found evidence of loggerhead turtle nesting in the Onslow region (C. Bell *pers. comm.*). More extensive surveys would be needed to establish the significance of the Onslow region as a loggerhead nesting rookery.

5.5 Hatchling Fans Indices and Light Impacts

The majority of measured nest fans showed hatchlings moving towards the sea without any misorientation. It is important to note that there is a low level of natural misorientation. This can occur particularly when nests are laid amongst dunes or vegetation in situations where hatchlings are exposed to the same light horizon in multiple directions which can adversely impact their sea finding capabilities. Despite the small sample size this data set can serve as a baseline for levels of hatchling orientation prior to development, although the sample size should be increased and broadened to include all species nesting in the area.

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The mainland beaches are unlikely to be directly impacted by lighting from the proposed development, apart from the low density flatback turtle nesting aggregation at Census beach four. This is approximately 5 km due west of the proposed development site. This rookery may also be under threat from fox predation of nests as 7 of 21 nests observed had been predated.

While there was no evidence of marine turtle nesting in the Onslow back beach area during this survey, previous surveys (B. Krueger *pers. comm.*) have found that there is also low density flatback turtle nesting in this area. Potential lighting impacts on this nesting aggregation also need to be addressed.

Hatchlings emerging from island rookeries in relatively close proximity to the proposed development may also be impacted by lighting. The rookery most at risk would be flatback turtles nesting on the eastern and southern coasts of Ashburton Island which is approximately 12 km from the proposed LNG site, and ~7 km from the proposed shipping channel.

The minimization of lighting levels for marine turtle management purposes during construction and operational phases of the proposed development should be included in all planning and front end engineering designs.

5.6 Hatch Success

The level of hatch success reported for flatback turtles (80.9 %, $n=9$) is similar to that found on Barrow Island, 84.9 % (Foster 2008) and is typical of these species (Miller 1997). The only nest to show abnormally low hatching was on the mainland, west of census beach four. There were a large number of full-term dead hatchlings in this nest. It is likely that heavy seas and rain from Cyclone Dominic resulted in this nest being at least partially flooded/washed over, which would account for the high mortality of full term hatchlings.

Mean hatch success for green turtles was higher than for flatback turtles in the region at 91.3 %, although the sample size is very small ($n=3$).

This survey overstates the likely mean hatch success and therefore productivity of the nesting beaches in the region as only nests with signs of hatching are excavated. Those nests with little or no hatchling emergence cannot be visibly identified as such (there are no hatchling tracks) and therefore are not excavated. To determine the true productivity of a nesting rookery it is necessary to accurately record and mark the exact location of representative sample number of nests (i.e. >30 nests) as they are laid and then to return to these same nests to determine hatch success for the entire sample, whether they have ultimately hatched or not.

5.7 Marine Turtles in the Water

This survey focused on the terrestrial nesting aspects of the marine turtle life-cycle. This phase of the life-cycle assesses only female reproductive behaviour during a very small proportion of their life-history. The survey did not assess the in-water turtle abundance, distribution, habitat use, location of mating aggregations and inter-nesting habitat or migratory pathways. Where

possible opportunistic sightings of turtles in the water were documented, either when travelling between nesting survey sites or while conducting nesting beach surveys.

Despite the opportunistic nature of the surveys and the generally poor visibility after the passage of Cyclone Dominic there were over sixty sightings of turtles in the water. Most of these were juvenile green turtles in near-shore habitats around the islands. These animals are likely to be residents at their foraging grounds. As these turtles were not tagged, and therefore not identifiable from each other in any way, it is possible that there were multiple sightings of the same turtle recorded. There were no turtle sightings in the water in the vicinity of the mainland beaches during this survey, although earlier aerial surveys (Prince, 2000) found turtles in the water in the Onslow back beach area. Trawling surveys have also found flatback turtles within several kilometres of the mainland coast in the Urala and Ashburton River delta areas (Kanga, 2007). The same surveys found green turtles at Onslow back beach and loggerhead turtles near Locker Point. It is likely that greater numbers of turtles would have been found in the current survey if in-water visibility had not been so poor.

Foraging green turtles are likely to be found in considerable numbers in sea grass and algal habitats around many of the islands in the region (Limpus et al 1994). Green turtles have also been found in association with coastal mangrove habitats in the Pilbara region (Pendoley et al. 1999). The Onslow region may be important foraging habitat for green turtles.

There were no sightings of hawksbills in the water during this survey. It is likely that hawksbills use the reef systems in the region as foraging habitat (Witzell 1983). Reef systems in this area have been observed in deeper water than seagrass and algal habitats and therefore these animals are less likely to be observed, than green turtles.

Foraging habitats for juvenile flatback turtles are unknown, although it is believed that turtles from North West Shelf rookeries remain on the Australian continental shelf between Exmouth and the Northern Territory. (Walker and Parmenter 1990a) Whereas hatchlings of most species of marine turtle have an oceanic development phase, hatchling, post-hatchling and juvenile flatback turtles are thought to remain in near shore foraging habitats, although the location of foraging aggregations in Western Australia is not known. White-bellied sea eagles are known to feed on small juvenile flatback turtles in Queensland (Walker and Parmenter 1990b) and in the Pilbara (Pendoley et al 2003, *unpublished data*) and the flatback turtle found in a white-bellied sea eagle nest on NE Twin Island indicates that the Onslow area is used as foraging habitat by this size class turtle.

The foraging habitat used by adult flatback turtles is also poorly documented. Satellite tracking of migrating female turtles from rookeries in the Pilbara have been shown to migrate to the Onslow area after their nesting season has concluded and are therefore likely to be using the area (in this case to the NW of Thevenard Island) as foraging habitat (Cemetery Beach, Port Hedland Satellite Tracking Project). Barrow Island nesting females have also been found to use the area to the north of Thevenard Island as foraging sites (Barrow Island Satellite Tracking Project, 2005-06).

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The relative proximity of the loggerhead nesting rookery at the Muiron Islands and the sighting of a large juvenile/sub-adult loggerhead turtle near the coast of SW Twin Island indicates that they are using the Onslow region as a foraging ground or at least as a migratory pathway. Satellite tracking indicates that loggerhead turtles utilize the vicinity of Serrurier and Thevenard Islands as a migratory pathway between their foraging grounds to the north and the nesting rookeries to the south (Ningaloo Turtle Project).

6 Management Recommendations

Management Recommendations will be supplied separately to this final report.

7 References

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Appendices

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Appendix 1: Snapshot survey track counts

Location	Date	Tracks below high tide line			Activity above last high spring tide		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	low	0	0	0	0	0
Thevenard Island (west)	25-Jan-09	0	Med	0	0	0	0
Bessieres Island	25-Jan-09	0	Low	0	0	0	0
Thevenard Island (West)	30-Jan-09	0	0	0	0	14	0
Direction Island	31-Jan-09	0	0	0	0	0	0
Tortoise Island	1-Feb-09	0	0	0	0	0	0
Ashburton River Delta	3-Feb-09	0	0	0	0	0	0
NE Twin	3-Feb-09	0	0	0	7	0	0
Serrurier Island East	4-Feb-09	ND	ND	ND	ND	ND	ND
Serrurier Island West	4-Feb-09	ND	ND	ND	ND	ND	ND
Serrurier Island South East	4-Feb-09	ND	ND	ND	ND	ND	ND
Table Island	4-Feb-09	0	0	0	2	0	0
Flat Island	4-Feb-09	0	0	0	6	5	0
Round Island	4-Feb-09	0	0	0	1	0	0
Locker Island	5-Feb-09	12	0	0	34	0	0
Mainland (Locker Pt/Urala)	5-Feb-09	0	0	0	0	0	0
SW Twin Island	6-Feb-09	0	0	0	0	0	0
Mainland (Onslow back beach)	6-Feb-09	0	0	0	0	0	0
Mainland (Coolgara/Beadon Ck)	6-Feb-09	0	0	0	0	0	0
Ashburton River Delta(2)	6-Feb-09	6	0	0	0	0	0

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Appendix 2: Snapshot survey: Marine turtle nests and animals sighted inwater

Location	Date	Potential nests			Hatched nests		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	0	0	0	4	0	0
Thevenard Island (west)	25-Jan-09	0	0	0	0	0	0
Bessieres Island	25-Jan-09	0	0	0	0	0	0
Thevenard Island (West)	30-Jan-09	0	0	0	0	1	0
Direction Island	31-Jan-09	0	0	0	0	0	0
Tortoise Island	1-Feb-09	0	0	0	0	0	0
Ashburton River Delta	3-Feb-09	0	0	0	0	0	0
NE Twin	3-Feb-09	0	0	0	0	0	0
Serrurier Island East	4-Feb-09	0	0	0	ND	ND	ND
Serrurier Island West	4-Feb-09	0	0	0	ND	ND	ND
Serrurier Island South East	4-Feb-09	0	0	0	ND	ND	ND
Table Island	4-Feb-09	0	0	0	0	0	0
Flat Island	4-Feb-09	0	0	0	0	0	0
Round Island	4-Feb-09	0	0	0	0	0	0
Locker Island	5-Feb-09	0	0	0	5	0	0
Mainland (Locker Pt/Urala)	5-Feb-09	0	0	0	0	0	0
SW Twin Island	6-Feb-09	0	0	0	0	0	0
Mainland (Onslow back beach)	6-Feb-09	0	0	0	0	0	0
Mainland (Coolgara/Beadon Ck)	6-Feb-09	0	0	0	0	0	0
Ashburton River Delta(2)	6-Feb-09	1	0	0	1	0	0

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Appendix 3 Snapshot survey: Inwater sightings

Location	Date	Juveniles in water					Adults in water		
		Flatback	Green	Hawksbill	Loggerhead	Unidentified	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	0	0	0	0	0	0	0	0
Thevenard Island (west)	25-Jan-09	0	0	0	0	0	0	0	0
Bessieres Island	25-Jan-09	0	0	0	0	0	0	0	0
Thevenard Island (West)	30-Jan-09	0	14	0	0	0	0	0	0
Direction Island	31-Jan-09	0	0	0	0	0	0	0	0
Tortoise Island	1-Feb-09	0	0	0	0	1	0	0	0
Ashburton River Delta	3-Feb-09	0	0	0	0	0	0	0	0
NE Twin	3-Feb-09	0	0	0	0	0	0	0	0
Serrurier Island East	4-Feb-09	0	5	0	0	0	0	2	0
Serrurier Island West	4-Feb-09	0	1	0	0	0	0	0	0
Serrurier Island South East	4-Feb-09	0	1	0	0	0	0	0	0
Table Island	4-Feb-09	0	0	0	0	0	0	0	0
Flat Island	4-Feb-09	0	0	0	0	0	0	0	0
Round Island	4-Feb-09	0	0	0	0	0	0	0	0
Locker Island	5-Feb-09	0	1	0	0	0	0	0	0
Mainland (Locker Pt/Urala)	5-Feb-09	0	0	0	0	0	0	0	0
SW Twin Island	6-Feb-09	0	0	0	1	0	0	0	0
Mainland (Onslow back beach)	6-Feb-09	0	0	0	0	0	0	0	0
Mainland (Coolgara/Beadon Ck)	6-Feb-09	0	0	0	0	0	0	0	0
Ashburton River Delta(2)	6-Feb-09	0	0	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

Appendix 4: Census Survey: First day line-in survey: Tracks

First Day Line In		Date	Tracks below high tide line			Activity above last high spring tide		
Location	Flatback		Green	Hawksbill	Flatback	Green	Hawksbill	
Ashburton Island	3	0	0	0	78	0	0	
Thevenard (North)	0	0	0	0	0	93	0	
Thevenard (South)	0	0	0	0	63	4	0	
Bessieres Island	0	0	0	0	4	181	0	
Ashburton Island	22	0	0	0	0	0	0	
Thevenard (North)	0	26	0	0	0	0	0	
Thevenard (South)	0	0	0	0	0	0	0	
Bessieres Island	0	22	2	0	0	3	0	
Mainland Beach 1	0	0	0	0	0	0	0	
Mainland Beach 2	0	0	0	0	0	0	0	
Mainland Beach 3	0	0	0	0	0	0	0	
Mainland Beach 4	0	0	0	0	18	0	0	
Mainland Beach 5	0	0	0	0	0	0	0	
Mainland Beach 6	0	0	0	0	0	0	0	
Mainland Beach 7	0	0	0	0	0	0	0	

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 5: Census Survey: First day line-in survey: Nests and inwater sightings

First Day Line in Location	Date	Hatched nests			Juveniles in water			Adults in water		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	4	0	0	0	0	0	0	0	0
Thevenard (North)	25-Jan-09	0	0	0	0	0	0	0	0	0
Thevenard (South)	25-Jan-09	0	0	0	0	0	0	0	0	0
Bessieres Island	25-Jan-09	0	1	0	0	0	0	0	0	0
Ashburton Island	31-Jan-09	2	0	0	0	0	0	0	0	0
Thevenard (North)	30-Jan-09	0	0	0	0	0	0	0	0	0
Thevenard (South)	30-Jan-09	0	0	0	0	0	0	0	0	0
Bessieres Island	30-Jan-09	0	2	0	0	0	0	0	0	0
Mainland Beach 1	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7	3-Feb-09	0	0	0	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

Appendix 6: Census survey Islands: Tracks

Location	Date	Tracks below high tide line			Overnight activity (X-line)		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island 1	1-Feb-09	0	0	0	0	0	0
Ashburton Island 2	2-Feb-09	0	0	0	0	0	0
Ashburton Island 3	3-Feb-09	0	0	0	0	0	0
Thevenard Island (North) 1	31-Jan-09	0	0	0	0	0	0
Thevenard Island (North) 2	1-Feb-09	0	0	0	4	0	0
Thevenard Island (North) 3	2-Feb-09	0	0	0	2	0	0
Thevenard Island (South) 1	31-Jan-09	0	0	0	2	0	0
Thevenard Island (South) 2	1-Feb-09	0	0	0	0	0	0
Thevenard Island (South) 3	2-Feb-09	0	0	0	0	0	0
Bessieres Island 1	31-Jan-09	0	0	0	0	4	0
Bessieres Island 2	1-Feb-09	2	0	0	0	4	0
Bessieres Island 3	2-Feb-09	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 7 Census survey Islands: Nests and Inwater sightings

Location	Date	Hatched nests			Juveniles in water			Adults in water		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island 1	1-Feb-09	0	0	0	0	1	0	0	0	0
Ashburton Island 2	2-Feb-09	0	0	0	0	4	0	0	0	0
Ashburton Island 3	3-Feb-09	0	0	0	0	4	0	0	0	0
Thevenard Island (North) 1	31-Jan-09	0	0	0	0	2	0	0	0	0
Thevenard Island (North) 2	1-Feb-09	0	0	0	0	0	0	0	0	0
Thevenard Island (North) 3	2-Feb-09	0	0	0	0	0	0	0	0	0
Thevenard Island (South) 1	31-Jan-09	0	0	0	0	14	0	0	0	0
Thevenard Island (South) 2	1-Feb-09	0	0	0	0	0	0	0	0	0
Thevenard Island (South) 3	2-Feb-09	0	0	0	0	8	0	0	0	0
Bessieres Island 1	31-Jan-09	0	1	0	0	0	0	0	0	0
Bessieres Island 2	1-Feb-09	0	1	0	0	1	0	0	0	0
Bessieres Island 3	2-Feb-09	1	1	0	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

Appendix 8: Census survey: Mainland beaches: Tracks

Location	Date	Tracks below high tide line			Overnight activity (X-line)		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Mainland Beach 1 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 1 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 1 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 2 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 2 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 2 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 3 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 3 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 3 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 4 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 4 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 4 Day 3	6-Feb-09	0	0	0	6	0	0
Mainland Beach 5 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 5 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 5 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 6 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 6 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 6 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 7 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 7 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 7 Day 3	6-Feb-09	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 9: Census survey: Mainland beaches: Nests and inwater sightings

Location	Date	Hatched nests			Juveniles in water			Adults in water		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Mainland Beach 1 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 1 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 1 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

Appendix 10: Nest Fan survey results

Location	Species	Date	Fan A	Fan B	Fan X	Bisect Angle	Fan Angle	Offset
Ashburton Island	Flatback	25-Jan-09	127	19	75	73	108	2
Ashburton Island	Flatback	25-Jan-09	91	2	45	46.5	89	1.5
Ashburton Island	Flatback	25-Jan-09	256	180	200	218	76	18
Ashburton Island	Flatback	25-Jan-09	116	204	174	160	88	14
Ashburton Island	Flatback	25-Jan-09	173	128	165	150.5	45	14.5
Ashburton Island	Flatback	25-Jan-09	115	159	139	137	44	2
Bessieres Island	Green	25-Jan-09	111	79	90	95	32	5
Bessieres Island	Green	30-Jan-09	65	79	92	72	14	20
Bessieres Island	Green	31-Jan-09	62	103	62	82.5	41	20.5
Bessieres Island	Green	1-Feb-09	68	107	89	87.5	39	1.5
Bessieres Island	Green	2-Feb-09	40	102	75	71	62	4
Bessieres Island	Flatback	2-Feb-09	59	120	89	89.5	61	0.5
Locker Island	Flatback	5-Feb-09	152	295	242	223.5	143	18.5
Locker Island	Flatback	5-Feb-09	205	245	225	225	40	0
Locker Island	Flatback	5-Feb-09	227	286	258	256.5	59	1.5
Locker Island	Flatback	5-Feb-09	248	268	262	258	20	4
Locker Island	Flatback	5-Feb-09	In all directions		290	NA		
Mainland Beach 4	Flatback	6-Feb-09	313	340	322	326.5	27	4.5

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 11 Hatching success

Location	Date	Species	Latitude	Longitude	Hatched Shells	Undeveloped	Embryo	Full term	Pipped dead	Pipped alive	Total Eggs	Hatched %
Ashburton	25-Jan-09	FB	21.59425	114.93650	30	2	1	1	1	0	35	85.71
Thevenard	30-Jan-09	GR	21.45506	114.97728	87	2	0	0	15	0	104	83.65
Ashburton	31-Jan-09	FB	21.59356	114.93792	37	4	1	0	0	0	42	88.10
Bessieres	1-Feb-09	GR	21.52709	114.76593	102	1	0	0	1	0	104	98.08
Bessieres	2-Feb-09	GR	21.52837	114.76593	105	6	0	1	0	2	114	92.11
Bessieres	2-Feb-09	FB	21.52652	114.76597	53	5	1	2	2	1	64	82.81
Locker	5-Feb-09	FB	21.71922	114.76631	46	1	0	0	0	0	47	97.87
Locker	5-Feb-09	FB	21.71899	114.76610	42	3	0	6	0	0	51	82.35
Locker	5-Feb-09	FB	21.71758	114.76541	45	4	0	1	0	0	50	90.00
Locker	5-Feb-09	FB	21.71778	114.76556	50	0	0	1	0	0	51	98.04
Locker	5-Feb-09	FB	21.71448	114.76556	47	12	0	0	0	0	59	79.66
Beach 4	6-Feb-09	FB	21.68611	114.94871	11	3	2	27	4	0	47	23.40

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

Appendix 12 Turtle nesting per night from census line counts

Census Beach	Mean Flatbacks per transect per night	Mean Greens per transect per night	Mean Hawksbills per transect per night	Transect Length (km)	Mean Flatbacks per km per night	Mean Greens per km per night	Mean Hawksbills per km per night
Ashburton	1.63	0	0	0.5	3.26	0	0
Thevenard North	0.43	1.86	0	0.5	0.86	3.72	0
Thevenard South	0.29	0	0	0.5	0.58	0	0
Bessieres	0.14	2.14	0.14	0.31	0.46	6.90	0.46
Mainland Beach 1	0	0	0	0.5	0	0	0
Mainland Beach 2	0	0	0	0.5	0	0	0
Mainland Beach 3	0	0	0	0.5	0	0	0
Mainland Beach 4	0	0	0	0.5	0	0	0
Mainland Beach 5	0	0	0	0.5	0	0	0
Mainland Beach 6	0	0	0	0.5	0	0	0
Mainland Beach 7	0	0	0	0.5	0	0	0

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Appendix 09

Possible Effects of Underwater Noise on Marine Fauna
and Fish in the Wheatstone Project Area

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Appendices

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Report

Possible Effects of Underwater Noise on Marine Fauna and Fish in the Wheatstone Project Area.

5 MAY 2010


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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 at a site 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, as the Project matures, from 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 WA level of assessment was set at Environmental Review and Management Programme (ERMP) and the Commonwealth level at Environmental Impact Statement (EIS).

The investigations outlined in this report have been conducted to support the environmental impact assessment process. The present report is a desktop study of underwater noise that will be generated by the project and its possible impacts on species of protected marine fauna and fish groups in the Project Area.

The Integrated Marine and Coastal Regionalisation of Australia (IMCRA) is a national spatial framework that classifies Australia's marine environment into bioregions that make sense ecologically and are at a scale useful for regional planning. The Wheatstone Project occurs in three IMCRA regions:

- Pilbara Nearshore Region;
- Pilbara Offshore Region; and
- North West Shelf.

Fauna and Fish Species Considered

Protected faunal species examined as part of this assessment were:

- humpback whale (*Megaptera novaeangliae*);
- blue whale (*Balaenoptera musculus*);
- pygmy blue whale (*B. musculus brevicauda*);
- dugong (*Dugong dugon*);
- green turtle (*Chelonia mydas*);
- leatherback turtle (*Dermochelys coriacea*);
- flatback turtle (*Natator depressus*);
- loggerhead turtle (*Caretta caretta*);
- hawksbill turtle (*Eretmochelys imbricata*); and
- whale shark (*Rhincodon typus*).

Fish were assessed in the following ecological groupings:

- cartilaginous fish (sharks, skates and rays);
- demersal teleosts (e.g. groper, cods, emperor, snapper);
- pelagic teleosts (e.g. mackerel); and
- prawns (specifically banana prawns [*Penaeus merguensis*]).

Executive Summary

Construction noise

Most of the noise generating activities, including those likely to produce the most noise, will occur in the Pilbara Nearshore Region during the construction phase of the Project. The most significant noise effects are as follows:

- Pile driving is likely to have the greatest potential impact upon marine fauna and fish due to its intense, repetitive nature. There are no known concentrations of protected species of marine fauna or fish in the Project area, particularly in the nearshore areas where pile driving may be proposed. Any effects from pile driving are likely to be behavioural disturbances, which may be more acute during the initial start up phase. Such impacts are likely to be more significant if activities coincide with key biological functions. However, as no significant habitat has been identified in the project area, including minimal marine fauna sightings adjacent to the proposed LNG Plant, it is unlikely any significant impacts would be posed by such activities.
- Dredging for the proposed navigation channel is the other major, and longer term, noise generating activity which will occur in the Pilbara Nearshore Region. While this activity may cause general disturbance to fauna and fish, resulting in avoidance of the area, impacts are not expected to be enduring or significant. The fact that no significant habitat exists in the area, coupled with other available habitat for refuge, suggests impacts from this activity will be minimal.

Potential impacts to marine fauna and fish in the Pilbara Offshore Region and the North West Shelf during the construction phase are likely to be associated with general disturbance behaviour. Small scale seismic activities, such as Vertical Seismic Profiling, will potentially generate louder noises (e.g. ~190 dB centred around 200 Hz), but these activities will be localised and temporary; therefore potential impacts are considered low. In particular, risks associated with baleen whales are unlikely to be significant given the area is not known to be used for breeding, calving or resting.

Operational noise

During the operational phase, the primary noise generating activities in all areas will be from increased vessel movements. Although this may result in localised, transient disturbance to some individuals, it is likely that impacts will be minimal, with individuals/populations potentially becoming habituated to the noise from vessels.

Introduction

Chevron Australia Pty Ltd (Chevron) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant 12 km south west of Onslow on the Pilbara coast (see Figure 1 1). The LNG and Domgas plants will initially process gas from fields located approximately 200 km offshore from Onslow in the West Carnarvon Basin (Figure 1 1) and, as the Project matures, from 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 the Environment, Water, Heritage and the Arts (DEWHA). The WA assessment level was set at Environmental Review and Management Programme (ERMP) and the Commonwealth level was set at Environmental Impact Statement (EIS).

The subsequently approved Environmental Scoping Document for the Wheatstone Project proposed that an assessment of marine noise emissions be undertaken for potential impacts arising from construction and operational activities using the risk assessment approach. The scoping document ranked the risk to protected marine fauna from underwater noise as low, with potential impacts related to general avoidance and behavioural effects. This conclusion was based on a reasonable level of confidence, noting that the key uncertainties related to the presence or absence of critical habitat for protected marine fauna and whether the nearshore waters are important as migratory pathways or foraging areas.

This report presents the assessment of marine underwater noise as proposed in the Scoping Document.

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1 Introduction

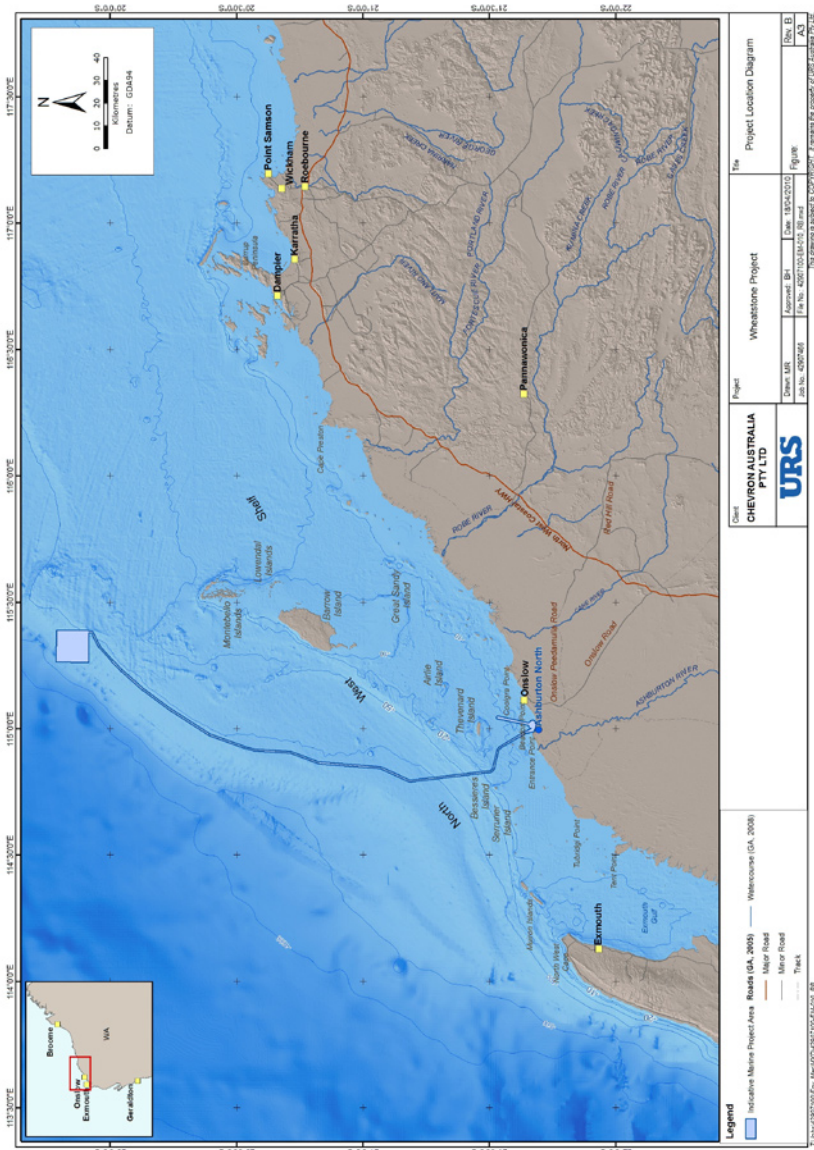


Figure 1-1 Location of the Wheatstone Project.



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Methods

2.1 Selection of Species for Assessment

2.1.1 Marine Fauna

URS (2009) undertook an analysis of marine fauna in the Wheatstone Project Area. 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
- 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 breviceauda* [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 will be considered further as its distribution in the Pilbara region is poorly understood.
- Five species of turtles are found in the Pilbara region (green turtle [*Chelonia mydas*], leatherback turtle [*Dermochelys coriacea*], flatback turtle [*Natator depressus*], loggerhead turtle [*Caretta caretta*], and hawksbill turtle [*Eretmochelys imbricate*]). Leatherback and loggerhead turtles are listed as endangered under the EPBC Act while the remaining species are listed as vulnerable. All species except the loggerhead are known to breed in the region. All species are listed as migratory under the EPBC Act (Cth) as well as being listed under CITES.
- 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 is also further considered.

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2.1.2 Fish

In their response to the Environmental Scoping Document, the DoF requested that the noise assessment include impacts on fish in the Project Area. As fish have not been included in most previous assessments of the effects of noise from LNG developments, there is little information available on the subject in Western Australia. Previous assessments have concentrated on fish that are protected under the EPBC Act or fisheries legislation. In the absence of information on other fish, the present project has identified a series of fish groups for consideration of the potential impacts of noise. Methods used to determine which fish to consider are described below:

- The URS (2009) desktop study found one species of significant conservation value in the region, the whale shark (*Rhincodon typus*). This species is included in the assessment.
- Onslow is a popular recreational fishing area in winter, with both intrastate and interstate tourists. There is little information on the amount of recreational fishing that occurs in the Pilbara, but it is thought to be less than 2% of the total catch (Fletcher and Santoro 2009). Commercial and recreational fishers both target a variety of species that encompass a wide taxonomic spectrum of fish, including both bony (teleost) fishes such as mackerel, snapper, groppers, etc. and cartilaginous (elasmobranch) fishes such as sharks.
- There is considerable overlap between the prime scalefish species targeted by the Pilbara Fish Trawl (Interim) Managed Fishery, Pilbara Trap Managed Fishery and the Mackerel Managed Fishery. There is good information on the commercial fisheries, but all of the scalefish fisheries are small in the Wheatstone Project Area. In the absence of major scalefish fisheries in the region, biologically relevant fish groups were selected for assessment. These were:
 - Cartilaginous fish (sharks, skates and rays) are biologically different from teleost (bony) fishes and are high level predators.
 - Demersal teleosts (e.g. groppers, cods, emperor, snapper) live in close association with the sea floor, and may be associated with coral reefs, rock outcrops, etc. Some of these fish, such as coral trout (*Plecotromus*), are territorial and may be unlikely to move away even if affected by underwater noise.
 - Pelagic teleosts (e.g. mackerel) live in the water column. They are mobile species that congregate near coral reefs, rock outcrops, etc. and will readily move if they are disturbed in an area.
- The Onslow Prawn Managed Fishery (ONPMF) is the largest fishery in the region (URS 2009a). Although catches vary substantially between years and have been poor in recent years, the banana prawn (*Penaeus merguensis*) is the major species caught in the ONPMF. Area 1 of the ONPMF, which includes the Wheatstone Project Area, is where banana prawn catches are concentrated. The possible effects of underwater noise on prawns are included in the assessment.

2.2 Delineation of Assessment Area

To enable a meaningful assessment of the effects of noise, the Project Area has been divided into three regions using the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) (Figure 2 1). IMCRA is a national spatial framework that classifies Australia's marine environment into bioregions that make sense ecologically and are at a scale useful for regional planning. The North West Shelf IMCRA Province is divided into three regions (Commonwealth of Australia 2006):

- Pilbara Nearshore Region;
- Pilbara Offshore Region; and

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- North West Shelf.

The Pilbara Nearshore Region is restricted to a depth of 10 m or less (Figure 2 1). Most of the marine Wheatstone Project construction activities will be along the shoreline and extend into the nearby shallow waters, but the proposed shipping channel will extend approximately 20 km into slightly deeper waters. To make the discussion of this document more biologically meaningful, the slightly deeper parts of the access channel and the spoil grounds are included in the Pilbara Nearshore Region.

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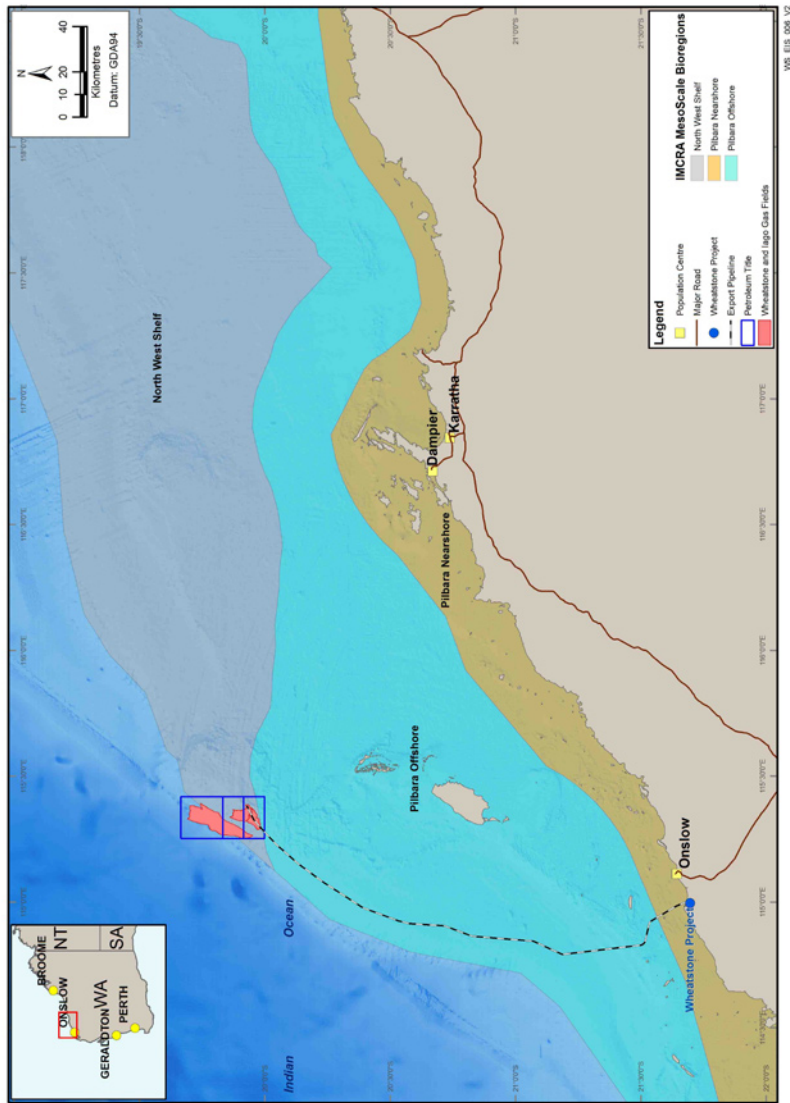


Figure 2-1 Noise assessment area of the Wheatstone Project.

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Marine Fauna & Fish

3.1 Protected Marine Fauna

As described in Section 2, the following species of marine fauna were examined in detail in the Wheatstone Project Area:

- humpback whale (*Megaptera novaeangliae*);
- blue whale (*Balaenoptera musculus*);
- pygmy blue whale (*B. musculus brevicauda*);
- dugong (*Dugong dugon*);
- green turtle (*Chelonia mydas*);
- leatherback turtle (*Dermochelys coriacea*); and
- whale shark (*Rhincodon typus*).

3.2 Fish Groups Considered

The possible effects of noise generated by the Wheatstone Project will be examined for the following fish groups:

- cartilaginous fish (sharks, skates and rays);
- demersal teleosts (e.g. gropers, cods, emperor, snapper);
- pelagic teleosts (e.g. mackerel); and
- prawns (specifically banana prawns).

3.3 Distribution

Table 3 1 summaries the distribution of protected marine fauna and fish groups in the project area. Nearshore Pilbara species are assumed to be more likely to be affected by noise and have been shaded in grey.

Table 3-1 Distribution of protected marine fauna and fish groups in the Wheatstone Project Area.

Fauna and Fish	Pilbara Nearshore Region	Pilbara Offshore Region	North West Shelf
Protected Marine Fauna			
Humpback whales	Seasonal	Seasonal	Seasonal
Blue whales			Seasonal
Pygmy blue whales			Seasonal
Dugongs	Year round	Year round	
Green turtles	Year round (seasonal nesting)	Year round (seasonal nesting)	
Flatback turtles	Year round (seasonal nesting)	Year round (seasonal nesting)	
Whale sharks			Seasonal
Fish Groups			
Cartilaginous fish	Year round	Year round	Year round
Demersal teleosts	Year round	Year round	Year round
Pelagic teleosts	Year round	Year round	Year round
Prawns	Seasonal		

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Underwater Noise

4.1 Introduction

It is important to understand that noise in water behaves differently than it does in air. Although sound in air or water is fundamentally the same phenomenon, the measurement and assessment of sound in water employs different units and exhibits some unique properties that make direct comparison with sound in the air incorrect. This section provides a general understanding of underwater noise, and an overview of how sound behaves and is measured in water compared with that of sound in air.

When considering underwater noise and potential impacts to marine fauna and fish, it is also important to gain an understanding of what species can hear, including the frequencies at which hearing sensitivity is greatest. This is crucial, as a species' ability to hear a particular noise will be an important factor when considering significance of potential effects.

4.2 Sound

Sound is generated by the vibration of an object. It is a form of wave energy that can travel through any elastic material such as air, water or rock. Sound travels by vibrating the medium through which it is propagated. The medium's vibration (oscillation) is the back and forth motion of its molecules parallel to the sound's direction of travel, thereby causing a corresponding increase then decrease to the medium's pressure, i.e. barometric pressure for sound in air and hydrostatic pressure for sound in water. Sound is manifested by two physical effects, acoustic pressure (force per unit area) and particle velocity (length per unit time plus amplitude and direction).

Most sounds are complex composites that have their power distributed over a band of frequencies that form its spectrum. If the frequency spectrum of a particular sound received by an animal has peaks within its audible frequency band, the sound will be able to be heard by the animal. However, the sound will not be heard if the amplitude of the peaks is too small to overcome the threshold of hearing at the frequency and/or the masking effect of ambient background noise and/or other sounds.

Ambient noise from multiple sources, such as a busy harbour, is a complex composite which causes the apparent level of other arriving sounds to drop. This is due to the increased average background pressure. Ambient noise is generated in the oceans by a variety of natural (both physical and biological) and anthropogenic sources, as outlined below.

4.2.1 Natural Sources of Sound

Physical sources include: Subterranean vents, tremors, earthquakes, eruptions, sediment slumps and other tectonic activity; lightning strikes, thermal noise, ice cracking, wind waves, surf, rainfall and tidal turbulence.

Biological sources include: Sea urchins, snapping shrimp, sciaenid croakers (jewfish, mullet, etc.), other fish choruses, high frequency whistles and echolocation clicks (dolphins and other toothed whales), low frequency vocalisations (great whales, including near-infrasonic calls from rorqual species) and other biotic sources.

The primary sources of physical and biological noise, with a general comparison against anthropogenic sources, are shown in Figure 4 1 (compiled by Wenz 1962; reproduced from Richardson *et al.* 1995). The frequency ranges and source levels of common natural physical and biological sources of relatively intense, persistent and/or frequent noise are also shown in Table 4 1 (Siomn *et al.* 2003).

4 Underwater Noise

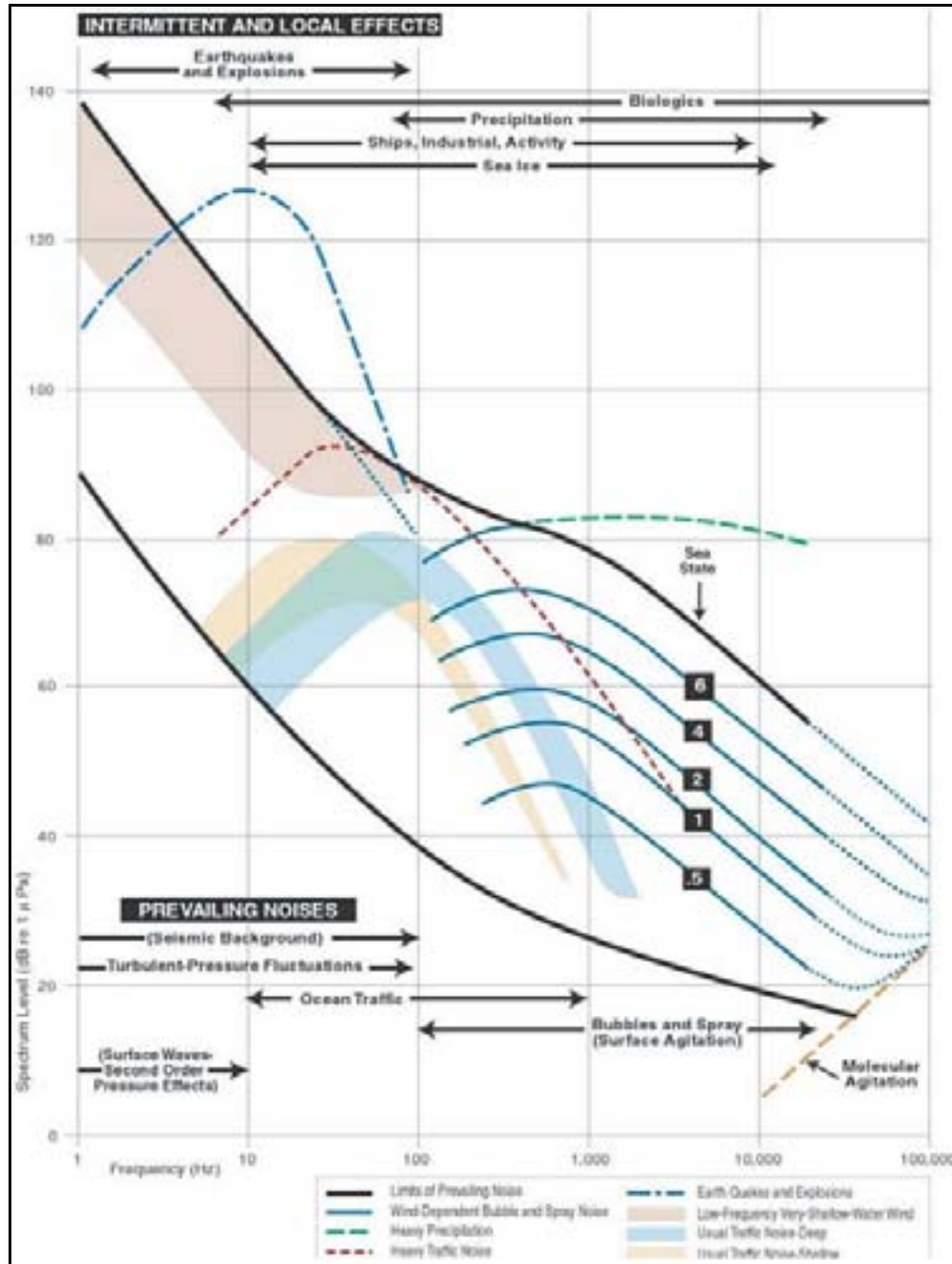


Figure 4-1 Generalised ambient noise spectra attributable to natural and anthropogenic sources.

Effects of Underwater Noise on Marine Fauna

4 Underwater Noise

Table 4-1 Examples of intense natural sound sources.

Source Type	Location or Timing	Perceived Direction	Periodicity	Frequency Range (Hz)	Source Level*
Tectonic quakes, tremors, eruptions	Unpredictable	Seafloor or circumferential	Sudden irregular transients (2-20 mins)	LF (10-100)	220-250
Lightning	Unpredictable	Surface	Sudden short pulses	Broadband	~260
Breaching and fluke slapping	Variable	Surface	Sudden pulse	Broadband	170-190
Baleen whale songs and moans	Variable	Variable	Variable continuous or transients	LF – MF + harmonics	170-195
Delphinid whistles and squeals	Variable	Variable	Mostly anticipated transients	HF-VHF (>10 kHz)	180-195
Sperm whale clicks, codas and creaks	Variable	Variable	Mostly anticipated transients	HF	180-235
Toothed whale echolocation sonar	Variable	Variable	Mostly anticipated pulses or click bursts	HF-VHF (>10 kHz)	190-232
Sea ice noise	Surface	Multiple surface points	Variable transients	Broadband	120-190
Rough sea condition and rain	Surface	Background	Irregular, continuous	Broadband	80-120*
Tide turbulence and saltation	Seafloor	Background	Regular, continuous	Broadband	80-120*
Fish choruses	Variable	Stationary / background	Regular, continuous	LF and MF/HF tonals	80-120*
Snapping shrimps	Seafloor	Stationary / background	Regular, continuous	LF-MF	80-120*

* dB = Decibel: a logarithmic unit of sound intensity. Unless otherwise stated, all dB levels in this report are dB re 1 μ Pa. (re uPa at 1 m) peak-peak.

4.2.2 Anthropogenic Sources

The main anthropogenic sources of noise in the marine environment include trading, working and recreational vessels, dredging activities, drilling and pile-driving programs, use of explosives, sonar (including depth sounders, fish finders and acoustic deterrents), geophysical sonar and noise from low flying aircraft and helicopters.

Typical frequency ranges of anthropogenic noise sources are shown in Table 4 2 (NRC 2003).



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Table 4-2 Typical frequency ranges of anthropogenic noise sources.

Frequency Band	Principal Contributors
<10 Hz	Ship propeller blade and shaft rotation, seismic surveys, explosives, aircraft sonic booms
10-100 Hz	Distant ships, explosives, seismic surveys construction and industrial activities
100-1,000 Hz	All sources of the 10-100 Hz band plus nearby ships cavitation, launches and other small craft, seismic airgun arrays, low frequency active sonar
1,000-10,000 Hz	Shipping sources (close range) plus outboard powered boat, military tactical sonars, seafloor profilers, dept sounders
10,000-100,000 Hz	Mine-hunting sonar, fish finders, some hydrographic surveys
>100,000 Hz	Mine-hunting sonar, fish finders, high-resolution seafloor mapping (side-scan sonar), some depth sounders, some oceanographic and research sonar for small-scale oceanic features, some hydrographic survey systems (Acoustic Doppler Current Profilers)

4.3 Hearing

As different groups and species of animals are able to hear different sounds, it is important to know the range of sounds heard by the various species that may be affected by anthropogenic noise in the Wheatstone Project Area. A noise that may disrupt the activities of one species may not be heard at all by a different group of animals.

The ability of animals to hear a sound is related to the amplitude of the received pressure waves and their frequency in relation to the hearing range of the animal. 'Noise' is any audible sound, i.e. its frequencies lie within, or at least overlap, the sonic (or 'hearing') range of animals. 'Signal' refers to a distinct or interpretable sound (i.e. conveys potential meaning).

The hearing process in both air and water depends on:

- the characteristics of the sound produced by its source;
- changes to sound characteristics as the sound moves away from the source;
- the auditory properties of the receiver; and
- the amount and type of ambient noise.

To humans ultrasonic (>20 kHz) and infrasonic (<20 Hz) sounds are inaudible. However, ultrasonic sounds can be heard by some seals, dolphins and other toothed whales, while infrasonic sounds can be detected by manatees and probably some of the larger baleen whales.

Whether or not a transmitted sound is eventually detected by a distant whale or turtle also depends on the animal's sensitivity to the frequency peaks within the arriving sound and the strength of these peaks relative to the ambient background noise. Whether or not a detectable sound is consciously noticed by an animal and elicits a response depends on the degree of processing (decoding) and interpretation applied by the auditory brain stem ('ear brain combination') and the nature of the perceived signal.

4 Underwater Noise

4.4 Hearing Capabilities of Marine Fauna

In assessing the potential effects of noise-intensive activities, it is important to compare the frequency spectrum of the noise with the known or estimated auditory range of the marine fauna and fish. A summary of the approximate auditory ranges of the marine fauna and fish is presented in Table 4 3.

Table 4-3 Approximate auditory ranges of important marine fauna.

Fauna	Auditory range
Baleen whales (e.g. blue and humpback whales)	200 Hz–10,000 Hz
Toothed whales (e.g. dolphins)	40-75 Hz up to 105,000–150,000 Hz
Sirenians (manatee and dugong)	400 Hz –46,000 Hz
Turtles	400–1,000 Hz
Sharks	20–800 Hz
Bony Fish (hearing specialists)	up to 3,000-4,000 Hz
Prawns	100 Hz-3,000 Hz.

4.4.1 Cetaceans

Whales, dolphins and porpoises produce and hear a wide range of sound between 10 Hz and 150 kHz. Dolphins and other toothed whales (Odontoceti) typically produce most of the higher frequency (>5 kHz) calls, whistles and echolocation pulses, the exception being male humpback whale songs. Baleen whales (Mysticeti) vocalise in the low to mid range, with the larger rorquals producing low to very low (infrasonic) frequencies (Richardson *et al.* 1995). Figure 4 2 (McCauley and Cato 2003) provides an indication of the hearing frequency range of some baleen whales and dolphins.

Hearing in the bottlenose dolphin extends from a low of 40-75 Hz to as high as 80 150 kHz. The greatest sensitivity is thought to occur in the frequency range of ~15 kHz to 50 kHz (McCauley and Salgado Kent 2008).

Baleen whales studied to date have inner ears that appear to be specialised for low frequency hearing. For example, Ketten (1997) deduced from comparative morphological studies of the blue whale auditory apparatus that these rorquals have good infrasonic hearing (10 20 Hz). Mathematical functions used to estimate frequency sensitivity of the humpback whale suggested a 200Hz 10kHz auditory range with maximum sensitivity between 2 6 kHz (e.g. Houser *et al.* 2001).

4 Underwater Noise

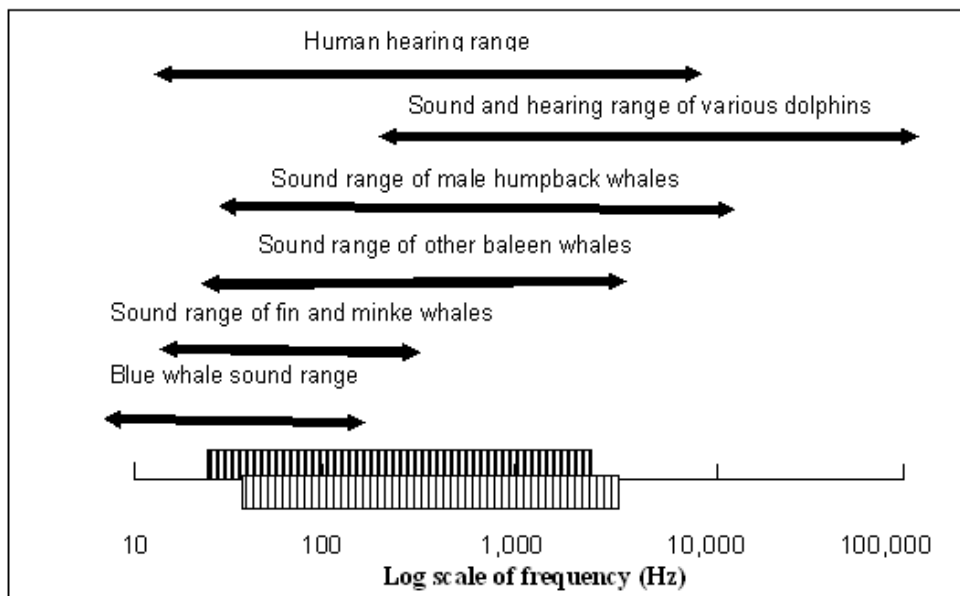


Figure 4-2 Hearing frequency range for some baleen whales and dolphins. NB: keyboard shows fundamental musical scale.

4.4.2 Dugongs

Little information is available on the auditory systems of sirenians (dugongs and manatees). Manatees have been better studied, with their auditory system described as a 'low frequency' ear with a narrow range, poor sensitivity and poor localisation ability (Richardson *et al.* 1995). It has been suggested that dugongs may have more sensitive hearing than manatees but Richardson *et al.* (1995) notes that there are no specific data to confirm this.

There are many anecdotal reports of dugongs avoiding areas with high boat traffic, but there has been little research undertaken to investigate the sensitivity of dugongs to noise. Anecdotal observations suggest dugongs may temporarily move from an area following blasting. Initial research results into auditory physiology and hearing sensitivity have highlighted significant anatomical differences between manatees and dugongs, as well as between sirenians and other marine mammals (URS 2004). The sensitive parts of dugong's auditory range appear to be restricted to the middle frequencies (1-18 kHz) (URS 2004). Dugong calls are believed to be within the range of 0.5 to 18 kHz with the peak spectra between 1 and 8 kHz (Ketten 1998).

4.4.3 Turtles

Sea turtles demonstrate a startle response to sudden noises (Lenhardt *et al.* 1983; McCauley *et al.* 2000). Their auditory sensitivity is believed to be centred in the 400-1,000 Hz range, with a rapid drop off in noise perception on either side of this range. This is supported by electro physical studies which have shown that the hearing range for marine turtles is approximately 100-700 Hz (McCauley 1994).

4 Underwater Noise

The hearing range of loggerhead turtles is from 250 to 1,000 Hz (Moein-Bartol *et al.* 1999) and the maximum sensitivity of green turtles is between 300 and 500 Hz (Ridgeway *et al.* 1969).

4.4.4 Sharks

The hearing ranges in bony (teleost) fishes are better known than in the elasmobranches (sharks and rays). Audiograms have been determined for about 80 fish species versus four for sharks and rays (Casper *et al.* 2003, Mann *et al.* 2006).

The best hearing sensitivity of the sharks is in the low frequency range of 20 Hz to 800 Hz. Sharks appear to use infrasound (0.1 Hz to 10 Hz) to detect potential prey such as struggling fish (Popper and Fay 1999). Myrberg (2001) noted that many species of sharks have hearing which is highly sensitive to irregularly pulsed, low-frequency sounds, especially in the range of 20 400 Hz.

Whale Sharks

There appears to be no specific information available on the hearing abilities of whale sharks. However, the anatomy of the whale shark includes the largest inner ear known of all animals. The diameter of the semicircular canals is near the theoretical maximum dimensions for such structures (Muller 1999).

Martin (2006) noted that the large size of a whale shark's inner ear may just be due to the species' enormity, and that it may suggest that its other auditory structures are proportional. If this is the case, it is possible that their large hearing structures may be most responsive to long wavelength, low frequency sounds (Myrberg 2001). It is reasonable to assume that whale sharks have similar hearing abilities as other sharks.

4.4.5 Bony Fish

The range of sensitivity to sound among teleost (bony) fishes is immense, and partly due to the diversity of anatomical structures involved in sound detection (Popper and Fay 1999). However, all fish tested to date appear capable of performing the same basic hearing functions as other marine vertebrates, such as discriminating between sounds, determining sound direction and filtering biologically relevant signals in the presence of ambient noise (Popper *et al.* 2003).

Fish that have morphological adaptations to link their otoliths (hearing organs) to their swim bladders or have gas filled bullae are considered 'hearing specialists'. Audiograms of 'hearing specialists' show high sensitivity to sound levels as low as 60 dB across a broad frequency range. Fish of the family Clupeidae, which includes herring (i.e. *Clupea harengus*) and anchovy (*Engraulis australis*), are examples of hearing specialists and have highly specialised auditory systems (Blaxter 1980; Nedwell *et al.* 2004). Hearing specialists are thought to be able to detect signals up to 3–4 kHz, with thresholds that are 20 dB or more lower than the generalists (Popper and Hastings 2005).

Many fish have a swim bladder (rather than the bulla of Clupeidae) that is physically linked to the inner ear. The swim bladder is a gas filled cavity that can transfer an impinging sound wave's pressure information to the otolith (Popper and Fay 1993).

Fish with the bulla generally have higher sensitivity to noise than those with a swim bladder, and those with a swim bladder in turn usually have greater sensitivity than fish without a swim bladder (Nedwell *et al.* 2004).

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4.4.6 Prawns

The hearing abilities of the prawn *Palaemon serratus* have been studied by Lovell *et al.* (2004). Demonstrated hearing abilities include low frequency sounds ranging from 100 Hz to 3 kHz. It was concluded that prawns have a similar hearing acuity to that of a generalist fish (Lovell *et al.* 2004).

Potential Noise Generating Activities

This section outlines potential noise generating activities which may be associated with the Wheatstone Project and provides examples of the noise characteristics of such activities. Table 5-1 summarises the noise generating activities which may potentially occur during the construction phase of the project and where these activities may occur. The cells shown in grey in Table 5-1 highlight those activities where there may be potential for greater impact. There are currently no plans for blasting in the Wheatstone Project Area. However, blasting is included in Table 5-1 in the event that it becomes necessary.

Table 5-1 Distribution of Potential Noise Generating Activities in the Wheatstone Project Area. During the Construction Phase. Grey cells indicate activities with a greater potential for impact.

Activity	Pilbara Nearshore Region	Pilbara Offshore Region	North West Shelf
Pile Driving	X		
Dredging and trenching	X		
Rock dumping	X		
Blasting	X		
Pipelaying	X	X	X
Drilling			X
Small scale seismic survey activities			X
Vessel movements	X	X	X

Table 5-2 summarises the noise generating activities which may potentially occur during the operational phase of the project, and where these activities may occur.

Table 5-2 Distribution of Potential Noise Generating Activities in the Wheatstone Project Area. During the Operational Phase.

Activity	Pilbara Nearshore Region	Pilbara Offshore Region	North West Shelf
Pipeline operation	X	X	X
Vessel movements	X	X	X

5.1 Pile Driving

The intense pulses of pile driving have been observed to injure swim bladders and kill salmonid fishes in limited circumstances, and they have the potential to elicit a startle response in cetaceans, particularly at start up.

A study of pile driving operations to construct a new wharf in Twofold Bay, NSW provided sound data that indicated each pile driving event comprised one or two intense impulses associated with the weight dropping, followed by two to six lower level bounces of the weight. Power spectra peaked mostly between 100 Hz and 1 kHz. Individual signals typically fell by 20-30 dB between the initial drops and the last bounce. The average intensity of the signals was 167 dB at 300 m from the

5 Potential Noise Generating Activities

operation, falling to 145 dB and 136 dB at 1.8 and 4.6 km respectively. Only 6.5% of the signals from the loudest recorded operation exceeded 140 dB at a distance of 4.8 km from the source (McCauley *et al.* 2002).

Recent field measurements have been made of pile driving at Gellibrand Pier, Port Phillip Bay Victory by CMST (2009). Noise from vibratory piling ranged from 172 dB at 49 m to 150 dB at 213 m. Noise levels from impact piling ranged from 186 dB at 39 m to 165 dB at 258 m.

Modelling to determine zones of physical and behavioural impacts on turtles was completed for proposed pile driving operations at Camp Lambert in the Pilbara (SVT 2009). Modelling was based on a physical injury threshold of 240 dB and a behavioural threshold of 120 dB for adults, and a threshold of 198 dB for potential physical damage to turtle hatchlings. Modelling concluded that potential injury to adult and juvenile turtles may occur within 10 m close to shore up to within 25 m at the end of the proposed jetty. Zones of avoidance were predicted to occur within a range of 300-400 m. Potential physical injury or hearing damage to turtle hatchlings was predicted to occur within a range of 400 m for operations close to shore and 600 m for operations at the end of the jetty (SVT 2009).

Pile driving in estuaries and waterways in British Columbia has been observed to cause salmon mortalities. The impacts of pile driving projects and the mitigating value of noise reducing bubble curtain rings were examined by the Canadian Department of Fisheries and Oceans (Vagle 2003). Their preliminary studies of four pile driving projects in the Vancouver region showed that:

- the intensity and frequency spectra generated from each project site, pile and hammer strike varied markedly with the pile driving equipment used (e.g. diesel hammering versus 1 tonne or 3.5 tonne drop weight hammers), the hammer drop height (1 to 7 m), the use of a wood block shock absorber, the material, diameter and design of the pile, the depth driven, and the type and density of the seabed strata;
- impulses needed to exceed 30 kPa to induce observable changes to fish movements and density; fatal swim bladder injuries to fish occurred with 120-150 kPa impulses;
- small bubble/low supply volume curtains attenuated sound levels by between 8-20 dB in the 50-1,000 Hz range, and by 18-30 dB in the 10-20 kHz range, while large bubble/high supply volume designs produced little effect;
- the efficiency of bubble curtains decreased with increased bubble ring depth and larger bubble sizes became agglomerated 'blobs' of air separated by large gaps;
- bubble curtain rings and apertures require careful maintenance to prevent gaps and 'holes' in the bubble screen from uneven bubble distribution, while tidal currents readily cause asymmetric distortions to the curtains.

5.2 Dredging and Trenching

Sound levels from some large trailer suction hopper dredges (TSHD) operating in rocky areas have been recorded in excess of 150 dB at 1 km, while large cutter suction dredges (CSD) can emit strong tones that are audible 20 to 30 km away (Richardson *et al.* 1995; Dames & Moore 1996). Underwater noise levels from self-propelled hopper barges engaged in transferring dredge spoil can often be higher than the noises from the dredge itself, particularly during the loading and dumping operation of rocky material.

Recorded noise levels for large cutter suction dredgers are higher than those associated with grab dredgers. Recorded broadband noise data for the large cutter suction dredger JFJ de Nul were given

5 Potential Noise Generating Activities

as 183 dB at Sakhalin Island, 2004. Measurements of two suction dredgers, Aquarius and Beaver Mackenzie, are reported in Nedwell and Howell (2004). Their octave band spectra peak between 80 and 200 Hz, with Aquarius having the higher of the two spectra peaking at approximately 177 dB. In the 20 1,000 Hz band, Beaver Mackenzie and the Aquarius were measured to have a 133 dB level at 0.19 km and a 140 dB level at 0.2 km, respectively.

Depending on the phase of the grab-retrieve-release operation, clamshell dredges emit varying sounds, with the strongest source levels of 150 to 162 dB centred at 250 Hz. The highest levels have been shown to generate a broadband source level of 167 dB from the operation of the bucket winch (Malme *et al.* 1989).

More recently, sound levels from the large TSHD Queen of the Netherlands were recorded from dredging in Port Philip Bay. Sound levels recorded were typically in the range of 143 dB to 154 dB at 100 m from the source (Huson and Associates 2009).

5.3 Rock and Dredge Spoil Dumping

Limited information is available on noise generated from rock dumping. However, it is reasonable to expect that the noise will be dominated by the splash, tumbles and grinding of rocks, possibly associated with mechanical transient noise generated by the operating gear. Given the normal pattern of rock dumping activities, it is anticipated that any noise will be intermittent.

Noises associated with the dumping, movement and settling of the rocks would probably be low frequency broadband. The intensity and duration of the noise would be influenced by factors such as the amount, size and mass of rocks dumped, the depth of water in which they were dumped and the type of surface upon which they landed and settled. Rocks released underwater by a hopper would be expected to produce less noise as no splash would be generated. The use of fall pipes would also produce minimal splash but increased noise would occur from the banging and clatter of rocks inside the pipe.

As dredge spoil is usually semi-fluid it's dumping is unlikely to generate any tangible noise. The operation may also have transient mechanical noise caused by the operation of bottom hopper doors if they are used. It is illustrative to consider the noise associated with the operation of a clamshell dredge. Richardson *et al.* (1995) described noise from a clamshell dredge as variable depending on the operating status. The strongest sounds were usually from the winch motor pulling a loaded clamshell back to the surface. This noise had a broadband source level of ~167 dB and included a fundamental tone of 125 Hz with many harmonics. Richardson *et al.* (1995) also noted that noise from the tug and barge used to transfer dredged material was greater than that produced by the dredge itself.

5.4 Pipelaying

Noise from marine pipelaying will vary in intensity and character. Most of the noise during pipelay is caused by the operation of the pipelay and support vessels, particularly if dynamic positioning vessels are employed, and allied construction tasks such as trenching and rock armour dumping (Shapiro and Associates 2004). Some noise will be generated by the movement and placement of the pipe, but this is likely to be transitory, and will depend on the size and type of pipe and method of placement.

5 Potential Noise Generating Activities

5.5 Drilling

Most of the source of noise during drilling is from the rig tenders, rather than the drilling rig or drilling operation. Drilling noise is generally low level, low frequency and continuous, with most below 1 kHz. Richardson *et al.* (1995) reported that near field measurements from four bottom-founded drilling platforms were in the order of 119 to 127 dB.

5.6 Small Scale Seismic Activities

Small scale seismic activities, for example Vertical Seismic Profiling (VSP), produce significantly less noise than large scale offshore seismic surveys. Offshore seismic surveys generally consist of up to 20 air guns, each operating at around 2,000 psi and expelling a volume of air of 4,000 cubic inches (cui). At the source, pulses are between 220-240 dB, typically reducing to 170-180 dB within 1 km and approximately 150 dB within 10 km. This compares to VSP, which is undertaken in a hole or well and may only use a two to three airgun cluster. Each airgun in VSP operates at around 2,000 psi, but only expels approximately 150 cui, creating a far smaller pressure pulse. The airgun cluster will typically be fired at intervals of 6-10 seconds, generating a sound of approximately 190 dB, with a frequency typically centred around 200 Hz.

5.7 General Vessel Movements

Surface shipping is the most widespread source of low frequency (<1,000 Hz) marine anthropogenic noise (Richardson *et al.* 1995; Simmonds and Hutchinson 1996; Popper *et al.* 1998). Ships generate substantial broadband noise from their propellers, engines, auxiliary machinery, gear boxes and shafts, plus their hull wake and turbulence. Diesel engines produce more noise than steam or gas turbines, but most long distance, low frequency noise is generated by the propeller.

Propeller noise originates from the propeller blade cavitation that forms gas-filled cavities whenever the pressure of the water accelerating over the face and any rough edges on each blade falls below critical values (propeller blades 'suck' ships forward by the very low pressures generated on their forward faces, and these rapid pressure falls cause the 'boiling' effect evident in ship's wake). Intense broadband sound is created when the bubbles subsequently collapse in either a turbulent stream or against the surface of the propeller. Cavitation noise is directly related to vessel speed; the faster the propeller rotates, the more cavitation plus the larger the wake, in which further air bubble generation and collapse occur.

For ships with constant pitch propellers, the intense 'hissing' noise begins above the cavitation inception speed (typically 7-14 knots for most merchant ships). For tugs, rig supply tenders and dynamically-positioned drilling ships equipped with variable pitch propellers, and/or thrusters, cavitation noise occurs at both low and high speeds, with cavitation-free speeds often restricted to the 7-10 knot range. Propeller blades also generate the distinct 'blade rate' tones that are proportional to the rotation rate of the propeller. 'Singing' propellers are not uncommon but are usually restricted to a narrow band of the vessel's overall speed range.

The key noise spectrum from merchant ships is typically 20-500 Hz with tonal peaks at approximately 50-60 Hz, often referred to as 'far field noise'. These low frequency noise components significantly contribute to the amount of low frequency ambient noise, particularly in regions with heavy ship traffic. Ship noise therefore needs to be treated in two categories: noise from nearby ships and that from distant traffic. Noise from nearby shipping is usually readily discernible as coming from an individual

5 Potential Noise Generating Activities

vessel, with each ship producing a specific noise signature often referred to as 'near field noise'. The sound level and frequency characteristics ('signature') of ships depend on their size, number of propellers, number and type of propeller blades, blade biofouling condition and machinery/transmission maintenance condition. In general, the larger the ship, the louder the source level and the lower its tonals. Ships also produce cavitation noise typically in the region of 500Hz 3kHz, depending on the size of the vessel.

Energy spectra measured by the Defence Science and Technology Organisation (unpublished) from a large bulk carrier sailing into and out of the Port of Dampier, Western Australia showed peak average noise was in excess of 180 dB at a frequency of 10 Hz, with 1 kHz tones at levels of 140 150 dB.

In the case of small power craft and patrol boats fitted with large outboard motors, these can produce relatively intense sound levels, particularly when travelling at planning speed. Single or twin outboard installations are the most common type of propulsion for <7 m long power boats in Australian coastal waters, i.e. inflatables, runabouts, small cabin cruisers, recreational fishing boats and rigid-hulled inflatable boats (RHIBs), and their fast rotating external machinery and small propellers produce intense and more complex sound spectra than those of launches fitted with inboard diesels (e.g. Gordon *et al.* 1992, Richardson *et al.* 1995, Au & Green 2000). Outboard motors produce broadband noise with many strong tonals and higher harmonics to 6,000 Hz or more, with peak source levels in the 150 180 dB range. They also produce cavitation noise with a peak frequency from 1,000 6,000 Hz, and producing noise up to 20 kHz or possibly even higher.

5.8 Pipeline Operations

Movement of a fluid through an undersea pipe generates noise that is radiated into the water column beyond the pipe. Such noise is a function of several factors, such as the type of fluid, its physical characteristics, velocity through the pipe, internal diameter of the pipe, pipe length and the material from which the pipe was made. These factors, as well as any covering over the pipe, such as rock armour or bottom sediment, influence both the transmission of vibration through the pipe and its acoustic coupling with the water.

An environmental assessment for an undersea gas pipeline across Georgia Strait, in the north east Pacific, considered noise that would be generated by the pipeline. Data were obtained for an existing 250 mm epoxy coated high-pressure marine natural gas pipeline, which identified radiated sound in the range of 60 72 dB (Birch *et al.* 2000). Further modelling and analysis concluded that the larger diameter gas pipeline proposed for Georgia Strait would have a lower frequency for any given operating pressure than a smaller diameter line, with an estimated radiated noise equal to or lower than 30 dB at frequencies of 16 kHz and above (Shapiro and Associates 2004).

Marko (2003) considered sound propagation through bare and concrete coated steel plates and longitudinal pipe sections. It was demonstrated that a concrete coating on a pipe acts as an acoustic insulator and reduces radiated noise.

It is possible that a pump located on land near the marine portions of a pipeline, particularly if it exhibits a good acoustic couple with the pipeline, increase in the level of any radiated noise. The size, speed, power and other operational parameters of the pump would be the principal determinants of any subsequent radiated noise, such as frequency and level, with the key factor being whether the pump flow was to or away from the immersed section of the pipeline.

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5.9 Marine Blasting

At the time of preparation of this report (October 2009) underwater blasting was not considered likely to be part of construction activities for the Wheatstone Project. However, as unforeseen circumstances may require blasting to be used, the characteristics of blasting are discussed briefly below.

Underwater blasting is generally used for removing or fracturing rock or other hard substrate. Surface and confined blasting are the two main techniques used. Surface blasting involves charges being placed directly on to the seabed/rock. Confined blasting, sometimes known as the “drill and blast” method, involves drilling small holes within the rock, placing small charges in the holes and firing the explosive as part of a pattern.

The potential effects from the drill and blast method are likely to be less significant than those from surface blasting operations because confined blasting requires a smaller charge to break up the rock and the explosive energy is largely confined to the rock strata (ECOS 1996).

A range of explosive charges detonated at or beneath the surface during Australian Defence Force (ADF) live-fire practices and other maritime activities was reviewed by URS (2003). The size of explosive charges ranged from 0.02 kg up to 428 kg. It was found that marine fauna was at minimal risk of blast induced trauma for even the largest of these charges at distances beyond a few hundred metres.

Potential Effects on Marine Fauna

This section provides a summary of the potential risks to marine fauna and fish from anticipated noise generating activities of the Wheatstone Project. Emphasis is on species with an increased likelihood of a potential impact, due to their susceptibility to noise or their use of or presence in an area of noise generation. Appendix A provides a general assessment of construction and operational activities on fauna and fish.

6.1 Marine Fauna and Fish Species Present

At the time of preparation of this report, the Centre for Whale Research (Jenner *et al.* 2009) was conducting a series of twice monthly flights over the Wheatstone Project Area to determine the numbers, distributions and seasonality of marine fauna species in the area. Data were available for six flights made between 17 May and 23 July 2009. A summary of the data is presented in Table 6-1. Figure 6-1 shows the results for 23 July 2009, the flight with the greatest concentration of humpback whales.

Table 6-1 Marine Faunal Species Recorded in Six Flights over the Wheatstone Project Area between 17 May and 23 July 2009 (Jenner *et al.* 2009).

Species	Numbers recorded			
	Minimum	Maximum	Total	Mean ± 1 S.E.
Humpback whales	0	97	228	38.0 \pm 21.1
Blue whales	0	0	0	0 \pm 0
Pygmy blue whales	0	0	0	0 \pm 0
Dugongs	2	31	86	14.3 \pm 5.8
Turtles*	14	122	422	70.3 \pm 21.7
Whale sharks	0	1	1	0.2 \pm 0.2
Vessels	41	55	279	47.0 \pm 2.5

*The flights did not differentiate between turtle species

Information to date shows humpback whales were concentrated over the outer continental shelf and slope (Pilbara Offshore Region and North West Shelf). Only isolated individuals were found inshore of Thevenard Island. No blue whales or pygmy blue whales were recorded during the six surveys. Individual sightings of sperm (*Physeter macrocephalus*), minke (*Balaenoptera acutorostrata*) and pilot whales (*Globicephala macrorhynchus*) were made on the outer slope to the south of the Wheatstone field, outside of the Project area and the area considered by this assessment. A pair of unidentified whales, possibly Bryde's whales (*Balaenoptera edeni*), were sighted in the Pilbara Offshore Region on one occasion. A single whale shark was found well offshore in the North West Shelf region. Dugongs were widely distributed in the flight area, but there were no aggregations in the area of the proposed dredged channel or pipeline route. Turtles were common, but not concentrated in the Wheatstone area.

Also at the time of preparation of this report, the Centre for Marine Science and Technology (McCauley 2009) reported on a preliminary analysis of data collected from a series of five sea noise loggers deployed in the Wheatstone Project area. Two loggers were deployed at nearshore sites located in 10 and 43 m of water. Three loggers were deployed in a triangular pattern offshore in approximately 200 m of water (North West Shelf). Initial results noted that the songs of humpback whales featured predominantly at the 43 m (Pilbara Offshore Region) and offshore logger sites. The

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offshore noise loggers also detected pygmy blue and dwarf minke whales, although these species were not detected at the inshore sites. A call with the characteristics of a Bryde's whale signal was also detected at the 43 m inshore site on a few occasions.

Fish were not surveyed during the flights. All of the fish groups are likely to be widespread in the Wheatstone Project Area, but will be most abundant near coral reefs, bommies and rock outcrops etc. There are no major islands or reefs near the pipeline route or the channel that would attract large numbers of fish.

The numbers of vessels seen during the flights were consistent, ranging from 41 to 55 per trip, with a mean of 47.

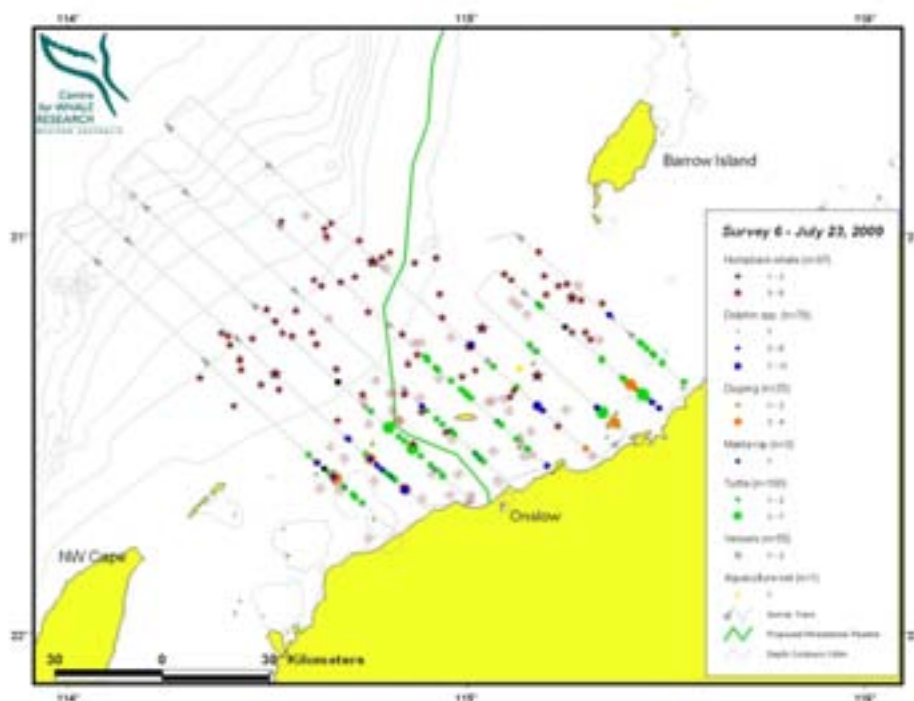


Figure 6-1 Marine Fauna Recorded in the Wheatstone Project Area on 23 July 2009 (Jenner *et al.* 2009).

There were no sightings of targeted marine fauna within the immediate area of shore based or adjacent marine infrastructure proposed for the Wheatstone Project i.e. within ~10 km of the proposed Wheatstone onshore site (See Figure 6 1 and also Figure 1 1). These initial results indicate that the immediate nearshore area contains no critical habitat for marine fauna and is not relied upon for important biological functions.

The sensitive auditory ranges of marine fauna species are compared with predicted noise frequencies during the construction and operation activities of the Wheatstone Project in Table 6-2.

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Table 6-2 Comparison of Fauna Hearing Range and Construction and Operation Noise Frequencies

Species	Activity							
	Pile Driving	Dredging/ Trenching	Rock & Spoil dumping	Drilling	Small scale Seismic activities	Large Vessel movements	Small vessel movements	Pipeline operations
Baleen whales	Orange	Orange	Yellow	Orange	Orange	Orange	Orange	Yellow
Toothed whales	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Orange
Sirenians	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow
Turtles	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green
Sharks	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green
Bony Fish	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green
Prawns	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green

Key

Yellow	Frequencies at the lower end of species' hearing sensitivity
Orange	Frequencies within species' hearing range
Green	Species unlikely to detect frequencies

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6 Potential Effects on Marine Fauna

6.2 Pilbara Nearshore Region

6.2.1 Construction Phase

Noise generated by the Wheatstone Project will be mainly concentrated in the Pilbara Nearshore Region. Intensive noise generating activities (e.g. pile driving) will be concentrated close to shore (e.g. within 1km) with a relatively small zone of influence in regard to any potential significant effects (most likely a few hundred metres). Other activities, such as dredging and pipelaying, will be less intense although more widespread. However, these activities will be temporary and transient in nature, thus limiting potential impacts.

As previously described, pile driving is likely to present the greatest risk, with its inherent repetitive, impulsive nature and the ability to cause physical damage to marine fauna and fish in some circumstances (Appendix A). Any such impacts would occur in the Pilbara Nearshore Region, within a localised area close to the actual pile driving activities (within a few hundred metres). However, potential impacts are considered low given no whales have been seen and there are no known concentrations of other protected marine faunal species within this immediate area.

Although pile driving operations may be undertaken 24 hours a day, it is reasonable to assume that not all of this time will actually be spent driving piles. There will be periods of respite between operations.

Potential effects from pile driving are most likely to be more acute during the initial start-up phase. These may be more significant if they coincide with key biological functions, such as turtle nesting and hatching periods. As no significant habitat has been identified in the vicinity of the proposed nearshore infrastructure, potential impacts posed by such activities are likely to be minimal. In addition, potential effects from pile driving would be further reduced due to the relatively high background noise levels as a result of the proximity of land and associated shore noise (e.g. from breaking waves). This is particularly true in sea conditions above approximately Sea State 3, where shore/wave noise dominate the spectrum from approximately 200Hz up to 15 kHz. Furthermore, there would be limited extended propagation of noise due to the shallow water where pile driving would occur.

The other major activity likely to occur in the Pilbara Nearshore Region is long-term dredging of the shipping channel and berthing pockets. Rock dumping will be relatively short term, but will be more episodic. Vessel movements will be continuous. Although these activities may occur for an extended period, their nature suggests that potential impacts to marine fauna and fish will primarily be general avoidance of the area. The fact that this area is believed to contain no significant habitat suggests that such general avoidance will have negligible effects. Furthermore, if such activities do disturb fauna and fish and cause them to leave the area, there are various areas nearby where refuge can be sought.

Although not anticipated at the time of this report, underwater blasting can pose a risk to marine fauna and fish. There is a risk of mortality in a relatively small area around the detonation point, with a wider, albeit relatively small (~300 500m) zone where injury is possible. Beyond the immediate vicinity of detonation there is a wider area where minor injury is also possible. However, the greatest effect from the use of explosives is likely to be the result of noise disturbance, rather than blast or impulse. If blasting is proposed, and management measures are considered necessary, it is likely that the

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implementation of marine fauna management zones around a blast source will be a successful mitigating factor.

6.2.2 Operational Phase

The primary noise generation in the Pilbara Nearshore Region during the operational phase will be vessel noise, with a relatively small portion originating from pipeline operations. Noise from large vessels will be transitory with the movement of LNG ships and other large vessels. There will also be an increase in small vessel movements.

Although it has been identified that noise from shipping and vessel traffic/movement can cause some disturbance to cetaceans, they are generally tolerant of such activities. This is demonstrated by the willingness of at least some species of dolphins to closely approach vessels.

The effects of noise from vessels associated with the Wheatstone Project are unlikely to be significant, since no critical habitat exists within the immediate nearshore area where vessel activity will be concentrated. Further, it is likely that fauna and fish within the area will already be habituated to vessel noise to at least some degree, given that fishing vessels and other support vessels operate out of nearby Onslow and within the project area. Marine fauna observation flights to date have recorded a mean of 47 vessels per flight in the region (Jenner *et al.* 2009).

6.3 Pilbara Offshore Region and North West Shelf

6.3.1 Construction Phase

There will be small scale seismic operations, such as VSP and drilling, on the gas fields in the North West Shelf area during the construction phase of the Wheatstone Project. There will also be increased vessel traffic and pipelaying in both the North West Shelf Area and the Pilbara Offshore Region.

Potential impacts to marine fauna and fish in the offshore area are likely to be general disturbance behaviour. Small scale seismic activities will generate localised transient noise. The potential impacts are considered to be insignificant.

VSP activities produce significantly less energy than large scale offshore seismic surveys, so therefore the potential effects on marine fauna and fish are considered to be much lower than those for typical offshore 3D seismic surveys. McCauley *et al.* (2000) observed that migrating humpback whales tended to avoid operating seismic sources when the received sound levels were greater than 157 164 dB. For general VSP activities, it is anticipated that levels will be below 150 dB at distances greater than 500 m from the source, and therefore present minimal risk of disturbance to cetaceans.

The number of wells to be drilled for the Project is still to be determined, but is likely to be between 18 and 36. Although drilling noise is likely to be heard by baleen whales, it will be a low source level. The fact that the area does not support any critical habitat is likely to reduce potential impacts. Furthermore, drilling will be temporary and therefore any behavioural impacts are likely to be short term.

Although baleen whales occur seasonally in both the Pilbara Offshore Region and North West Shelf, potential impacts are unlikely to be significant given the area is not known to be used for breeding, calving or resting and due to the fact that construction activities will be temporary.

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6.3.2 Operational Phase

As with the Pilbara Nearshore Region, significant noise generation in the Pilbara Offshore Region and North West Shelf during the operational phase will be restricted to vessel movements.

As stated in Section 6.2.2, there is the potential that vessel movements may cause some level of disturbance, but this is not considered to be significant.

Although various fish species occur within the Pilbara Offshore Region and North West Shelf, no known important habitat or aggregation areas have been identified. In addition, the abundance of fish that accumulate adjacent to operating industrial infrastructure (oil/gas production platforms, wharves, ship loaders, etc.) indicates that at least some species/populations habituate to noise.

6.4 Conclusions

Wheatstone Project activities will produce noise, primarily low frequency broadband concentrated in the construction phase. It is concluded that noise from the Project is unlikely to trigger any long-term, persistent, or significant impacts upon marine fauna and fish in the project area. This conclusion is founded upon several key points:

- the relatively low levels of noise expected to be generated by the Project;
- the absence of any identified critical or important habitat in the Project area for important marine fauna and fish, particularly in the immediate vicinity (e.g. within 5 km) of the proposed nearshore infrastructure;
- the intermittent nature of the most intense source, pile driving, noting that respite periods will be available;
- the temporary nature of the predicted noise disturbances;
- the availability of nearby alternative areas for temporary refuge; and
- the fact that the area is already subject to some anthropogenic noise.

It is likely that some of the proposed activities, particularly pile driving in the nearshore region, will elicit some short term behavioural changes. These are expected to be limited to startle responses, changes to feeding patterns and general avoidance or temporary abandonment of portions of areas of noise generating activity. None of these potential impacts is anticipated to result in long term harm to either individuals or populations of any of the marine fauna or fish considered.

These conclusions are consistent with the findings of Southall *et al.* (2007) who undertook an exhaustive review of behavioural and physiological effects of anthropogenic noise upon marine mammals (See Appendix B).

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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 4.7 dated 6 July 2009.

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

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Effects of Underwater Noise on Marine Fauna

A

Appendix A Synthesis of Underwater Noise Assessments

Table A-1 Summary of Potential Risk to Marine Fauna and Fish in the Pilbara Nearshore Region (Construction Phase).

	Pile Driving	Dredging/ Trenching	Rock dumping	Vessel Movements
Baleen Whales	Unlikely to occur in significant numbers No significant Habitat If baleen whales enter area, impacts likely to be limited to startle/avoidance response Breaks in piling will provide respite	Unlikely to occur in significant numbers No significant Habitat Impacts likely to be limited to general avoidance	Unlikely to occur in significant numbers No significant Habitat If baleen whales enter area, impacts likely to be limited to startle/avoidance response	Unlikely to occur in significant numbers No significant habitat Impacts likely to be limited to general avoidance
Toothed Whales	Majority of noise below optimal hearing Impacts limited to startle response/avoidance Breaks in piling will provide respite	Majority of noise below optimal hearing Impacts limited to avoidance, mainly from general disturbance of activity and not noise	Noise will be intermittent and transient Impacts limited to general avoidance	Noise can cause disturbance to some degree, but species generally tolerant
Dugongs	Within hearing range No critical habitat, impacts limited to startle response and avoidance of area Breaks in piling will provide respite	Noise may disturb dugongs No critical habitat, impacts limited to general avoidance. Refuge/ alternative areas are available limiting impacts	No critical habitat Impacts limited to general avoidance	No critical habitat Impacts likely to be limited to general avoidance behaviour More perceivable risk from vessel strike
Turtles	May elicit startle responses No significant impact as no known nesting/ breeding sites in area May cause disruption to feeding however refuge/ alternative areas are available Breaks in piling will provide respite	Unlikely to generate startle response to the degree of pile driving No critical breeding/nesting sites in area.	May elicit startle responses No significant impact as no nesting/ breeding sites in area	No significant impact anticipated as no nesting/ breeding sites in area
Cartilaginous Fish	Within hearing range Possible impacts but only in close proximity	Will detect noise Noise unlikely to be at levels known to generate physiological stress	Will detect noise Any impact likely to be short-term and non-persistent	May avoid approaching vessels Only temporary disturbance
Demersal Teleosts	Within hearing range Possible acute damage/mortality if at extremely close range Impacts limited due to no critical habitat/ aggregation areas	Will detect noise Noise unlikely to be at levels known to generate physiological stress	Will detect noise Any impact likely to be short-term and non-persistent	May avoid approaching vessels Only temporary disturbance



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	Pile Driving	Dredging/ Trenching	Rock dumping	Vessel Movements
Pelagic Teleosts	Within hearing range Impacts limited as species likely to leave area at start-up	Will detect noise Noise unlikely to be at levels known to generate physiological stress	Will detect noise Any impact likely to be general avoidance of activity	May avoid approaching vessels Only temporary disturbance
Prawns	Within hearing range Possible acute damage/ mortality if at very close range	Will detect noise Noise unlikely to be at levels known to generate physiological stress	Will detect noise Any impact likely to be short-term and non-persistent	May avoid approaching vessels Impacts unlikely given prawns are caught by approaching trawlers

Note: An individual evaluation is not presented for pipe laying as the potential for risk is minimal, and more likely from associated activities (e.g. vessel movements and dredging/trenching).

Table A-2 Summary of Potential Risk to Marine Fauna and Fish in the Pilbara Nearshore Region (Operational Phase).

	Pipeline operation	Vessel Movements
Baleen Whales	The actual operation of the pipeline is unlikely to generate any noise of any biological significance. Any noise that is generated would be minimal and inconsequential in comparison with the ambient noise environment	Humpbacks do occur in this area although not in significant numbers Area is not known to be calving / resting area and as such impact considered minimal
Toothed Whales		Noise can cause disturbance to some degree, but species generally tolerant. Possibly will become habituated
Dugongs		No critical habitat Impacts likely to be limited to general avoidance behaviour. Possibly will become habituated More perceivable risk from vessel strike
Turtles		Impacts likely to be limited to general avoidance behaviour. No significant impact anticipated as no nesting/ breeding sites in area Possibly will become habituated More perceivable risk from vessel strike
Cartilaginous Fish		May avoid approaching vessels Possibly will become habituated
Demersal Teleosts		May avoid approaching vessels Possibly will become habituated
Pelagic Teleosts		May avoid approaching vessels Possibly will become habituated
Prawns		May avoid approaching vessels Impacts unlikely given prawns are caught by approaching trawlers

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Table A-3 Evaluation of Potential Risk to Marine Fauna and Fish in the Pilbara Offshore Region (Construction and Operational Phase).

	Pipe Laying (Construction only)	Vessel Movements
Baleen Whales	An individual evaluation is not presented for pipeline installation and operation as the potential for risk is minimal, and more likely from associated activities (e.g. vessel movements).	Humpbacks may occur in this area although considered uncommon Area is not known to be calving / resting area and as such impact considered minimal
Toothed Whales		Noise can cause disturbance to some degree, but species generally tolerant.
Dugongs		No critical habitat Impacts likely to be limited to general avoidance behaviour. More perceivable risk from vessel strike
Turtles		May cause startle responses and behavioural disturbance Impact only likely to be considerable if important breeding / nesting sites are in close proximity to activities. More perceivable risk from vessel strike
Cartilaginous Fish		May avoid approaching vessels Possibly will become habituated
Demersal Teleosts		May avoid approaching vessels Possibly will become habituated
Pelagic Teleosts		May avoid approaching vessels Possibly will become habituated

Table A-4 Evaluation of Potential Risk to Marine Fauna and Fish in the Offshore Project Area (Construction and Operational Phase).

	Drilling	Small Scale Seismic Activities*	Vessel Movements
Baleen Whales	Potential for drilling noise to affect species – possible avoidance behaviour Impact limited due to area not considered critical for breeding / calving	Potential risk as species will detect noise Risk considered minimal due to small scale and temporary nature of activity Area not considered critical for breeding / calving Risk can be mitigated	May cause disturbance but species generally tolerant
Toothed Whales	Noise generated at levels which toothed whales have reduced hearing sensitivity – unlikely to cause impact	Minimal risk given noise is likely to be below optimal hearing of most toothed whales No known critical habitat	Noise can cause disturbance to some degree, but species generally tolerant. Possibly will become habituated
Cartilaginous Fish	Will detect noise Presence of fish that accumulate adjacent to operating industrial infrastructure indicates that at least some species / populations are able to habituate to some noise	Potential risk if in close proximity to the source No known critical habitat / aggregation areas Surveys will be short-lived and temporary	May avoid approaching vessels Possibly will become habituated
Demersal Teleosts			May avoid approaching vessels Possibly will become habituated



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	Drilling	Small Scale Seismic Activities*	Vessel Movements
Pelagic teleosts	No known critical habitat near offshore field		May avoid approaching vessels Possibly will become habituated

* Construction phase only

Effects of Underwater Noise on Marine Fauna

B

Appendix B Synthesis of Anthropogenic Noise Impacts and Physiological and Behavioural Effects Upon Marine Mammals

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Synthesis of Anthropogenic Noise Impacts and Physiological and Behavioural Effects Upon Marine Mammals.

This section provides a summary of information prepared by Southall *et al.* (2007), who collated and analysed research and findings from a seven year period from a group of acoustic research experts from behavioural, physiological and physical disciplines. The key aim of the group was to:

- 1) Review the expanding literature on marine mammal hearing and on physiological and behavioural responses to anthropogenic noise
- 2) Propose criteria for certain effects.

All available data were reviewed and employed to predict noise exposure levels, above which adverse impacts on various marine mammals would be expected to occur. Predications were considered for:

- 1) Injury
- 2) Behavioural disturbance.

The proposed criteria for the onset of the above effects were separated according to the hearing capabilities of different marine mammal groups and the different categories and metrics of anthropogenic sounds in the ocean. While Southall *et al.* (2007) report that many of the group's objectives were achieved during the study, there are limitations in the proposed criteria because of the lack of, or in some cases complete absence of, information for some key topics.

State of Current Knowledge

Available data on the effects of noise on marine mammals are variable in quantity and quality. In many cases data gaps have severely restricted the derivation of scientifically based noise exposure criteria.

Controlled experiments in laboratory settings have expanded current understanding of marine mammal hearing and the effects of underwater sound. Understanding of marine mammal hearing capacities remains rudimentary, but there is a reasonable understanding of underwater hearing for representative odontocetes and sirenians.

Behavioural responses are strongly affected by the context of the exposure as well as the animal's experience, degree of habituation, motivation and condition and the ambient noise characteristics and habitat setting. This has greatly influenced the formulation of broadly applicable behavioural response criteria for marine mammals based on exposure level alone, where Southall *et al.* (2007) may have attempted such criteria.

Noise Exposure Criteria

Southall *et al.* (2007) formalised sound exposures which are believed to cause direct auditory injury to marine mammals. The minimum exposure criterion for injury is defined as the level at which a single exposure is estimated to cause onset of permanent hearing impairment, defined as Permanent Threshold Shift (PTS), and has been calculated based on data on Temporary Threshold Shift (TTS)¹ in marine mammals, and on patterns of TTS growth and its relation to PTS in other mammals. It should be understood that due to the limited availability of relevant data on TTS and PTS, the extrapolation procedures used in order to make such estimations were deemed by Southall *et al.* (2007) to be necessarily precautionary.

Marine mammals were categorised according to functional hearing groups (Table B-1). Dual criteria for injury were established for each hearing group in order to account for all of the possible effects associated with exposure. These criteria were based on instantaneous peak pressure (unweighted) and total energy

¹ For example, temporary loss of hearing.

(M-weighted²). Further, criteria were given for pulse and nonpulse sounds, as well as for single and multiple exposures (Table B-2). Pulse sounds are brief, broadband, often atonal and transient, largely characterised by rapid rise time to maximum pressure (e.g. pile driving, seismic airgun pulses and sonar pings). Nonpulse sounds can be either intermittent or continuous as well as either tonal, broadband, or both (e.g. general vessel noise and drilling). However, regardless of the anthropogenic sounds, it is to be assumed likely that auditory injury will occur if a marine mammal's exposure exceeds the relevant (pulse or nonpulse) criterion.

Table Error! No text of specified style in document.-1 Functional marine mammal hearing groups, auditory bandwidth (estimated lower to upper frequency hearing cut-off), genera represented in each group, and group-specific (M) frequency weightings

Functional hearing group	Estimated auditory bandwidth	Genera represented (Number species/subspecies)	Frequency-weighting network
Low-frequency cetaceans	7 Hz to 22 kHz	<i>Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera</i> (13 species/subspecies)	M _{lf} (lf: low-frequency cetacean)
Mid-frequency cetaceans	150 Hz to 160 kHz	<i>Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcaella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon</i> (57 species/subspecies)	M _{mf} (mf: mid-frequency cetacean)
High-frequency cetaceans	200 Hz to 180 kHz	<i>Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus</i> (20 species/subspecies)	M _{hf} (hf: high-frequency cetaceans)

(From Southall *et al.* 2007)

Table Error! No text of specified style in document.-2 Sound types, acoustic characteristics and selected examples of anthropogenic sound sources

Sound type	Acoustic characteristics (at source)	Examples
Single pulse	Single acoustic event; > 3dB difference between received level using impulse vs equivalent continuous time constant	Single explosion; sonic boom; single airgun, watergun, pile strike, or sparker pulse; single ping of certain sonars, depth sounders, and pingers
Multiple pulses	Multiple discrete acoustic events within 24 h; > 3dB difference between received level using impulse vs equivalent continuous time constant	Serial explosions; sequential airgun, watergun, pile strikes, or sparker pulses; certain active sonar; some depth sounder signals
Nonpulses	Single or multiple discrete acoustic events within 24 h; < 3dB difference between received level using impulse vs equivalent continuous time constant	Vessel/aircraft passes; drilling; many construction or other industrial operations; certain sonar systems (LFA, tactical mid-frequency); acoustic harassment/deterrent devices; acoustic tomography sources (ATOC); some depth sounder signals

(From Southall *et al.* 2007)

Exposure Criteria for Injury

The criteria proposed by Southall *et al.* (2007) relate to injury to certain marine mammal groups and are based on received sound levels that meet the definition of PTS onset. However, due to the lack of data in regard to PTS, criteria have been derived from measured or assumed TTS onset thresholds and growth rate estimates for each marine mammal group.

² A generalised frequency weighting function developed for each of the five groups of marine mammals based on similarities in their hearing ranges.

In the case of deriving criteria for cetaceans, published TTS data are limited to two mid frequency species, the bottlenose dolphin (*Tursiops truncatus*) and beluga whale (*Delphinapterus leucas*), with data available for exposure to single pulse and nonpulsed sounds. There are no published TTS data for any other mid or high frequency cetaceans, or any low frequency mysticetes.

The proposed injury criteria for individual marine mammals exposed to 'discrete' noise events as proposed by Southall *et al.* (2007) are presented in Table B-3.

Table Error! No text of specified style in document.-3 Proposed injury (i.e. PTS) criteria for individual marine mammals exposed to 'discrete' noise events, either single or multiple exposures within a 24 h period

Marine Mammal Group	Single pulses	Multiple pulses	Nonpulses
<i>Low-frequency cetaceans</i>			
Sound pressure level	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)
Sound exposure level	198 dB re: 1 µPa ² -s (M _{HF})	198 dB re: 1 µPa ² -s (M _{HF})	215 dB re: 1 µPa ² -s (M _{HF})
<i>Mid-frequency cetaceans</i>			
Sound pressure level	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)
Sound exposure level	198 dB re: 1 µPa ² -s (M _{MF})	198 dB re: 1 µPa ² -s (M _{MF})	215 dB re: 1 µPa ² -s (M _{MF})
<i>High-frequency cetaceans</i>			
Sound pressure level	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)
Sound exposure level	198 dB re: 1 µPa ² -s (M _{HF})	198 dB re: 1 µPa ² -s (M _{HF})	215 dB re: 1 µPa ² -s (M _{HF})

Note: Criteria in the "Sound pressure level" lines are based on the peak pressure known or assumed to elicit TTS-onset, plus 6 dB. Criteria in the "Sound exposure level" lines are based on the SEL eliciting TTS-onset plus (1) 15 dB for any type of marine mammal exposed to single or multiple pulses, (2) 20 dB for cetaceans in water exposed to nonpulses.

(From Southall *et al.* 2007)

Exposure Criteria for Behaviour

A key challenge in the development of behavioural criteria is being able to distinguish a significant behavioural response from an insignificant, momentary alteration in behaviour. To assess and quantify significant behavioural effects to noise exposure it is necessary to understand the impact such changes might have on critical biological changes, including growth, survival and reproduction.

Southall *et al.* (2007) found that most behavioural response studies to date have focused on short term and localised behavioural changes whose relevance to individual effects, let alone population factors, is considered low. As an example, it is believed unlikely that a startle response to a brief, transient event would persist long enough to create any response which could be deemed significant. In addition, even

strong behavioural responses to single pulses would be expected to dissipate rapidly enough to have limited long term effect on individuals, let alone populations.

In respect of behavioural responses to sound exposure, it is also evident that many more factors affect behaviour than just simple acoustic metrics. These include animal activity at the time of exposure, habituation and sensitisation to the sound, as well as the presence or absence of acoustic similarities between the anthropogenic sound and biologically relevant signals in the animal's environment (e.g. calls of conspecifics, predators or prey).

When considering information regarding behavioural responses, it is also worth considering information presented by Wartzok and Tyack (2007), who have elaborated on the Population Consequences of Acoustic Disturbance (PCAD) Model developed by the US National Research Council. Wartzok and Tyack (2007) supported the findings of Southall *et al.* (2007) and reported that behavioural dose-response variability is greater than physiological dose response variability. In addition, they report that behavioural variability can also depend on age, sex, reproductive status, time of year and behavioural state.

Single Pulses

Noting the lack of available data for behavioural thresholds, Southall *et al.* (2007) propose that significant behavioural disturbance following exposure to a single pulse should be considered to occur at the lowest level of noise exposure that has a measurable transient effect on hearing (i.e. TTS onset). TTS is not technically a behavioural effect, but is used because it is believed that any compromise to hearing, even if temporary, will potentially affect vital rates and therefore behaviour.

The recommended behavioural disturbance criteria for all cetaceans exposed to single pulses have been developed based on the results for TTS onset in a beluga whale exposed to a single pulse. Proposed unweighted peak sound pressure criteria have been set at 224 dB (re 1 μ Pa). The weighted sound exposure level³ criteria for mid frequency cetaceans have been set at 183 dB (re 1 μ Pa²-s). Through extrapolation, the same criteria have also been set for low and high frequency cetaceans. The only difference is the influence of the respective frequency weighting functions for sound exposure criteria (see Southall *et al.* 2007: 439).

Multiple Pulses and Nonpulses

In the case of multiple pulses and nonpulses, Southall *et al.* (2007) report that it is not currently possible to derive explicit criteria for behavioural disturbance. This conclusion is based on the large degree of variability in responses between groups, species and individuals. However, most research in respect of low frequency cetaceans and nonpulses indicates no or very limited responses at a received level range of 90 to 120 dB (re 1 μ Pa) and an increasing probability of avoidance and other behavioural effects, albeit generally minor, at a range of 120 to 160 dB (re 1 μ Pa).

In the absence of data necessary to develop behavioural based criteria, Southall *et al.* (2007) undertook a severity scaling analysis of available observational data. This analysis was undertaken for the three cetacean groups, and includes a list of response scores from 0 to 9 with a corresponding behavioural reaction for each score (Table B-4). These scores are based on either individual and/or independent group behaviour.

Table Error! No text of specified style in document.-4 Functional marine mammal hearing groups, auditory bandwidth (estimated lower to upper frequency hearing cut-off); genera represented in each group, and group specific (M) frequency-weightings

³ Sound exposure level is a measure of energy. Specifically, it is the dB level of the time integral of the squared-instantaneous sound pressure normalised to a one second (1-s) period. It is useful in assessing cumulative exposure because it enables sounds of differing duration to be compared in terms of total energy (Southall *et al.* 2007).

Response score	Corresponding behaviours (Free-ranging subjects)	Corresponding behaviours (Laboratory subjects) ⁱⁱ
0	- No observable response	- No observable response
1	- Brief orientation response (investigation/visual orientation)	- No observable response
2	- Moderate or multiple orientation behaviours - Brief or minor cessation/modification of vocal behaviour - Brief or minor change in respiration rates	- No observable negative response; may approach sounds as a novel object
3	- Prolonged orientation behaviour - Individual alert behaviour - Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate change in respiration rate - Minor cessation or modification of vocal behaviour (duration < duration of source operation), including the Lombard Effect	- Minor changes in response to trained behaviours (e.g., delay in stationing, extended inter-trial intervals)
4	- Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Brief, minor shift in group distribution - Moderate cessation or modification of vocal behaviour (duration ≈ duration of source operation)	- Moderate changes in response to trained behaviours (e.g., reluctance to return to station, long inter-trial intervals)
5	- Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate shift in group distribution - Change in inter-animal distance and/or group size (aggregation or separation) - Prolonged cessation or modification of vocal behaviour (duration > duration of source operation)	- Severe and sustained changes in trained behaviours (e.g., breaking away from station during experimental sessions)
6	- Minor or moderate individual and/or group avoidance of sound source - Brief or minor separation of females and dependent offspring - Aggressive behaviour related to noise exposure (e.g., tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds) - Extended cessation or modification of vocal behaviour - Visible startle response - Brief cessation of reproductive behaviour	- Refusal to initiate trained tasks
7	- Extensive or prolonged aggressive behaviour - Moderate separation of females and dependent offspring - Clear anti-predator response - Severe and/or sustained avoidance of sound source - Moderate cessation of reproductive behaviour	- Avoidance of experimental situation or retreat to refuge area (> duration of experiment) - Threatening or attacking the sound source
8	- Obvious aversion and/or progressive sensitization - Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms - Long-term avoidance of area (> source operation) - Prolonged cessation of reproductive behaviour	- Avoidance of or sensitization to experimental situation or retreat to refuge area (> duration of experiment)
9	- Outright panic, flight, stampede, attack of conspecifics, or stranding events - Avoidance behaviour related to predator detection	- Total avoidance of sound exposure area and refusal to perform trained behaviours for greater than a day

(From Southall *et al.* 2007)

In assessing behavioural responses to noise, a response score of 0 to 6 would be considered a minor or transitory impact, 7 the threshold of significant behavioural response and a score of 8 to 9 would be considered significant, as it is likely to affect vital rates. The PCAD model (Figure B-1) was developed to

describe and assess acoustic stimuli in relation to population level effects. It is a first attempt at tracing acoustic disturbance through the life history of a marine mammal and determining the final consequences for a population (National Research Council 2005).

The PCAD model requires an understanding of normal behaviour and use of sound and involves five different variables (sound, behaviour change, life function, vital rate and population effect) that are linked by four transfer steps. The first step relates the acoustic source to a behavioural response. The second defines the behavioural disruption in terms of potential effects on critical life functions (e.g. feeding and breeding). The third step integrates these responses over daily and seasonal cycles, and links them to vital rates in life history. The final step relates the changes in individual animals to overall population effects. However, it should be noted that the PCAD model is intended to serve as a conceptual model only (National Research Council 2005).

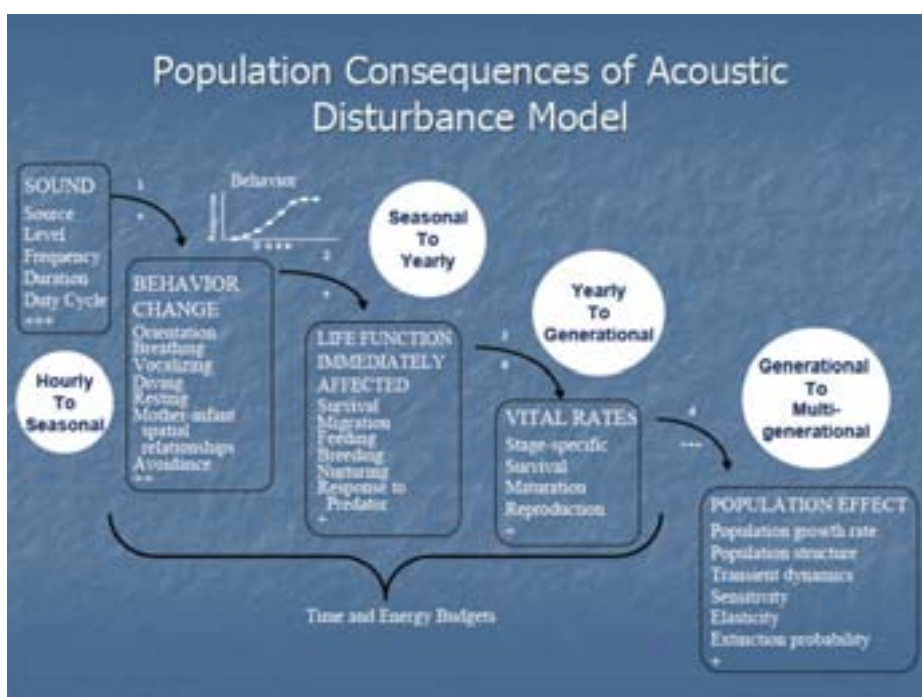


Figure Error! No text of specified style in document.-1 PCAD model

(from Wartzok and Tyack, 2007)

The PCAD model (Figure B-1) complements the information on behavioural disturbance presented by Southall *et al.* (2007). Response scores presented by Southall *et al.* (2007) up to a score of 6 are most likely to fall within the first two consequence stages of the PCAD model. This supports the conclusion that responses at these levels are unlikely to be significant unless sustained over an extended period of time, as they are otherwise unlikely to affect vital rates or result in population effects.

The severity scale analysis undertaken by Southall *et al.* (2007) for low frequency cetaceans and multiple pulses reports that only one out of 197 recorded responses resulted in a score above 6 (a score of 7), which occurred at the 150 to <160 dB (re 1 µPa) range. Furthermore, a further 15 or so out of the 197 observations recorded no significant response up to 180 dB (re 1 µPa).

In the case of mid frequency cetaceans, a limited number of behavioural responses have been made for multiple pulses. However, the majority of 16 observations recorded a score of zero and no responses were

recorded above 6. No data are presented in respect of high frequency cetaceans and multiple responses as data are lacking.

For low frequency cetacean responses to nonpulses, only four of 1,319 observations had a response score of 7; all of these occurred in the range of 130-150 dB (re 1 μ Pa). There were no observational data available for any animal exposed to received levels greater than 150 dB (re 1 μ Pa).

In the case of mid frequency cetaceans exposed to nonpulses, some field studies showed high severity scores to exposures from 90 to 100 dB (re 1 μ Pa), while others failed to exhibit responses to exposures up to 170 dB (re 1 μ Pa). In some controlled studies exposing bottlenose dolphins to received levels at up to 200 dB, some observations displayed no discernable response, while an equal number of observations recorded a response level of 8. It is believed that contextual variables other than received levels, as well as species differences, are the likely reasons for this variability. It is also noted that exposures within captive settings generally exceeded 170 dB (re 1 μ Pa) before a response was recorded.

Out of the 214 observations of mid frequency cetaceans exposed to nonpulses, 20 recorded a response score of 8. Of these 20 observations, 14 were at received levels of 90 to 150 dB (re 1 μ Pa), with eight of these observations made at received levels between 90 to 110 dB (re 1 μ Pa) (although these observations involved relatively quiet Arctic waters). By way of contrast, 194 other observations were made at levels up to 200 dB (re 1 μ Pa), with no significant response recorded.

For high frequency cetaceans exposed to nonpulses, 109 observations were made at received levels up to 170 dB, none of which recorded a response score above 6.

When considering the described above, Southall *et al.* (2007) identified some behavioural responses at their ascribed levels of 7 or above that were described as acute effects. However, when placed in the context of the PCAD model, any anthropogenic noise impact, especially at the level of around 6 to 7, would need to exert a chronic (or sustained) ongoing influence at this level to begin manifesting as population level effects.

Conclusion

The work by Southall *et al.* (2007) has advanced our understanding of underwater anthropogenic noise and potential impacts on marine mammals. In particular the study provides an up-to-date review of available literature and the derivation of quantitative criteria for auditory injury to marine mammals. However, further information and research is required. For example, it is widely accepted that it is not possible at present to propose any meaningful criteria in respect of an individual's behavioural disturbance. How individual behavioural effects may impact upon populations is also unknown. This is largely due to the limited amount of data, limited species information and the dearth of contextual information regarding the influences of factors such as duration, habituation and the ambient noise environment, etc.

The need for extrapolation and precautionary assumptions by Southall *et al.* (2007) to develop their criteria highlights the need for research in a variety of areas. Noting this, it is important that the information presented by Southall *et al.* (2007) is not considered definitive. In many cases the proposed criteria for an entire marine mammal group are based on precautionary results for a single species within that group, even though anecdotal and other empirical data exist which show higher exposures are required to induce the same event in other circumstances. Similarly, care must be exercised when considering the information presented on behavioural effects, as the recorded observations are limited to a small number of species and only certain received sound levels and sources.



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Appendix 010

Potential Interactions with the Onslow
Prawn Managed Fishery

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Abbreviations

Abbreviation	Description
ONPMF	Onslow Prawn Managed Fishery
DOF	Department of Fisheries (Western Australia)
SMFG	Size Management Fishery Ground
NPF	Northern Prawn Fishery

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Report

The Wheatstone Project

Potential Interactions with the Onslow Prawn Managed Fishery

13 MAY 2010

Prepared for
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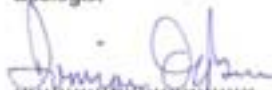
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Executive Summary

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 Western Australian Department of Fisheries (DOF) manages seven prawn trawl fisheries in Western Australia, with a total value in 2006 of \$38 million. The Onslow Prawn Managed Fishery (ONPMF) is a small fishery, with a 2006 value of \$0.65 million (the catch was so low in 2007 that the value was not recorded). The average catch of 96.8 tonnes is dominated by tiger prawns (60 per cent) and king prawns (21 per cent), with significant contributions from endeavour prawns (10 per cent) and banana prawns (8.8 per cent). Minor species in the fishery include Moreton bay bugs, squid, blue swimmer crabs, cuttlefish and other prawns such as black tiger and coral prawns, and some finfish species. Catches are variable, particularly for banana prawns, which have varied from zero to 90 tonnes in recent years.

The ONPMF is located on the north coast of Western Australia, centred near the town of Onslow. There are three areas in the 39 748 km² fishery; Area 1 is a small section in the southwest corner of the fishery off the mouth of the Ashburton River; Area 2 is essentially the western half of the fishery, including most of the shoreline of Barrow Island; and Area 3 extends from the eastern shores of Barrow Island east to 116°45' east longitude. The ONPMF is very large and extends from the shore out to the 200 m depth contour, but only a very small portion (< 5 per cent) of the region is consistently fished. The mouth of the Ashburton River (Area 1) is the key site for banana prawns; up to 50 per cent of this region is trawled. There are 31 licences in the fishery, each of which allows trawling in specific parts of the fishery. Only four licences allow trawling in Area 1. Banana prawn catches have been very poor in the last six years for which data are publicly available (2002-2007), when a total of only 11 tonnes was caught (DOF 2004). Area 1 was not fished at all in 2005 and 2006. Seasonal employment in the fishery in 2007 was six skippers and deckhands and up to six people working in the processing facility.

The Project will potentially impact on the ONPMF. Area 1 will be most affected because nearshore facilities will be constructed near the Ashburton Size Management Fishery Ground (SMFG). This is the key region for banana prawns in the ONPMF. Catches of this species are highly variable. Although catches are low in most years, the occasional good year for banana prawns is an important component of the fishery. The fishery will be affected by dredging the navigation channel, placement of dredged material at offshore and nearshore sites, and the construction of the trunkline from the production platform to the Ashburton North Strategic Industrial Area (Ashburton North SIA). The area which is directly impacted will be small, less than 4 per cent of the Ashburton SMFG.

In addition to the direct loss of habitat, there are five potential impacts on the ONPMF of dredging the navigation channel and placement of dredged material at offshore and nearshore site:



Executive Summary

- Direct mortality during dredging from smothering;
- Increased turbidity;
- Potential release of contaminants during dredging;
- Sedimentation of the sea floor in prawn habitats; and
- Introduction of diseases into the prawn fishery.

During dredging there will be some losses of juvenile and adult prawns being sucked up by the dredge or being smothered by the release of dredged material at the dredge material placement areas.

Dredging will increase the turbidity of the sea water, potentially stressing prawns in the area by, for example increasing clogging of gills. Turbidity will be greatest in the area adjacent to and down current from the dredge, and will decrease with distance from the dredge. Adult prawns can readily move to areas further from the dredging and dredge material placement areas. Dredging in Area 2 is unlikely to affect the prawn catch as it occurs in areas which are not prime prawn habitat. However, dredging in Area 1 will potentially affect an area that is consistently fished for banana prawns, and where there is an inshore banana prawn nursery area. Young juvenile prawns may not be able to move far enough to avoid the increased turbidity. The area is however subject to periodic high levels of natural turbidity arising from wind and wave driven re-suspension and discharges from the Ashburton river following flood events.

The increased sediment load in the water column will increase the sedimentation rate, possibly covering the sea floor with new sediment that may be unsuitable for prawns in the short term. Over a period of time the sediment will stabilise, and the prawns will be able to re-colonise the area. This will probably not affect prawn catches in Area 2, but may potentially affect banana prawn catches in Area 1 if dredging occurs during a favourable year for prawn fishing. Also, the sedimentation may adversely affect juveniles if they are present.

Contaminants are not expected to be released from sediments as there is expected to be little contamination of existing sediments. URS has prepared a separate report on biosecurity risks associated with the Project. The report indicates that there is a low risk of introducing diseases into the ONPMF through activities associated with the Project (URS 2010).

Chevron has undertaken initial consultation with ONPMF licensees regarding this Project and further consultation is planned.

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 study is to provide an analysis of the Onslow Prawn Managed Fishery (ONPMF) and the potential effects of the Project on this fishery. Desktop reviews were made of the following:

1. Prawn trawl fisheries in Western Australia, including the number of licensees, location of fisheries, open seasons, relative catch values, and species caught.
2. The implications of multiple licensing in the industry.
3. Assessment of the ONPMF including: vessels licensed to fish in the industry; recent catch levels; species caught; season species caught; dollar value of catches; and other fisheries the vessels may be licensed in.
4. Seasonal employment in the fishery and associated processing.
5. Details of management areas for the ONPMF, and where different prawn species are caught.
6. Potential impacts of construction of the Project and its associated infrastructure on the ONPMF.
7. Potential areas alienated to fishing by the Project (fishing restrictions near trunklines, etc.).
8. Possible requirement for meetings with prawn fishery licensees in Onslow.

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Prawn Trawl Fisheries in Western Australia

There are a number of trawl fisheries in Western Australia that catch a wide variety of species of scale fish, prawns, scallops, Moreton Bay bugs, blue swimmer crabs, cuttlefish and other commercially valuable species (Figure 2-1). All of the fisheries are similar in that a trawl is hauled behind a trawler to collect the target species. Most of the trawls are hauled over the bottom, though a few operate in midwater. The trawls are not selective, and each catches a wide variety of species. Different nets, mesh sizes and hauling strategies are used to concentrate on scale fish, prawns or scallops. There is an overlap between the scallop and prawn fisheries. For example, the 27 boats in the Shark Bay Prawn Managed Fishery are all licensed to trawl in the Shark Bay Scallop Managed Fishery (Fletcher and Santoro 2007). Conversely, vessels in the Abrolhos Islands Midwest Trawl Fishery concentrate on scallops in the Abrolhos, but also may target prawns along the continental coast.

The prawn trawl fisheries in Western Australia target species of prawns of the family Penaeidae: western king prawns (*Penaeus latisulcatus*), brown tiger prawns (*Penaeus esculentus*), endeavour prawns (*Metapenaeus endeavouri*) and banana prawns (*Penaeus merguensis*). The fisheries are located in coastal areas of the State, with each fishery being named after the area in which it occurs (Table 2-1).



Figure 2-1 Main commercial prawn trawling areas in Western Australia (DoF 2004)

2.1 Economic value of Western Australian prawn fisheries

Prawn fisheries constitute one of the most important fishery types in Western Australia. The total catch in 2006 was valued at about \$38 million (Fletcher and Santoro 2007). In addition to being important on a state-wide basis, the prawn trawl fisheries are important to the economies of the regions in which they fish.

All seven of the prawn fisheries listed in Table 2-1 are managed by the Western Australian Department of Fisheries (DOF). The Northern Prawn Fishery extends from the Queensland side of the Gulf of Carpentaria across the north coast of Australia to the Kimberley, Western Australia. This large fishery is managed by the Commonwealth Department of Agriculture, Fisheries and Forestry. As it is

2 Prawn Trawl Fisheries in Western Australia

managed separately from the fisheries managed by DOF, the Northern Prawn Fishery (NPF) is not considered here. However, it should be noted that many Western Australian registered trawlers fish in the NPF, and many NPF vessels from the Northern Territory and Queensland work in the Kimberley Prawn Managed Fishery.

Table 2-1 demonstrates that the Shark Bay Prawn Managed Fishery (2006 value of \$20.2 million) and the Exmouth Gulf Prawn Managed Fishery (\$10 million) are the largest prawn fisheries in Western Australia, with about three quarters of the total catch. The other prawn fisheries were all relatively small in 2006, and this reflects their average importance. However, prawn fisheries worldwide can change in value from year to year, and in any given year the value of one or more of the smaller fisheries in Western Australia may be much greater than shown in Table 2-1.

Table 2-1 Prawn trawl fisheries in Western Australia in 2006 (Fletcher and Santoro 2007)

Fishery	Number of licenses (number of vessels that fished in 2006)	Value (\$million)	Target catch range (tonnes)	Open season	Species caught
Kimberley Prawn Managed Fishery	137 (22)	3.1	240-500	15 Apr–10 Jun; 1 Aug–15 Nov	Banana, brown tiger, endeavour, western king,
Broome Prawn Managed Fishery	5 (4)	0.5	55-260	14 Jun–3 Sep	Western king, coral
Nickol Bay Prawn Managed Fishery	14 (11)	3.7	120-180	15 Mar–30 Oct	Western king, brown tiger, endeavour, banana
Onslow Prawn Managed Fishery	31 over three areas (3)	0.7	60-180	21 Apr–31 Oct	Western king, brown tiger, endeavour, banana
Exmouth Gulf Prawn Managed Fishery	16	10	260-390	17 Apr–1 Dec	Western king, brown tiger, endeavour
Shark Bay Prawn Managed Fishery	27	20.2	1501-2330	Varies	Western king, brown tiger, endeavour
South West Prawn Managed Fishery	14	0.1	8	All year round	Western king

2.2 The Onslow Prawn Managed Fishery area

Management of each of the prawn fisheries listed in Table 2-1 is controlled through an agreed management plan for that particular fishery. The licence areas for the ONPMF are described as follows (DOF 2004):

Onslow Prawn Managed Fishery

2 Prawn Trawl Fisheries in Western Australia

“The *Onslow Prawn Fishery Management Plan 1991*, defines the fishery as existing within ‘all Western Australian waters of the Indian Ocean below high water mark lying west of 116°45’ east longitude and east of a line commencing at the high water mark on the mainland due south of the southernmost extremity of Locker Island drawn due north to the high water mark at the extremity; thence north-westerly to the high water mark at the southern most extremity of Serrurier Island; thence northerly along the high water mark of that island on its western shore to its northernmost point; thence due north’. The waters within the fishery are further divided into three fishing areas: Area 1, Area 2, and Area 3. In addition, there are also three designated nurseries: Ashburton Nursery, Coolgra Point Nursery and Fortescue Nursery.”

The locations of the ONPMF fisheries described in the DOF (2004) document are shown in Figure 2-2. It is noted that the nursery areas are now described as Size Management Fishery Grounds (SMFG) and is discussed further in Section 3.1.

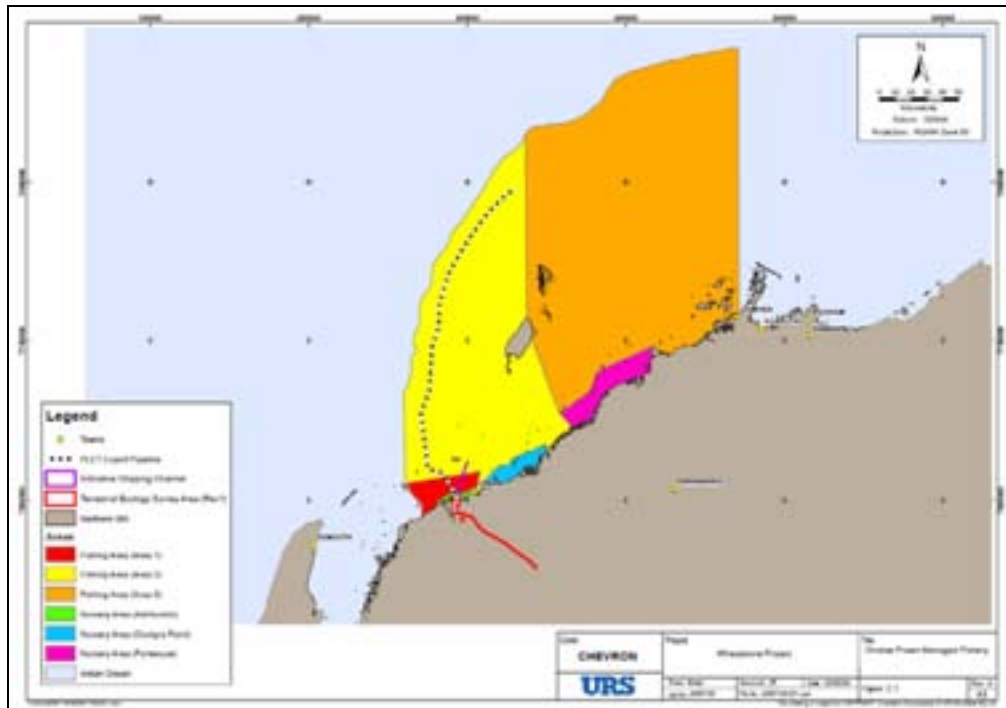


Figure 2-2 Onslow Prawn Managed Fishery licence areas and Size Managed Fishery Grounds (from DOF 2004)

This definition includes all Australian waters out to the 200 m depth contour. Western Australian State waters actually only extend out to three nautical miles from the mean high tide springs, but under agreement with the Commonwealth, DOF manages most fisheries in Commonwealth waters off Western Australia. The licence areas are extremely large because the intent of the legal definition of the fishery limits is to define all available waters as being part of a managed fishery. This means that no additional prawn fisheries can be requested in an “unfished” area.



2 Prawn Trawl Fisheries in Western Australia

In reality, the areas fished by each prawn trawl fishery are much smaller than the gazetted area of the fishery; usually less than 10 per cent of the total area. This is because prawn populations are not evenly distributed within each licence area and because of the limited areas that are suitable for trawling.

2.3 Prawn trawling locations

Prawn trawls can be operated only on clean sandy and muddy bottoms. This is because rocky bottoms or coral reefs will damage the nets. Additionally, some muddy and sandy areas that could be fished do not have sufficient prawn stocks to be commercially viable and are not fished.

Many of the prawn trawl fisheries have nursery areas that are permanently closed to trawling to protect the larvae and juvenile prawns.

The resulting effect is that only a small area is actually fished and this area tends to be consistent between years. This is discussed further in Section 3.1.

2.4 Prawn life cycle

Following fertilisation of the egg while it is still attached to the female, prawns have a planktonic larval stage that spends a relatively short time in the water column. The larvae settle to the bottom and develop into juvenile stage prawns in shallow coastal areas including estuaries. The young grow rapidly, reaching adult size within several months. As they near the adult stage, the young prawns migrate offshore into the fishery area. Adult and juvenile populations are thus spatially separated.

2.5 Management of prawn fisheries

Management of prawn fisheries is dynamic. The DOF management plans set the broad parameters within which the fishery is managed, but there is a considerable level of adaptive management to meet the needs of each season. Various management methods are used to help ensure that prawn populations are maintained at a sustainable level and that catch value is maximised.

Catch ranges are monitored to ensure that the prawn population is maintained. For example, the expected catch in the ONPMF ranges from 60 to 180 tonnes (Table 2-1). Catches outside the predicted ranges are closely examined to ensure the prawns are not being overfished, but prawn populations are also naturally variable. Variations to prawn populations may occur for reasons such as: current patterns not delivering the larvae to the nursery areas; temperature patterns during the year; salinity variations; and rainfall or flood events. This is discussed further in Section 3.

The DOF conducts annual pre-season surveys to determine prawn stock levels in the various fisheries. This information is shared with industry, and a determination is made on the length of the season and total fishing effort for each fishery for that year. Seasons are modified every year to allow the fishery to target the larger, more commercially valuable prawns, rather than those that have just reached adult size.

Within the seasonal limits for a given year, there may be further restrictions to fishing times or methods. This may include closures during a full moon when the prawns remain on the bottom and catches are low, restrictions on the type of fishing gear used, and limits on the total fishing effort in the fishery.

2 Prawn Trawl Fisheries in Western Australia

Although it is not apparent from the different periods for open and closed seasons shown in Table 2-1, seasons in the various prawn trawl fisheries are staggered during each year. This allows a vessel to fish sequentially in several fisheries. This management system ensures that the high cost vessels are utilised to the maximum extent possible and allows crews to be employed for larger parts of the year. DOF's goal is to achieve catches within the ecologically sustainable levels of each fishery that maximise the commercial value of the catch and minimise costs.

2.6 Licensing

All of the prawn trawl fisheries (and other major fisheries in Western Australia) are limited entry; that is there is only a specific number of licences available for each fishery. In general, the licences are transferable across all of the Western Australian fisheries so a new entrant to the fishery must buy an existing licence from another fisher.

The number of licences in each prawn fishery is shown in Table 2-1, with a total of 244 licences issued by the DOF across the seven fisheries. However, there are actually far fewer trawlers licensed to fish in Western Australian waters. Most of the boats have multiple licences that allow them to fish in more than one prawn fishery, or even in other species fisheries. There is no requirement that a licence must actually be used, so the number of vessels that fish in a particular fishery in a given year is often less than the total number of licences (Table 2-1).

2.7 Prawn fishing methods

There are detailed restrictions on boat size and the types of gear that can be used in the prawn fishery. Two major trawling set-ups are used in the ONPMF. The first type is used in Area 1 and the second type in Areas 2 and 3.

2.7.1 Trawl gear in Onslow Prawn Managed Fishery Area 1

Trawlers in Area 1 use twin demersal otter trawl gear, with an operational headrope length of 10.98 m (Figure 2-3). This is effectively the width of the trawl net path. The gear is further modified in Area 1 by using differing nets for different target species. Flat nets are used for western king and brown tiger prawns and 'banana' nets are used when targeting banana prawn aggregations. The 'banana' nets are two flat nets sewn together with effectively one wide opening.

2 Prawn Trawl Fisheries in Western Australia

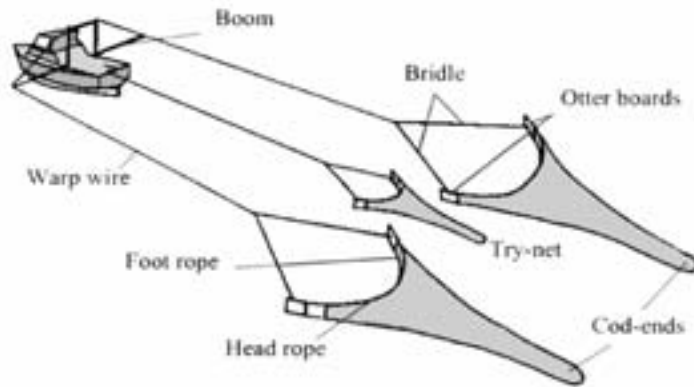


Figure 2-3 A standard twin demersal otter trawl used by prawn trawlers in Area 1 of the ONPMF (DOF 2004)

2.7.2 Trawl gear in Onslow Prawn Managed Fishery Area 2 and 3

The otter trawls used in Onslow Areas 2 and 3 can be varied as long as the headrope length of each net does not exceed 5 m and the total length of the headropes does not exceed 29.27 m. A typical net arrangement for Onslow Areas 2 and 3 is shown in Figure 2-4.

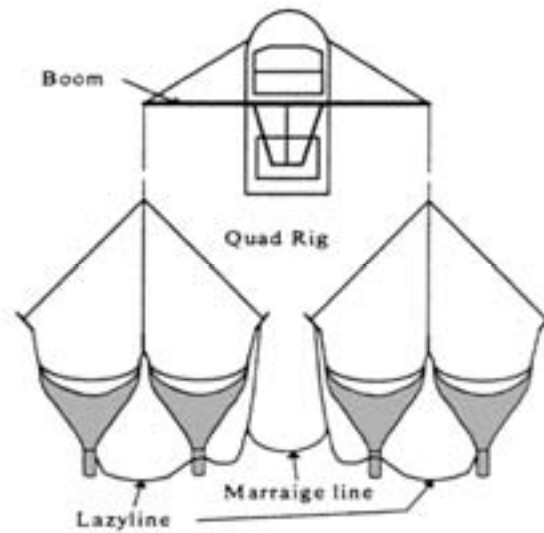


Figure 2-4 A standard quad otter rig used by prawn trawlers in Area 2 and Area 3 of the ONPMF (DOF 2004)

Onslow Prawn Managed Fishery

3.1 ONPMF management areas and fishing locations

The legal definition of the ONPMF boundaries is given in Section 2 and these boundaries are illustrated in Figure 3-1. The 39 748 km² ONPMF has three areas. Area 1 is a small section in the southwest corner of the fishery centred at the mouth of the Ashburton River and includes the Ashburton SMFG. Area 2 is essentially the western half of the fishery, including most of the shoreline of Barrow Island. Area 3 extends from the eastern shores of Barrow Island east to 116°45' east longitude. Three small nursery areas along the continental coastline are shown in Figure 3-1: Ashburton, Coolgra Point and Fortescue. The Ashburton nursery area is approximately 7 450 ha extending 8 km along the coast to Beadon Point. The nursery areas are managed as Size Management Fishery Grounds (SMFG) to allow sections of these areas to be fished when the prawns have grown to an appropriate size.

Trawl shots in the ONPMF usually vary between 90 and 180 minutes in duration, with variations due to the species targeted. Banana prawns form dense schools that create 'boils' on the surface that can be directly targeted, allowing trawls to be as short as 30 minutes. The presence of these aggregations means populations can be rapidly fished during the season. For example, in the much larger Northern Prawn Fishery the biomass of aggregations of banana prawns can be reduced by 93 per cent in the first three weeks of the season (Die and Ellis 1999). Similarly, the depths at which trawling takes place depends on the species targeted. Trawls for banana prawns are usually made near river mouths in three to six metres of water. Most trawls for the other prawn species are made in depths ranging from eight to 18 metres of water. The trawler moves at a speed of three to four knots when trawling (DOF 2004).

As indicated in Section 2, the gazetted area of the ONPMF is much larger than the area actually fished. Figure 3-1 shows the gazetted boundaries for each area of the ONPMF and the sections where trawling is concentrated. Consistent annual effort for banana and king prawns occurs in Area 1 along the shoreline between the mouth of the Ashburton River and Onslow. Half of this region is consistently fished. Mangrove Passage in Area 2 is also consistently fished for tiger prawns. King prawn densities are too low in most areas to be economically fished, and trawling occurs over a very small proportion (< 5 per cent) of the available areas for these species (DOF 2004).

3 Onslow Prawn Managed Fishery

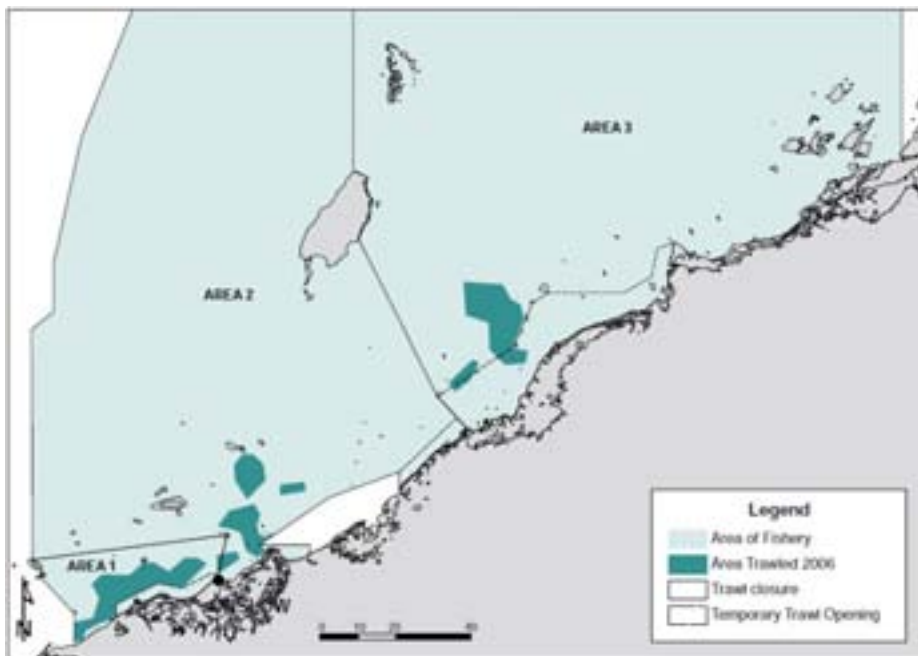


Figure 3-1 Areas fished in the ONPMF in 2006 (Sporer *et al.* 2007)

3.2 Licensing and multi-licensing

Table 3-1 shows licences in the ONPMF. Class A licences may be used in all three of the ONPMF areas; only four Class A licences are issued. Class B licences can be used in Areas 2 and 3, of which three are issued. Class C licences may only be used in Area 2 of the ONPMF. All 12 of the Class C licences are held by fishers in the Exmouth Gulf Prawn Managed Fishery which is the adjoining area to the south. Similarly, all 12 licences permitting use in ONPMF Area 3 are held by fishers from the adjacent Nickol Bay Prawn Managed Fishery.

Trawlers in the ONPMF tend to be multi-licensed. As described above, 24 of the 31 ONPMF licences are held by trawlers from the Exmouth and Nickol Bay fisheries. The trawlers also tend to be licensed for the Kimberley Prawn Managed Fishery and the Northern Prawn Fishery. Of the four licences for Area 1 of the ONPMF, two are held by one boat based in Onslow. The remaining two Area 1 licences are owned by MG Kailis and are operated out of Learmonth (Kangas 2009)

3 Onslow Prawn Managed Fishery

Table 3-1 Licensees in the Onslow Prawn Managed Fishery in 2006 (Sporer *et al.* 2006)

Class of licence	Fishing area/s	Number of licences
A	Area, 1, Area 2 and Area 3	4
B	Area 2 and Area 3	3
C	Area 2	12
D	Area 3	12
Total		31

3.3 Catches in the ONPMF

The ONPMF is a relatively small prawn fishery. Over the ten years from 1998 to 2007, the total catch was 968 tonnes (Table 3-2), with an average of 96.8 tonnes per annum. The catch is dominated by tiger prawns (580 tonnes, 60 per cent) and king prawns (204 tonnes, 21 per cent). Endeavour prawns (97 tonnes, 10 per cent) and banana prawns (86 tonnes, 8.8 per cent) are relatively minor components of the total catch. Bycatch species in the fishery include Moreton bay bugs, squid, blue swimmer crabs, cuttlefish, other prawns such as black tiger (*Penaeus monodon*) and coral prawns, and some finfish species.

Prawn catches in the ONPMF are closely related to environmental conditions. Tiger and endeavour prawns can be negatively impacted by strong storm events, such as cyclones. The effects are particularly severe when juveniles are in shallow seagrass beds. King prawn catches are decreased by flooding in the Ashburton River, which disperses the stock and reduces catch rates. In addition, debris from flooding can hamper fishing efforts. Banana prawns can benefit from storm events and the associated high rainfall. There is typically a lag of one year when high summer rainfall is followed by high catches of banana prawns the following year (Sporer and Kangas 2005, Sporer *et al.* 2006, Sporer *et al.* 2007).

Tiger prawns show one of the most stable catch rates; with catches in seven of the last ten years ranging from 14 to 77 tonnes. There were two excellent years in 2003 and 2004, when 172 and 150 tonnes respectively were caught. There were also good catches in the years before and after this (2002 and 2005). With the exception of the years 2006 and 2007 when only 2 tonnes and <1 tonne respectively were caught, king prawn catches ranged from 12 to 42 tonnes. Two tonnes of endeavour prawns were also caught in 2006 and < 1 tonne in 2007. In the other years, endeavour prawn catches ranged from 6 to 20 tonnes.

In 2007, catches of all species were very poor. Only one boat fished and for a total of only 53 days (Sporer *et al.* 2008). The total catch in 2007 was 4 tonnes of all prawn species. With the recent good rains and flooding of the Ashburton River (February 2009), it is anticipated that there will be good banana prawn catches in 2010, with other prawn catches improving in 2011 (Kangas 2009).

Onslow Prawn Managed Fishery

3 Onslow Prawn Managed Fishery

Table 3-2 Catches in the Onslow Prawn Managed Fishery from 1998 to 2007 (DOF 2004).

Year	Total value (\$ million)	Banana value (\$ million)	Prawn catches (tonnes)				
			Total prawn catch	King	Tiger	Endeavour	Banana
1998	0.9	0.02	62	35	14	11	2
1999	1.4	0.10	93	38	26	20	9
2000	1.5	0.79	87	12	18	6	51
2001	0.9	0.15	63	15	28	7	13
2002	1.7	0.01	135	42	77	14	1
2003	2.4	0.01	194	12	172	9	1
2004	2.2	0.00	194	27	150	17	0
2005	1.0	0.00	85	20	55	10	0
2006	0.65	0.02	51	2	39	2	8
2007	Not recorded	Not recorded	4	<1	<1	<1	<1
Total	12.65	1.10	968	204	580	97	86
Average	1.3	0.11	96.8	20.4	58.0	9.7	8.6

Note: Values of banana prawn catches are not reported separately by the DOF, so this banana prawn value has been reported by multiplying the reported catch for the year in tonnes by the average value banana prawns obtained for that year as reported by the DOF.

3 Onslow Prawn Managed Fishery

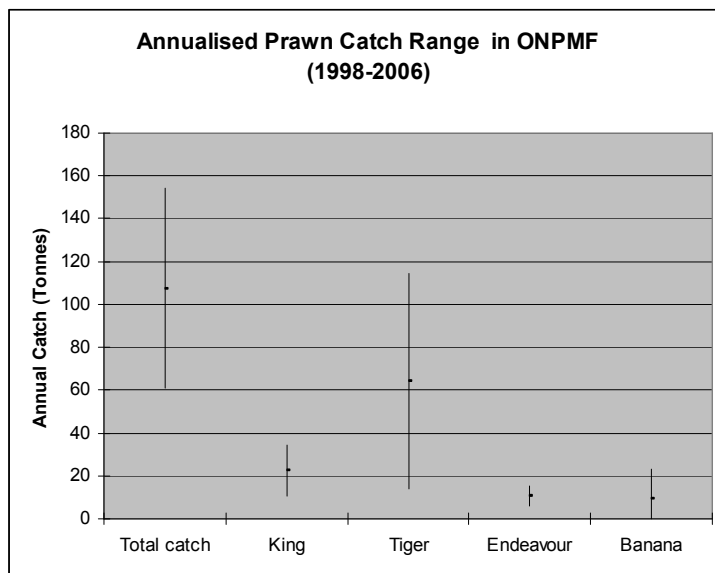


Figure 3-2 Mean and range of annual catches of individual species in the Onslow Prawn Managed Fishery (after DoF).

3.3.1 Variability in the banana prawn fishery

Banana prawn catches are highly variable in the ONPMF. As rainfall in the Onslow region is typically very low, the banana prawn catches tend to be low. The highest historical catch of banana prawns in recent years was 90 tonnes in 1997 following good rains. The catch dropped by about 98 per cent the following year, to 2 tonnes (Table 3-2). An excellent catch of 51 tonnes was obtained in 2000. Since then catches have been poor, dropping to 13 tonnes in 2001. The low catches of 1 tonne per year in 2002 and 2003 were followed by zero catches in 2004 and 2005, when banana prawn stocks were so low they were not fished. This was expected as the rainfall during the period 2004 to 2005 was only 4 mm. Rainfall of 272 mm was received during the period 2005 to 2006 and therefore good catches were expected in 2006 (Sporer *et al.* 2006). However, the expected good catches in 2006 did not occur, with only 8 tonnes caught. The low catches were thought to be caused by low breeding stock remaining from the previous year. At the time of preparing this report Banana prawns were not targeted in the Ashburton SMFG to allow breeding stocks to recover (Sporer *et al.* 2007).

The relationship between rainfall and abundance of banana prawns mirrors the situation in Queensland, where Vance *et al.* (1998) undertook a detailed six year study of the fishery. Vance *et al.* (1998) related the abundances of three life stages (planktonic postlarvae, benthic postlarvae, and juveniles) to commercial catches, but found there was no clear relationship. Instead, wet season impacts were the primary determinant of variations in the commercial catch. Vance *et al.* (1998) concluded that increased emigration of juveniles from the estuaries was positively correlated with rainfall. In turn, the primary determinant of juvenile populations in estuaries was the settlement of postlarvae from planktonic larval stages spawned offshore. The greatest densities of larvae were in the upper reaches of small creeks, not in the major river systems.



Onslow Prawn Managed Fishery

3 Onslow Prawn Managed Fishery

3.4 Seasonal employment in the fishery

The prawns and retained bycatch species are usually graded and frozen on board the trawlers (DOF 2004) before being processed on shore. The *State of the Fisheries Reports* for the years 2000 to 2005 show employment of 12-15 skippers and deckhands and up to ten people working in the processing facility in Onslow. In 2006 this reduced to nine skippers and deckhands and up to eight people working in the processing facility. There was a further reduction in 2007 to six skippers and deckhands and up to six people working in the processing facility. The employment season is unlikely to be year round, but the duration of employment is not provided.

In 2006, the ONPMF was open for trawling from 21 April until 1 October (Sporer *et al.* 2007), but the report does not indicate when trawling actually occurred. The purchase of two Area 1 licences by the MG Kailis Group means that it is likely that processing of the catch from these licences is undertaken in Learmonth (Kangas 2009)

Potential Effects of the Project on the Prawn Fishery

4.1 Prawn fishery areas affected by the Project

The Project is likely to have some short-term adverse impact on the ONPMF. Area 1 is likely to be the most affected of the three licence areas because the nearshore components of the Project will be constructed adjacent to the Ashburton SMFG. This is the key region for banana prawns in the ONPMF. While catches of this species are highly variable, banana prawns are an important component of the fishery. Less than four per cent of the Ashburton SMFG will be affected by nearshore components of the project in the long term.

The trunkline from the offshore sites to the Ashburton North Strategic Industrial Area (Ashburton North SIA) may affect the fishery, although the area directly affected is expected to be relatively small. The trunkline will be constructed by trenching the offshore components.

A portion of Area 2 offshore of the Ashburton North SIA can be trawled for other prawn species, but is not a major trawling region. A small part of this area will be removed from the fishery by construction of the navigation channel, creation of the proposed nearshore and offshore dredge material placement sites and an exclusion zone east and west of the navigation channel.

It should be noted that any exclusion zones and habitat modifications resulting from the Project will simply be an extension of a process that is already occurring. The DoF (2004) reported five years ago that some of the Western Australia inshore prawn trawling grounds had been permanently closed due to navigation hazards or exclusion zones around existing iron ore, salt and gas loading jetties.

4.2 Potential impact of dredging on the ONPMF

Dredging to construct a navigation channel for the passage of ships from deep water to the Ashburton North SIA will change the habitat of the seafloor. Several immediate environmental changes will occur, such as: increased depth and pressure at the bottom of the channel; reduced light intensities at the surface of the seafloor; and possibly changes in dissolved oxygen concentrations. The effects of dredging on marine benthic communities have been extensively studied (e.g. Newell *et al.* 1998, Smith and Rule 2001, Boyd *et al.* 2005, Bolam *et al.* 2006) but there appears to be no work to date on the effects of dredging on prawn fisheries specifically. There is usually a rapid initial colonisation of newly dredged areas, but there may be differences in community structure that can be measured for years or even decades after initial dredging occurred (Wilson 1998, Fraser *et al.* 2006).

In addition to the direct loss of habitat discussed in Section 4.1 above, there are five potential impacts of dredging the navigation channel on the ONPMF:

- Direct mortality during dredging from smothering;
- Increased turbidity;
- Potential release of contaminants during dredging;
- Sedimentation of the sea floor in prawn habitats; and
- Introduction of diseases into the prawn fishery.

These impacts are discussed in more detail in Section 4.2.1 to Section 4.2.5.

4.2.1 Direct mortality from smothering

During dredging there will be some losses of juvenile and adult prawns. Direct mortality results from two sources: prawns that are sucked up by the dredge; and prawns that are smothered by the release of dredged material at the dredge material placement areas.

4 Potential Effects of the Project on the Prawn Fishery

4.2.2 Increased turbidity during dredging

Dredging will increase the turbidity of the sea water. This can potentially stress prawns in the area by, for example, increased clogging of gills. Turbidity will be greatest in the area adjacent to and down current from the dredge, and will decrease with distance from the operational area. The inshore areas along the Onslow coastline tend to be muddy, and the sea water consequently already has high sediment content. Turbidity is variable depending on season, tide, wind, and storm activity.

Increased turbidity from dredging is unlikely to cause mortality of adult prawns, as they can readily move to areas further from the dredging and dredge material placement areas. The portion of the ONPMF Area 2 near the proposed navigation channel is not trawled consistently therefore dredging is unlikely to affect prawn catches in Area 2. However, dredging in Area 1 may affect an area that is consistently fished for banana prawns, and where there is an inshore banana prawn nursery area. Young juvenile prawns may not be able to move far enough to avoid the increased turbidity which may cause some mortality.

Increased vessel activity in the new navigation channel may also cause increased turbulence (Hopkins and White 1998), and thus increased turbidity during the operational phase.

4.2.3 Potential release of contaminants during dredging

Dredging can disturb contaminants such as heavy metals, hydrocarbons, industrial chemicals, etc., that have accumulated on the sediment surface of the sea floor. The contaminants can then be released into the water column, with the potential for entry into the food chain.

There is very little industrial activity in Onslow, and none near the proposed Project site, so there is only a small chance that such contamination is actually present in the area. URS has conducted sampling and analysis of sediments from areas in the proposed dredge footprint and placement sites. This is a routine and necessary step to obtain a Commonwealth permit for offshore placement of dredge material (NAGD, 2009). The material to be dredged was found not to be contaminated and is suitable for both offshore and onshore placement without further treatment (URS, 2010a).

4.2.4 Sedimentation on the sea floor in prawn habitats

Dredging will not only increase turbidity (Section 3.6.2), but sediment in the water will settle to the bottom and cover the sea floor as a new layer of sediment. Catches in Area 2 will probably not be affected by sedimentation of habitat as the prawns are not currently sufficiently dense to be economically fished. However, sedimentation in Area 1 will be in a region actively fished for banana prawns. During a favourable season, catches could be adversely affected. Additionally, sedimentation may adversely affect juveniles if they are present in Area 2 SMFG. Over a period of time the sediment will stabilise and prawns will recolonise areas affected by sedimentation.

4 Potential Effects of the Project on the Prawn Fishery

4.2.5 Introduction of diseases into the prawn fishery

Australian prawn fisheries and farms have a reputation for being disease free, but this is not strictly true. A separate report on the potential risks of marine pests and diseases from construction and operation of the Project has been developed (URS 2010b). The report indicates that there is a low risk of introducing diseases into the ONPMF through activities associated with the Project.

4.3 Possible requirement for meetings with licensees in Onslow

Fishing has a long history in Onslow, and the prawn industry has been a major part of fishing in the Onslow area. The management plan for the ONPMF was established in 1991 nearly 20 years ago. The ONPMF is in a state of flux, with poor catches through 2007. The fishery already has areas where trawling has been permanently prohibited due to industrial developments along the Onslow coastline, and there are other current proposals for the region in addition to the proposed Project. MG Kailis Group and the Western Australian Fishing Industry Council opposed the proposed Yannarie Solar Salt Facility at Exmouth Gulf partly out of concern for the effects of dredging on the Exmouth Gulf prawn fishery (MG Kailis Group and WAFIC 2007).

During the period when this report was being compiled, Chevron commenced working with the ONPMF licensees to provide information about the potential affects of the Project and begin responding to any concerns raised. Further consultation is planned with ONPMF licensees in forthcoming months.

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Onslow Prawn Managed Fishery

5

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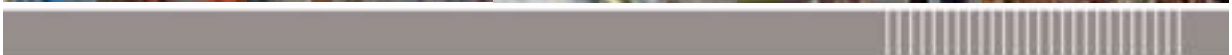
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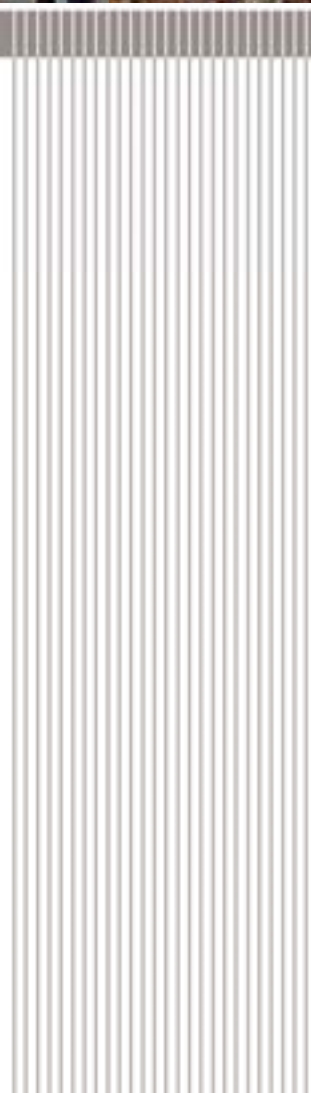


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Appendix 011

Marine Turtles Technical Report

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**TECHNICAL APPENDIX
MARINE TURTLES**

Wheatstone Project EIS/ERMP





**TECHNICAL APPENDIX
MARINE TURTLES**

Wheatstone Project EIS/ERMP

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ACRONYMS AND DEFINITIONS

Term/Abbreviation	Definition
AHT	Above the high tide mark
BHT	Below the high tide mark
CCL	Curved carapace length
Chelonid	Hard-shelled marine turtles of the family Cheloniidae. Extant species are green, flatback, hawksbill, loggerhead, olive ridley and Kemp's ridley turtles
DEC	Department of Environment and Conservation (Western Australia)
DEWHA	Department of the Environment, Water, Heritage and the Arts (Commonwealth)
EIS	Environmental Impact Statement
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i> (Commonwealth)
ERMP	Environmental Review and Management Programme
GBR	Great Barrier Reef
GIS	Geographic Information System
HSE	Health, safety and environment
Inter-nesting period	The time between consecutive clutches of eggs laid by an individual turtle during a nesting season
MU	Management Unit – An area encompassing genetically related breeding populations of marine turtles
Natal beach	The beach where a marine turtle hatched
Neritic zone	Inshore marine environment where water depth is less than 200 m – generally includes the continental shelf
Nesting success	The proportion of female emergences on a beach that result in a nest being laid
NES	National Environmental Significance
Oceanic zone	Open ocean environment where water depth is greater than 200 m
Project footprint	Potential marine construction areas, including the shipping channel, pipeline route, MOF and jetty
QA/QC	Quality assurance/quality control
SE	Standard error
WC Act	<i>Wildlife Conservation Act 1950</i> (Western Australia)



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SUMMARY

Chevron Australia, as owner and operator of the Wheatstone Project, proposes to construct and operate a multi-train LNG plant and Domgas plant at Ashburton North, 12 km south-west of Onslow on the Pilbara coast of Western Australia. As part of a suite of investigations to support the environmental impact assessment process, Chevron Australia commissioned marine turtle studies in the vicinity of the proposed Ashburton North development site.

The main aspects of the development with potential to impact marine turtles include construction and maintenance dredging of the shipping channel, construction of the onshore facilities, lighting from the onshore and marine facilities and increased levels of shipping. The potential impacts to marine turtles from these aspects of the development are:

- Dredging
 - Entrainment of turtles in the dredge drag head
 - Loss of critical habitat
- Construction of onshore facilities
 - Loss of critical nesting habitat
- Lighting
 - Deterrence of nesting turtles from optimal nesting beaches
 - Misorientation of hatchlings (both on the nesting beach and in the water), resulting in increased hatchling mortality
- Shipping
 - Vessel-strike resulting in fatality/permanent injury

Marine turtle studies were designed to determine the significance of the proposed Ashburton North development site and associated Project footprint (i.e. the potential marine construction areas, including the shipping channel, pipeline route, MOF and jetty) site for nesting, inter-nesting, hatching and foraging turtles. The marine turtle studies to date were undertaken as part of the first phase of environmental surveys and further studies will be planned to address remaining knowledge gaps.

The mainland beach directly adjacent to the proposed development site is unsuitable nesting habitat for marine turtles. The Ashburton River Delta supports flatback turtles attempting to nest and the offshore islands adjacent to the Project footprint, including Ashburton Island, Thevenard Island and Direction Island, support both green and flatback turtles.

Given the proximity of the Ashburton River Delta nesting beach and Ashburton Island to the proposed development site and the Project footprint, it is recommended that the potential for Project light spill to affect nesting and hatching turtles on these beaches be investigated.



Preliminary satellite tracking data (up to 31 January 2010) for six flatback turtles that nested at Ashburton Island indicates that these turtles spend the inter-nesting period between Ashburton Island, Baresand Point, Onslow and Direction Island, generally staying within 20 km of the nesting beach at Ashburton Island. Satellite tracking data also shows that flatback turtles use nearby island beaches for nesting. Further analysis of the satellite tracking data, including the time-depth data, is planned.

Foraging by marine turtles within and adjacent to the Project footprint occurs predominantly in offshore reef habitats, and is largely by juvenile green turtles. Although it appears that the majority of resident foraging turtles occupy reef habitats, it is not known whether these turtles remain in the reef habitats or move between habitats.

I.0 INTRODUCTION

Chevron Australia Pty Ltd (Chevron Australia) proposes to construct and operate a multi-train Liquefied Natural Gas (LNG) plant and a domestic gas (Domgas) plant at Ashburton North, 12 km south-west of Onslow on the Pilbara coast. These plants will initially process gas from the Wheatstone natural gas fields, approximately 200 km offshore from Onslow in the West Carnarvon Basin. The Wheatstone Project will require the installation of gas gathering, exporting and processing facilities in Commonwealth and State waters and on Council (Shire of Ashburton) land. The LNG plant will be part of a “hub” with a combined maximum capacity of 25 Million Tonnes Per Annum (MTPA) of LNG.

The Wheatstone Project has been referred to the Western Australian Environmental Protection Authority (EPA) and the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA), with the assessment level set at EIS/ERMP. The marine turtle investigations outlined in this report have been conducted to support the environmental impact assessment process.

The marine turtle studies described in this Technical Appendix to the Wheatstone Project EIS/ERMP were designed to establish baseline information on marine turtle activity within the Project footprint and to identify further required studies. The studies comprised:

- Desktop review of existing literature.
- Field studies by Pendoley Environmental.
- Field studies by RPS.

The studies presented herein were undertaken as part of the first phase of environmental surveys. Further studies will be planned to address gaps in information on marine turtle use of the Project area as the Project progresses.



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2.0 BACKGROUND INFORMATION

Six species of marine turtle occur in Australian waters, and possibly within the Project footprint; the green turtle (*Chelonia mydas*), flatback turtle (*Natator depressus*), hawksbill turtle (*Eretmochelys imbricata*), loggerhead turtle (*Caretta caretta*), olive ridley turtle (*Lepidochelys olivacea*), and leatherback turtle (*Dermochelys coriacea*) (Environment Australia 2003).

The conservation status of these marine turtles is summarised in Table I. All six species are listed in Schedule I (fauna that is rare or likely to become extinct) of the Western Australian *Wildlife Conservation Act 1950* (WC Act) and are of National Environmental Significance (NES) requiring protection under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Green, flatback, hawksbill, and leatherback turtles are listed as “vulnerable”, and loggerhead and olive ridley turtles are listed as “endangered” under the EPBC Act. All six species are listed as “migratory” under the EPBC Act.

Marine turtles are also listed under the Convention for the Conservation of Migratory Species of Wild Animals (CMS/Bonn Convention) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The World Conservation Union (IUCN) has assigned “Critically Endangered” status to hawksbill and leatherback turtles and “Endangered” status to green, and loggerhead turtles, while flatback turtles are listed as “Data Deficient”.

Table I: Conservation Status of Australian Marine Turtles

Common Name	Scientific Name	Protection under Australian Legislation		International Conservation Status		
		EPBC Act	WC Act	IUCN Red List	CMS/Bonn Convention Appendix	CITES Appendix
Green turtle	<i>Chelonia mydas</i>	Migratory, Vulnerable	Rare or likely to become extinct	Endangered	I & II	I only
Flatback turtle	<i>Natator depressus</i>	Migratory, Vulnerable	Rare or likely to become extinct	Data Deficient	II only	I only
Hawksbill turtle	<i>Eretmochelys imbricata</i>	Migratory, Vulnerable	Rare or likely to become extinct	Critically Endangered	I & II	I only
Loggerhead turtle	<i>Caretta caretta</i>	Migratory, Endangered	Rare or likely to become extinct	Endangered	I & II	I only
Olive ridley turtle	<i>Lepidochelys olivacea</i>	Migratory, Endangered	Rare or likely to become extinct	Vulnerable	I & II	I only
Leatherback turtle	<i>Dermochelys coriacea</i>	Migratory, Vulnerable	Rare or likely to become extinct	Critically Endangered	I & II	I only



2.1 Marine Turtle Lifecycle

Marine turtles are migratory animals that use a variety of habitats, including marine, intertidal and beach habitats, during their life history (Lohmann et al. 1997). The general marine turtle lifecycle comprises eight broad phases, as summarised below and in Figure 1:

1. Migration from foraging to mating areas (pre-mating migration).
2. Mating.
3. Nesting.
4. Inter-nesting.
5. Migration from nesting beaches to foraging areas (post-nesting migration).
6. Egg development/hatching.
7. Post-hatchling development.
8. Foraging (juvenile and post-nesting adult turtles).

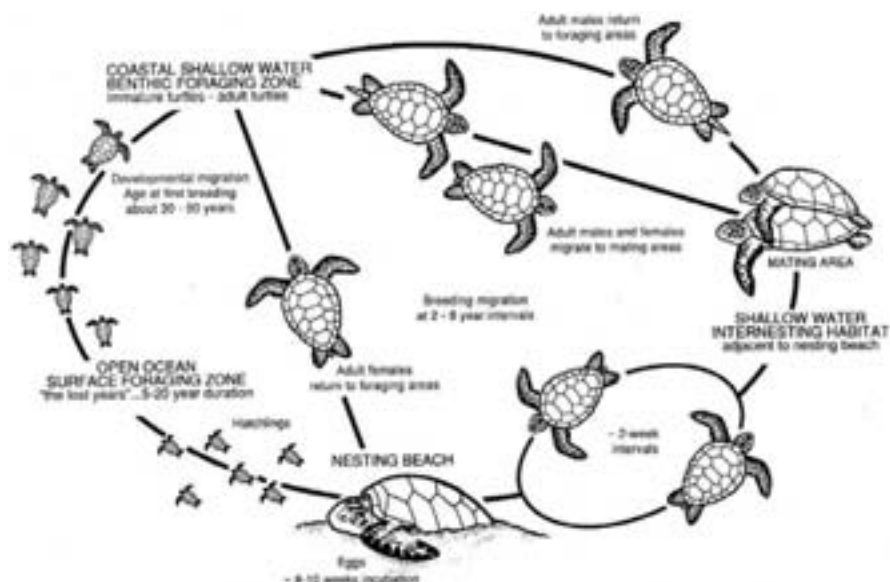


Figure 1: Basic Marine Turtle Lifecycle
Source: Miller (1997, p. 53)

The first five phases of the marine turtle lifecycle (i.e. pre-mating migration, mating, nesting, inter-nesting, post-nesting migration) are primarily associated with reproduction. The reproductive phases are similar for all species of marine turtle and most marine turtle species exhibit strong reproductive seasonality (Hamann et al. 2003).

Marine turtles reach sexual maturity at between approximately 10 and 35 years of age, depending on the species (Spotila 2004). Female turtles only reproduce on average every four years; male turtles may reproduce more often than female turtles, but not all males reproduce every year (Hamann et al. 2003; Spotila 2004). Reproduction is thought to occur only periodically in order to allow time for the turtles to regain sufficient body condition to undertake the reproductive phases, particularly the pre-mating and post-nesting migrations (Kwan 1994).

2.1.1 Pre-mating Migration

Prior to the mating season, both male and female marine turtles migrate from foraging grounds to a mating area, generally near the female's nesting grounds (Hamann et al. 2003). Migrations can cover between tens and thousands of kilometres (Lohmann et al. 1997). Males tend to migrate earlier than females, and thus reach the mating grounds first (Spotila 2004).

2.1.2 Mating

Mating generally occurs near the nesting beach (Hamann et al. 2003), in a range of water depths, and sometimes on the shoreline or beach (Broderick and Godley 1997; Plotkin 2003). Both male and female turtles mate with multiple partners each mating season (Hamann et al. 2003). Females are receptive to mating for about 7–10 days in the month prior to the nesting season, and males are sexually active for about a month (Miller 1997). However the mating season can last for several months as individual turtles arrive at the mating area at different times during the mating season (Hamann et al. 2003).

2.1.3 Nesting

Marine turtles nest at, or nearby their natal beach, i.e. the beach where they themselves hatched (Lohmann et al. 1997). Most marine turtles nest at night, though some species, including flatback and hawksbill turtles, may also nest during the day (Hamann et al. 2003).

Nesting beach habitat requirements are broadly similar for all marine turtle species. A suitable nesting beach is characterised by:

1. Clear access from the sea.
2. Adequate elevation to prevent inundation of the eggs by tides or an underlying water-table.
3. A sandy substrate which facilitates gas diffusion.
4. Sand that is moist and fine enough to prevent collapse of the egg chamber during construction (Miller 1997).

The nesting process is similar for all species of marine turtle, and can be divided into seven distinct stages:

1. Emerging from the ocean.
2. Crawling up the beach.
3. Excavating a body pit.
4. Excavating an egg chamber.
5. Laying the eggs.
6. Covering the eggs.
7. Returning to the ocean.

The nesting process can take between 1 and 6 hours, depending on the species and the suitability of the nesting site (Bustard 1972; Spotila 2004). Turtles may return to the water without laying for a variety of reasons, including disturbance — by human presence, other nesting turtles or artificial light — and inability to successfully dig a nest, due to hitting an obstruction during digging, or the sand being too dry (Bustard 1972). Turtles that return to the water without laying usually attempt to nest again on the same or a nearby beach, either the same night or within the next few nights (Miller 1997).

Tracks and markings left in the sand by nesting turtles can be interpreted to determine the species of turtle, and whether it successfully nested (Pritchard and Mortimer 1999). It is preferable to count the number of nests as well as the number of tracks as, if many turtles return to the ocean without laying, counting only tracks will result in an overestimate of nesting activity for that beach.

2.1.4 Inter-nesting

Female turtles lay between 1 and 7 clutches per nesting season, at intervals of approximately two weeks (Plotkin 2003; Spotila 2004). The time between consecutive clutches is known as the inter-nesting period. Most marine turtle species generally spend the inter-nesting period in shallow water near the nesting beach, although flatback and leatherback turtles may move up to 70 km and several hundred kilometres from their nesting beach, respectively (Plotkin 2003; Godley *et al.* 2008; Chevron Australia 2009).

2.1.5 Post-nesting Migration

After a female has laid her final clutch of eggs for the season, she migrates back to her foraging grounds in either the neritic zone (coastal habitat, <200 m water depth) or oceanic zone (open water habitat, >200 m water depth).

Satellite tracking data has identified two general post-nesting migration patterns (Godley et al. 2008):

1. Type A Turtle swims directly from the breeding area to a fixed feeding area (generally in the neritic zone).
2. Type B Turtle swims to oceanic habitat, then performs long-distance wandering movements.

Type A migrations can be further distinguished as A1, A2 and A3, as follows (Godley et al. 2008):

1. Type A1 Oceanic and/or coastal movements to neritic foraging grounds.
2. Type A2 Coastal shuttling between summer foraging and wintering sites.
3. Type A3 Local residence.

Most chelonid turtles (i.e. hard-shelled species such as green, flatback and hawksbill turtles) conform to the Type A migration pattern, although some individuals undertake Type B migrations (Chevron Australia 2008; Godley et al. 2008). Leatherback turtles typically conform to the Type B migration pattern (Godley et al. 2008).

2.1.6 Egg Development/Hatching

Turtle eggs incubate in the nest for 50–80 days (Ackerman 1997). Successful embryonic development is dependent on nest temperature, humidity, salinity and oxygen levels remaining within a narrow range (Ackerman 1997). Disturbance of the nest can change the nest microclimate and hinder embryonic development (Ackerman 1997).

Sand temperature within the nest influences the length of the incubation period and also determines the sex of the hatchlings through a process known as Temperature-dependent Sex Determination (TSD). Warmer nest environments tend to produce females, while males are produced by cooler nest environments. The threshold temperature for sex determination is between 28 °C and 30 °C (Wibbels 2003).

Hatchlings usually emerge from nests in small groups in the early evening over consecutive nights. The emergence of the first hatchlings from the nest initiates a “hatchling frenzy”, whereby the majority of hatchlings emerge from the nest and crawl towards the sea. Hatchlings orientate toward the sea by crawling towards the brighter, lower oceanic horizon and away from the elevated silhouettes of the vegetation and dunes (Salmon et al. 1992; Salmon and Witherington 1995; Witherington and Martin 2000). Natal beach recognition imprinting is likely to occur as a hatchling emerges from the nest and may be reinforced during the first nesting attempt as a mature adult (Lohmann et al. 1997).

2.1.7 Post-hatchling Developmental Stage

The post-hatchling developmental stage is often referred to as the “lost years”, because very little is known about turtle movements during this period (Spotila 2004).

Upon reaching the ocean, hatchlings of most species swim to the open ocean, appearing to use the direction of the oncoming waves as a cue for navigation (Lohmann et al. 1997). It is thought that once the hatchlings are away from the shore, and any wave cues, they use the earth’s magnetic field to navigate to the open ocean, where ocean currents carry them to areas of convergence (Lohmann et al. 1997). The hatchlings are then thought to take up residence amongst large rafts of floating seaweed in these areas of convergence, for approximately 1–10 years, depending on the species (Musick and Limpus 1997; Spotila 2004; Limpus 2009). While floating rafts of *Sargassum* thalli have been observed off the Western Australian coast, the use of this habitat by juvenile turtles in Western Australia has not been substantiated.

It appears that flatback turtle hatchlings may not migrate offshore, but may instead remain within shallow, coastal, turbid waters (Musick and Limpus 1997; Spotila 2004).

2.1.8 Foraging

After the “lost years”, most marine turtle species re-enter coastal waters, where they take up residence at juvenile foraging grounds (Musick and Limpus 1997). Leatherback turtles do not return to coastal areas to forage, but instead remain in the open ocean for this period (Spotila 2004).

Foraging grounds for juvenile turtles tend to be in structured reefs or shallow waters, where juveniles are afforded some protection from predation (Musick and Limpus 1997). Adult foraging grounds reflect adult dietary preferences (Musick and Limpus 1997). In some areas adult and juvenile foraging areas overlap, whereas as in other areas they are relatively distinct (Musick and Limpus 1997).

2.2 Marine Turtles in the Pilbara Region and Wheatstone Project Footprint

2.2.1 General

Limited research on marine turtles has been undertaken in the Pilbara region and the Wheatstone Project footprint. The information currently available is limited to nesting and post-nesting surveys of adult female turtles, primarily from the Barrow Island rookery (Pendoley 2005; Chevron Australia 2009) and aerial surveys over coastal and offshore areas (Prince 2001; Jenner et al. 2010).

The offshore islands of the Pilbara region, including those in the Project area, are recognised by the Western Australian government as important marine turtle nesting habitat (Department of Conservation and Land Management 2002). Significant marine turtle rookeries have been identified on Barrow Island, Varanus Island, the Montebello Islands, the Muiron Islands and within the Dampier Archipelago, with many other Pilbara islands supporting lower levels of marine turtle nesting (DEC 2009).

The Pilbara region also appears to support a population of resident foraging turtles that favour reef habitats, including the waters around the offshore islands. Aerial surveys of the Pilbara coast between Tubridgi Point and the De Grey River and out to the 20 m isobath in April 2000 recorded a total of 2,631 turtles, which is equivalent to a density of 0.13 turtles/km² (Prince 2001). The majority of turtles were in close proximity to the offshore islands and reef habitats. Given the timing of the survey (April) it is likely that the majority of observed turtles were resident foraging turtles. Species identification was not possible during the survey, however all turtles were chelonids.

Fortnightly aerial surveys of the Pilbara region between May and December 2009 recorded an average of 93 turtles per survey, with the total numbers of turtles recorded during each of the seven surveys ranging from 14–261 (Jenner et al. 2010). The flight paths of the seven surveys covered two areas; i) between Urala and the Mangrove Islands and out to approximately the 1000 m isobath, and ii) between the Mangrove Islands and the Mary Anne Island Group and out to approximately the 40 m isobath. The majority of turtles seen were inside of the 100 m isobath, with very few turtles seen in water deeper than 100 m (Jenner et al. 2010).

2.2.2 Species-specific

All six species of Australian marine turtle occur within the Pilbara region and are expected to use habitats within the Project footprint at some stage of their lifecycle. Four species of marine turtle — green, flatback, hawksbill and loggerhead turtles — are also likely to mate and nest in the Project area.

The expected peak timing of lifecycle phases in the Pilbara region varies between the four species, as shown in Table 2. These peaks are when the highest number of turtles are likely to be engaged in these lifecycle phases, and lower numbers of turtles can be expected to be engaged in these phases in the months before and after the peak periods (i.e. the shoulder periods). The shoulder periods for the nesting and inter-nesting life history phases are also included in Table 2.

Due to the nearshore location of the Project footprint, the only species that is expected to possibly use the Project footprint for the post-hatchling developmental stage is the flatback turtle, and this lifecycle phase is not included in Table 2. If post-hatchling flatback turtles remain in the area, they are likely to be present throughout the year.



Table 2: Expected Peak Timing of Lifecycle Phases for Green, Flatback, Hawksbill and Loggerhead Turtles in the Pilbara Region. Paler Colours indicate Shoulder Periods for Nesting and Inter-nesting

Marine Turtle Species	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Pre-nesting migration												
Green			?	?								
Flatback				?	?							
Hawksbill		?	?									
Loggerhead				?	?							
Mating												
Green				?	?	?						
Flatback					?	?						
Hawksbill			?	?								
Loggerhead					?	?						
Nesting and inter-nesting												
Green ^{a, b}												
Flatback ^b												
Hawksbill ^{a, b}												
Loggerhead ^{c, d, e}												
Post-nesting migration												
Green ^a												
Flatback												
Hawksbill ^a												
Loggerhead												
Hatching												
Green												
Flatback ^b												
Hawksbill												
Loggerhead ^e												
Post-hatchling development												
Green												
Flatback ^b												
Hawksbill												
Loggerhead												
Foraging (Post-nesting)												
Green	?	?										
Flatback	?	?	?									
Hawksbill	?											
Loggerhead	?	?	?									

^a Source: Pendoley (2005).
^b Source: Chevron Australia (2009).
^c Source: Mau and Balcazar (2007).
^d Source: Markovina (2008).
^e Source: Prince (1994).
 ? Unconfirmed, but inferred from timing of other lifecycle events for that species, as well as literature on timing and duration of lifecycle events for other turtle species/other geographic areas (e.g. Hamann et al. (2003)) and anecdotal observations.

2.2.2.1 Green Turtles

Green turtles are the most widespread and abundant turtle species in Western Australia, including in the Pilbara region (Prince 1994a). Green turtles are likely to use the Project footprint for all phases of their life history, except for the post-hatching developmental stage.

There are seven recognised breeding stocks or “Management Units” (MUs) of green turtles in Australia (Figure 2). Green turtles that nest in the Pilbara region are part of the North West Shelf MU (Moritz et al. 2002), which is one of the world’s largest green turtle populations (Limpus 2009).

Barrow Island, the Montebello Islands and North West Cape are three of the principal nesting areas for green turtles from the North West Shelf MU (Limpus 2009). Green turtles also nest on other offshore Pilbara islands, including the Muiron Islands, Thevenard Island, Airlie Island, Varanus Island, Serrurier (Long) Island and Locker Island (Prince 1994a; Mau and Balcazar 2007; DEC 2009).

The nesting population at Barrow Island is estimated to comprise 20,000 female green turtles (Pendoley 2005). Population estimates are not available for the other principal Pilbara green turtle nesting areas (Pendoley 2005; Markovina 2008; Limpus 2009).

A survey of mainland and island beaches in the vicinity of the Project footprint in early January 2009 (Pendoley Environmental 2009a) recorded no green turtle tracks on the mainland at or adjacent to the proposed Ashburton North development site. Green turtle tracks were recorded on islands offshore from the proposed Ashburton North development site, including Bessieres Island, Serrurier Island, Thevenard Island, Direction Island, Locker Island and Tortoise Island; however these islands were not thought to support levels of nesting as high as Barrow Island or the Montebello Islands (Pendoley Environmental 2009a). Green turtle tracks were not recorded on Ashburton Island (Pendoley Environmental 2009a).

Satellite tracking of green turtles on nesting Barrow Island indicated that some of these turtles (n=4) inter-nested along the coast of Barrow Island and migrated northwards at the conclusion of the nesting season to various Pilbara and Kimberley locations, including Legendre Island, the De Grey River mouth and Cape Bossut (Pendoley 2005). Other green turtles (n=2) migrated south; one stopped transmitting near Locker Island, the other was tracked to Shark Bay (Pendoley 2005).

Green turtles are predominantly herbivorous, feeding principally on seagrass, a wide range of algae and mangrove fruits (Whiting and Miller 1998; Read and Limpus 2002). They also feed on soft-bodied pelagic and benthic invertebrates, including jellyfish, salps and sponges (Heithaus et al. 2002; DEC 2009).



Limited studies of any marine turtle foraging have been undertaken in Western Australia. Pendoley (2005) reported that adult and juvenile green turtles are commonly observed feeding on turfing algae on the west coast of Barrow Island. Juvenile green turtles have been observed in the waters around Locker Island (Mau 23 July 2009 pers. comm.), Ashburton Island, Thevenard Island, Serrurier Island and Direction Island (Pendoley Environmental 2009a), presumably at their foraging grounds.

Immature and adult green turtles of the Southern Great Barrier Reef Management Unit feed in intertidal and subtidal habitats, including coral and rocky reefs, seagrass meadows, algal turfs on sand or mud flats, in the eastern Arafura Sea, Gulf of Carpentaria, Torres Strait, Gulf of Papua, Coral Sea, Great Barrier Reef, Hervey Bay, Moreton Bay and NSW coastal waters (Limpus 2009). Green turtles are expected to forage within similar habitats within the Project footprint.

Mating aggregations of green turtles have been recorded on the west coasts of Barrow Island and Trimouille Island (one of the Montebello Islands) prior to the nesting season, in November 1999 and 2002 (Pendoley 2005) and low numbers of mating green turtles have been observed near Serrurier Island in January 2009 (Pendoley Environmental 2009a), indicating that Pilbara green turtles mate near nesting beaches.

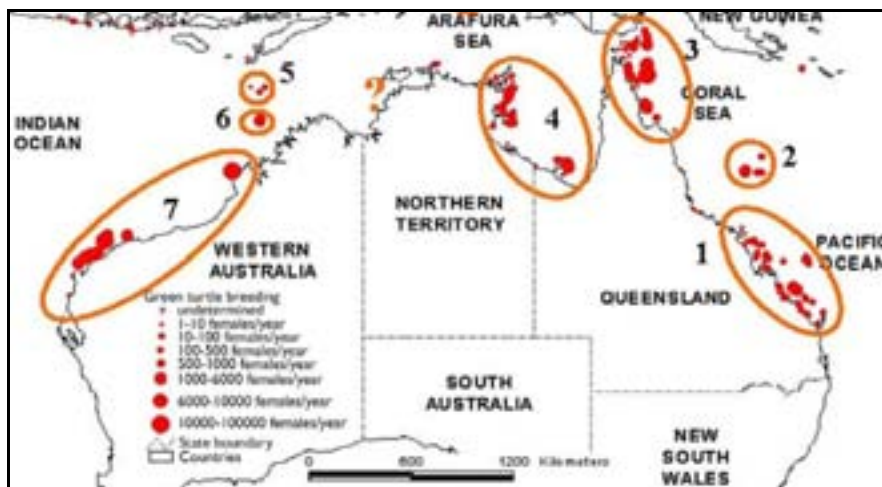


Figure 2: Seven Recognised Australian Green Turtle Management Units
Source: Limpus (2009)

2.2.2.2 Flatback Turtles

There is limited publicly available information about flatback turtles in Western Australia as the majority of research has been undertaken on behalf of private industry and is subject to confidentiality agreements. The majority of information about flatback turtles in Western Australia is from studies conducted at the Barrow Island rookery.

There are four recognised flatback turtle MUs in Australia (Figure 3). Flatback turtles that nest in the Pilbara region are part of the North West Shelf MU (Limpus 2009).

Known major rookeries for flatback turtles from the North West Shelf MU include Barrow Island, the Montebello Islands, Thevenard Island, Varanus Island, Rosemary Island and the Dampier Archipelago, as well as stretches of mainland coast between Mundabullangana and Broome (DEC 2009; Limpus 2009).

Lesser rookeries include the Muiron Islands, the mainland between Locker Point and Onslow, Ashburton Island, Bessieres Island, Thevenard Island, Direction Island, Tortoise Island, Locker Island, Airlie Island, Bridled Island, Delambre Island and Cape Lambert (DEC 2009; Pendoley Environmental 2009a).

It is estimated that approximately 1,700 flatback turtles nest annually on Mundabullangana Station and that approximately 1,600 nest annually at Barrow Island, with limited inter-annual variation (DEC 2009a; Pendoley Environmental 2009b). These numbers equate to approximately 17–26% and, 16–24% of the North West Shelf MU, respectively. It is estimated that between 500 and 1,000 flatback turtles (approximately 8–10% of the North West Shelf MU) nest in the area between Onslow and Exmouth Gulf (including Ashburton island, Direction Island, Thevenard Island, Tortoise Island and Twin Islands) each year (DEC 2009a).

While there is limited inter-annual variation in the numbers of flatback turtles nesting on Barrow Island (Pendoley Environmental 2009b), high variability in the number of flatback turtle tracks recorded on Barrow Island in January has been observed over 5 consecutive years (2004–2008), suggesting that there may be high inter-annual variation in the timing of the peak of the nesting season (Pendoley Environmental 2008).

Flatback turtles that nest at Barrow Island prefer low energy (i.e. protected) beaches with deep sand (Pendoley 2005; Chevron Australia 2008) and nesting is strictly seasonal (Chevron Australia 2009), unlike some rookeries in the Northern Territory and Queensland, where year-round nesting has been recorded (Limpus 2009).

Satellite tracking of flatback turtles nesting at Barrow Island indicates that many of these turtles spend the inter-nesting period in the shallow waters off Barrow Island, while others spend this time near the Pilbara mainland (Chevron Australia 2008). Many of these individuals migrate along the inner continental shelf to the Kimberley region, at the end of the nesting season (Chevron Australia 2008).

Flatback turtles are carnivorous, feeding principally on soft-bodied invertebrates including soft corals, sea pens, holothurians and jellyfish (Limpus 2009).

Flatback turtle feeding grounds in Western Australia are yet to be determined. Recent studies in Western Australia indicate that post-nesting flatback turtles inhabit waters of 25–100 m depth and spend large amounts of time in clear deep water (Chevron Australia 2008), where they may feed on benthic or pelagic prey. It appears that post-nesting flatback turtles do not migrate to a single foraging area, but may move between several feeding grounds (Chevron Australia 2008), which means that turtle densities at foraging areas may vary with time.

In north-eastern Australia and the Gulf of Carpentaria, flatback turtles forage in turbid, shallow, inshore waters in depths between 5 and 20 m (Bjorndal 1997) and are rarely found foraging in intertidal seagrass meadows or coral reef habitats (Limpus 2009). Flatback turtles have been captured in soft bottomed habitats of 6–35 m water depth and 11–40 m during trawl fishery activities within the Great Barrier Reef region and Torres Strait, respectively; it is presumed that these turtles were in their foraging habitat (Limpus 2009). Flatback turtles are regularly reported in prawn trawl catches in the Gulf of Carpentaria and the Great Barrier Reef region and are recognized as a regular inhabitant of shallow inshore turbid waters and bays in these presumed foraging areas (Limpus et al. 1983).

Little is known about the mating habitat of flatback turtles. A male flatback turtle was seen off the east coast of Barrow Island in December 2008 (Smith pers. comm. 8 September 2009), which is within the presumed flatback turtle mating season (refer Table 2). The circling behaviour of this male turtle suggests that he may have been in the area for mating (Crowell Comuzzie and Owens 1990). Flatback turtles have been observed mating in the Northern Territory on the shores of Bare Sand Island and at Roche Reef, 10–15 km from a nesting beach at Bare Sand Island (Guinea pers. comm. 2007). Mating flatback turtles were also observed on four occasions in the water (approximately 0.7 m deep) adjacent to a nesting beach on Crab Island, on the tip of Cape York Peninsula (Limpus et al. 1993). This information suggests that flatback turtles mate near their rookeries, but that mating is not restricted to the immediate vicinity of nesting beaches.

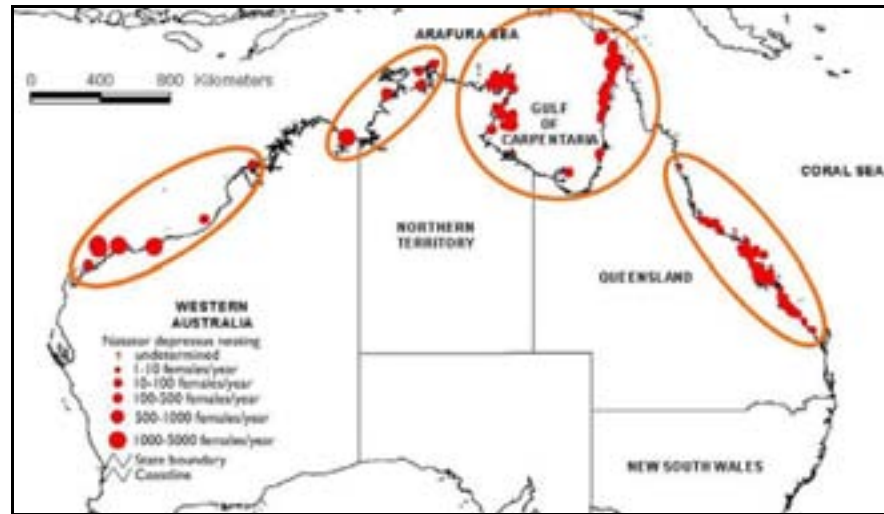


Figure 3: Four Recognised Australian Flatback Turtle Management Units
Source: Limpus (2009)

2.2.2.3 Hawksbill Turtles

There are presently two recognised Australian hawksbill turtle MUs (Figure 4), one that nests in Western Australia and one that nests in the Northern Territory and Queensland (Limpus 2009). The Western Australian breeding population of hawksbill turtles is one of the largest in the world (Limpus 2009).

The most important rookeries for the Western Australian hawksbill turtle MU are in the Dampier Archipelago and on the Montebello Islands. Lower density nesting also occurs at the Lowendal Islands, Barrow Island, Airlie Island, the Muiron Islands and the North West Cape (DEC 2009; Limpus 2009). The Project footprint is to the south of the main hawksbill turtle rookeries, but falls within the recorded nesting range of this species.

Nesting surveys completed on mainland and island beaches in the vicinity of the Project footprint in early January 2009 did not record any evidence of hawksbill turtle nesting, (Pendoley Environmental 2009a) however these surveys were completed outside of the peak nesting season for this species (refer Table 2).

Unlike in eastern Australia, where year-round nesting has been recorded, the Western Australian hawksbill turtle MU is thought to nest seasonally, (Limpus 2009).

Satellite tracking of hawksbill turtles nesting on offshore Pilbara islands indicated that they remained close to their nesting beach during the inter-nesting period (Pendoley 2005). Following the nesting season, the tracked hawksbill turtles migrated to their presumed foraging grounds in the Pilbara region, including the De Grey River mouth, Great Sandy Island, Mary Anne Islands, Nickol Bay and Sholl Island (Pendoley 2005).

Hawksbill turtles have a unique diet comprised primarily of sponges (Spotila 2004). They also forage on cephalopods, gastropods, cnidarians, seagrass and seaweed (Carr and Stancyk 1975; Witzell 1983; Limpus 1992; Whiting 2000). Hawksbill turtles have been found foraging over seagrass and reef habitats within the Darwin Harbour at low densities (Whiting 2001). Hawksbill turtles are expected to forage in similar habitats within the Project footprint.

Little is known about mating activity of hawksbill turtles in Western Australia (Limpus 2009), but they are expected to mate in shallow waters close to nesting beaches (Plotkin 2003).

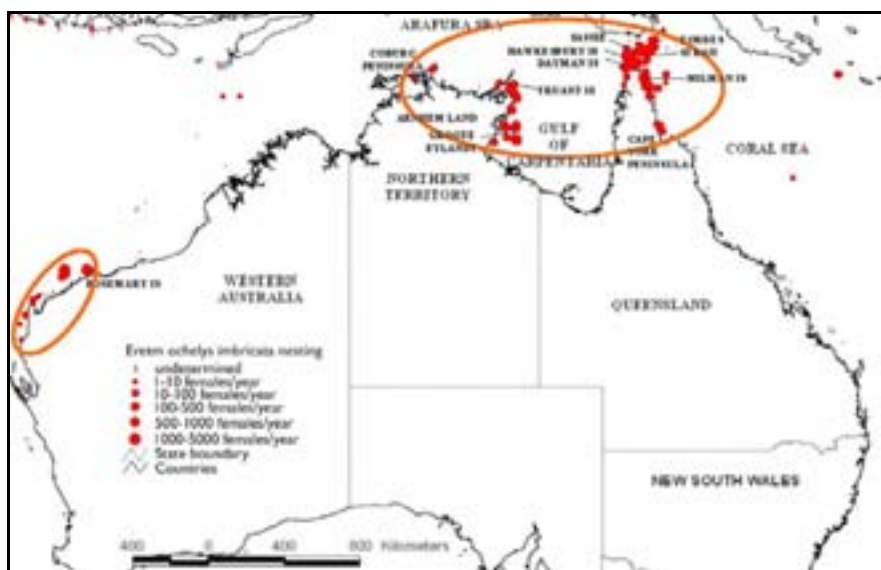


Figure 4: Two Recognised Australian Hawksbill Turtle Management Units
Note: Data are incomplete for the western Northern Territory and Western Australia
Source: Limpus (2009)

2.2.2.4 Loggerhead Turtles

There are two recognised loggerhead turtle MUs in Australia (Figure 5), one that nests in Western Australia and one that nests in eastern Australia (Limpus 2009). The majority of nesting by loggerhead turtles in the Western Australian MU occurs in the Gascoyne and lower Pilbara regions, between Shark Bay and the Muiron Islands. Lower density nesting occurs to the north of this area (Prince 1994a; Limpus 2009). Major loggerhead turtle rookeries in Western Australia include Dirk Hartog Island and the Muiron Islands.

Loggerhead turtle nesting has been recorded on Locker Island, Serrurier Island, Barrow Island, Varanus Island and Rosemary Island (Mau and Balcazar 2007; DEC 2009), however these islands, and the Project footprint, are outside (north) of the main loggerhead turtle nesting areas and are unlikely to be important loggerhead turtle rookeries.

Surveys of mainland and island beaches in the vicinity of the Project footprint, completed in early January 2009 recorded one loggerhead turtle nest on Bessieres Island; there was no evidence of loggerhead turtles nesting on Ashburton Island, Locker Island, Thevenard Island, Round Island, Direction Island or Tortoise Island, or on mainland beaches adjacent to the proposed Ashburton North Development site (Pendoley Environmental 2009a).

There is limited information on the in-water movements of loggerhead turtles in Western Australia. Loggerhead turtles tracked from their nesting beaches on the North West Cape spent the inter-nesting period near North West Cape, but migrated to a wide range of foraging grounds, including the Sahul Banks (Timor Sea), Cape York, Port Hedland and Shark Bay, after the nesting season (DEC 2009b). One individual remained at the North West Cape (DEC 2009b). Nesting loggerhead turtles that were tagged at the Muiron Islands have been recaptured in Indonesia and the Northern Territory (Baldwin et al. 2003), indicating potential overlap of the Project footprint with the post-nesting (and pre-mating) migratory pathway of at least some individuals of this species.

Loggerhead turtles are carnivorous and feed primarily on crustaceans and molluscs, including scallops, clams and crabs, as well as sea anemones and jellyfish (Spotila 2004). The results of various satellite tracking and flipper tagging programs indicate that post-nesting loggerhead turtles forage over a relatively small area, in the order of tens of square kilometres, moving between preferred sites within the larger foraging area (Schroeder et al. 2003). Some individuals may migrate between several foraging areas (Schroeder et al. 2003).

Shark Bay is the best-known foraging area for loggerhead turtles in Western Australia (Limpus 2009), however there is limited published information about the diet and movements of loggerhead turtles in this area (Heithaus et al. 2005). Loggerhead turtles from the eastern Australian Management Unit forage over a wide range of habitats, including coral and rocky reefs, seagrass meadows and soft-bottomed sand/mud habitats (Limpus 2009). It is likely that loggerhead turtles forage in similar habitats in the Pilbara region, including in the vicinity of the Project footprint.

Little is known about loggerhead turtle mating in Western Australia (Limpus 2009), but it is expected to occur either en-route or adjacent to nesting beaches (Plotkin 2003).

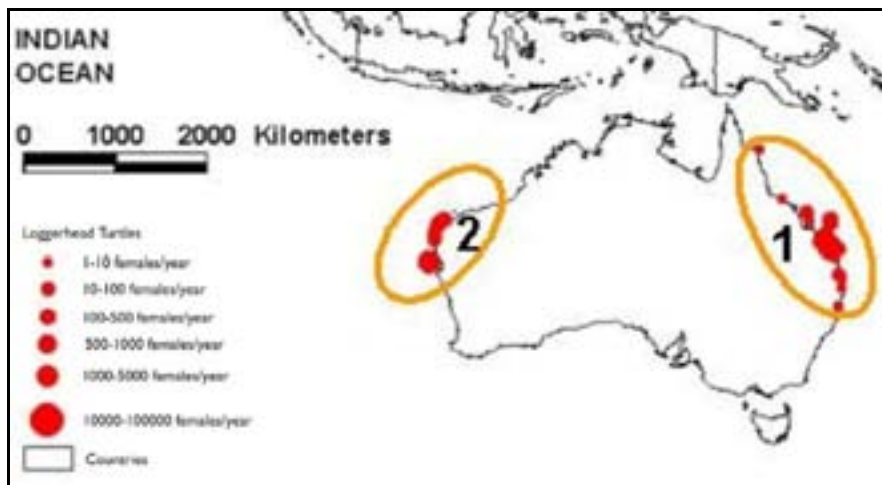


Figure 5: Two Recognised Australian Loggerhead Turtle Management Units
Note: Data are incomplete for the western Northern Territory and Western Australia
Source: Limpus (2009)

2.2.2.5 Olive Ridley Turtles

There is limited information on movements of olive ridley turtles in Western Australia. This species forages within the shallow benthic habitats of northern Western Australia and is thought to feed primarily on gastropods and small crabs within the benthic, soft-bottomed communities of the continental shelf (Limpus 2009).

Olive ridley turtles in Western Australia are known only from a few individuals caught by fishers off the Kimberley–Pilbara coast (Robins et al. 2002) and from two recent records of nests, one recorded near Cape Leveque in March 2008 (Oades pers. comm. 26 August 2009), and one on Darcy Island, an offshore island in the Kimberley region, in June 2008 (DEC 2009).

2.2.2.6 Leatherback Turtles

Leatherback turtles are oceanic and occur worldwide throughout tropical and temperate oceans (Spotila 2004). Leatherback turtles are not known to mate or nest in Western Australia, but have been recorded in the waters off Broome and between Bunbury and Shark Bay (Limpus 2009). Leatherback turtles could occasionally occur within the Project footprint.

Leatherback turtles are carnivorous and feed predominantly on soft-bodied invertebrates, including jellyfish, throughout the water column (Spotila 2004; Limpus 2009).

There are no confirmed records of leatherback turtles nesting within Western Australia (Limpus 2009).

2.3 Existing Threats

The DEC (2009) recognises the following threats to marine turtles in Western Australia:

- Industrial and urban development (lighting, vessel operation, dredging and noise).
- Predators (introduced and natural).
- Recreation and tourism.
- Climate change.
- Salt production and aquaculture.
- Fisheries (commercial and recreational).
- Hunting (indigenous and illegal).
- Marine debris/spills/pollution.

Given these threats are generally associated with activities on the mainland, the Western Australian government (Department of Conservation and Land Management 2002; DEC 2009) considers the protection of marine turtle nesting areas on offshore islands in the Pilbara region a high priority. The island rookeries are considered critical habitats because:

1. Predation of nests by introduced animals, particularly foxes, is seriously affecting the productivity of WA mainland nesting beaches, while offshore Pilbara islands are largely free from introduced predators (DEC 2009).
2. The area between the North West Cape and Port Hedland has the highest incidence of artificial lighting on turtle nesting beaches in Western Australia, the cumulative impacts of which have not been assessed (DEC 2009).
3. Turtles that nest on the mainland may be disturbed by tourists, whereas there is limited tourism on the offshore islands (DEC 2009).



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3.0 RATIONALE FOR THE RESEARCH

Marine turtles are vulnerable to disturbance from a variety of anthropogenic factors including artificial light, noise and vibration, vessel movements and loss of habitat (Committee on Sea Turtle Conservation 1990). All of these anthropogenic factors will occur at various times and in various locations during construction and operations activities of the Wheatstone Project.

The vulnerability of marine turtle populations to disturbance from anthropogenic factors varies according to the life history phase(s) and species of the exposed turtles, whether the habitats affected are critical for any life history phase and the proportion of a turtle population exposed to the factor. The seasonality of marine turtle life histories (refer Table 2), means that the potential for impact will change throughout the year.

The Wheatstone Project has the potential to affect marine turtles during each of their life history phases. The main aspects of the Project with potential to impact marine turtles include dredging, lighting (both onshore and offshore) and increased levels of shipping in the region. The significance of potential impacts from these aspects of the Project on marine turtles depends on the importance of affected habitats to the regional population¹.

As outlined in the previous sections, little is known about the distribution and habitat use of marine turtles in the Pilbara region, and more specifically, the proposed Project footprint. The main gaps in knowledge that, if filled, would help to determine the likelihood of impacts to marine turtles from the Project, and the need for management measures include the:

- Importance of mainland and island beaches within the Project footprint for nesting by the regional genetic population of each marine turtle species (required for determining potential impacts from and need for management of Project lighting).
- Presence/location of mating and inter-nesting habitats within the Project footprint, and the importance of these habitats to the regional genetic population (required for determining potential impacts from and need for management of Project dredging and shipping).

¹ For the purposes of this report, regional marine turtle populations are considered at two levels: genetic populations and resident populations. The genetic population includes all turtles (regardless of life history phase) that belong to the same MU as those turtles that nest in the Pilbara region. For most species, this will be the North West Shelf MU. The resident population includes all resident foraging turtles in the Pilbara region.



- Importance of the Project footprint for the regional marine turtle foraging population (required for determining potential impacts from and need for management of Project dredging and shipping).
- Migratory pathways and foraging ground locations for turtles that nest in the vicinity of the Project footprint (required for determining potential impacts from and need for management of Project dredging and shipping).

4.0 AIMS AND OBJECTIVES

The aims of the studies within this report were to assess the importance of the Project footprint for marine turtle nesting, inter-nesting, migration and foraging and to provide baseline data relating to hatching success and hatching orientation, in order to guide management of potential impacts to marine turtles from the Project.

The specific objectives of these studies were:

Nesting Density

- Identify the species of marine turtle that nest within the Project footprint.
- Determine the relative density of nesting for each turtle species.
- Determine the suitability of beaches in the vicinity of the Project footprint for marine turtle nesting.
- Determine the importance of the Project footprint for nesting turtles.

Inter-nesting Movements

- Determine the importance of the Project footprint for inter-nesting turtles.
- Determine the time spent by inter-nesting turtles on the sea-bottom and at/near the sea surface within the Project footprint (to determine the vulnerability of inter-nesting turtles to impacts from dredging and shipping).

Post-nesting Migration

- Determine the importance of the Project footprint for migrating turtles.
- Determine the of time spent on the sea-bottom and at/near the sea surface within the Project footprint by migrating turtles (to determine the vulnerability of migrating turtles to impacts from dredging and shipping).

Hatching Success

- Determine the productivity of nesting beaches within the Project footprint (so that any change in productivity during Project construction and operation can be identified).



Hatchling Dispersion

- Establish a baseline of hatchling dispersion patterns after emergence from the nest, (so that any effects of Project construction and operation lighting on hatchling dispersion patterns can be identified and mitigated).

Foraging Habitat

- Determine the most prevalent marine turtle species and size classes using the Project footprint during the peak foraging season.
- Identify important habitats for foraging marine turtles within and adjacent to the Project footprint.

Further studies will be planned to address remaining gaps in knowledge not addressed in these studies.

5.0 METHODS

5.1 Nesting Studies

Surveys of marine turtle nesting activity in the vicinity of the proposed Wheatstone Project footprint were conducted between 24 January and 7 February 2009 by Pendoley Environmental and between 15 and 19 December 2009 by RPS. Refer to Appendix I for the Pendoley Environmental survey report. The survey methods for both the Pendoley Environmental and RPS surveys are summarised below.

5.1.1 Pendoley Environmental Studies

The nesting studies conducted by Pendoley Environmental comprised track count studies and a visual assessment of potential nesting habitat for marine turtles. Track-count surveys and visual assessments were conducted on both mainland and offshore island beaches within and adjacent to the Project footprint.

5.1.1.1 Survey Design

Pendoley Environmental completed two types of track-count surveys:

- a) Snapshot surveys:
 - Counts of turtle tracks were completed on a single day at each beach surveyed. Tracks were recorded as either:
 - “Below the high tide mark” (BHT); meaning that the track extended below the latest high tide mark (which indicates that the turtle was on the beach subsequent to the last high tide; a maximum of 6 hour previously)
 - “Above the high tide mark” (AHT); meaning that the track does not extend below the high tide mark (which indicates that the track is older).
- b) Census surveys
 - Counts of turtle tracks were completed on four consecutive days. A “census line” was drawn across the length of the beach above the high tide mark each day. BHT tracks and return tracks left by turtles crossing the census line were counted the following day.

Census surveys were completed at 11 sites and snapshot surveys were completed at 17 sites (Table 3). Figure 6 shows the locations of all survey sites except for the Onslow Mainland Beach sites 1–7; the locations of these beaches are shown in Figure 7. Census surveys were completed on potential nesting beaches near the proposed Ashburton North development site. Snapshot surveys were completed on beaches further away from Ashburton North, or where limited nesting was expected due to poor nesting habitat.



Track-count surveys were conducted during daylight, according to techniques described in Pendoley (2005) and consistent with the methods recommended by Schroeder and Murphy (1999). Observations included:

- Species identification from track characteristics (e.g. width, shape and tail drag marks).
- Whether the track extended below the high tide mark.
- Whether the turtle nested (evidenced from the size, shape and compaction of sand at the potential nest site).
- Evidence of nest predation (e.g. animal footprints, digging, egg shell/hatchling remains).
- The presence of any dead or stranded turtles, including skeletons.
- Beach characteristics, including profile, approach from the sea, sand grain size and sand colour.

Each beach where track-counts were undertaken was assessed for its suitability for marine turtle nesting. Suitability was assessed by general observations of beach slope, ease of access from the sea and substrate composition.

Table 3: Census and Snapshot Beaches Surveyed by Pendoley Environmental January–February 2009

Survey Site	Snapshot Survey Date	Census Survey Date
Offshore Island Beaches		
Ashburton Island	25 Jan	31 Jan – 03 Feb
Bessieres Island	25 Jan	30 Jan – 02 Feb
Direction Island	31 Jan	–
Flat Island	04 Feb	–
Locker Island	05 Feb	–
North-east Twin Island	03 Feb	–
Round Island	04 Feb	–
Serrurier Island (east coast)	04 Feb	–
Serrurier Island (south coast)	04 Feb	–
Serrurier Island (west coast)	04 Feb	–
South-west Twin Island	06 Feb	–
Table Island	04 Feb	–
Thevenard Island (northern section)	–	30 Jan – 02 Feb
Thevenard Island (southern section)	–	30 Jan – 02 Feb



Survey Site	Snapshot Survey Date	Census Survey Date
Thevenard Island (western section)	25 Jan 30 Jan	–
Tortoise Island	01 Feb	–
Mainland Beaches		
Ashburton River Delta	03 Feb 06 Feb	–
Coolgra – Beadon Creek	06 Feb	–
Locker Point – Urala	05 Feb	–
Onslow Mainland Beach 1	–	03 Feb–06 Feb
Onslow Mainland Beach 2	–	03 Feb–06 Feb
Onslow Mainland Beach 3	–	03 Feb–06 Feb
Onslow Mainland Beach 4	–	03 Feb–06 Feb
Onslow Mainland Beach 5	–	03 Feb–06 Feb
Onslow Mainland Beach 6	–	03 Feb–06 Feb
Onslow Mainland Beach 7	–	03 Feb–06 Feb
Onslow Back Beach	06 Feb	–



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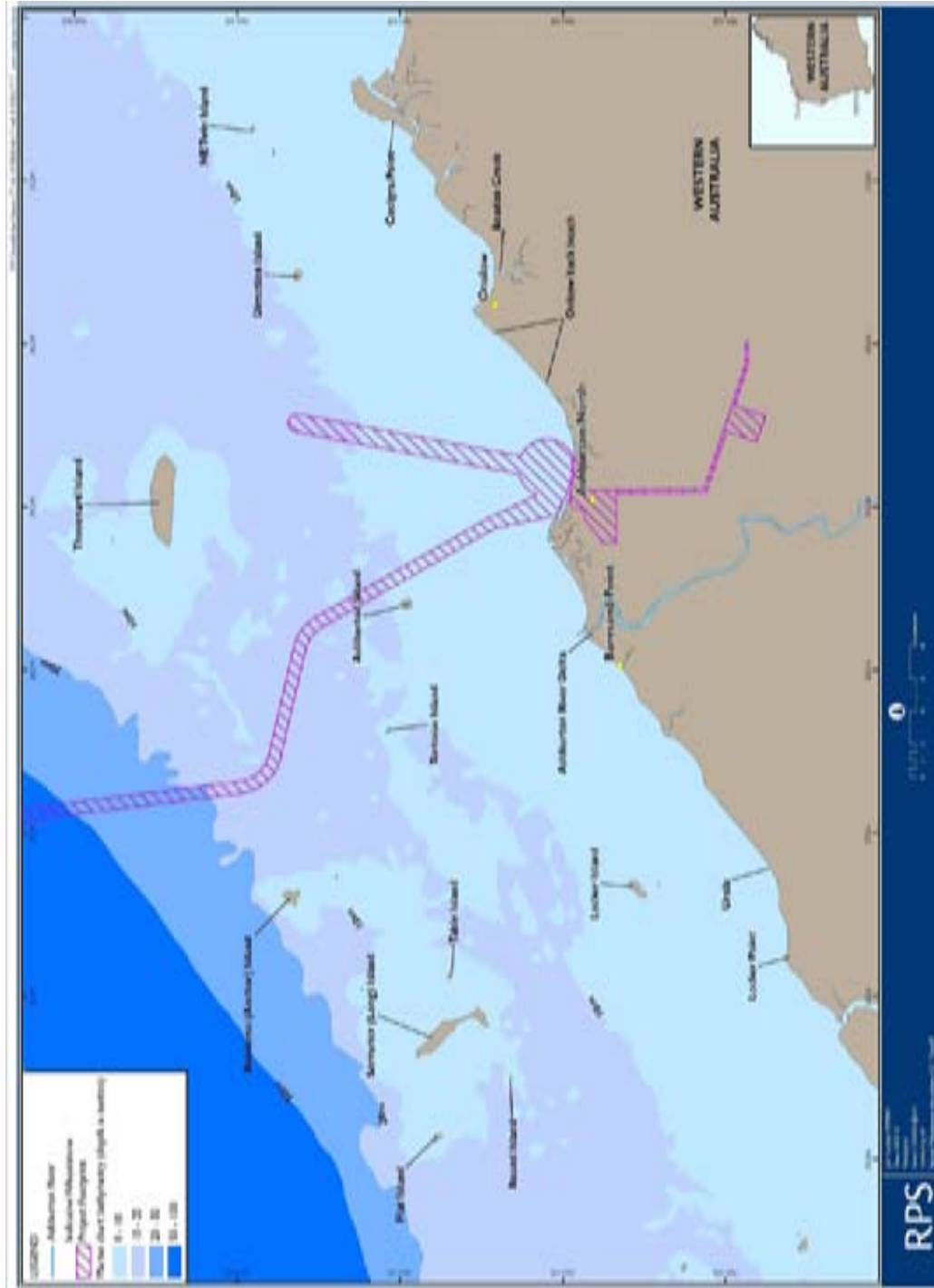


Figure 6: Survey Sites for the Penderley Environmental Nesting Studies (Excluding Onslow Mainland Beaches 1-7)

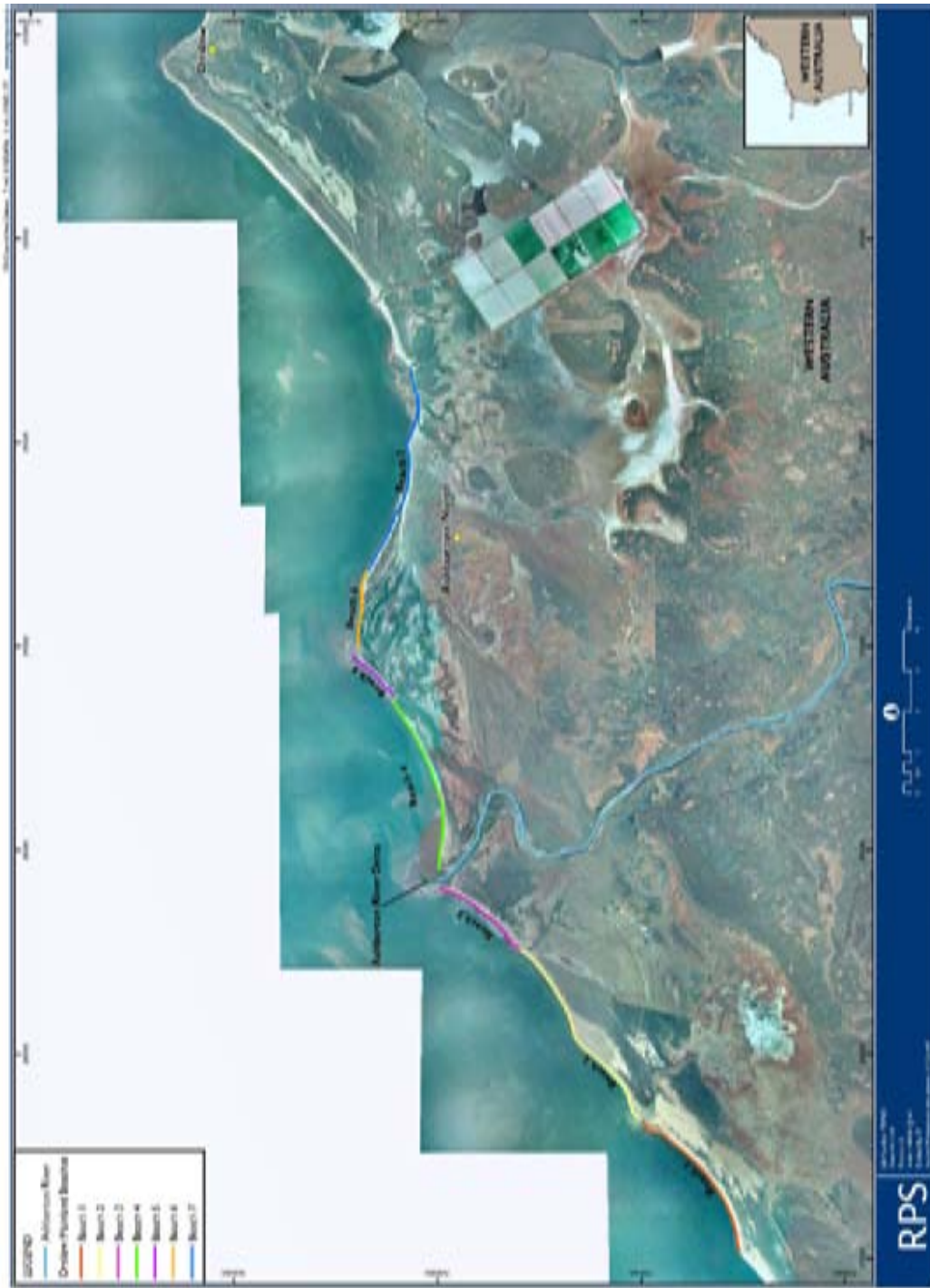


Figure 7: Locations of Onslow Mainland Beaches Surveyed by Pendoley Environmental (2009)

5.1.1.2 Research Personnel

The research personnel involved in the design and execution of the Pendoley Environmental (2009) nesting studies were Kellie Pendoley, Barry Krueger, Nicholas Sillem and Anna Vitenbergs.

5.1.1.3 Data Analysis

Data from the Pendoley Environmental (2009) snapshot surveys was summarised to show the total number of AHT and BHT return tracks of each species at each survey site.

Pendoley Environmental (2009) census survey data was analysed to determine the total numbers of return tracks (BHT and census line tracks) of each species at each site. Track densities were then calculated as follows:

$$\text{Track density (\# tracks/ km/ night)} = \frac{(\text{Total no. of tracks}) \div (\text{Transect length (km)})}{(\text{No. of census days})}$$

A qualitative assessment of suitable nesting habitat was conducted based on criteria outlined in Section 2.1.3.

5.1.2 **RPS Studies**

The RPS nesting studies also comprised track counts and visual assessment of the suitability of beaches for marine turtle nesting. These preliminary nesting studies were completed as a secondary objective during the satellite telemetry studies (refer Section 5.2).

5.1.2.1 Survey Design

RPS completed two types of track count surveys in the Project area (Figure 8):

- Counts of fresh turtle tracks and nests at Ashburton Island.
- Vessel-based observations of AHT and BHT tracks on mainland beaches between Onslow and Baresand Point

Counts of Fresh Turtle Tracks and Nests at Ashburton Island

Counts of fresh turtle tracks and nests were completed over a 686 m transect on the south-east side of Ashburton Island on 15 December 2009 (Table 4; Figure 8). Surveys were also planned for 16–20 December, however strong winds prevented access to the island on those dates.

Fresh turtle tracks were identified as those that either:

- a) Crossed a line drawn in the sand above the high tide mark the previous day (census line).
- b) Were entirely below the previous night's high tide mark.

As each turtle that emerges to nest leaves two tracks on the beach (an emerge and a return track), return tracks only were recorded, to represent a single turtle on the beach. Return tracks generally provide a clear mark in the sand below the high tide and it is more efficient to follow return tracks than emerge tracks when locating nests.

To distinguish between nesting crawls and false crawls, each return track was followed to where the turtle had last dug in the sand. As per Schroeder and Murphy (1999), nests were identified from false crawls by the presence of:

- Sand misted over the emerge track (evidence of front flippers flicking sand back).
- An escarpment where the primary body pit had been filled in.
- A shallow secondary body pit.
- Damp sand thrown in the vicinity of the secondary body pit.

Vessel-based Observations of AHT and BHT Tracks on Mainland Beaches

Vessel-based observations of AHT and BHT tracks were conducted opportunistically at mainland beaches between Onslow and Baresand Point (Figure 8) on 17, 18 and 19 December 2009 (Table 4; Figure 8), during periods of poor weather when Ashburton Island could not be accessed. The objective of the vessel-based observations was to confirm Pendoley Environmental's assessment of the suitability of mainland beaches for nesting.

Vessel-based observations were used in lieu of beach based surveys, for several reasons including:

- The opportunistic nature of the surveys.
- The large area to be covered.
- The inability to access some of the beaches from either road or vessel.

Each beach was divided into transects ranging in length from 173 m to 3.015 m (Table 4). Due to the opportunistic nature of the surveys and weather constraints, the transect lengths were not standardised.

The vessel tender was driven parallel to the shoreline along the length of transects, at a distance of approximately 50–250 m from the shoreline (depending on the height of the tide at the time). One person observed tracks, using binoculars to assist with vision, and another person recorded the observations.

The total number of tracks in each transect was recorded, as it was not possible to distinguish between emerge and return tracks from the vessel. AHT tracks were recorded on the first survey day at each beach only, to avoid counting old tracks twice.



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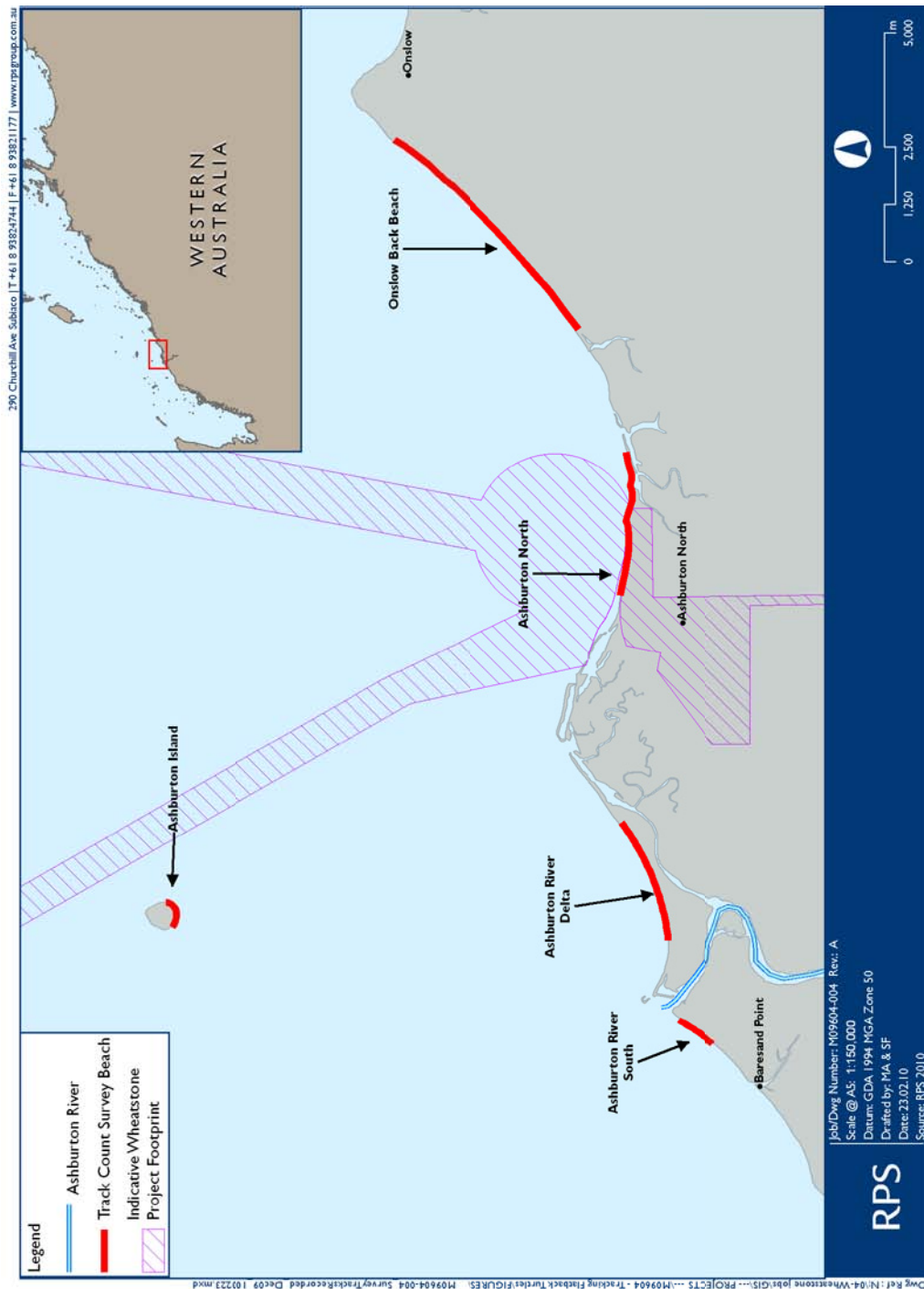


Figure 8: Beaches Surveyed by RPS in December 2009



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Table 4: Survey Schedule for RPS Track Count Surveys

Date	Beach	Transect Start Location	Transect End Location	Transect Length (km)	Total Length Surveyed (km)
15/12/2009	Ashburton Island	-21°35.553 114°56.304	-21°35.633 114°56.271	0.686	0.686
17/12/2009	Onslow Back Beach	-21°38.350 115°05.852	-21°38.815 115°05.478	1.074	2.79
		-21°38.815 115°05.478	-21°39.477 115°04.780	1.716	
	Ashburton River Delta	-21°40.919 114°57.153	-21°40.959 114°57.058	0.180	2.691
		-21°40.959 114°57.058	-21°41.086 114°56.890	0.373	
		-21°41.086 114°56.890	-21°41.248 114°56.667	0.487	
		-21°41.248 114°56.667	-21°41.332 114°56.417	0.458	
		-21°41.332 114°56.417	-21°41.412 114°56.118	0.537	
		-21°41.412 114°56.118	-21°41.458 114°55.741	0.656	
	Ashburton River South	-21°41.606 114°54.633	-21°41.976 114°54.364	0.826	1.263
		-21°41.976 114°54.364	-21°39.477 115°04.780	0.437	
18/12/2009	Ashburton North	-21°40.894 115°01.881	-21°41.044 115°01.122	1.332	2.199
		-21°41.044 115°01.122	-21°41.026 115°00.620	0.867	
	Ashburton River Delta	-21°40.981 114°57.150	-21°41.340 114°56.509	1.289	1.725
		-21°41.340 114°56.509	-21°41.359 114°56.411	0.173	
19/12/2009	Onslow Back Beach	-21°38.857 115°05.270	-21°40.040 115°04.065	3.015	4.332
		-21°40.040 115°04.065	-21°40.469 115°03.455	1.317	
	Ashburton North	-21°40.984 115°01.631	-21°40.900 115°00.159	2.544	2.544
	Ashburton River Delta	-21°40.849 114°57.203	-21°41.338 114°56.424	1.619	2.749
		-21°41.338 114°56.424	-21°41.468 114°55.784	1.13	



5.1.2.2 Research Personnel

The research personnel involved in the design and execution of the RPS nesting studies were Jeremy Fitzpatrick, Leanne Smith, Paul McCann and Mike Mackie.

5.1.2.3 Data Analysis

The data from the counts of fresh tracks and nests at Ashburton Island were summarised to determine the total numbers of tracks, nests, false crawls and nesting success. The nesting success was calculated as follows:

$$\text{Nesting success} = \frac{\text{No. of nests}}{(\text{No. of nests} + \text{No. of false crawls})} \times 100$$

The total number of BHT tracks recorded on each mainland beach during the vessel-based track count survey was determined by adding the numbers of BHT tracks recorded during each transect.

The daily total number of fresh tracks for each mainland beach was roughly estimated from the total number of BHT tracks recorded, assuming the following conditions:

- a) A third of all tracks were erased by the high tide, which occurred between 22:30 and 00:00 during the survey period.
- b) Half of all the tracks were return tracks from a single turtle.

To compensate for one-third of all tracks being erased by the tide, the total number of BHT tracks recorded was multiplied by 1.5, and to compensate for half the tracks being emerge tracks, the result of previous calculation was divided by two, as follows:

$$\text{Estimated no. of fresh return tracks} = \frac{(\text{Total no. of BHT tracks}) \times 1.5}{2}$$

The daily total number of fresh nests on the mainland beaches was extrapolated from the nesting success on Ashburton Island using the following equation:

$$\text{Total no. of fresh nestss} = (\text{Estimated no. of fresh return tracks}) \times 0.23$$

5.1.2.4 QA/QC

The RPS track count survey team included experienced and competent marine turtle researchers, with specific skills in track count surveys.

Leanne Smith has more than eight years experience in track count surveys, including identification of green, flatback, loggerhead and hawksbill turtle tracks and nests in the Pilbara and Kimberley regions of Western Australia. Leanne has been certified competent in track count surveys through the Ningaloo Marine Park Community Turtle Monitoring Program Certificate of Competency.

Paul McCann is experienced in the identification of hawksbill, olive ridley and green turtle tracks and nests having completed turtle beach monitoring in the Seychelles over four nesting seasons.

5.2 Satellite Telemetry Studies

5.2.1 Survey Design

Six Mk10-AF (Wildlife Computers Inc.) Platform Terminal Transmitters (PTTs) were attached to nesting flatback turtles at Ashburton Island in December 2009. The Mk10-AF is specifically designed to collect time-depth data of underwater animals. The PTTs transmit locations via Argos satellites and transfer data when the turtle is at the surface of the water.

The Mk10-AF transmitters were programmed to collect both location and depth data, in order to determine the distribution of flatback turtles and their behaviour:

1. Within the Project footprint.
2. Resting on the sea-bottom, where they are more vulnerable to entrainment in the dredge.
3. Near the sea surface, where they are more vulnerable to vessel strike.

5.2.1.1 Location Data

Once the PTT is attached and deployed, its location is determined through two satellite systems:

1. Argos-linked satellites.
2. The Global Positioning System (GPS).

Positions acquired by the Argos-linked satellites are transmitted to receiving stations, which then forward the information to processing centres. Positions acquired by the GPS are transmitted from the PTT to the Argos-linked satellites, before being transmitted to the receiving stations and forwarded to the processing centres (CLS 2008).

The acquisition of GPS positions relies on relatively new Fastloc™ technology. Positions acquired through the GPS are generally more accurate than positions acquired through the Argos system (location error of <100 m, compared with <250 m to >1500 m); however they use more battery power than Argos transmissions, and can significantly shorten the operational life of the PTT.

The Mk10-AF transmitters are user-programmable, allowing researchers to select how often the PTTs should attempt to acquire GPS positions and how often they should transmit data to the Argos-linked satellite, thus allowing for a balance between the number of acquired positions and the required operational life of the PTT.

The position acquisition and transmission settings for this study were selected to ensure that high accuracy location data was collected during the inter-nesting period when there is a greater chance that the turtles will frequent the Project area and that the batteries in the transmitters would last long enough to determine the foraging ground locations for tracked turtles.

The transmitters were programmed to collect and transmit location data only on certain days, as follows:

- December–February – every day.
- March–May – every second day.
- June–November – every fourth day.

On these days, Argos locations were attempted every 45 seconds but the number of GPS location acquisitions was limited to a maximum of 3 per hour (maximum of 72 locations per day) to increase battery life.

In order to identify subsequent nesting events (and thus be able to determine the inter-nesting period), the transmitters were programmed to enter ‘haul-out’ mode after 10 consecutive ‘dry minutes’, with a dry minute defined by the wet/dry sensor being dry for 60 seconds in a minute. The transmitters were programmed to exit haul-out mode if the wet/dry sensor was wet for 10 (not necessarily consecutive) seconds in a minute.

5.2.1.2 Time-depth Data

The transmitters were programmed to collect three types of dive profile data:

- Dive maximum depth.
- Time-at-depth.
- Dive duration.

For each of these types of data, 14 bins were selected, as detailed in Table 5. The depth bins (dive maximum depth and time-at-depth) were chosen to provide high resolution at shallow depths, as water depth in the Project area rarely exceeds 10 m. The time bins (dive duration) were also selected to provide high resolution.

Dive profiling commenced once the turtle dived below 0.5 m. To account for the effects of swell and wind-waves, a dive was only logged if it was deeper than 1 m and longer than 20 seconds.

Table 5: Programmed Dive Profile Bins for the Mk10-AF Transmitters

Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dive maximum depth (m)	2	4	6	8	10	12	14	16	18	20	50	100	150	>150
Time-at depth (m)	2	4	6	8	10	12	14	16	18	20	50	100	150	>150
Dive duration (minutes)	1	2	3	4	5	10	15	20	25	30	40	50	60	>60

5.2.2 Field Survey Techniques

PTTs were attached to turtles using harnesses (Plate 1), which were developed specifically for flatback turtles (Sperling and Guinea 2004; Pendoley 2005). PTTs were attached to turtles on their way back to ocean after completing a nest or a false crawl. If a second turtle was seen returning to the ocean nearby, she was restrained in a wooden pen (150 cm x 150 cm x 60 cm) for up to an hour until the survey team had finished with the first turtle (Plate 2).

In addition to PTT attachment, the turtles were tagged in both front flippers with titanium flipper tags issued by the Department of Environment and Conservation (DEC) (Plate 3), and the following information was recorded:

- Date and time of capture.
- Curved carapace length and width (CCL and CCW).
- Left and right flipper tag numbers.
- Whether the turtle nested.

Flipper tagging and carapace measurements followed standard procedures (Balazs 1999; Bolten 1999).



Plate 1: PTT and Harness being attached to a Flatback Turtle



Plate 2: Turtle restrained in the Holding Pen



Plate 3: Titanium Flipper Tag inserted in the Left Front Flipper

5.2.3 Research Personnel

The research personnel involved in the design and execution of the satellite telemetry studies were Jeremy Fitzpatrick, Leanne Smith, Paul McCann and Mike Mackie.

5.2.4 Data Analysis

The satellite tracking location data for December 2009 and January 2010 are presented in this report. Further data from the PTTs will be processed as it becomes available. Time-depth data is yet to be analysed and is not presented in this Technical Appendix.

Text files supplied by Argos were processed through Wildlife Computers Data Analysis Program software version 2.0 and converted into .CSV files.

Argos location data was filtered to only include Location Class G, 3 and 2 locations (Table 6). Erroneous location points (i.e. any data points that were well inland or would have required the turtle to swim >5 km/h) were also removed (c.f. Luschi et al. 1998).

Location data were plotted in a Geographic Information System (GIS) to produce maps showing the movements of the turtles. The data were grouped in two week periods to indicate movements of the turtles within an inter-nesting period. Haul-out locations and dates (refer Section 5.2.1.1) were also identified on the maps.



Very few haul-outs were recorded by the PTTs and it appeared that not all nesting events were captured in the haul-out data. Therefore, a nesting event was defined according to the following criteria:

- a) A position recorded over land or within 150 m of the shoreline that occurred within the expected inter-nesting period (13–17 days; Pendoley Environmental 2009b).
- b) If positions were recorded both on land and within 150 m of the shoreline, the position over land was considered the nesting event.
- c) If several positions that met the above criteria were acquired over a period of <1 week, the last recorded position before the turtle moved out of the area was considered to be the nesting event.

A turtle was considered to have completed her nesting season and commenced her post-nesting migration if she had not had a nesting event for more than 17 days. Post-nesting migrations were considered to commence immediately after a turtle’s final nesting event for the season.

Table 6: Definitions of Argos and GPS Location Classes

Location Class	Type	Estimated Error	No. of Messages Received per Satellite Pass
G	GPS	< 100 m	≥ 1
3	Argos	< 250 m	≥ 4
2	Argos	250 > 500 m	≥ 4
1	Argos	500 > 1500 m	≥ 4
0	Argos	> 1500 m	≥ 4
A	Argos	No accuracy estimation	3
B	Argos	No accuracy estimation	2
Z	Argos	Invalid location	–

5.3 Egg Development/Hatching Studies

Egg development/hatching studies were completed at the same time as the nesting studies (24 January – 7 February 2009) by Pendoley Environmental. The methods used are described in full in Appendix I and summarised below.

5.3.1 Hatchling Dispersion

Pendoley Environmental (2009) measured the dispersion of hatchlings from the nest and excavated emerged nests to assess hatching success.

Hatchling dispersion from the nest was measured by recording the spread of hatchling tracks (known as the “fan”) from their nest.

Measurements of tracks from each emerged nest are depicted in Figure 9, and included the:

- Bearing of each outside edge of the fan (A and B).
- Bearing of the most direct line from the nest to the ocean (X).
- Bearing along the midpoint of bearings A and B (C).
- GPS location of each nest.

Hatchling dispersion was measured only from those nests having five or more hatchling tracks not obscured by other nests or bird/animal tracks.

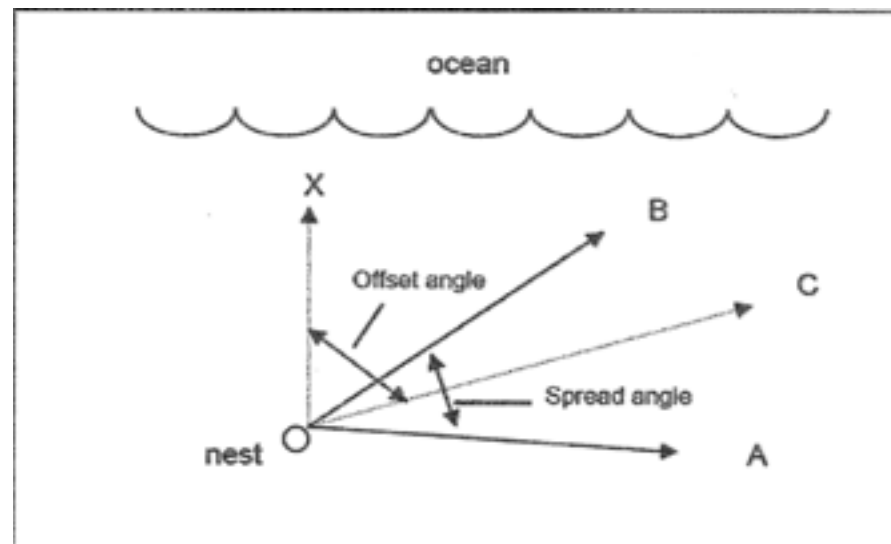


Figure 9: Fan Mapping Parameters
Source: Pendoley (2005)

5.3.2 Hatching Success

Hatching success is a measure of the proportion of eggs in a nest that hatch. It is different to emergence success, which refers to the proportion of eggs in a nest from which hatchlings emerge to the beach surface (Miller 1999).

Nests were sampled opportunistically for hatching success when hatchling tracks were observed on a beach during track count surveys. As it can be difficult to identify nests from which very few hatchlings have emerged, hatching success was measured only from those nests having five or more hatchling tracks.



Hatching success was measured by excavating nests after hatchlings had emerged and counting the total number of hatched and unhatched eggs. Unhatched eggs were classed as undeveloped (egg unhatched with no obvious embryo), embryo (egg unhatched with obvious embryo), full term (egg unhatched with dead full term embryo), pipped dead (egg unhatched, but pipped, with a dead hatchling) and pipped alive (egg unhatched, but pipped, with a live hatchling).

5.3.3 Research Personnel

The research personnel involved in the design and execution of the egg development/hatching studies were Kellie Pendoley, Barry Krueger, Nicholas Sillem and Anna Vitenbergs, from Pendoley Environmental.

5.3.4 Data Analysis

Mean offset and spread angles for flatback and green turtle nests were calculated for the whole dataset.

Hatching success was calculated separately for flatback and green turtles as the percentage of hatchlings successfully emerged from eggs prior to nest excavation, as follows:

$$\text{Hatching success (\%)} = \frac{\text{No. of hatched eggs}}{(\text{No. of hatched eggs}) + (\text{No. of unhatched eggs})} \times 100$$

5.4 Foraging Studies

RPS conducted a vessel-based survey of potential marine turtle foraging areas in the vicinity of the Project footprint in July and August 2009.

5.4.1 Survey Design

The survey area was selected to be of a size large enough to provide perspective on the regional importance of the Project area to marine turtles and to gain an idea of the local importance of the area within the Project footprint. The regional location of the survey area is shown in (Figure 10).

The survey area was divided into a Development Buffer Zone and two Reference Zones (Figure 11). Given that specific information on the alignment and positioning of the marine infrastructure (such as the shipping channel and pipeline route) were not available at the time of survey design, the Development Buffer Zone was based on the Potential Development Footprint present in the Wheatstone Environmental Scoping Document (Chevron Australia 2009a). The Reference Zones included all parts of the survey area outside of the Development Buffer Zone (Figure 11). Progress in the planning for the Project since July 2009 has led to designation of the Indicative Wheatstone Project Footprint within the Development Buffer Zone (Figure 11).

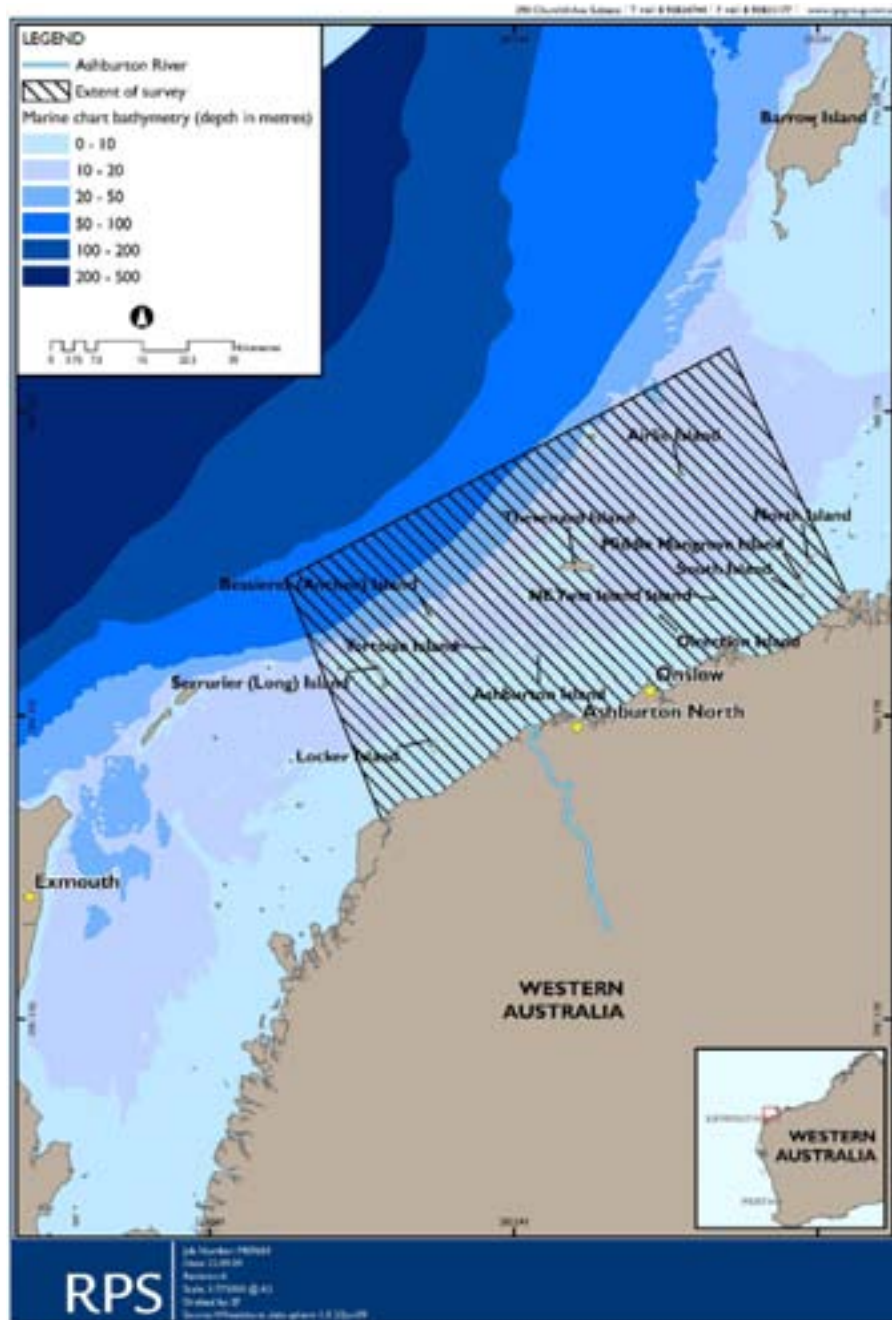


Figure 10: Extent of Foraging Studies Survey Area

The survey area was categorised into three habitat groups, defined below and shown in Figure 11. These habitat groups were selected to represent potential marine turtle foraging habitats, including seagrass meadows, coral reefs and macroalgae-covered limestone pavements. If significant marine turtle aggregations were encountered during the survey, these areas were to be re-visited and the benthic habitat ground-truthed.

- Reef (all areas, regardless of water depth, with a rocky or hard substrate).
 - Represents potential macroalgae, coral reef and limestone reef habitats.
- Coastal non-reef (all non-Reef areas within the 0–10 m depth contour).
 - Represents potential nearshore seagrass meadows.
- Offshore non-reef (all non-Reef area outside of the 0–10 m depth contour).
 - Represents potential soft-bottomed benthic invertebrate assemblages.

Habitat group boundaries were based on Hydrographic Chart AUS00328 and the preliminary habitat maps created for the Wheatstone EIS/ERMP, which indicated that the coastal areas supported seagrass assemblages and that the offshore areas supported benthic invertebrates.

Between 50 and 100 potential transect start locations were randomly allocated within each of the three habitat groups (coastal non-reef, offshore non-reef and reef). Islands and petroleum exclusion zones (with buffers) were excluded from the random allocation process. The start bearings of the transects were generated using the random number generator in Microsoft Excel and GIS software.

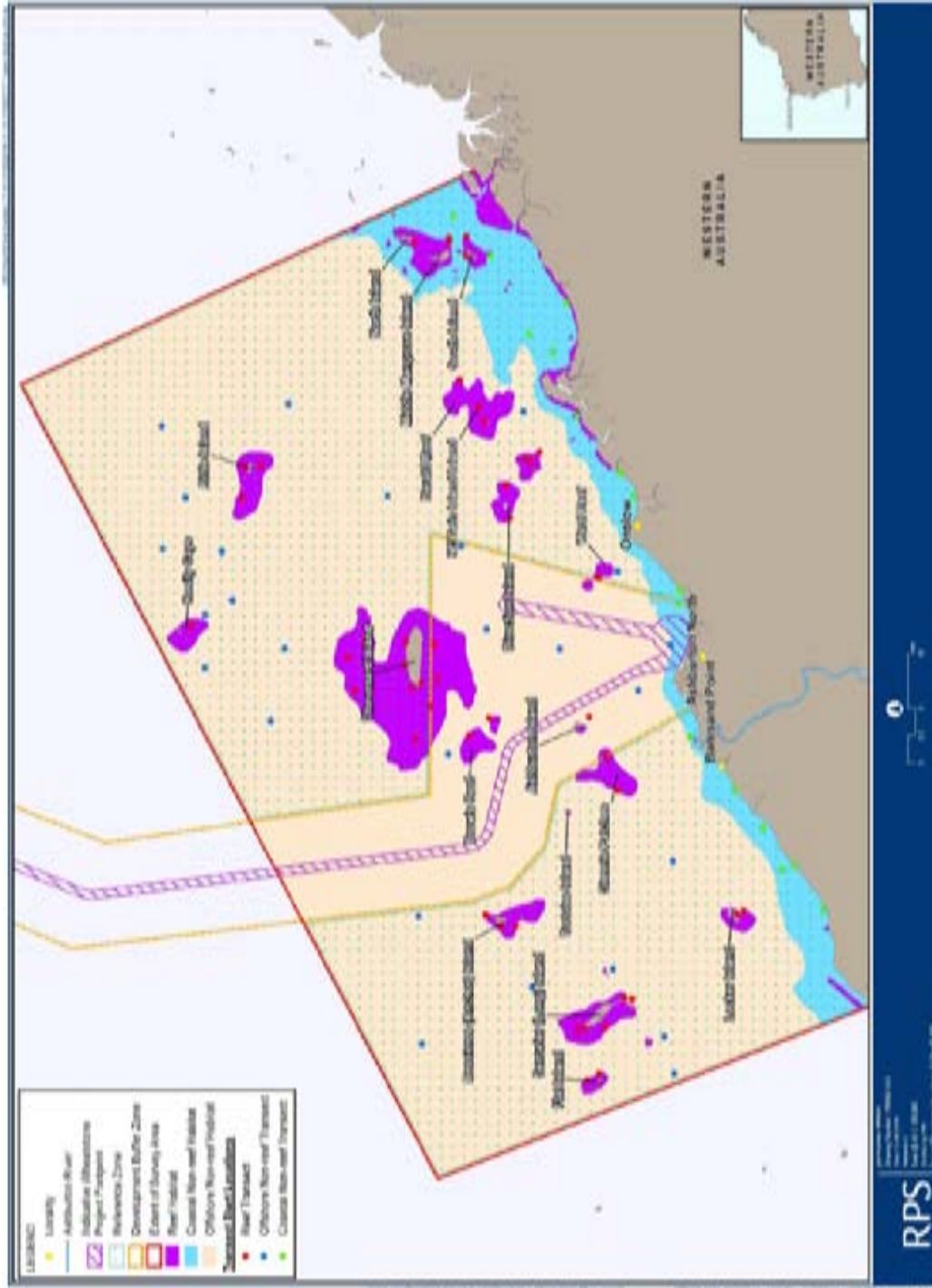


Figure 11: Habitat Groups within the Survey Area and Transect Start Locations for Vessel-based Transect Surveys in July–August 2009



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5.4.2 Field Survey Techniques

The marine turtle foraging survey was undertaken over 14 days between 25 July and 7 August 2009.

Transects were sampled using two vessels; the *MV Northerner* (Northerner) and the *Jackman Island Cabin* (Jackman). The Northerner, being a larger vessel with a draught of approximately 2 m, was generally used for the deeper water offshore non-reef transects, whereas the Jackman, with a draught of approximately 0.5 m, was used for the shallower offshore reef and coastal transects. All transects were conducted at a speed of approximately 3 knots.

Turtle densities were expected to be lower in the offshore non-reef habitats, than in the offshore reef and coastal transects, therefore transects sampled from the Northerner were approximately 2 km long, whereas transects sampled from the Jackman were approximately 1 km long. Transects surveyed from the Northerner were 100 m wide and transects from the Jackman 50 m wide, due to differences in the height of the viewing platform and hence viewing ability from the two vessels.

In instances where the pre-generated transect bearing meant that observers would be facing into the sun, or the transect would run into water too shallow for the vessel, the bearing for that transect was haphazardly re-selected.

Each transect was sampled by two observers at the vessel bow, each observing turtles within a 90° quadrant in front of the vessel. Each observer was assigned a recorder, who was positioned nearby, but out of the observer's field of view, to record observations.

Weather conditions and water depth were recorded at the start and end of each transect.

For each marine turtle observed during a transect, the following information was recorded, where discernible:

- Species.
- Gender.
- Size-class (adult or juvenile).
- Time.
- GPS position of vessel.
- Distance and bearing from vessel to turtle.
- Observer.
- Level of confidence in observation (certain/ possible/ uncertain).

Size-class was determined according to the minimum curved carapace length (CCL) of breeding adults for each species (Table 7).



Table 7: Specifications for Size-class Allocation

Marine Turtle Species	CCL of Adult-sized Turtles (cm)	CCL of Juvenile-sized Turtles (cm)
Green	> 85	< 85
Flatback	> 80	< 80
Hawksbill	> 75	< 75
Loggerhead	> 80	< 80
Olive Ridley	> 65	< 65
Leatherback	> 150	< 150

5.4.3 Research Personnel

The research personnel involved in the design and execution of the vessel-based transects were Jeremy Fitzpatrick, David Waayers, Leanne Smith, Andrew Limbourn, Craig Styran, Rachel Strom and Martin Buck.

5.4.4 Data Analysis

Vessel-based transect data were used to determine:

- The density of marine turtles within each habitat group.
- Estimates of relative abundance of turtles within different habitat groups within the survey area, Development Buffer Zone and Project footprint.
- Species breakdown and size class frequency for each habitat group.

Analyses included all observed turtles, regardless of the certainty ranking (certain, possible, uncertain) for species, size-class and gender, or whether the turtle was observed above or below the water surface.

The density of marine turtles in each habitat group was calculated as follows:

$$\text{Turtle density (\# turtles/ km}^2\text{)} = \frac{\text{Total no. of turtles seen}}{\text{Total area covered during transects}}$$

To estimate relative turtle abundance within different habitats within the survey area, Development Buffer Zone and Project footprint, turtle densities in each habitat were multiplied by the area of that habitat within the survey area, Development Buffer Zone and the Project footprint.

5.4.5 QA/QC

In order to identify (and thus mitigate) observer bias during the foraging survey, quality assurance/quality control (QA/QC) transects were undertaken at the beginning of, and throughout, the survey period.

QA/QC transects involved two persons observing the same ninety degree quadrant and relaying their observations to separate recorders. Observers wore ear muffs so that they couldn't hear the other observer.

Foraging survey data was also subject to QA/QC, whereby each database entry was checked against the original data sheet for errors, by an independent person.

5.5 Limitations of Studies

5.5.1 Nesting Studies

5.5.1.1 Pendoley Environmental Surveys

Only a proportion of a breeding population of marine turtles reproduce each year (Hamann et al. 2003; Spotila 2004). Individual green turtles nest, on average, every six years (Limpus 2009), suggesting that only 17% of the population nest in a given year. Limited information about breeding population size, reproductive output and nesting activity trends can therefore be drawn from one season's nesting data (Schroeder and Murphy 1999). The completion of nesting studies in and adjacent to the Project footprint in one nesting season provides useful baseline data, including what species nest in the region, the duration of the nesting season, and the preferred/most productive nesting beaches within a rookery, assuming these parameters are relatively constant among years.

Counts of fresh turtle tracks are not as accurate for determining levels of turtle nesting activity, as counts of fresh turtle nests. Turtles make "false crawls" (crawling up the beach but returning to the water without laying) for a variety of reasons, including disturbance (by human presence, other nesting turtles or artificial light) and inability to successfully dig a nest (due to hitting an obstruction during digging, or the sand being too dry) (Bustard 1972). Green turtles are known to make false crawls particularly often (Bustard 1972). Turtles that return to the water without laying usually attempt to nest again on the same or a nearby beach, either the same night or within the next few nights (Miller 1997).

If conditions are poor for nesting, counting turtle tracks, as opposed to turtle nests, will result in an overestimate of nesting activity for that beach. Approximately 30% (n = 6277) of all turtle emergences recorded by the Ningaloo Turtle Program in the 2007–2008 nesting season (n = 20,507) resulted in a nest being laid (Markovina 2008); the majority of these emergences were by green turtles (Markovina 2008). Although

there are many variables that contribute to marine turtles making false crawls, it can be roughly estimated that only 30% of green and flatback turtle tracks recorded by Pendoley Environmental (2009) were from turtles that nested, and that 70% of recorded tracks were false crawls.

The passage of Tropical Cyclone Dominic through the survey area interrupted and shortened the nesting studies. Strong winds and heavy rain associated with this cyclone obscured evidence of prior turtle nesting (Pendoley Environmental 2009) and it is likely that the number of AHT tracks were underestimated.

In addition, the late January – early February timing of the nesting studies was outside the hawksbill turtle nesting season and outside the peak flatback and loggerhead turtle nesting seasons (refer Table 2); higher number of tracks may be recorded for these species in November–December.

5.5.1.2 RPS Surveys

The RPS track count surveys provide a snapshot of turtle nesting activity during the peak of the flatback turtle nesting season and supplementary information to the survey by Pendoley Environmental (2009). Limitations of the surveys include:

- The small number of surveys days, both at Ashburton Island (1 day) and on mainland beaches (maximum of 3 days per beach) mean it is difficult to generalise the results.
- The inability to access the beaches at the Ashburton River Delta meant that the tracks could not be identified to species level.
- The estimates of the numbers of fresh tracks and nests per night at the Ashburton River Delta are based on rough calculations with many assumptions.

5.5.2 **Satellite Telemetry Studies**

Preliminary results only are reported in this Technical Appendix. Further analysis of the satellite tracking data, including the time-depth data, will be undertaken and the results will be presented in a separate report.

The attachment of satellite transmitters to six nesting flatback turtles at Ashburton Island provides insight into the movements of those six turtles during the inter-nesting and post-nesting migration periods; however the results cannot be generalised to all turtles that nest in the region.

The maps generated from the location data show only locations where the turtles were at the surface of the water, and where the transmitters received adequate satellite coverage to generate a location. Consequently the maps do not show the exact routes travelled by the turtles, or all locations that the turtles may have frequented; particularly if there were several hours or days between recorded locations.

5.5.3 Egg Development/Hatching Studies

The sample sizes for the hatchling dispersion and hatching success studies were very small, and unlikely to be representative of the population. In addition, the surveys were completed early in the peak hatching season for flatback turtles and outside of the peak hatching season for green turtles (refer Table 2).

Because nests for the hatching success studies were sampled opportunistically when hatchling tracks were encountered during the track counts, the results do not include any nests with zero hatching success, and are likely to be overestimates. A more accurate method for determining hatching success is to mark nests as they are laid and return to excavate these nests after the incubation period (refer section 2.1.6).

5.5.4 Foraging Studies

The limitations of vessel-based studies of foraging marine turtle include:

- Turtles being difficult to see at distance, particularly in choppy or turbid waters.
- Only turtles at or near the surface of the water are typically observed.
- It is not always possible to determine the species and activity of the turtle, as they may only be seen momentarily.
- Smaller-sized turtles may not be seen.

It is likely that the results of the vessel-based surveys were affected by variable water clarity throughout the survey area. The coastal non-reef areas in particular were highly turbid, making it impossible to see any turtles below the water surface. In contrast, in areas of high water clarity, such as at the Mangrove Islands, turtles were seen swimming next to or away from the vessel under the water, without surfacing to breathe during the transects. It is possible that marine turtle abundance was underestimated in turbid waters.

As a result of the above mentioned limitations, the present study can only provide an index of relative marine turtle abundance in different parts of the survey area.

Since this survey was completed outside of the peak seasons for migration, mating and nesting, it is presumed that the observed turtles were within their foraging area.



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6.0 RESULTS

6.1 Nesting Studies

6.1.1 Pendoley Environmental Surveys

This section summarises the results of the nesting activity studies, as reported in Pendoley Environmental (2009); this complete report is provided as Appendix I.

6.1.1.1 Snapshot Surveys

Green and flatback tracks only were recorded during the snapshot (single day) surveys. All tracks were recorded on offshore island beaches, with no tracks recorded on any of the surveyed mainland beaches. The numbers of tracks recorded on Serrurier Island were not presented by Pendoley Environmental (2009).

Green turtle tracks were recorded on the western section of Thevenard Island (14 AHT tracks, 0 BHT tracks) and Flat Island (5 AHT tracks, 0 BHT tracks). Low (unspecified) numbers of BHT green turtle tracks were also recorded on Bessieres Island. No green turtle tracks were recorded on Ashburton Island, Direction Island, Locker Island, North-east Twin Island, Round Island, South-west Twin Island, Table Island, Tortoise Island or any of the mainland beaches.

Flatback turtle tracks were recorded on Locker Island (34 AHT tracks, 12 BHT tracks), North-east Twin Island (7 AHT tracks, 0 BHT tracks), Flat Island (6 AHT tracks, 0 BHT tracks), Table Island (2 AHT tracks, 0 BHT tracks) and Round Island (1 AHT tracks, 0 BHT tracks). Low (unspecified) numbers of BHT flatback turtle tracks were also recorded on Ashburton Island. No flatback turtle tracks were recorded on Bessieres Island, Direction Island, South-west Twin Island, the western section of Thevenard Island, Tortoise Island or any of the mainland beaches.

6.1.1.2 Census Surveys

Tracks of green, flatback and hawksbill turtles were recorded during the census (4 day) surveys. The majority of these tracks were recorded on offshore island beaches.

Green turtle tracks were recorded on Bessieres Island (30 tracks) and the northern section of Thevenard Island (26 tracks). Densities of green turtle tracks were higher on Bessieres Island (24.2 tracks/km/night; SE = 15.9) than on the northern section of Thevenard Island (13.0 tracks/km/night; SE = 13.0).

No green turtle tracks were recorded on Ashburton Island, the southern section of Thevenard Island, or any of the mainland beaches.

Flatback turtle tracks were recorded on Ashburton Island (22 tracks), the northern section of Thevenard Island (6 tracks), Onslow Mainland Beach 4 (6 tracks), Bessieres Island (2 tracks) and the southern section of Thevenard Island (2 tracks).

Densities of flatback turtle tracks were highest on Ashburton Island (Mean = 11.0 tracks/km/night; n = 4 nights; SE = 11.0), followed by the northern section of Thevenard Island and Onslow Mainland Beach 4 (Mean = 3.0 tracks/km/night; n = 4 nights; SE = 1.9), Bessieres Island (Mean = 1.6 tracks/km/night; n = 4 nights; SE = 1.6) and the southern section of Thevenard Island (Mean = 1.0 tracks/km/night; n = 4 nights; SE = 1.0).

No flatback turtle tracks were recorded on Onslow Mainland Beaches 1–3 or 5–7.

Two hawksbill turtle tracks were recorded on Bessieres Island, which equates to a mean density of 1.0 tracks/km/night (n = 4 nights; SE = 1.0). No other hawksbill turtle tracks were recorded.

6.1.1.3 Visual Assessment of Potential Nesting Habitat for Marine Turtles

At least some beaches that appeared to be suitable for marine turtle nesting were identified on each of the offshore islands (Table 8). On most islands, the eastern and/or southern beaches were most suitable for marine turtle nesting and the northern and western beaches were the least suitable.

Most mainland beaches appear to provide at least some suitable nesting habitat (Table 8). The mainland beach at the proposed Ashburton North development site (Onslow Mainland Beach 7) was inundated during spring high tides, and therefore is unlikely to be suitable for egg development (Miller 1997). Nests laid on low-lying beaches like this are expected to have a zero to low hatching success.

Table 8: Suitability of Island and Mainland Beaches for Marine Turtle Nesting, as Described by Pendoley Environmental (2009)

Survey Site	Survey Location	Suitability for Nesting	Description
Offshore Island Beaches			
Ashburton Island	South and east coasts	Suitable	Broad, gently sloping sandy beaches
Bessieres Island	North and west coasts	Unsuitable	Largely rocky beaches with difficult access from the ocean
Direction Island	All coasts	Suitable	Turtle tracks recorded on all beaches
	East coast	Suitable	Broad, gently sloping sandy beach and sand-spit
	North, west and south coasts	Unsuitable	Largely rocky beaches, with signs of recent erosion
	South-east coast	Suitable	Large sand-spit and a broad gently sloping beach with fine-grained sand
	North-east and south-west coasts	Unsuitable	Rocky shoreline
	West coast	Possibly suitable	Rocky intertidal zone, with sand (~70%) and rock (~30%) above the high water mark to the base of the dunes
Locker Island	North, east and south coasts	Suitable	Gently sloping beaches with medium to coarse-grained sand and low, grass-covered dunes
	West coast	Suitable	Rocky coast with 5 m wide strip of sand between the rocks and dunes
	East coast	Suitable	Medium density turtle tracks recorded on this beach
	West and south coasts	Unsuitable	Coarse-grained sand beach with low, grass-covered dunes
North-east Twin Island	North coast	Possibly suitable	Rocky beaches
	East coast	Suitable	Mostly rocky beaches
	South, west and north coasts	Unsuitable	Sandy beach and turtle tracks recorded
	East and south coasts	Suitable	Rocky, narrow beach
	North and west coasts	Suitable	Broad, gently sloping beaches with fine-grained sand and low, grass-covered dunes
	East coast	Suitable	Rocky, narrow beaches but medium-low density nesting recorded
	North, west and south coasts	Unsuitable	Small, gently sloping beach with medium-grained sand and low, grass-covered dunes
	East, south-west and west coasts	Suitable	Rocky beach with shrubs to the high water mark
	North-east coast	Unsuitable	Gently sloping beach with fine-grained sand interspersed with coral rubble
			Rocky beach



Survey Site	Survey Location	Suitability for Nesting	Description
Thevenard Island	Western section	Mostly suitable	Narrow, gently sloping beach with low, grass-covered dunes Beach is wider and dunes are higher in some parts Some areas are actively eroding
Tortoise Island	East coast	Suitable	Fine-grained sand beach
	North, west and south coasts	Unsuitable	Rocky beach
Mainland Beaches			
Coolgra – Beadon Creek	Whole beach	Mostly suitable	Broad and gently sloping beach with fine-grained sand and low, grass-covered dunes At some areas there are shrubs to water line and a rocky ledge where the beach narrows and the dunes are higher
Locker Point – Urala	Whole beach	Mostly suitable	Broad and gently sloping beach with medium-grained sand and low, grass-covered dunes Nearshore area sandy Some areas of exposed beach rock
Onslow Back Beach	Whole beach	Mostly suitable	Wide and gently sloping beach with fine-grained sand and shell fragments and low, grass-covered dunes Lots of vehicle tracks along beach
Onslow Mainland Beach 1	Whole beach	Suitable	Broad, flat, fine-grained sand beach with low, grass-covered dunes
Onslow Mainland Beach 2	Whole beach	Suitable	Broad and gently sloping beach with fine-grained sand interspersed with pebbles and large, unvegetated dunes
Onslow Mainland Beach 3	Whole beach	Possibly suitable	Broad and flat beach with fine-grained sand and low, grass-covered dunes
Onslow Mainland Beach 4	Whole beach	Mostly suitable	Broad and gently sloping beach with fine-grained sand and low, grassy dunes Beach access partially blocked by tree trunks below the high water mark
Onslow Mainland Beach 5	Whole beach	Possibly suitable	Partly broad and gently sloping beach with grass-covered dunes Partly eroded beach with 0.5 m drop Large amount of natural wooden debris observed
Onslow Mainland Beach 6	Whole beach	Suitable	Broad and gently sloping beach with fine-grained sand
Onslow Mainland Beach 7	Whole beach	Suitable	Flat and gently sloping beach with fine-grained sand. The area above the high water mark is littered with mussel shells

6.1.2 RPS Surveys

6.1.2.1 Counts of Fresh Turtle Tracks and Nests at Ashburton Island

Flatback turtle tracks only were recorded on Ashburton Island on 15 December. A total of 42 fresh flatback turtle tracks were recorded over the 686 m transect on the south-east side of Ashburton Island, which is equivalent to a density of 61.2 tracks/km.

Of the 42 tracks, 30 were false crawls, 9 were nesting emergences and 3 tracks were undetermined. The nesting success of flatback turtles on Ashburton Island was 23%.



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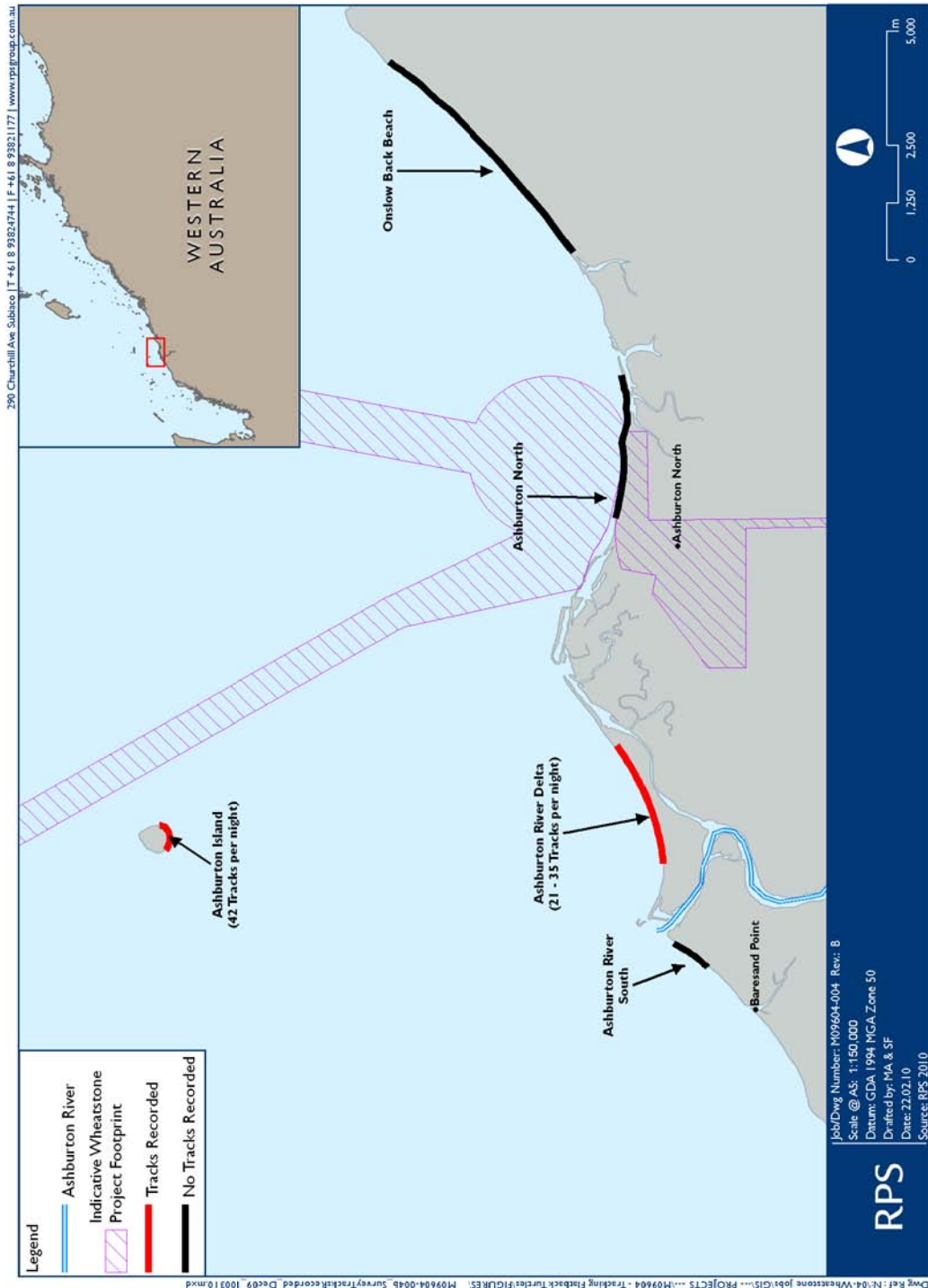


Figure 12: Estimated Number of Fresh Tracks per Night at Beaches Surveyed by RPS in December 2009



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6.1.2.2 Vessel-Based Observations of AHT and BHT Tracks on Mainland Beaches

AHT tracks were recorded at the Ashburton River Delta (40 AHT tracks) and Ashburton River South (2 AHT tracks) during the vessel-based surveys (Table 9). BHT tracks were recorded at the Ashburton River Delta only, with between 28 and 47 BHT tracks recorded each day (Figure 12; Table 9).

Based on the track count conversion calculations (Section 5.1.2.3), it is estimated that 21–35 fresh tracks and 5–8 fresh nests were present during the survey period (Table 9).

The majority of tracks recorded at the Ashburton River Delta were towards the eastern end of the beach (Figure 13).



Table 9: Numbers and Densities of Turtle Tracks Recorded on Mainland Beaches by RPS in December 2009

Beach	Date	Total No. of AHT Tracks	Total No. of BHT Tracks	Estimated Total No. of Fresh Tracks	Estimated No. of Fresh Nests	Length of Beach Surveyed (km)	Density of BHT Tracks (Tracks/km/Night)	Estimated Density of Fresh Tracks (Tracks/km/Night)
Ashburton Island	15-12-09	-	-	42	9	0.686	-	61.20
Onslow Beach	17-12-09	0	0	0	0	2.790	0	0
	19-12-09	-	0	0	0	4.332	0	0
Ashburton North	18-12-09	0	0	0	0	2.199	0	0
	19-12-09	-	0	0	0	2.544	0	0
Ashburton River Delta	17-12-09	40	47	35	8	2.691	17.47	13.08
	18-12-09	-	46	34	8	1.725	28.41	20.00
	19-12-09	-	28	21	5	2.749	10.19	7.64
Ashburton River South	17-12-09	2	0	0	0	1.263	0	0

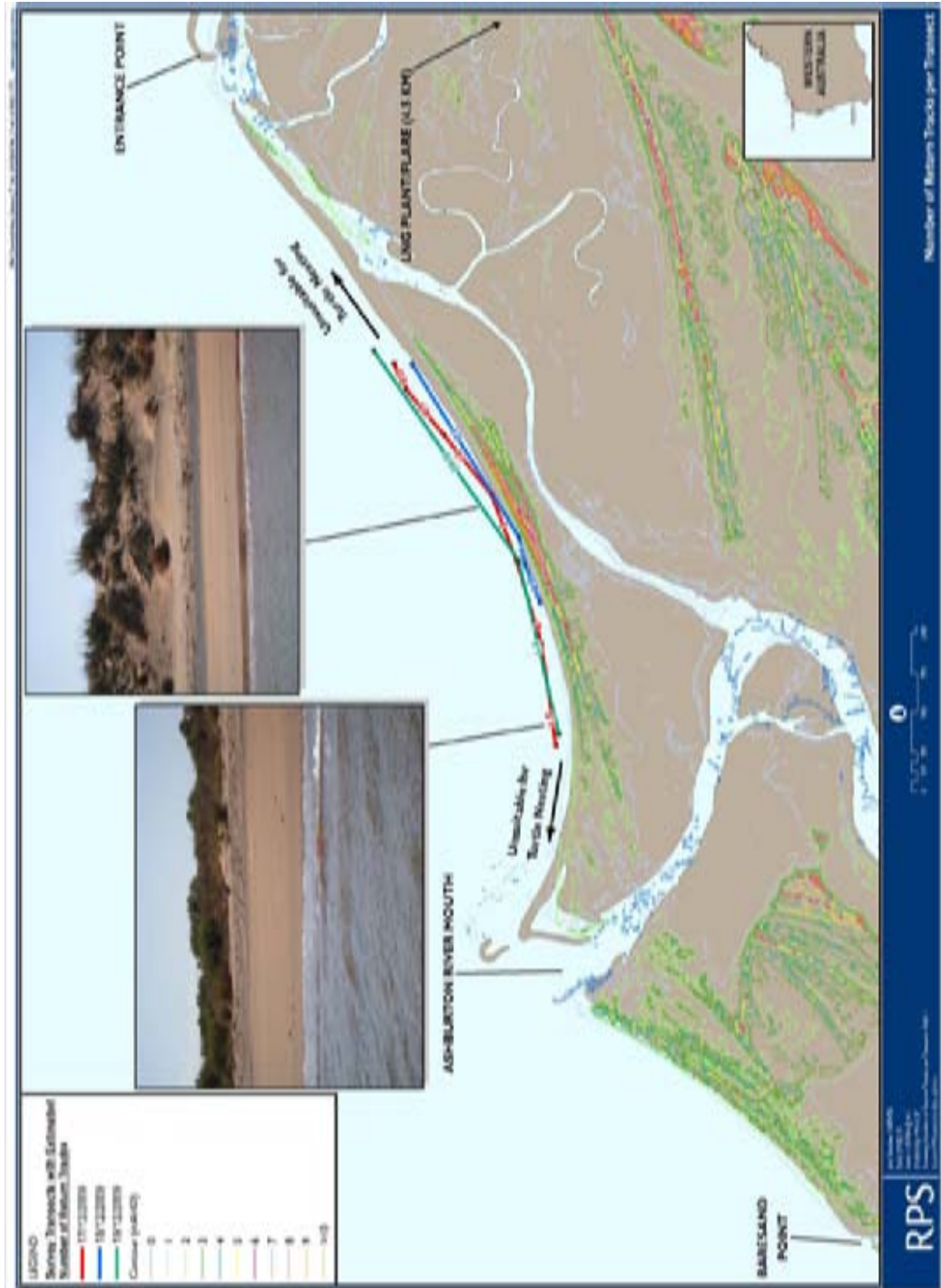


Figure 13: Numbers of Turtle Tracks Recorded along Transects at the Ashburton River Delta in December 2009



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6.1.2.3 Assessment of Suitable Nesting Habitat

A visual assessment of mainland beaches showed that the beach directly adjacent to Ashburton North is not inundated by the spring high tide, but that there is a lagoon approximately 15–20 m behind the beach front, making the beach unsuitable for marine turtle nesting (Figure 14).

The east and west extents of the Ashburton River Delta beach were also considered unsuitable for nesting due to:

- a) The presence of a dead mangal (at the eastern end of the beach; Figure 15)
- b) The absence of a developed dune system
- c) Low beach topography causing tidal inundation

Onslow Back Beach and the beach at Ashburton River South appeared to be suitable for nesting, comprising a broad and gently sloping beach front and low primary dune. Observations indicated tyre tracks on Onslow Back Beach, suggesting a high level of human activity on this beach.



Figure 14: Beach adjacent to Ashburton North showing the Lagoon approximately 15-20 m behind the Beach Front



Figure 15: Dead Mangal at the Eastern End of the Ashburton River Delta making the Beach Unsuitable for Marine Turtle Nesting



6.2 Satellite Telemetry Studies

Satellite transmitters (PTTs) were attached to six female flatback turtles at Ashburton Island on 14 December 2009 (Table 10). Four of the turtles were known to have nested prior to the PTT being attached. It is not known whether the other two turtles had nested.

Table 10: Flipper Tag Numbers, Carapace Measurements and Nesting Activity for Turtles that were Tagged at Ashburton Island in December 2009

Date Deployed	Time Deployed/ Tagged	Transmitter ID #	Left Flipper Tag #	Right Flipper Tag #	CCL (Cm)	CCW (Cm)	Nested?
14-12-09	18:10	52963	70352	70351	87.7	74.2	Y
14-12-09	19:10	52941	70354	70353	81.8	75.0	NR*
14-12-09	21:20	52952	70359	70360	90.0	73.6	Y
14-12-09	22:10	52955	70362	70361	87.4	76.0	Y
14-12-09	22:45	52942	70365	70364	NR*	NR*	NR*
14-12-09	23:50	52953	70458	70459	86.6	74.4	Y

* Not recorded

6.2.1 Location Data

All six turtles spent large amounts of time near the mainland during the inter-nesting period. Four of the six turtles spent time in the nearshore waters adjacent to the Ashburton River Delta and three turtles spent time in the vicinity of the proposed MOF. Three turtles travelled to Direction Island during the inter-nesting period, one of which nested on the island.

6.2.1.1 Turtle 52963

Preliminary location data for turtle 52963 is presented in Figure 16. Turtle 52963 nested on Ashburton Island the night that the PTT was attached (14 December; Table 10). While she was tagged on 14 December 2009, the first transmission for turtle 52963 was received on 25 December 2009, at which time she was approximately two thirds of the way between Ashburton Island and Onslow. Two days later (13 days after the PTT was attached) she returned to Ashburton Island, probably to nest. She left Ashburton Island the following day (28 December) for the mainland and spent the next 10 days in the coastal waters between the Ashburton River Delta and Baresand Point.

Turtle 52963 returned to Ashburton Island on 9 January, 12 days after she had left the island, presumably to nest again. She remained at Ashburton Island for two days before heading back towards the mainland. She spent the next six days (11–16 January) between the Ashburton River Delta and Locker Island. On 17 January she began travelling to the north-east and by 18 January she had reached Direction Island and by the end of January she had reached the Dampier Archipelago (Figure 16).

Although no haul-outs (times when the PTT wet/dry sensors are dry) were recorded for turtle 52963, it is likely that she nested at Ashburton Island when she returned on 27 December (13 days after the PTT was attached) and 9–10 January (13–14 days later) (Table 11). At last transmission, turtle 52963 had finished nesting and was migrating north-east along the coast of Western Australia to her post-nesting area (Table 11).

6.2.1.2 Turtle 52941

Preliminary location data for turtle 52941 is presented in Figure 17. It is not known whether turtle 52941 nested on Ashburton Island the night that the PTT was attached (Table 10). Turtle 52941 left Ashburton Island the day after the PTT was attached (i.e. 15 December) and spent much of the next fortnight near the mainland at the Ashburton River Delta, but also travelled through the nearshore area of the Project footprint. She returned to Ashburton Island 16 days after the PTT was attached (30 December; Table 11) and left the following day (31 December) for the coastal waters off the Ashburton River Delta beach, where she remained for the next five days.

On 5 January turtle 52941 began travelling in a north-easterly direction, staying within approximately 25 km of the WA coastline. By 6 January she had reached Direction Island and by 13 January she had reached the Dampier Archipelago. At the end of January she was off the coast of Port Hedland.

Although a haul-out was not recorded, Turtle 52941 may have nested on Ashburton Island the day after the PTT was attached (15 January; Table 11) because she was recorded on the island on this date and then left the island. It is also likely that she nested again at Ashburton Island when she returned at the end of December, as she was recorded on the island on 30 and 31 December (15 and 16 days after she was previously recorded on the island), although a haul-out was not recorded (Table 11).

6.2.1.3 Turtle 52952

Preliminary location data for turtle 52952 is presented in Figure 18. Turtle 52952 nested on Ashburton Island the night that the PTT was attached (14 December; Table 10). While she was tagged on 14 December 2009, the first transmission for turtle 52952 was on 17 December 2009, in the coastal waters near the Ashburton River Delta beach. Turtle 52952 remained at the Ashburton River Delta Beach for the next four days (until 21 December), before heading north-east to Onslow, arriving on 23 December. She spent the next four days travelling back to the coastal waters near the Ashburton River Delta beach, arriving on 27 December. She remained in the coastal waters near the Ashburton River Delta beach and Baresand Point for eight days (until 4 January) and then spent the next three days travelling north-west towards Barrow Island. She reached the west coast of Barrow Island by 7 January, and by 9 January was at the Montebello Islands. She then headed towards the WA coast, arriving at the Dampier Archipelago five days after leaving the Montebello Islands (i.e. on 14 January). From the Dampier Archipelago she headed east and by the end of January she had reached Port Hedland.

Turtle 52952 does not appear to have nested since her first transmission, with no haul-outs or transmissions over land recorded by her PTT (Table 11).

6.2.1.4 Turtle 52955

Preliminary location data for turtle 52955 is presented in Figure 19. Turtle 52963 nested on Ashburton Island the night that the PTT was attached (14 December; Table 10). She left Ashburton Island immediately after the PTT was attached, travelling slowly in a south-westerly direction.

After three days of travelling turtle 52955 turned back towards Ashburton Island, arriving on 19 December (five days after the PTT was attached). She remained nearby Ashburton Island for three days but was only recorded on the island once (on 19 December). She left Ashburton Island again on 22 December, travelling in a north-easterly direction and spent the next two days travelling in a large loop past Direction Island then backtracking to the coastal waters near Entrance Point, arriving on 24 December. She remained at the coastal waters near Entrance Point for the next two days.

Turtle 52955 returned to Ashburton Island for a second time on 27 December (13 days after the PTT was attached), and left the following day (28 December). She spent the next seven days (29 December – 5 January) in the coastal waters between Ashburton North and Baresand Point before travelling in a large loop around Direction Island and out past Thevenard Island.

Turtle 52955 returned to Ashburton Island for the third time on 12 January, 7 days after leaving the mainland and 16 days after previously leaving the island. She remained at Ashburton Island for two days (until 14 January) then headed towards the Ashburton River Delta beach, where she remained for the next few days.

Turtle 52955 returned to Ashburton Island for the fourth time on 17 January, three days after previously leaving the island. She left Ashburton Island for Baresand Point the following day (18 January). She spent the next seven days travelling north-east along the mainland coast. Once she reached Coolgra Point she turned around and began travelling south-west. By 27 January she was at Onslow.

Given that turtle 52955 nested the night that the PTT was attached (Table 10), it is unlikely that she nested on 19 January (5 days after the PTT was attached), even though she was recorded on the island (Miller 1996). Based on the average inter-nesting period for flatback turtles at Barrow Island being 14.7 days (Pendoley Environmental 2009b), it is more likely that she nested when she returned to Ashburton Island on 27 December; 13 days after her previous nesting event (Table 11). It is also likely that she nested while she was at Ashburton Island between 12 and 14 January; 15–17 days after her previous nesting event. At this stage it is not clear whether or not Turtle 52955 has completed her nesting season (Table 11).

6.2.1.5 Turtle 52942

Preliminary location data for turtle 52942 is presented in Figure 20. It is not known whether turtle 52942 nested on Ashburton Island the night that the PTT was attached (Table 10) and she left Ashburton Island for the coastal waters near the Ashburton River Delta immediately after the PTT was attached (14 December).

Turtle 52942 returned to Ashburton Island the following day (15 December) and was recorded on the island on both 16 and 17 December. Turtle 52942 remained at Ashburton Island for two days, before heading to the Ashburton River Delta. She remained in the coastal waters at the Ashburton River Delta for three days (18–20 December) and was recorded on the mainland on 20 December (six days after the PTT was attached).

Turtle 52942 left the Ashburton River Delta area on 21 December, travelling in a north-easterly direction for three days, past Direction Island. She spent the next five days (24–28 December) approximately 12 km to the north-east of Direction Island before backtracking to Direction Island on 29 December. She remained at Direction Island for the next five days (until 3 December), during which time three haul-outs were recorded on Direction Island by her PTT (from 30–31 December).

Turtle 52942 left Direction Island on 3 December, travelling in a north-westerly direction to an area approximately 10 km north-west of Thevenard Island, where she remained for three days (4–6 January). She spent the next eight days (7–14 January) travelling in a large loop, travelling as far as approximately 20 km north-west of Barrow Island. She returned to the area approximately 10 km north-west of Thevenard Island on 14 January, where she remained at the end of January.

Given that turtle 52942 did not nest on the night that the PTT was attached (14 December), it is likely that she nested either on 17 December (at Ashburton Island, 3 days aft the PTT was attached) or 20 December (on the mainland, 6 days after the PTT was attached), although no haul-outs were recorded (Table 11). It also appears that turtle 52942 completed two false crawls on Direction Island before nesting on the island on 31 December (Table 11). Turtle 52942 has most likely completed nesting for the season as she has not neared land or recorded a haul-out for over a month (Table 11).

6.2.1.6 Turtle 52953

Preliminary location data for turtle 52953 is presented in Figure 21. Turtle 52953 nested on Ashburton Island the night that the PTT was attached (14 December; Table 10). She left Ashburton Island immediately after the PTT was attached for the coastal waters between Ashburton North and Onslow, where she remained for six days (15–21 December). She spent the next two days (22–23 December) travelling in a loop between Direction Island and Thevenard Island, returning to the Onslow area on 24 January. She spent the next three days (24–27 December) travelling from Onslow to Ashburton Island.

Turtle 52953 returned to Ashburton Island on 28 December (14 days after the PTT was attached) where she remained for three days (28–30 December). She left Ashburton Island on 31 December and spent the next 10 days off the coast of Onslow.

Turtle 52953 returned to Ashburton Island for a second time on 11 January (11 days after previously leaving the island) and left the same day. From Ashburton Island she headed approximately 12 km east-south-east, before heading north to Thevenard Island. She arrived at Thevenard Island two days after she left Ashburton Island (13 January) and recorded a haul-out the following day (14 January; Table 11).

On 15 January Turtle 52953 departed Thevenard Island for Coolgra Point, arriving on 18 January. She spent the next four days (19–22 January) to the north of the Mangrove Islands, before travelling to the north-east of Thevenard Island, where she remained for two days (23–24 January). On 25 January she began travelling in a north-easterly direction towards the west coast of Barrow Island. By 27 January she was approximately 10 km west of Barrow Island and by 28 January she was approximately 40 km north of Barrow Island.

Although no haul-outs were recorded, it is likely that turtle 52953 nested at Ashburton Island when she returned on 28 January (14 days after the PTT was attached; Table 11). It is unlikely that she nested again on both 11 January (at Ashburton Island) and 14 January (at Thevenard Island) as turtles physiologically require greater than six days between clutches (Miller 1996). It is more likely that turtle 52953 false crawled at Ashburton Island and nested on Thevenard Island. Given that her last recorded nesting event (at Thevenard Island on 14 January) was only 15 days before her last received transmission (29 January), it is not yet clear whether or not turtle 52953 has completed her nesting season (Table 11).

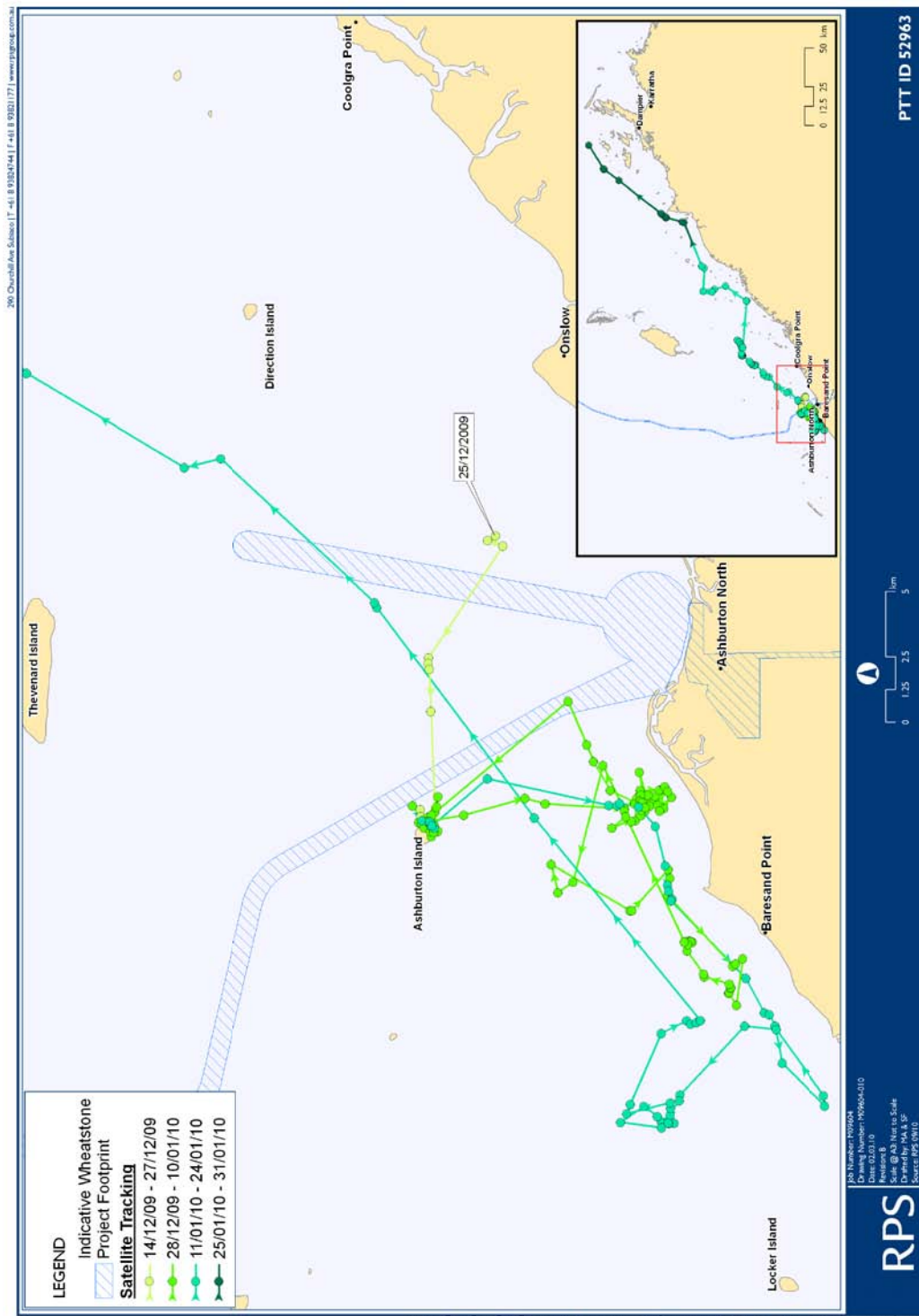


Figure 16: Preliminary Location Data for Turtle 52963

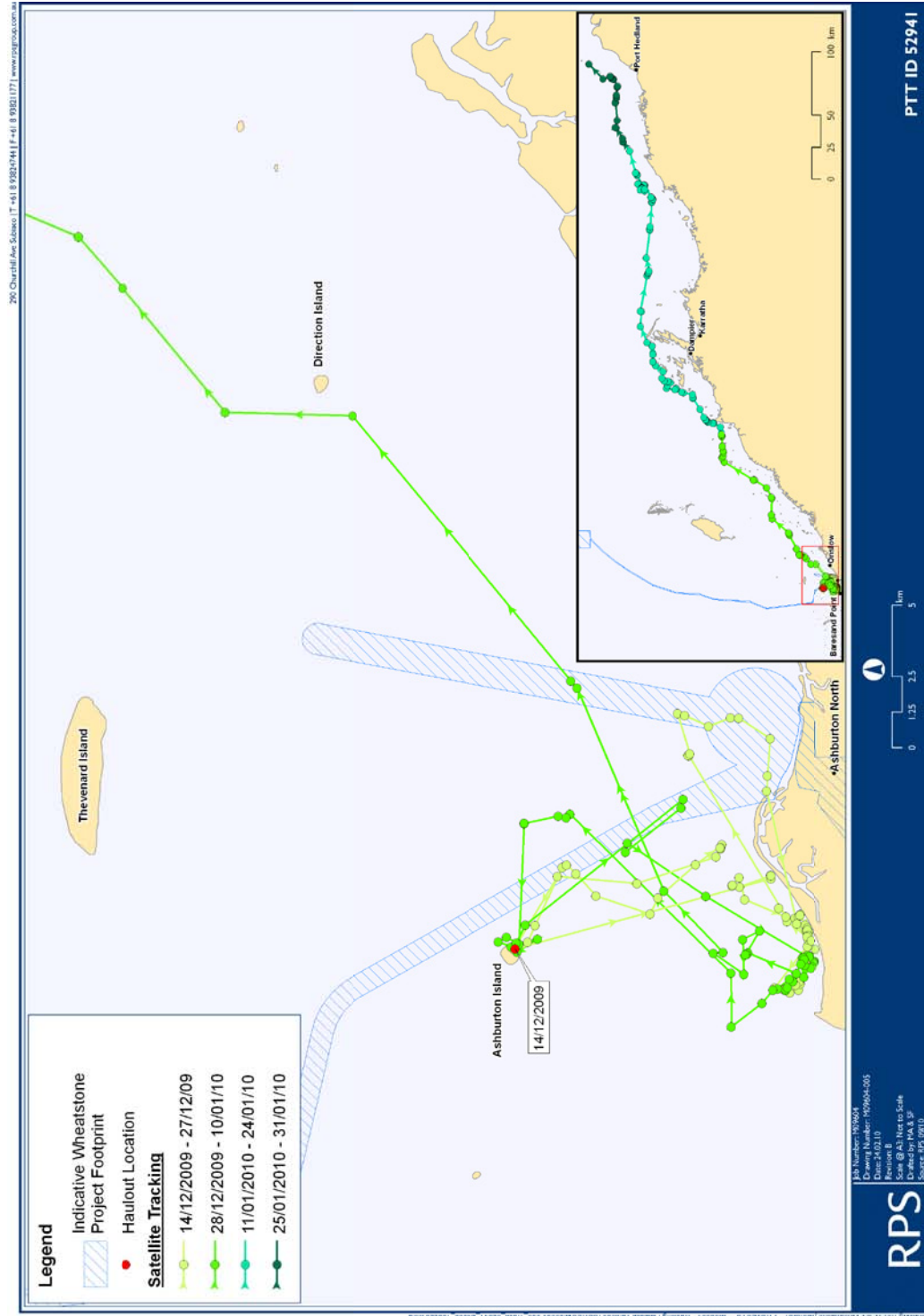


Figure 17: Preliminary Location Data for Turtle 52941

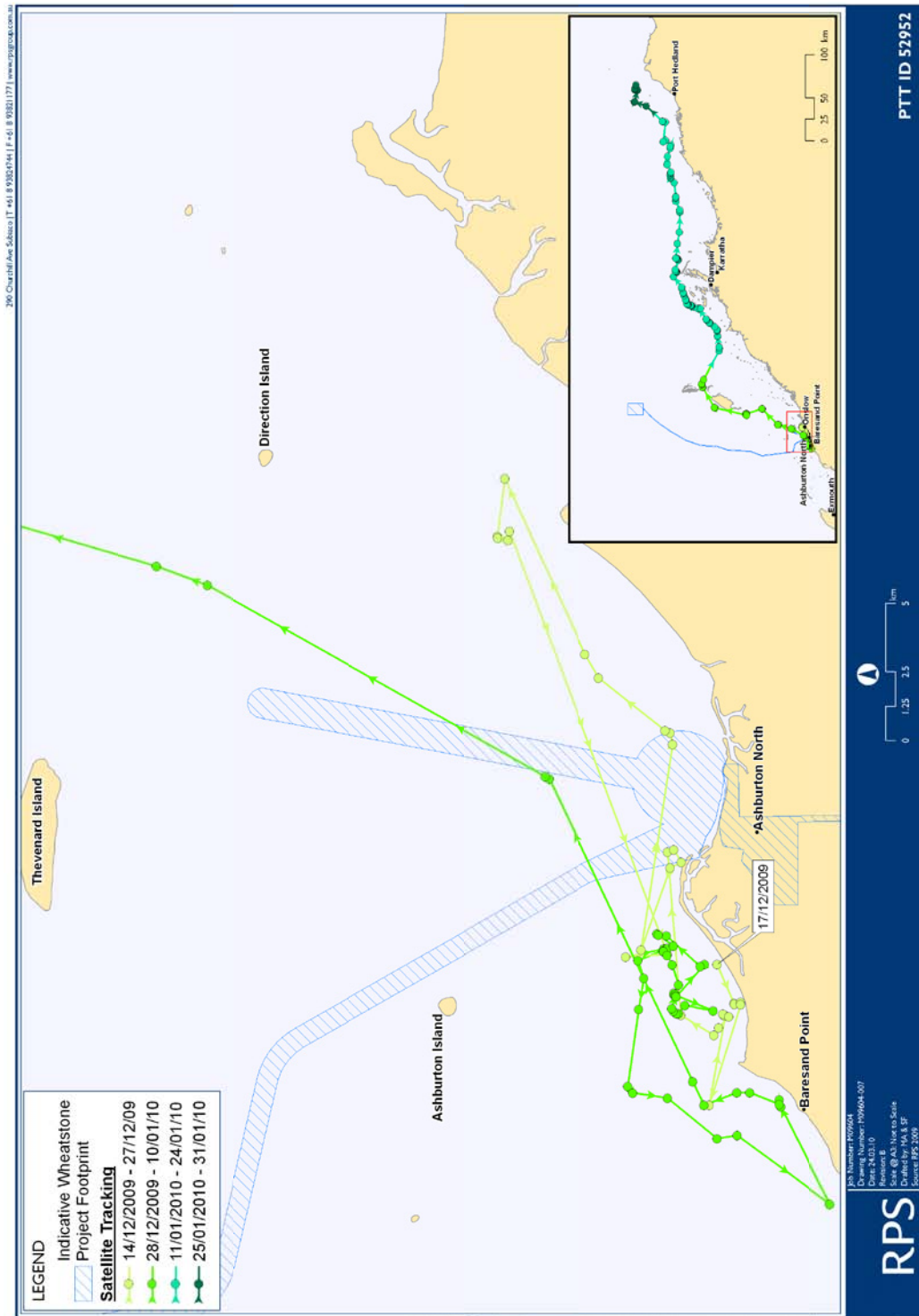


Figure 18: Preliminary Location Data for Turtle 52952

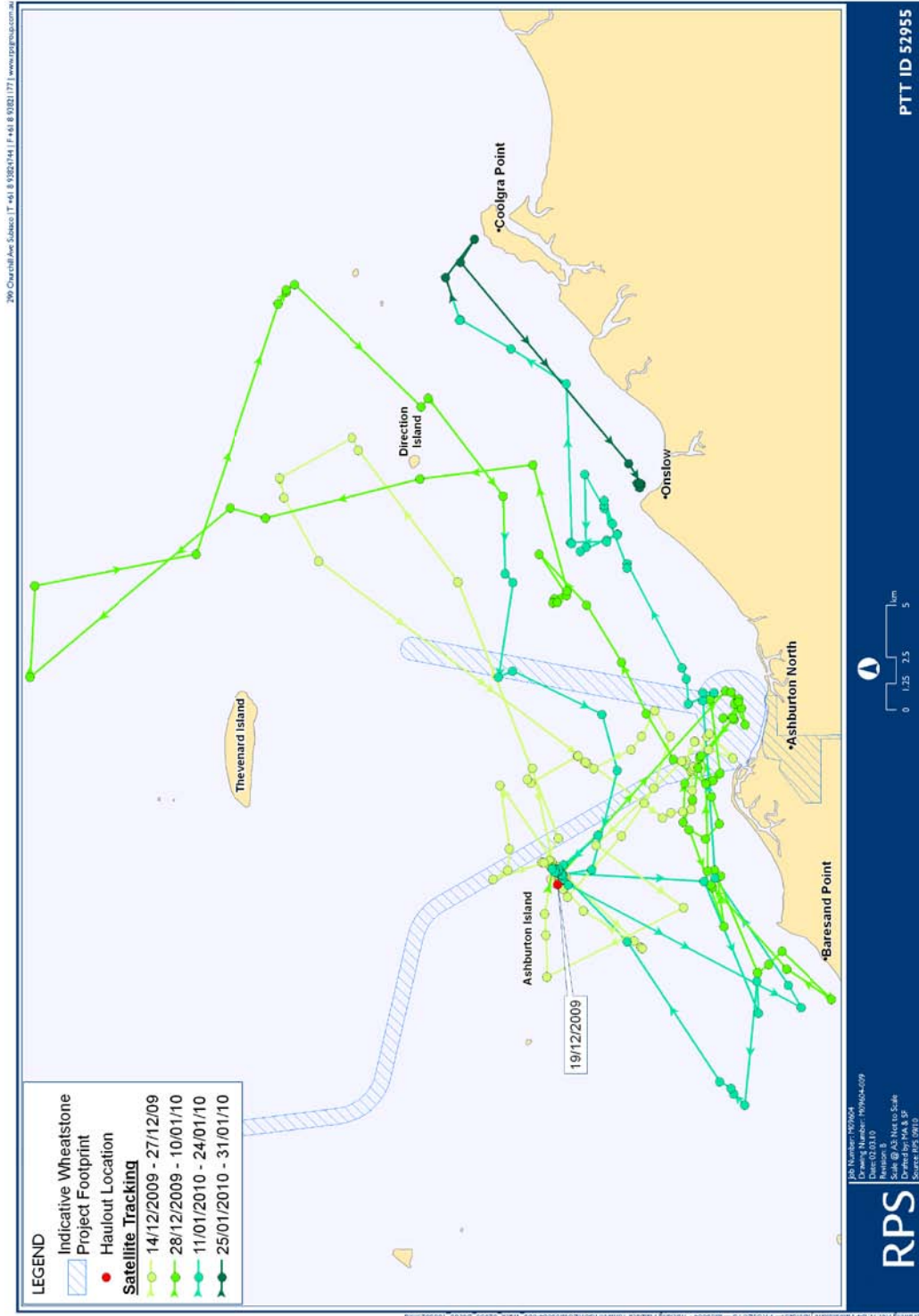


Figure 19: Preliminary Location Data for Turtle 52955

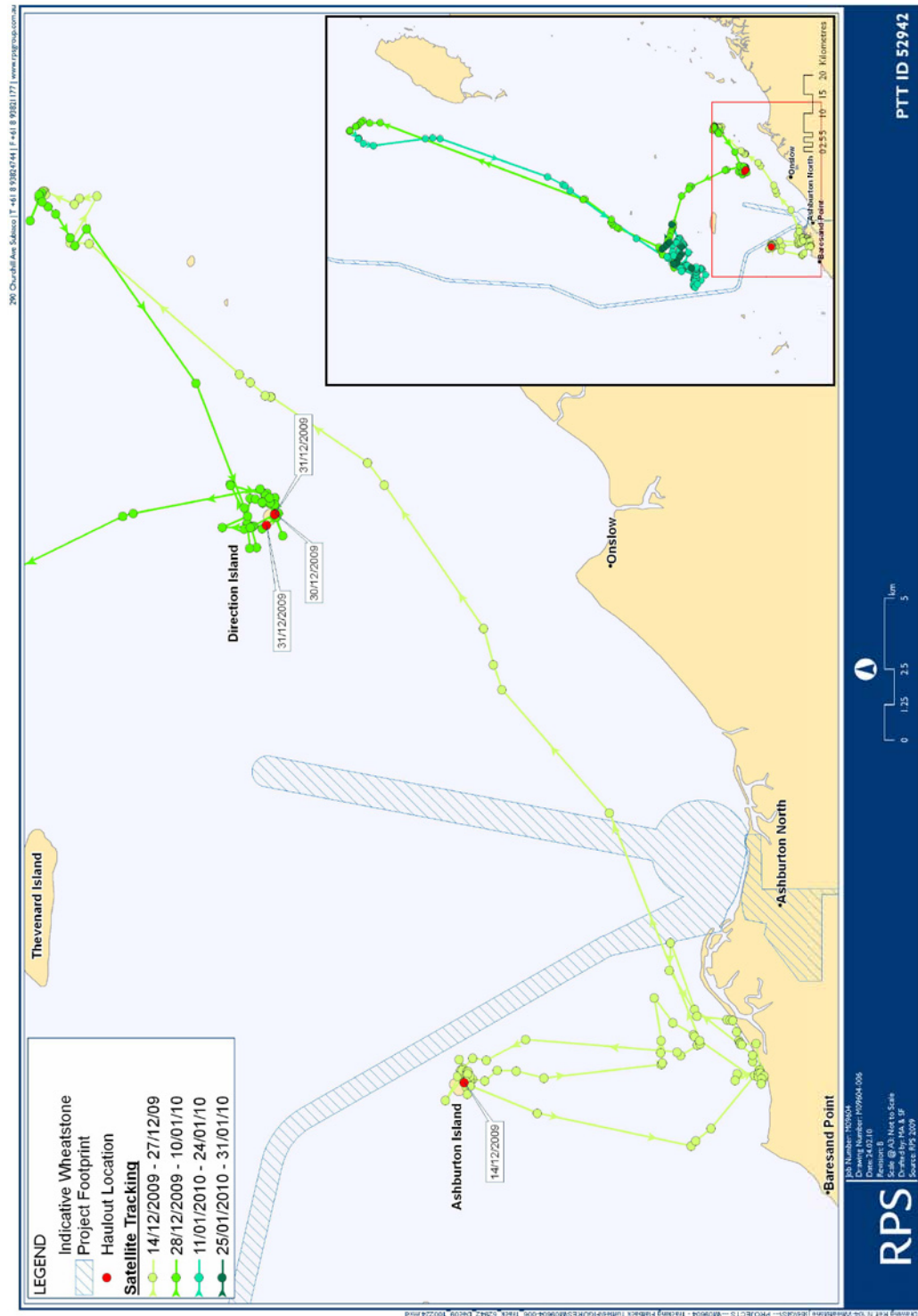


Figure 20: Preliminary Location Data for Turtle 52942

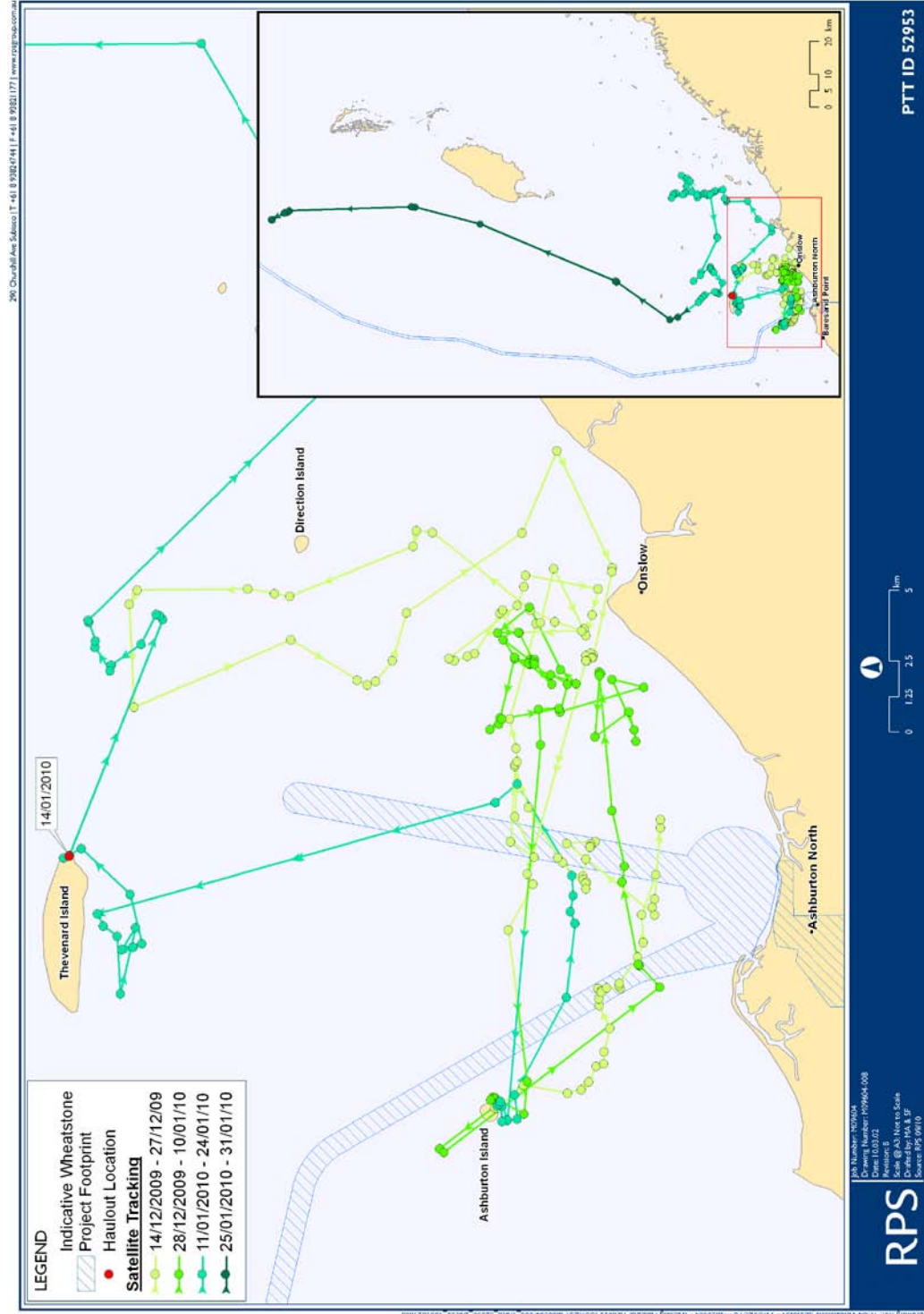


Figure 21: Preliminary Location Data for Turtle 52953

Table 11: Dates and Locations of Nesting and Migration Events for Turtles Fitted with Satellite Transmitters on Ashburton Island

PTT ID No.	1 st Recorded Nesting		2 nd Recorded Nesting		No. of days between 1 st and 2 nd nesting		3 rd Recorded Nesting		No. of days between 2 nd and 3 rd Nesting		Post-nesting Migration Commenced ?	Location at Last Transmission	Date of Last transmission
	Date	Location	Date	Location	Date	Location	Date	Location	No. of days	No. of days			
52963	14-12-09	Ashburton Island	27-12-09	Ashburton Island	13	Ashburton Island	10-01-10	Ashburton Island	13	Yes	Dampier Archipelago	27-01-10	
52941	15-12-09	Ashburton Island	31-12-09	Ashburton Island	16	Ashburton Island	-	-	-	Yes	Port Hedland	28-01-10	
52952	14-12-09	Ashburton Island	-	-	-	-	-	-	-	Yes	Port Hedland	28-01-10	
52955	14-12-09	Ashburton Island	27-12-09	Ashburton Island	13	Ashburton Island	12-01-10	Ashburton Island	15	Unsure	Onslow	27-01-10	
52942	17-12-09 or 20-12-09	Ashburton Island or Ashburton River Delta	31-12-09	Direction Island	11-14	Direction Island	-	-	-	Yes	approx. 10 km NE of Thevenard Island	27-01-10	
52953	14-12-09	Ashburton Island	28-12-09 - 31-12-09	Ashburton Island	14-17	Ashburton Island	14-01-10	Thevenard Island	14-17	Unsure	approx. 40 km N of Barrow Island	29-01-10	



6.2.2 Time-depth Data

The time-depth data has not yet been analysed and will be presented in a separate report.

6.3 Egg Development/Hatching Studies

6.3.1 Hatchling Dispersion

Hatchling dispersion after leaving the nest was measured for 13 flatback and 5 green turtle nests. Seventeen of these nests were on offshore islands; Ashburton Island (6 nests), Bessieres Island (6 nests) and Locker Island (4 nests). One flatback turtle nest was on Onslow Mainland Beach 4.

Figure 22 and Figure 23 show the average hatchling dispersion patterns from green and flatback turtle nests. Mean fan angles were low for green turtle nests (37.6°; n = 5; range = 14° – 62°) and for most flatback turtle nests (66.7°; n = 13; range = 20° – 108°); the exception was one flatback turtle nest on Locker Island, where hatchling tracks were dispersed in all directions (this nest was excluded from the analyses as there were no obvious outside edges of a ‘fan’ from which to measure bearings). The low mean fan angles indicate that all of the hatchlings followed a similar path to the sea. The mean offset angles were also low for green turtle hatchlings (10.2°, range = 1.5° – 20.5°) and flatback turtle hatchlings (6.8°, range = 0° – 18.5°), indicating the hatchlings took a fairly direct path to the sea.

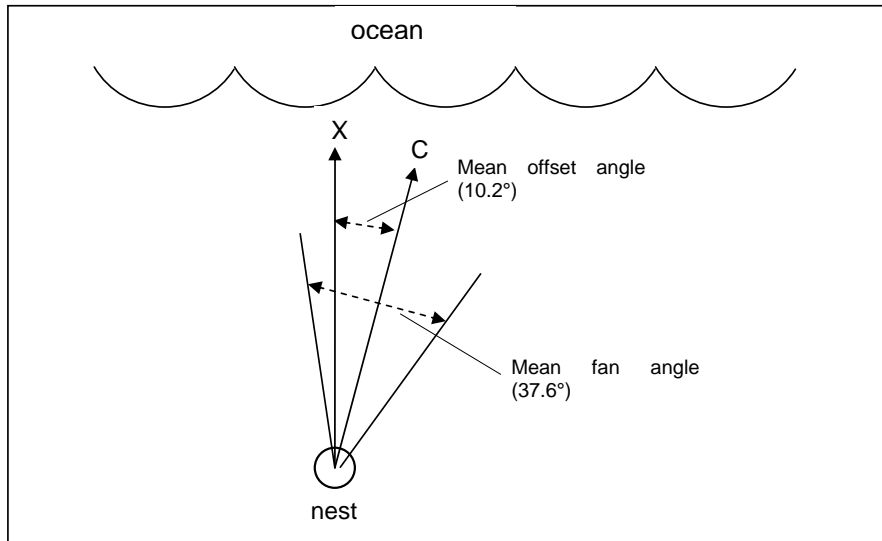


Figure 22: Average Green Turtle Hatchling Dispersion from the Nest
X = Bearing of the Most Direct Line from the Nest to the Ocean
C = Bearing along the Midpoint of the Outside Edges of the Fan

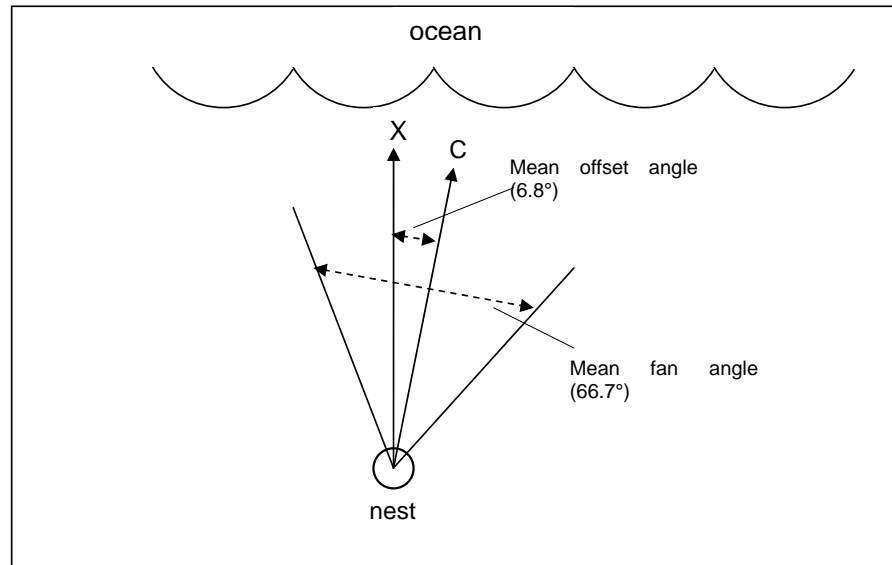


Figure 23: Average Flatback Turtle Hatchling Dispersion from the Nest
X = Bearing of the Most Direct Line from the Nest to the Ocean
C = Bearing along the Midpoint of the Outside Edges of the Fan

6.3.2 Hatching Success

Twelve nests were excavated to determine hatching success. Eleven nests were on offshore islands, including Ashburton Island (2 nests), Thevenard Island (1 nest), Bessieres Island (3 nests) and Locker Island (5 nests), and one was on Onslow Mainland Beach 4.

Hatching success for green turtle nests ($n = 3$) was consistently high and ranged between 83.6 and 98.1% and averaged 91.3% (± 2.96 SE). Mean hatching success for flatback turtle nests was high (80.9% ± 7.50 SE, $n = 9$) but more variable. Flatback turtle hatching success ranged between 23.4 and 97.9%.

The flatback turtle nest on a mainland beach had a hatching success of 23.4%. More than half of the eggs from this nest were full term but unhatched (egg unhatched with dead full term embryo). It is thought that this nest may have been flooded as Tropical Cyclone Dominic passed over the region in January 2009.

Clutch sizes for green turtles ranged between 104 and 114 eggs per nest, and averaged 107.3 (± 2.36 SE) eggs per nest. Clutch sizes for flatback turtles ranged between 35 and 64 eggs per nest, and averaged 49.6 (± 2.85 SE) eggs per nest.



6.4 Foraging Studies

6.4.1 Vessel-based Surveys

6.4.1.1 Densities within Habitat Groups

A total of 104 marine turtles were observed during 92 vessel-based transects covering almost 28 km² of the sea surface within the survey area. Turtle densities throughout the survey area are shown in Figure 24.

The majority (82.7%) of turtles were observed over reef habitats. Turtle densities in transects over reef habitats (12.6 turtles/km²) were more than 12 times greater than densities in transects over offshore non-reef and coastal non-reef habitats (Table 12).

Table 12: Numbers of Turtles Recorded in Each Habitat Group during Vessel-based Transect Surveys in July–August 2009

Habitat Group	# Turtles	% of Turtles	Total Transect Area (km ²)	Density (# Turtles/km ²)
Reef	86	82.7	6.8	12.6
Offshore Non-reef	17	16.3	17.6	1.0
Coastal Non-reef	1	1.0	3.3	0.3
Total	104	100	27.7	3.8

Of the surveyed reef habitats, the greatest number of turtles was observed along three transects at Bessieres Island (24.4% of all turtles observed in reef habitat, n = 21; Table 13). The highest densities of turtles were observed around Locker Island (60.0 turtles/km²), Bessieres Island (52.5 turtles/km²) and Ashburton Island (50.0 turtles/km²) (Table 13).

There was no difference in the density of turtles on reefs adjacent to mangrove habitat (at the Mangrove Islands), compared with other reef habitats (Table 13).

Table 13: Number and Density of Turtles Observed at Each of the Reef Sites in July–August 2009

Site	# Turtles Observed	% of All Turtle Observed	Area Covered (km ²)	Density (# Turtles/km ²)
Bessieres Island	21	24.4	0.4	52.5
Mangrove Islands	13	15.1	0.8	16.3
Locker Island	12	14.0	0.2	60.0
Thevenard Island	11	12.8	1.7	6.5
Serrurier Island	9	10.5	0.8	11.3
Airlie Island	7	8.1	0.4	17.5
Ashburton Island	5	5.8	0.1	50.0
Rosily Cays	4	4.7	0.1	40.0
Glennie Patches	2	2.3	1.2	1.7
Direction Island	1	1.2	0.4	2.5
Herald Reef	1	1.2	0.6	1.7
Ward Reef	0	0.0	<0.1	0.0
Total	86	100.0	6.8	12.6



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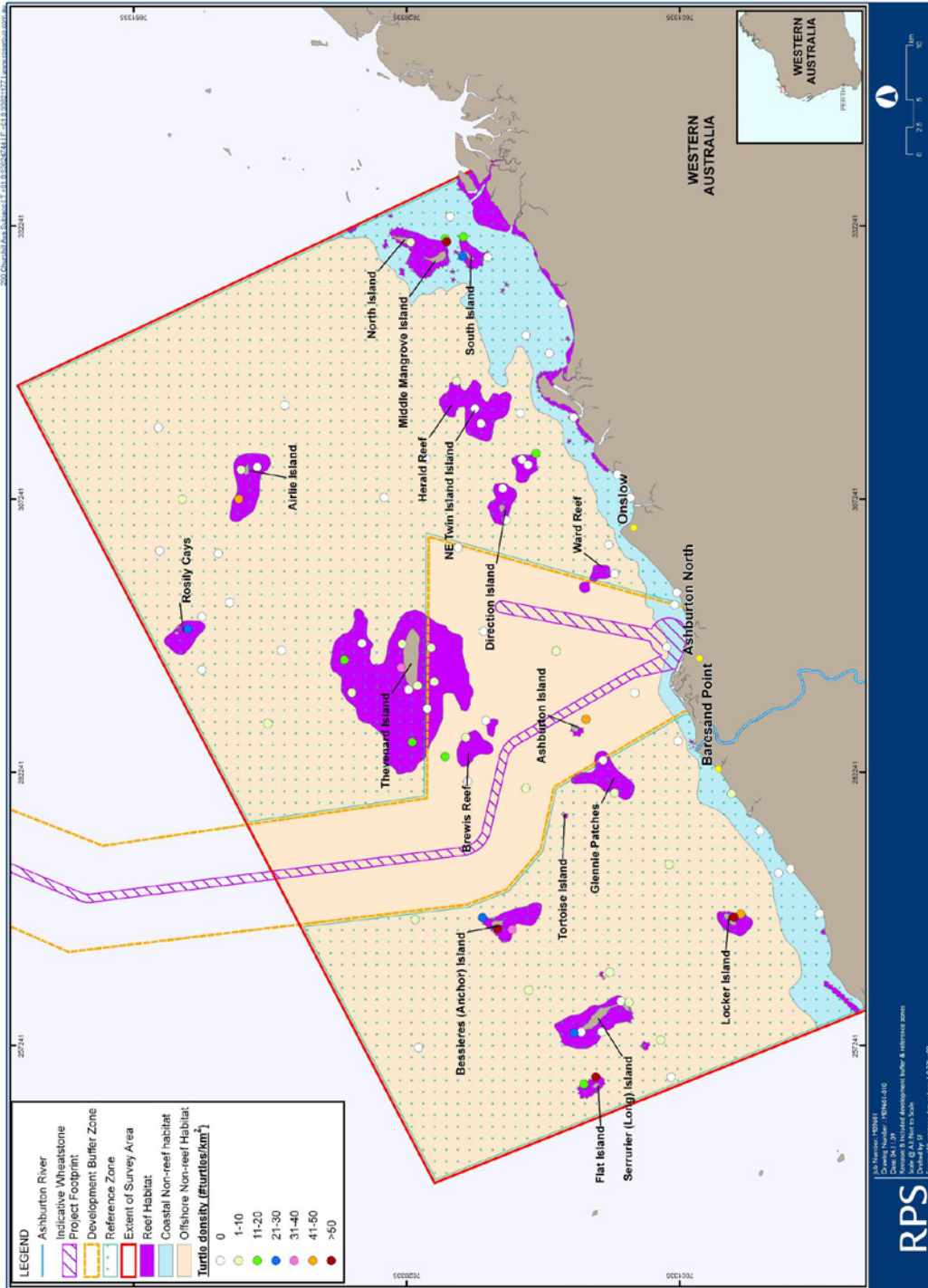


Figure 24: Turtle Densities from Vessel-based Transect Surveys in July-August 2007



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6.4.1.2 Estimates of Turtle Abundance

The estimated relative abundance of turtles in the survey area, Development Buffer Zone and Project footprint is provided in Table 14. Within the survey area and Development Buffer Zone, while the densities are higher over the reefs, there are likely to be similar numbers of turtles in reef and offshore non-reef habitats and very few turtles within the coastal non-reef habitats (Table 14).

The Project footprint does not include any reef habitat, but comprises mainly offshore non-reef habitat. Only a small proportion of the turtles within the survey area that forage in the offshore non-reef habitats (< 2%) are expected to occur within the Project footprint at any given time (Table 14).

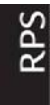


Table 14: Estimated Numbers of Turtles in the Survey Area, Development Buffer Zone and Project Footprint

Habitat Group	Density (# Turtles/km ²)	Total Habitat Area Within Survey Area (km ²)	*Estimated # Turtles in Survey Area	Total Habitat Area Within Development Buffer Zone (km ²)	*Estimated # Turtles in Development Buffer Zone	Total Habitat Within Project Footprint (km ²)	*Estimated # Turtles in Project Footprint	% of Turtles in Survey Area likely to occur in Project Footprint
Reef	12.6	241.38	3052.74	38.45	486.28	0.00	0.00	0.00
Offshore non-reef	1.0	3094.66	2989.16	604.34	583.74	53.78	51.95	1.74
Coastal non-reef	0.3	303.07	91.84	18.56	5.62	7.79	2.36	2.57
Total	3.8	3639.12	6133.74	661.35	1075.64	61.57	54.30	0.89

*Abundance estimates derived from estimates of areal coverage of habitats and observed turtle densities in each habitat, during vessel-based transect surveys in July-August 2009.

6.4.1.3 Species Breakdown

Three turtle species (green, loggerhead and flatback turtles) were recorded during the foraging survey (Table 15). The majority of turtles recorded within each habitat were green turtles. Very few loggerhead and flatback turtles were recorded. However, almost half of the turtles observed could not be identified to species, due to the difficulty in identifying turtles at a distance, and turtles were only seen momentarily.

Table 15: Species of Turtle Observed in Each Habitat Group During Vessel-based Transect Surveys in July–August 2009

Habitat Group	# Green Turtles	# Loggerhead Turtles	# Flatback Turtles	# Unidentified Turtles	Total
Reef	63	3	1	19	86
Offshore non-reef	5	0	1	11	17
Coastal non-reef	1	0	0	0	1
Total	69	3	2	30	104

6.4.1.4 Size-class Frequency

Size-class was determined for the majority of turtle observations (Table 16). Juvenile-size turtles were only seen in reef habitat and made up 60% of turtles in this habitat group. Only adult-size turtles were seen in the offshore non-reef and coastal non-reef habitats (Table 16).

Table 16: Number of Individuals in each Size-class Observed within Habitat Groups during Vessel-based Transect Surveys in July–August 2009

Habitat Group	# Adult-size Turtles	# Juvenile-size Turtles	# Undetermined Size Class	Total
Reef	29	49	8	86
Offshore non-reef	13	0	4	17
Coastal non-reef	1	0	0	1
Total	43	49	12	104



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7.0 DISCUSSION

7.1 Nesting

Prior to the nesting studies by Pendoley Environmental (2009) and RPS, little was known about the importance of beaches in the vicinity of the Wheatstone Project footprint for marine turtles.

The data presented in this report confirm the following conclusions:

- The beach at Ashburton North is unsuitable for marine turtle nesting
- Flatback turtles nest on the beach at the Ashburton River Delta.
- Green and flatback turtles nest on many of the islands adjacent to the Project footprint.

7.1.1 Mainland Beaches

The beach adjacent to Ashburton North is unsuitable habitat for turtle nesting. The absence of a primary dune and presence of a lagoon approximately 15–20 m behind the beach render the beach unsuitable for nesting and egg production (Miller 1997).

Tracks recorded during the vessel surveys at the Ashburton River Delta beach, though not identified to species level, were assumed to be flatback turtle tracks, as no other species of turtle have been recorded nesting on mainland beaches in the region previously (DEC 2009; Pendoley Environmental 2009a).

The nesting beach at the Ashburton River Delta, with an estimated 21-34 tracks/night during the December peak, appears to support lower levels of flatback turtle nesting than Barrow Island, where an average of approximately 52 flatback turtle tracks/night has been recorded during the January peak (Pendoley Environmental 2008).

No clutch studies have been undertaken to determine the productivity of the Ashburton River Delta beach.

The current studies did not target the peak nesting season for hawksbill turtles (October–December) and the importance of the Ashburton River Delta beach for hawksbill turtle nesting is not known. However, given that hawksbill turtle nesting has not previously been recorded on the Pilbara mainland (Mau and Balcazar 2007; DEC 2009; Pendoley Environmental 2009a), they are not expected to nest at the Ashburton River Delta.

7.1.2 Island Beaches

The majority of nesting activity in vicinity of the Project footprint is by green and flatback turtles on offshore islands.

7.1.2.1 Green Turtles

Green turtle track densities during the census surveys were consistently higher at Bessieres Island, and were also high at Thevenard Island (Pendoley Environmental 2009; 2009a).

The highest numbers of BHT green turtle tracks recorded during the snapshot surveys were on Serrurier Island (160 BHT tracks), Thevenard Island (94 BHT tracks), Tortoise Island (1 BHT track) and Locker Island (1 BHT track) in early January 2009 (Pendoley Environmental 2009; 2009a). No BHT green turtle tracks were recorded on Direction Island (Pendoley Environmental 2009; 2009a).

The densities of green turtles tracks on Bessieres Island and Thevenard Island (24.2 tracks/km/night and 13.0 tracks/km/night, respectively) (Pendoley Environmental 2009) were higher than the density of green turtle tracks recorded during the same period in 2008 at the North West Cape (approximately 10 tracks/km/night (Markovina 2008), and within the average density range of green turtle tracks on Barrow Island green turtle nesting beaches in January (approximately 10–70 tracks/km/night per beach) (Pendoley Environmental 2008). However, the small area of nesting habitat on Bessieres and Thevenard Island means the nesting population on these islands is likely to be much smaller than the nesting populations at the North West Cape and Barrow Island.

7.1.2.2 Flatback Turtles

Ashburton Island consistently had the highest density of flatback turtle tracks, with between 6.0 tracks/km/night and 61.2 tracks/km/night recorded in census surveys in mid December 2009 (RPS survey), early January 2009 (Pendoley Environmental 2009a) and late January/early February 2009 (Pendoley Environmental 2009).

Densities of flatback turtle tracks on Ashburton Island in December 2009 were comparable with average densities of flatback turtle tracks on Barrow Island beaches during the January peak (52 flatback turtle tracks/night; Pendoley Environmental 2008). However given the limited area of available nesting habitat on Ashburton Island, compared to Barrow Island, the total number of turtles nesting is likely to be much lower on Ashburton Island.

Flatback turtle tracks were also recorded on Locker Island, Thevenard Island and Direction Island during snapshot surveys in early January 2009 and late January/early February (Pendoley Environmental 2009; 2009a). Flatback turtle tracks have previously been recorded on Thevenard Island and Locker Island (Mau and Balcazar 2007; DEC 2009), but Direction Island has not previously been identified as a flatback turtle rookery.

The density of flatback turtle tracks recorded at Ashburton Island in December 2009 (61.2 tracks/km/night) was much higher than the estimated density for the Ashburton River Delta beach (7–13 tracks/km/night). The actual numbers of tracks were however calculated to be relatively similar, with 42 tracks/night recorded at Ashburton Island and an estimated 21–34 tracks/night at the Ashburton River Delta.

7.1.2.3 Loggerhead Turtles

Low numbers of loggerhead turtles have previously been recorded nesting on islands south of the Project footprint in mid-January 2007 (Mau and Balcazar 2007). Pendoley Environmental (2009) did not record any loggerhead turtle tracks or hatched nests in their late January 2009 survey, however Pendoley Environmental (2009a) recorded a hatched loggerhead turtle nest on Bessieres Island in early January 2009, which suggests that at least some loggerhead turtle nesting occurs on islands offshore from Ashburton North.

7.1.2.4 Hawksbill Turtles

Low numbers of hawksbill turtles have previously been recorded nesting on islands to the south of the Project footprint in mid-January (Mau and Balcazar 2007). Pendoley Environmental (2009) recorded two hawksbill turtle tracks on Bessieres Island in late January 2009, but no hatched hawksbill turtle nests. Pendoley Environmental (2009a) did not record any evidence of hawksbill turtle nesting during their survey in early January 2009. The low levels of hawksbill turtle nesting activity recorded in the January 2009 surveys is possibly due to the timing of the study (outside of the peak hawksbill turtle nesting season), or that the Project footprint is outside of the major rookery areas for these species (Prince 1994a; Limpus 2009) and they may only rarely nest in this area.

7.1.2.5 Other Species

Nesting by olive ridley and leatherback turtles was not recorded during the current studies, although the nesting survey was completed outside the peak olive ridley nesting season (April–June) (Limpus 2009).

7.1.3 **Nesting Site Fidelity**

Preliminary satellite tracking data for flatback turtles nesting at Ashburton Island shows that at least some turtles do not nest exclusively on Ashburton Island, but also nest on other nearby islands and possibly the mainland. As such, all islands and beaches in the vicinity of the Project footprint that support marine turtle nesting should be treated as a single rookery, which probably extends beyond the islands in the survey area. Impacts to turtles nesting at one beach/island may affect nesting densities on other beaches/islands.

7.2 Inter-nesting

Preliminary satellite tracking data for flatback turtles tagged on Ashburton Island shows that these turtles travel extensively during the inter-nesting period. All of the tracked turtles passed through the Project footprint at least once during the inter-nesting period, with some turtles (52941, 52953 and 52955) passing through several times. As turtles are most at risk of impact from dredging when resting on the sea floor and from vessel-strike when in the surface waters, the analysis of the time-depth data will provide further information on the proportion of the time the turtles spend in these higher risk areas.

The inter-nesting periods inferred from the satellite transmitter data ranged from 13 to 17 days, which is similar to the range for flatback turtles nesting at Barrow Island (12–16 days) but longer than for flatback turtles nesting at Mundabullangana (10–13 days) (Pendoley Environmental 2009b). Pendoley Environmental (2009b) hypothesize that the shorter inter-nesting period for Mundabullangana flatback turtles may be related to their inter-nesting areas being closer to their nesting beach than the inter-nesting areas for Barrow Island turtles, which may travel up to 70 km to their inter-nesting areas. The turtles tracked from Ashburton Island travelled up to about 40 km from the nesting beach (turtle 52955), which is further than the Mundabullangana turtles (which remain in shallow water immediately adjacent to the nesting beach during the inter-nesting period), but not as far as the Barrow Island turtles.

7.3 Hatching

7.3.1 Dispersion from the Nest

Baseline studies on hatchling dispersion can be useful for determining if hatchlings are misoriented from a relatively direct line to the sea, by artificial lights. Pendoley Environmental's (2009) hatchling dispersion study indicates that there is natural low-level hatchling misorientation, however the small number of sampled nests do not provide an adequate baseline from which increases in hatchling misorientation caused by the development could be detected.

7.3.2 Hatching Success

Hatching success data is important for determining the productivity of a nesting beach. Although many nests may be laid on a beach, the beach will only be productive if those nests successfully incubate eggs and produce hatchlings (Miller 1999). The preliminary hatching success data indicates a high hatching success for both green and flatback turtles on offshore islands within and adjacent to the Project footprint, and a low hatching success for a single nest on the mainland (Pendoley Environmental 2009). Mean green turtle hatching success in the survey area (91%) was much higher than for other Australian green turtle rookeries, including: Raine Island in Queensland (79%), Ashmore

Reef, off the coast of northern Western Australia (52%), and Bramble Cay, north of Cape York Peninsula (68%) (Limpus et al. 2001; Limpus et al. 2003; Limpus 2009). Mean flatback turtle hatching success (80.9%) was slightly lower than for Barrow Island (84.9% (Foster 2008)), but was still relatively high.

7.4 Foraging

The RPS foraging studies identified that similar numbers of turtles occupy reef and offshore non-reef habitats in the survey area during the peak foraging season, but that densities are greater in the reef habitats, confirming the findings of regional aerial surveys (Prince 2001; Jenner et al. 2010).

There is no reef habitat (as defined in Figure 11) within the Project footprint and the highest abundance of turtles in the Project footprint is likely to be in offshore non-reef habitat. The majority of turtles observed in the offshore non-reef habitat group were unidentified adult-sized turtles. These turtles may be moving between reef habitats to forage, or foraging in the deeper waters between the reefs.

The foraging studies also indicated that most of the foraging turtles in the survey area were green turtles. These turtles appeared to favour the reef habitats around the offshore islands. Most of the turtles in reef habitats were juvenile-sized and such areas may be regionally important habitat for juvenile green turtles. There also appears to be a resident population of adult green turtles, which are common in reef habitats but travel throughout the area.

Given that both juvenile and adult green turtles are known to forage over macroalgae, coral reef and limestone reef habitats (Limpus 2009), and that the foraging studies were conducted during the peak foraging season, it is likely that the adult and juvenile green turtles observed in the reef habitats were resident foraging turtles.

No juvenile flatback turtles were observed during the foraging survey, indicating that the survey area is not a major foraging area for these turtles. However, a juvenile flatback turtle carapace was found in a sea eagle nest on the east coast of North East Twin Island (Pendoley Environmental 2009), and it is possible a proportion of the unidentified turtles during the foraging survey were juvenile flatback turtles. It is also possible that juvenile flatback turtles were present but were too small to be seen from the vessel.

Given that leatherback turtles are easily distinguished from chelonid turtles (Pritchard and Mortimer 1999), it is clear that the Project footprint is not an important foraging area for this species. Flatback, hawksbill, loggerhead and olive ridley turtle feeding grounds in the region remain unknown, but these species appear to be rare in the survey area during the non-reproductive time of year.



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APPENDIX I

Pendoley Environmental (2009) Survey Report



Wheatstone Project

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Onslow Mainland Area and Nearby Islands
25 January – 6 February 2009

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Marine Turtle Beach Survey
Onslow Mainland Area and Nearby Islands
25 January – 6 February 2009



Report to
URS – Chevron Wheatstone Project Team
By
Pendoley Environmental Pty Ltd
August 2009
R-J03008
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Executive Summary

This report presents the results of a marine turtle survey conducted in the Onslow region from 24th January to 7th February, 2009 for Chevron Wheatstone. Ground surveys were conducted at all mainland and island beaches within a 30 km radius of the project site. This encompassed mainland beaches from Locker Point to Coolgara, as well as Ashburton, Bessieres, Direction, Flat, Locker, Round, Serrurier, Table, Thevenard, Tortoise, NE Twin and SW Twin Islands.

Data were collected regarding identification of species present at each site, level of nesting activity, identification of emerged nests, hatching success and hatchling orientation, site specific physical characteristics and additional observations of relevant flora and fauna.

There was no evidence of any nesting for any species of marine turtle at the proposed development site. Knowledge of characteristics of preferred marine turtle nesting habitat precludes this area from exhibiting notable levels of nesting activity. Based on the findings of this survey the Onslow mainland area supports very low levels of nesting that are unlikely to be of regional significance.

It is unlikely that survey results were substantially impacted by the passing of Tropical Cyclone Dominic, although it did result in a lower than expected count at some of the sites. Cyclonic activity erased evidence of nesting prior to the survey period. The path of the cyclone impacted more heavily upon islands within the eastern sector of the survey area. The passing of the cyclone delayed the survey period by five days which consequently fell just outside peak nesting for flatback turtles but still within peak nesting for green turtles.

Nesting on the mainland was found at Census beach four. Activity documented at this site comprised one newly laid and one emerged flatback turtle nest and evidence of 18 nests laid prior to the survey period, five of which were confirmed as flatback nests. This level of flatback turtle nesting along mainland beaches is not regionally or even locally significant based on current knowledge of marine turtle nesting within the region.

Twelve islands were assessed during the survey. Level of nesting during the survey period varied from island to island. Ashburton, Bessieres, Locker, Serrurier and Thevenard showed the highest level of marine turtle activity. Nesting at Serrurier and Bessieres Islands was predominantly by green turtles with small numbers of flatback turtles documented. Thevenard Island recorded mostly flatback turtle nesting on the south-western coast and green turtle nesting along the north-western coast. Nesting at Ashburton and Locker Islands was dominated by flatback turtles.

Small areas of suitable nesting habitat and low to moderate density nesting were identified at Direction, Flat, NE Twin, Table, Tortoise, Round and SE Twin Islands.

For the most part, the highest nesting density beaches occurred on the eastern and southern coasts of surveyed islands. This pattern is dictated by available nesting habitat in these areas.

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Within the survey region and study period, flatback turtles nested on islands closer to the mainland while green turtles nested on islands further offshore. No green turtle nesting was found on the mainland. There was one record of hawksbill turtle nesting documented on Bessieres Island. No records were made of loggerhead turtle nesting during this survey. More extensive surveys would be needed to establish the significance of hawksbill or loggerhead nesting within the Onslow region.

A total of nine flatback and three green turtle nests were excavated after hatchlings had emerged to determine the hatch success of each nest. Mean hatch success and clutch size for green and flatback turtles were within the known range for these species (Miller 1997).

Hatchling orientation was measured for five green and 13 flatback turtle nests. Levels of misorientation were found to be low for both species; one flatback and one green turtle nest showed signs of disrupted sea-finding behaviour.

Importantly, 58 sightings of juvenile green turtles were documented in the shallow near shore waters of surveyed islands. Two adult green turtles were recorded off the northern coast of Serrurier Island. One large juvenile/sub-adult loggerhead turtle was seen off the coast of SW Twin Island and one unidentified small juvenile turtle was seen at Tortoise Island. There were no sightings of turtles in the water along the mainland coast although turbid waters may limit visibility in this area. There were no sightings of flatback or hawksbill turtles in the water.

Other marine fauna, notably dolphins, sharks, rays and dugongs were observed during the survey.

Although abundance of nesting at the project site was limited, nesting by three marine turtle species was documented within the survey area. Assessment of indices of reproductive success show values within the typical range for these species. Hatchling emergence patterns indicate little disruption to sea-finding behaviour. Temporal constraints of survey execution preclude meaningful assessment of nesting by hawksbill turtles and it is recommended that this be assessed. Near-shore waters of several offshore islands support foraging habitat for juvenile green turtles. It would be of value to further characterise these foraging assemblages where they occur within the project impact area.

I Objective and Scope

This report presents the results of a marine turtle survey conducted on all mainland and island beaches within a 30 km radius of the project site. This comprised the Ashburton River Delta mainland beaches near Onslow and the Ashburton River Delta and on Ashburton, Bessieres, Direction, Thevenard, Tortoise, Serrurier, Table, Flat, Round, SW Twin, NE Twin and Locker Islands (Figure 1). The survey was conducted from 24th January to 7th February, 2009.

There were two primary objectives of this survey:

1. To gather evidence of marine turtle nesting activity on regional beaches, to identify the species using the nesting habitat and to obtain an estimate of the size of the nesting population. These beach surveys used track census techniques on selected 'census' and 'snapshot' beaches to document the distribution of the four most common marine turtle species that nest locally, as well as the relative density of adult nesting.
2. To collect data on the number of nests emerging successfully and the orientation of hatchlings as they make their way to the ocean following emergence from the nest. Counts of successful nest emergences provide an indication of the productivity of the survey beaches. Monitoring hatchling emergence fan indices provides indication of how successful the hatchlings are in sea-finding after emerging from the nest. These indices document occurrences of potential misorientation hatchlings may display as a result of artificial light sources nearby.
3. The beach surveys also documented physical characteristics of the beaches, actual and potential nest predation, near shore observations of turtles (principally foraging juveniles), in addition to opportunistic observations of avian and marine fauna in the area.

Benthic habitat (including coral reef, seagrass/algae and soft bottom) in the potential zone of impact and influence will be identified during baseline subtidal surveys as part of the environmental approvals process but are outside of the scope of this survey.

2 Biology & Ecology of Marine Turtles on the North-west Shelf of Australia

Marine turtle activity within the survey area has not been systematically studied; little has been published in the scientific literature on marine turtles in this area. Consequently, the bulk of background information within comes from grey literature including government reports, previous surveys conducted by Pendoley Environmental staff and anecdotal sources.

Six species of marine turtles from two families (*Cheloniidae*, *Dermochelyidae*) inhabit West Australian waters (Table 1). All six species are considered endangered or vulnerable and are protected by state and federal legislation and international organisations (Table 1).

Of these six species, only four are known to be reproductively active in the North-Western Shelf region of Australia. Among these populations, Prince (1994a, 1994b) and Pendoley (2005) have identified the following as being of regional significance:

- Green turtle rookeries at Northwest Cape, Muiron Islands, Barrow Island, Varanus Island, Rosemary Island and the Lacepede Islands;
- Hawksbill turtle rookeries at Northwest Cape, Rosemary and Varanus Islands. Additional nesting occurs at Delambre Island in the Dampier Archipelago, North and South Muiron Islands, Airlie, Barrow, Beacon, Bridled, Hermite, Parakeelya, Trimouille and Varanus Islands in the Lowendal group.
- Flatback turtle rookeries at Barrow Island, within the Montebello Island complex, on Varanus Island within the Lowendal Island complex, on Cowrie Beach on Mundabullangana Station, at Eighty Mile Beach in the southern Kimberley region and at Cape Domett in the Northern Kimberley (Whiting et al. 2008)
- Loggerhead turtle rookery at Dirk Hartog Island, Northwest Cape and the Muiron Islands (Baldwin et al. 2003).

Knowledge of loggerhead turtle populations within the study region is sparse. No large olive ridley turtle rookeries have been recorded in Western Australia. There has been one nesting event recorded at Darcy Island though this record remains unconfirmed and exists only as anecdotal evidence. Leatherback turtles are occasional visitors to Western Australian waters and have not been documented nesting.

Table 1: The conservation status of marine turtle species occurring in Western Australian waters

Species	Wildlife Conservation Act 1950	Environment Protection and Biodiversity Conservation (EPBC) Act 1999	Convention on Migratory Species (CMS) Appendix (as at May 2009)	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix (as at May 2009)	International Union for Conservation of Nature (IUCN) Status (as at May 2009)
Loggerhead Turtle <i>Caretta caretta</i>	Schedule I*	Endangered	I & II	I	Endangered
Green Turtle <i>Chelonia mydas</i>	Schedule I	Vulnerable	I & II	I	Endangered
Hawksbill Turtle <i>Eretmochelys imbricata</i>	Schedule I	Vulnerable	I & II	I	Critically Endangered
Olive Ridley Turtle <i>Lepidochelys olivacea</i>	Schedule I	Endangered	I & II	I	Vulnerable
Flatback Turtle <i>Natator depressus</i>	Schedule I	Vulnerable	Not listed	I	Data Deficient
Leatherback Turtle <i>Derموchelys coriacea</i>	Schedule I	Vulnerable	I & II	I	Critically Endangered

* Schedule I. Fauna that is rare or likely to become extinct

2.1 Nesting Habitat and Reproductive Periods

Nesting beaches used by female turtles for egg laying are generally sandy. Eggs incubate within nesting beaches over a 6-8 week period, following which, hatchlings emerge and head into the water.

Nesting beach habitat most commonly associated with the three turtle species typically found in the Pilbara region has been described by Pendoley (2005) as follows:

- Hawksbill turtles are found associated with beaches located close to nearshore coral reefs and the beach sediment typically comprises a shallow bed of coarse sand and coral rubble (e.g. Beacon Island and Rosemary Island).
- Green turtles nest on high energy, steeply sloped beaches comprising deep well sorted medium grain sized sand, with a deep water approach to the beach independent of tide state (i.e. the intertidal zone is narrow or absent, e.g. west coast of Barrow Island and exposed beaches of North West and Trimouille Islands in the Montebello group).
- Flatback turtles favour low energy beaches that are typically narrow with moderate grain size and a low to moderate beach slope. The beach bed is often shallow (underlain by rock platform or clay) and the beach approach obstructed by broad

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intertidal mud or limestone intertidal platforms (e.g. east coast of Barrow Island, south coast of Thevenard Island and Mundabullangana).

It is worth noting that this description represents currently known preferred habitat only and is not exclusive of others types of unknown, less preferable or potentially less suitable habitat types.

Within the Onslow region marine turtle nesting is well documented within the Barrow-Montebello-Lowendal Island complex. Three species of marine turtle nest in significant numbers in this region, a distance of approximately 100-150 km north east from the survey area. These are the green turtle, the hawksbill turtle and the flatback turtle. Loggerhead turtles are very occasionally observed nesting in the area (Pendoley 2005).

Four species of marine turtle are likely to utilize the Onslow region for nesting. These are: green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), flatback turtle (*Natator depressus*) and loggerhead turtle (*Caretta caretta*). The magnitude of nesting for each species is not well documented in the area.

There have been no records of leatherback (*Dermochelys coriacea*) or olive ridley (*Lepidochelys olivacea*) nesting in the Onslow region.

The locations of mating aggregations for marine turtles have not been formally documented for the survey area. Mating aggregations for green (Limpus 1993) and hawksbill turtles (Witzell 1983) typically occur in close proximity to the nesting beaches. The location of mating aggregations for flatback turtles is not known. At the large nesting rookeries on Barrow Island green turtles mating aggregations are seen within several metres of shore, while flatback turtles are not regularly seen in near-shore waters and sightings of male flatback turtles are virtually unknown (Pendoley 2005). It is possible that flatback mating aggregations occur at some greater distance from their nesting rookery habitat than for other species of marine turtles.

Precise breeding periodicity for marine turtles within the Onslow region has yet to be comprehensively defined. Temporal duration of this survey was based on findings from the Barrow-Montebello-Lowendal Island complex (Pendoley 2005). Within this complex, flatback turtle nesting occurs from November to March with peak nesting during December and January and green turtle nesting takes places from November to April with peak nesting from December to February (Pendoley 2005). Hawksbill nesting takes place from August to April and peaks earlier during October and November. Nesting in hawksbill turtles is more temporally diffuse and has been known to occur year round in other locations (Beggs et al. 2007).

Migratory pathways for marine turtles nesting in the Pilbara and Gascoyne regions include the coastal waters of the Onslow region. Green, hawksbill and flatback turtles nesting on Barrow Island and Varanus Island have been tracked via satellite telemetry and are known to move through these coastal waters (Barrow Island flatback turtle tracking, Barrow Island green turtle tracking, Varanus Island hawksbill turtle tracking; Pendoley, *unpublished data*).

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Inter-nesting movements and habitats for marine turtles nesting in the Onslow region are not known. However, it is likely that green (Carr 1974) and hawksbill (Starbird et al 2001) turtles remain within the general vicinity of their nesting beaches during their inter-nesting period. Flatback turtles nesting at Barrow Island have been tracked via satellite telemetry and are known to routinely use the near shore habitats of the mainland coast 50-60 km to the south-east of Barrow Island during their inter-nesting period (Barrow Island flatback turtle tracking project). Flatback turtles nesting at Mundabullangana and Cemetery Beach however, remain within ~20 km of their mainland nesting rookeries (Cemetery Beach, Port Hedland turtle tracking project, Mundabullangana Station turtle tracking project). Information regarding inter-nesting areas, migratory pathways or foraging grounds has not yet been elucidated for marine turtles in the Onslow region. It is not known if flatback turtles nesting in the Onslow region travel similar distances during their inter-nesting period and where they may be moving to.

Foraging habitat for green, hawksbill or flatback turtles has not been specifically identified in the survey area; however, it is reasonable to expect green turtles to occur in the vicinity of sea grass or algae beds, hawksbill turtles on or near coral reef habitat and flatback turtles over soft bottom habitat supporting sea pens or other infauna (Pendoley 2005). Recent flatback turtle satellite tracking studies indicate potential foraging in a wide variety of habitats and in water depths of 10–50 m off the Western Australian coast (Pendoley Environmental, *unpublished data*). Aerial surveys conducted outside the typical marine turtle nesting season to focus on spatial distribution and abundance of resident turtles, indicate aggregations of turtles around Locker, Serrurier, Bessieres, Ashburton and Thevenard islands (Prince 2000). Although positive identification of species was not always possible due to survey design constraints, it is probable that most animals observed were juvenile green turtles.

3 Methods

3.1 Survey Site

Beaches were assessed either via 'census' where beaches were visited daily over a period of four days to assess overnight nesting during the survey period or by 'snapshot' where beaches were visited once during the survey period.

Census locations were selected based on their proximity to proposed project infrastructure and potential (Table 2) for or knowledge of marine turtle rookeries in these areas. Census beaches were identified on the north and south coasts of Thevenard Island, east coast of Ashburton and Bessieres Islands and seven selected mainland beaches within a 10 km radius of the Ashburton River Delta.

'Snapshot' surveys were conducted on Tortoise, Serrurier, Flat, Round, Table, SW Twin, NE Twin and Locker Islands and selected mainland beaches within a 30 km radius of the Ashburton River Delta. Snapshot beaches were generally located further away from proposed project infrastructure or contained limited or poorer quality nesting habitat.

An overview of the region is shown in Figure 1. A summary of the survey dates and locations is shown in Table 3.

Table 2: Distance of surveyed area from Proposed LNG facility

Location	Distance from Proposed LNG Facility (km)
Ashburton Island	12.4
Bessieres Island	30.1
Thevenard Island	25.7
Tortoise Island	18.3
Direction Island	22.4
NE Twin Island	30.8
SW Twin Island	28.9
Locker Island	23.3
Serrurier Island	33.6
Flat Island	39.6
Round Island	35.4
Table Island	29.8
Mainland Beach One	15.8
Mainland Beach Two	12.4
Mainland Beach Three	9.2
Mainland Beach Four	4.4
Mainland Beach Five	3.5
Mainland Beach Six	1.2
Mainland Beach Seven	3.5

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Figure 1: Overview of the area surveyed in January and February 2009

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Table 3: Summary of dates and locations of marine turtle surveys conducted in the Onslow area and nearby islands, 24th January-7th February, 2009

Date	Task	Survey Locations			
24-Jan-09	Mobilization to field				
25-Jan-09	Census Line-in Snapshot	Ashburton Is Thevenard Is (west)	Bessieres Is	Thevenard Is.	
26-Jan-09	Demobilize for Cyclone				
27-Jan-09	Demobilize for Cyclone				
28-Jan-09	Demobilize for Cyclone				
29-Jan-09	Remobilize to field				
30-Jan-09	Census Line-in		Bessieres Is	Thevenard Is.	
31-Jan-09	Census Line-in Census Day One Snapshot	Ashburton Is Direction Is	Bessieres Is	Thevenard Is.	
1-Feb-09	Census Day One Census Day Two Snapshot	Ashburton Is Tortoise Is	Bessieres Is	Thevenard Is.	
2-Feb-09	Census Day Two Census Day Three	Ashburton Is	Bessieres Is	Thevenard Is.	
3-Feb-09	Census Day Three Census Line-in Snapshot	Ashburton Is Mainland Beach 1-7 NE Twin Is			
4-Feb-09	Census Day One Snapshot	Mainland Beach 1-7 Serrurier Is	Table Is	Round Is	Flat Is
5-Feb-09	Census Day Two Snapshot	Mainland Beach 1-7 Locker Is	Urala/Locker Pt	Onslow Back Beach	Coolgara/ Beadon Ck
6-Feb-09	Census Day Three Snapshot	Mainland Beach 1-7 SW Twin Is			
7-Feb-09	Demobilize				

3.2 Data Collection

The primary data collected from each survey beach are listed below.

Track census and nest counts

The track census survey methodology used for this program was based on techniques developed for beach surveys within the Barrow/Montebello/Lowendal Island complex (Pendoley 2005) and is consistent with IUCN SSC Marine Turtle Specialist Group methodology (Schroeder and Murphy, 1999).

Observation and documentation was made as follows:

- Marine turtle tracks below high tide mark (BHT). These tracks indicate the number of animals attempting to nest since the overnight high tide. This is therefore an underestimation of the number of turtles traversing the beach overnight as it does not account for animals crawling up and down the beach before the high tide had come and gone, thereby sweeping the beach clean of all tracks.
- Marine turtle tracks above high tide level (AHT). This information provides an indication of marine turtle activity on the beach in the recent past. This could be days to months dependent upon metocean conditions (e.g. Cyclones, storms, wind, rain and tidal surge will wipe the beach clean), along with the size, orientation and sediment characteristics of the beach. Secondary visual cues were also used to determine past nesting attempts, such as crab burrow holes through less-recent tracks, overlay of hermit crab, perentie or bird tracks and erosion level of crawls.
- Observations of marine turtles on the beach and in the water. Behaviour of animals in the water provides an indication of habitat usage and may include mating aggregations, developmental habitat or foraging grounds.
- Number of nests. Indicators used to assess whether eggs have been laid included the size, shape and compaction of sand in disturbed areas at the potential nest site, and track characteristics (where observable).
- All surveys were undertaken during the day and nesting female turtles were therefore unlikely to be encountered on the beaches. Track and nest characteristics e.g.: track width, shape and orientation of flipper marks, tail drag marks, morphology and depth of nest pit and associated mound were used to determine the species of the nesting turtle. Where the species could not be reliably identified from track or nest characteristics the tracks were recorded as unidentified.
- Nest predation. Nest predation was recorded for nests that clearly show evidence of animal foot prints and digging to egg/hatchling depth. Eggs, egg shell or hatchling remains may be visible. Where possible the predator was identified from tracks, dig marks etc.

Quantification of nesting effort during snapshot surveys was assessed using the following density scale:

- Low density = 1 track or crater per 10m+, very widely spaced tracks or craters with large areas of fresh sand visible.
 - Medium density = 1 track or crater per 5m – 10m.
 - High density = 1 track or crater per 1m, tracks and craters may be overlapping each other and little fresh sand is visible on the beach.
- Quantification of nesting effort during census surveys is calculated by the number of turtles arriving over the census line per night, averaged over three nights, per kilometre of beach. Density values are based on nesting levels at what are regarded as regionally and nationally significant nesting rookeries at Barrow Island and Mundabullangana.
 - Low density = <2 turtles per km/night.
 - Medium density = >2 and <20 turtles per km/night.
 - High density = >20 turtles per km/night.
 - Stranded turtles or carcasses and skeletons. The presence of dead turtles or turtle remains in the nesting habitat can be used to verify the species utilizing the beach to nest. Stranded turtles around the high-water mark indicate the presence of the species in near-by waters.
 - White-bellied sea-eagle (*Haliaeetus leucogaster*) nests were checked for the presence of any turtle remains.

Hatchling Emergence Fan monitoring methods

- The total number of emerged nests were counted and a GPS location taken for each. Nests are seen as expanding 'fans' of hatchling tracks from a distinct source point. Nests were recorded as a successful emergence when 5 or more tracks are sighted.
- Fan data were collected from suitable nests. Nests that displayed a clear fan not obscured by other nest fans, bird or other animal tracks were deemed suitable.
- The methods used to document hatchling emergence fan indices follow those developed by Pendoley (2005). Typically the angle of spread of the fan will increase under the influence of light (both natural and artificial) while lights behind, or at the end of the beach will cause the fan orientation to shift away from a direct line to the ocean.
- The spread of the fan was measured using a sighting compass to record the bearing along the outside arms of each fan. The bearing was taken at the point where the tracks cross the high tide line, or from the nest for fans that are orientated parallel to the ocean.

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- An angle of spread was then calculated from these bearings. The orientation of the fan relative to the most direct line to the ocean is termed the fan offset angle and is determined by calculating the angle between the most direct line to the ocean (X) and the bearing bisecting the fan spread angle (C).
- As with the nesting track count, fans may not be visible for survey due to wind, rain, or animal tracks erasing them. Furthermore heavy cyclonic rain can prevent hatchlings emerging from the sand in the days following.

3.3 Survey limitations

- The timing of the survey was dictated by 3rd party logistical and operational constraints and meeting client safety requirements.
- The passage of Tropical Cyclone Dominic through the region on 26th-27th January interrupted the surveys. No surveys were carried out between 26th and 29th January. This interruption forced the survey to take place 5 days later than planned. This was within the known peak nesting period for green turtles but outside the known peak period for flatback turtles.
- Strong winds and heavy rain associated with the cyclone obscured evidence of prior turtle nesting on some beaches. This was most evident on mainland beaches near Onslow and Ashburton and Direction Islands.
- The movement of a storm system through a marine turtle nesting region may also lower the magnitude of turtle nesting activity in the short term. It is therefore likely that the surveys undertaken have resulted in a minimum estimate of marine turtle nesting activity in these locations.
- Nesting marine turtle populations often exhibit large fluctuations in the number of turtles nesting per night on a beach. Flatback turtle nesting numbers have fluctuated from under 5 per night to over 250 per night during the peak nesting season at Barrow Island (Pendoley 2005 and unpublished data). In some cases nesting numbers can be influenced by the timing and magnitude of tides while there are also many unknown variables. Counts made over the course of just one or a few nights are not necessarily indicative of the mean level of nesting throughout a season.
- While this survey takes place during the peak nesting seasons for green and flatback turtles, it is recognized that hawksbill nesting occurring outside of the project period may not be accurately represented by these findings; an additional survey during this period is recommended to capture these data.
- High density turtle nesting may obscure previous turtle tracks from being counted or identified.

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- Hatch success rates are over estimated when only successfully emerged nests are excavated. Nests with little or no hatchling emergence cannot be visibly identified as such (there are no hatchling tracks) and therefore are not excavated and are thereby excluded from hatching success data.

3.4 Acknowledgements

The field survey was designed by Dr Kellie Pendoley and implemented by Mr Barry Krueger, Mr Nicholas Sillem, Dr Kellie Pendoley and Ms Anna Vitenbergs (Pendoley Environmental Pty Ltd), experienced marine turtle ecologists/biologists. Marine support for accommodation and transportation was provided by Broadsword Marine. Photographs were taken by B. Krueger. Plate 2, photograph by K. Pendoley. Figures were produced using Google Earth Pro Ref ID# 1839881.

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4 Results

Marine turtle nesting activity was found to be very low in the mainland survey area. Large sections of coastline exhibit no signs of marine turtle nesting activity. Low density flatback nesting was identified at one site to the west of the Ashburton River (Figure 41).

There is no evidence from this survey of marine turtle nesting for any species in the immediate vicinity of the proposed site for the Wheatstone LNG facility. The beach in this area has also been observed to be inundated by high spring tides (A. Vitenbergs, pers.com) making it unsuitable for marine turtle nesting (Figure 2).

Marine turtle nesting densities on the nearby islands varied significantly from island to island. The highest density nesting took place on Serrurier, Bessieres, Thevenard, Locker and Ashburton Islands. Nesting at Serrurier and Bessieres Islands was largely by green turtles with small numbers of flatback turtles. Thevenard Island had mainly flatback turtle nesting on the south-western coast and mainly green turtle nesting along the north-western coast. Nesting at Ashburton and Locker Islands was dominated by flatback turtles.

Smaller islands such as Tortoise, Round, Table, SE Twin and Direction Islands had small areas of suitable nesting habitat and very low density nesting activity. Other smaller islands such as Flat and NE Twin Islands, while also having smaller areas of suitable nesting habitat, have moderate levels of nesting within that habitat.

The highest nesting density beaches generally occurred on the east and southern coasts of the majority of islands surveyed.

Flatback turtles were found to be predominately nesting on the islands closer to the mainland and mainland beaches. Green turtles were found to be nesting on the islands further offshore. No green turtle nesting was found on the mainland. There was only one record of hawksbill turtle nesting, which occurred on Bessieres Island. There were no indications of loggerhead turtle nesting during this survey.

Survey results are presented in detail by island/area and the full data are tabulated in Appendices A-G.



Figure 2: Tidal inundation of project site.

4.1 Census Beaches

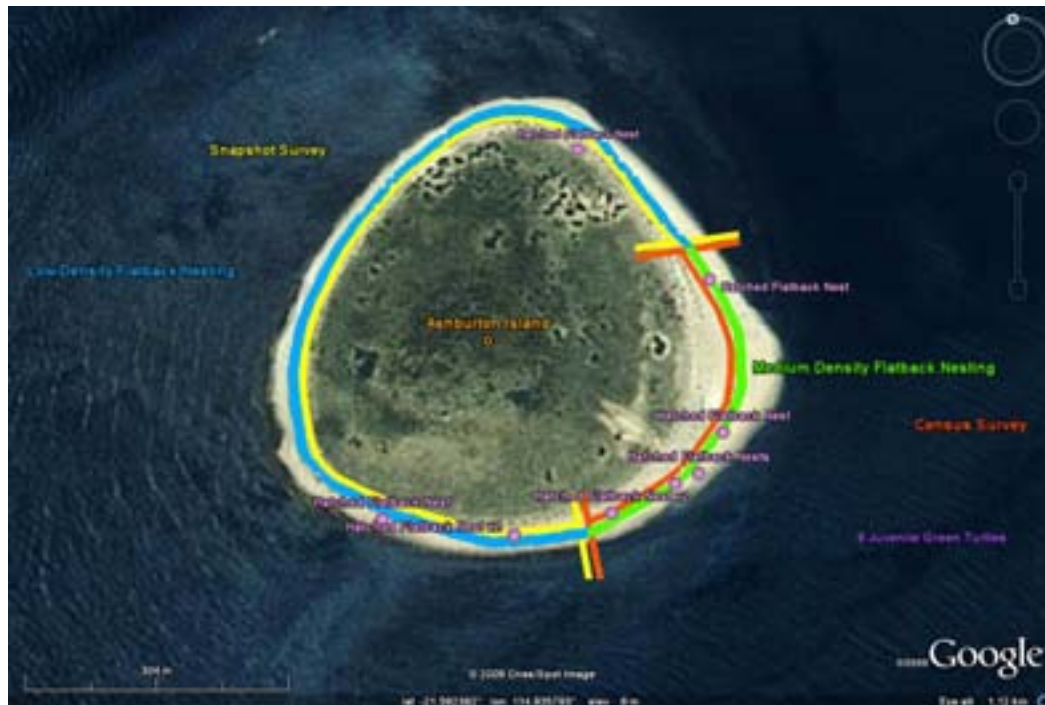


Figure 3: Ashburton Island - survey sites and results

Snapshot survey	Yellow line
Line-in census	Blue line
Low density nesting	Light blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Ashburton Island

The results of a line-census and snapshot survey on Ashburton Island (Figures 3 & 4) are presented below.

East Coast: Survey Date: 25th January, 2009. There were seventy eight flatback turtle tracks (up and down tracks, representing 39 turtles) observed above high tide (AHT), on the first survey. There were an additional three flatback tracks since the last high tide. Five emerged flatback turtle nests were found. No turtles were seen in the water although the water conditions were turbid.

Line census: line-in survey date: 31st January, 2009. There were twenty two flatback tracks AHT since the passage of cyclone Dominic on the 27th of January, 2009. There were an additional three green turtle tracks since the last high tide. Two emerged flatback turtle nests were observed. No turtles were seen in the water although the water conditions were turbid.

Line Census Surveys:

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1st February, 2009. No turtle tracks or emerged nests were observed. One juvenile green turtle was seen in the near shore waters.

2nd February: No turtle tracks or emerged nests were observed. Two juvenile green turtles were seen in the near shore waters.

3rd February, 2009. No turtle tracks or emerged nests were observed. Four juvenile green turtles were seen in the near shore waters.

Snapshot survey was carried out on 25th January, 2009. There was less than one track per 10 metres; and therefore, low density flatback turtle nesting along the north, west and south coasts of the island outside the east coast census area. Four emerged flatback nests were seen. There were no sightings of turtles offshore although the water conditions were turbid.

The south and east coasts have suitable nesting habitat for turtles with broad gently sloping beaches. The northern and western coasts are less suitable, being largely rocky with difficult access to the beach.



Figure 4: South coast of Ashburton Island with wind-blown turtle tracks in the foreground

Wheatstone Marine Turtle Survey
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Figure 5: Bessieres Island - survey sites and results

Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink dot

Bessieres Island

The results of a line-census and snapshot survey on Bessieres Island (Figures 5 & 6) are presented below.

East Coast: Survey Date: 25th January, 2009. There were four flatback and one hundred and eighty-one green turtle tracks observed AHT on the first survey. One emerged green turtle nest was found. No turtles were seen in the water although the water conditions were turbid.

Census line in survey date: 30th January, 2009. There were twenty two flatback and two hawksbill tracks AHT since the passage of cyclone Dominic on the 27th of January, 2009. There were an additional three green turtle tracks since the last high tide. Two emerged green turtle nests were observed. No turtles were seen in the water although the water conditions were rough and turbid.

Line Census Surveys:

31st January, 2009. Four green turtle tracks were observed (i.e. two overnight nesting attempts). One green turtle nest emerged. No turtles were seen in the water.

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Onslow mainland area and nearby Islands

1st February. Two flatback and four green turtle tracks were observed. One green turtle nest emerged. One juvenile green turtle was seen in the water.

2nd February, 2009. No fresh tracks were observed. One flatback and one green turtle nest emerged. No turtles were seen in the water.

Snapshot survey was carried out on 25th January, 2009. Low density green turtle nesting was observed along the north, west and south coasts of the island outside the east coast census area. There were no sightings of turtles in the water.



Figure 6: Green turtle nesting on the east coast of Bessieres Island

Wheatstone Marine Turtle Survey
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Figure 7: Western Thevenard Island - survey sites and results

Thevenard Island

The results of a line-census and snapshot survey on Thevenard Island (Figure. 7) are presented below. An initial snapshot survey was conducted on the north-west, west and south-west coasts of the island. Two 500m census lines were then put in on the north-west and south-west coasts.

South Coast: AHT survey date: 25th January, 2009. There were sixty three flatback and four green turtle tracks observed on the first survey. No turtles were seen in the water.

Census line in survey date: 30th January, 2009. There were no turtle tracks since the passage of cyclone Dominic on the 27th of January, 2009. No turtles were seen in the water.

Line Census Surveys:

31st January, 2009. No turtle tracks were observed. Fourteen juvenile green turtles were seen in the water. Numerous sharks and rays were seen in near shore waters.

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Onslow mainland area and nearby Islands

1st February, 2009. Two flatback turtle tracks were observed. No turtles were seen in the water.

2nd February, 2009. No turtle tracks were observed. Eight juvenile green turtles were seen in the water. Numerous sharks and rays were seen in near shore waters.

North Coast: AHT survey date: 25th January, 2009. There were ninety three green turtle tracks observed on the first survey. Previous nesting density was high. No turtles were seen in the water.

Census line in survey date: 30th January, 2009. There were twenty six green tracks AHT since the passage of cyclone Dominic on the 27th of January, 2009. No turtles were seen in the water.

Line Census Surveys:

31st January, 2009. No turtle tracks were observed. Two juvenile green turtles were seen in the water.

1st February, 2009. Two flatback turtle tracks were observed. No turtles were seen in the water.

2nd February, 2009. Four flatback turtle tracks were observed. No turtles were seen in the water.

West Coast: A snapshot survey was carried out on 25th January, 2009. Medium density green turtle nesting was observed on the west coast of the island between the north and south coast census areas. Additional survey carried out 30th January, 2009. Seven green turtles had come ashore in the three days since the passage of cyclone Dominic on 27th January, 2009. One emerged green turtle nest was found. Fourteen juvenile green turtles were seen in the near shore waters.

The south-western coastline consists of a narrow gently sloping beach backed by low grass covered dunes. Turtle nesting occurs mostly within this dune area. The northern half of the west coast and northern coast consists of a slighting wider gently sloping beach backed by significantly higher dunes. The southern half of the west coast segment is actively eroding the face of the sand dunes that lie along the long axis of Thevenard Island. The dunes drop straight into the sea and dominate the supratidal zone.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 8: The mainland coast west of Onslow - survey sites

Mainland west of Onslow

The results of a line-census and snapshot survey for the mainland coast between Urala and Onslow Back Beach (Figures 8 to 13) are presented below.

A snapshot survey was carried out on 3rd February, 2009 between Urala and Onslow Back Beach area. No evidence of current or prior turtle nesting was seen although the beaches were heavily windblown. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Onslow mainland: Beach One

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad (~10 m to high water mark) and flat with fine grain light brown coloured sand. Low grassy dunes were backed by higher shrub covered dunes (Figure 9). There was no evidence of reef structures off shore.



Figure 9: Census line in place on mainland beach one

Onslow mainland: Beach Two

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad and gently sloping with fine grain medium brown coloured sand interspersed with pebbles. There was a fine layer of black sand ~5 m wide around the high water mark. Large un-vegetated dunes backed the beach (Figure 10).



Figure 10: Looking towards the east on mainland beach two

Wheatstone Marine Turtle Survey
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Onslow mainland: Beach Three

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. Two rib bones from an unidentified but adult sized turtle were found ~2 m above the high water mark. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad and flat with fine grained medium brown coloured sand. A ~5 m wide strip of fine grained black sand was found around the high water mark. The beach was backed by low grassy dunes with slightly higher shrub covered dunes further inland (Figure 11).



Figure 11: Mainland beach three looking towards the north-east

Onslow mainland: Beach Four

There was evidence of thirteen previous turtle nesting activities on the first visit to this beach, although all activities were difficult to observe due to earlier high winds and heavy rain from Cyclone Dominic. A further five nests were only visible due to them having been partially or completely predated by foxes (Figure. 13). No additional nesting was recorded during the three day census survey period. The nests were too wind-blown to determine the species that laid them although all five predated nests had the remains of flatback turtle shells present. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach was broad and gently sloping with fine grained dark brown coloured sand. A ~5 m wide strip of fine grained black sand was found around the high water mark. Low grassy dunes backed the beach with no dunes further inland. There was an extensive stand of tree trunks below the high water mark and immediately to the east of the census line (Figure 12).



Figure 12: Looking eastwards from mainland beach four

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 13: Fox predation of a flatback turtle nest at mainland beach four

Onslow mainland: Beach Five

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. A section of carapace from an unidentified but probably adult sized turtle was found on the beach. This section of beach was very heavily wind-blown. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The census line started 50 m north of the mouth of a creek. The beach consisted of a 0.5 m vertical eroded drop at the western end which gradually decreased to a gently sloping broad flat beach at the eastern end. The beach was backed by low grassy dunes ~50 m from the high water mark. A large amount of natural wooden debris was found on the beach (Figure 14).



Figure 14: Mainland beach five looking towards the east

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Onslow mainland: Beach Six

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach is broad and gently sloping and consists of fine grained medium brown coloured sand. There is a ~5 m wide strip of fine grained, black coloured sand around the high water mark (Figure 15).



Figure 15: Mainland beach six looking towards the east

Onslow mainland: Beach Seven

No evidence of prior turtle nesting was found and no new nesting was recorded during the three day survey period. No hatchling tracks were seen. No turtles were seen in the water although the water conditions were turbid.

The beach is broad, flat and gently sloping and consists of medium coloured, fine grained sand. There is a ~5 m wide strip of fine grained black coloured sand around the high water mark. The beach above the high water mark is heavily littered with mussel shells (Figure 16).



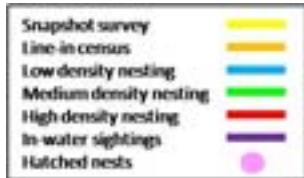
Figure 16: Mainland beach seven looking towards the east

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

4.2 Snapshot Beaches



Figure 17: Serrurier Island – a snapshot survey encompassed the entire island



Serrurier Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Serrurier Island (Figure 17 to 20) are presented below.

South East Coast: Based on presence of old body pits and associated nest mounds, there was evidence of high density green turtle nesting in the southern bay, along the south-eastern sand spit and the lower eastern coast. The majority of the nesting activity was by green turtles with lower levels of flatback nesting activity also present. One dead nesting green turtle was found on the beach. This animal had a curved carapace length of 96 cm. One juvenile and two adult green turtles were seen in near shore waters off the south eastern coast and one juvenile green turtle was seen off the southern bay.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 18: Serrurier Island east coast with recent green turtle tracks

East coast: There was evidence of medium density green turtle nesting along the remainder of the eastern coastline. Lower levels of flatback turtle nesting were also seen. Five juvenile green turtles were seen in near shore waters.

The sand dune height behind the east coast beaches increased in height towards the northern end of the island. In some cases turtles were nesting considerable distances up steeply sloping sand dunes (Figures 18 & 19).

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 19: Recent green turtle nesting on the north-east coast of Serrurier Island



Figure 20: Serrurier Island west coast

West coast: Low density green turtle nesting was observed along the entire west coast (Figure 20). There was no evidence of flatback nesting along the west coast. One juvenile green turtle was seen in near shore waters.

The east coast beaches are generally broad and gently sloping and consist of fine grained, light brown coloured sand. There are several rocky areas on the east coast which become more common and pronounced towards the north. The beach narrows at the northern point of the island and the dunes become higher. The west coast beaches are generally narrower. There are also more rocky areas. The south western point is mostly rocky and generally not suitable for marine turtle nesting. The bay on the south coast has a gently sloping beach backed by low grass covered dunes.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	
Line-in census	
Low density nesting	
Medium density nesting	
High density nesting	
In-water sightings	
Hatched nests	

Figure 21: Tortoise Island - a snapshot survey encompassed the entire island

Tortoise Island

The results of a snapshot survey, carried out on 1st February, 2009, around the entire coast of Tortoise Island (Figure 21) are presented below.

There was no evidence of current turtle nesting seen, although the beaches were heavily windblown. There were several old nesting pits in the AHT zone that could be discerned, indicating a very low level of prior nesting on the east coast. There was no evidence of any nesting around the remainder of the island. Eight sea-eagle nests were checked for marine turtle remains. No remains were found. One unidentified juvenile turtle was seen in the water. Eight dark coloured, unidentified dolphins were seen to the north west of Tortoise Island. Three lighter coloured unidentified dolphins were seen west of Tortoise Island.

The only suitable nesting habitat was on the small east coast beach and sand-spit (Figure 23). The sand on the east coast was light brown in colour and fine grained. The north, west and south coasts of the island were rocky (Figure 22).

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 22: South coast of Tortoise Island



Figure 23: Small east coast beach and sand spit on Tortoise Island

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 24: Direction Island - a snapshot survey encompassed the entire island

Direction Island

The results of a snapshot survey, carried out on 31st January, 2009, around the entire coast of Direction Island (Figure 24) are presented below.

No evidence of current turtle nesting was seen, although the beaches were heavily windblown and eroded. There were several older nesting pits from unidentified species on the eastern side of the island in the AHT zone. There was no evidence of recent hatching. No turtles were seen in the water.

There was a broad gently sloping beach and sand-spit on the eastern side of the island. The northern, western and southern coastlines were largely rocky and exhibited signs of recent erosion. A tourist shack is located on the south-west coast of the island.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 25: SW Twin Island - a snapshot survey encompassed the entire island

SW Twin Island

The results of a snapshot survey, carried out on 6th February, 2009, around the entire coast of SW Twin Island (Figure 25) are presented below.

The beaches were heavily windblown and eroded and there was evidence of seven previous nest pits in the AHT zone, from unidentified turtle species. There was no recent nesting activity. There was no evidence of hatchling tracks. Three sea-eagle nests were examined for turtle remains although none were found. One large, probably sub-adult, loggerhead turtle was seen in the water, on the surface, approximately 200 m south-east of the island in water approximately 10 m deep.

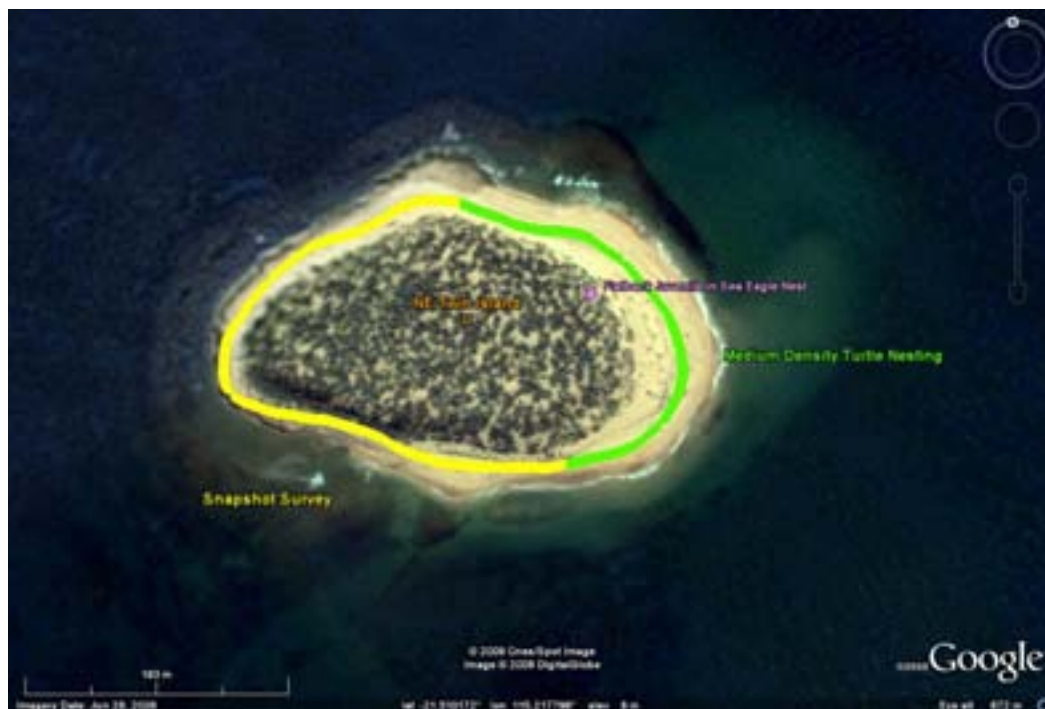
The east coast has a small gently sloping beach on the east coast which consists of moderately coarse grained and medium brown coloured sand (Figure 26). The beach is backed by small grassy dunes and the interior of the island is mostly covered in low shrubs of up to 0.5 m high. The north-west, west and south west coasts are rocky with shrubs to the high water line.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Figure 26: Small east coast beach on SW Twin Island, looking towards NE twin Island

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink dot

Figure 27: NE Twin Island – a snapshot survey encompassed the entire island

NE Twin Island

The results of a snapshot survey, carried out on 3rd February, 2009, around the entire coast of NE Twin Island (Figure 27) are presented below.

Although the beaches were heavily windblown and eroded there was evidence of thirty old nest pits from unidentified turtle species. There were an additional seven activities observed that could be identified as being flatback turtle nests and tracks. Two of these had occurred since the passage of Cyclone Dominic on 27th January, 2009. There was no evidence of any hatchling tracks. Four sea-eagle nests were examined and the remains of one ~15 cm long post-hatchling flatback turtle were discovered in a nest on the eastern side of the island (Figure 28). No turtles were seen in the water.

The main suitable nesting habitat was on the east coast beach and sand-spit. The sand is a medium brown colour and course grained. There was a large amount of seaweed washed up on the beach. There were low grass covered dunes behind the east coast beaches. The centre of the island was mostly covered in shrubs, some reaching to a height of ~2 m. The north east

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Onslow mainland area and nearby Islands

coast has a narrow beach area suitable for nesting. The remainder of the north coast is rocky. The west coast and south west coast is rocky.



Figure 28: Juvenile flatback sea turtle remains (turtle carapace next to nest in the lower right corner) at a white-bellied sea eagle nest on the east coast of NE Twin Island

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	Yellow line
Line-in census	Blue line
Low density nesting	Light blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 29: Table Island - a snapshot survey encompassed the entire island

Table Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Table Island (Figure 29) are presented below.

One flatback turtle had come ashore since the passage of cyclone Dominic on 27th January, 2009. There was evidence of low density nesting by unidentified turtle species on the small east coast beach. No hatchling tracks were seen. The skeletal remains of an unidentified adult turtle were found on the east coast in the dune nesting habitat. No turtles were seen in the water.

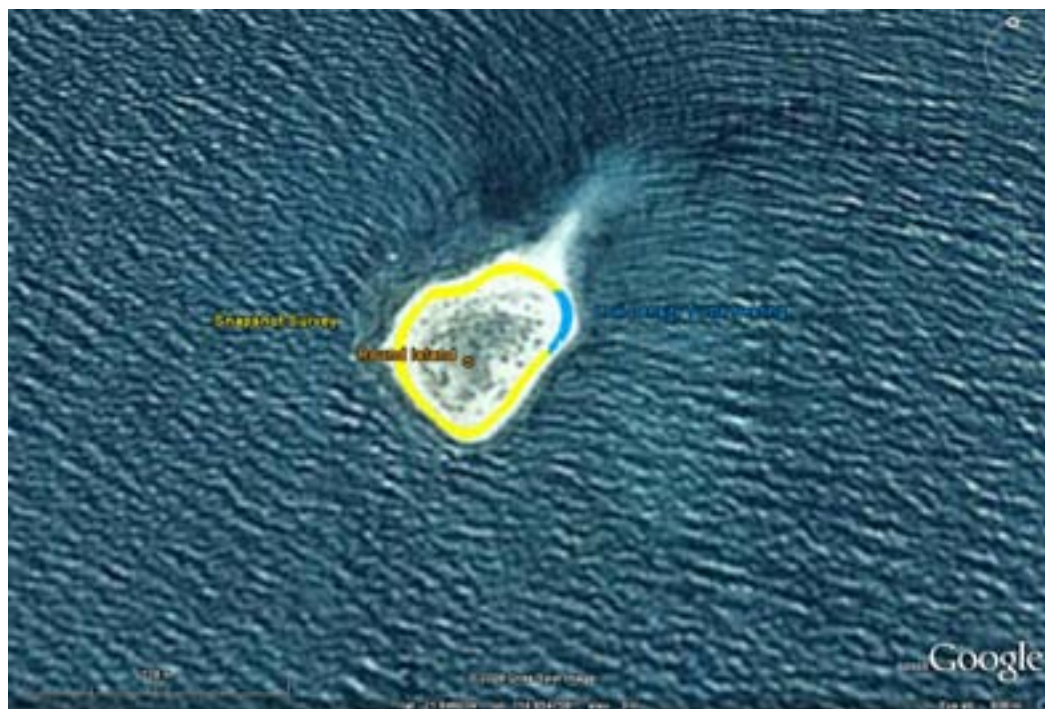
The small east coast beach was gently sloping and consisted of fine grained light brown sand. The north eastern coast was all rocky and coral rubble and unsuitable for turtle nesting (Figure 30). The south-west and western coasts consist of a mixture of fine grain sand with large amounts of coral rubble dispersed through it. The interior of the island has only about 50 % ground cover with the highest shrubs reaching 0.5 m.

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Figure 30: Sand spit and small east coast beach of Table Island

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Snapshot survey	Yellow line
Line-in census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Figure 31: Round Island - a snapshot survey encompassed the entire island

Round Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Round Island (Figure 31) are presented below.

One flatback turtle had come ashore since the passage of Cyclone Dominic on 27th January, 2009. There was evidence of low density nesting by unidentified turtle species on the small east coast beach. One sea eagle nest was examined but no turtle remains were found (Figure 32). No hatchling tracks were seen. No turtles were seen in the water.

The small east coast beach consists of medium grain light brown coloured sand. The south, west and north coast are rocky with a narrow (~2 m) wide sandy beach beyond the rocks. There is coral debris mixed through the medium grained sand. The interior of the island has 70 % of covering with grass.

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Onslow mainland area and nearby Islands



Figure 32: Looking over a White-bellied sea-eagle nest to the small south-east coast beach on Round Island

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Onslow mainland area and nearby Islands



Figure 33: Flat Island - a snapshot survey encompassed the entire island

Flat Island

The results of a snapshot survey, carried out on 4th February, 2009, around the entire coast of Flat Island (Figure 33) are presented below.

Three flatback and three green turtles had come ashore since the passage of Cyclone Dominic on the 27th January, 2009. Medium density green and flatback turtle nesting was observed along the east coast of the island. Low density green turtle nesting was found along the west coast of the island. Two dead nesting green turtles were found on the east coast beach (Figure 34). One old sea eagle nest was examined but no turtle remains were found. Seven black-tipped reef sharks were seen within 10 m from shore in ~1 m deep water on the south coast. No hatchling tracks were seen. No turtles were seen in the water.

There is a large sand-spit on the south-eastern side of the island and a broad mildly sloping beach on the east coast which consists of light brown coloured, fine grained sand. There is a rocky shoreline on the north-east and south-west coasts. The west coast has coral rock to the waterline with a 3m wide line of rock to the high water mark (Figure 35). There is a mix of ~70 % sand and ~30 % rock to the base of the dunes.

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The interior of the island has a ~95 % covering of shrubs which reach a maximum height of ~1 m.



Figure 34: The remains of a nesting female green turtle on the east coast of Flat Island

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Figure 35: Low density nesting on the exposed western coast of Flat Island

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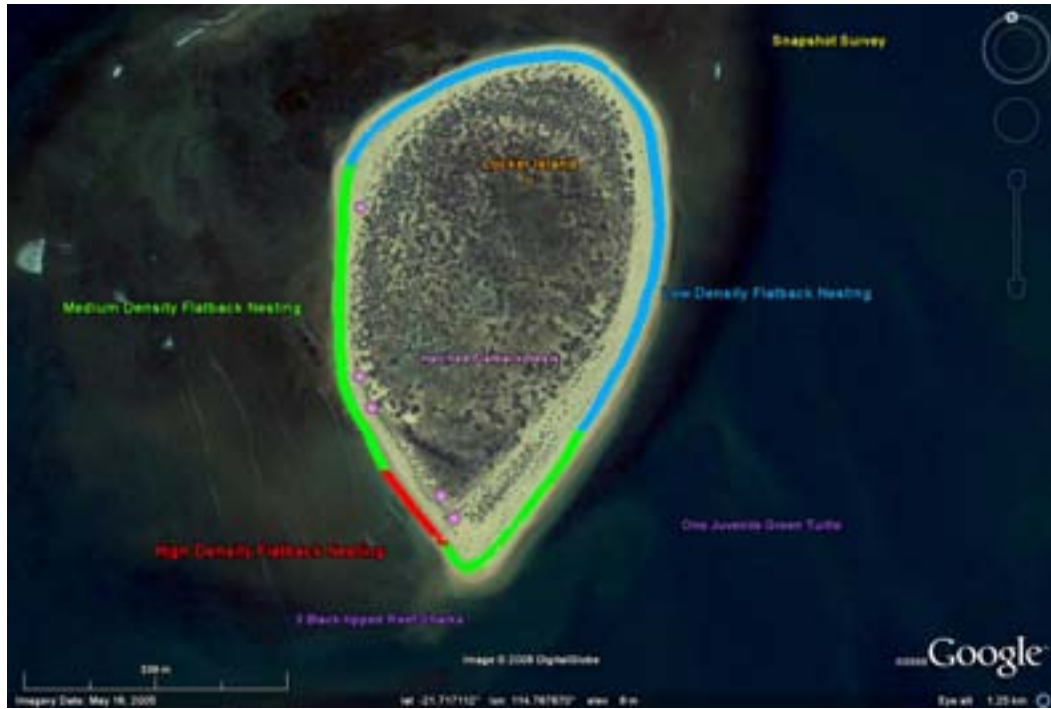


Figure 36: Locker Island - a snapshot survey encompassed the entire island

Locker Island

The results of a snapshot survey, carried out on 5th February, 2009, around the entire coast of Locker Island (Figure 36) are presented below.

Six flatback turtles had come ashore since the passage of cyclone Dominic on 27th January, 2009. Tracks from an additional seventeen flatback turtles could be identified AHT from prior to the passage of the cyclone. Flatback turtle nesting density was high on the south west coast (Figure 37) medium along the southeast and west coasts and low along the east and north coast. One juvenile green turtle was seen in near shore waters. Five flatback nest emergences were seen along the south western coast. One sea eagle nest was examined but no turtle remains were found. Three black-tipped reef sharks were seen within <10 m from shore in ~1 m deep water on the south coast.

There is a gently sloping beach surrounding the island. It is at its widest on the east and south east coasts. The sand is medium/coarse grained and light brown in colour and is mixed in with

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

some coral debris. The beach is backed by low grassy dunes with higher shrub covered dunes in the interior. The west coast is rocky with a 5 m wide beach above the rocks.



Figure 37: High density flatback turtle nesting on the south west coast of Locker Island

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Figure 38: Urala to Locker Point - survey site

Snapshot survey	Yellow line
Line-in-census	Orange line
Low density nesting	Blue line
Medium density nesting	Green line
High density nesting	Red line
In-water sightings	Purple line
Hatched nests	Pink circle

Urala to Locker Point

The results of a snapshot survey, carried out on 6th February, 2009, between Urala and Locker Point (Figure 38) are presented below.

No evidence of current or prior turtle nesting was seen although the beaches were heavily windblown. No turtles were seen in the water although the water conditions were turbid.

The beach survey was a total of 7 km in length. The beach was broad and gently sloping and consisted of medium brown coloured and medium grain sized sand. In some areas there was a ~5 m wide strip of fine grained black sand at the high water mark while in other areas this strip narrowed or disappeared completely. The beach was generally backed by low grass covered dunes. Water visibility was 2-3 m and a sandy bottom could be seen near-shore. A reef was found from ~700 m east of Locker Point until ~3 km east of Locker Point. There was exposed beach rock between 5.1 km and 5.7 km east of Locker Point. Several sections of beach, each 300-400 m long, had a 0.5 m vertical erosion line on the beach.

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 Onslow mainland area and nearby Islands



Figure 39: Onslow back beach - survey site

Onslow Back Beach

The results of a snapshot survey, carried out on 6th February, 2009, on Onslow Back Beach (Figure 39) are presented below.

No evidence of current or prior turtle nesting activity was seen although the beaches were heavily windblown. No turtles were seen in the water although the water conditions were turbid.

This beach survey was a total of 6 km in length. The beach was wide with a gentle slope and consisted of medium brown coloured fine grain sand mixed with shells. The beach is backed by low grass covered dunes with slightly higher shrub covered dunes inland. There were significant numbers of vehicle tracks seen along the greater part of this beach.

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands



Snapshot survey	
Line-in census	
Low density nesting	
Medium density nesting	
High density nesting	
In-water sightings	
Hatched nests	

Figure 40: Coolgara to Beadon Creek - survey site

Coolgara to Beadon Creek

The results of a snapshot survey, carried out on 6th February, 2009, between Coolgara and Beadon Creek (Figure 40) are presented below.

No evidence of current or prior turtle nesting activity was seen although the beaches were heavily windblown. No turtles were seen in the water although the water conditions were turbid.

The beach survey was a total of 11 km in length. The beach is broad and gently sloping and backed by low grass covered dunes with higher shrub covered dunes inland. The beach is made up of fine grained, medium brown coloured sand. At 150 m, 1 km and 5 km from Coolgara Point there are 2.5 m high shrubs down to the water-line. At 5 km from Coolgara Point there is a ~100 m long rocky ledge. West of the rocky ledge the beach becomes narrower and the dunes higher. About 8 km from Coolgara Point the beach becomes wider and is backed by lower dunes until reaching Beadon Creek.

4.3 Additional sightings

On 6th of February, three sets of recent flatback turtle tracks were seen en route to Census Beach four several hundred metres to the west of the survey area (Figure 41). One activity resulted in a potential nest while the others were unsuccessful nesting attempts. One emerged flatback nest was found in the same area. Two older fox predated nests were also seen. These nests had not been recognizable as marine turtle nests during the snapshot survey conducted on the 3rd February 2009 as the area was heavily wind-blown and the fox predation had occurred since that survey was undertaken.



Figure 41: Flatback turtle tracks and nest along the mainland coast west of census beach four

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Onslow mainland area and nearby Islands

4.4 Hatchling Fan Indices

Hatchling fans were measured for five green and thirteen flatback turtle nests (Figure 42). The results are presented in Appendix E. There was no hatchling misorientation for 92.3 % of flatback nests monitored where the X value (direction of the sea) was within the fan spread (A & B) and offset angles were low. There was no misorientation in 80 % of green turtle nests monitored. There was significant hatchling misorientation in one flatback and one green turtle nest.



Figure 42: Flatback hatchling tracks lead away from an emerged nest west of mainland census beach four

4.5 Hatching Success

A total of nine flatback and three green turtle nests were excavated after hatchlings had emerged to determine the hatch success of each nest. Results are presented in Appendix F. The mean hatch success for the green turtle nests was 91.3 %, with a range of 83.6-98.1 %. The mean hatch success for flatback turtles was 80.9 % with a range of 23.4-97.9 %. The mean number of eggs laid per clutch was 107.3 with a range of 104-114 for green turtles and 49.6 with a range of 35-64 for flatback turtles. All emergences apart from one flatback nest were found on the islands.



Figure 43: Hatchling flatback turtles at Bessieres Island

4.6 Inwater sightings

There were a total of sixty-two turtle sightings in the water. All sightings occurred within several hundred metres of shore around the islands. There were no sightings of turtles in the water along the mainland coast. Fifty-eight sightings were classified as juvenile green turtles, based on size, although size is not always a good indicator of maturity in marine turtles. The only two adult sized turtles seen in the water were green turtles off the northern coast of Serrurier Island. One large juvenile/sub-adult loggerhead was seen off the coast of SW Twin Island and one unidentified small juvenile turtle was seen at Tortoise Island. The remaining sixty in-water sightings were of green turtles. There were no sightings of flatback or hawksbill turtles in the water.

4.7 Other Observations

- **Dugong** (*Dugong dugon*)

There were two sightings of dugongs during the survey. One adult was seen in the shallow water off the north-western coast of Thevenard Island at ~10:00, 30-Jan-09. One adult was seen in Beadon Creek, Onslow, at 21:30, 5-Feb-09, while the survey vessel, 'Adrenaline Sprint', was at its mooring.

- **Cetaceans**

There were two sightings of unidentified dolphins during the survey. One pod of eight individuals west seen at ~11:15, 1-Feb-09, west of Tortoise Island while a second pod of three lighter coloured individuals was seen at ~11:30, 1-Feb-09 also to the west of Tortoise Islands.

- **Sharks and rays**

Seven black-tipped reef sharks (*Carcharhinus melanopterus*) (Figure 44) were seen off the southern coast of Flat island. Three black-tipped reef sharks were seen off the southern coast of Locker Island. Numerous sharks, rays and large fish were seen off the north western, western and south western coasts of Thevenard Island.

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Figure 44: Black-tipped reef sharks close to shore on the south coast of Flat Island

5 Discussion

There is no evidence of any nesting for any species of marine turtle along the mainland coast at the proposed development site. Subsequent observations made at this site documented high tide waters over topping the sand bar on sections of this beach (A. Vitenbergs, C. Bell pers. com.; Figure 2). It appears unlikely that marine turtles utilize this site for nesting in any significant numbers, if at all.

Apart from the low density nesting west of the Ashburton River at census beach four, there was no marine turtle nesting activity seen on mainland beaches during this survey. There is anecdotal evidence (B. Krueger pers. comm.) of low level flatback turtle nesting in the Onslow back beach area. There has also been a low level of nesting activity recorded between Beadon Creek and Coolgara (B. Krueger pers. comm.) All of the nesting activity observed on the mainland beaches has been very low density with large sections of beach apparently having no nesting activity at all.

The level of marine turtle nesting varies significantly from island to island. There is substantial nesting activity on the large (Serrurier and Thevenard) and moderate (Bessieres, Locker and Ashburton) sized islands, made of up a combination of flatback and green turtle nesting.

Smaller islands such as Tortoise Island have very small areas of suitable nesting habitat and very low density nesting activity (figure 45). Other smaller islands such as Flat, Table, Direction and the Twin Islands, while also having small areas of suitable habitat, have moderate levels of nesting activity within that habitat.

It is likely that the passage of Tropical Cyclone Dominic has resulted in a lower than expected count of marine turtle nesting activity for the survey period. The beaches were heavily wind-blown and nests laid prior to the passage of the cyclone were no longer visible and could therefore not be documented in many areas.

Census line track counts, indicating currents levels of marine turtle nesting activity were low. The passing of Tropical Cyclone Dominic may have contributed to lower than expected counts as cyclonic activity erased evidence of nesting prior to the survey period and altered the timing of the survey which was conducted late in the turtle nesting season for all species.



Figure 45: Wind-blown beach on Tortoise Island

5.1 Flatback Turtles

The results of this survey indicate that most marine turtle nesting that occurs on mainland beaches in the Onslow region is by flatback turtles. While most nest sites were too wind-blown to enable nest characteristics to be used to identify species, all fox predated nests had remains of flatback turtle egg shells in them. The only hatched nest observed in the area was also confirmed as a flatback nest after examination of the nest contents. Existing nesting records for the mainland region near Onslow are all of flatback turtle nesting (Pendoley *pers. comm.*).

The level of flatback turtle nesting along mainland beaches is not regionally or even locally, significant based on the current surveys. Other flatback rookeries in the region have been reported hosting much larger numbers of nesting females. For example, over 1700 flatback turtles nest annually at Mundabullangana (Pendoley *et al.* in press), and an estimated 1600 flatback turtles nest annually at Barrow Island (Pendoley 2005).

There is a marked division of flatback and green turtle nesting between locations. Flatback turtles are predominately found on the near shore islands with smaller aggregations on the mainland and the south coast of Thevenard Island.

5.2 Green Turtles

Green turtles were found to nest predominately on the outer islands such as Bessieres, Serrurier and the north and west coasts of Thevenard Island. These islands appear to support regionally significant nesting rookeries for this species; however none of these rookeries approach the size of the green turtle rookeries at Barrow Island and in the Dampier Archipelago. The potential for negative impacts to green turtle nesting is expected to be lower than for flatback turtles, in part due to their major rookeries being at a greater distance to the proposed development site.

5.3 Hawksbill Turtles

Only one hawksbill nest was documented during the survey period. Many of the sites examined in this survey, particularly the mainland beaches, do not exhibit the preferred beach characteristics that hawksbill turtles normally utilize. It is therefore unlikely that any of the beaches in the region host large hawksbill nesting rookeries. However, it is difficult to assess with certainty which species have created older nesting pits. This is particularly significant for hawksbills as their preferred nesting season peaks earlier than that for green and flatback turtles. Hawksbills in the North-West shelf region tend to commence nesting in August, with peak nesting occurring between October and November (Pendoley 2005). Hawksbill turtles are the smallest of the marine turtles found in the region and their tracks and nests can be obscured by the larger and later season nesting green and flatback turtles. It is possible that significant levels of hawksbill nesting may take place on some of the island beaches during this earlier period.

5.4 Loggerhead Turtles

While no loggerhead turtle nesting was found in the Onslow region during this survey, occasional loggerhead turtle nesting has been reported in the Barrow/Montebello/Lowendal complex of islands (Pendoley 2005) and the closest known significant loggerhead turtle rookery is located at South Muiron Island, only about 65 km to the west of the Ashburton River delta. This island supports an annual nesting population of 150-350 females per year (Baldwin 2003). Previous surveys have found evidence of loggerhead turtle nesting in the Onslow region (C. Bell *pers. comm.*). More extensive surveys would be needed to establish the significance of the Onslow region as a loggerhead nesting rookery.

5.5 Hatchling Fans Indices and Light Impacts

The majority of measured nest fans showed hatchlings moving towards the sea without any misorientation. It is important to note that there is a low level of natural misorientation. This can occur particularly when nests are laid amongst dunes or vegetation in situations where hatchlings are exposed to the same light horizon in multiple directions which can adversely impact their sea finding capabilities. Despite the small sample size this data set can serve as a baseline for levels of hatchling orientation prior to development, although the sample size should be increased and broadened to include all species nesting in the area.

The mainland beaches are unlikely to be directly impacted by lighting from the proposed development, apart from the low density flatback turtle nesting aggregation at Census beach four. This is approximately 5 km due west of the proposed development site. This rookery may also be under threat from fox predation of nests as 7 of 21 nests observed had been predated.

While there was no evidence of marine turtle nesting in the Onslow back beach area during this survey, previous surveys (B. Krueger *pers. comm.*) have found that there is also low density flatback turtle nesting in this area. Potential lighting impacts on this nesting aggregation also need to be addressed.

Hatchlings emerging from island rookeries in relatively close proximity to the proposed development may also be impacted by lighting. The rookery most at risk would be flatback turtles nesting on the eastern and southern coasts of Ashburton Island which is approximately 12 km from the proposed LNG site, and ~7 km from the proposed shipping channel.

The minimization of lighting levels for marine turtle management purposes during construction and operational phases of the proposed development should be included in all planning and front end engineering designs.

5.6 Hatch Success

The level of hatch success reported for flatback turtles (80.9 %, $n=9$) is similar to that found on Barrow Island, 84.9 % (Foster 2008) and is typical of these species (Miller 1997). The only nest to show abnormally low hatching was on the mainland, west of census beach four. There were a large number of full-term dead hatchlings in this nest. It is likely that heavy seas and rain from Cyclone Dominic resulted in this nest being at least partially flooded/washed over, which would account for the high mortality of full term hatchlings.

Mean hatch success for green turtles was higher than for flatback turtles in the region at 91.3 %, although the sample size is very small ($n=3$).

This survey overstates the likely mean hatch success and therefore productivity of the nesting beaches in the region as only nests with signs of hatching are excavated. Those nests with little or no hatchling emergence cannot be visibly identified as such (there are no hatchling tracks) and therefore are not excavated. To determine the true productivity of a nesting rookery it is necessary to accurately record and mark the exact location of representative sample number of nests (i.e. >30 nests) as they are laid and then to return to these same nests to determine hatch success for the entire sample, whether they have ultimately hatched or not.

5.7 Marine Turtles in the Water

This survey focused on the terrestrial nesting aspects of the marine turtle life-cycle. This phase of the life-cycle assesses only female reproductive behaviour during a very small proportion of their life-history. The survey did not assess the in-water turtle abundance, distribution, habitat use, location of mating aggregations and inter-nesting habitat or migratory pathways. Where

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possible opportunistic sightings of turtles in the water were documented, either when travelling between nesting survey sites or while conducting nesting beach surveys.

Despite the opportunistic nature of the surveys and the generally poor visibility after the passage of Cyclone Dominic there were over sixty sightings of turtles in the water. Most of these were juvenile green turtles in near-shore habitats around the islands. These animals are likely to be residents at their foraging grounds. As these turtles were not tagged, and therefore not identifiable from each other in any way, it is possible that there were multiple sightings of the same turtle recorded. There were no turtle sightings in the water in the vicinity of the mainland beaches during this survey, although earlier aerial surveys (Prince, 2000) found turtles in the water in the Onslow back beach area. Trawling surveys have also found flatback turtles within several kilometres of the mainland coast in the Urala and Ashburton River delta areas (Kanga, 2007). The same surveys found green turtles at Onslow back beach and loggerhead turtles near Locker Point. It is likely that greater numbers of turtles would have been found in the current survey if in-water visibility had not been so poor.

Foraging green turtles are likely to be found in considerable numbers in sea grass and algal habitats around many of the islands in the region (Limpus et al 1994). Green turtles have also been found in association with coastal mangrove habitats in the Pilbara region (Pendoley et al. 1999). The Onslow region may be important foraging habitat for green turtles.

There were no sightings of hawksbills in the water during this survey. It is likely that hawksbills use the reef systems in the region as foraging habitat (Witzell 1983). Reef systems in this area have been observed in deeper water than seagrass and algal habitats and therefore these animals are less likely to be observed, than green turtles.

Foraging habitats for juvenile flatback turtles are unknown, although it is believed that turtles from North West Shelf rookeries remain on the Australian continental shelf between Exmouth and the Northern Territory. (Walker and Parmenter 1990a) Whereas hatchlings of most species of marine turtle have an oceanic development phase, hatchling, post-hatchling and juvenile flatback turtles are thought to remain in near shore foraging habitats, although the location of foraging aggregations in Western Australia is not known. White-bellied sea eagles are known to feed on small juvenile flatback turtles in Queensland (Walker and Parmenter 1990b) and in the Pilbara (Pendoley et al 2003, *unpublished data*) and the flatback turtle found in a white-bellied sea eagle nest on NE Twin Island indicates that the Onslow area is used as foraging habitat by this size class turtle.

The foraging habitat used by adult flatback turtles is also poorly documented. Satellite tracking of migrating female turtles from rookeries in the Pilbara have been shown to migrate to the Onslow area after their nesting season has concluded and are therefore likely to be using the area (in this case to the NW of Thevenard Island) as foraging habitat (Cemetery Beach, Port Hedland Satellite Tracking Project). Barrow Island nesting females have also been found to use the area to the north of Thevenard Island as foraging sites (Barrow Island Satellite Tracking Project, 2005-06).

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The relative proximity of the loggerhead nesting rookery at the Muiron Islands and the sighting of a large juvenile/sub-adult loggerhead turtle near the coast of SW Twin Island indicates that they are using the Onslow region as a foraging ground or at least as a migratory pathway. Satellite tracking indicates that loggerhead turtles utilize the vicinity of Serrurier and Thevenard Islands as a migratory pathway between their foraging grounds to the north and the nesting rookeries to the south (Ningaloo Turtle Project).

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6 Management Recommendations

Management Recommendations will be supplied separately to this final report.

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Appendices

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Appendix 1: Snapshot survey track counts

Location	Date	Tracks below high tide line			Activity above last high spring tide		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	low	0	0	0	0	0
Thevenard Island (west)	25-Jan-09	0	Med	0	0	0	0
Bessieres Island	25-Jan-09	0	Low	0	0	0	0
Thevenard Island (West)	30-Jan-09	0	0	0	0	14	0
Direction Island	31-Jan-09	0	0	0	0	0	0
Tortoise Island	1-Feb-09	0	0	0	0	0	0
Ashburton River Delta	3-Feb-09	0	0	0	0	0	0
NE Twin	3-Feb-09	0	0	0	7	0	0
Serrurier Island East	4-Feb-09	ND	ND	ND	ND	ND	ND
Serrurier Island West	4-Feb-09	ND	ND	ND	ND	ND	ND
Serrurier Island South East	4-Feb-09	ND	ND	ND	ND	ND	ND
Table Island	4-Feb-09	0	0	0	2	0	0
Flat Island	4-Feb-09	0	0	0	6	5	0
Round Island	4-Feb-09	0	0	0	1	0	0
Locker Island	5-Feb-09	12	0	0	34	0	0
Mainland (Locker Pt/Urala)	5-Feb-09	0	0	0	0	0	0
SW Twin Island	6-Feb-09	0	0	0	0	0	0
Mainland (Onslow back beach)	6-Feb-09	0	0	0	0	0	0
Mainland (Coolgara/Beadon Ck)	6-Feb-09	0	0	0	0	0	0
Ashburton River Delta(2)	6-Feb-09	6	0	0	0	0	0

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Appendix 2: Snapshot survey: Marine turtle nests and animals sighted inwater

Location	Date	Potential nests			Hatched nests		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	0	0	0	4	0	0
Thevenard Island (west)	25-Jan-09	0	0	0	0	0	0
Bessieres Island	25-Jan-09	0	0	0	0	0	0
Thevenard Island (West)	30-Jan-09	0	0	0	0	1	0
Direction Island	31-Jan-09	0	0	0	0	0	0
Tortoise Island	1-Feb-09	0	0	0	0	0	0
Ashburton River Delta	3-Feb-09	0	0	0	0	0	0
NE Twin	3-Feb-09	0	0	0	0	0	0
Serrurier Island East	4-Feb-09	0	0	0	ND	ND	ND
Serrurier Island West	4-Feb-09	0	0	0	ND	ND	ND
Serrurier Island South East	4-Feb-09	0	0	0	ND	ND	ND
Table Island	4-Feb-09	0	0	0	0	0	0
Flat Island	4-Feb-09	0	0	0	0	0	0
Round Island	4-Feb-09	0	0	0	0	0	0
Locker Island	5-Feb-09	0	0	0	5	0	0
Mainland (Locker Pt/Urala)	5-Feb-09	0	0	0	0	0	0
SW Twin Island	6-Feb-09	0	0	0	0	0	0
Mainland (Onslow back beach)	6-Feb-09	0	0	0	0	0	0
Mainland (Cooligara/Beadon Ck)	6-Feb-09	0	0	0	0	0	0
Ashburton River Delta(2)	6-Feb-09	1	0	0	1	0	0

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Appendix 3 Snapshot survey: Inwater sightings

Location	Date	Juveniles in water					Adults in water		
		Flatback	Green	Hawksbill	Loggerhead	Unidentified	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	0	0	0	0	0	0	0	0
Thevenard Island (west)	25-Jan-09	0	0	0	0	0	0	0	0
Bessieres Island	25-Jan-09	0	0	0	0	0	0	0	0
Thevenard Island (West)	30-Jan-09	0	14	0	0	0	0	0	0
Direction Island	31-Jan-09	0	0	0	0	0	0	0	0
Tortoise Island	1-Feb-09	0	0	0	0	1	0	0	0
Ashburton River Delta	3-Feb-09	0	0	0	0	0	0	0	0
NE Twin	3-Feb-09	0	0	0	0	0	0	0	0
Serrurier Island East	4-Feb-09	0	5	0	0	0	0	2	0
Serrurier Island West	4-Feb-09	0	1	0	0	0	0	0	0
Serrurier Island South East	4-Feb-09	0	1	0	0	0	0	0	0
Table Island	4-Feb-09	0	0	0	0	0	0	0	0
Flat Island	4-Feb-09	0	0	0	0	0	0	0	0
Round Island	4-Feb-09	0	0	0	0	0	0	0	0
Locker Island	5-Feb-09	0	1	0	0	0	0	0	0
Mainland (Locker Pt/Urala)	5-Feb-09	0	0	0	0	0	0	0	0
SW Twin Island	6-Feb-09	0	0	0	1	0	0	0	0
Mainland (Onslow back beach)	6-Feb-09	0	0	0	0	0	0	0	0
Mainland (Coolgara/Beadon Ck)	6-Feb-09	0	0	0	0	0	0	0	0
Ashburton River Delta(2)	6-Feb-09	0	0	0	0	0	0	0	0

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Appendix 4: Census Survey: First day line-in survey: Tracks

First Day Line In Location	Date	Tracks below high tide line			Activity above last high-spring tide		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	3	0	0	78	0	0
Thevenard (North)	25-Jan-09	0	0	0	0	93	0
Thevenard (South)	25-Jan-09	0	0	0	63	4	0
Bessieres Island	25-Jan-09	0	0	0	4	181	0
Ashburton Island	31-Jan-09	22	0	0	0	0	0
Thevenard (North)	30-Jan-09	0	26	0	0	0	0
Thevenard (South)	30-Jan-09	0	0	0	0	0	0
Bessieres Island	30-Jan-09	0	22	2	0	3	0
Mainland Beach 1	3-Feb-09	0	0	0	0	0	0
Mainland Beach 2	3-Feb-09	0	0	0	0	0	0
Mainland Beach 3	3-Feb-09	0	0	0	0	0	0
Mainland Beach 4	3-Feb-09	0	0	0	18	0	0
Mainland Beach 5	3-Feb-09	0	0	0	0	0	0
Mainland Beach 6	3-Feb-09	0	0	0	0	0	0
Mainland Beach 7	3-Feb-09	0	0	0	0	0	0

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Appendix 5: Census Survey: First day line-in survey: Nests and inwater sightings

First Day Line In Location	Date	Hatched nests			Juveniles in water			Adults in water		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island	25-Jan-09	4	0	0	0	0	0	0	0	0
Thevenard (North)	25-Jan-09	0	0	0	0	0	0	0	0	0
Thevenard (South)	25-Jan-09	0	0	0	0	0	0	0	0	0
Bessieres Island	25-Jan-09	0	1	0	0	0	0	0	0	0
Ashburton Island	31-Jan-09	2	0	0	0	0	0	0	0	0
Thevenard (North)	30-Jan-09	0	0	0	0	0	0	0	0	0
Thevenard (South)	30-Jan-09	0	0	0	0	0	0	0	0	0
Bessieres Island	30-Jan-09	0	2	0	0	0	0	0	0	0
Mainland Beach 1	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6	3-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7	3-Feb-09	0	0	0	0	0	0	0	0	0

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Appendix 6: Census survey Islands: Tracks

Location	Date	Tracks below high tide line			Overnight activity (X-line)		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island 1	1-Feb-09	0	0	0	0	0	0
Ashburton Island 2	2-Feb-09	0	0	0	0	0	0
Ashburton Island 3	3-Feb-09	0	0	0	0	0	0
Thevenard Island (North) 1	31-Jan-09	0	0	0	0	0	0
Thevenard Island (North) 2	1-Feb-09	0	0	0	4	0	0
Thevenard Island (North) 3	2-Feb-09	0	0	0	2	0	0
Thevenard Island (South) 1	31-Jan-09	0	0	0	2	0	0
Thevenard Island (South) 2	1-Feb-09	0	0	0	0	0	0
Thevenard Island (South) 3	2-Feb-09	0	0	0	0	0	0
Bessieres Island 1	31-Jan-09	0	0	0	0	4	0
Bessieres Island 2	1-Feb-09	2	0	0	0	4	0
Bessieres Island 3	2-Feb-09	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 7 Census survey Islands: Nests and Inwater sightings

Location	Date	Hatched nests			Juveniles in water			Adults in water		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Ashburton Island 1	1-Feb-09	0	0	0	0	1	0	0	0	0
Ashburton Island 2	2-Feb-09	0	0	0	0	4	0	0	0	0
Ashburton Island 3	3-Feb-09	0	0	0	0	4	0	0	0	0
Thevenard Island (North) 1	31-Jan-09	0	0	0	0	2	0	0	0	0
Thevenard Island (North) 2	1-Feb-09	0	0	0	0	0	0	0	0	0
Thevenard Island (North) 3	2-Feb-09	0	0	0	0	0	0	0	0	0
Thevenard Island (South) 1	31-Jan-09	0	0	0	0	14	0	0	0	0
Thevenard Island (South) 2	1-Feb-09	0	0	0	0	0	0	0	0	0
Thevenard Island (South) 3	2-Feb-09	0	0	0	0	8	0	0	0	0
Bessieres Island 1	31-Jan-09	0	1	0	0	0	0	0	0	0
Bessieres Island 2	1-Feb-09	0	1	0	0	1	0	0	0	0
Bessieres Island 3	2-Feb-09	1	1	0	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 8: Census survey: Mainland beaches: Tracks

Location	Date	Tracks below high tide line			Overnight activity (X-line)		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Mainland Beach 1 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 1 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 1 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 2 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 2 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 2 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 3 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 3 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 3 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 4 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 4 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 4 Day 3	6-Feb-09	0	0	0	6	0	0
Mainland Beach 5 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 5 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 5 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 6 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 6 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 6 Day 3	6-Feb-09	0	0	0	0	0	0
Mainland Beach 7 Day 1	4-Feb-09	0	0	0	0	0	0
Mainland Beach 7 Day 2	5-Feb-09	0	0	0	0	0	0
Mainland Beach 7 Day 3	6-Feb-09	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 9: Census survey: Mainland beaches: Nests and inwater sightings

Location	Date	Hatched nests			Juveniles in water			Adults in water		
		Flatback	Green	Hawksbill	Flatback	Green	Hawksbill	Flatback	Green	Hawksbill
Mainland Beach 1 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 1 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 1 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 2 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 3 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 4 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 5 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 6 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7 Day 1	4-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7 Day 2	5-Feb-09	0	0	0	0	0	0	0	0	0
Mainland Beach 7 Day 3	6-Feb-09	0	0	0	0	0	0	0	0	0

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 10: Nest Fan survey results

Location	Species	Date	Fan A	Fan B	Fan X	Bisect Angle	Fan Angle	Offset
Ashburton Island	Flatback	25-Jan-09	127	19	75	73	108	2
Ashburton Island	Flatback	25-Jan-09	91	2	45	46.5	89	1.5
Ashburton Island	Flatback	25-Jan-09	256	180	200	218	76	18
Ashburton Island	Flatback	25-Jan-09	116	204	174	160	88	14
Ashburton Island	Flatback	25-Jan-09	173	128	165	150.5	45	14.5
Ashburton Island	Flatback	25-Jan-09	115	159	139	137	44	2
Bessieres Island	Green	25-Jan-09	111	79	90	95	32	5
Bessieres Island	Green	30-Jan-09	65	79	92	72	14	20
Bessieres Island	Green	31-Jan-09	62	103	62	82.5	41	20.5
Bessieres Island	Green	1-Feb-09	68	107	89	87.5	39	1.5
Bessieres Island	Green	2-Feb-09	40	102	75	71	62	4
Bessieres Island	Flatback	2-Feb-09	59	120	89	89.5	61	0.5
Locker Island	Flatback	5-Feb-09	152	295	242	223.5	143	18.5
Locker Island	Flatback	5-Feb-09	205	245	225	225	40	0
Locker Island	Flatback	5-Feb-09	227	286	258	256.5	59	1.5
Locker Island	Flatback	5-Feb-09	248	268	262	258	20	4
Locker Island	Flatback	5-Feb-09	In all directions		290	NA		
Mainland Beach 4	Flatback	6-Feb-09	313	340	322	326.5	27	4.5

Wheatstone Marine Turtle Survey
Onslow mainland area and nearby Islands

Appendix 11 Hatching success

Location	Date	Species	Latitude	Longitude	Hatched Shells	Undeveloped	Embryo	Full term	Pipped dead	Pipped alive	Total Eggs	Hatched %
Ashburton	25-Jan-09	FB	21.59425	114.93650	30	2	1	1	1	0	35	85.71
Thevenard	30-Jan-09	GR	21.45506	114.97728	87	2	0	0	15	0	104	83.65
Ashburton	31-Jan-09	FB	21.59356	114.93792	37	4	1	0	0	0	42	88.10
Bessieres	1-Feb-09	GR	21.52709	114.76593	102	1	0	0	1	0	104	98.08
Bessieres	2-Feb-09	GR	21.52837	114.76593	105	6	0	1	0	2	114	92.11
Bessieres	2-Feb-09	FB	21.52652	114.76597	53	5	1	2	2	1	64	82.81
Locker	5-Feb-09	FB	21.71922	114.76631	46	1	0	0	0	0	47	97.87
Locker	5-Feb-09	FB	21.71899	114.76610	42	3	0	6	0	0	51	82.35
Locker	5-Feb-09	FB	21.71758	114.76541	45	4	0	1	0	0	50	90.00
Locker	5-Feb-09	FB	21.71778	114.76556	50	0	0	1	0	0	51	98.04
Locker	5-Feb-09	FB	21.71448	114.76556	47	12	0	0	0	0	59	79.66
Beach 4	6-Feb-09	FB	21.68611	114.94871	11	3	2	27	4	0	47	23.40

Wheatstone Marine Turtle Survey
 Onslow mainland area and nearby Islands

Appendix 12 Turtle nesting per night from census line counts

Census Beach	Mean Flatbacks per transect per night	Mean Greens per transect per night	Mean Hawksbills per transect per night	Transect Length (km)	Mean Flatbacks per km per night	Mean Greens per km per night	Mean Hawksbills per km per night
Ashburton	1.63	0	0	0.5	3.26	0	0
Thevenard North	0.43	1.86	0	0.5	0.86	3.72	0
Thevenard South	0.29	0	0	0.5	0.58	0	0
Bessieres	0.14	2.14	0.14	0.31	0.46	6.90	0.46
Mainland Beach 1	0	0	0	0.5	0	0	0
Mainland Beach 2	0	0	0	0.5	0	0	0
Mainland Beach 3	0	0	0	0.5	0	0	0
Mainland Beach 4	0	0	0	0.5	0	0	0
Mainland Beach 5	0	0	0	0.5	0	0	0
Mainland Beach 6	0	0	0	0.5	0	0	0
Mainland Beach 7	0	0	0	0.5	0	0	0

Appendix 012

Marine Mammals Technical Report

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**TECHNICAL APPENDIX
MARINE MAMMALS**

Wheatstone Project EIS/ERMP





**TECHNICAL APPENDIX
MARINE MAMMALS**

Wheatstone Project EIS/ERMP

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ACRONYMS AND DEFINITIONS

Acronym	Definition
CMST	Centre for Marine Science and Technology
CWR	Centre for Whale Research
DEC	(Western Australia) Department of Environment and Conservation
DEH	(Commonwealth) Department of Environment and Heritage (now DEWHA)
DEWHA	(Commonwealth) Department of the Environment, Water, Heritage and the Arts
EIS	Environmental Impact Statement
EPA	(Western Australia) Environmental Protection Authority
EPBC Act	(Commonwealth) Environment Protection and Biodiversity Conservation Act 1999
ERMP	Environmental Review and Management Programme
ESD	Environmental Scoping Document
EEZ	Exclusive Economic Zone
IMCRA	The Interim Marine and Coastal Regionalisation of Australia
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
LNG	Liquefied Natural Gas
MNES	Matters of National Environmental Significance
MOF	Marine Offloading Facility
MTPA	Million Tonnes Per Annum
NMB	National Marine Bioregionalisation
NWS	North West Shelf
PIN	Pilbara Nearshore Region
PIO	Pilbara Offshore Region
UNEP	United Nations Environment Program
WA	Western Australia



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EXECUTIVE SUMMARY

As part of the Wheatstone Project, Chevron Australia Pty Ltd (Chevron) 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. Natural gas for the plant will be brought ashore from gas fields about 200 km offshore.

Key environmental features of the Project Area influencing the distribution and abundance of marine mammals in the area are specific to the NMB Northwest Provincial Bioregion and the Pilbara Offshore (PIO) and the Pilbara Nearshore (PIN) IMCRA mesoscale bioregions. The petroleum titles from which the gas will be extracted are situated on the steep, very deep, outer edge of the continental slope. This is the edge of the North-west Province, where upwellings from canyons, slopes and plateaus bring nutrient-rich waters upwards, which attract pelagic fish and predatory cetacean species, including oceanic dolphins and sperm whales.

The offshore subsea pipeline will traverse both the continental slope and shelf, largely through the PIO bioregion. This bioregion contains migratory routes for species such as whale sharks and humpback whales and has a number of islands, some of which support resident dolphin and dugong populations. . Most of the LNG plant's marine infrastructure will be located closer to shore, within the PIN bioregion. This area is characterised by turbid conditions due to cyclonic and heavy rainfall events. It provides a complex array of habitats: rocky coastline, sandy substrate with mangrove and sandy substrate with seagrass that support dugong and fish, which coastal dolphin species prey upon.

The online EPBC Protected Matters search tool was used to identify Threatened, Migratory and other protected marine mammal species likely to be in the Project Area. DEC's Protected Fauna list was also examined for marine mammals specially protected under the *WA Wildlife Conservation Act 1950* that may occur in the area. Further baseline data were gathered to establish the importance of the broad development area for these species, in particular their distribution and abundance, through aerial and acoustic surveys that were run for eight months in the Project Area. The surveys are to continue until May 2010.

This Appendix to the Wheatstone EIS/ERMP summarises contextual information and preliminary results from these surveys to support the assessment of potential impacts of the Wheatstone Project on marine mammals and the development of associated management measures and monitoring programs. A description of the key marine mammal species found in the Project Area, including their conservation status, likely occurrence in the area and their general habitats, is summarised in Table I.



Table I: Summary of Key Marine Mammal Species of the Project Area

Detection Method	Species and Listing under the EPBC Act	Occurrence in the Area	General Habitat
→ ◀	Blue whale (<i>Balaenoptera musculus</i>) "Endangered" and "Migratory"	Migratory, October to December.	Deep waters of the continental slope and beyond.
→ ◀	Humpback whale (<i>Megaptera novaeangliae</i>) "Vulnerable" and "Migratory"	Migratory, June to November.	Approximately 50 km offshore of Onslow in waters of the continental slope, when northbound, and approximately 35 km offshore in waters of the continental shelf when southbound. An aggregation occurs inside Exmouth Gulf (a critical habitat) during the first weeks of October.
	Indo Pacific humpback dolphin (<i>Sousa chinensis</i>) "Migratory"	Expected within the project area but whether migratory or resident in the area remains unknown.	Coastal waters of the continental shelf.
	Spotted bottlenose dolphin (<i>Tursiops aduncus</i>) "Migratory"	Expected within the project area. Movements between the project area and other areas are unknown.	Coastal waters of the continental shelf.
→	Dugong (<i>Dugong dugon</i>) "Migratory"	Detected within the project area but whether migratory or resident in the area remains unknown.	Coastal waters of the continental shelf generally in water depths less than 12 m. Seagrass beds provide foraging habitat while breeding and calving occurs in protected, shallow waters. Exmouth Gulf provides important habitat but movements between there and the project area are largely unknown.

- Species recorded by aerial survey
- ◀ Species recorded by acoustic survey

Blue whales, humpback whales, Indo Pacific humpback dolphins, spotted bottlenose dolphins and dugongs should be given special consideration in the impact assessment process and prescription of management measures for the Wheatstone Project. Of these species, the dolphins, dugong and humpback whale should be assessed as "key factors". The dolphins and dugongs utilise the nearshore area where most marine infrastructure will be constructed and humpback whales are seasonally abundant through the area where shipping may occur. Blue whales are less likely to interact with aspects of the Project.

1.0 INTRODUCTION

Chevron Australia Pty Ltd (Chevron) proposes to develop the Wheatstone and Iago gas fields. The construction and operation of the development will include a multi-train liquefied natural gas (LNG) and domestic gas (domgas) plant 12 km south-west of Onslow on the Pilbara coast (Figure 1). 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 and will extend across Commonwealth and State waters, with processing and export facilities on the Western Australian (WA) mainland. The LNG plant will have a maximum production capacity of 25 million tonnes per annum (MTPA) of LNG.

The Wheatstone Project has been referred to the WA Environmental Protection Authority (EPA) and the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) for assessment under the WA *Environmental Protection Act 1986* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* respectively. The EPA has assigned an Environmental Review and Management Programme (ERMP) level of assessment and DEWHA deemed the project to be a “controlled action” to be assessed via an Environmental Impact Statement (EIS). The State and Commonwealth assessments are being undertaken through a parallel, coordinated approach.

The Environmental Scoping Document (ESD) (Chevron 2009), prepared as part of the assessment process, outlined environmental studies to be undertaken. The ESD determined the need for a description of marine megafauna distribution within the Project Area and its surrounds. It also identified the humpback whale (*Megaptera novaeangliae*), dugong (*Dugong dugon*) and four marine turtle species as the key marine fauna species with the potential to be impacted by aspects of the Wheatstone Project.

Although some information exists on marine megafauna within the south-west Pilbara area, in particular around North West Cape and Exmouth Gulf (Section 2.3), limited survey work has been undertaken directly within the nearshore Onslow area. To address this information, CWR commenced a 12 month aerial survey in May 2009. A series of aerial surveys was conducted west of North West Cape from 2000 through 2008 by the Centre for Whale Research (CWR), but did not cover the nearshore or offshore areas out from Onslow.

To enhance the aerial survey data being gathered by CWR, the Centre for Marine Science and Technology (CMST) was commissioned to undertake an acoustic survey of the area by deploying sea noise loggers at selected sites within the Project Area.



This document synthesises key information on marine mammals, in particular for humpback whales and dugongs, provided through desktop research and these field surveys.

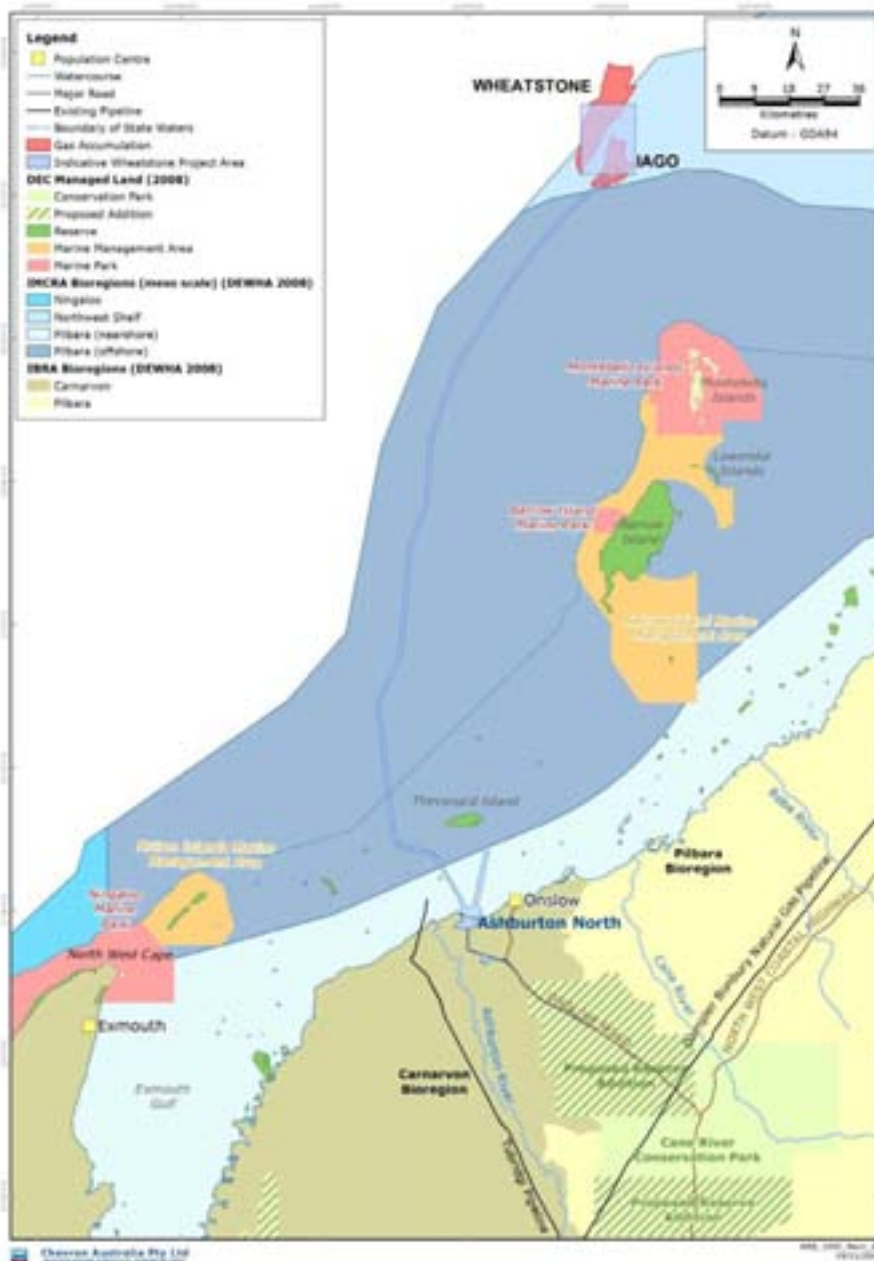


Figure 1: Location of the Project Area

2.0 BACKGROUND

2.1 Bioregional Setting and Surrounding Habitats

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). There are two levels of bioregion profiling. The National Marine Bioregionalisation (NMB) has created Provincial Bioregions which are broad areas in deep, off-shelf waters. The Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0 2006) identifies a finer scale “mesoscale” regionalisation for waters nearer to shore. These two levels sometimes overlap.

The upstream components of the Wheatstone Project are situated on the steep, very deep, outer edge of the continental slope (Figure 2), primarily in the NMB Northwest Province. Situated entirely on the continental slope in depths ranging from 500 to 5000 m, this province consists of deep, open ocean. 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).

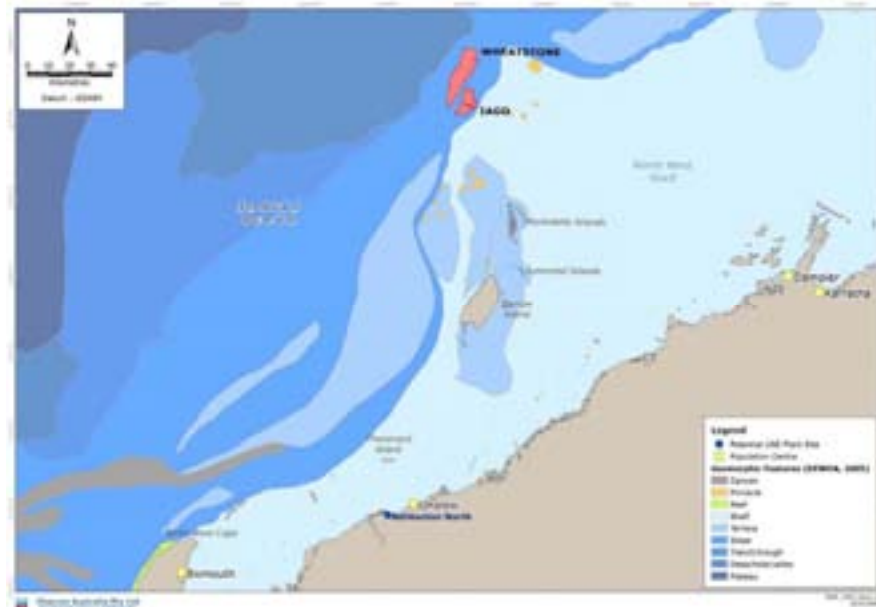


Figure 2: Major Seabed Features surrounding the Project Area (DEWHA 2008)



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.

The PIO 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 PIN 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). PIN waters are characteristically turbid following cyclonic storms, large internal swells or heavy rainfall. Within the surrounding waters are the following important areas for cetaceans:

1. 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).
2. Mangrove and Middle Islands, which provide seagrass and mangrove habitat for dugong, fish and turtles (DEWHA 2008).
3. Exmouth Gulf, which supports aggregations of resting humpback whales and a large population of dugongs (DEWHA 2008).

2.2 Legislative Context

In Western Australia, marine mammals are protected under the following Australian legislation:

- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).
- Western Australian *Wildlife Conservation Act 1950*.

2.2.1 EPBC Act

The EPBC Act is administered by DEWHA. This Act reflects conservation status assigned by the International Union for the Conservation of Nature and Natural Resources (IUCN) and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

All marine mammals within Australian waters are protected under the EPBC Act. Species whose survival is considered Threatened (Endangered or Vulnerable) and / or are recognised as Migratory are also protected as Matters of National Environmental Significance (MNES).

All cetaceans are further protected through the establishment of the Australian Whale Sanctuary, which means that it is an offence to kill, injure, take, trade, keep, move or interfere with a cetacean in the Exclusive Economic Zone (EEZ).

2.2.2 Wildlife Conservation Act

All marine mammals in Western Australia are protected by the Wildlife Conservation Act, administered by the State's Department of Environment and Conservation (DEC).

Schedule 1 of the Wildlife Conservation Act identifies Threatened species (including those that are Endangered or Vulnerable) that are "likely to become extinct or is rare" and specially protected fauna as those "otherwise in need of special protection". Fauna with priority for conservation are listed (Priority One to Four), based on available knowledge and species representation on the conservation estate.

DEC's operational objective under this Act is to conserve these species by protecting them from being "taken" (killed, captured, disturbed or molested) from the wild.

2.3 Marine Mammals of the Onslow Region

Desktop research was undertaken for marine mammals identified by the online EPBC Protected Matters search tool for the Project Area (Figure 3) (DEWHA 2009a; Appendix 1). This search identified Threatened, Migratory and other species listed under the EPBC Act likely to be in the Project Area. The DEC Threatened fauna list (DEC 2009) was consulted to verify the conservation status of species under the Wildlife Act.

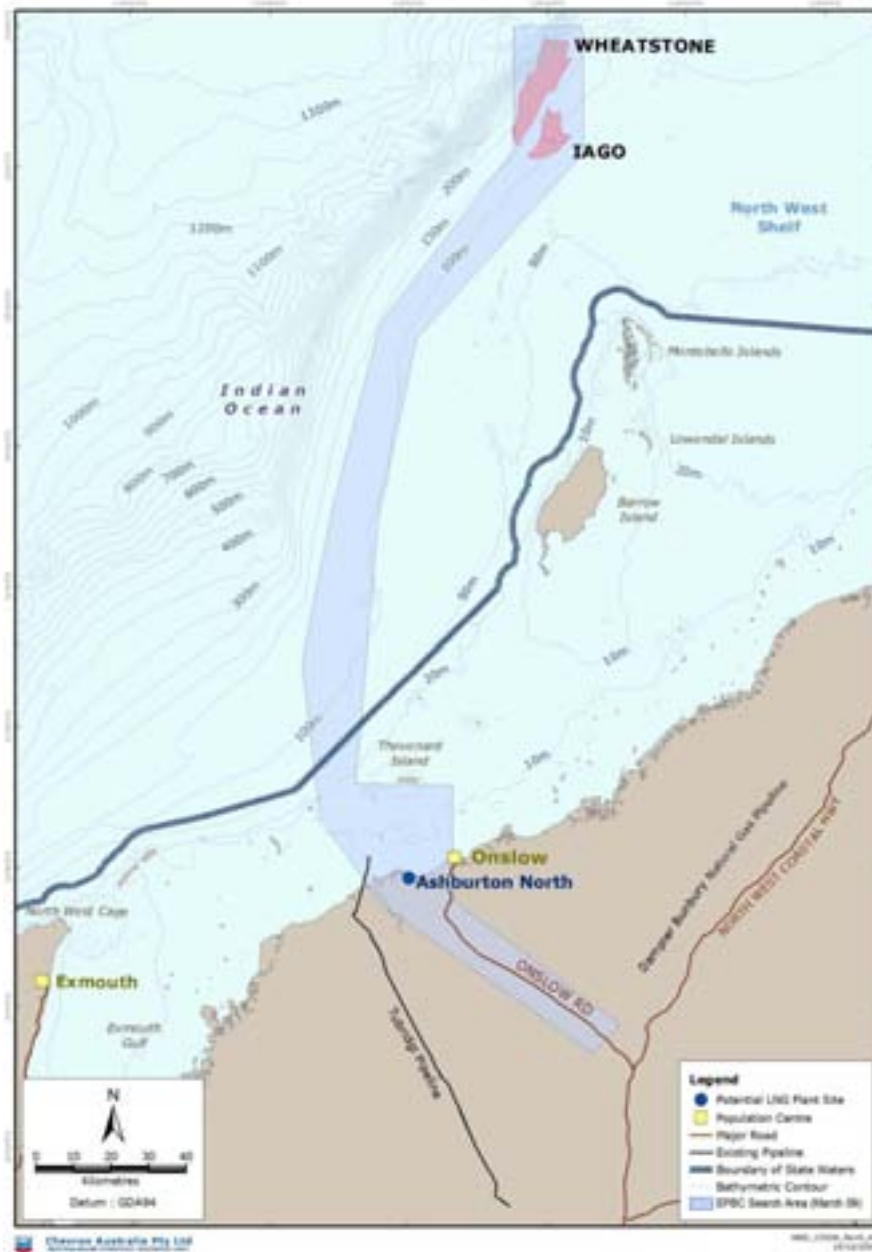


Figure 3: EPBC Act Protected Matters Database Search Area

Information on these listed species was sourced from the available scientific literature. The humpback whale and dugong were the main focus of the desktop research as they were identified by the Wheatstone ESD as key environmental factors for the project.

2.3.1 Baleen Whales

Baleen whales, or mysticetes, are filter feeders; they sieve food from seawater or substrates using baleen, which are hair-fringed plates made from keratin. These whales are most often “gulp” feeders, capturing schooling or swarming prey by engulfing it rapidly in large mouthfuls. Gulp feeding is believed to be suitable for capturing larger, faster-swimming plankton, such as fish and krill (Kawamura, 1980; Gaskin, 1982). Baleen whales are estimated to consume about 3-4% of bodyweight in food per day when feeding maximally (Brown and Lockyer, 1984). Most feeding occurs in high latitudes and upwellings, but opportunistic feeding has been recorded in other locations (Gill et al. 1998; Stockin & Burgess 2005; Stamation et al. 2007).

The baleen family of whales consist of two sub-families that are present in Australian waters: rorquals and right whales. Rorquals are whales with pleats, or ventral grooves, under their throats, and include the humpback whale.

2.3.1.1 Humpback Whales

The humpback whale is a moderately large whale (<18 m length) that has a global distribution and several distinct populations. Humpback whales make yearly migrations from their polar summer feeding grounds to tropical winter breeding grounds.

Humpback whales are readily recognised by their very long pectoral fins, humped dorsal fin, active surface displays, and individually identifiable markings on the underside and trailing edge of their tail flukes. They are also known for the variety and complexity of their underwater sounds, particularly songs produced by males.

Male humpback whales mature at 3–6 years (approximately 11.3 m) and females at 4–5 years (11.9 m) (Chittleborough 1959; Chittleborough 1965). Typically, mature females have a two-year breeding cycle, which includes a “resting” year (Chittleborough 1958; Chittleborough 1965). Gestation takes approximately 11.5 months, with calves born in the breeding ground in August of the following year. Information on current breeding rates is not readily available. Variability in calving rates is likely to be influenced by the inter-annual variability of prey in their feeding grounds.

Life expectancy is estimated to be more than 48 years, but this may be an underestimate given the longevity of other baleen whales (Clapham et al. 2000).

Humpback population numbers declined severely as a result of commercial whaling exploitation. Consequently, the species has been listed as Threatened internationally and has been listed as Vulnerable in Australia since 1963 (DEC 2009) under both the EPBC Act and Wildlife Act. This species is therefore considered as a MNES. However, in response to evidence of recovery in humpback whale numbers, the IUCN changed its status to “least concern” in 2008.



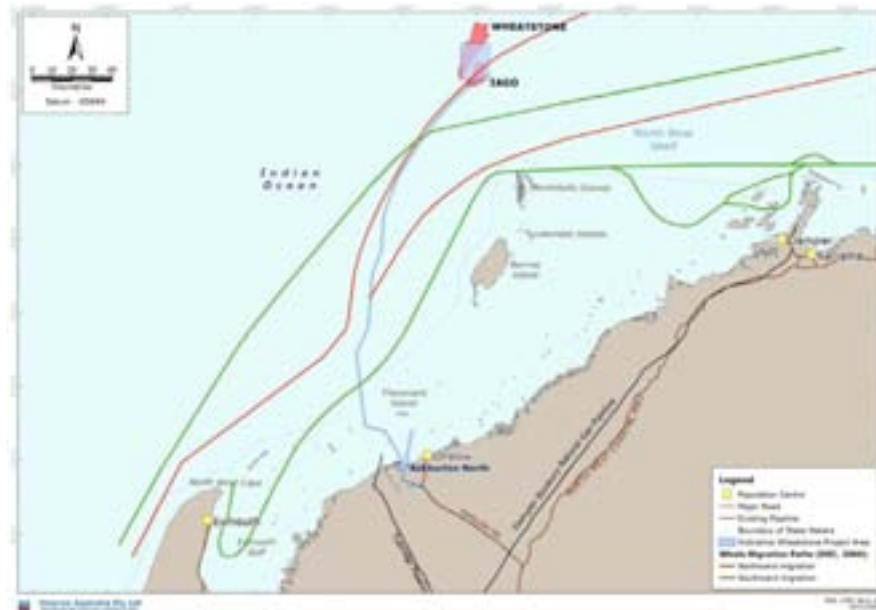
Humpback whales that migrate along the west coast of Australia are linked to the Antarctic Feeding Area IV population 70–130°E (referred to as Group IV) (Chittleborough 1965; Bannister 1991; Bannister and Hedley 2001). Good abundance and trend information is available for the humpback whale population within the Project Area. Population estimates for Group IV in West Australian waters started in earnest from 1976 off Shark Bay in response to reports of increased sightings of whales (Bannister and Hedley 2001). Up to 1991, the population was estimated at 2,000 to 3,000 whales (Bannister 1991; Bannister et al. 1991; Bannister 1994; Bannister and Hedley 2001). Continued aerial surveys in 1991, 1994 and 1999 of northbound migrating whales off Shark Bay calculated a population estimate of 8,207-13,640 individuals (relative estimate 3,441).

Aerial and land-based surveys continued in 2005, with a population estimate of 11,500 (Paxton et al. 2006). In 2008 the absolute abundance estimate was 21,750 (95% CI: 17,550–43,000) with an increase rate of 12.5% pa since 2005 (Hedley, Bannister, and Dunlop 2009).

Group IV humpback whales undertake an extensive (approximately 6,700km) northward migration from feeding grounds in Antarctica to the Kimberley between June and November each year (Chittleborough 1965; Jenner et al. 2001). Generally, the northbound and southbound migration paths of Group IV humpback whales off the West Australian coast is landward of the continental shelf break (i.e. inside the 200 m depth contour) (Jenner and Jenner 1991; Jenner et al. 2001). However, in the regions of the Perth Basin, Dampier Archipelago and the Kimberley, surveys have shown that the migration for southbound whales is generally further offshore (Jenner et al. 2001). Migration routes are shown in Figure 4.

Aggregation areas for migrating humpback whales have been identified at Augusta, Geographe Bay, Shark Bay and Exmouth Gulf (DEH 2005). Other important areas are believed to be in waters of the Houtman Abrolhos, Montebello and Barrow Islands (Chittleborough 1953; Jenner et al. 2001; DEWHA 2005; DEWHA 2008; Jenner and Jenner, 2005).

In the south-west Pilbara and Exmouth Gulf region, annual migration patterns are predictable, but complicated (Jenner, Jenner and McCauley 2009). The north-bound migration off the south-west Pilbara coast extends from June to early August, while south-bound migration runs from late August to December (Jenner, Jenner and McCauley 2009; Sleeman et al. 2007). The peak north-bound migration period for the region is the last week of July, while the peak south-bound migration period is late August to mid-September, with cow-calf pairs following a few weeks later in early October (Jenner and Jenner 2005).



(DEC 2000)

Figure 4: Generalised Migration Routes (Northbound and Southbound) of Humpback Whales

Exmouth Gulf, which is used mainly during the southern migration (Jenner, Jenner and McCabe, 2001), is visited by whales from early August to late November, peaking in early October with the arrival of south-bound cow-calf pairs (Jenner and Jenner, 2005). Whales occur predominantly in the central and western portions of Exmouth Gulf in water depths of 8–17 m (Jenner and Jenner, 2005). However, it appears that not all whales enter Exmouth Gulf on their southbound journey (McCauley et al., 1998; CWR unpublished data).

The timing of migration can vary by three weeks between years with the difference attributed by Chittleborough (1965) to food variability in their Antarctic feeding grounds. The Humpback Whale Recovery Plan 2005-2010 (DEWHA, 2005) also notes water temperature, extent of sea-ice, predation risk, prey abundance and location of feeding grounds as influential in the timing of migration.

There is evidence that not all whales undertake the full migration (Kellogg 1929), with some whales, such as late northbound pregnant females, found not to move beyond the southern coast of WA (Kellogg 1929; Chittleborough 1965).

Although the Kimberley coast from Broome to north of Camden Sound has been identified as a major calving area (Jenner et al. 2001; DEWHA 2005 2008), calving may also less frequently occur elsewhere along the northward migration route. Young calves have been observed at numerous locations, including at Albany (35°S) and Carnarvon (24°S) (Chittleborough 1953; Chittleborough 1965; CWR unpublished data).



There are a number of documented cases of humpback whales feeding during migration (Gill et al. 1998; Stockin and Burgess 2005; Stamation et al. 2007). However, the vast majority of feeding takes place in Antarctic feeding grounds where humpback whales prey on dense aggregations of *Euphausia superba*.

2.3.1.2 Blue Whales

There are two recognised subspecies of blue whale in Australian waters: the true blue whale of the southern hemisphere (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*Balaenoptera musculus brevicauda*). The blue whale is listed as Endangered and Migratory under the EPBC Act and the Wildlife Act.

Blue whales are the largest of the whale species, growing to a length of up to 33 m and weighing up to 180 tonnes. They can be distinguished from other whale species by their large size, flat u-shaped head and mottled blue-grey colouration (Reeves et al. 2002). The maximum length of a pygmy blue whale is generally around 25 m, so identification between large individuals of this species and smaller individuals of the true blue species can be difficult.

Both subspecies of blue whale may be found in all waters around Australia, and in the waters off Australia's Antarctic Territory (Bannister et al. 1996). Two key feeding/aggregation localities exist for blue whales in Australia: the Bonney Upwelling in South Australia, where true blue whales aggregate, and the Perth Canyon to the west of Rottnest Island near Perth in WA, where pygmy blue whales aggregate (DEWHA 2009b). Blue whales are also known to aggregate further south in WA, in Geographe Bay. They have been reported (visually and acoustically) as far north as the Barrow-Montebello area (Jenner 2008; McCauley et al. 2004).

True blue and pygmy blue whales were hunted heavily during the 1950s and 1960s, and almost driven to extinction. In 2000, Bannister and Burton estimated the population of true blue whales to be between 1,000 and 2,000 animals. Bannister (1996) also estimated the population of pygmy blue whales to be 6,000 individuals.

Blue whale migration is oceanic and no specific migration routes have been identified in the Australasian region (DEWHA 2009b). They generally feed in mid-high latitudes (south of Australia) during the summer months and move to temperate-tropical waters in the winter for mating and breeding (DEWHA 2009).

During summer-autumn, true blue whales feed mainly, if not exclusively, on euphausiids or krill, in the Antarctic (Mackintosh and Wheeler 1929, Kawamura 1980, Yochem and Leatherwood 1985). Pygmy blue whales are not generally found in the Antarctic, and are thought to feed during summer-autumn in productive regions in temperate latitudes. Therefore, most sightings that occur between late spring and autumn in the recognised feeding areas in Australian waters are believed to be pygmy blue whales (DEWHA 2009b).

Blue whales consume up to two tonnes of prey per day, more than any other predatory species (Croll et al. 2005). Feeding by blue whales is primarily at the surface however, in response to prey, they often undertake non-surface feeding by diving to depths of between 100–150 m (Fiedler et al. 1998).

Sexual maturity in blue whales is reached between seven and ten years, with a gestation period of 11 months (DEWHA 2009b). The main mating season for the blue whale extends over four to five months during the winter, from early April to late August, with the peak conception period occurring in late May to early June. The approximate calving period for the blue whale in the southern hemisphere is about mid-April (Gampbell 1979).

2.3.1.3 Minke Whales

The minke whale (*Balaenoptera acutorostrata*) is listed on the EPBC Act, although not as Threatened or Migratory and therefore is not considered a MNES.

A subspecies of the “true” minke whale from the Northern Hemisphere exists as the “dwarf” minke in Australian waters. It was first recognised as a distinct form in the mid-1980s and very little is known about them (Arnold and Birtles 1999). Dwarf minke whales migrate as far north as 11°S (Bannister et al. 1996; Perrin and Brownell 2002 in DEWHA 2009). The distinction between the subspecies is not yet represented in the EPBC Act listings.

Minke whales are a medium sized whale, growing up to 10.7 m in length, with females generally growing larger than males (Bannister et al 1996). The dorsal fin is tall and hooked, they have a V-shaped head and their back is black/dark grey (DEH 1999).

The dwarf minke whale is distributed throughout Australia, except in the Northern Territory (NT), and mostly occurs along the most northern coastline of WA and Queensland (Bannister et al. 1996). In Australian waters, populations of the dwarf minke whales are considered to be stable/secure (DEWHA 2009a). The southern hemisphere population totals around 700,000 individuals (Bannister et al. 1996).

The precise migratory patterns of the dwarf minke whale are unknown as they are less predictable than other rorquals; however, it is believed they undertake seasonal migration from cold water feeding grounds to warm water breeding grounds (Bannister et al. 1996). Although generally oceanic, these whales have been recorded in coastal waters (Bannister et al 1996).

Male dwarf minke whales reach sexual maturity around 5–8 years, while females reach sexual maturity between 6–8 years (Bannister et al. 1996). Limited data exist regarding the reproductive cycle for dwarf minke whales; however, it is believed that the gestation period for the species lasts approximately ten months, with lactation continuing for an additional four to five months (DEWHA 2009a). Calving is thought to occur in warm temperate to tropical waters between May and July, although no specific dwarf minke whale calving grounds are known for Australia (Bannister et al. 1996).



Although no specific feeding grounds have been discovered in Australia, information suggests dwarf minke whales feed mainly on small planktonic crustacean species, such as euphausiids.

2.3.1.4 Antarctic Minke Whales

The Antarctic minke whale (*Balaenoptera bonaerensis*) is listed as Migratory under the EPBC Act. This species is more full-bodied than the other baleen whales, and can grow to nearly 10 m in length (DEWHA 2009a). Antarctic minke whales are generally a solitary animal, swimming either alone or in pairs, and tend to prefer colder waters (DEWHA 2009a). The species has been recorded in all Australian states, but not in waters of the Northern Territory.

The Antarctic minke whale is a migratory whale often associated with deep, offshore waters along the shelf edge, frequently in depths exceeding 600 m (DEWHA 2009a). The species is regularly sighted in cold, Antarctic waters near the ice edge, feeding during winter months and migrating north during summer for breeding. However, the species does not migrate as far north as dwarf minke whales (Section 2.3.1.3) or other baleen whale species (DEWHA 2009a).

In Australia, limited information is available on the reproductive cycle of Antarctic minke whales, although information from the Antarctic suggests that mating peaks in August and September, and then, following a ten-month gestation period, calving peaks in May and June (DEWHA 2009a).

Antarctic minke whales' diet consists mostly of Antarctic krill found on the edge of the ice pack. Due to the lack of prey availability in lower latitudes, it is unlikely they feed while in warm water breeding grounds (DEWHA 2009a).

2.3.1.5 Bryde's Whales

The Bryde's whale (*Balaenoptera edeni*) is listed as Migratory under the EPBC Act, and is therefore considered as MNES. Bryde's whales grow up to 15.5 m in length (DEH, 1999). These whales have a generalist feeding regime of euphausiids, copepods, fish and squid.

The distribution of Bryde's whales is known to be Australia-wide, in both oceanic and shelf waters (Bannister et al. 1996). Some evidence suggests there may be a distinct deep water population, although this is not fully verified (DEWHA 2009a). In WA, Bryde's whales are known to aggregate around the Abrolhos Islands.

2.3.2 Right Whales

2.3.2.1 Southern Right Whales

The southern right whale (*Eubalaena australis*) is listed as Endangered under the EPBC Act. This is a stocky, large whale up to 17 m long which lacks a dorsal fin (DEH, 1999). Southern right whales were hunted to near extinction in Australian waters at the end of the 19th century (Jackson et al 2008) and, although recovering, the Australian population is still very low, currently estimated at around 1,500 individuals.

The southern right whale feeds in deep oceanic waters in summer and move into coastal waters during the summer months (Bannister et al. 1996). This whale is primarily distributed along the southern coastline of Australia and is occasionally observed in Perth waters between May and October (Bridgewater 1990). Sightings in more northerly waters are relatively rare, but there have been recorded sightings in Exmouth (DEWHA 2009a). These may coincide with the winter migration, when the species moves into warmer waters (Thiele and Gill 1999). However, sightings at this latitude are likely to be vagrant individuals.

2.3.3 Toothed Whales

Odontocetes, or “toothed” whales, typically have simple teeth for gripping prey, such as fish, squid, crustaceans or small marine mammals. This family is the largest group of cetaceans and includes sperm (*Physeter macrocephalus*), pygmy sperm (*Kogia breviceps*), beaked whales and “true” dolphins.

2.3.3.1 Sperm Whales

The sperm whale family (Physeteridae) includes three species: sperm whale, pygmy whale and dwarf sperm whales (*Kogia sp.*). Of these, the EPBC search indicated that sperm and pygmy sperm whales may be present in the Project Area.

Sperm whales are listed under the EPBC Act as Threatened and as a Priority Four” (in need of monitoring) species under the Wildlife Act. They are large whales growing up to 18 m in length, with a large head and bluff, and a dorsal hump and tail stock ridges (DEH 1999). These whales may migrate through waters along the entire Australian coastline, although their distribution in the northernmost coastal regions is limited (DEH 1999). Sperm whales are known to dive for long periods of time and surface nearby, indicating that they have a preference for deep water (>200 m) (DEWHA 2009a). Sperm whales are commonly encountered in the region of the Java trench, Timor Sea, between May and October (B. Kah, 2006 pers. comm., Feb 22).

While possessing some of the distinguishing characters of the larger sperm whale, the pygmy sperm whale is a much smaller whale, growing to only 3.5 m (Bannister et al 1996). It is believed that the outer shelf areas and continental slope are important for *Kogia* species (DEWHA 2008). It is therefore unlikely that this species would be present in waters shallower than 500 m.



2.3.3.2 Beaked Whales

Beaked whales (Ziphiidae), including Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales are not listed under the EPBC Act as Threatened or Migratory, and therefore not considered as MNES.

Many ziphiid species are difficult to identify and differentiate from one another because their diagnostic morphological features are generally subtle (Hrvoje 2006). They are rather robust and cigar-shaped, with a small falcate (sickle-shaped) dorsal fin and relatively small flippers (Culik 2003d, in DEWHA 2009a). While Cuvier's beaked whale may reach up to 9.8 m in length, Blainville's beaked whale only reach up to 6.4 m, with a maximum weight of about one tonne (DEWHA 2009a).

Blainville's beaked whale prefers tropical and warm temperate waters around the world and is a deep water species primarily living off the continental shelf (DEWHA 2009a), while Cuvier's beaked whale are found in all oceans of the world (Bannister et al. 1996).

Beaked whales inhabit deep oceanic waters and make among the longest and deepest dives of any cetacean, with some species foraging at depths of 1,000 m during the day (Baird et al. 2007). They are known to feed in deep-water regions characterized by steep topography (Hain et al. 1985; Waring et al. 2001, in Auster and Watling 2008), targeting primarily cephalopods, which occur both in the water column and near or on the seafloor, as well as mid-water and demersal fishes (Waring et al. 2001; MacLeod et al. 2003 in Auster and Watling 2008).

Cuvier's beaked whales are not considered abundant in Australia, as sightings and strandings are rare. The population potentially includes less than 10,000 mature individuals within Australian waters (Peddemors & Harcourt 2006, pers. comm., in DEWHA 2009a). The population abundance of Blainville's beaked whale is unknown (Bannister et al. 1996).

2.3.3.3 Dolphins

There are a number of dolphin species that are highly mobile and utilise deep waters of the open ocean and continental shelf and slope, feeding in areas of high productivity, such as those found on the shelf slope (Jenner 2008). The spatial and temporal distribution of these dolphins is highly variable, influenced by environmental, biotic and anthropogenic factors (Davis et al. 1998). Some spinner dolphins and killer whales are known also to occur in shallower waters of the continental shelf (DEWHA 2009). Bottlenose dolphins are discussed in 2.3.3.4 as "coastal dolphin species" although they can also be found in deep water.

Due to their high mobility, a number of these dolphins could occur within offshore waters of the Project Area at some time. A summary of distribution, abundance, habitat and foraging areas for species listed by the EPBC search is presented in Table 2.



Three dolphin species are listed under the EPBC Act as Migratory:

- Killer whale (*Orcinus orca*)
- Fraser’s dolphin (*Lagenodelphis hosei*)
- Spinner dolphin (*Stenella longirostris*).

Table 2: Summary of Offshore Dolphin Species and their Key Ecological Characteristics

Species	Distribution and Abundance	Habitat, Foraging Areas and Prey
Short-finned pilot whale (<i>Globicephala macrorhynchus</i>)	No population estimates are available for short-finned pilot whales in Australian waters, although they are generally considered to be relatively abundant.	Short-finned pilot whales prefer deep water between 600 and 1,000 m (Davis et al. 1998) and occur mainly at the edge of the continental shelf, and over deep submarine canyons. Spends more time foraging near the surface at night time (Baird et al. 2007). Feeds mainly on squid, cuttlefish, octopus and some fish.
Killer whale (<i>Orcinus orca</i>)	Listed by EPBC search as Migratory species and is known to be distributed in polar to tropical waters during all seasons. Widest distribution of any dolphin species. Often been sighted in the Exmouth Gulf (Jenner 2005). Sighted in the Barrow Island area in 1971 and strandings on Barrow Island in 1970 (Butler 1975, in Bannister et al 1996)	Found in deep oceanic waters and shallower waters of the continental shelf. A cosmopolitan species, they are in both warm and cold waters (Bannister et al, 1996). Corkeron & Connor (1999) suggests killer whale migration is closely linked to availability of their primary marine mammal prey – pinnies, (seals and sea lions) which are found in colder waters at higher latitudes.
Pygmy killer whale (<i>Feresa attenuata</i>)	Tropical and subtropical species that inhabits oceanic waters around the globe. Considered to be in relatively low abundance in Australian waters.	Unknown if it is pelagic or favours areas of the continental shelf. Predator of other cetaceans including <i>Stenella</i> species and the common dolphin.
False killer whale (<i>Pseudorca crassidens</i>)	Circumglobal, from equator to 45°N to 25°S. Although widely distributed, apparently not abundant in any location.	Oceanic waters, possibly attracted to zones of enhanced prey abundance along the continental shelf (Bannister et al. 1996). Preys upon squid and large pelagic fish.
Common dolphin (<i>Delphinus delphis</i>)	Found in offshore waters. They have been recorded in waters off all Australian states and territories, but are rarely seen in northern Australian waters. Two main locations around Australia, with one cluster in the southern south-eastern Indian Ocean and another in the Tasman Sea.	In most areas where they have been studied, common dolphins appear to occur mainly in medium water depths over the continental shelf. They have been found in deep ocean, shallower shelf and near the coast (Bannister et al. 1996). Feeds on a variety of small prey, mainly fishes and squids, but also on other cephalopods and crustaceans (Bearzi et al. 2003; Evans 1994; Perrin 2002, in DEWHA 2009). Diet may vary with season as well as region (Evans 1994).
Risso's dolphin (<i>Grampus griseus</i>)	All oceans, from equator north and south but lower latitudes, recorded from south-western Australia.	Oceanic, found in deep waters on the continental slope (Davis et al. 1998). Feeds primarily on squid, some octopus



Species	Distribution and Abundance	Habitat, Foraging Areas and Prey
	Reasonably abundant throughout the main part of its range.	and possibly fish.
Fraser's dolphin (<i>Lagenodelphis hosei</i>)	Low latitudes of all three major ocean basins. Distribution in south west Indian Ocean may be localised. Records outside of low latitudes may be vagrant.	Pelagic and oceanic (Bannister et al. 1996). Either feeds at depths (250-500 m) or at night. Preys upon fish, squid crustaceans.
Melon-headed whale (<i>Peponocephala electra</i>)	Northern and southern hemisphere. Indian, Pacific and Atlantic oceans-primarily tropical and subtropical (mainly equatorial).	Pelagic and oceanic (Bannister et al. 1996). Generally in upwelling areas Squid and variety of fish
Spinner dolphin (<i>Stenella longirostris</i>)	DEC lists this as a priority 4 species, in need of further monitoring (DEC 2009). Distributed across northern Australia with Exmouth Gulf the most southerly limit (Bannister et al 1996).	Offshore and inshore open waters, feeds mostly on shoaling fish. Deep waters on the continental slope (Davis et al. 1998).
Pantropical spotted dolphin (<i>Stenella attenuata</i>)	Northern and southern hemisphere, in Pacific, Atlantic and Indian oceans, recorded off WA south to Augusta. No population estimates for Australian waters.	Pelagic and oceanic but also found on the shelf and continental shelf. Deep depths on the continental slope (Davis et al. 1998) Preys upon fish, squid-diet varies with region and reproductive state
Striped dolphin (<i>Stenella coeruleoalba</i>)	Northern and southern hemisphere, all oceans at low to medium latitudes. No population estimates for Australia but relatively frequent strandings in WA suggests this species is not uncommon in WA waters.	Deep water and outer edge of continental slope. Tropical, subtropical and warm temperate waters. Targets small (<300 mm length) prey small including fish, shrimp and squid (Bannister et al. 1996).
Rough-toothed dolphin (<i>Steno bredanensis</i>)	Occurs in low latitudes of Atlantic, Indian and Pacific Ocean, likely to be vagrant outside of these areas.	Deep depths on the continental slope (Davis et al. 1998). Preys upon pelagic squid, octopus and reef fish.

2.3.3.4 Coastal Dolphin Species

The coastal waters of the Pilbara support small populations of dolphins, the majority of which appear to be species of *Tursiops* (bottlenose dolphin) and Indo Pacific humpback dolphins (*Sousa chinensis*) (Prince 2001).

Indo Pacific Humpback Dolphin

This species is listed by the EPBC Act as Migratory. The Indo Pacific humpback dolphin is a medium sized dolphin with a full body and a triangular-shaped dorsal fin (2009a). Their colouration is uniformly grey, with flanks softening to off-white. Australian Indo Pacific humpback dolphins reach lengths of up to 2.62 m (DEWHA 2009a), with males weighing up to 260 kg and females up to 170 kg Bannister et al. 1996). Adults are generally found singly or in pairs, while immature individuals are found in groups (Bannister et al. 1996; DEWHA 2009a).

Home ranges for Indo Pacific humpback dolphins are extensive, with only certain individuals showing “resident” behaviour. In WA, “resident” populations have been identified within the shallow waters of the inner Rowley Shelf, to the north of Exmouth Gulf. In recent years this species has showed signs of population decline (GBRMPA 2007).

Large migrations reportedly occur, with evidence of movements between national boundaries; however, no recognised migratory pathways have been identified in Australia.

The global range of the Indo Pacific humpback dolphin extends from the north coast of Australia to the east coast of Africa. In Australia, the Indo Pacific humpback dolphin is found along the coastline of the NT and Queensland, and along the northern coastline of WA as far south as Shark Bay (Jenner 2008). They primarily inhabit coastal and estuarine waters less than 20 m deep, although records also indicate that they occur in river systems and shallow offshore areas on occasion (Parra et al. 2005; Bannister et al. 1996).

The shallow inshore waters inhabited by Indo Pacific humpback dolphins are their feeding areas (Minton and Peter, 2009); with estuarine entrances providing important feeding opportunities (Mustoe and Edmunds, 2008). Indo Pacific humpback dolphins are opportunist-generalist feeders and target a variety of shallow water coastal, estuarine and reef-associated fishes, although cephalopods and crustaceans species are also reportedly consumed (Bannister et al. 1996). Foraging behind fishing trawlers has been recorded in Moreton and Cleveland Bays (Bannister et al. 1996; DEWHA 2009a). This behaviour may occur elsewhere in Australia (DEWHA 2009a).

Male and female dolphins reach sexual maturity at approximately 13 and 10 years of age respectively (DEWHA a). Mating and calving areas have not been identified in Australia, but they are likely to occur in sheltered areas close to the coast. Reproductive activities occur year round, with a peak calving season possibly occurring during the summer months (Bannister et al. 1996).

As a coastal species, the Indo Pacific humpback dolphin is susceptible to human impacts (Parra et al. 2005), including boating, netting and run-off resulting in degraded water quality (GBRMPA 2007). The Indo Pacific humpback dolphin population is susceptible to fragmentation due to coastal developments (Parra et al. 2005).

Bottlenose Dolphins

Two species of bottlenose dolphins occur in Australian waters:

- Common bottlenose dolphin (*Tursiops truncatus*)
- Spotted bottlenose dolphin (*Tursiops aduncus*).



The common bottlenose dolphin is not listed as Threatened or Migratory under the EPBC Act and is therefore not considered a MNES. This species has a worldwide distribution and may be found in both temperate and tropical waters (DEWHA 2009a). Although it is believed that an offshore ecotype exists (Section 2.3.4.3), they tend to be a coastal species, often found in water depths of less than 10 m. In many inshore areas, bottlenose dolphins maintain long-term home ranges (DEWHA 2009a; IUCN 2009) rendering them sensitive to population fragmentation from local disturbances.

The spotted bottlenose dolphin is listed as Migratory under the EPBC Act and therefore considered as a MNES. This species inhabits warm water coastal or nearshore areas, in waters less than 10 m (Bannister et al. 1996), and is distributed mainly along the north-western coast of the NT and northern WA coastline.

Group sizes of bottlenose dolphins are variable and can range from groups with fewer than five individuals (usually males) to groups including over 1,000 individuals (Bannister et al. 1996), although *T. truncatus* species are generally the more social of the two species. Both species of bottlenose dolphins occur in mixed schools, with recent data from Shark Bay reporting a hybridized population of bottlenose dolphins consisting of DNA from both *T. aduncus* and *T. truncatus* (DEWHA 2009b). Large whales and other delphinid species are also known to associate with the bottlenose dolphin species (IUCN 2009).

Both species of bottlenose dolphin species prey mainly upon fish and cephalopods, although feeding may also occur in “association with human activities” such as trawling (Bannister et al. 1996).

2.3.4 Dugong

The dugong (*Dugong dugong*) is an internationally recognised Threatened species (Gales et al. 2004) and is listed as Migratory under the EPBC Act, therefore considered a MNES.

The dugong is long-lived with, a lifespan of 50–70 years, is considered mature at approximately 2.5 m in length and becomes sexually mature between six and 15 years of age (Saalfield and Marsh 2004). Dugongs typically travel either solitary, in pairs or in small groups (around three to six individuals), but can be found in large herds of 20 or more.

Dugongs have a very slow and highly inconsistent reproductive rate (Lanyon, 2007). There is high investment in each offspring as dugongs calve once every three to seven years, have a gestation period of approximately 13 months and suckle the calf for a period of at least 14 months (Saalfield and Marsh 2004; NAILSMA 2006). The period of August / September to November has been recorded as the dugong calving season in northern Australia (Townsville to Cairns) (Marsh et al. 1984 cited in Marsh, 1995) but calving seasons within Western Australia are unconfirmed. Protected shallow waters such as tidal sandbanks and estuaries are considered important sites for calving (Limpus and Chatto, 2004).

While dugongs frequent coastal waters, including estuarine creeks and streams, and have been observed travelling upstream in creeks for several kilometres, they have also been sighted in deeper water further offshore (Lawler et al. 2002; Saalfield and Marsh 2004). Dugongs tend to aggregate in wide, shallow protected bays and mangrove channels, and on the sheltered side of large inshore islands (Heinsohn et al. 1979) that coincide with feeding grounds (DEWHA 2008).

Dugongs are primarily herbivorous, feeding on seagrass. Seagrass varieties that dugongs prefer include *Halodule* and *Halophylla* sp. These seagrass species are represented within the Project Area at low densities; their occurrence known to be ephemeral and affected by cyclonic activity (URS 2009). When seagrass is not readily available, dugongs consume marine algae (Saalfield and Marsh 2004; Chatto and Limpus 2004). Macroinvertebrates are also part of a dugong's diet, especially for those at higher latitudes (Limpus and Chatto 2004), including those in WA (NAILSMA 2006).

Estimates put dugong seagrass consumption per day at 28–40 kg (Chilvers 2003; Limpus and Chatto 2004). Originally, it was thought that dugongs grazed on whatever seagrasses were readily available. However, there is some indication that these mammals graze according to the nutritional quality of the seagrass (Limpus and Chatto 2004). If there is insufficient food, dugongs will delay breeding (NAILSMA 2006; DEWHA 2008).

Studies on the diving behaviour of dugongs by Chilvers et al. (2004) in Shark Bay indicated that dugongs spend the majority of their daily activities foraging in less than 3 m of water. However, during travel, dugongs make repeat deep dives, rather than travelling at the surface, and conduct short and regular surface intervals, which makes them vulnerable to capture in fishing nets and injury from high speed boats (Sheppard et al. 2006; Anderson 1981). Vocalisation may play an important role in the social organisation of dugongs, such as territorial behaviour and mother-calf bonding, which indicates that the species has excellent hearing ability (GBRMPA 1997).

Dugongs are sensitive to temperatures below approximately 20 °C and tend to be found in warmer waters, in the range of 21–27 °C (Sleeman et al. 2007). Due to their sensitivity to water temperature, they usually occur in the tropical and sub-tropical shallow waters of the Indian and Pacific oceans, but are most abundant in the marine waters of northern Australia that support seagrasses beds.

Dugongs are migratory and, although seasonal movements are little understood, appear to move in response to food availability or water temperature (Marsh et al. 2002; Gales et al. 2004). Individuals are known to travel over larger distances between Australia and other countries, such as the Timor and Papua New Guinea, ranging 100– 600 km (Parks and Wildlife Service 2003; DEWHA 2008). Gales et al. (2004) acknowledged evidence of large-scale movements of dugongs that reside in the Exmouth Gulf and Ningaloo Reef area to areas north in response to natural habitat changes, such as those associated with storm events. Such large movements are thought to be linked to the ephemeral nature of their preferred seagrass species (DEWHA 2008) and the search for suitable foraging grounds or warmer waters (Marsh et al. 2002; Gales et al. 2004). According to Hodgson (2007), migration between populations in north-western WA is largely unknown.



It is generally accepted that Australia supports the world’s most abundant dugong population (Parks and Wildlife Service 2003). The total Australian dugong population is estimated at more than 80,000 individuals (Saafeld and Marsh, 2004). Dugongs are generally spread across the northern half of Australia, in coastal waters off the NT, Queensland and Torres Strait, and northern WA. On the west coast, Shark Bay is the southernmost area of their range and, on the east coast, the coastal waters of northern New South Wales (NAILSMA, 2006).

Important dugong habitats in WA include Shark Bay, Exmouth Gulf, Ningaloo Reef, the Kimberley coast and Ashmore Reef (Marsh et al. 2002; DEWHA 2008). The Pilbara coastal and offshore region is also an important area for dugong due to potential seagrass habitat around Barrow Island, the Montebello Islands and Serrurier Island (DEWHA 2008). Population estimates are shown in Table 3.

Table 3: Population Estimates of Dugongs in Shark Bay, Ningaloo Reef, Exmouth Gulf and the Pilbara Coastline

Year (Date)	Shark Bay	Ningaloo Reef	Exmouth Gulf	Pilbara Coast	Reference
1989 (4–11 July)	10,146 (se±1,665)	634 (se±127)	1,062 (se±321)	-	*Preen et al. (1997) cited in Hodgson (2007)
1994 (21–30 June)	10,529 (se±1,464)	968 (se±320)	1,006 (se±494)	-	*Preen et al. (1997) cited in Hodgson (2007)
1999 (8–16 July)	13,929 (se±1,652)	163 (se±148)	174 (se±82)	-	*Gales et al. (2004) cited in Hodgson (2007)
2000 (6–16 April)	-	-	95 (se±62)	2046 (se±376)	*Prince (2001)
2002 (4–10 Feb.)	11,021 (se±1,357)	-	-	-	*Holley et al. (1997) cited in Hodgson (2007)
2007 (30 March – 16 June)	14,022 (se±1,230)	-	1,411 (se±561)	-	*Hodgson (2007)
2007 (30 March – 16 June)	9,347 (se±1204)	-	704 (se±354)	-	#Hodgson (2007)

*Marsh and Sinclair (1989) method
Marsh and Sinclair (1989) as refined by Pollock et al. (2006) method

Shark Bay represents 10 per cent of the world’s dugong population, the second largest resident population in the world (Hodgson 2007). This area is considered to be internationally significant for this species because it offers the best conservation opportunities for a dugong population (Hodgson 2007). Gales hypothesised that the increase in population from 1994 to 1999 could be due to dugongs migrating from Ningaloo Reef / Exmouth Gulf in search of seagrass following Cyclone Vance (Gales et al 2004).

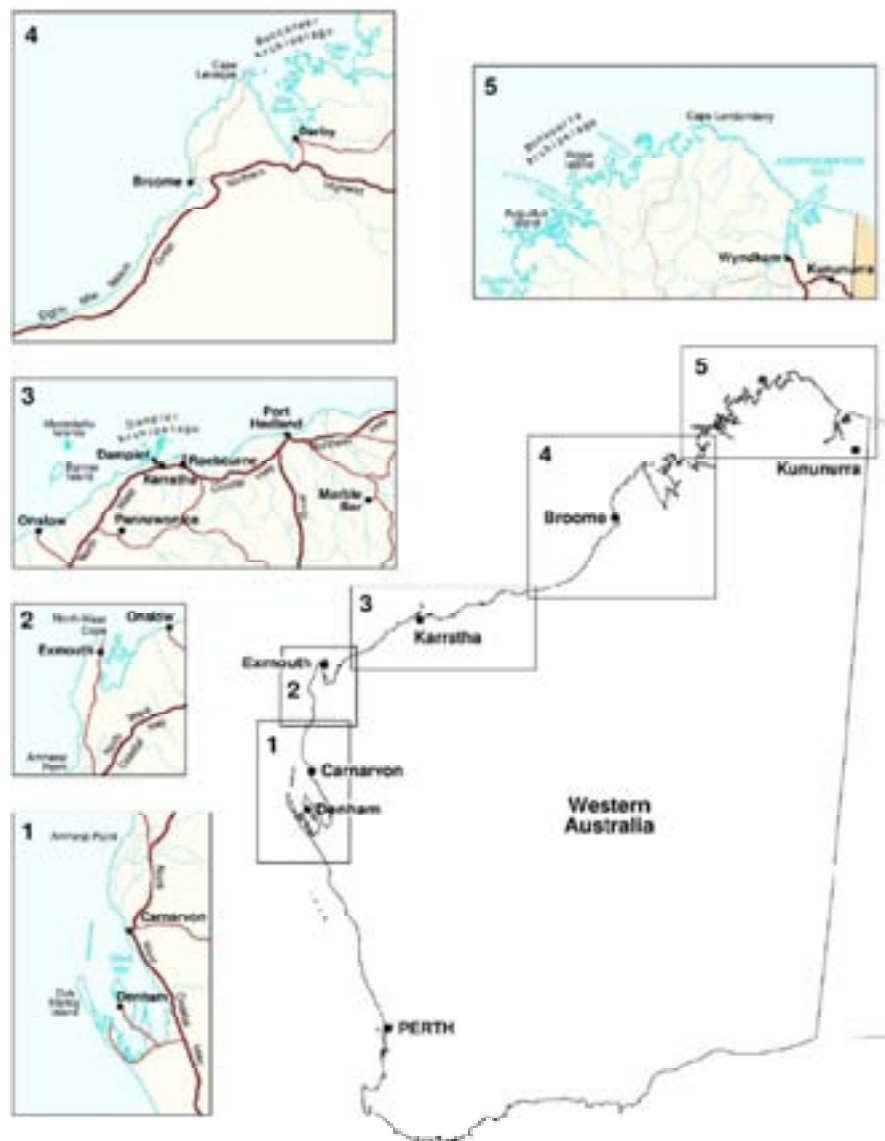
Research has indicated that Exmouth Gulf is an important feeding and breeding area for this species (Jenner and Jenner 2005), with critical dugong habitat present (Prince 2001). Aerial surveys indicated that dugongs were distributed in water depths less than 12 m and concentrated in the south-eastern portion of the gulf (Jenner and Jenner 2005).

To date, dugong abundance and distribution north of Exmouth Gulf is poorly documented. In the late 1970s, reconnaissance surveys off the Pilbara coast, from Exmouth Gulf to De Grey River (70 km north of Port Hedland), hypothesised that this area may be important for dugongs. This was not scientifically verified until 2000, when surveys found a relatively small, but widely distributed, population of 2,046 dugongs (Prince 2001) (Table 3).

Sightings off the Pilbara coast north-east of Onslow since the late 1990s confirm the presence of dugongs in nearshore areas:

- Dugongs were observed in March 2004 at Varanus Island and over Barrow Shoals (Fitzpatrick, J. 2004. pers. comm.)
- Dugongs have been observed off the east coast of Barrow Island, at the Lowendal Islands to the north-east of Onslow, and at a number of other islands of the region (Prince 2001)
- Dugong feeding trails have been identified in dense seagrass meadows off Middle and North Mangrove Islands (Fitzpatrick, J. 2004. pers. comm.)
- Dugongs are relatively common in the shallows of islands nearshore from Onslow (CALM 2002)
- Serrurier Island provides a resting area for dugongs (Western Australian Planning Commission 2003).

Holley and Prince (2008) suggest that DEC will implement a dugong management program based on a series of management units along the coast. As depicted in Figure 5, these management units largely reflect the areas discussed above, with units 3 and 4 relevant to the Project Area.



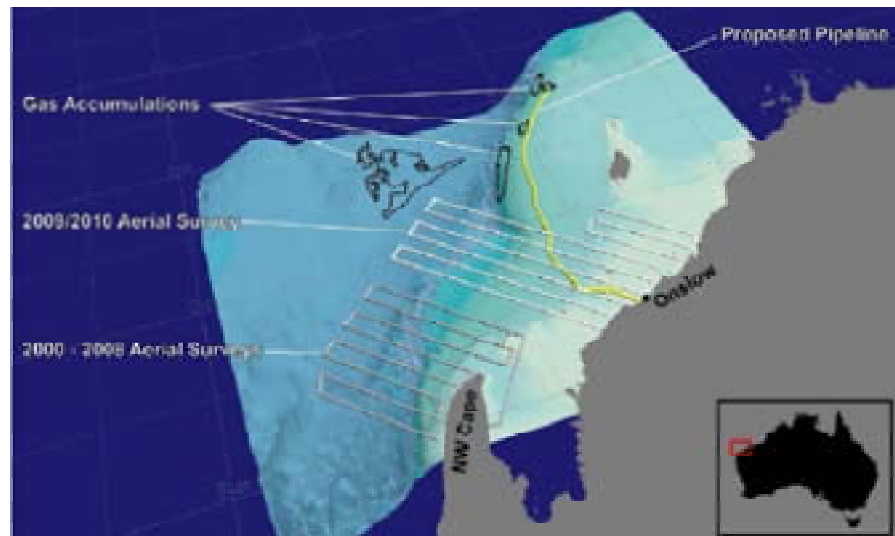
(DEC 2007 presented in Holley and Prince, 2008)

Figure 5: Dugong Management Units for Western Australia

3.0 METHODOLOGY

3.1 Centre for Whale Research Aerial Surveys

The CWR aerial survey entailed sampling a series of systematic parallel transect lines every two weeks commencing in May 2009. The location of transects are shown in Figure 6.



(Jenner and Jenner 2009)

Figure 6: Design of the Aerial Survey Transects

The CWR survey aimed to:

- Build on existing datasets and fill knowledge gaps regarding cetaceans and other megafauna that can be sampled from the air, including their distribution and abundance along the inshore and offshore regions of the south-west Pilbara.
- Determine the seasonal distribution and relative abundance of cetaceans and other megafauna along the inshore and offshore regions of the south-west Pilbara.

A preliminary survey report was produced that analysed the first eight months of data for use in the Wheatstone ERMP/EIS (Appendix 2). This report includes data acquired during 17 flights undertaken at approximately two-week intervals from 17 May 2009 to 24 December 2009, totalling 119.2 survey hours.

Further details on methodology used to conduct this survey are provided in Appendix 2.

A final report will be produced which will include a complete 12-month dataset by mid-2010.



3.2 Centre for Marine Science and Technology Acoustic Survey

The primary objective of the acoustic survey was to gather information on ambient sea noise and the presence and movements of cetacean species in and around the Project Area.

A total of five sea noise loggers were deployed (Figure 7). Two loggers were deployed in the nearshore region west of Onslow, including one at the 10 m depth contour and one at the 43 m depth contour. The remaining three noise loggers were deployed in a 2 km triangular configuration on the 200 m isobath, located on the shelf break north of the Montebello Islands. This configuration was designed so that individual animals could be tracked using triangulation.

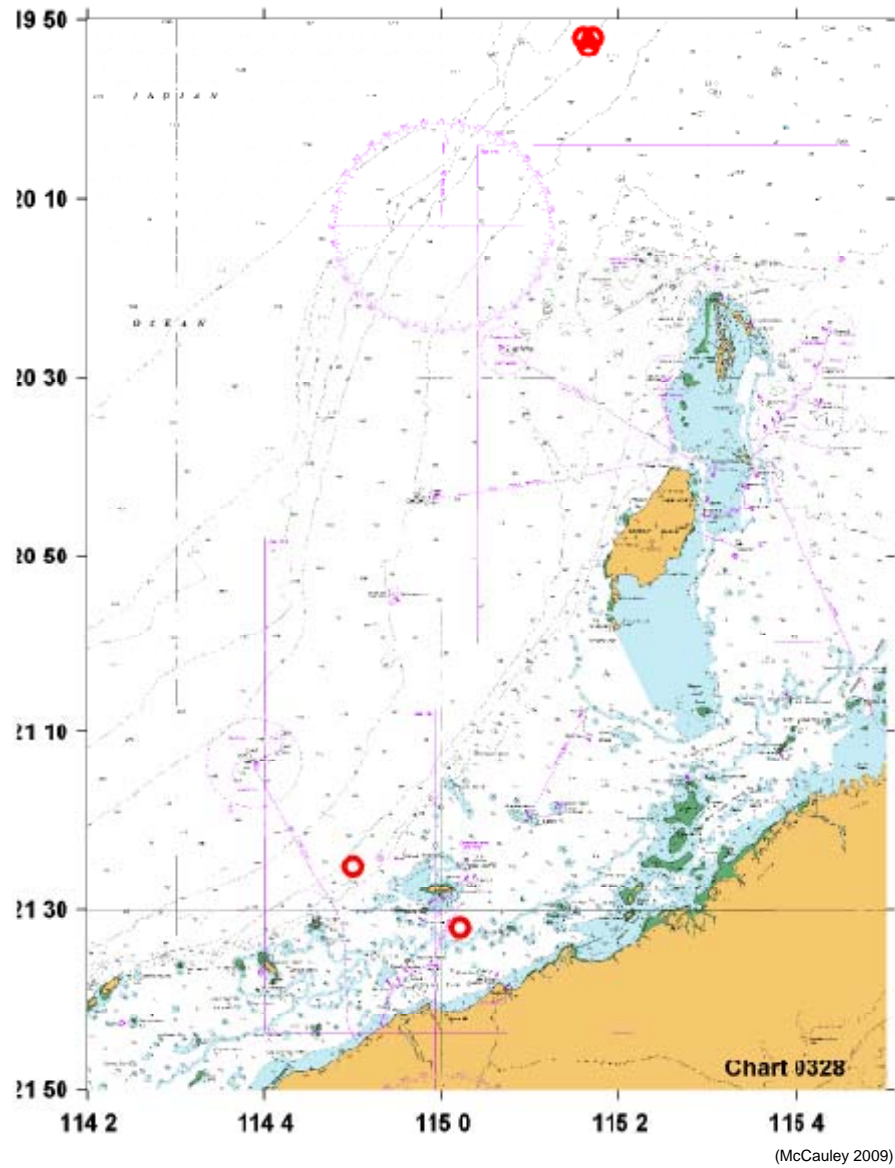


Figure 7: Location of Sea Noise Loggers (McCauley 2009)

The noise loggers were deployed in two stages, with the nearshore loggers set on 16 April 2009 and the offshore noise loggers on 5 May 2009. The noise loggers were retrieved between 22 and 23 July 2009 so that preliminary data analysis could be conducted and results used in the ERMP/EIS (Appendix 3).

The loggers were then redeployed to acquire a full 12-month dataset, to be reported by mid-2010.



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4.0 KEY FINDINGS OF PRELIMINARY SURVEY REPORTS

A synopsis of key findings from the preliminary field survey reports is presented in the following sections, with details of marine mammal species identified for the Project Area through the EPBC Act search tool and / or the field surveys summarised in Table 4. Survey reports are provided in full in Appendices 2 and 3.

The surveys undertaken by CWR and CMST over an eight-month period have captured the main northward and southward migrations of humpbacks and have provided an insight into dugong and dolphin numbers and distributions for this period. However, it does not provide details of the full seasonal changes in species distribution and abundance within the Project Area, which will be available once a full 12-month dataset has been collected and reported.

Table 4: Summary of Marine Mammals potentially occurring within the Project Area

ID	Common Name	Scientific Name	Australian Conservation Status	
			Commonwealth	WA
→ ◀	Humpback whale	<i>Megaptera novaeangliae</i>	Vulnerable/ Migratory	Vulnerable
→ ◀	Blue whale (includes pygmy blue whale)	<i>Balaenoptera musculus intermedia</i> (and <i>m. breviceauda</i>)	Endangered/ Migratory	Endangered
→ ◀	Minke whale	<i>Balaenoptera acutorostrata</i>	Listed (cetacean)	No priority listing
	Antarctic minke whale	<i>Balaenoptera bonaerensis</i>	Migratory	No priority listing
◀	Bryde's whale	<i>Balaenoptera edeni</i>	Migratory	No priority listing
	Southern right whale	<i>Eubalaena australis</i>	Endangered/ Migratory	Vulnerable
→	Sperm whale	<i>Physeter macrocephalus</i>	Migratory	P4: Taxa in need of monitoring
	Pygmy sperm whale	<i>Kogia breviceps</i>	Listed (cetacean)	No priority listing
	Blainville's beaked whale	<i>Mesoplodon densirostris</i>	Listed (cetacean)	No priority listing
	Cuvier's beaked whale	<i>Ziphius cavirostris</i>	Listed (cetacean)	No priority listing
→	Pilot whale sp.	<i>Globicephala sp.</i>		
	Short-finned pilot whale	<i>Globicephala macrorhynchus</i>	Listed (cetacean)	No priority listing
→	Killer whale	<i>Orcinus orca</i>	Migratory	No priority listing
	Pygmy killer whale	<i>Feresa attenuata</i>	Listed (cetacean)	No priority listing



ID	Common Name	Scientific Name	Australian Conservation Status	
			Commonwealth	WA
	False killer whale	<i>Pseudorca crassidens</i>	Listed (cetacean)	No priority listing
	Common dolphin	<i>Delphinus delphis</i>	Listed (cetacean)	No priority listing
	Risso's dolphin	<i>Grampus griseus</i>	Listed (cetacean)	No priority listing
	Fraser's dolphin	<i>Lagenodelphis hosei</i>	Listed (cetacean)	No priority listing
	Melon-headed whale	<i>Peponocephala electra</i>	Listed (cetacean)	No priority listing
	Pantropical spotted dolphin	<i>Stenella attenuata</i>	Listed (cetacean)	No priority listing
	Spinner dolphin	<i>Stenella longirostris</i>	Listed (cetacean)	P4: Taxa in need of monitoring
	Striped dolphin	<i>Stenella coeruleoalba</i>	Listed (cetacean)	No priority listing
	Rough-toothed dolphin	<i>Steno bredanensis</i>	Listed (cetacean)	No priority listing
	Indo Pacific humpback dolphin	<i>Sousa chinensis</i>	Migratory	P4: Taxa in need of monitoring
→	Bottlenose sp.	<i>Tursiops sp.</i>		
	Spotted bottlenose dolphin	<i>Tursiops aduncus</i>	Migratory	No priority listing
	Bottlenose dolphin	<i>Tursiops truncatus</i>	Listed (cetacean)	No priority listing
→	Dugong	<i>Dugong dugon</i>	Migratory	Other specially protected fauna

- Species / taxon recorded by CWR aerial survey
- ◀ Species / taxon recorded by CMST acoustic survey

4.1 CWR Aerial Surveys

Presence of the following species within the Project Area was confirmed by the aerial surveys (Jenner and Jenner 2009):

- Humpback whale
- Blue whale
- Minke whale
- Sperm whale
- Killer whale
- Dugong.



In addition to these species, the following taxa were recorded by the aerial surveys, but could not be identified to species level:

- Bottlenose dolphins.
- Pilot whale.

4.1.1 Humpback Whales

- A total of 1,221 humpback whales were counted during the aerial surveys and it was the most commonly sighted large cetacean.
- Humpback whales were present in the study area from early to mid-June to mid-December.
- There was a steady increase in humpback whale sightings from mid-June to late August (Figure 8).
- Humpback whales were sighted at an average distance of 50 km from shore during the northbound migration and 35 km during the southbound migration (Figure 9).
- 45% (n=256) of pods observed between June 12 and August 5 were northbound.
- A decline in the proportion of northbound pods was observed during the mid-August flights, with a noticeable increase in the proportion of pods identified as resting and / or milling (Figure 9).
- Cow-calf pods were found in highest numbers within the 50 m depth contour, 35 km off the coastline. These pods were observed to be predominantly resting.

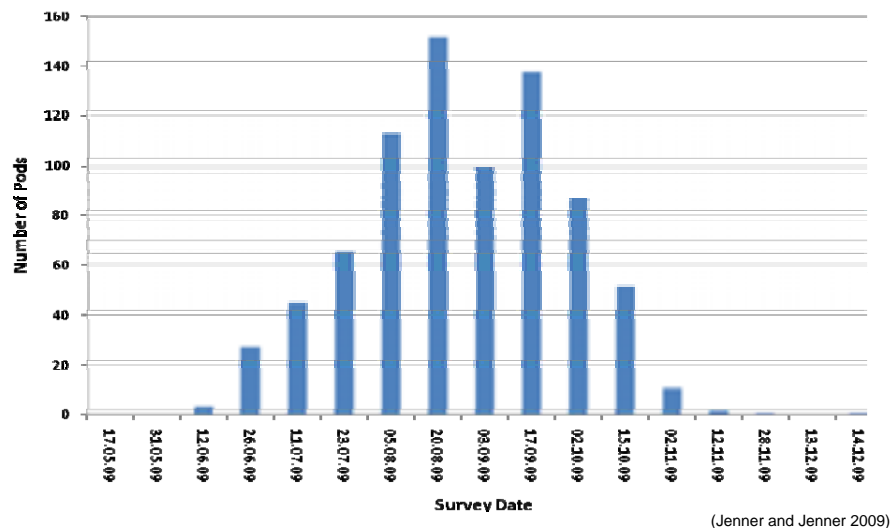


Figure 8: Numbers of Humpback Whales Sighted per Flight from 17 May to 24 December 2009



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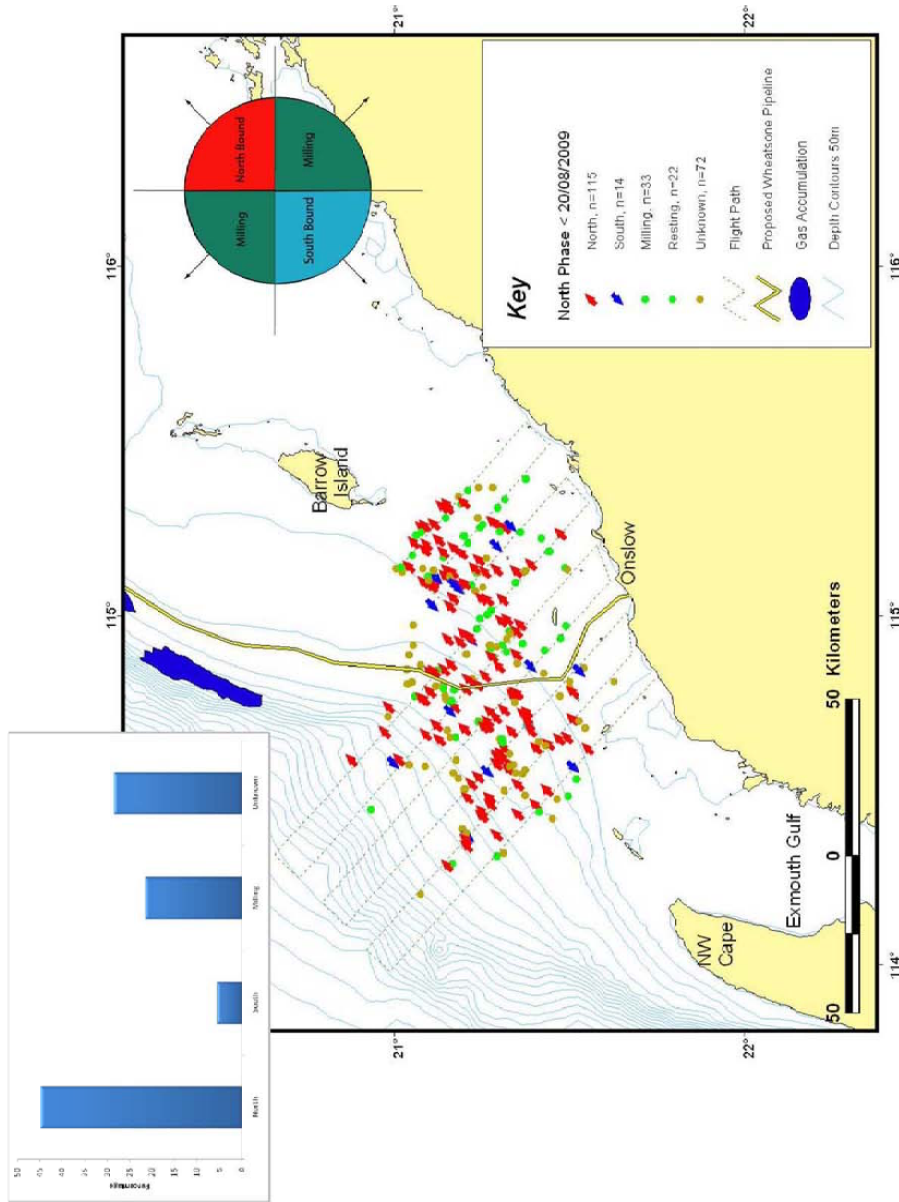


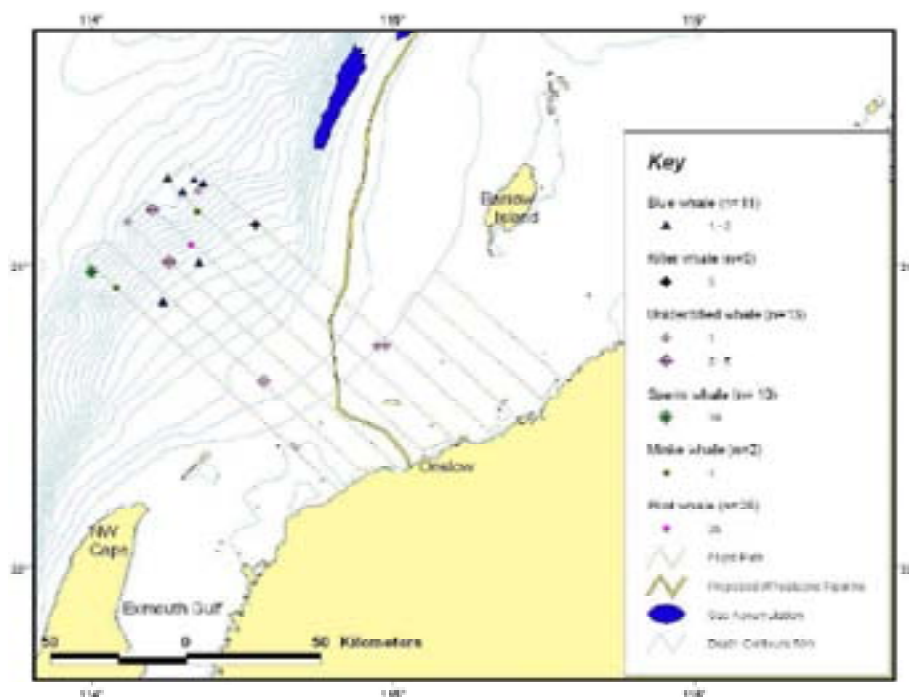
Figure 9: Swim Direction of Humpback Whale Pods recorded between June 12 and August 05 2009 (Northern Migration) (Jenner and Jenner 2009)



4.1.2 Cetaceans other than Humpback Whales and Dolphins

Locations of sightings of other cetaceans are shown in Figure 10 and summarised below:

- Two minke whales were recorded on the 600 m and 650 m isobaths.
- A pod of 25 pilot whales was recorded on the 450 m isobath.
- A pod of 10 sperm whales was recorded on the 830 m isobath.
- A pod of five killer whales was recorded on the 400 m isobath.
- Eleven blue whales were recorded between the 750 m and the 850 m isobaths and between the 300 m and the 350 m isobaths. All blue whales were observed to be moving southwards.



(Jenner and Jenner 2009)

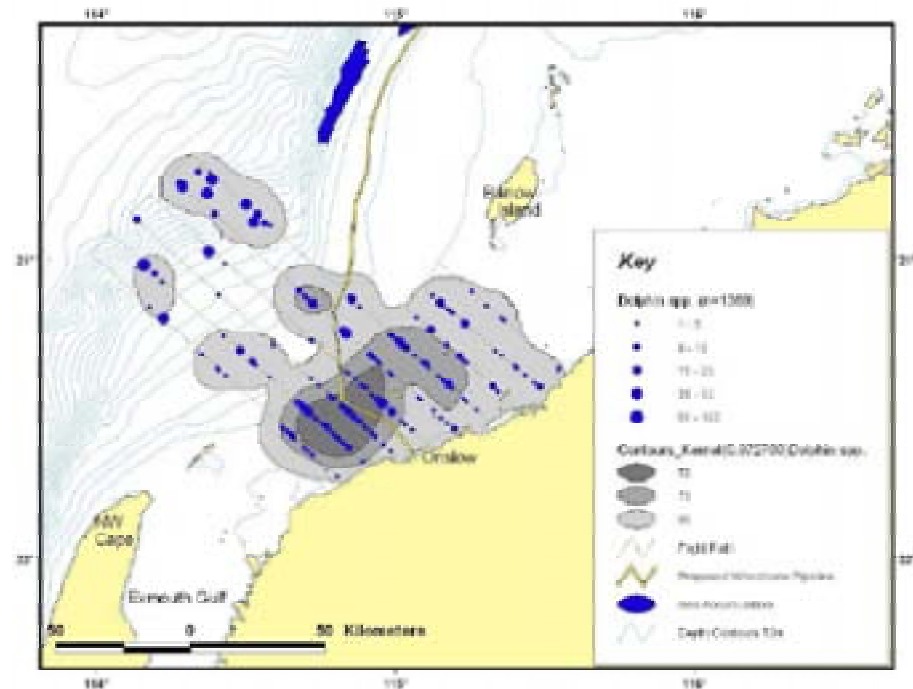
Figure 10: Location of other Large Cetaceans Recorded during 17 May to 23 December 2009

4.1.3 Dolphins

Sightings of dolphins are shown in Figure 11 and summarised as:

- Dolphins were sighted during each survey flight.

- A total of 1,369 dolphins were recorded, with large pods (>100 individuals) sighted offshore.
- Dolphins were predominantly sighted in the south-western sector of the survey area in water depths less than 50 m.



(Jenner and Jenner 2009)

Figure 11: Distribution and Relative Density of Dolphin Species Sighted from 17 May to 24 December 2009

At 1,000 ft, the altitude at which the aerial surveys were flown was too high to positively identify dolphins to species level. Presence of individual species could only be inferred from vessel-based anecdotes (Jenner and Jenner 2009).

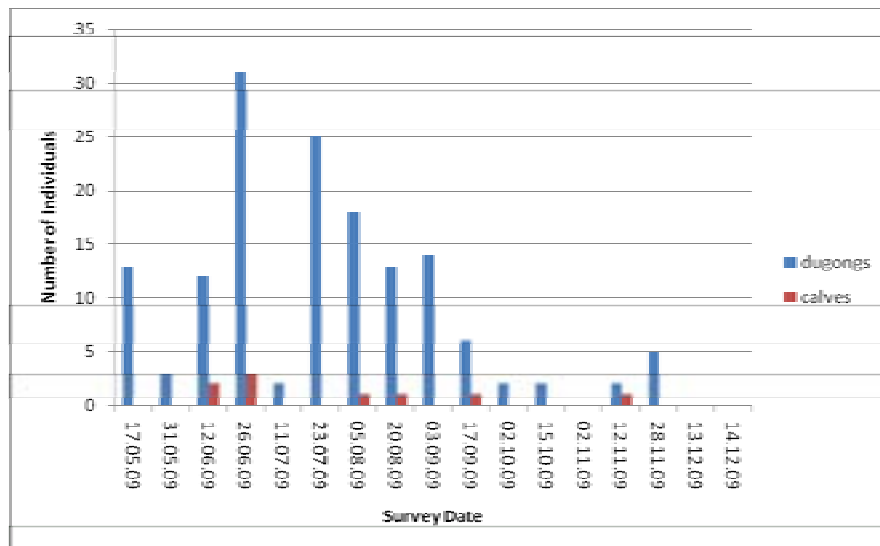
4.1.4 Dugongs

The sightings frequency and distribution of dugong are shown in Figure 12 and Figure 13 respectively and discussed below.

- A total of 148 dugongs were sighted over the 17 May to 24 December survey period, with numbers peaking in late June.

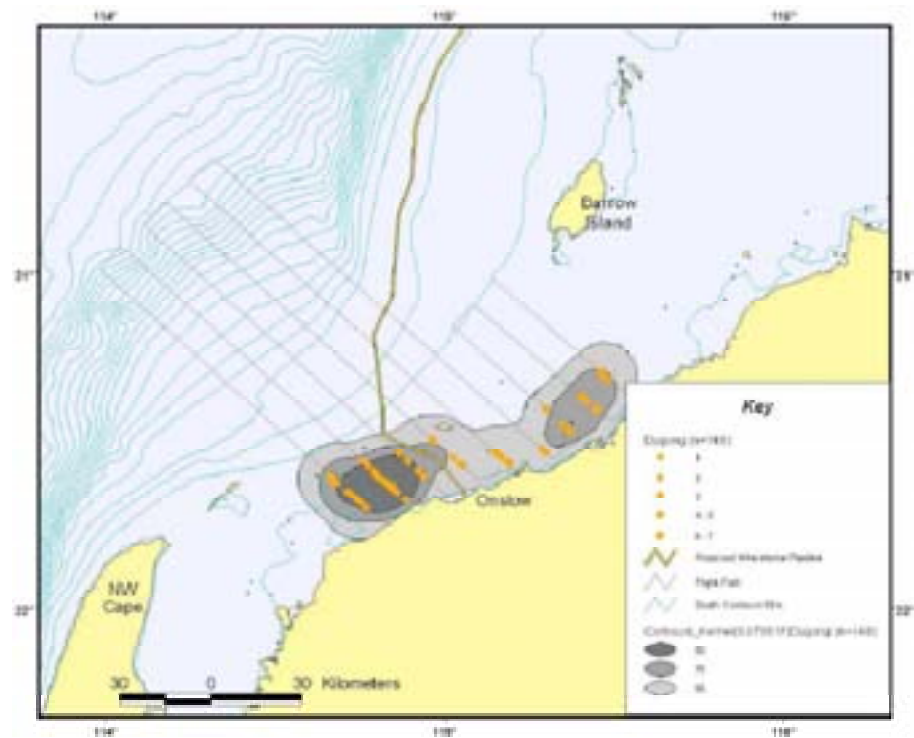


- Dugong herds with cow-calf pairs accounted for 10 per cent of all sightings.
- Dugongs were predominantly sighted in the south-western sector of the survey area, in water depths less than 10 metres.



(Jenner and Jenner 2009)

Figure 12: Number of Dugongs and Calves Sighted from 17 May to 24 December 2009



(Jenner and Jenner 2009)

Figure 13: Distribution and Relative Density of Dugong Herds Sighted from 17 May to 24 December 2009

4.2 CMST Acoustic Surveys

Presence of the following species was confirmed by the acoustic surveys (McCauley 2009):

- Humpback whale.
- Pygmy blue whale.
- Minke whale - recorded as “dwarf minke”.
- Bryde’s” whale.

The following information was also reported:

- Pygmy blue whales were detected at the offshore site from 19 May to 17 July.
- Blue whale detections came in pulses, averaging at 4.2 ± 2.6 days apart with up to six whales calling at any point in time. Each of the individual blue whale calling bouts had instances of multiple whales calling.



- Using data collected from other loggers nearby, the seasonal trend of blue whales through the region can be established: a sharp southerly pulse of steadily swimming animals has been identified over October to December each year with a more prolonged northerly pulse between March and August.
- Six times fewer pygmy blue whale detections were collected in 2009 compared with 2006.
- Dwarf minke whale signals were present in the recording sets from the offshore site, their numbers tending to increase in late June.
- 7.3 times fewer dwarf minke whales detections were obtained in 2009 compared with the dataset collected by nearby loggers in the same season in 2006.
- Bryde's whale signals were recorded at the 43 m depth inshore site.
- Humpback whale song featured prominently in the inshore site (43 m) and at the offshore tracking site. These data will enable the counting of calling individuals within the Project Area. However, given the short time frame available for the preliminary analysis of noise logger data, the full analysis of humpback singing has not yet been completed. Once completed, a comparison between numbers of humpback whales recorded within the Project Area and regional datasets will be undertaken.
- Very little biological noise source activity in the 10 m site west of Onslow, 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 centred near 1 kHz.
- Seismic survey noise dominated the offshore site the entire duration of the recording period.
- Vessel noise was also prevalent, particularly at the offshore site.
- Humpback signals were largely obscured at the offshore site by seismic survey or vessel noise, and partly obscured at the inshore 43 m site by seismic noise.

The noise logger study did not detect any dolphins despite the aerial survey having recorded dolphins in proximity to the noise loggers deployed in the nearshore. Possible reasons include:

- Calls or clicks may not yet have been found in the data.

- The short listening range for the loggers, short range of mid-high frequency sounds and low densities of dolphins meant the probability of detection was low (i.e. need for longer listening periods).
- The loggers were not located in preferred dolphin habitat.
- Dolphins were not using echolocation.



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5.0 DISCUSSION AND CONCLUSIONS

This section discusses the significance of survey findings for marine mammal species found within the Project Area. Emphasis has been placed on those species whose presence has been confirmed by the surveys, those likely to have high conservation status and those with higher susceptibility to potential impacts from aspects of the Wheatstone Project.

5.1 Baleen Whales (Mysticeti)

5.1.1 Humpback Whale

To date, a total of 1,221 humpback whales have been reported by the aerial surveys. Humpback whales were recorded in the Project Area from mid-June onwards (Jenner and Jenner 2009).

Full season data from aerial and acoustic surveys are expected to further clarify aspects of spatial distribution in the Project Area. Once acoustic data processing is complete, it is anticipated that information on the passage of whales through the Project Area and counts of whales will be available, with potential for comparison with other regional datasets (McCauley 2009).

5.1.1.1 Northbound Migration

The acoustic survey data showed humpback whales occurring in a range of depths within the Project Area, with calls recorded both offshore around the 200 m depth contour (near Wheatstone, ~19°52'S, 115°16"E) and in 43 m deep shelf waters (near Onslow, 21°25'S, 114°50"E) (McCauley 2009). The aerial surveys indicated that, generally, whales were located further offshore during the northbound migration than the southbound migration. On average, whales travelled approximately 50 km offshore when northbound and 35 km offshore when southbound (Jenner and Jenner 2009).

The survey recorded a relatively high proportion of whales presumed to be milling or resting, as opposed to migrating, which was unexpected. Previous studies of the nearby North West Cape area demonstrated that typically 80-100% of whales are northbound in June-August (Jenner and Jenner 2009). During the two July flights in this survey, only 28% and 9% of humpback whales were recorded as heading northwards whilst 22% and 48% were milling / resting (Jenner and Jenner 2009).

Three females with calves of the year were recorded in the Project Area during aerial surveys in late July 2009 (Jenner and Jenner 2009). Opportunistic observations of cows with very young and new born calves were recorded by RPS during a marine turtle survey in the first week of August 2009 (Appendix 4). Although this was during the generalised northbound migration period, it is unknown what stage of migration these animals were at, or which habitats they had utilised for calving.



5.1.1.2 Peak Abundance

Aerial surveys confirm that the humpback whale abundance in the Project Area peaks in late August, during the cross-over between northern and southern migrations. Aerial surveys also showed that the mean distance (55.6 km from shore) of humpback whale pods from shore during peak levels was greater than that observed during the northbound and southbound migration. It is believed that whales spread over a much wider area and depth range to minimise mating competition (Jenner and Jenner 2009).

5.1.1.3 Southern Migration

The southern migration has been reported to start in mid-August to early September, with peak numbers of cow-calf pairs following a few weeks later in early October (Jenner and Jenner, 2005). Increasing numbers of resting and milling whales were recorded during the surveys, which confirm that the southern migration is a slower migration, with whales resting on their southward route. The surveys also confirmed that the southbound migration occurs closer to the coast, with a migration corridor centred around 36 km offshore, and cow-calf pods found in highest numbers inside the 50 m depth contour.

5.1.1.4 Conclusions

The area offshore of Onslow is transited by humpback whales as part of their migration pathway on both their south and north bound journeys; this is likely to overlap with proposed offshore pipeline and shipping routes. The migratory path is wide; the mean distance of humpbacks from shore was 50 km when northbound and 35 km when southbound.

The data shows that only a small proportion of whales venture into shallow waters where the majority of marine infrastructure will be constructed. Cows and calves predominantly rest when inshore of the 50 m isobath (Jenner and Jenner 2009), with some whales, including cows and calves, recorded in water less than 10 m deep during the latter part of the migration. Although observations indicated that some calves may be born and/or suckled in the Project Area, the data do not indicate that the area has the same importance for resting or calving that Exmouth Gulf or Camden Sound have.

Humpback whales should be considered a key species for the nearshore and offshore development activities.

5.1.2 **Blue Whale**

The 2009 CMST acoustic survey has detected pygmy blue whales at the deep water site (near the gas fields) from 19 May to 17 July. These are believed to be northbound whales returning to low latitudes after spending summers feeding in temperate waters. Blue whales are known to undertake winter migration through the Project Area (Jenner 2008).

Survey data has confirmed that blue whale migration occurs in deep waters offshore and over the continental shelf edge between March and August (northward) and October and December (southward).

The time integrated count of individual calling pygmy blue whales from the deep water site from a nearby dataset 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. It is not yet known why this season recorded fewer whales.

5.1.2.1 Conclusions

The data suggest that blue whales only transit through deep waters surrounding the gas field site in fairly low numbers from May to August when northbound, and October to January when southbound. They should be considered in management plans for construction and operational activities near the gas field.

5.1.3 **Minke Whale**

The Project Area falls within the minke whale's northern most range in WA, so it can be expected that these highly mobile animals may be present at times throughout the year. The survey data collected has supported this.

The noise logger survey indicated that dwarf minke whales were present in the Project Area between April 2009 to July 2009, with a greater number detected between June 2009 and July 2009 at the offshore site (McCauley 2009). Seven times fewer dwarf minke whale detections were made in 2009 than 2006 at the offshore site. The cause for these patterns is unknown. The CWR aerial surveys detected a single minke at approximately the 650 m isobath on the continental slope, which is an area of seasonal upwelling (DEWHA, 2008).

5.1.3.1 Conclusions

The data suggest that minke whales transit through oceanic waters in low numbers and should be considered in management plans for construction and operational activities near the gas field.

5.1.4 **Antarctic Minke Whale**

This species was not recorded by the field surveys and is unlikely to be present within the Project Area due to its preference for cold waters.



5.1.5 Bryde's Whale

It is expected that Bryde's whales may be found in deep waters offshore and over the continental shelf edge near the Project Area. The survey data collected has supported this. On a few occasions, Bryde's whales were detected at a distance from the 43 m noise logger site, west of Onslow (McCauley 2009). Their frequencies and densities in the area are yet to be determined by the CMST survey.

5.1.5.1 Conclusions

The data suggest that Bryde's whales transit through deep water areas around the gas field sites and over the continental shelf in low to very low numbers, so should be included in management plans for offshore activities. Right Whales (Balaenidae).

5.1.6 Southern Right Whales

This species was not listed by DEC as occurring in the Pilbara (DEC 2008) and has not been detected by the field surveys to date. The survey findings support the expectation that the species is unlikely to occur in the Project Area.

5.2 Toothed Whales (Odontoceti)

5.2.1 Sperm Whales

As there is a generalised southward movement of this whale species during summer, it is expected that sperm whales may migrate through deeper waters past the Project Area in these warmer months. The sperm whale was detected by the aerial survey, while the pygmy sperm whale was not detected by either survey.

A pod of 10 sperm whales was recorded on the 830 m isobath by the aerial survey. This is consistent with reports that waters of the inner edge of the Exmouth Plateau, around the Montebello trough, may be an important feeding site for sperm whales (DEWHA 2008).

5.2.1.1 Conclusions

The data suggests that sperm whales sometimes occur in the deep oceanic waters surrounding the gas field site, possibly when foraging or transiting between foraging areas. They should be considered in management plans for construction and operational activities near the gas field, particularly for loud noise-generating activities.

5.2.2 Beaked Whales

It can be expected that beaked whales may be present in deep offshore waters of the Project Area. However, no species of beaked whale was recorded by the aerial or acoustic surveys. This lack of survey record may be due to survey limitations. In particular, beaked whales are difficult to record from aerial surveys as they dive for 40-50 minutes and only surface for a very short period of time. They are also difficult to distinguish from the air.

5.2.2.1 Conclusions

It is possible that beaked whales are present in the deep oceanic waters but in small numbers only. They should be considered in management plans for construction and operational activities near the gas field, particularly for loud noise-generating activities.

5.2.3 “True” Dolphins (Delphinidae)

5.2.3.1 Offshore Dolphin Species

It is expected that a range of highly mobile deep water dolphins may utilise the offshore waters of the Project Area at any time. The aerial surveys supported this by reporting a number of delphinid species.

A pod of 25 pilot whales was recorded on the 450 m isobath on the continental slope. (Jenner and Jenner 2009). As described in Section 2.3.3.3, this species may be attracted to the upper and middle parts of the continental slope that have important demersal fish and squid communities (DEWHA, 2008).

There was one sighting of killer whales recorded during the aerial surveys. A pod of five killer whales was recorded in waters 400 m deep in November 2009, close to a humpback whale pair, presumed to be travelling southwards. As suggested by Corkeron and Connor (1999), killer whale movements are largely linked to those of smaller marine mammals which they prey upon. It is likely that killer whales move into this area at certain times of the year in predatory pursuit of humpback whale calves (Jenner, C., pers. comm.).

A pod of up to 12 dolphins (unidentified species) was recorded by the aerial survey in waters of approximately 550 m depth (Jenner and Jenner 2009) on the upper slopes of the North West Province. While this sighting was not identified to species level, according to vessel-based observations, species present in the area included *Stenella* species.

5.2.3.2 Conclusions

Several species of delphinids are likely to be present in deep water areas around the gas field sites and over the continental shelf in low to moderate numbers, so should be included in management plans for offshore activities.



5.2.3.3 Coastal Dolphin Species

Most dolphins recorded during the aerial surveys were in the coastal area, inside the 50 m isobath. To date, the noise loggers have been unable to detect these species. The altitude at which the aerial surveys were flown was too high to positively identify dolphins to the species level. However, it is inferred that the Indo Pacific humpback dolphin and both species of bottlenose dolphins were present, based on other vessel-based anecdotal observations (Jenner and Jenner 2009).

It can be expected that these coastal dolphin species may be present in shallow and nearshore waters of the Project Area at any time. All three coastal species typically occur in low numbers and are widely dispersed. It is likely that the Indo Pacific humpback dolphin will move between different shallow water estuaries and inlets along the coast.

5.2.3.4 Conclusions

Dolphins utilising nearshore habitats or foraging areas will have the highest sensitivity to habitat modification because it is in the coastal area where most of the proposed marine development will occur. They are more susceptible to population fragmentation and displacement than the larger deep water species. Indo Pacific humpback dolphins and spotted bottlenose dolphins should be given special consideration in the impact assessment process and prescription of management measures for the Wheatstone Project.

5.3 **Dugongs**

Dugongs were consistently sighted throughout the aerial surveys, at times with calves, and the majority of the recordings were in water less than 10 m deep. Areas of higher densities of dugong to the north-east and to the south-west of the Project Area were recorded (Jenner and Jenner 2009). However, data showed that dugongs did occur within areas proposed for marine infrastructure. Migratory patterns for dugongs in this area are largely unknown.

5.3.1.1 Conclusions

The area does not appear to have the same importance for dugongs that Exmouth Gulf or Shark Bay does, but dugongs are likely to be present in the nearshore area throughout the year, particularly the area to the north west of the onshore development area. It remains unclear whether they are resident or migratory, or a mixture of the two. The habitat surveys show that adequate quantities of seagrass meadows are present in the nearshore area to support some dugongs and that foraging probably occurs, although this activity was not recorded. The data also show that calves are present, albeit in small numbers. It remains unclear whether all key life processes of feeding, mating, calving and weaning occur in this area.



Due to their presence in nearshore waters, dugongs could be susceptible to habitat modification or loss and to population fragmentation. Therefore, they should be given special consideration in the impact assessment process and prescription of management measures for the Wheatstone Project.



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APPENDIX I

EPBC Protected Matters Search Result



Australian Government
Department of the Environment, Water, Heritage and the Arts

Protected Matters Search Tool

You are here: [Environment Home](#) > [EPBC Act](#) > [Search](#)

12 March 2009 16:57

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected. Information on the coverage of this report and qualifications on data supporting this report are contained in the [caveat](#) at the end of the report.

You may wish to print this report for reference before moving to other pages or websites.

The Australian Natural Resources Atlas at <http://www.environment.gov.au/atlas> may provide further environmental information relevant to your selected area. Information about the EPBC Act including significance guidelines, forms and application process details can be found at <http://www.environment.gov.au/epbc/assessmentsapprovals/index.html>

Search Type: Area
Buffer: 0 km
Coordinates: -19.66539,115.251396, -
19.665389,115.418067, -
19.967446,115.42094, -
20.410189,115.019762, -
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21.4672,114.873185, -
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21.744606,115.107734, -
22.041884,115.507474, -
22.110925,115.445, -
21.755568,114.934635, -
21.548847,114.788454, -
21.180021,114.744029, -
20.813927,114.817559, -
20.373661,114.932018, -
19.959858,115.251373



This map may contain data which are
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- Report Contents:** [Summary](#)
[Details](#)
- [Matters of NES](#)
 - [Other matters protected by the EPBC Act](#)

- [Extra Information](#)
- [Caveat](#)
- [Acknowledgments](#)

Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance - see

<http://www.environment.gov.au/epbc/assessmentsapprovals/guidelines/index.html>.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Significance: (Ramsar Sites)	None
<u>Commonwealth Marine Areas:</u>	Relevant
Threatened Ecological Communities:	None
<u>Threatened Species:</u>	12
<u>Migratory Species:</u>	30

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place and the heritage values of a place on the Register of the National Estate. Information on the new heritage laws can be found at <http://www.environment.gov.au/heritage/index.html>.

Please note that the current dataset on Commonwealth land is not complete. Further information on Commonwealth land would need to be obtained from relevant sources including Commonwealth agencies, local agencies, and land tenure maps.

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species. Information on EPBC Act permit requirements and application forms can be found at <http://www.environment.gov.au/epbc/permits/index.html>.

<u>Commonwealth Lands:</u>	1
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Commonwealth Heritage Places:	None
Places on the RNE:	1
Listed Marine Species:	67
Whales and Other Cetaceans:	27
Critical Habitats:	None
Commonwealth Reserves:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	1
Other Commonwealth Reserves:	None
Regional Forest Agreements:	None

Details

Matters of National Environmental Significance

Commonwealth Marine Areas [[Dataset Information](#)]

Approval may be required for a proposed activity that is likely to have a significant impact on the environment in a Commonwealth Marine Area, when the action is outside the Commonwealth Marine Area, or the environment anywhere when the action is taken within the Commonwealth Marine Area. Generally the Commonwealth Marine Area stretches from three nautical miles to two hundred nautical miles from the coast.

EEZ and Territorial Sea

Threatened Species [[Dataset Information](#)] Status Type of Presence

Birds

[Macronectes giganteus](#)
Southern Giant-Petrel Endangered Species or species habitat may occur within area

Mammals

[Balaenoptera musculus](#)
Blue Whale Endangered Species or species habitat may occur within area

[Dasyercus cristicauda](#)
Mulgara Vulnerable Species or species habitat likely to occur within area

[Eubalaena australis](#)
Southern Right Whale Endangered Species or species habitat may occur within area

[Megaptera novaeangliae](#)
Humpback Whale Vulnerable Congregation or aggregation known to occur within area

[Rhinonictoris aurantius \(Pilbara form\)](#)
Pilbara Leaf-nosed Bat Vulnerable Species or species habitat likely to occur within area

Reptiles

[Caretta caretta](#)
Loggerhead Turtle Endangered Species or species habitat may occur within area

Chelonia mydas Green Turtle	Vulnerable	Species or species habitat may occur within area
Dermochelys coriacea Leathery Turtle, Leatherback Turtle	Endangered	Species or species habitat may occur within area
Eretmochelys imbricata Hawksbill Turtle	Vulnerable	Species or species habitat may occur within area
Natator depressus Flatback Turtle	Vulnerable	Species or species habitat may occur within area
Sharks		
Rhincodon typus Whale Shark	Vulnerable	Species or species habitat may occur within area
Migratory Species [Dataset Information]	Status	Type of Presence
Migratory Terrestrial Species		
Birds		
Haliaeetus leucogaster White-bellied Sea-Eagle	Migratory	Breeding known to occur within area
Hirundo rustica Barn Swallow	Migratory	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater	Migratory	Species or species habitat may occur within area
Migratory Wetland Species		
Birds		
Ardea alba Great Egret, White Egret	Migratory	Species or species habitat may occur within area
Ardea ibis Cattle Egret	Migratory	Species or species habitat may occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel	Migratory	Species or species habitat may occur within area
Glareola maldivarum Oriental Pratincole	Migratory	Species or species habitat may occur within area
Numenius minutus Little Curlew, Little Whimbrel	Migratory	Species or species habitat may occur within area
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift	Migratory	Species or species habitat may occur within area
Ardea alba Great Egret, White Egret	Migratory	Species or species habitat may occur within area
Ardea ibis Cattle Egret	Migratory	Species or species habitat may occur within area
Macronectes giganteus Southern Giant-Petrel	Migratory	Species or species habitat may occur within area
Sterna anaethetus Bridled Tern	Migratory	Breeding known to occur within area
Sterna caspia Caspian Tern	Migratory	Breeding known to occur within area
Migratory Marine Species		

Mammals

<i>Balaenoptera bonaerensis</i> Antarctic Minke Whale, Dark-shoulder Minke Whale	Migratory	Species or species habitat may occur within area
<i>Balaenoptera edeni</i> Bryde's Whale	Migratory	Species or species habitat may occur within area
<i>Balaenoptera musculus</i> Blue Whale	Migratory	Species or species habitat may occur within area
<i>Dugong dugon</i> Dugong	Migratory	Species or species habitat likely to occur within area
<i>Eubalaena australis</i> Southern Right Whale	Migratory	Species or species habitat may occur within area
<i>Megaptera novaeangliae</i> Humpback Whale	Migratory	Congregation or aggregation known to occur within area
<i>Orcinus orca</i> Killer Whale, Orca	Migratory	Species or species habitat may occur within area
<i>Physeter macrocephalus</i> Sperm Whale	Migratory	Species or species habitat may occur within area
<i>Sousa chinensis</i> Indo-Pacific Humpback Dolphin	Migratory	Species or species habitat may occur within area
<i>Tursiops aduncus (Arafura/Timor Sea populations)</i> Spotted Bottlenose Dolphin (Arafura/Timor Sea populations)	Migratory	Species or species habitat likely to occur within area

Reptiles

<i>Caretta caretta</i> Loggerhead Turtle	Migratory	Species or species habitat may occur within area
<i>Chelonia mydas</i> Green Turtle	Migratory	Species or species habitat may occur within area
<i>Dermochelys coriacea</i> Leathery Turtle, Leatherback Turtle	Migratory	Species or species habitat may occur within area
<i>Eretmochelys imbricata</i> Hawksbill Turtle	Migratory	Species or species habitat may occur within area
<i>Natator depressus</i> Flatback Turtle	Migratory	Species or species habitat may occur within area

Sharks

<i>Rhincodon typus</i> Whale Shark	Migratory	Species or species habitat may occur within area
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Other Matters Protected by the EPBC Act

Listed Marine Species [[Dataset Information](#)] Status Type of Presence

Birds

<i>Apus pacificus</i> Fork-tailed Swift	Listed - overfly marine area	Species or species habitat may occur within area
<i>Ardea alba</i> Great Egret, White Egret	Listed - overfly marine	Species or species habitat may occur within area

	area	
Ardea ibis Cattle Egret	Listed - overfly marine area	Species or species habitat may occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel	Listed - overfly marine area	Species or species habitat may occur within area
Glareola maldivarum Oriental Pratincole	Listed - overfly marine area	Species or species habitat may occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle	Listed	Breeding known to occur within area
Hirundo rustica Barn Swallow	Listed - overfly marine area	Species or species habitat may occur within area
Larus novaehollandiae Silver Gull	Listed	Breeding known to occur within area
Macronectes giganteus Southern Giant-Petrel	Listed	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater	Listed - overfly marine area	Species or species habitat may occur within area
Numenius minutus Little Curlew, Little Whimbrel	Listed - overfly marine area	Species or species habitat may occur within area
Sterna anaethetus Bridled Tern	Listed	Breeding known to occur within area
Sterna caspia Caspian Tern	Listed	Breeding known to occur within area
Mammals		
Dugong dugon Dugong	Listed	Species or species habitat likely to occur within area
Ray-finned fishes		
Acentronura larsonae Helen's Pygmy Pipehorse	Listed	Species or species habitat may occur within area
Bulbonaricus brauni Braun's Pughead Pipefish, Pug-headed Pipefish	Listed	Species or species habitat may occur within area
Campichthys tricarinatus Three-keel Pipefish	Listed	Species or species habitat may occur within area
Choeroichthys brachysoma Pacific Short-bodied Pipefish, Short-bodied Pipefish	Listed	Species or species habitat may occur within area

<i>Choeroichthys latispinosus</i> Muiron Island Pipefish	Listed	Species or species habitat may occur within area
<i>Choeroichthys suillus</i> Pig-snouted Pipefish	Listed	Species or species habitat may occur within area
<i>Corythoichthys flavofasciatus</i> Yellow-banded Pipefish, Network Pipefish	Listed	Species or species habitat may occur within area
<i>Cosmocampus banneri</i> Roughridge Pipefish	Listed	Species or species habitat may occur within area
<i>Doryrhamphus dactyliophorus</i> Ringed Pipefish	Listed	Species or species habitat may occur within area
<i>Doryrhamphus excisus</i> Indian Blue-stripe Pipefish, Blue-stripe Pipefish	Listed	Species or species habitat may occur within area
<i>Doryrhamphus janssi</i> Cleaner Pipefish, Janss' Pipefish	Listed	Species or species habitat may occur within area
<i>Doryrhamphus multiannulatus</i> Many-banded Pipefish	Listed	Species or species habitat may occur within area
<i>Doryrhamphus negrosensis</i> Flagtail Pipefish, Negros Pipefish	Listed	Species or species habitat may occur within area
<i>Festucalex scalaris</i> Ladder Pipefish	Listed	Species or species habitat may occur within area
<i>Filicampus tigris</i> Tiger Pipefish	Listed	Species or species habitat may occur within area
<i>Halicampus brocki</i> Brock's Pipefish	Listed	Species or species habitat may occur within area
<i>Halicampus grayi</i> Mud Pipefish, Gray's Pipefish	Listed	Species or species habitat may occur within area
<i>Halicampus nitidus</i> Glittering Pipefish	Listed	Species or species habitat may occur within area
<i>Halicampus spinostris</i> Spiny-snout Pipefish	Listed	Species or species habitat may occur within area
<i>Haliichthys taeniophorus</i> Ribbioned Seadragon, Ribbioned Pipefish	Listed	Species or species habitat may occur within area
<i>Hippichthys penicillus</i> Beady Pipefish, Steep-nosed Pipefish	Listed	Species or species habitat may occur within area
<i>Hippocampus angustus</i> Western Spiny Seahorse, Narrow-bellied Seahorse	Listed	Species or species habitat may occur within area
<i>Hippocampus histrix</i> Spiny Seahorse	Listed	Species or species habitat may occur within area
<i>Hippocampus kuda</i> Spotted Seahorse, Yellow Seahorse	Listed	Species or species habitat may occur within area
<i>Hippocampus planifrons</i> Flat-face Seahorse	Listed	Species or species habitat may occur within area
<i>Hippocampus spinosissimus</i> Hedgehog Seahorse	Listed	Species or species habitat may occur within area
<i>Micrognathus micronotus</i> Tidepool Pipefish	Listed	Species or species habitat may occur within area

<i>Phoxocampus belcheri</i> Rock Pipefish	Listed	Species or species habitat may occur within area
<i>Solegnathus hardwickii</i> Pipehorse	Listed	Species or species habitat may occur within area
<i>Solegnathus lettiensis</i> Indonesian Pipefish, Gunther's Pipehorse	Listed	Species or species habitat may occur within area
<i>Solenostomus cyanopterus</i> Blue-finned Ghost Pipefish, Robust Ghost Pipefish	Listed	Species or species habitat may occur within area
<i>Syngnathoides biaculeatus</i> Double-ended Pipehorse, Alligator Pipefish	Listed	Species or species habitat may occur within area
<i>Trachyrhamphus bicoarctatus</i> Bend Stick Pipefish, Short-tailed Pipefish	Listed	Species or species habitat may occur within area
<i>Trachyrhamphus longirostris</i> Long-nosed Pipefish, Straight Stick Pipefish	Listed	Species or species habitat may occur within area
Reptiles		
<i>Acalyptophis peronii</i> Horned Seasnake	Listed	Species or species habitat may occur within area
<i>Aipysurus apraefrontalis</i> Short-nosed Seasnake	Listed	Species or species habitat may occur within area
<i>Aipysurus duboisii</i> Dubois' Seasnake	Listed	Species or species habitat may occur within area
<i>Aipysurus eydouxii</i> Spine-tailed Seasnake	Listed	Species or species habitat may occur within area
<i>Aipysurus laevis</i> Olive Seasnake	Listed	Species or species habitat may occur within area
<i>Astrotia stokesii</i> Stokes' Seasnake	Listed	Species or species habitat may occur within area
<i>Caretta caretta</i> Loggerhead Turtle	Listed	Species or species habitat may occur within area
<i>Chelonia mydas</i> Green Turtle	Listed	Species or species habitat may occur within area
<i>Dermochelys coriacea</i> Leathery Turtle, Leatherback Turtle	Listed	Species or species habitat may occur within area
<i>Disteira kingii</i> Spectacled Seasnake	Listed	Species or species habitat may occur within area
<i>Disteira major</i> Olive-headed Seasnake	Listed	Species or species habitat may occur within area
<i>Emydocephalus annulatus</i> Turtle-headed Seasnake	Listed	Species or species habitat may occur within area
<i>Ephalophis greyi</i> North-western Mangrove Seasnake	Listed	Species or species habitat may occur within area
<i>Eretmochelys imbricata</i> Hawksbill Turtle	Listed	Species or species habitat may occur within area
<i>Hydrophis czeblukovi</i> Fine-spined Seasnake	Listed	Species or species habitat may occur within area
<i>Hydrophis elegans</i>	Listed	Species or species habitat may occur

Elegant Seasnake		within area
Hydrophis ornatus a seasnake	Listed	Species or species habitat may occur within area
Natator depressus Flatback Turtle	Listed	Species or species habitat may occur within area
Pelamis platurus Yellow-bellied Seasnake	Listed	Species or species habitat may occur within area
Whales and Other Cetaceans [Dataset Information]	Status	Type of Presence
Balaenoptera acutorostrata Minke Whale	Cetacean	Species or species habitat may occur within area
Balaenoptera bonaerensis Antarctic Minke Whale, Dark-shoulder Minke Whale	Cetacean	Species or species habitat may occur within area
Balaenoptera edeni Bryde's Whale	Cetacean	Species or species habitat may occur within area
Balaenoptera musculus Blue Whale	Cetacean	Species or species habitat may occur within area
Delphinus delphis Common Dolphin, Short-beaked Common Dolphin	Cetacean	Species or species habitat may occur within area
Eubalaena australis Southern Right Whale	Cetacean	Species or species habitat may occur within area
Feresa attenuata Pygmy Killer Whale	Cetacean	Species or species habitat may occur within area
Globicephala macrorhynchus Short-finned Pilot Whale	Cetacean	Species or species habitat may occur within area
Grampus griseus Risso's Dolphin, Grampus	Cetacean	Species or species habitat may occur within area
Kogia breviceps Pygmy Sperm Whale	Cetacean	Species or species habitat may occur within area
Kogia simus Dwarf Sperm Whale	Cetacean	Species or species habitat may occur within area
Lagenodelphis hosei Fraser's Dolphin, Sarawak Dolphin	Cetacean	Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale	Cetacean	Congregation or aggregation known to occur within area
Mesoplodon densirostris Blainville's Beaked Whale, Dense-beaked Whale	Cetacean	Species or species habitat may occur within area
Orcinus orca Killer Whale, Orca	Cetacean	Species or species habitat may occur within area
Peponocephala electra Melon-headed Whale	Cetacean	Species or species habitat may occur within area
Physeter macrocephalus Sperm Whale	Cetacean	Species or species habitat may occur within area
Pseudorca crassidens False Killer Whale	Cetacean	Species or species habitat may occur within area

Sousa chinensis Indo-Pacific Humpback Dolphin	Cetacean	Species or species habitat may occur within area
Stenella attenuata Spotted Dolphin, Pantropical Spotted Dolphin	Cetacean	Species or species habitat may occur within area
Stenella coeruleoalba Striped Dolphin, Euphrosyne Dolphin	Cetacean	Species or species habitat may occur within area
Stenella longirostris Long-snouted Spinner Dolphin	Cetacean	Species or species habitat may occur within area
Steno bredanensis Rough-toothed Dolphin	Cetacean	Species or species habitat may occur within area
Tursiops aduncus (Arafura/Timor Sea populations) Spotted Bottlenose Dolphin (Arafura/Timor Sea populations)	Cetacean	Species or species habitat likely to occur within area
Tursiops aduncus Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin	Cetacean	Species or species habitat likely to occur within area
Tursiops truncatus s. str. Bottlenose Dolphin	Cetacean	Species or species habitat may occur within area
Ziphius cavirostris Cuvier's Beaked Whale, Goose-beaked Whale	Cetacean	Species or species habitat may occur within area
Commonwealth Lands [Dataset Information]		
Unknown		
Places on the RNE [Dataset Information]		
Note that not all Indigenous sites may be listed.		

Natural[Islands Exmouth Gulf and Rowley Shelf WA](#)**Extra Information**State and Territory Reserves [[Dataset Information](#)]

Thevenard Island Nature Reserve, WA

Caveat

The information presented in this report has been provided by a range of data sources as [acknowledged](#) at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the *Environment Protection and Biodiversity Conservation Act 1999*. It holds mapped locations of World Heritage and Register of National Estate properties, Wetlands of International Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under "type of presence". For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the [migratory](#) and [marine](#) provisions of the Act have been mapped.

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as [extinct or considered as vagrants](#)
- some species and ecological communities that have only recently been listed
- [some terrestrial species](#) that overfly the Commonwealth marine area
- migratory species that are very [widespread, vagrant, or only occur in small numbers](#).

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites;
- seals which have only been mapped for breeding sites near the Australian continent.

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Acknowledgments

This database has been compiled from a range of data sources. The Department acknowledges the following custodians who have contributed valuable data and advice:

- [New South Wales National Parks and Wildlife Service](#)
- [Department of Sustainability and Environment, Victoria](#)
- [Department of Primary Industries, Water and Environment, Tasmania](#)
- [Department of Environment and Heritage, South Australia Planning SA](#)
- [Parks and Wildlife Commission of the Northern Territory](#)
- [Environmental Protection Agency, Queensland](#)
- [Birds Australia](#)
- [Australian Bird and Bat Banding Scheme](#)
- [Australian National Wildlife Collection](#)
- Natural history museums of Australia
- [Queensland Herbarium](#)
- [National Herbarium of NSW](#)
- [Royal Botanic Gardens and National Herbarium of Victoria](#)

- [Tasmanian Herbarium](#)
- [State Herbarium of South Australia](#)
- [Northern Territory Herbarium](#)
- [Western Australian Herbarium](#)
- [Australian National Herbarium, Atherton and Canberra](#)
- [University of New England](#)
- Other groups and individuals

[ANUCLiM Version 1.8, Centre for Resource and Environmental Studies, Australian National University](#) was used extensively for the production of draft maps of species distribution.

Environment Australia is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Last updated: Thursday, 20-Nov-2008 14:17:56 EST

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Heritage and the Arts](#)

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APPENDIX 2

Description of Megafauna Distribution and Abundance (CWR Mid Study Field Report)

Field Report

A Description of Mega Fauna Distribution and Abundance in the SW Pilbara Using Aerial and Acoustic Surveys - Mid-Study December 2009



Prepared for Chevron Australia and URS by:

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January 29, 2010

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 1221 humpback whales were sighted in 17 aerial surveys over the SW Pilbara off-shore region during May to December, 2009. 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 Decemebr, 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 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 an inshore 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 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 pipeline just north of Exmouth Gulf) is of great interest to managers.

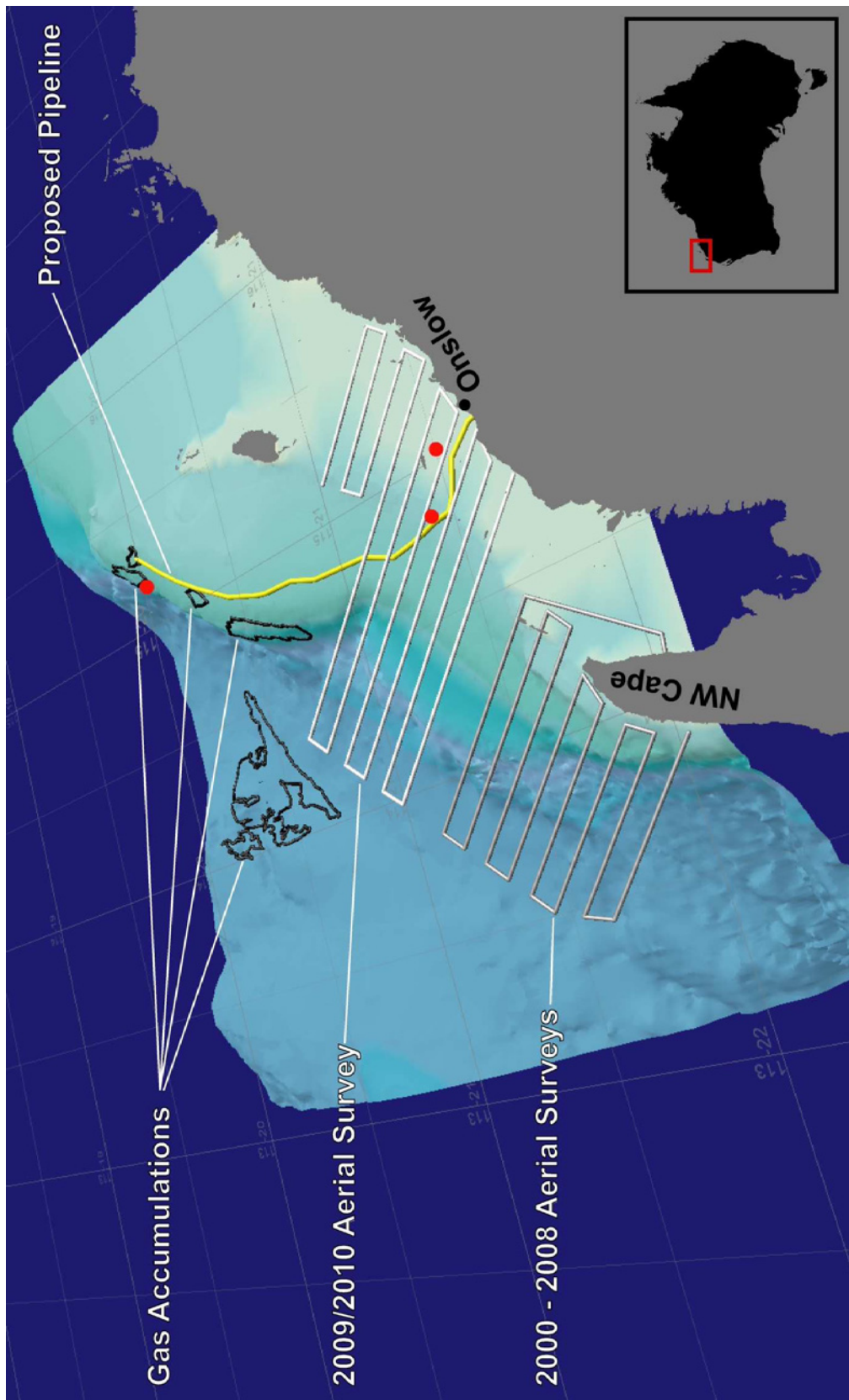


Figure 1. Aerial survey flight paths for the 2009/2010 study period showing proximity to the 2000 – 2008 CWR aerial survey flight path near NW Cape and 2009 acoustic logger positions (red dots). Continental Slope and Continental Shelf depth contours (>500m) are shades of green.

3.1 Humpback Whales at Exmouth Gulf/NW Cape

The migration of humpback whales both north and south past Exmouth Gulf follows 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 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 congregates 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).

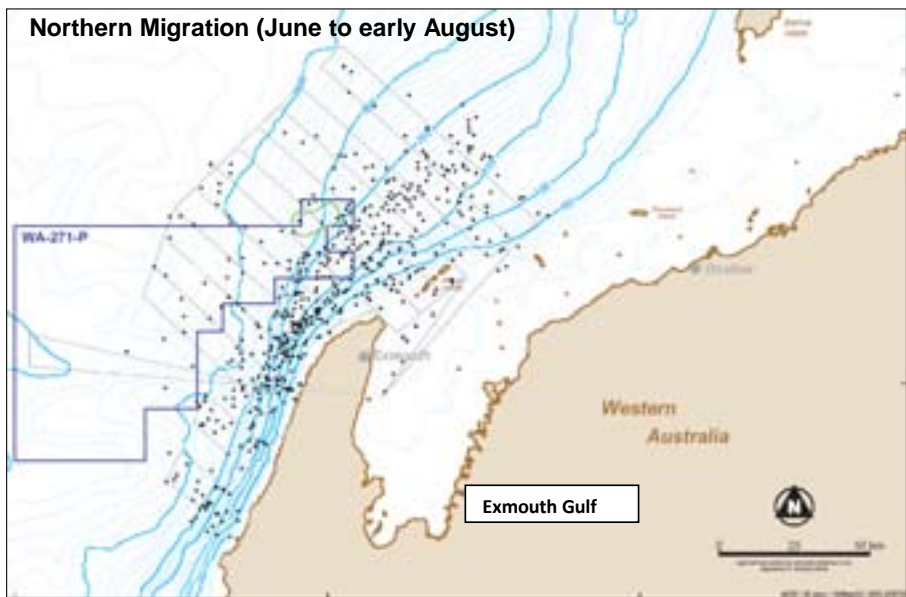


Figure 2. Aerial survey sightings of humpback whales during the northern migratory period (June to early August) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

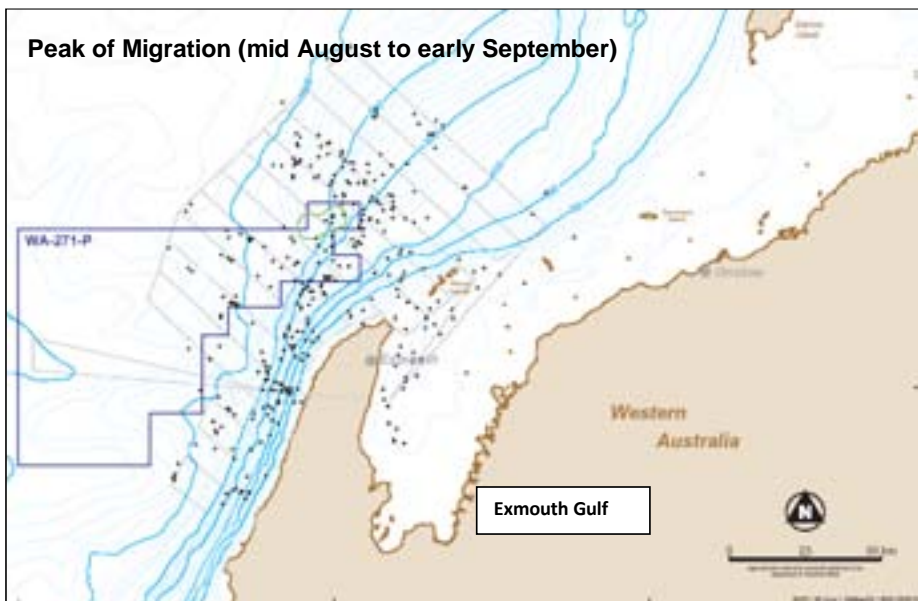


Figure 3. Aerial survey sightings of humpback whales during the Transition Phase (mid August to early September) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

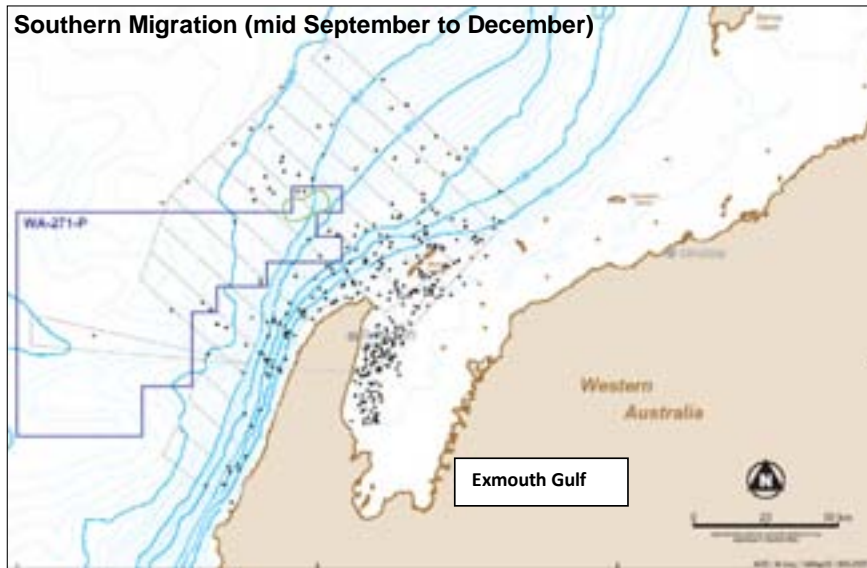


Figure 4. Aerial survey sightings of humpback whales during the southern migratory period (mid September to December) in 2000 and 2001. Data from CWR aerial surveys in Woodside Energy EIS Document (2002) section 2.3.2.5.

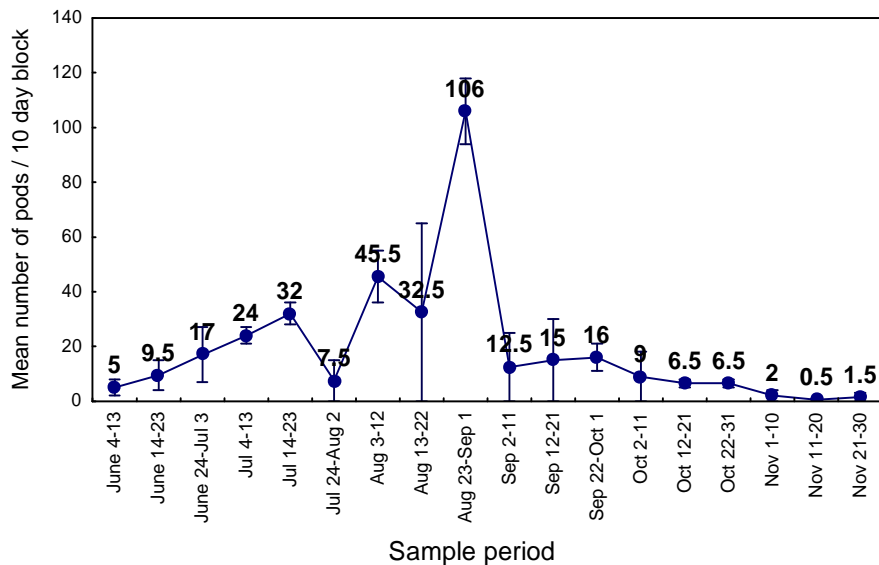


Figure 5. Mean number of humpback whale pods recorded during aerial surveys in 10 day sample blocks during the months of June to October during 2000 and 2001 ($\bar{x} \pm 1$ SE). Data from CWR aerial surveys west of, and not including, Exmouth Gulf for Woodside Energy 2000/2001, EIS document.

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).

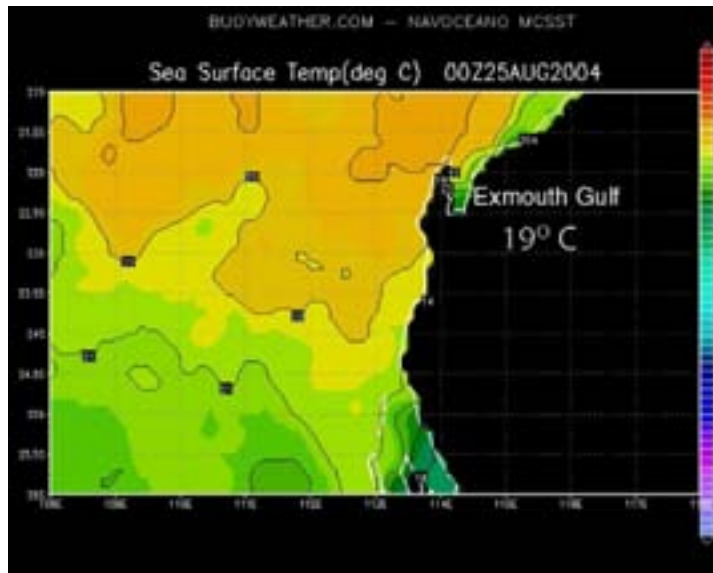


Figure 6. Sea surface temperature map for late August 2004 (during the transition phase with peak numbers of whales off-shore) showing the cooler water inside Exmouth Gulf and the inshore SW Pilbara region.

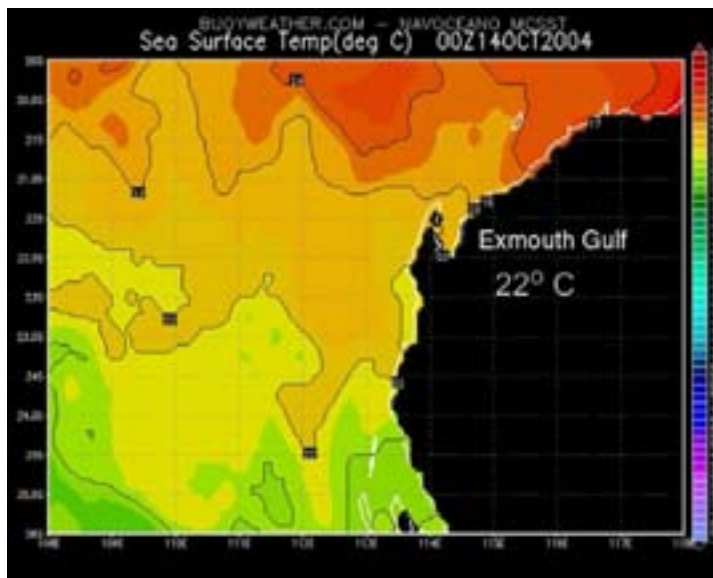


Figure 7. Sea surface temperature map for mid-October 2004 showing the increase in temperature inside Exmouth Gulf during the period when peak numbers of cow/calf pods rest in the Gulf and inshore SW Pilbara Region.

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, which has been included here as Appendix 4.

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-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 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 was one of the goals of this project.

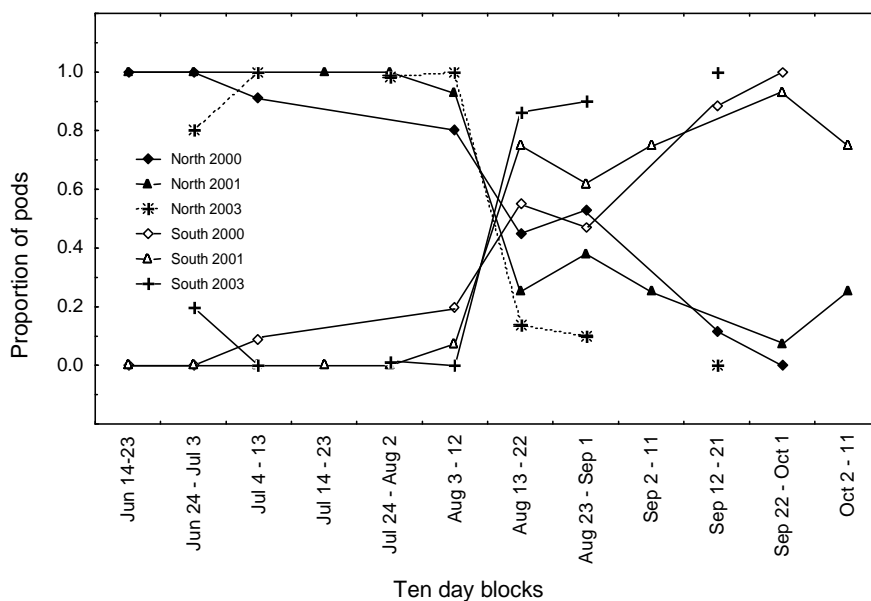


Figure 8. Migratory direction of humpback whale pods recorded during aerial surveys at NW Cape, showing June and July as a northern migration period (from Jenner *et al.*, in prep.). Non-migrating whales (i.e. resting or milling) are not plotted.

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 were 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 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 Appendix 4. 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 seventeen flights at approximately two week intervals from May 17, 2009, to December 24, 2009, totalling 119.2 survey hours over the south western Pilbara off-shore region resulted in 4491 mega fauna 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 cetacean while small cetacean sightings of pilot whales and dolphin species were also reported.

Table 1. Mega fauna 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 1). 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 during the first 6 flights of a 26 flight series.

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 6 (Figure 9).

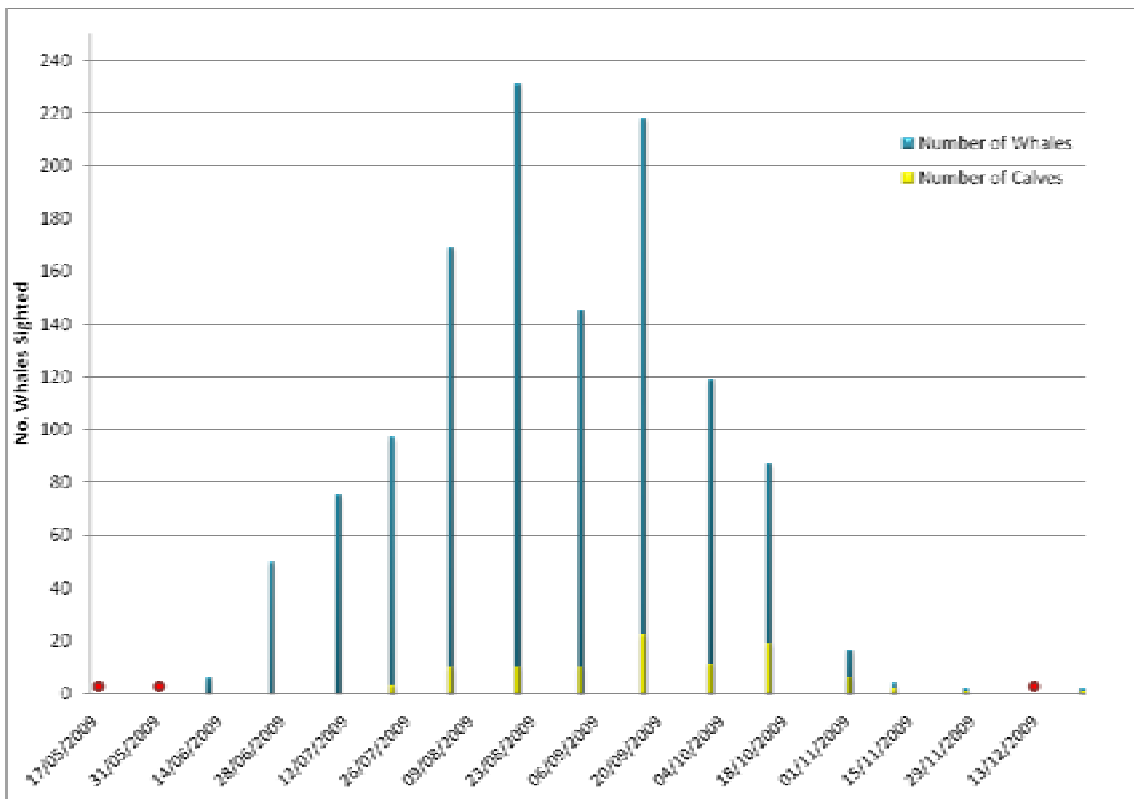


Figure 9. Numbers of humpback whales and numbers of calves sighted per flight for the first seventeen flights (red dot indicates a flight but no sightings).

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).

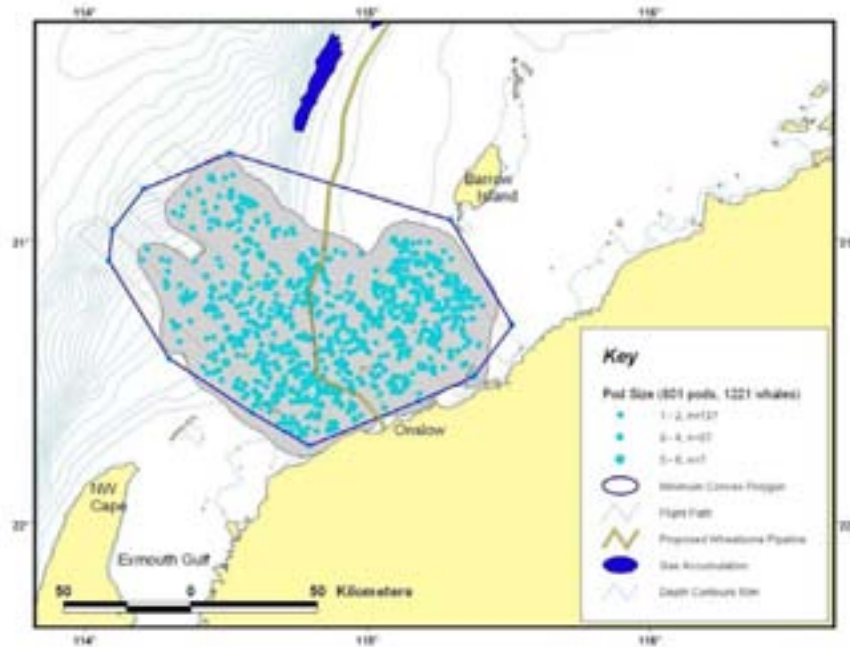


Figure 10. The Minimum Convex Polygon used to select the smoothing factor for the June to December humpback whale dataset ($h=0.056538$) and the resulting 95% kernel contour for all sightings. Positions of all pods ($n=1221$) are shown.

Maps showing ranked kernel density polygons (highest to lowest) for flights 4 to 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).

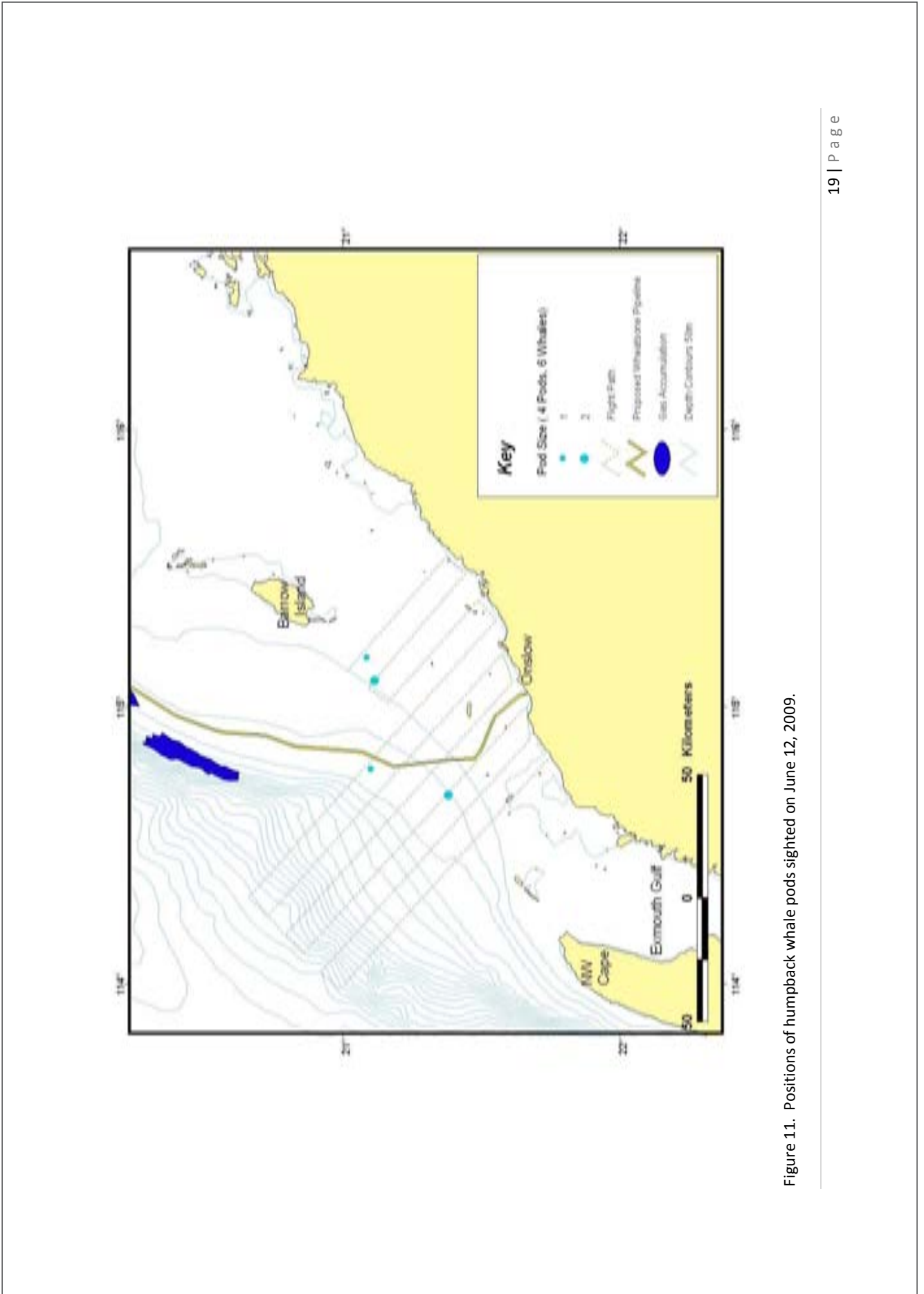


Figure 11. Positions of humpback whale pods sighted on June 12, 2009.

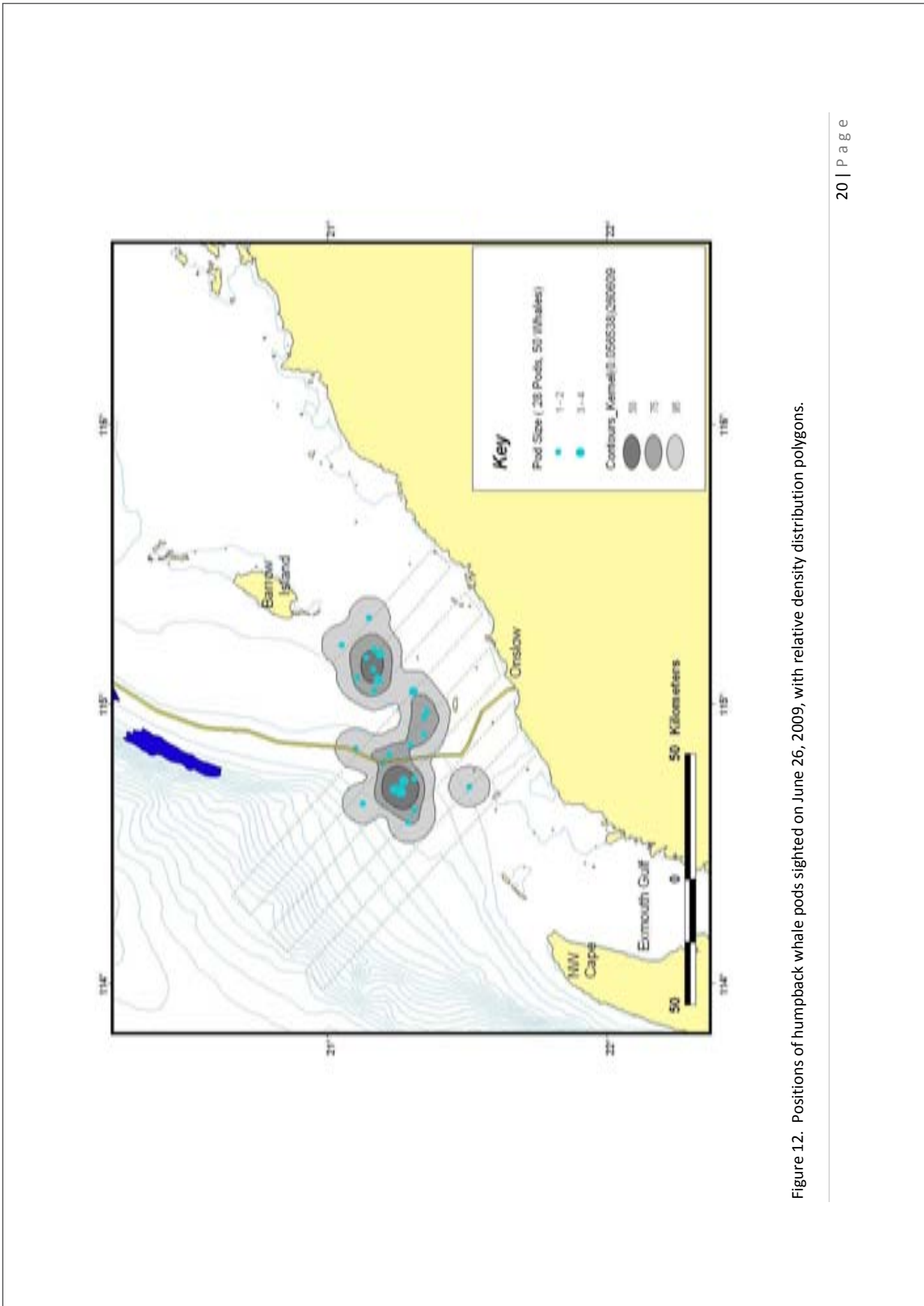


Figure 12. Positions of humpback whale pods sighted on June 26, 2009, with relative density distribution polygons.

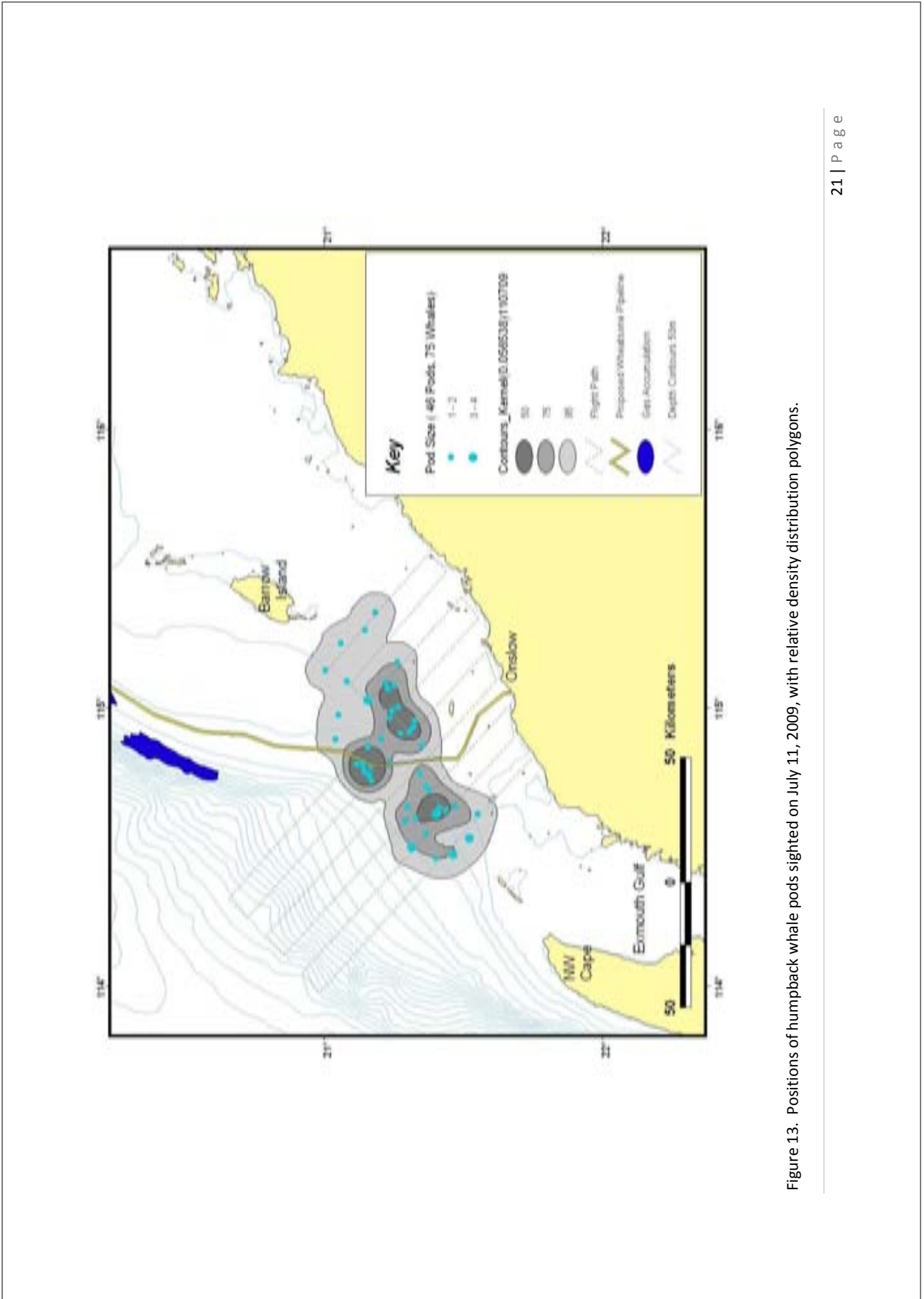


Figure 13. Positions of humpback whale pods sighted on July 11, 2009, with relative density distribution polygons.

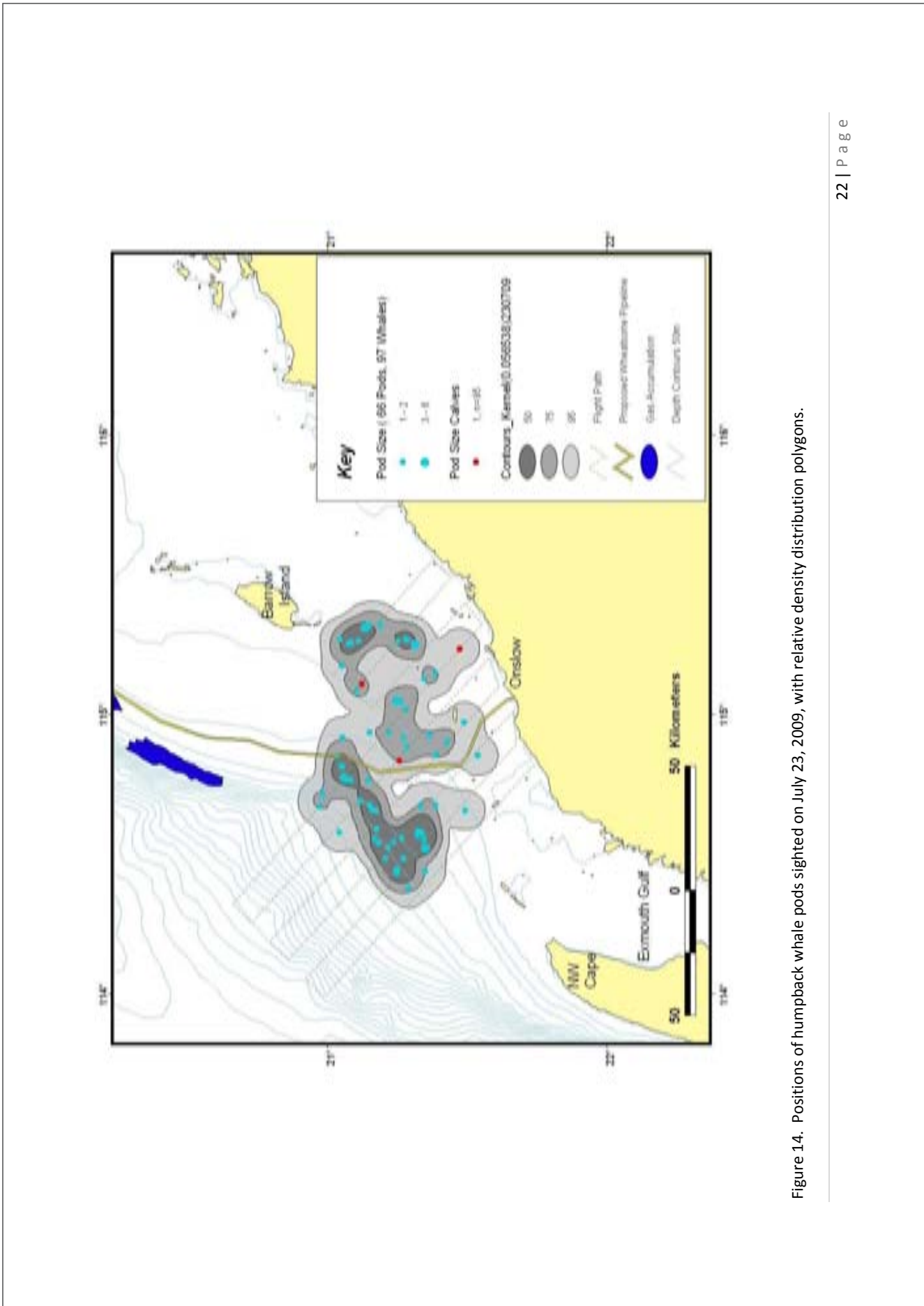


Figure 14. Positions of humpback whale pods sighted on July 23, 2009, with relative density distribution polygons.

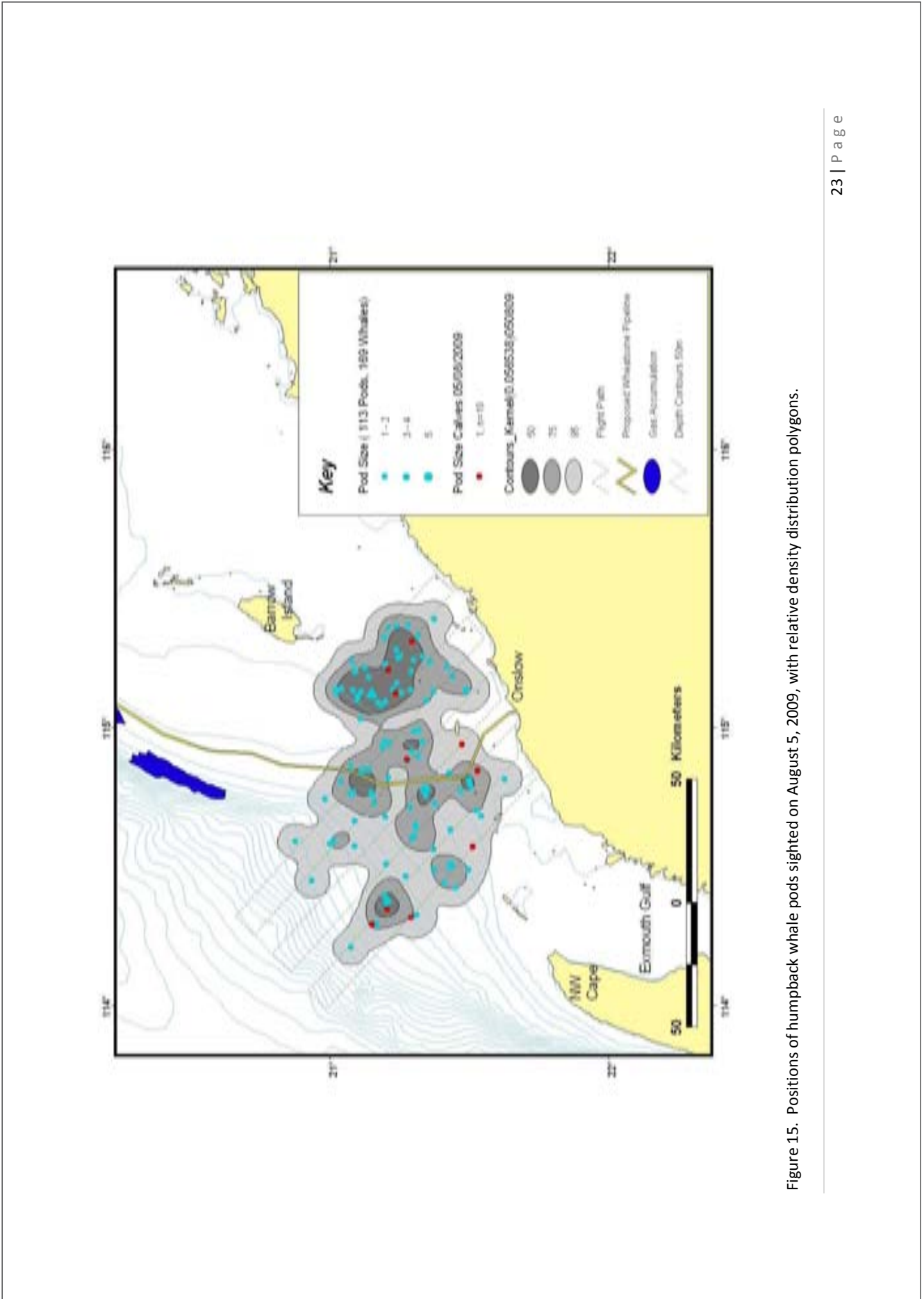


Figure 15. Positions of humpback whale pods sighted on August 5, 2009, with relative density distribution polygons.

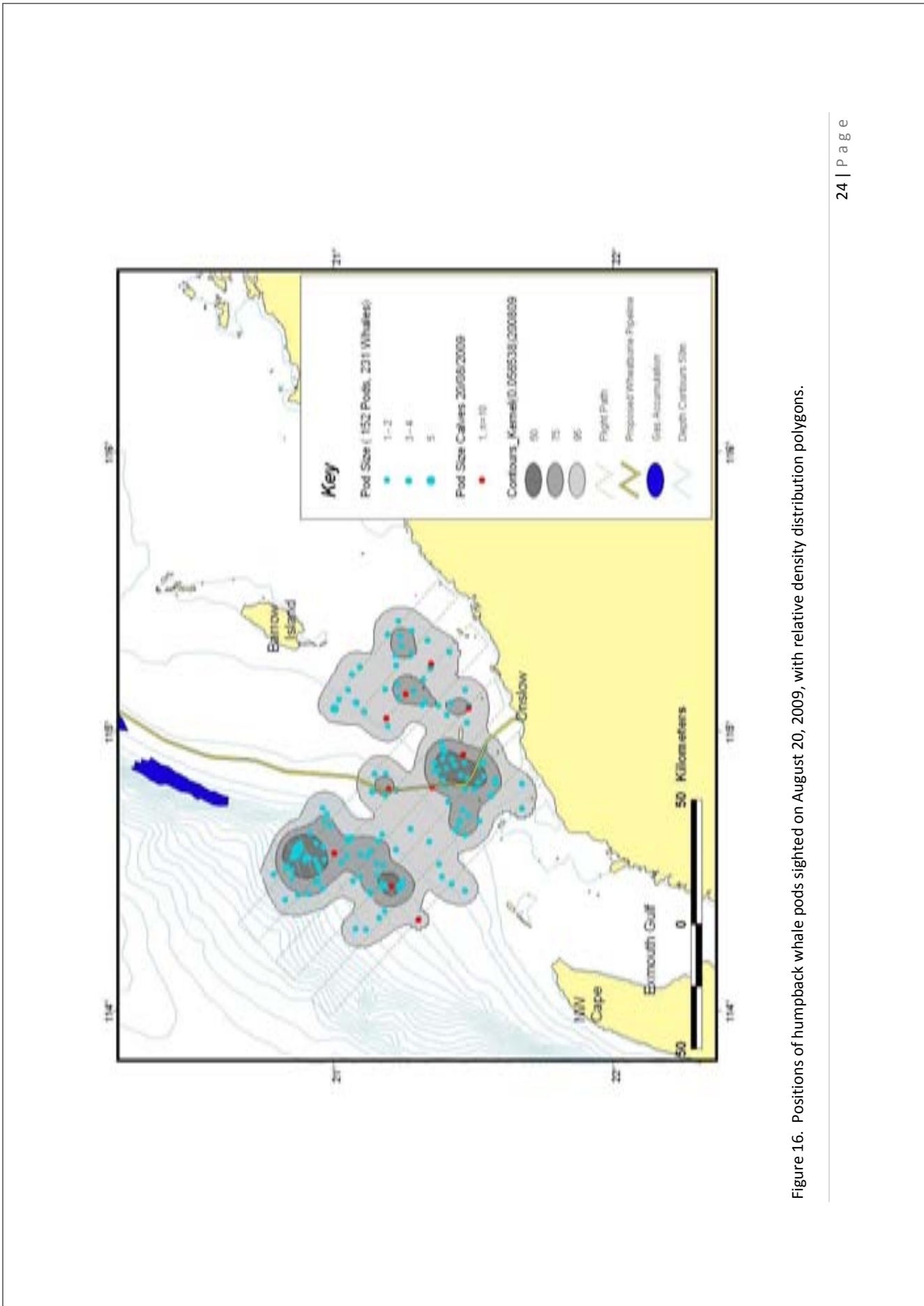


Figure 16. Positions of humpback whale pods sighted on August 20, 2009, with relative density distribution polygons.

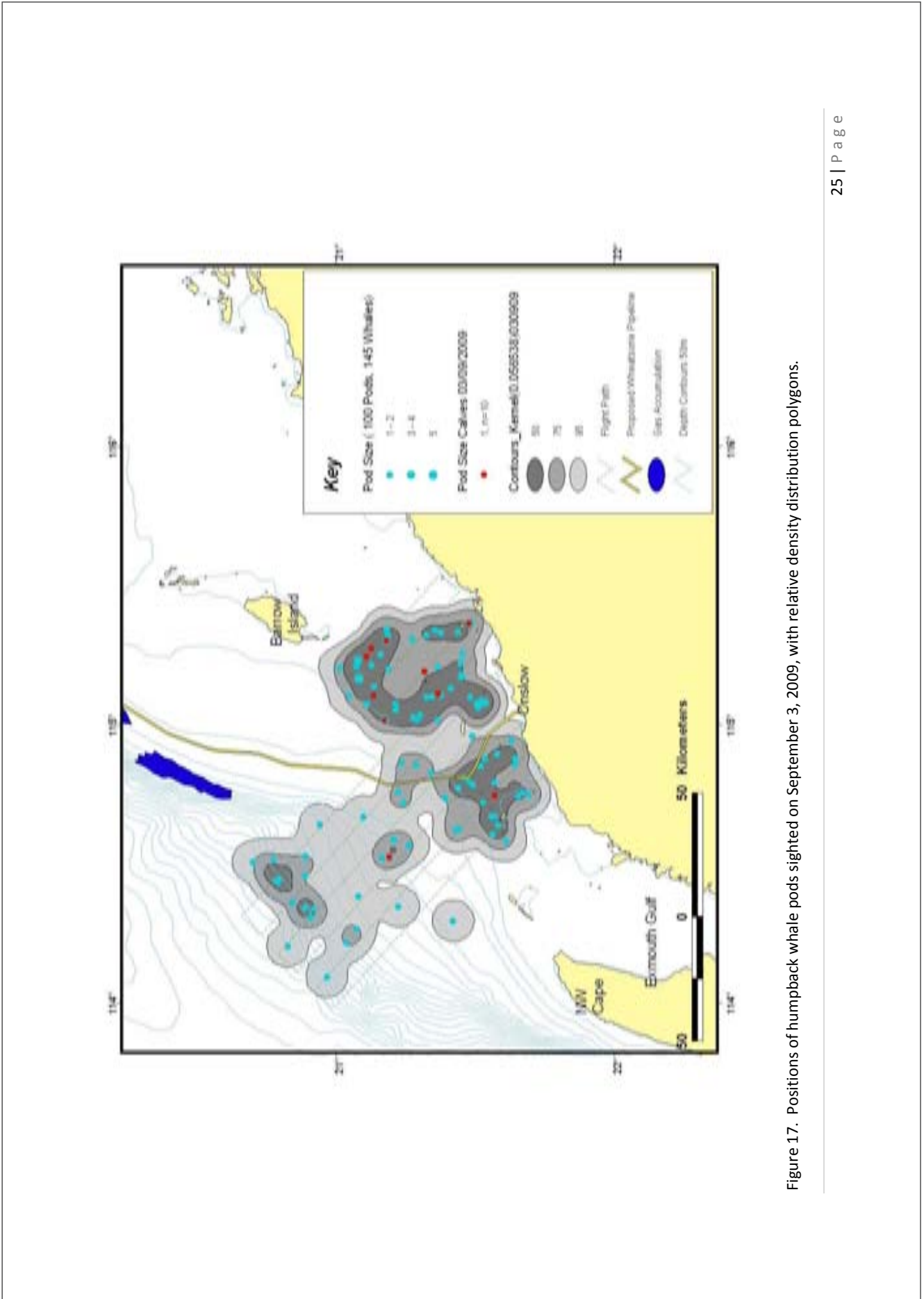


Figure 17. Positions of humpback whale pods sighted on September 3, 2009, with relative density distribution polygons.

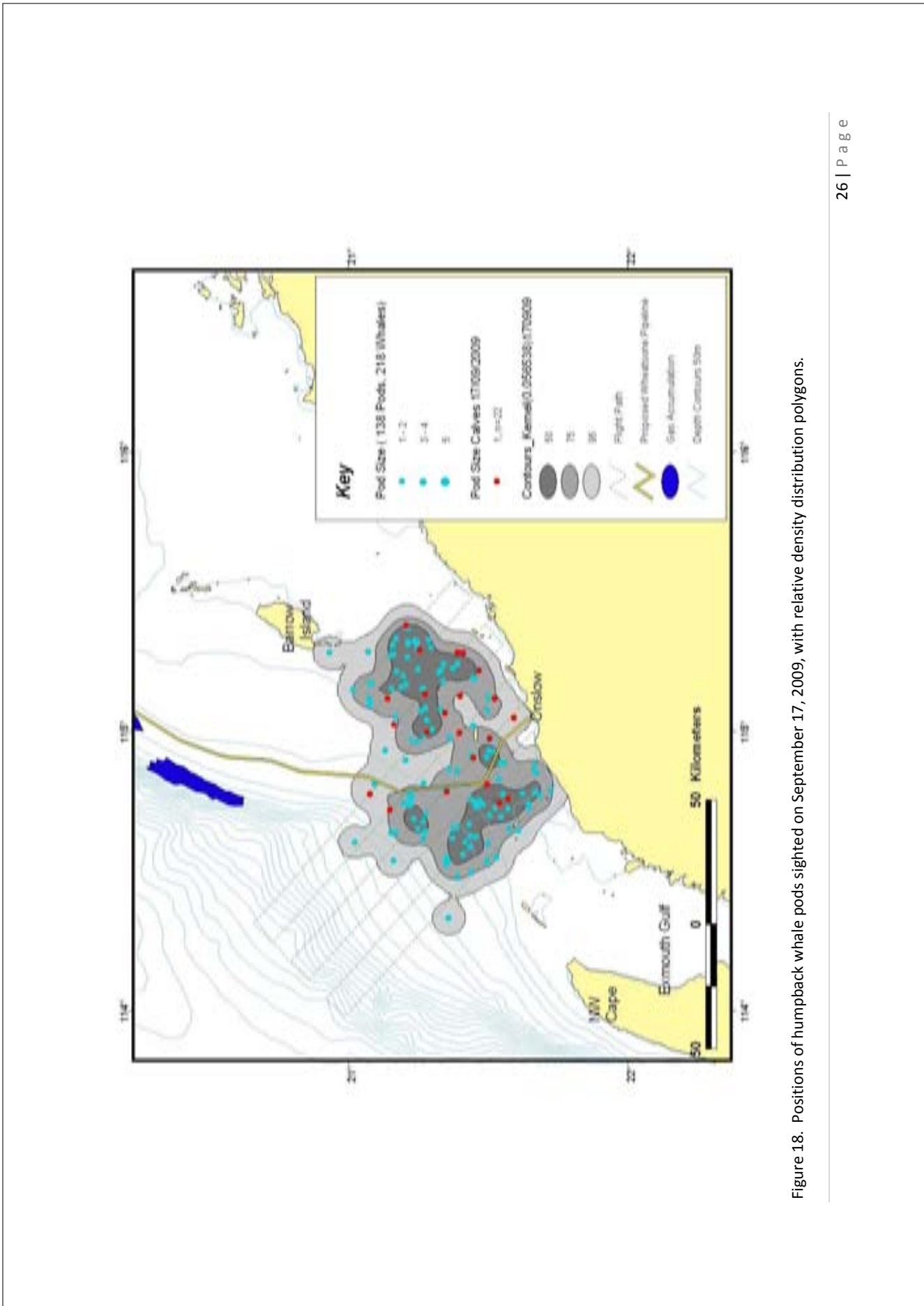


Figure 18. Positions of humpback whale pods sighted on September 17, 2009, with relative density distribution polygons.

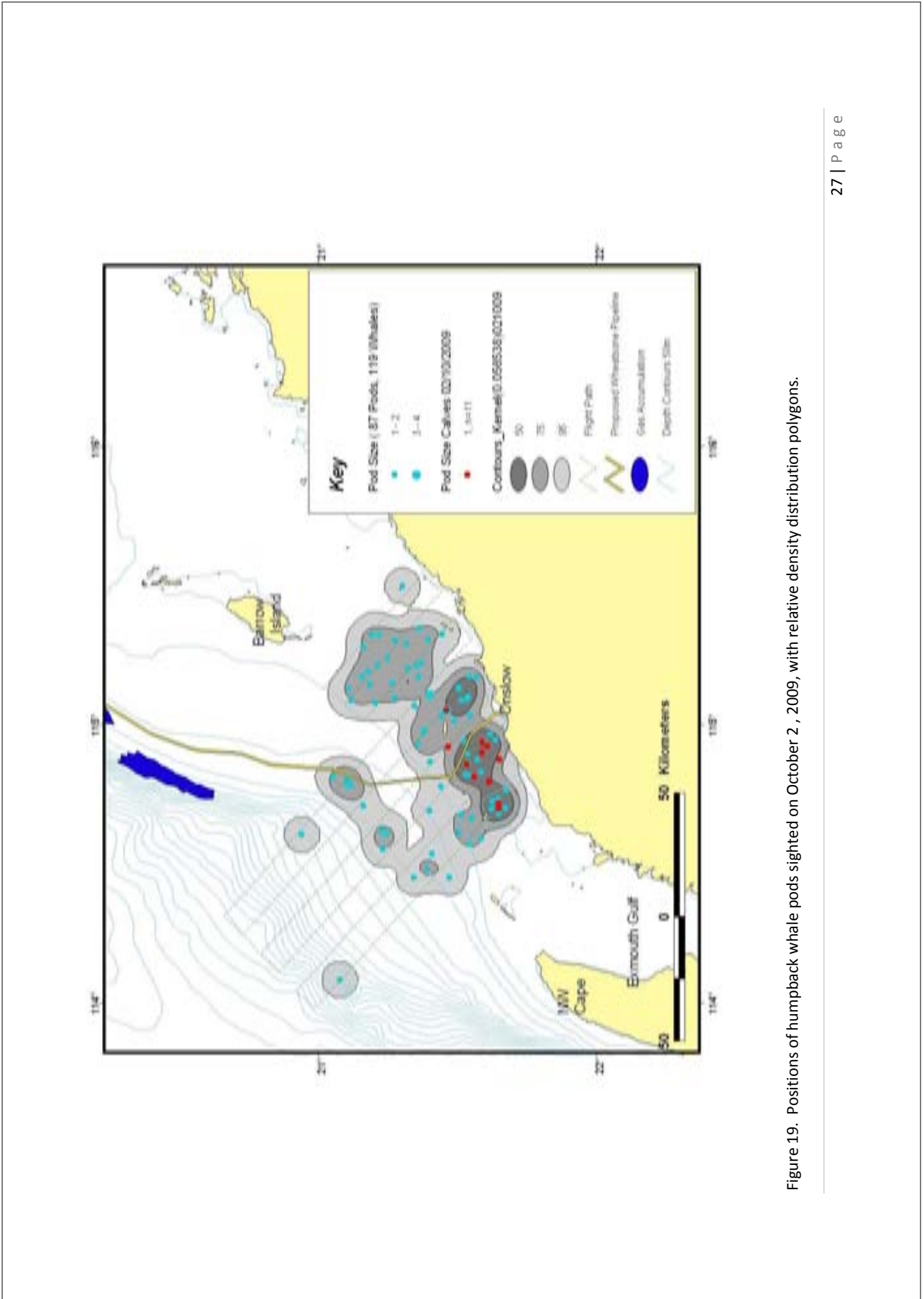


Figure 19. Positions of humpback whale pods sighted on October 2, 2009, with relative density distribution polygons.

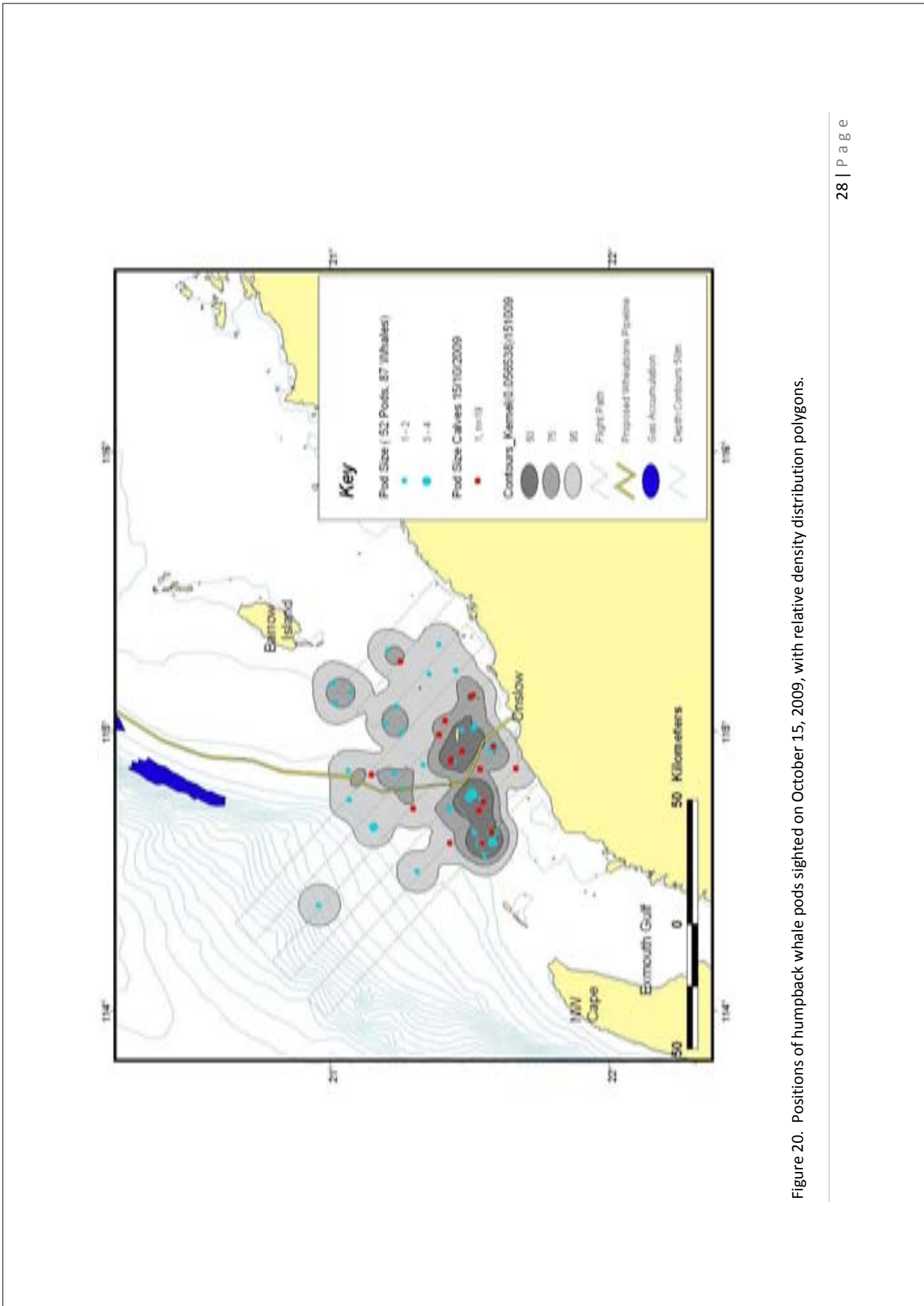


Figure 20. Positions of humpback whale pods sighted on October 15, 2009, with relative density distribution polygons.

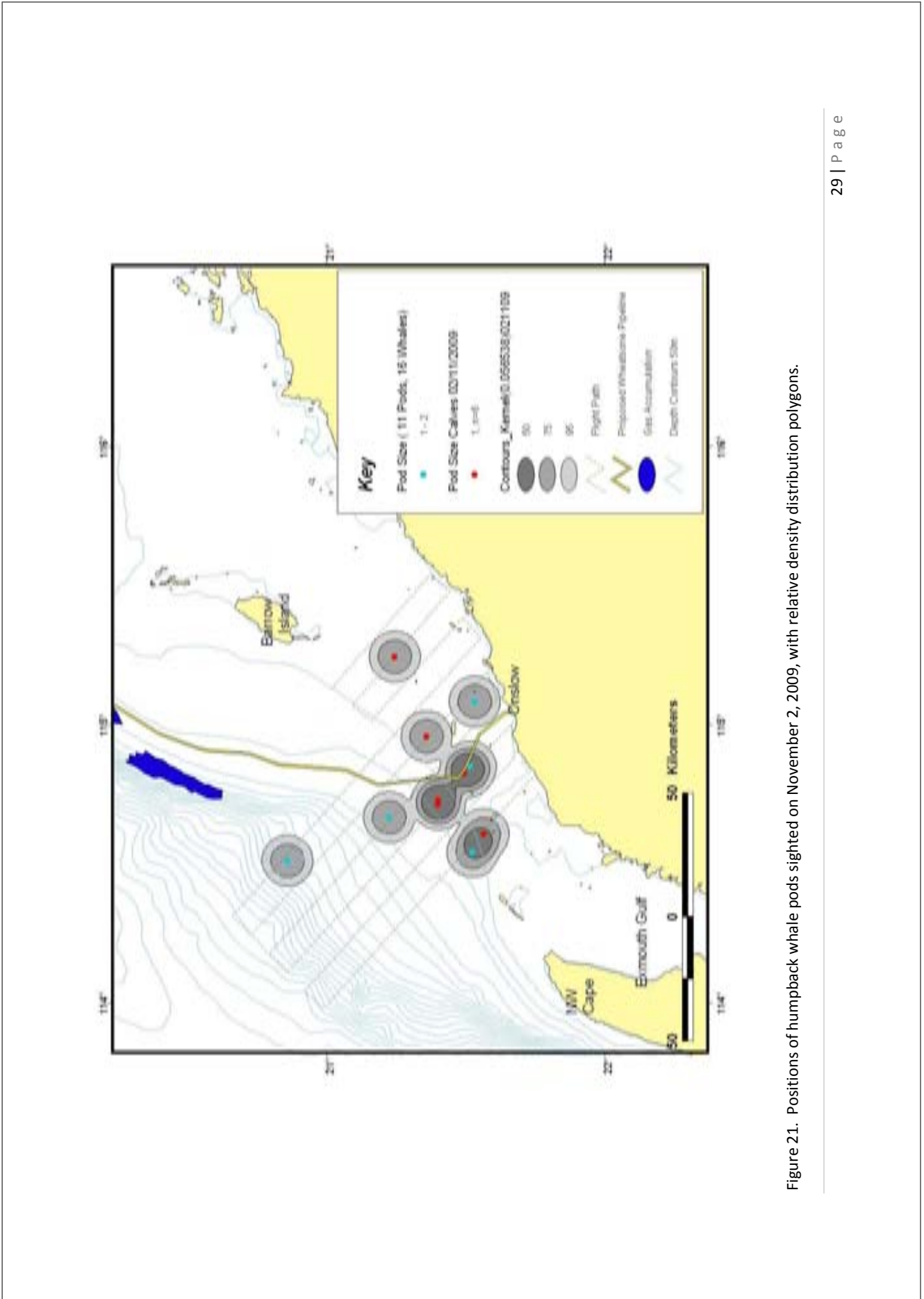


Figure 21. Positions of humpback whale pods sighted on November 2, 2009, with relative density distribution polygons.

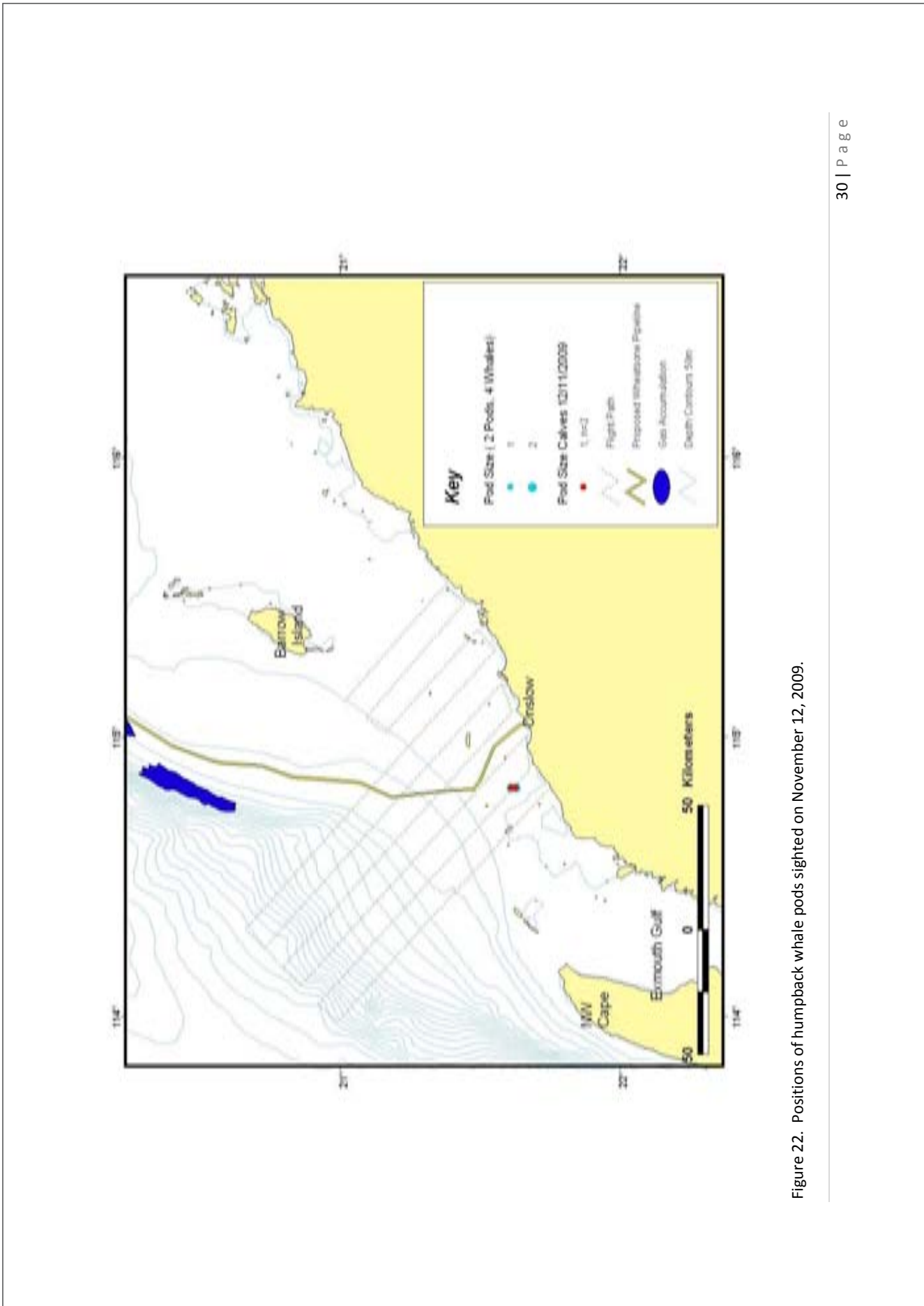


Figure 22. Positions of humpback whale pods sighted on November 12, 2009.

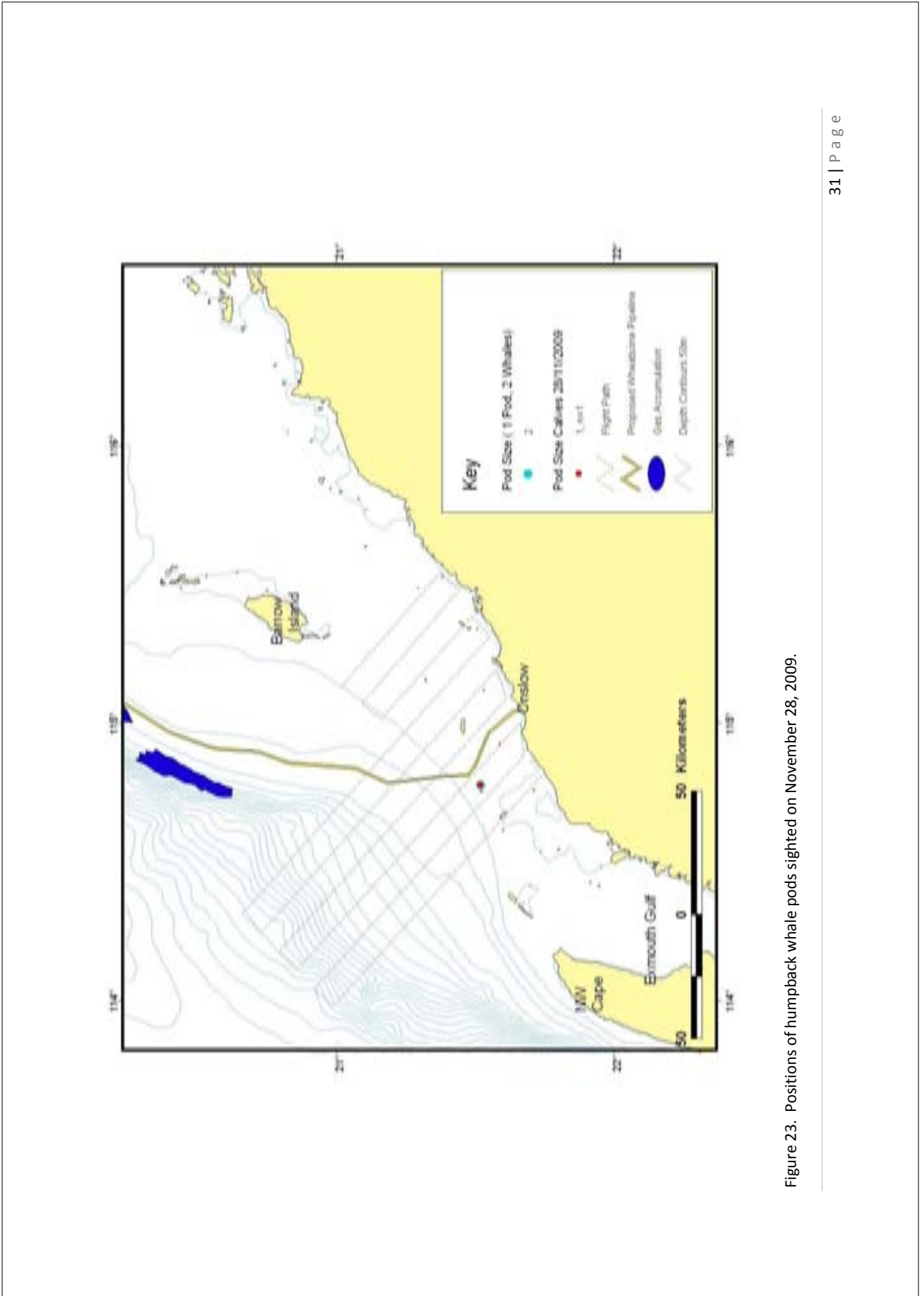


Figure 23. Positions of humpback whale pods sighted on November 28, 2009.

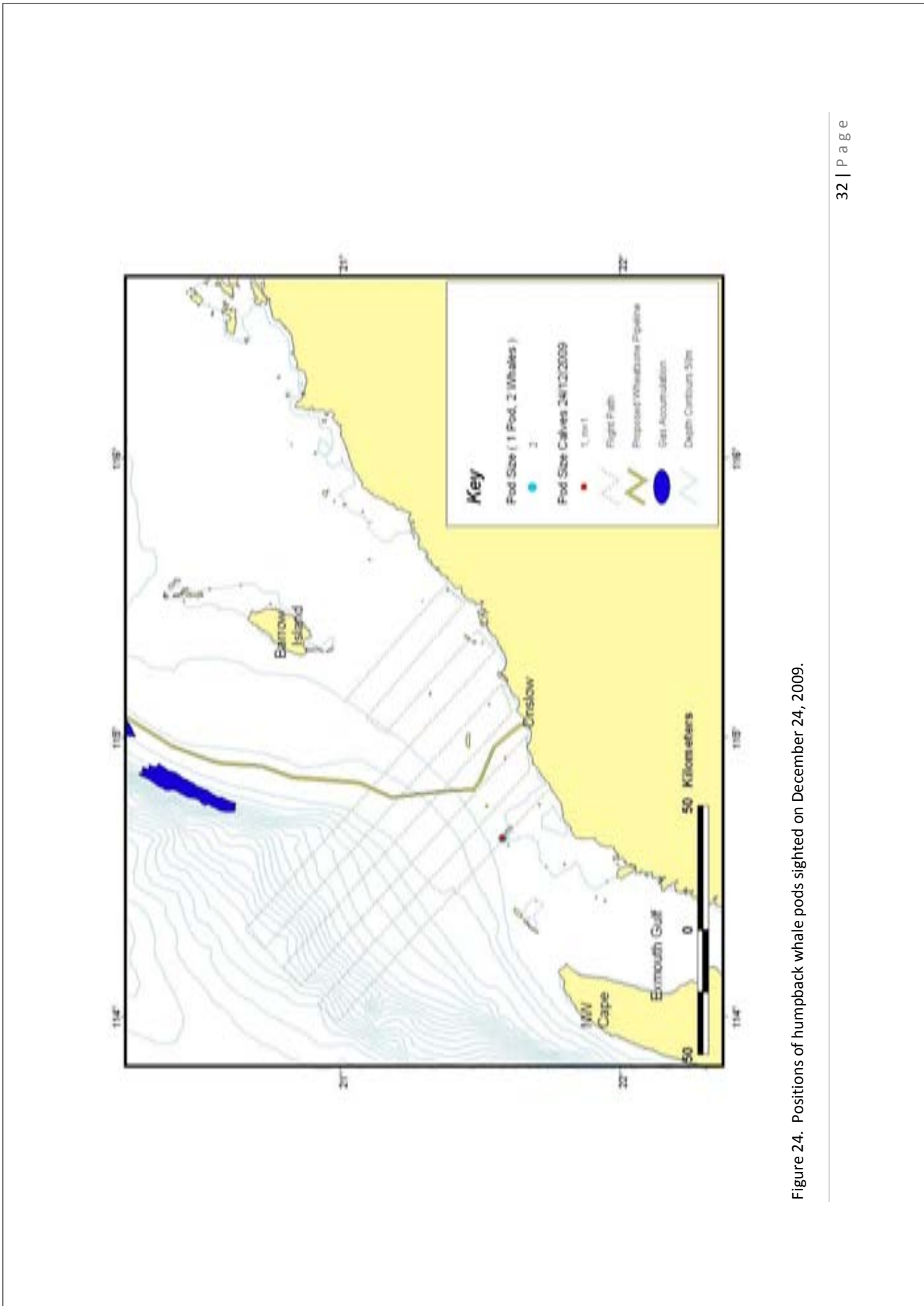


Figure 24. Positions of humpback whale pods sighted on December 24, 2009.

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.

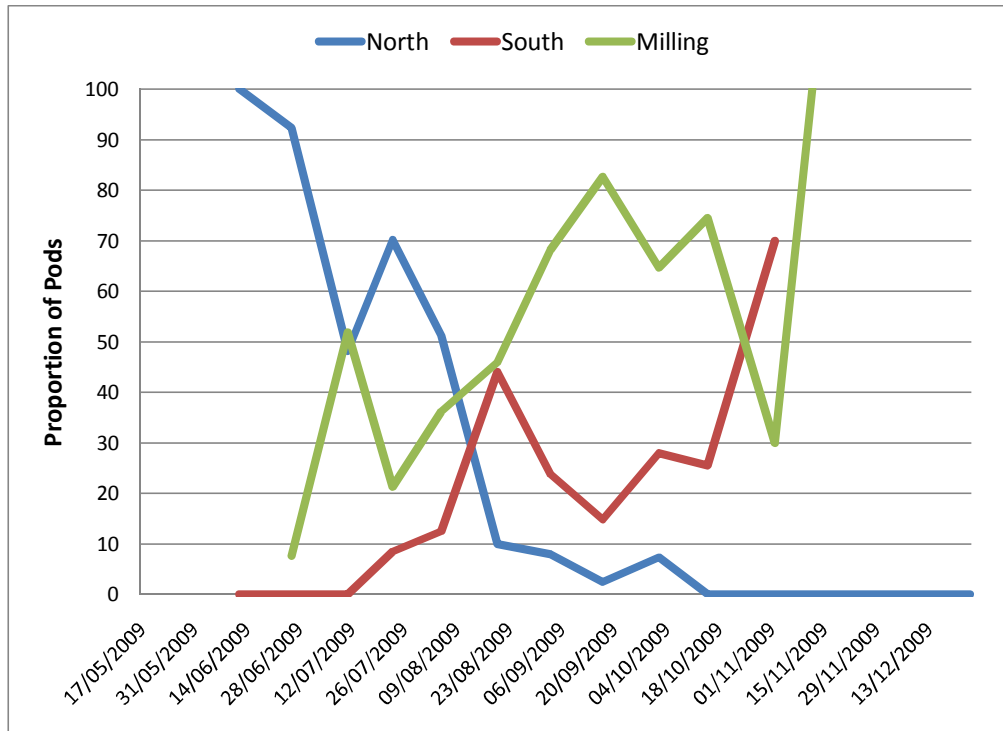


Figure 25. Proportion of humpback whale pods sighted swimming northbound, southbound or milling during the June 12 to December 24, 2009, study period.

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) off-shore while during the southern migration (after August 20, 2009) whales were an average of 35.9 km (± 1.2 , n=392) off-shore. Whales sighted on August 20, the peak of season in terms of sightings numbers, were significantly further off-shore than during the northern or southern phases (mean = 55.6 km ± 2.4 SE, n=152) (Figure 26).

Swim direction during the northern migratory phase was consistently northbound while peak of season contained approximately equal proportions of southbound and milling whales (Figures 27 and 28). The southern migration was mostly made up of milling/resting pods. (Figure 29). Cow/calf pods were also mostly resting and in less than 50m water depth (Figure 30).

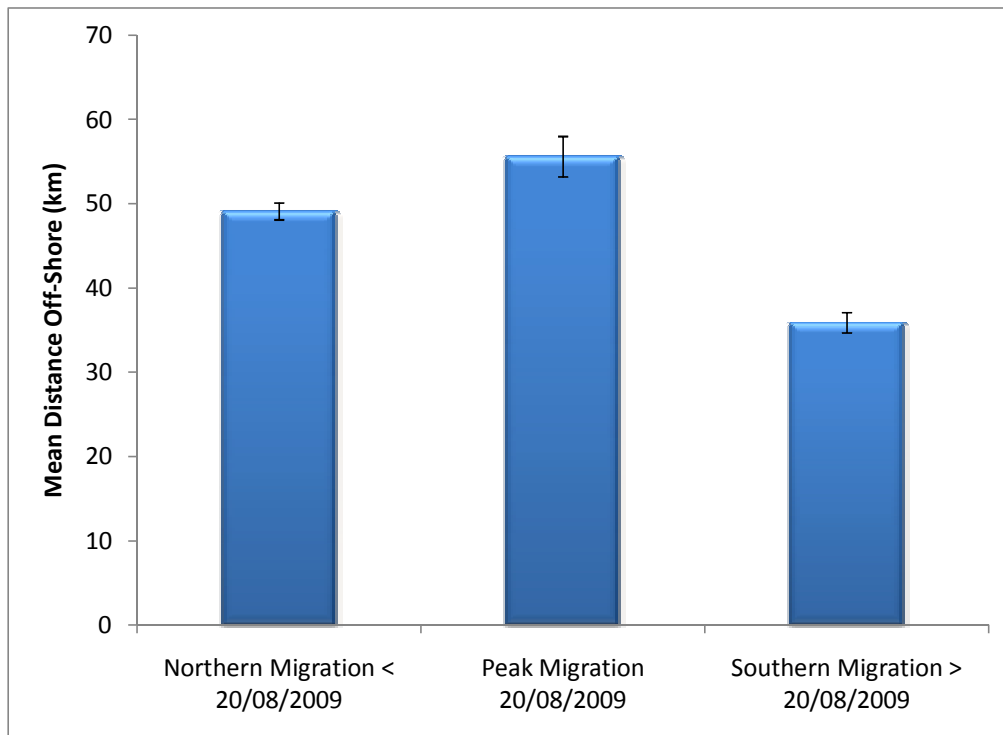


Figure 26. Results of “Spider distance” measurements from each pod to the nearest section of coastline for the northern, peak and southern migration phases.

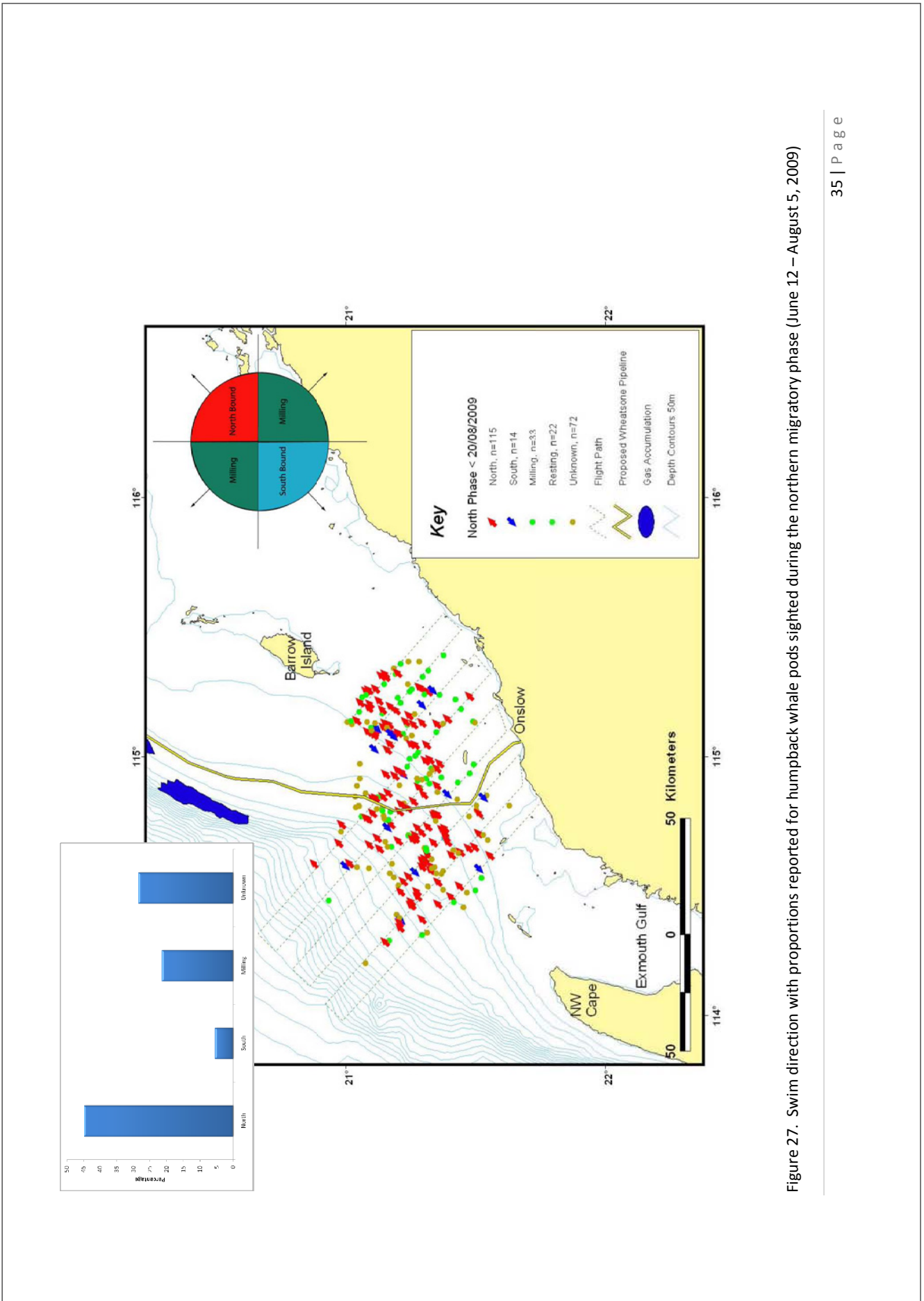


Figure 27. Swim direction with proportions reported for humpback whale pods sighted during the northern migratory phase (June 12 – August 5, 2009)

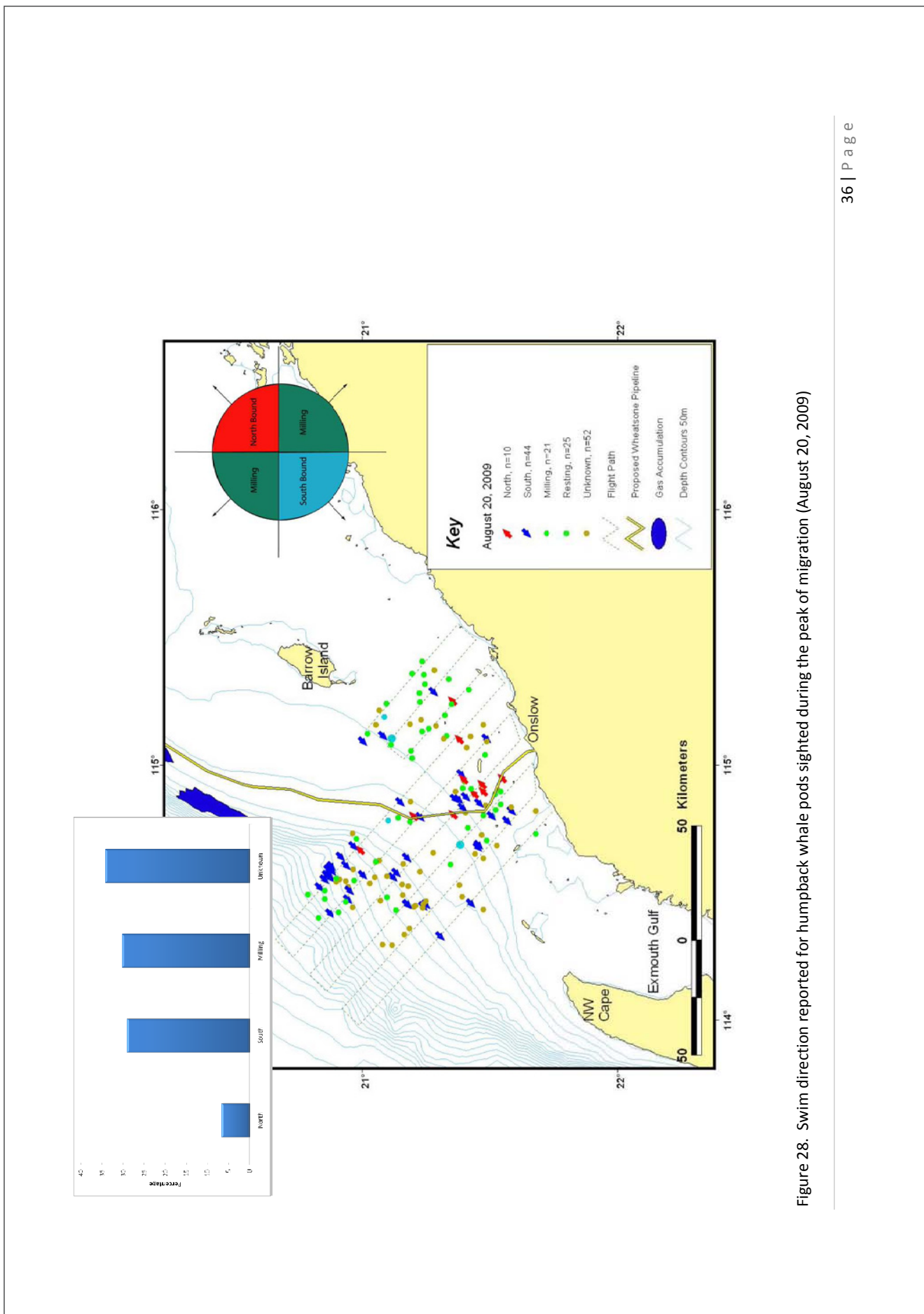


Figure 28. Swim direction reported for humpback whale pods sighted during the peak of migration (August 20, 2009)

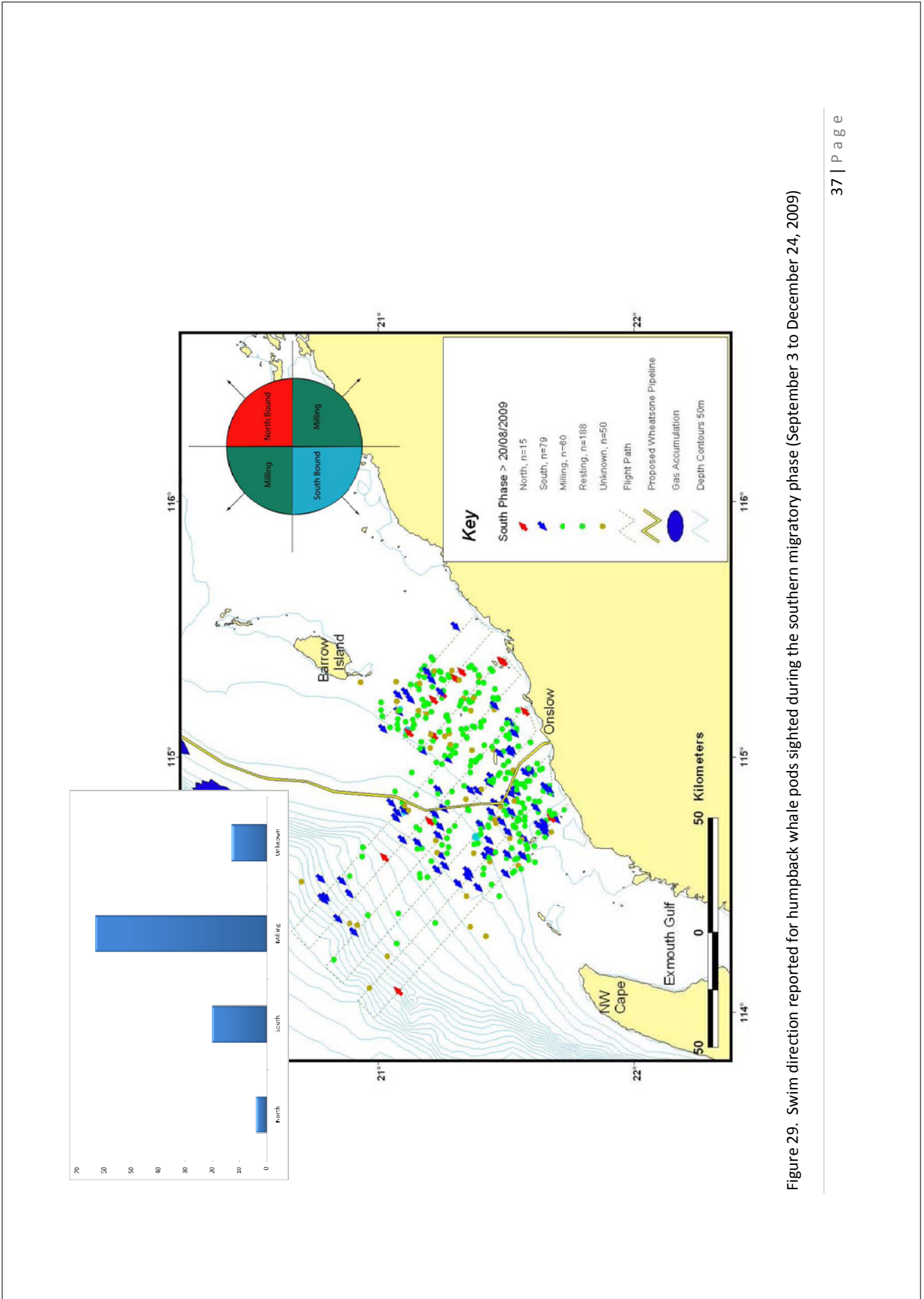


Figure 29. Swim direction reported for humpback whale pods sighted during the southern migratory phase (September 3 to December 24, 2009)

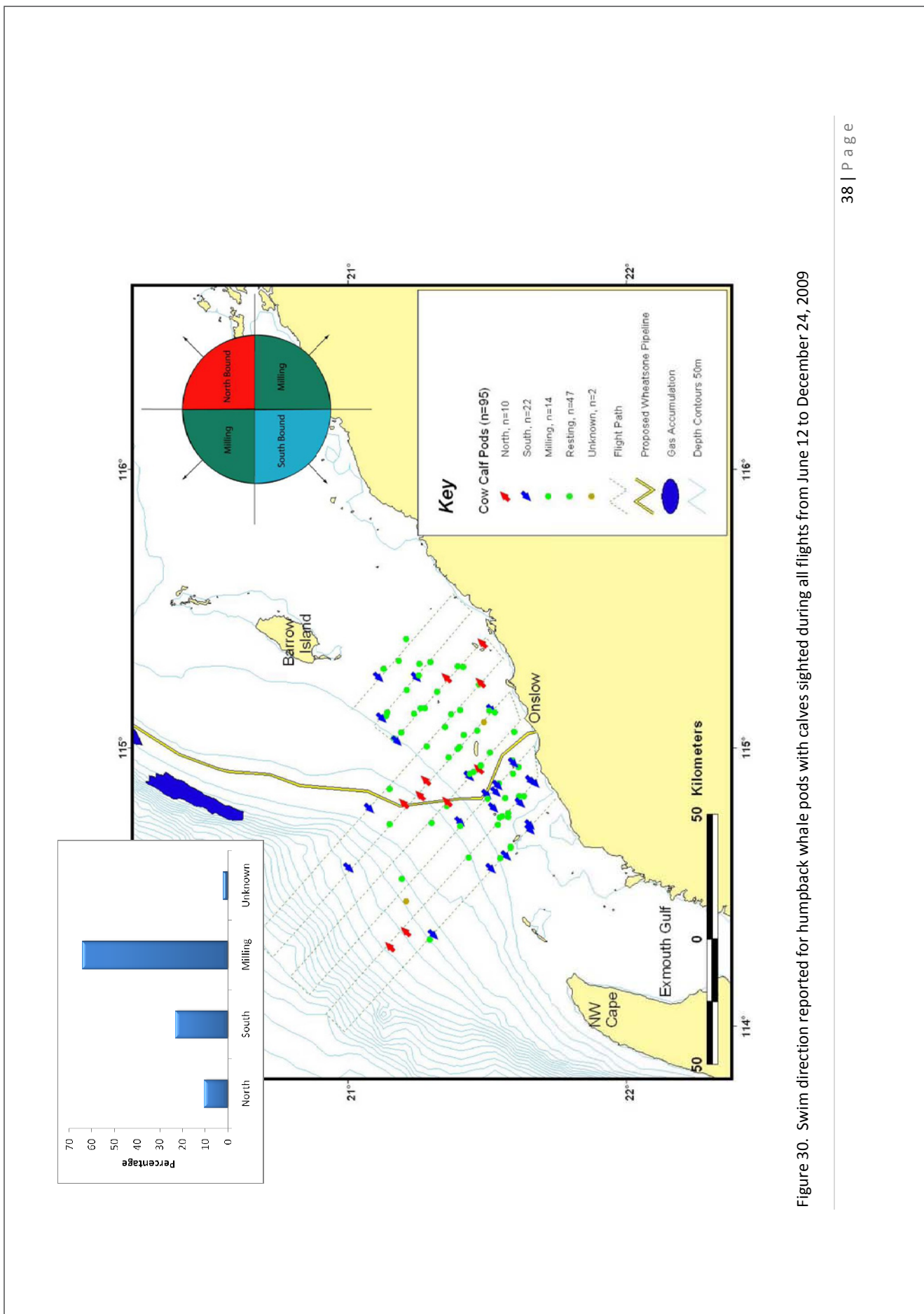


Figure 30. Swim direction reported for humpback whale pods with calves sighted during all flights from June 12 to December 24, 2009

5.4 Other Mega Fauna

5.4.1 Dugongs

Dugongs were sighted throughout the study period and peaked in late June (Figure 31). 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 south western portion of the study area in water depths less than 10m (Figure 32).

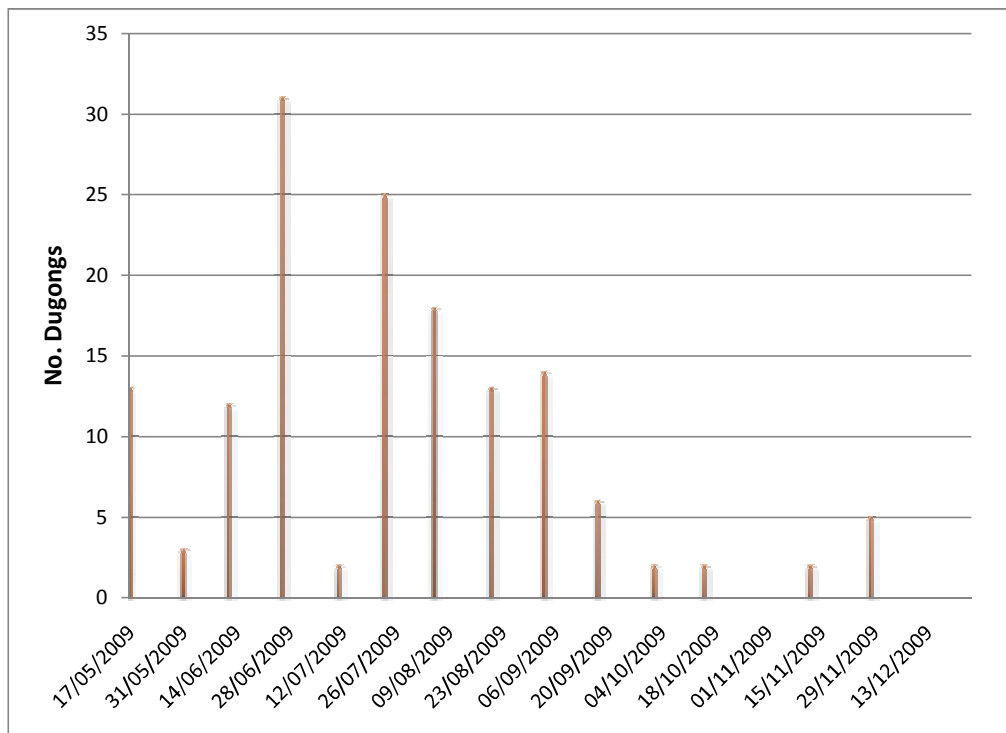


Figure 19. Numbers of Dugongs sighted during each flight from May 17 to July 23, 2009.

Table 4. Numbers of Dugongs sighted per flight

Flight Date	Dugong Herds	No. Dugongs	Dugong Calves
17/05/2009	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

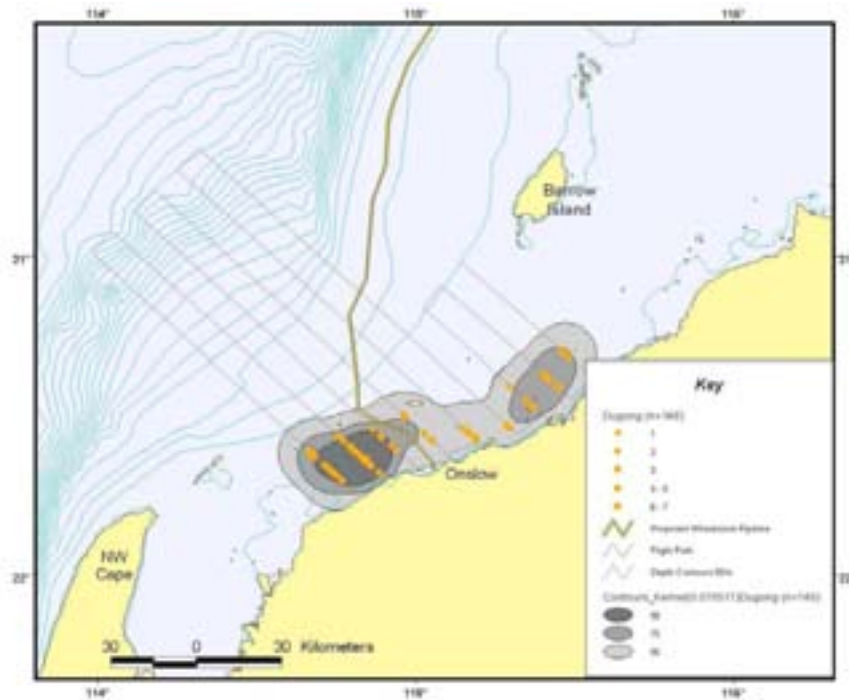


Figure 32. Distribution and relative density of Dugong herds sighted from May 17 to December 24, 2009.

5.4.2 Dolphins

Dolphins are likely to either be 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 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 33). Only nine 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 50 m, although some large pods (>100 individuals) were sighted off-shore (Figure 34).

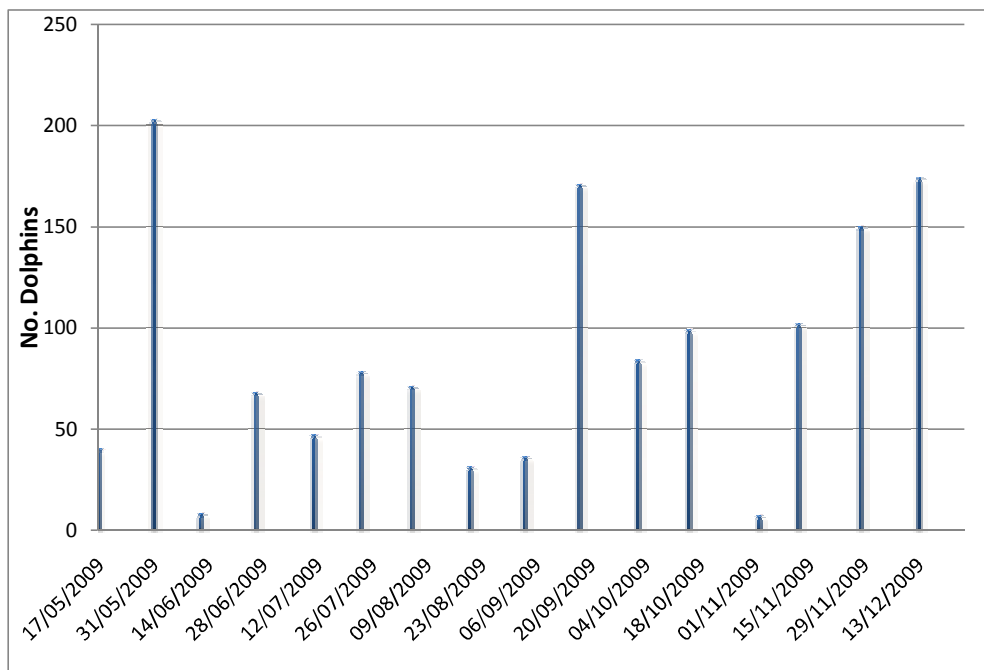


Figure 33. Numbers of dolphins sighted during each flight from May 17 to July 23, 2009.

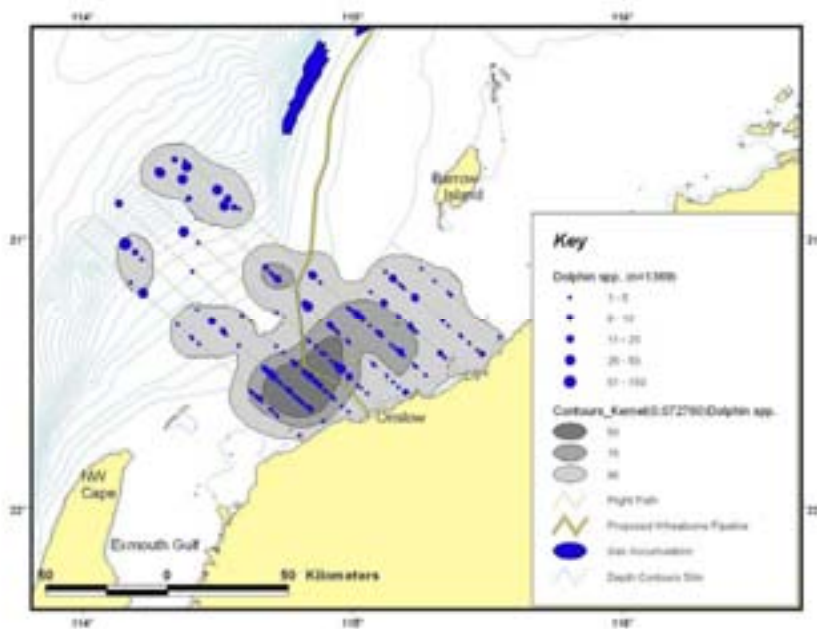


Figure 34. Distribution and relative density of dolphin species sighted from May 17 to December 24, 2009.

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 35, Table 6). 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.

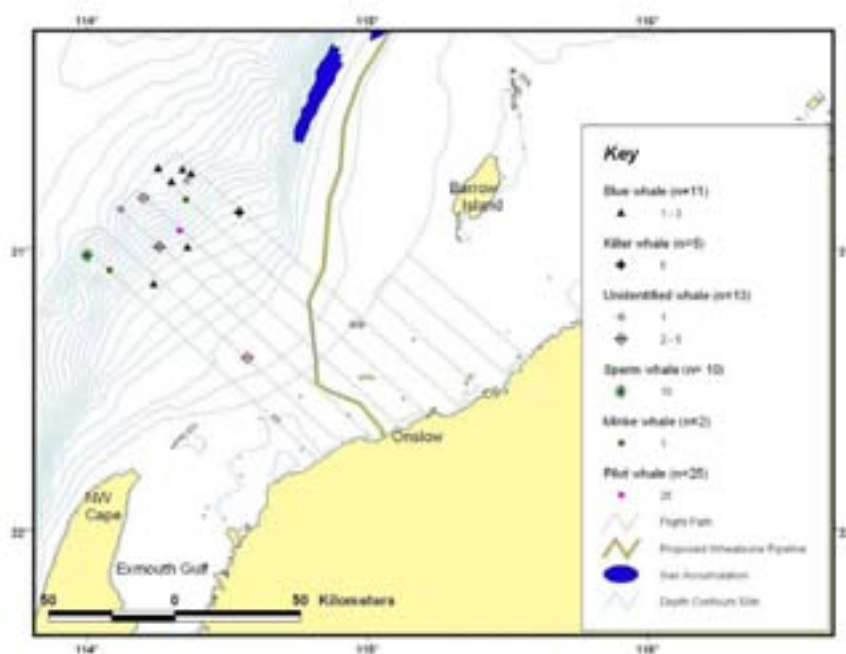


Figure 35. Distribution of other cetacean species sighted during the May 17 to December 24, 2009, period.

Table 6. Other cetacean species sighted per flight

Flight Date	Pilot whale	Minke whale	Sperm whale	Unidentified whale	Killer whale	Blue whale
17/05/2009	0	0	0	0	0	0
31/05/2009	0	0	0	0	0	0
12/06/2009	25	0	0	0	0	0
26/06/2009	0	1	0	0	0	0
11/07/2009	0	0	10	2	0	0
23/07/2009	0	0	0	0	0	0
05/08/2009	0	1	0	2	0	0
20/08/2009	0	0	0	0	0	0
03/09/2009	0	0	0	0	0	0
17/09/2009	0	0	0	2	0	0
02/10/2009	0	0	0	0	0	0
15/10/2009	0	0	0	0	0	0
02/11/2009	0	0	0	0	5	2
12/11/2009	0	0	0	5	0	0
28/11/2009	0	0	0	1	0	6
13/12/2009	0	0	0	1	0	3
24/12/2009	0	0	0	0	0	0
TOTAL	25	2	10	13	5	11

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 7). A single whaleshark was sighted during the May 17, 2009, flight and no further whalesharks 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 36). Manta rays were more broadly and sparsely distributed and were sighted near the 50m depth contour as well as inshore near a mangrove area known as the Passage Islands (Figure 37).

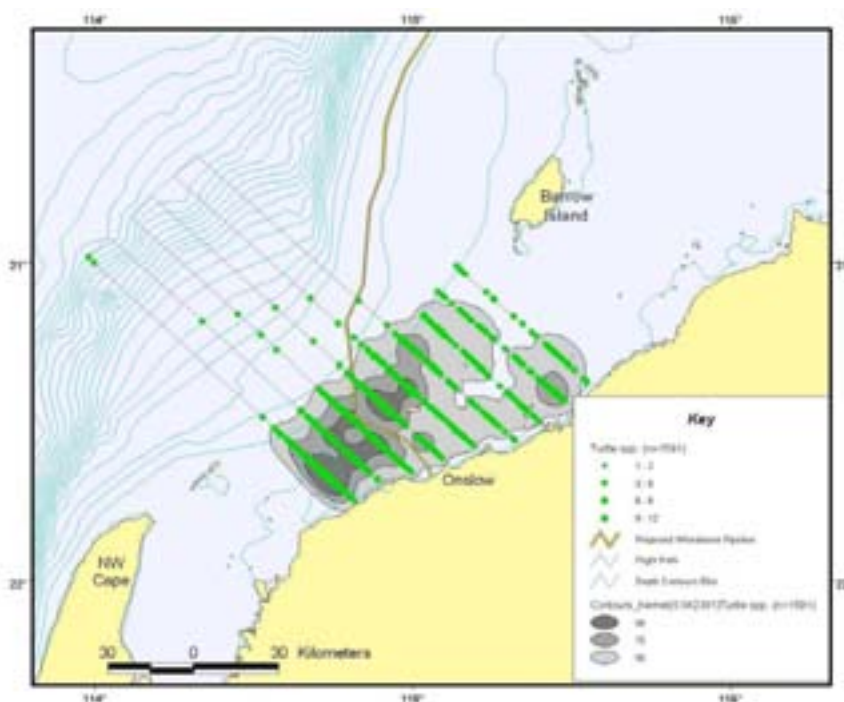


Figure 36. Distribution and relative abundance of turtle species sighted during the May 17 to December 24, 2009, period.

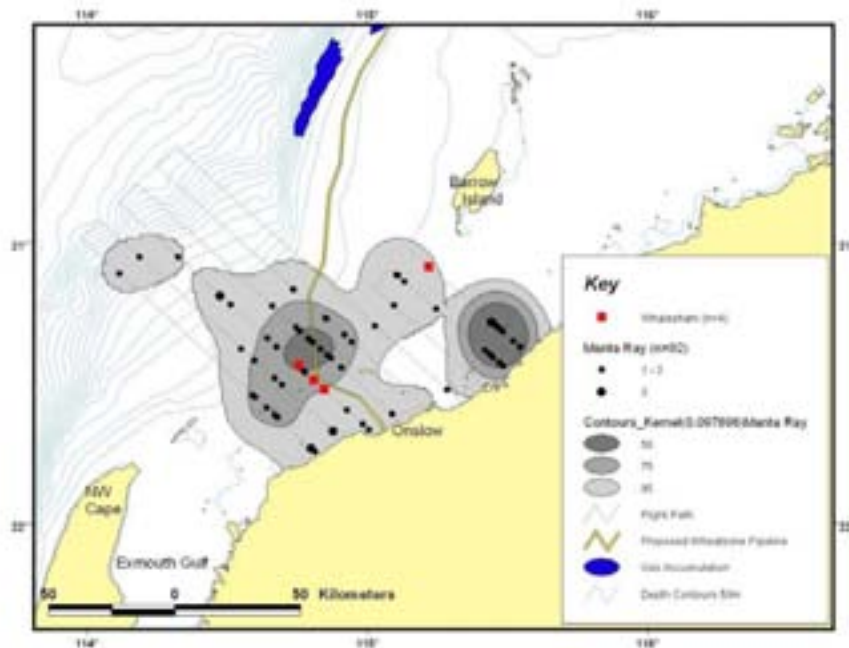


Figure 37. Distribution and relative abundance of manta rays and distribution of whalesharks sighted during the May 17 to December 24, 2009, period.

Table 7. Numbers of turtles, manta rays and whalesharks sighted per flight.

Flight Date	Turtle spp.	Manta Ray	Whale Shark
17/05/2009	53	2	1
31/05/2009	101	0	0
12/06/2009	32	4	0
26/06/2009	122	12	0
11/07/2009	14	1	0
23/07/2009	100	3	0
05/08/2009	261	21	0
20/08/2009	31	3	0
03/09/2009	159	9	0
17/09/2009	112	4	0
02/10/2009	14	4	0
15/10/2009	174	3	0
02/11/2009	61	4	0
12/11/2009	134	5	2
28/11/2009	140	11	0
13/12/2009	50	5	1
24/12/2009	33	1	0
TOTAL	1591	92	4

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 8). 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 38). Of note was a seismic survey that was ongoing from mid-June until late July.

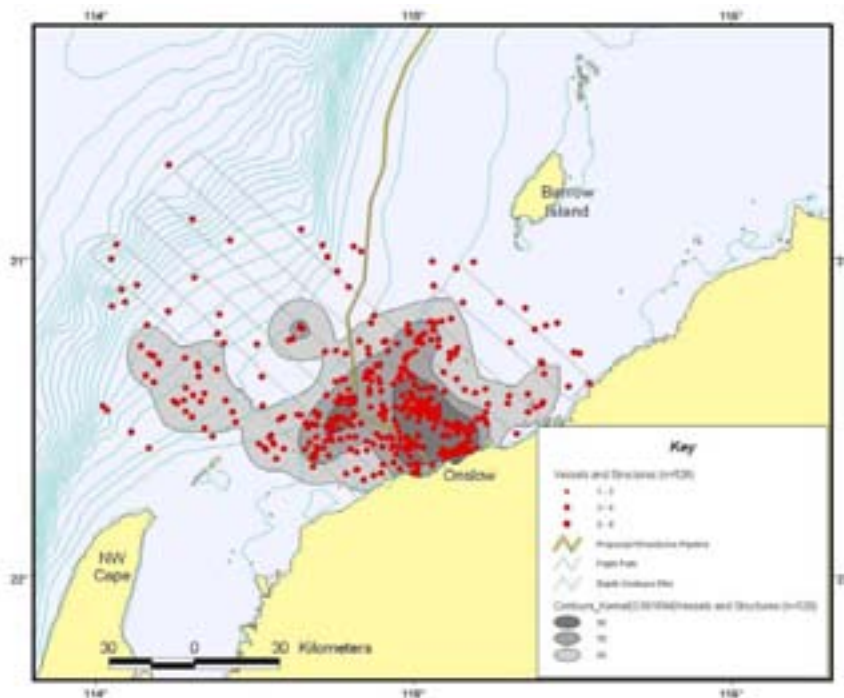


Figure 38. Distribution and relative abundance of vessels and man-made structures during the May 17 December 24, 2009, period.

Table 8. Numbers of vessels sighted per flight

Flight Date	Vessels
17/05/2009	50
31/05/2009	46
12/06/2009	36
26/06/2009	50
11/07/2009	48
23/07/2009	55
05/08/2009	32
20/08/2009	27
03/09/2009	37
17/09/2009	22
02/10/2009	33
15/10/2009	15
02/11/2009	9
12/11/2009	16
28/11/2009	25
13/12/2009	20
24/12/2009	5
TOTAL	526

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 (Appendix 4) from bottom mounted sea noise loggers. The results presented in this document and Appendix 4 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 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 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 as expected. 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 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 (see Appendix 4 below).

Other aspects of the humpback whale migration appear more similar to anticipated patterns such as the general spatial distribution of the migratory herd (Figures 39). 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 the period of the southern migration is dominated by this observation class. 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 new born 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 near shore waters at this time of year.

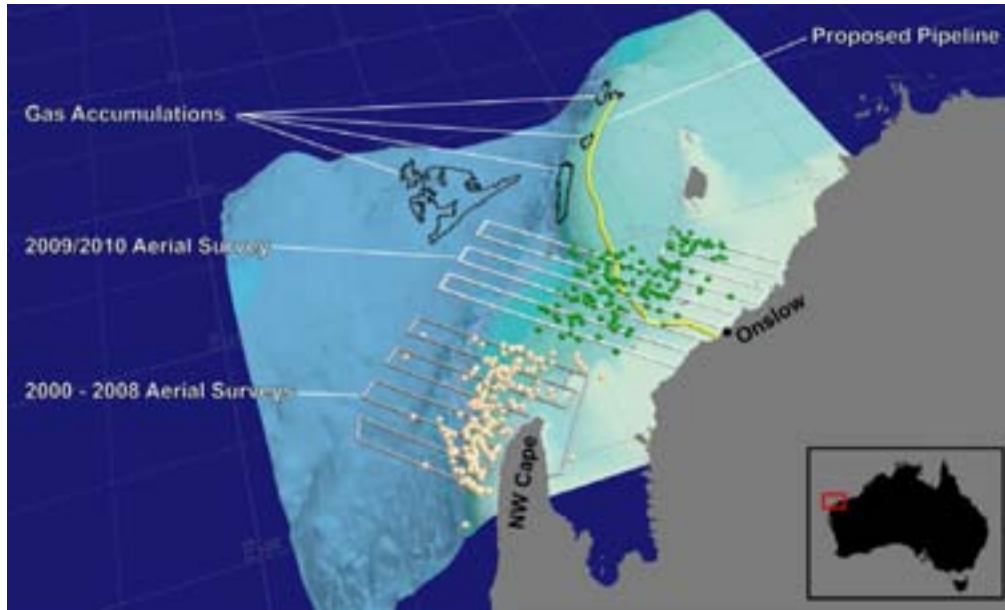


Figure 39. The 2009 humpback whale dataset (green) compared to the 2006 northern migration near NW Cape (CWR, unpubl. data).

Similarly, during the 2009 surveys, the near shore waters were significantly cooler than the off-shore waters (Figure 40) and a similar paucity of whales in this region was reported in this study. Water temperatures inshore of the 50m depth contour increase during August and September, coinciding with the arrival of the southern migratory body.

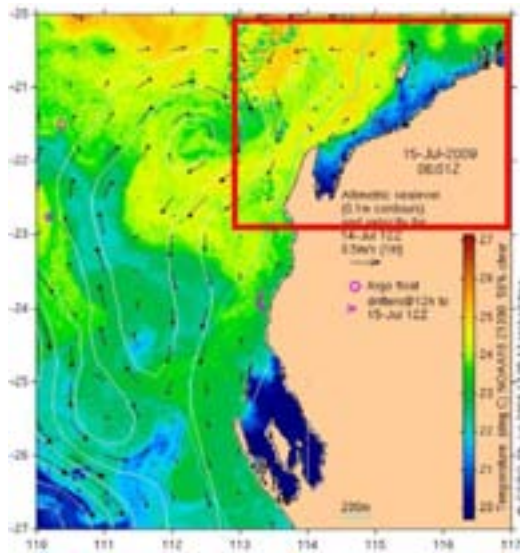


Figure 40. Sea surface temperature map from July 15, 2009, showing the cools near shore waters extending from Exmouth Gulf, northeast along the SW Pilbara Off-shore region (red box).

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 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 off-shore and a southern corridor 35 km off-shore.
- 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 inshore of the 50m bathymetry, although for unknown lengths of time.
- 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, 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 (see Appendix 4).
- 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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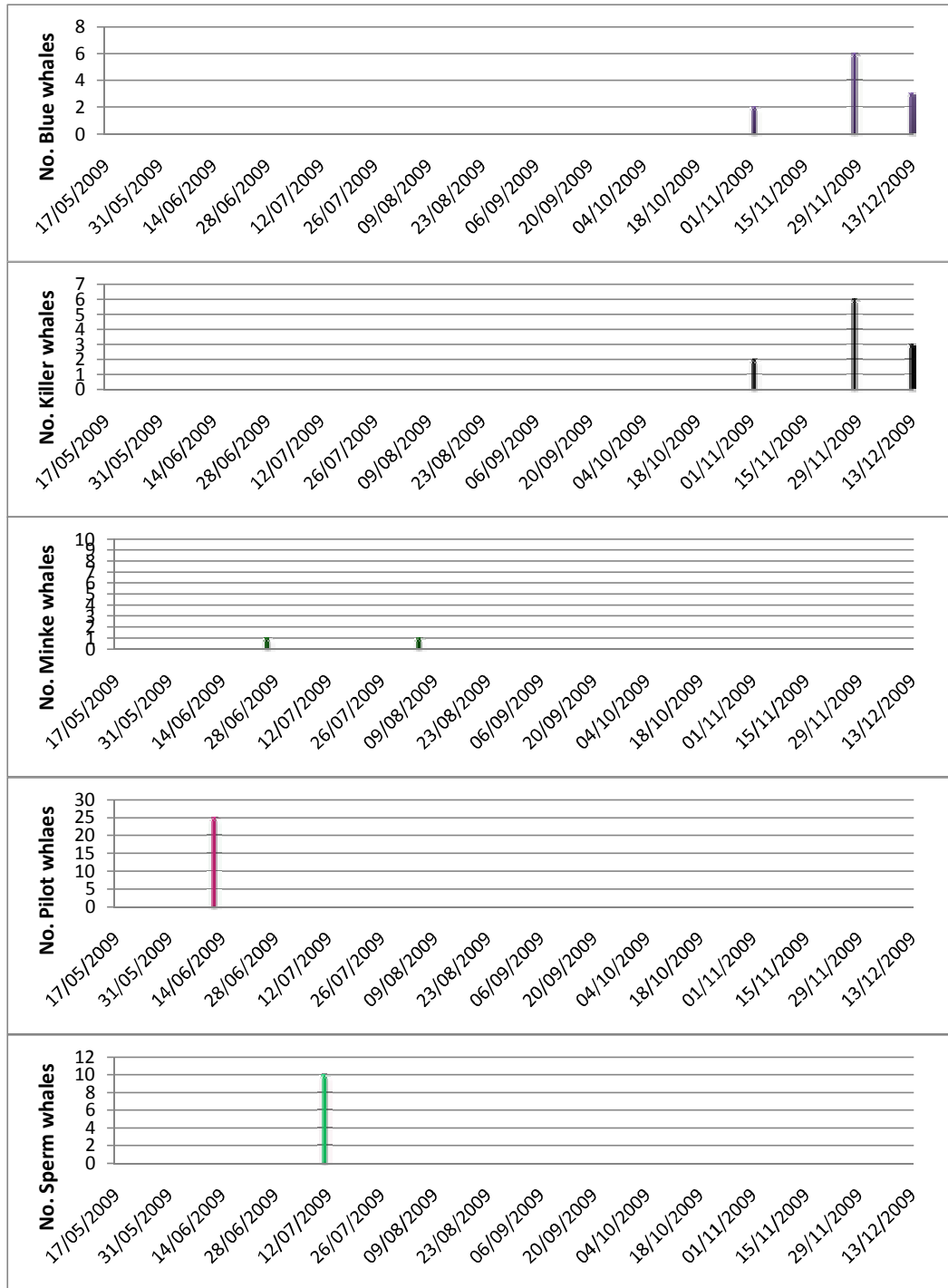
Appendix 1 – Beaufort Sea State for all transects during each flight – darker shades indicate stronger wind.

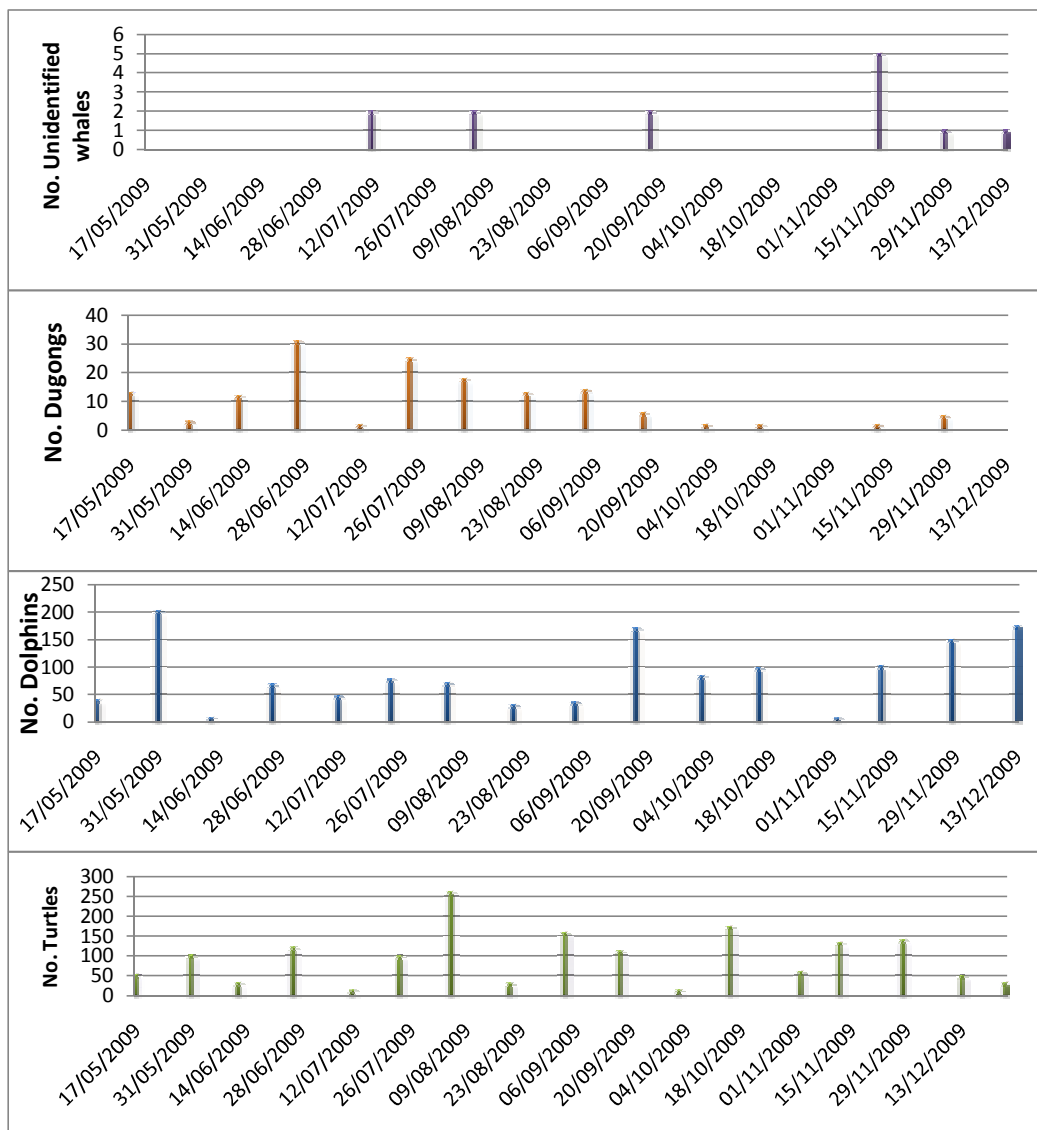
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Flight Date	17/05/2009	31/05/2009	12/06/2009	26/06/2009	11/07/2009	23/07/2009	05/08/2009	20/08/2009	03/09/2009	17/09/2009	02/10/2009	15/10/2009	02/11/2009	12/11/2009	28/11/2009	13/12/2009	24/12/2009
TRANSECT 1	3	3	4	1/2	3	2	1	1/2	3	2	2	1	2	2	2	2	2
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

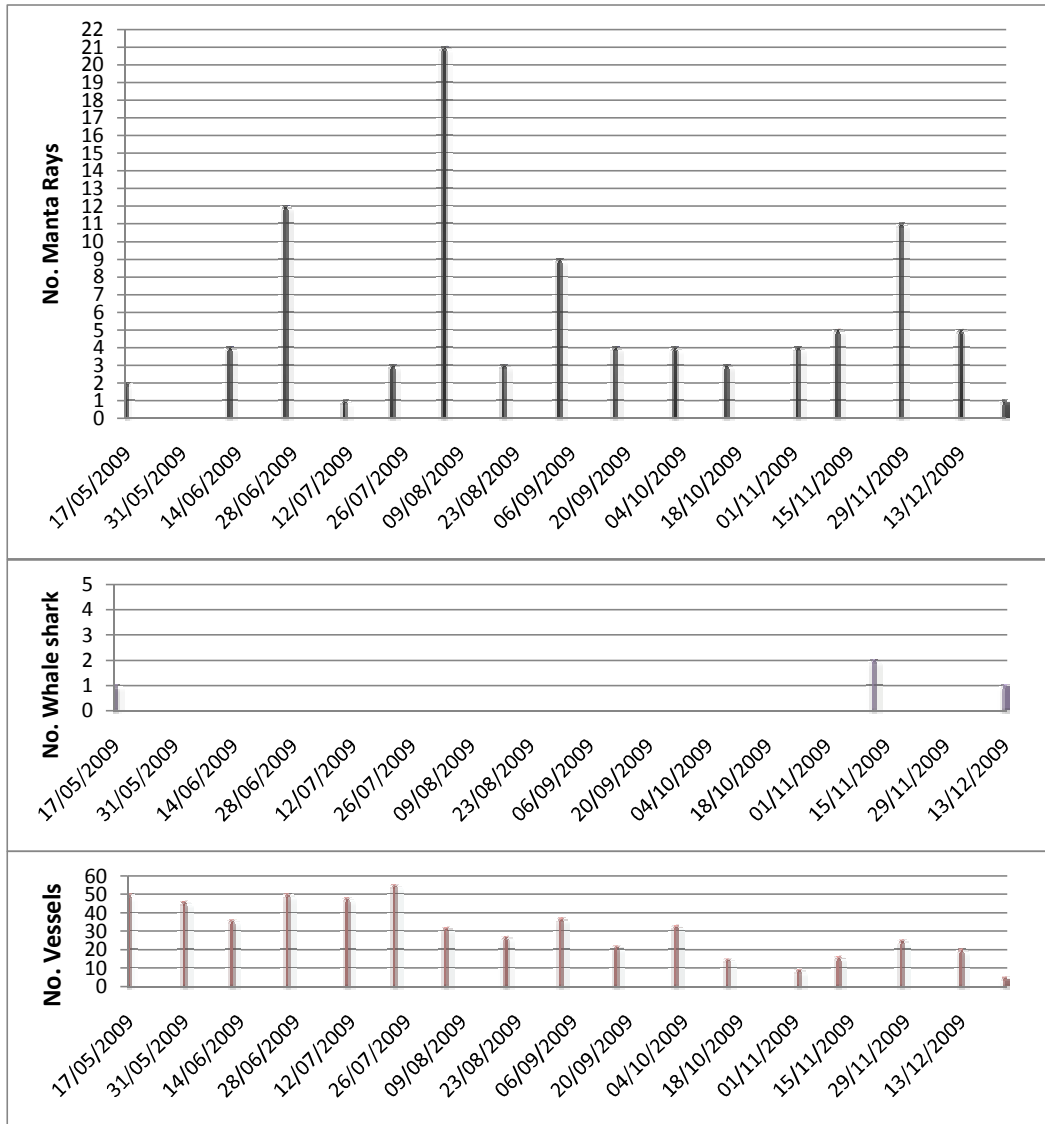
Appendix 2 – Sea State as a sighting variable. Peak values per species/object in yellow for May to July.

Flight Date	Vessels	Aquaculture Net	Spinn 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







Appendix 4 – CMST Acoustic Survey Report

RPS

APPENDIX 3

Sea Noise Logger Deployment Wheatstone and Onslow (CMST Preliminary Analysis)



**Centre for Marine Science and Technology
Curtin University**

**SEA NOISE LOGGER DEPLOYMENT WHEATSTONE
AND ONSLOW, APRIL TO JULY 2009
PRELIMINARY ANALYSIS**

By:

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27-Oct-2009

For - URS / Chevron

**PROJECT CMST 829
REPORT R2009-34**

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 are believed 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 and counted at the offshore site. 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 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 quite 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 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 but the counts have not yet been analysed for trends or timing. The first detection of humpbacks at the 43 m inshore site, on the known migratory route was on the 30-May-2009. Regular evening fish choruses were heard at the 43 m depth inshore site but not at a 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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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 brought 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 summarises the data sets recovered and presents what analysis could be carried out in the time frame available. No discussion is presented here.

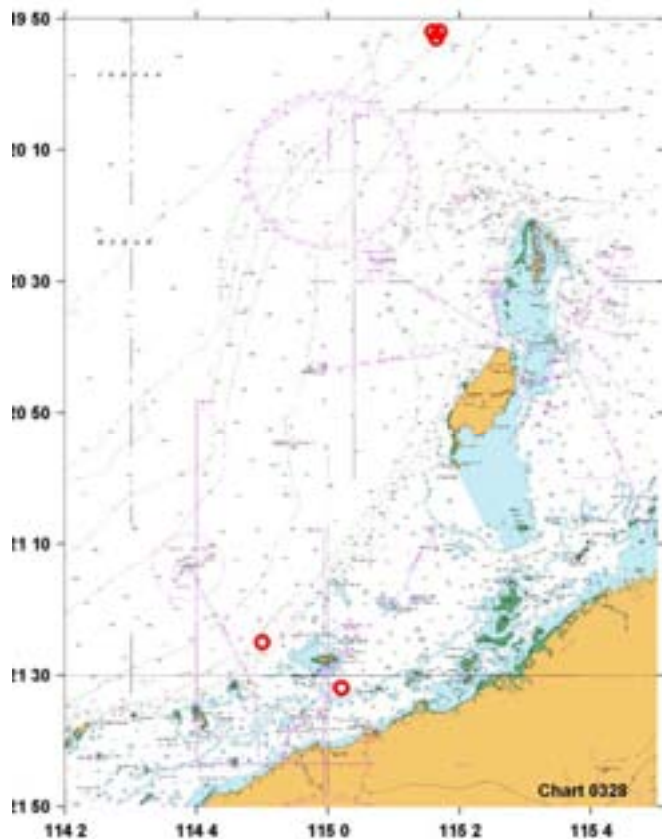


Figure 1: Location of noise loggers set in Phase I. All noise loggers were redeployed at similar locations. The Phase I locations have been given the numbers: 2808 – logger closest to shore; 2809 logger in 43 m water nearshore; set 2810, southern-most logger of offshore grid; 2811, western-most logger of offshore grid; and 2812 the eastern-most logger of the offshore grid.

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.

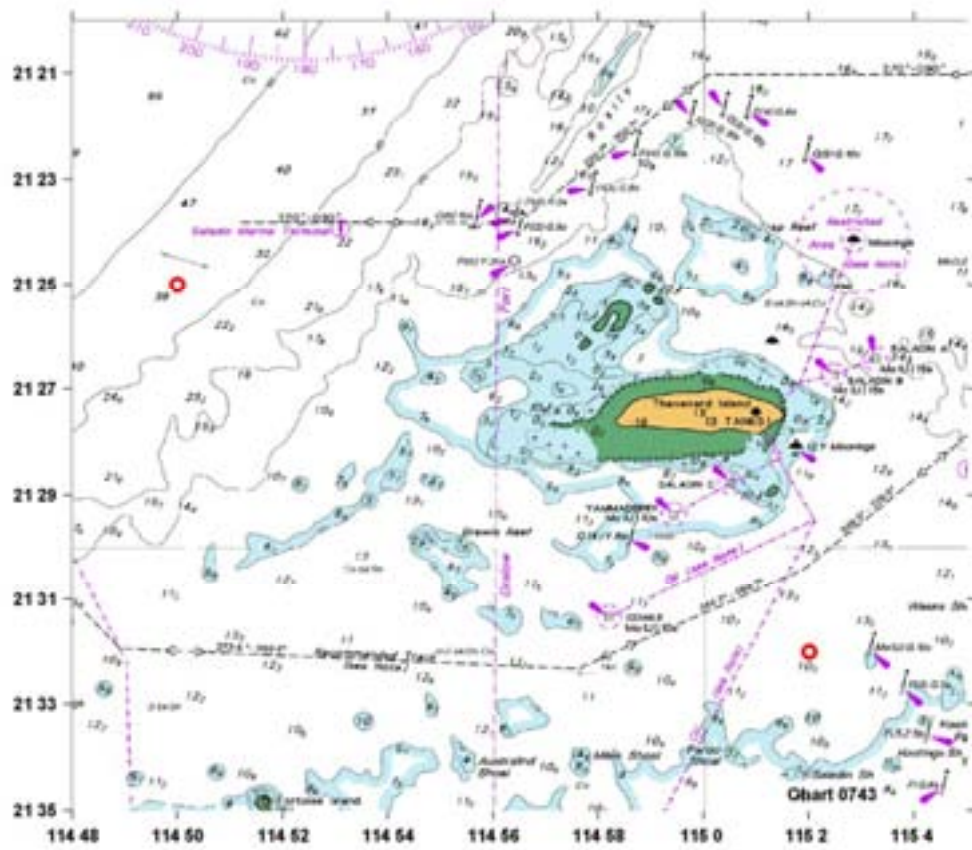


Figure 2: Location of the two Phase I inshore loggers (red circles). Set 2808 is the eastern one, set 2809 the western one.

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).

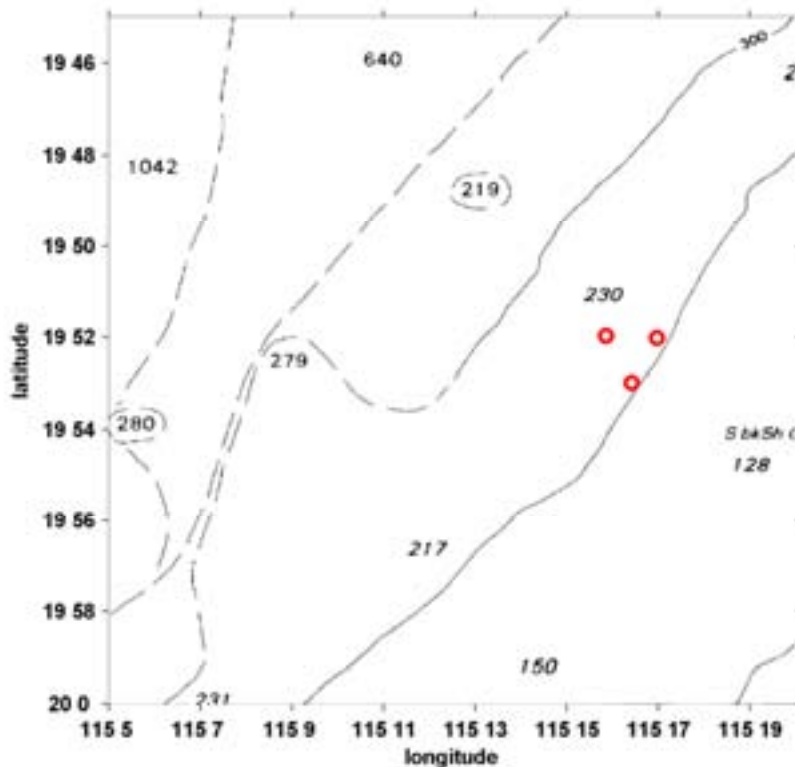


Figure 3: Location of offshore noise loggers (red circles) with bathymetry contours shown (from the east, 200, 300, 500 and 1000 m). Set 2810 is the southern location, 2811 the western location and set 2812 the eastern location.

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.

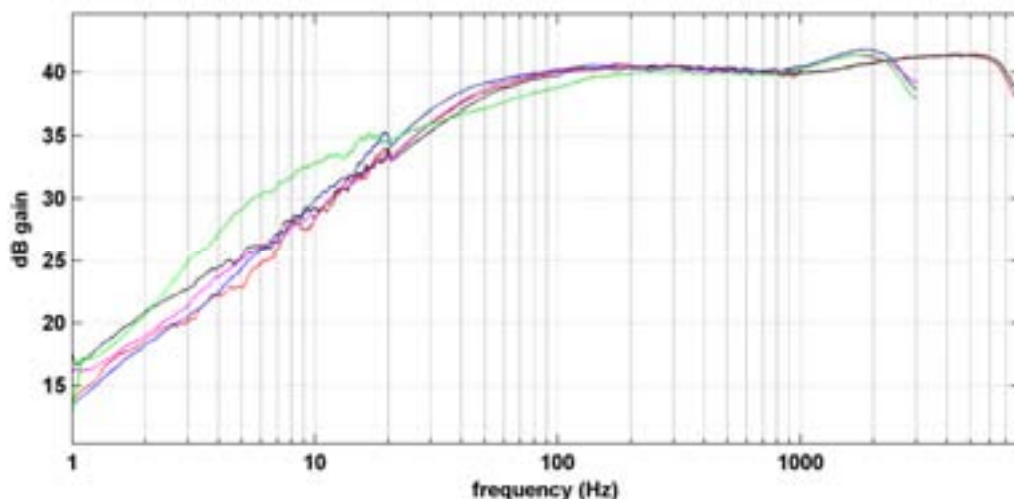


Figure 4: Calibration curves for the Wheatstone Phase I sea noise loggers.

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 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.

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 m	Siiticon	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
2809	Onslow – 45 m	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
2810	Wheatstone-1	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	Wheatstone-1	Redo	HTO 011	22, 200/86,400	19° 52.011'	115° 16.966'	211	
2811	Wheatstone-2	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
2814	Wheatstone-2	Revenge	HTI 032	22, 200/86,400	19° 51.972'	115° 15.858'	238	
2812	Wheatstone-3	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
2815	Wheatstone-3	Perceval	Massa 495	22, 200/86,400	19° 52.973'	115° 16.419'	202	

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 decouple 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.

The units and their definitions used in this report are:

- **dB re 1 μ Pa²/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 most 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 1 μ Pa** – 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, as discussed below

- **dB re 1 μ Pa 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 1 μ Pa 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 1 μ Pa 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.
- **dB re 1 μ Pa @ 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 1 μ Pa².s SEL & dB re 1 μ Pa msp** – The first measure, SEL this is widely termed as *sound exposure level*.. It is a measurement which is approximately proportional to the 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 the 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 μ Pa²/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.

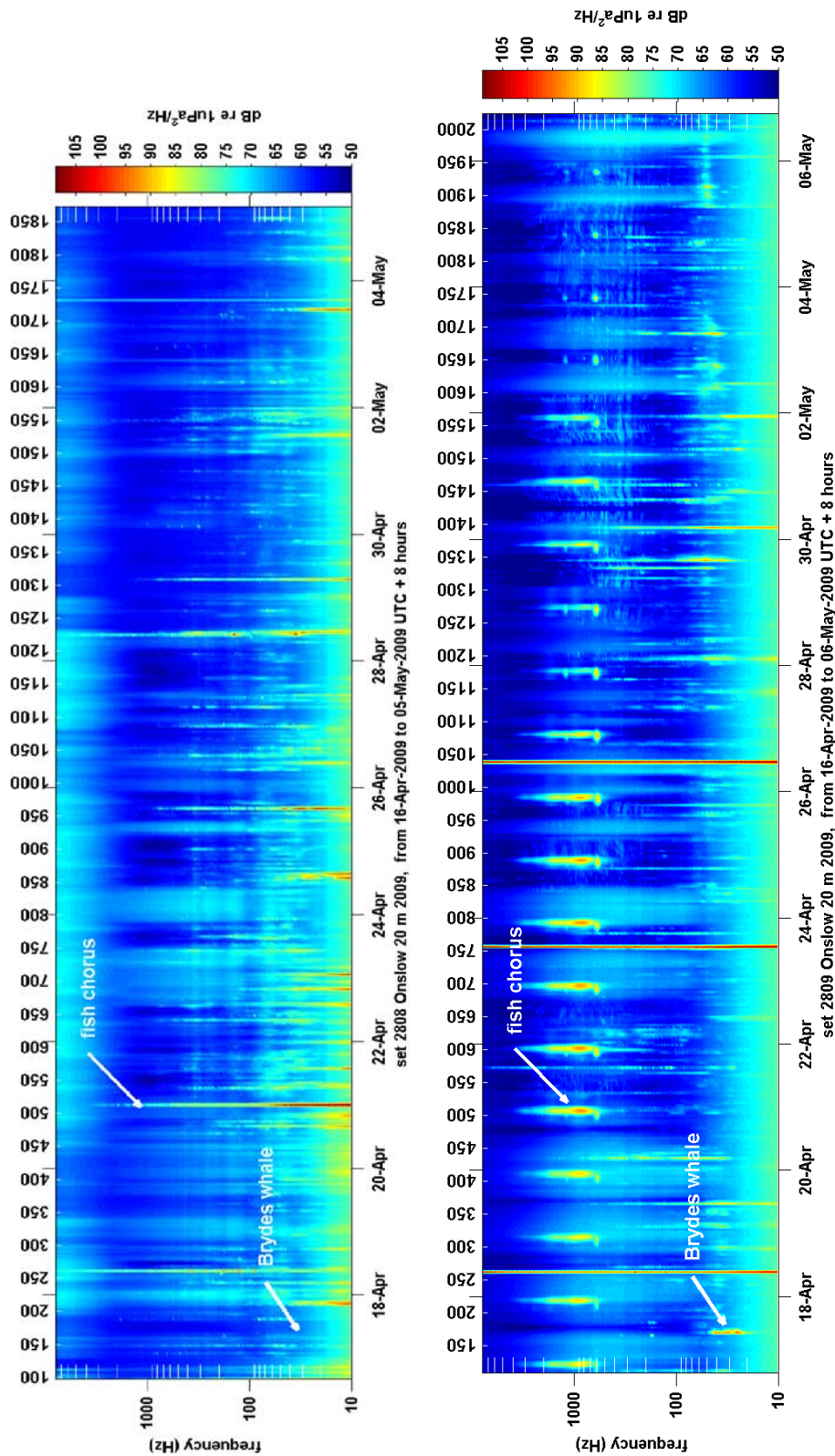


Figure 5: Stacked sea noise spectra (18.5 and 20 day period) for the 10 m site (set 2808, top) and the 43 m site (2809, bottom) over 16-Apr-2009 15:30 to 06-May-2009 18:15. The frequency scale is logarithmic from 10-8000 Hz.

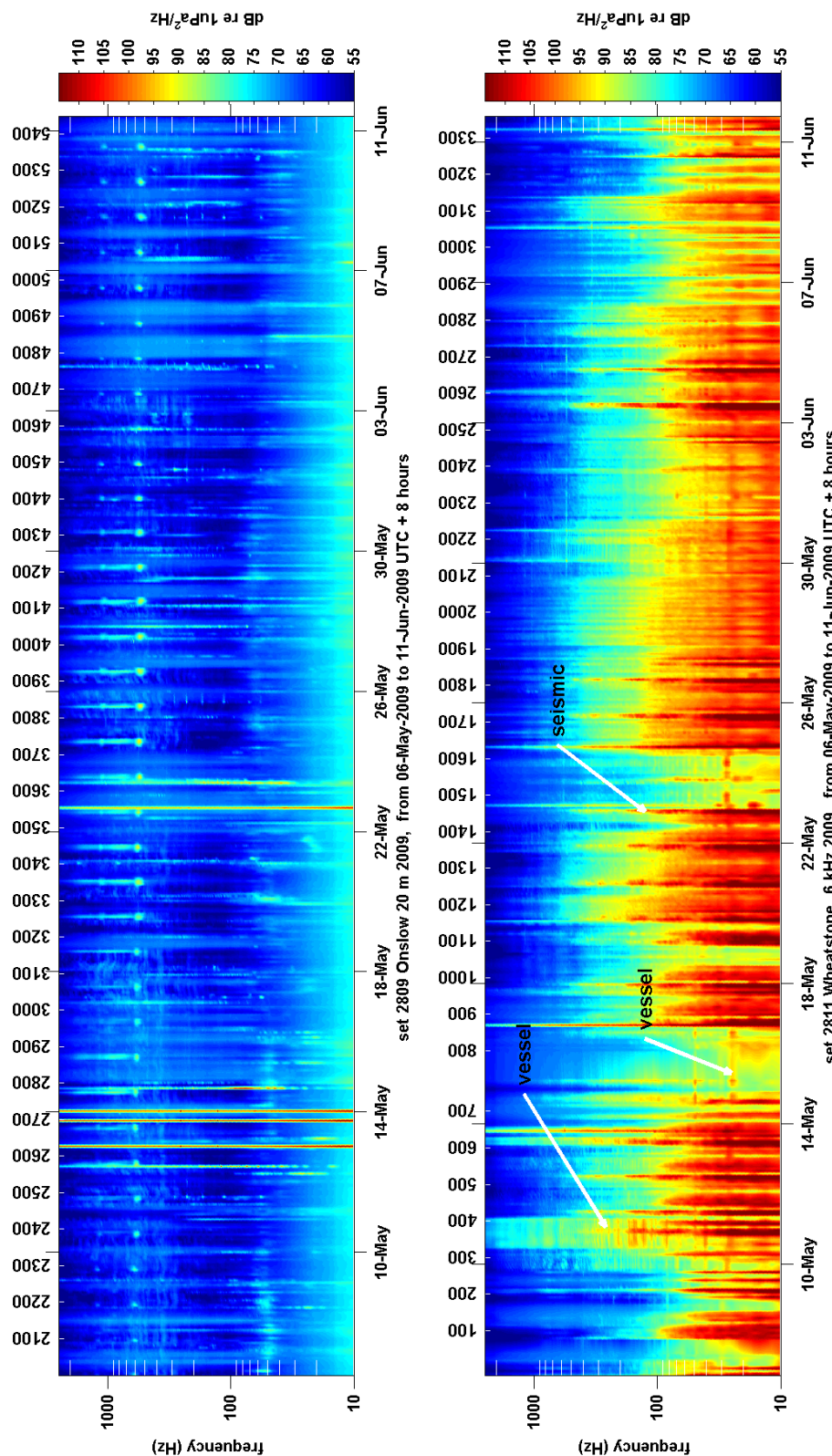


Figure 6: Stacked sea noise spectra (36 day period) for the 43 m site (set 2809, top) and the westernmost logger (set 2811, bottom) of the offshore site (see Figure 1 for locations) over 06-May-2009 18:15 to 11-Jun-2009 18:15. The frequency scale is logarithmic from 10-2500 Hz.

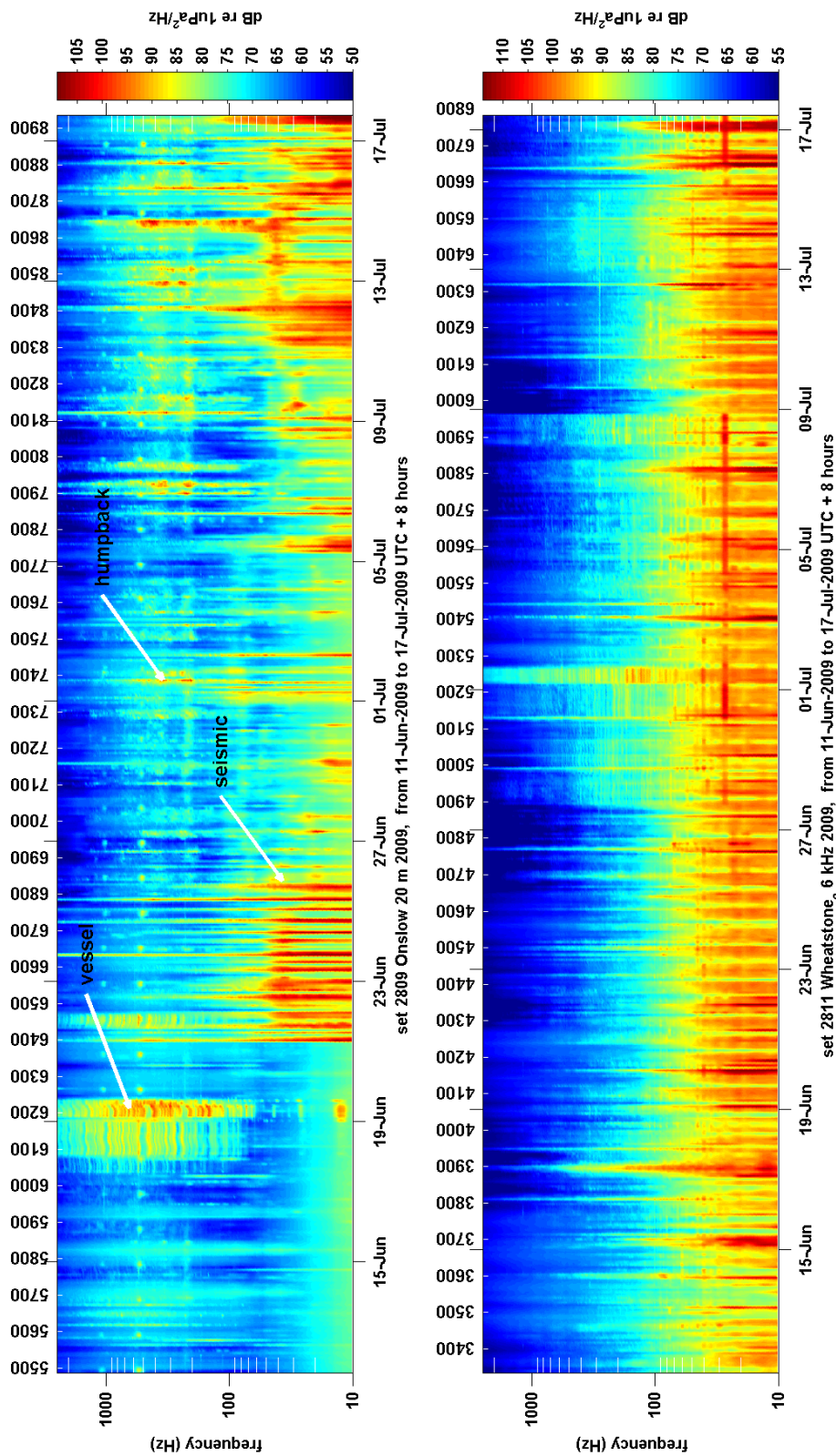


Figure 7: Stacked sea noise spectra (36 day period) for the 43 m site (set 2809) and the westernmost logger (2811) of the offshore site (see Figure 1 for locations) over 11-Jun-2009 18:15 to 17-Jul-2009 18:15. The frequency scale is logarithmic from 10-2500 Hz.

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 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.

To expedite the estimations made here a single seabed type was used and a constant water depth profile was used for each of the three sites. While all sites do not have constant depth profiles running away from the receiver an all headings, this technique was used to give a first approximation of listening ranges. 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. The seabed types assumed two m of sand over limestone at the inshore site and five m of sand over limestone at the offshore, Wheatstone site. The parameters used in modelling are listed in Table 2. Constant depth profiles of 10 m, 40 m and 200 m were assumed for sets 2808, 2809 and 2810-2812 respectively.

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 inshore, 5 m offshore m	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 10 below) of 183 dB re $1\mu Pa$ (rms) has been given in McCauley et al (2000) 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 $1\mu Pa$. The higher order estimate of the source level was used in estimating detection ranges (188 dB re $1\mu Pa$). McCauley et al (2000) 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 has not been reduced to account for bandwidth about the spectral maximum (ie. making sure the source and background noise level units were similar).

McCauley et al (2000) 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 1 μ Pa (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 (authors observations on WA song). 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 and averaged over the source depth range of 20-30 m (5-8 m in the 10 m water depth case) was used to estimate the transmission loss with range for humpback song. 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 1 μ Pa) to the same units as the ambient noise (dB re 1 μ Pa²/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.

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 1 μ Pa²/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 1 μ Pa²/Hz, thus for humpbacks ambient noise of 63 and 80 dB re 1 μ Pa²/Hz have been used in estimating song detection range to compare the detection range under quiet conditions with those 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 1 μ Pa²/Hz for all sources and sites, plus the average ambient noise of 80 dB re 1 μ Pa²/Hz for humpbacks at the offshore site. While the sound transmission modelling did not account for the different bathymetry paths around each noise loggers site, 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 8. 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, reducing the detection range by more than three times.

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 9. The broadband noise level 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 (km²) 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 (km²)
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
40 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	10 / 314
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

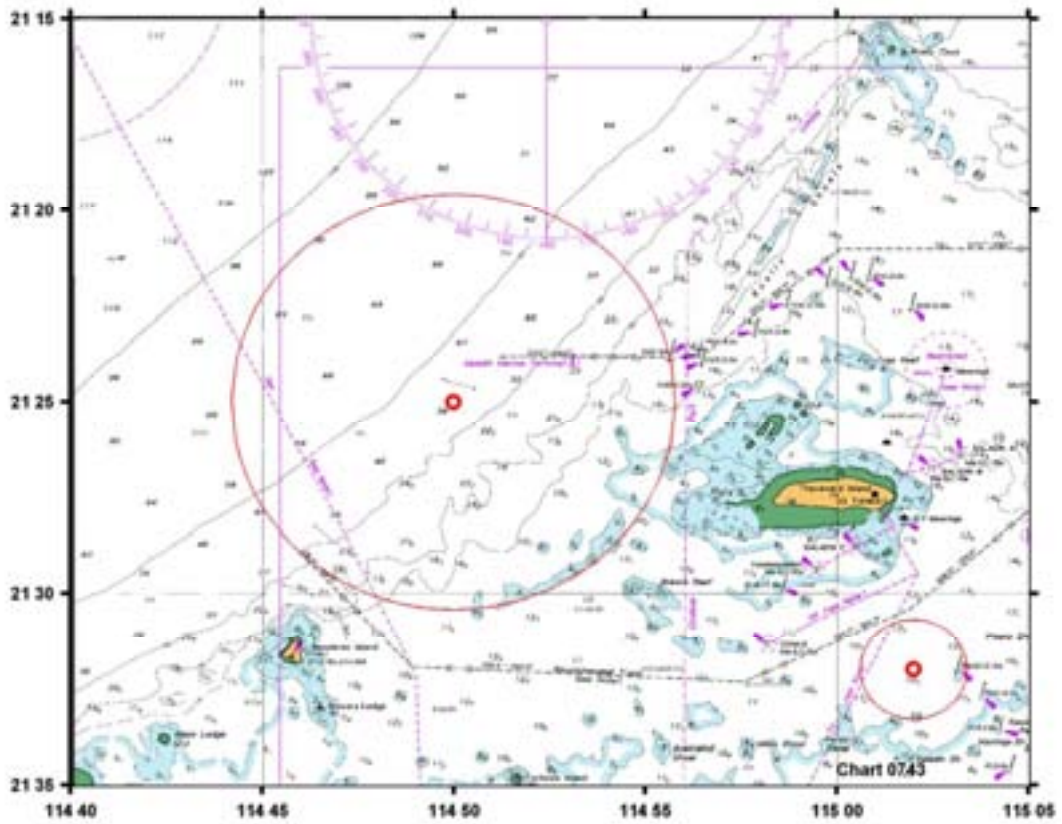


Figure 8: Estimated listening area of inshore loggers for humpback whales.

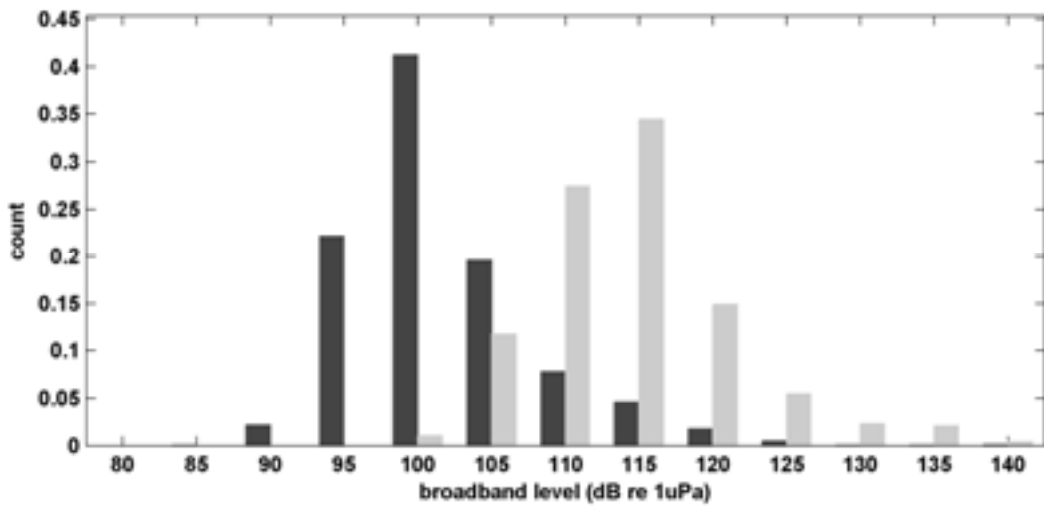


Figure 9: Distribution of broadband ambient noise levels averaged across each sample, for the full recording periods of the site 2809 (dark bars) and the offshore site 2811 (light bars). The count (y-axis) is normalised.

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 10. 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.

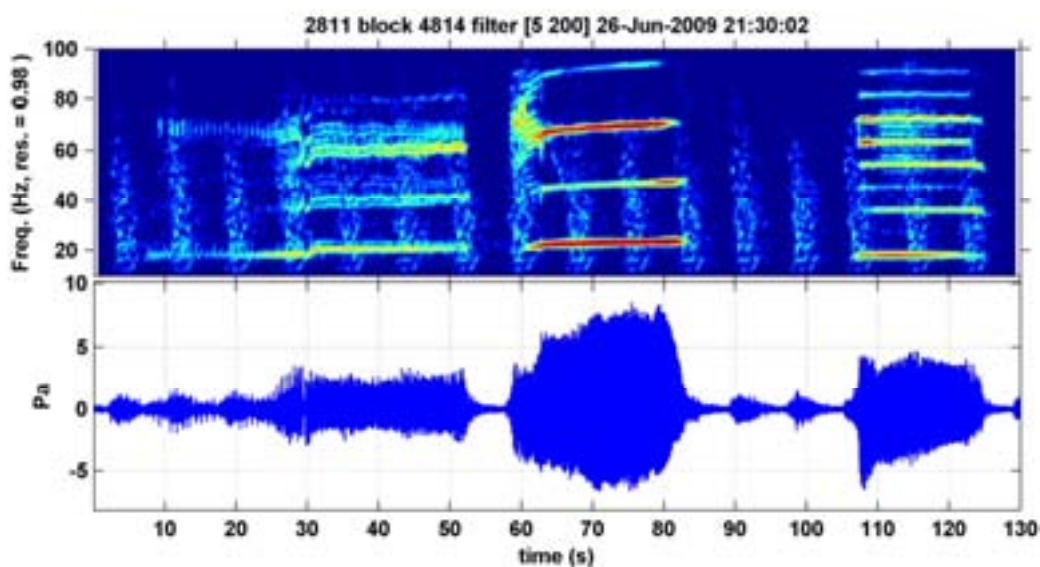


Figure 10: Example of pygmy blue whale call spectrogram (top) and waveform recorded from the offshore site. The call is stereotypical composed of three long tones. The vertical bursts of energy in the background are distant air gun signals.

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° 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° to 55° 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 10). 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 11 along with a smoothed curve showing the trend (\pm 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 12. 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.

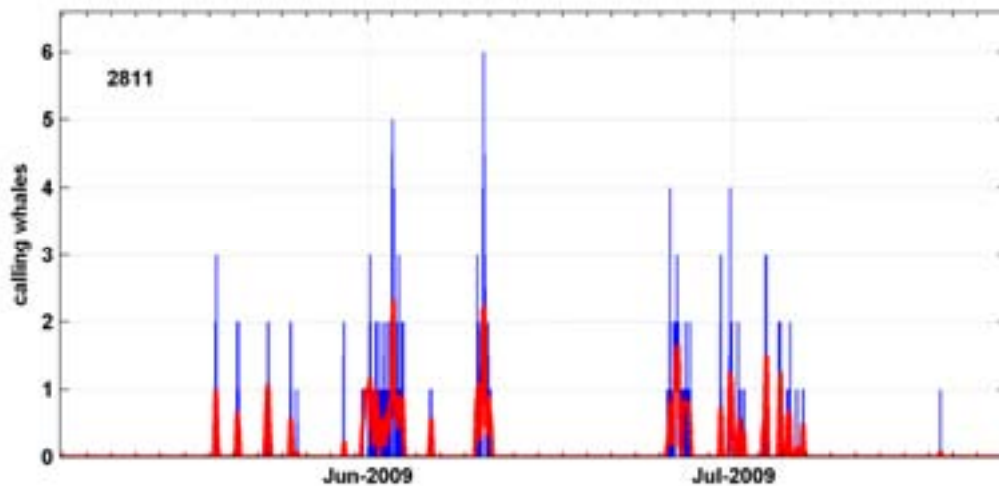


Figure 11: Counts of calling pygmy blue whales from the western logger of the Wheatstone offshore site (2811). The red curve is a three hour running average. The minor tick increments are two days apart.

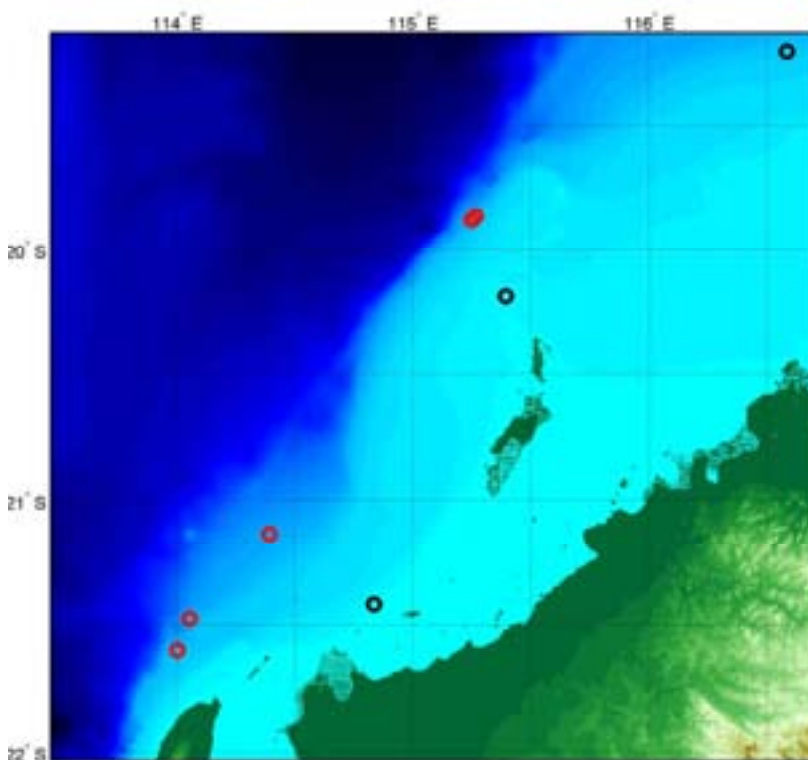


Figure 12: Locations of sites sampled in region over periods where pygmy blue whales have been expected to pass. The red circles represent places where pygmy blue whales have been detected and the black circles places where they have not been detected despite sampling over expected migratory periods.

The 24 hour averaged counts of individual pygmy blue whales passing through the area for four of the shelf edge sites (shown on Figure 12) including the Wheatstone site, are shown on Figure 13. The two 'Exmouth' data sets are the southernmost sites shown on Figure 12 (from McCauley and Jenner 2001 and McCauley 2006), the lower two panels of Figure 13 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 13, 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.

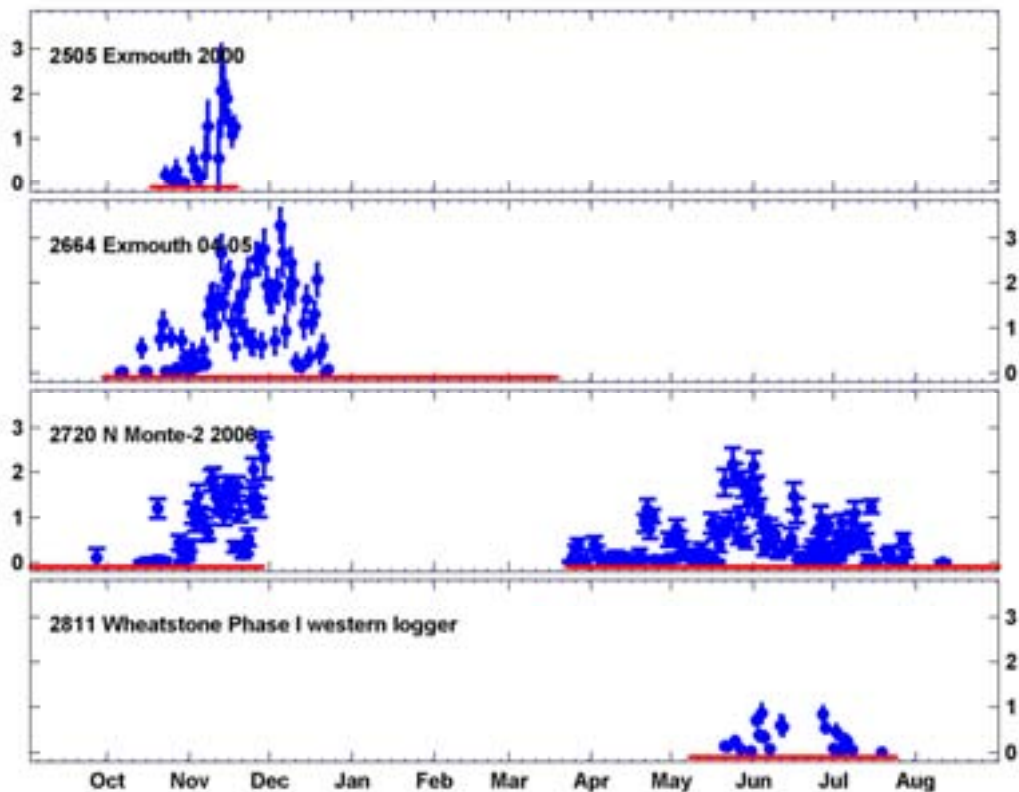


Figure 13: Numbers of individual pygmy blue whale callers averaged over 24 hour periods from sites off Exmouth and in the Wheatstone area (set 2720 and 2811).

A notable difference evident in Figure 13 in the two sites near the Wheatstone tracking grid (lower two panels of Figure 13) 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 were 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 14 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.

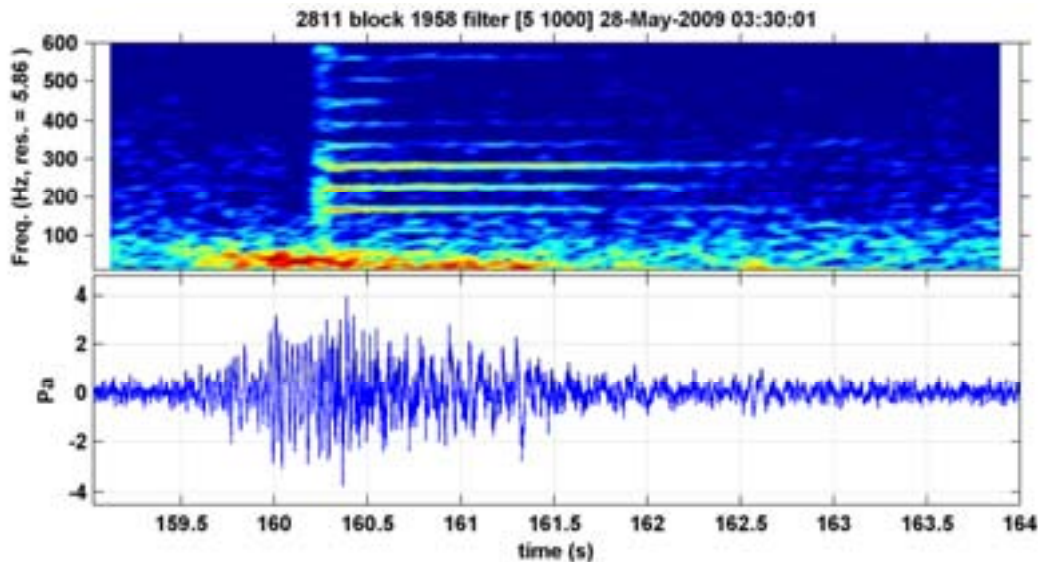


Figure 14: Example of a dwarf minke whale call (set of harmonics over 160.2 to 162.5 s with energy above 100 Hz) overlying a long range air gun signal (energy below 100 Hz).

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 15. The search algorithm data has not been manually cross checked as the pygmy blue whale data has. From Figure 15 it appears that at the offshore site dwarf minke whales were present at low levels throughout the full recording period of the Phase I deployment, but tended to increase in numbers in late June.

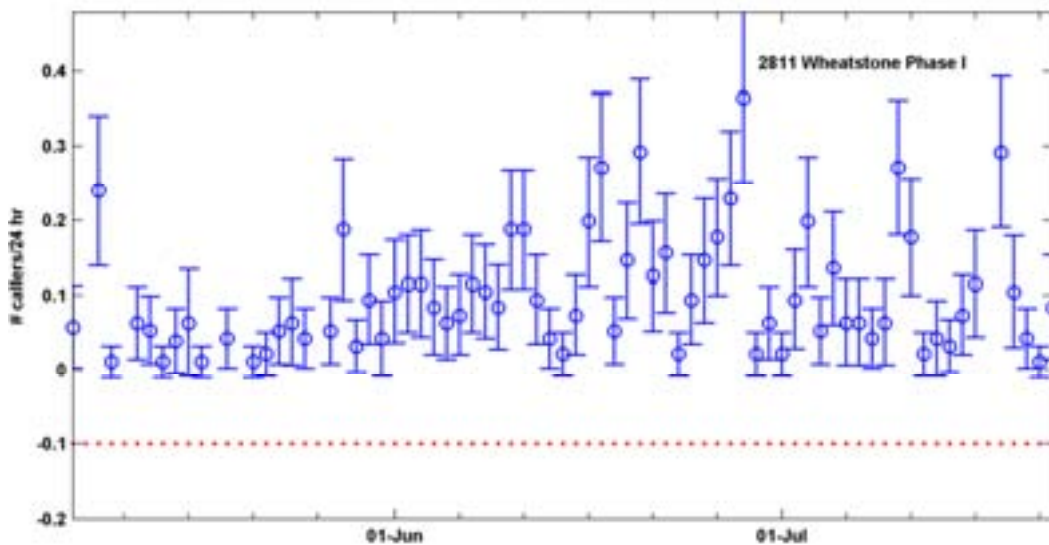


Figure 15: Dwarf minke whale detections from the offshore site 2811 (westernmost logger) over the Phase I recording period. The values shown are 24 hour means (12:00 one day to 12:00 the next) of the number of individual calling dwarf minke whales. The red points indicate days sampled. The error bars 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 16. 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.

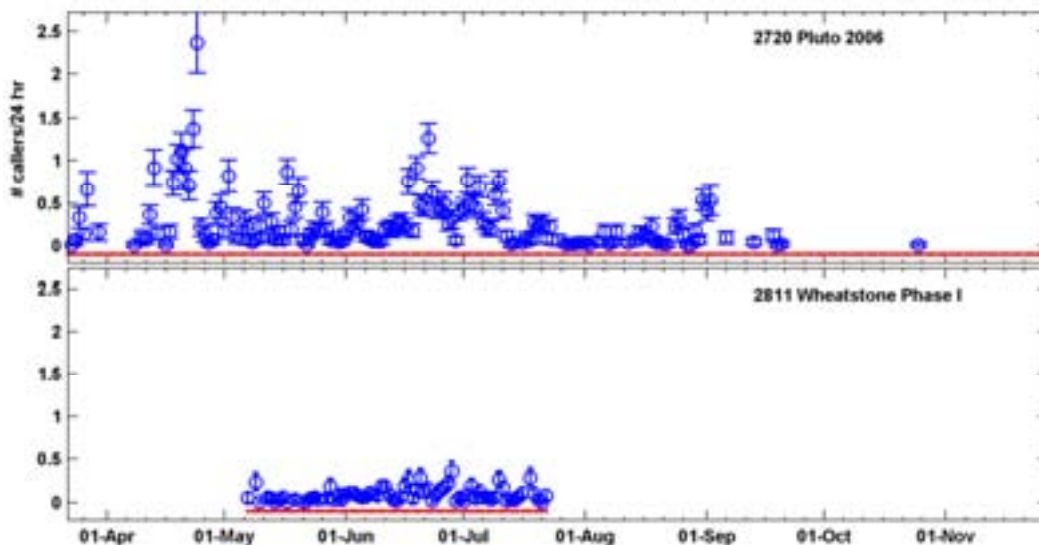


Figure 16: Dwarf minke whale individual callers averaged in 24 hour periods with 95% error bars shown, from the Wheatstone site in 2006 and 2009.

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 17. 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 17. 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.

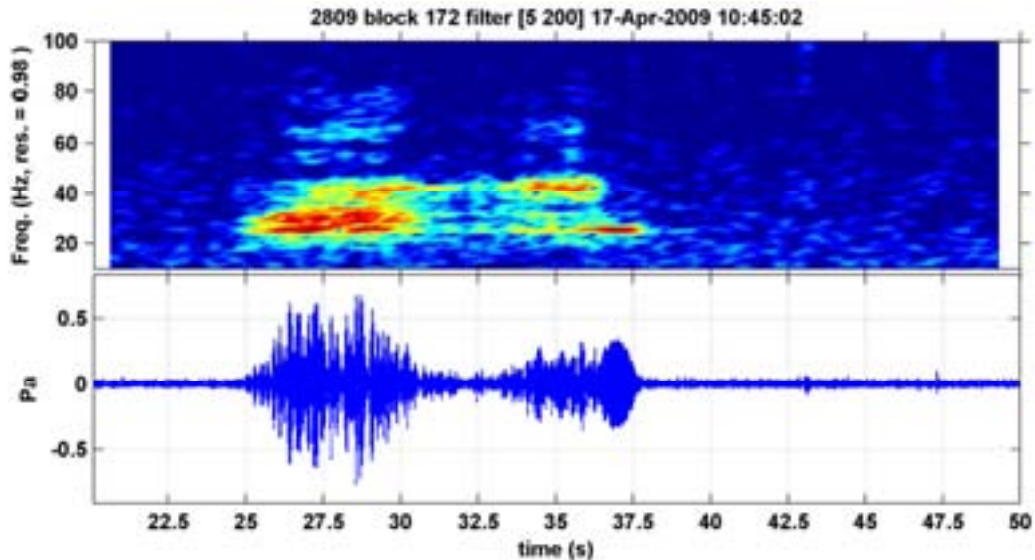


Figure 17: Example of a call type heard at the 43 m depth inshore site (2809) and believed produced by a Brydes whale.

3.6 Humpback whales

Humpback whale song featured prominently in the inshore set 2809 (43 m) and later, at the offshore tracking site although it was much more difficult to locate signals at the offshore site. It is difficult to obtain counts of the numbers of singing humpbacks as the song structure is fluid, made up of many elements and often involves multiple overlapping singers. The aim of analysis with humpback song is to gain counts of the numbers of calling animals at any point in time, or a 200 s sample here. Given the short time frame available for this preliminary analysis then obtaining the full analysis of humpback singing has not been completed. Once the counts have been completed we can compare the numbers of humpbacks with larger scale regional data sets.

An example of a noise logger sample with two humpbacks singing from the 43 m depth inshore site is shown on Figure 18. 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.

Quantifying humpback singing at the offshore site has 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 9 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 (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.

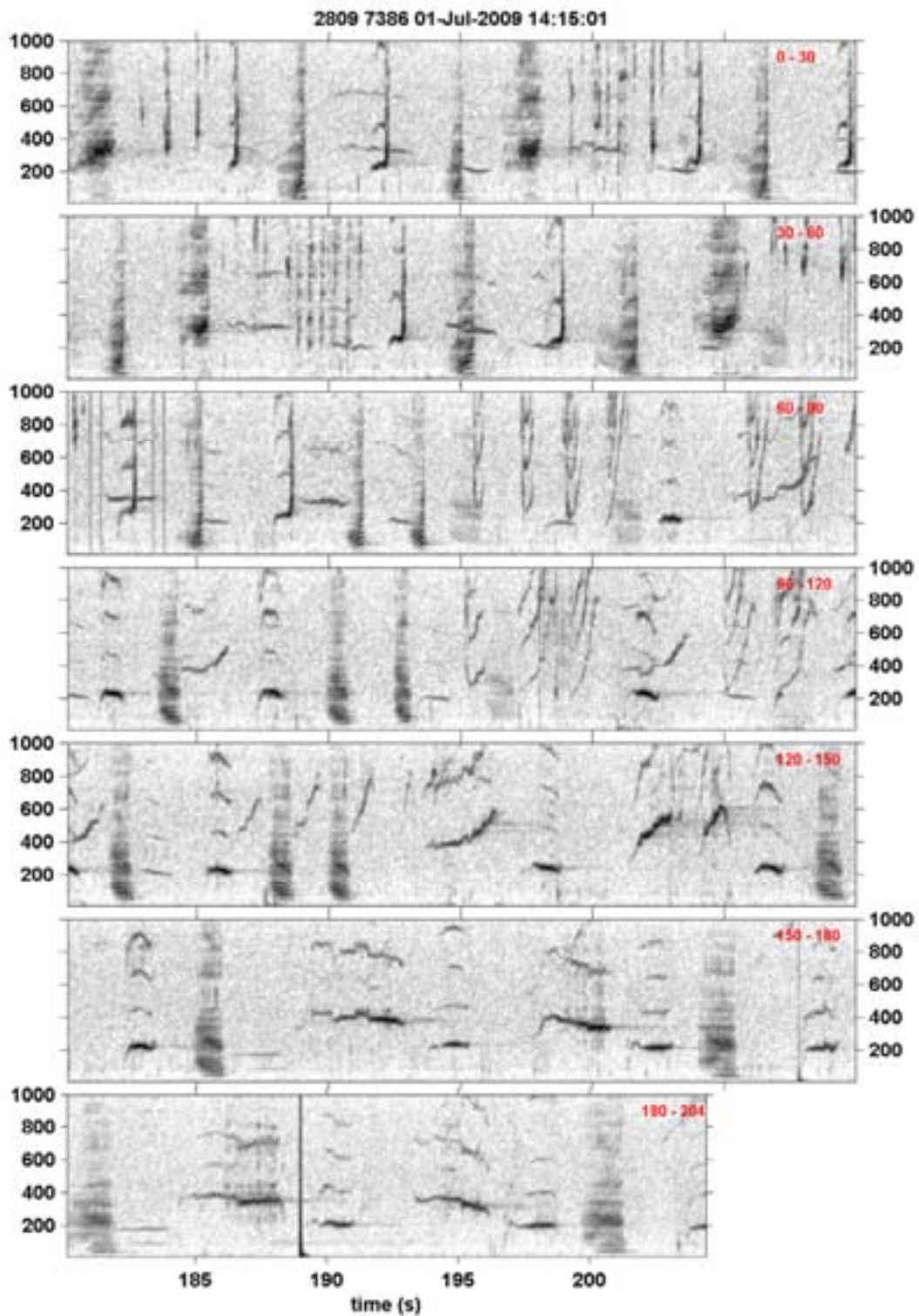


Figure 18: Spectrograms of 204 s of section with two humpback singers from the 43 m site in July.

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. The full analysis of humpback singing is awaiting analysis. Humpbacks were present at times within less than a km of the receiver.

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 19 (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.

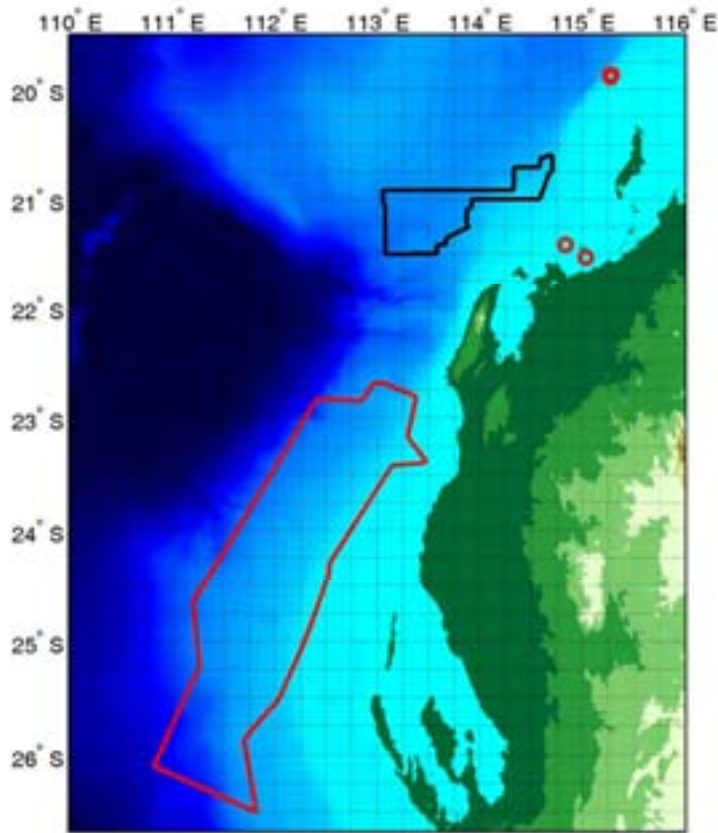


Figure 19: Location of seismic survey regions where vessels were known to be operating over the Wheatstone Phase I period. The red survey area had one vessel run by Gardline, the black survey area had two vessels operated by Fugro Surveys.

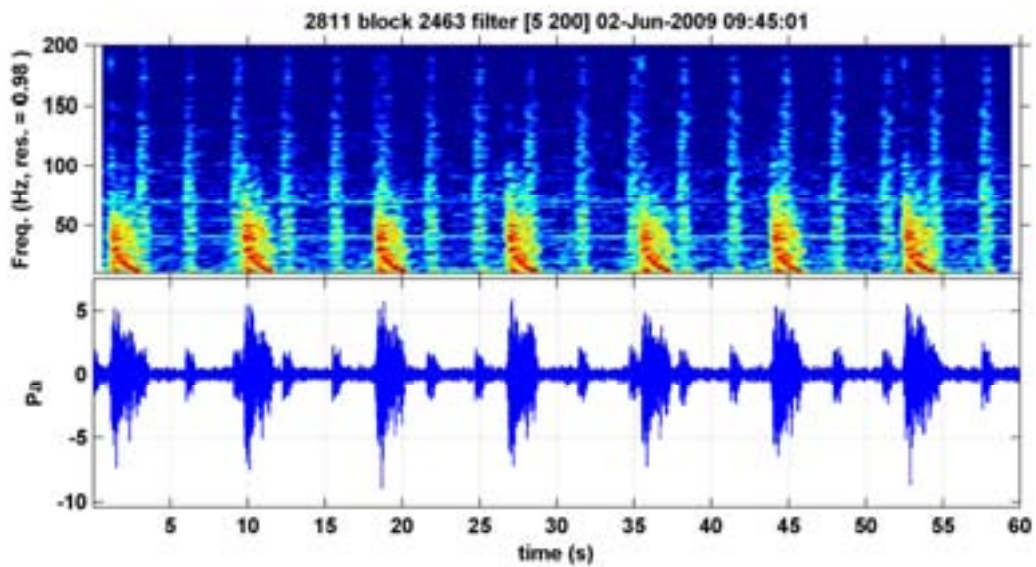


Figure 20: Example of period from the Wheatstone site with three seismic vessels operating.

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 21 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.

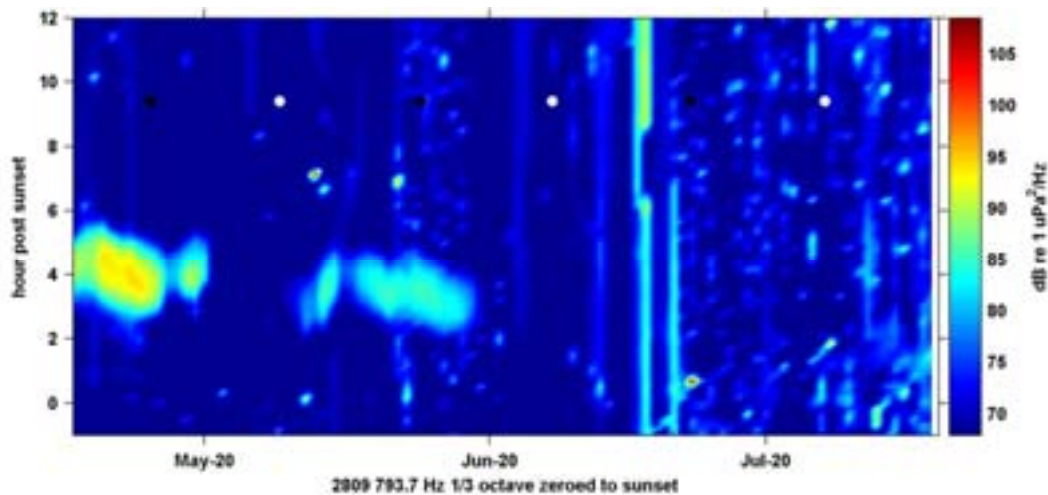


Figure 21: The 800 Hz 1/3 octave levels across each evening from the inshore 43 m site, as indicative of the nocturnal planktivorous fish choruses. The evening time scale was zeroed to time of local sunset. The fish choruses are evident as the energy over 2-6 hours into late May. The small circles are 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 km²) 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 4

Opportunistic Observations of Humpback Cow-Calf Pairs in Waters Nearshore of Onslow



APPENDIX 4: Opportunistic Sightings of Humpback Cows with Calves, Early August 2009

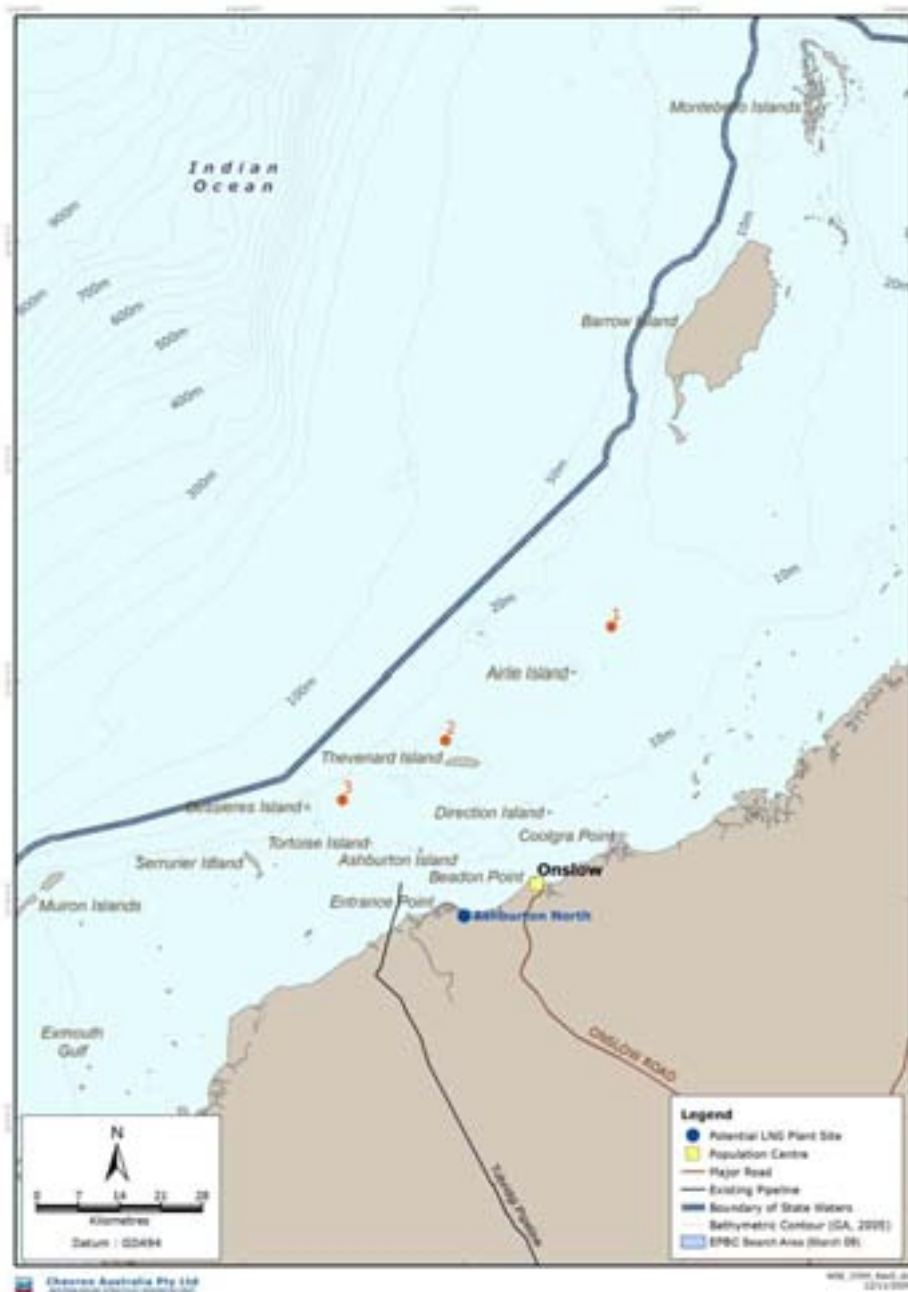


Figure one: Locality of observations



Sighting One: Very Young Humpback Calf (Mother not in Photo)

The size, proportions and possible folded dorsal fin indicate that this is a very young calf. Photo taken 02 August 2009, water depth approximately less than 20 metres.



Photo: L. Smith

Sighting Two: Humpback Cow Exhibiting Potential Feeding Behaviour

This position was held for over twenty minutes with calf successively diving down, spending a period under water then surfacing. Photo taken 05 August 2009, water depth approximately less than 10 metres.



Photo: R. Strom



Sighting Three: Humpback Cow with Very Young Calf

The calf's short body and rostrum length and largely proportioned tail flukes indicate that this is a very young calf. It possibly also has a folded dorsal fin and foetal folds and it appears that the mother is supporting it to the surface at times. Photo taken 06 August 2009, water depth approximately less than 20 metres.



Photo: D. Hanf



Photo: M. Buck



Photo: M.Buck



Photo: M.Buck

Appendix P1

Coastal Geomorphology of the Ashburton River
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**COASTAL GEOMORPHOLOGY
OF THE ASHBURTON RIVER DELTA
AND ADJACENT AREAS**



Damara WA Pty Ltd

May 2010

Report 82-01-01



Executive Summary

Chevron Australia Pty Ltd (Chevron) 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 Wheatstone Project is referred to as the Project and the Ashburton North Strategic Industrial Area (Ashburton North SIA) is the proposed site for the LNG and Domgas 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 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.

Development of coastal infrastructure to support the Project, includes construction of a dredged navigation channel, product loading facility (PLF), a materials offloading facility (MOF) and an incoming natural gas condensate (condensate) and LNG trunkline. The proposed site lies west of Onslow, near the eastern end of the low-lying Ashburton deltaic system, which exhibits a complex structure suggesting alternating erosive and depositional sequences.

Sediment dynamics determine a number of the key management requirements for the facility and its impacts, including coastal stability, trunkline engineering, breakwater configuration, maintenance dredging and potential disruption to existing habitats.

The specific objectives of the geomorphic investigations are to:

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



Several aspects of aspects of the coast were examined. These include the regional setting of the site; metocean drivers affecting coastal stability and change; landforms of the site and its surrounds; and an assessment of coastal change. Their ramifications for site development are summarised below.

Landform assemblages and geomorphic components

Geology

Geology is significant as foundation for the proposed Project coastal infrastructure through identification of its clastic and non-clastic components, as well as for its influence on coast stability and development. In the latter context it determines the character and distribution of landforms; and potential impacts of environmental change on, and potentially as a result of, the proposed development.

The hard-rock geology provides a fixed framework, including topographic controls shaping the arcuate shelf plan form and its surface structures on the shoreface between Tubridgi Point and Cape Preston. Offshore, chains of islands and shoals form lines approximately parallel to the shore between the mouth of Exmouth Gulf and Barrow Island. Their presence has ramifications for wave-diffraction, water-current patterns and sediment movement in the nearshore environment. Closer to shore, the geologic framework forms a discrete sediment cell extending along the coast and in the nearshore waters from Tubridgi Point to Coolgra Point.

At least two deltaic complexes comprised of coalescing limestone structures contribute to the geologic framework; one crossed by the Ashburton River, the other forming the undulating pavement supporting the catchments of Hooley Creek and Four Mile Creek. The limestone structures include lithified forms of antecedent shorelines, beach ramps, fringing coral reefs, rock platforms, palaeo-river channels, overbank basins and topographic rises. It is anticipated these topographic features would provide the framework structure of the shoreface from the shore to the 50m isobath.

Geomorphology

Geomorphology of the coast at the proposed site and its environs has been investigated by field reconnaissance and survey; interpretation of aerial imagery and desktop analysis of available metocean data. A selected set of field samples have been assessed using radiometric dating, to identify the sequence and age of the geomorphic features identified through field survey and aerial image analysis.

At a regional scale three distinct compartments are discernable along the coast: from Locker Point at the mouth of Exmouth Gulf to Coolgra Point; Coolgra Point to the longitude of Passage Island; and from there to Cape Preston, after which the geology of the coast changes significantly. The western, (Ashburton) compartment is a single sediment cell extending over 70 km from approximately Tubridgi Point to Coolgra Point. Its distinguishing geomorphological features include the active delta and tidal creeks of the Ashburton River, long sandy beaches and dunes as well as island chains running approximately parallel to the shore.



At a sub-regional scale functioning of the western (Ashburton) compartment as a sediment cell is especially relevant to marine and coastal management at the proposed development site because disruption of one part of the cell is highly likely to affect the stability of the coast downstream. The cell has two sectors: west of the mouth of the Ashburton River between Tubridgi Point and Entrance Point; and the eastern shore from the river mouth to Coolgra Point. Sediment in the western sector is largely marine material reworked by erosional processes acting on the shoreface and beach as well as by littoral drift along the shore. In contrast to this, sediment in the eastern sector including the coast of the proposed development site, is of largely fluvial origin and reworked as chenier spits migrating eastwards from the mouth of the Ashburton River.

The major transport path in the cell is eastwards along the shore, at the beachface, with much of the material being supplied as littoral drift along spits fed from the Ashburton River. There is also some evidence of sediment movement along slope breaks on the inner shelf and perhaps across the shelf pavement. Although these are not as substantial as the littoral pathway they may have ramifications for dispersion of dredged material placed on the shoreface and the rate of sedimentation for dredged navigation channels. Sediment sinks include long chenier spits, coastal dunes and inshore shoals as well as deposition on mudflats by tidal creeks.

At a local scale the active delta of the Ashburton River has been produced by the interaction of low to intermediate wave energy, strong littoral drift, micro- to meso-tidal fluctuations and modally low to moderate fluvial discharge; all of which may be overwhelmed by extreme conditions during tropical cyclones. The active deltaic plain is highly dynamic and provides a source of sediment for intermittent accumulation at the mouths of the Hooley Creek – East Creek tidal creek complex.

Sediment is exchanged between the coastal wetlands (salt flats and mud flats) and inshore waters via the tidal creeks. Hence the role of the tidal creeks in exchanging sediment between the terrestrial and marine environments warrants further scrutiny since this process is likely to affect and be affected by the proposed development. The dominant sediment transport mechanism apparently switches between two extremes. First, erosional scour of the salt flat and mud flat margins occurs as water levels fall after flood inundation by fluvial run off. Second, the tidal creeks may deposit silty sands and mud on the mudflats in places where the flood-tide flows are dominant and/or fluvial run-off is hindered.



Coastal and marine processes

Onslow is located towards the western margin of the North West Shelf. It experiences an arid sub-tropical (sub-monsoonal) climate. The majority of weather systems are tropical in origin, including occasional tropical cyclones, which are clearly associated with all the most severe wind observations on record. During summer months, rainfall mainly occurs from thunderstorms, with a highly variable contribution from tropical cyclones.

Ambient Winds

Two long-term weather stations have recorded wind; at Onslow Jetty from 1957 (BOM site 5016) and Onslow Airport from 1940-1975 and 1998 onwards (BOM site 5017). Observations have been made with variable frequency, with the Onslow Jetty data from 9am and 3pm only. Data from Onslow Airport is 3 hourly, but largely only during daylight hours for the period 1940-1975.

Although the general pattern of prevailing westerlies and a weak northerly component is consistent between the two sites there is a marked difference between the records from them. The key implication of this difference is that there are factors requiring careful interpretation if the locally observed winds are to be used for the validation of regional wind fields such as the NOAA or MesoLAPS data sets.

Wind direction frequencies for each 3-hour intervals for observations made at Onslow Airport identify the land-sea breeze cycle at Onslow. Such local winds are poorly represented by global wind field models although they locally modulate nearshore waves and currents; something that is difficult to represent accurately using numerical modelling. It creates potential misinterpretation when using coastal winds for the validation of modelled or gridded wind data sets. The significance of local winds upon nearshore waves and currents has not been assessed at the development site through the metocean instrumentation program (Metocean Engineers 2008).

Tropical Cyclones

Analysis of the directions associated with strong winds at Onslow Airport indicates they most frequently occur from the northeast quadrant. However, this directional bias is not reflected in the distribution of winds stronger than 75 km/h, which have occurred from a wider range of directions. Although median wind speeds are not great, Onslow has historically experienced very strong winds, and is classified within Category D in the Australian wind code, which represents the most severe wind conditions (Standards Australia 2002). Comparison of the strong wind record against the Bureau of Meteorology tropical cyclone database suggests that effectively all wind events above 60 km/hr may be attributed to tropical cyclones. The region frequently experiences intense tropical cyclones with cyclones causing gusts above 90 km/hr at Onslow approximately once every two years.

Tropical cyclones passing to the northwest, particularly systems that track parallel to the North West Shelf are more frequent than those from other onshore directions. This suggests that tropical cyclones will typically reinforce the eastwards sediment transport, with occasional reversal of transport. It also indicates the diversity of possible cyclone paths relative to the site needs consideration in numerical modelling of nearshore sediment transport.



The severity of tropical cyclone impacts has been evaluated for wind, surge and river flow. Comparison of the cyclone paths associated with high river flow, strong winds or high surges indicate that different design cyclones may need to be considered for the extremes of each environmental parameter.

- High river flow is largely associated with tropical cyclones that recurve towards the southeast, passing over the Ashburton catchment in the southern Pilbara;
- Strong winds have principally been recorded when Onslow is on the leading left quadrant of the cyclone system, matching expected behaviour (Holland 1983). Consequently, the majority of strong wind events have been associated with tropical cyclones that pass to the north of Onslow;
- The most extreme observed surges are associated with extreme onshore wind events, caused by tropical cyclones passing nearby to the west of Onslow. However, more frequent moderate surges may also be generated by tropical cyclones travelling parallel to the coast. It is understood that this is likely to be a result of shelf wave formation, when winds are shelf-parallel.

Interannual variability

Climate analyses suggest relatively complex relationships between regional climate indices and the monsoon, with the Southern Oscillation and Madden-Julian Oscillations affecting to the onset, intensity and termination of the monsoon period, as measured by winds and rainfall. As Onslow is sub-monsoonal, the relationship between wind and rainfall variation is weaker than the tropical regions. However comparison of annual cumulative summation winds against the Ashburton River flow record from Nanutarra suggests a period of weaker easterly trades from 1996 to 2002 corresponded to a spike in runoff and coincided with a period of enhanced tropical cyclone activity.

Variation of the wind conditions over inter-annual and inter-decadal time scales has implications for the relative stability of coastal sedimentary features, as changes in the regional wind regime affects the direction and persistence of nearshore waves and currents.

Waves

Wave conditions at the Project site are presently being measured through a dedicated metocean monitoring program, offshore from the project site by RPS Metocean on behalf of Chevron. Two acoustic wave and current meters (AWACs) and a directional wave rider buoy have been deployed (Metocean Engineers 2008).

Metocean observations made from January to September 2009 show moderate wave conditions at the offshore waverider buoy site (52m depth) and generally mild wave conditions at the inshore AWAC site (8m depth). The median wave conditions are 0.89m significant wave height and 11s period, from 270° at the directional waverider buoy, with the corresponding conditions of 0.22m wave height and 7.8s period, from 300° at the inshore AWAC. The significant change between the two locations indicates the degree of sheltering, including the effects of friction, diffraction and refraction from outside Thevenard and Bessieres Islands through to the nearshore region. The large change of modal direction clearly indicates the role of refraction.



Although a complete annual cycle has not yet been recorded, the transition from 'summer' to 'winter' conditions is evident at both sites. The most significant feature is the relative increase in swell wave activity, resulting in longer wave periods during winter. The mild increase in offshore wave height does not carry through to the inshore site, as it is effectively counteracted by the increased refraction developed by the more westerly wave direction.

Due to the limited extent of time series available, it is unlikely that the observations cover the full range of synoptic conditions, particularly the potential for cyclonic winds to drive waves from a range of directions. Consequently, interpretation of the wave height-direction distribution is limited, and preliminary in nature. The behaviour of non-cyclonic waves should be confirmed using a record that extends for at least one year. Interpretation of the distribution should be considered, say using a long-term hindcast, for direction-critical facilities due to the large degree of inter-annual variability identified within the wind record.

Water Levels

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 mixed, mainly semi-diurnal tides are meso-tidal with a spring tide range of 1.9m.

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, a 4.4 year cycle developed from lunar elliptic motion and a 19.6 year cycle developed from lunar nodical motion. Cyclonic storm surges measured at the Beadon Creek gauge are up to 0.8m but are likely to be higher on the exposed coast at the Project site. Based on observed debris lines, larger surges have occurred.

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 (>2.8m CD) over the majority of the year. The relative timing of the tidal and mean sea level peaks provides increased potential for extreme water level events to occur as a result of late season tropical cyclones, in March or April. Modelling of extreme cyclonic water levels for the Onslow town site and Onslow Salt has estimated the 100-year ARI water level as 4.7m AHD (6.2m CD), including allowance for wave setup. This is significantly higher than water levels recorded at Beadon Creek tide gauge over the last 20 years, although no data was available from the gauge during the two most severe cyclones in this period.



Currents

Limited information has been collected regarding currents in the Ashburton region. Nearshore, the boundary effect of the coast causes all currents to run nearly shore parallel. In general, further offshore, the direction more closely follows the direction of forcing, with the notable exception of tide, which becomes more shore-normal near the shelf break.

Observation of bottom and surface currents at the proposed dredge material placement site, in 51m depth, shows direct response to weather systems. Background drift is not apparent within the record available, from January to April 2009

Rainfall & Runoff

The Ashburton River is subject to highly variable flow conditions, with extended periods of low flow and short periods of intense flow, generally associated, although not always, with extreme rainfall due to tropical cyclones. An apparent dramatic increase in the magnitude of flood events occurred over the period 1995 to 2000, compared with the preceding period from 1972 to 1995. However, the longer rainfall record from Onslow suggests that similar decadal scale fluctuations have occurred previously.

A major implication of the highly variable river flow regime is the capacity for the Ashburton River to episodically release massive sediment loads. Some indication of sediment carrying capacity is suggested by the very high associated turbidity.

Landform components

Four sets of landforms comprise the coastal area of the wider Ashburton River delta. These include the active deltaic complex of the Ashburton River, the Saddle Hill dune ridge and back-barrier flats, the Onslow mudflats and tidal creeks, and the active sandy beaches and associated coastal dunes. Additionally, the shoreface topography and distribution of rock outcrops along the beach, between Casugrina Point, at the eastern margin of the Ashburton Delta, and Four Mile Creek provides the geologic framework supporting local landforms and processes comprising the active foreshore and nearshore components of the coast.

Ashburton River Delta and cheniers

Throughout the Quaternary at least, the shifting Ashburton River has built a suite of coalescing deltas with the deltaic plain consisting of overlapping and inter-fingering delta lobes against a northwest facing rocky shore. The switching pattern has commonly resulted from channel avulsion with one of the few distributaries present at any time carrying the majority of water and sediment discharge. Channel avulsion, the change in channel position associated with extreme flood events, is typically associated with river systems bearing a high sediment load, under relatively low wave and tide conditions

Changes in channel position are apparent as palaeochannels on the floodplains, forming elongate depressions that may carry fluvial flood waters, contain tidal creeks along part of their length or form billabongs in wet seasons. The channels may be reactivated by tidal creek incursion, avulsion of the main river channel or engineered redirection of runoff on the mudflats.



At present, the active delta is asymmetrical with the river feeding chenier spits on the eastern side of its mouth. Its shape and the spits are indicative of a coastal environment subject to strong littoral transport along the lower swash zone of sandy beaches. Additionally, the cheniers and sand spits of the foreland constitute a substantial store of sediment that is highly unstable and could easily be remobilised by fluctuation in the intensity of fluvio-marine processes.

Sediment samples were collected from the beaches between Ashburton River and Beadon Creek for particle size analysis. The majority of beach sediments collected had a narrow size range, with a median size of 0.24 to 0.28mm (Figure 4-20). Slightly coarser sediments were observed at locations more exposed to wave action west of Beadon and Entrance Points, where winnowing of sediments is likely to have occurred.

West Saddle Hill dune complex and beaches

Several distinct landscapes form the West Saddle Hill dune complex: From east to west they include two ridges trending approximately SW to NE. The ridges are linked by dunes extending E to W along the coast and separated by backbarrier flats and a riverine plain to landward. The long NE trending ridge has formed on one of several Pleistocene shorelines apparent on the deltaic plain. The Onslow Mudflats lie to the east of the dune ridge.

A low, undulating riverine plain at an elevation similar to the Onslow Mudflats lies to the immediate west of the dune ridge. This is the area of interest for development. In its central area the plain supports a complex network of palaeochannels and overbank basins that hold water after inundation from the Ashburton River.

Further west, the NNE-trending western ridge is apparently comprised of parallel coastal dunes built on a chenier complex with recurved spits extending onto the riverine plain from the main body of the dune ridge as well as from its seaward margins. Reversal of the dominant littoral drift from an easterly to westerly flow is indicated by recurved spits at the seaward and landward limits of western margin of the coastal dunes. Here lobes of sediment abut the western ridge and spill onto the active delta of the Ashburton River. The size of the spits indicates a need to consider the potential reversal of littoral drift in any modelling of sediment transport along the coast.

The chenier spit spilling eastwards from the mouth of the Ashburton River at Entrance Point impounds a shallow lagoon along the coast between Casugrina Point and Hooley Creek. The lagoon is approximately 50m wide for much of its length, with a narrow beach, low rocky cliff and high vegetated dunes perched on the rocky basement evident on the landward side of the lagoon. The spit is welded to the beach at a rocky salient and beach ramp near the mouth of Hooley Creek. This is the proposed plant site for development.

Onslow mudflats and tidal creeks

Palaeochannels, tidal creeks, mudflats and residual mounds comprise the natural landforms of the Onslow Mudflats. Water flow through the tidal creeks provides the major exchange of sediment between the nearshore marine and terrestrial areas. With river flooding, it is a process affecting floodplain development through raising or lowering the elevation of mudflats and saltflats.



Constraint on floodwater discharge, particularly its restriction to a single discharge outlet adjacent to the development area, may result in channel entrenchment and enhanced erosion of the floodplain landward of the existing saltflats. It is also possible for this to be intensified by avulsion of the main channel of Ashburton River in association with extreme flooding events if tidal creek incursion reactivates a palaeochannel. While these are matters for consideration in site design and environmental management, flood discharge from a reduced number of tidal creeks also will affect littoral sediment transport processes.

The eastern beaches and dunes

Beadon Point is backed by high dunes fronted by a deep swale and lower primary dune. The beach to the south east of the Point is very narrow and appears to be eroding, with small rock groynes apparent. Onslow townsite is protected from erosion by a long revetment seawall and adjacent beach however the depth of the toe of this seawall is uncertain. The section of the seawall closest to the Point, protecting the local memorial, is in poor condition with rubble apparent along the toe.

Rocky shore

Limestone outcrops discontinuously along the coast between Casugrina Point and Beadon Creek. The outcrops include low aeolianite bluffs at the seaward margin off the frontal dunes; platform and bluff along the southern shore of the lagoon near the Project site and in the vicinity of Four Mile Creek, where it joins a beachrock ramp sloping seaward onto a subtidal pavement.

Several affects are apparent. First, the low bluff along the shore of the lagoon inhibits, but does not prevent development of a sandy beach along the shore. Second, breaks between rock outcrops are areas of potential coastal instability, areas where erosion is most likely to occur under prolonged storm conditions and/or rising sea level. Third, away from Casugrina Point, the updrift, eastern margin of breaks between outcrops commonly have frontal dunes which are higher than those landward of the adjacent outcrops.

Coastal development during the Late Holocene

Coastal change occurs over a wide range of temporal and spatial scales, all requiring consideration in the context of long-term planning for site development and maintenance.

A broad indication of the geologically development of coastal landforms has been made through radiometric dating; particularly an old, coral-dominated platform on a rock outcrop in the mudflats of Hooley Creek tidal complex at 21°41.47'S and 115°00.78'E; shell material from borehole samples obtained through the geotechnical investigations; Recent (<50,000 years before present) landforms in the highly-active chenier foreland plain comprising the eastern delta of the Ashburton River; and modern wrack lines in the foredunes at Casugrina Point.



The age of the corals is currently estimated at approximately 120,000 years BP – the time of the last interglacial high sea level. The estimated date, beach-rock platform on which the corals had grown and its apparent relationship to sea levels past and present are of scientific significance. For this reason Saddle Hill is likely to attract attention as a potential Geological Monument under Commonwealth Government legislation. The extent of such features outside the development site remains to be established.

The next series of dates obtained were taken from the geotechnical cores at 3m to 6.5m below the surface of the floodplain. These approximately correspond to the beginning of the last glacial maximum and coincide with the end of a period of rapid global sea level fall, and thus probably mark a phase corresponding to the lowest of influence of marine conditions and inundation at the site. These results suggest the site was sensitive to sea level variations that were occurring in many parts of the world at this time. Modern sea levels established after about 6,000 years before present.

Shallow core samples from the eastern delta of the Ashburton region gave dating that varied from modern to approximately 7,500 years, which is consistent with development of the modern delta surface over the late Holocene standstill. Lithified strata underlying much of the eastern delta, and emergent in parts, is considered likely to be older, probably Pleistocene, but has not yet been dated.

The modern wrack lines in the foredunes at Casugrina Point are significant because they occur at approximately 5m and 13m above present mean sea level. They provide evidence of either tsunami activity, which is suggested by the assemblage of taxa present; or extremely high storm surge levels; approximately 700 years ago. Further fieldwork is needed to determine which is most likely; confirm the elevation of the high level wrack line at Casugrina Point; establish the geographic distribution of the deposit; and identify other geomorphic evidence for the occurrence of high sea level events.

Ramifications for site development

Rocky features of Pleistocene age may provide a basement platform for the site. These outcrop within 6 metres of the surface south of a discontinuous line trending approximately WSW from Four Mile Creek onto Urala Station where its presence remains to be confirmed. There are outcrops of older material north of this line, including dune features of undetermined age and some rock pavements.

Most of the surface material north of the line and those areas associated with the Hooley Creek and Four Mile Creek systems is subject to redistribution during extreme events associated with river flooding and storm surge inundation. In places modern shell beds interfinger older marine sediments and fluvial mud in the surficial 3m of sediment. These provide a contrast with the older surfaces found over 2km from the highly dynamic shore. Interfingering of the old and modern marine material is evidence of high magnitude events occurring in the past 3,000 years. This appears to be unmatched in the past 100,000 years.



Geoheritage

Examples of geoheritage features which would potentially attract interest include:

1. The chenier plain comprising the eastern delta of the Ashburton River;
2. The Last Interglacial platform identified through radiometric analyses of embedded coral and shell is intermittent and cut by the Ashburton River;
3. The interglacial shore on Urala Station. The shore includes 120,000+ yr BP landforms backed by coastal dunes. Both have been crossed by younger linear desert dune;
4. Biogeography of the system with its sub-fossil shell taxa; and
5. High level wrack deposits of the 700 year old tsunami or storm surge on the western part of the coastal dune ridge that provide evidence of the low-frequency high-magnitude events affecting the Ashburton River delta.

With the exception of the chenier foreland the extent of these features along the coast and their potential ramifications for site management remain largely unknown at the time of writing.

Areas of relative instability and potentially subject to risk

Shoreline movements in the vicinity of the proposed development site have been examined using photogrammetric analysis of historic aerial imagery from 1963, 1973, 1986, 1993, 2001, 2004, 2007 and 2009. Despite very high variability of forcing conditions, historic photographs show that the Ashburton coast has generally maintained a similar, slowly accreting shoreline position, with only local features experiencing significant change, including the deltas, cheniers and spits at the mouths of tidal creeks.

Ashburton Delta

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

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



The Hooley Creek complex

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

In 1973, the entrance was located further west towards the centre of the three tidal creeks. There were two spits in the order of 1.0km length on both sides of the entrance with the western spit further offshore. During the 2009 field inspection the entrance bar at Hooley Creek was estimated to be about 1.2km in length. The sequence of change and its ramifications for water discharge from the site will be examined as part of the hydrological survey program.

Sediment Transport Rates

Analysis of the shoreline movement plans over the period 1963-2009 provides indication of the rates of sediment transport along the shore:

- Supply to the west of the Project site 60,000 to 105,000 m³/yr
- Loss from the east of the Project site 35,000 to 70,000 m³/yr

These rates are consistent with modelled wave driven transport modelled by DHI (2010), indicating a net accumulation on the western side of the MOF breakwaters and downdrift erosion to the east.



1. Introduction

Chevron Australia Pty Ltd (Chevron) 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 Wheatstone Project is referred to as the Project and the Ashburton North Strategic Industrial Area (Ashburton North SIA) is the proposed site for the LNG and Domgas 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 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 investigative approach used has included field reconnaissance and survey; interpretation of aerial imagery and desktop analysis of available metocean data. A selected set of field samples have been collected for chronological assessment using radiometric dating to identify the sequence and age of the geomorphic features identified through field survey and aerial image analysis.

It is intended that the results of the interpretation will assist with the development of coastal modelling, and provide information regarding sediment dynamics for the environmental impact assessment being undertaken by URS Australia. It is believed that much of this information is likely to be relevant for the engineering design of the facility.

1.1. OBJECTIVES

The broad objectives of this component of the environmental assessment are to identify recent historical changes to the geomorphology of the Project area and establish them in the broad contexts of Late Holocene coastal evolution and projected future changes, including the construction of Project infrastructure.

The more specific objectives are to:

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

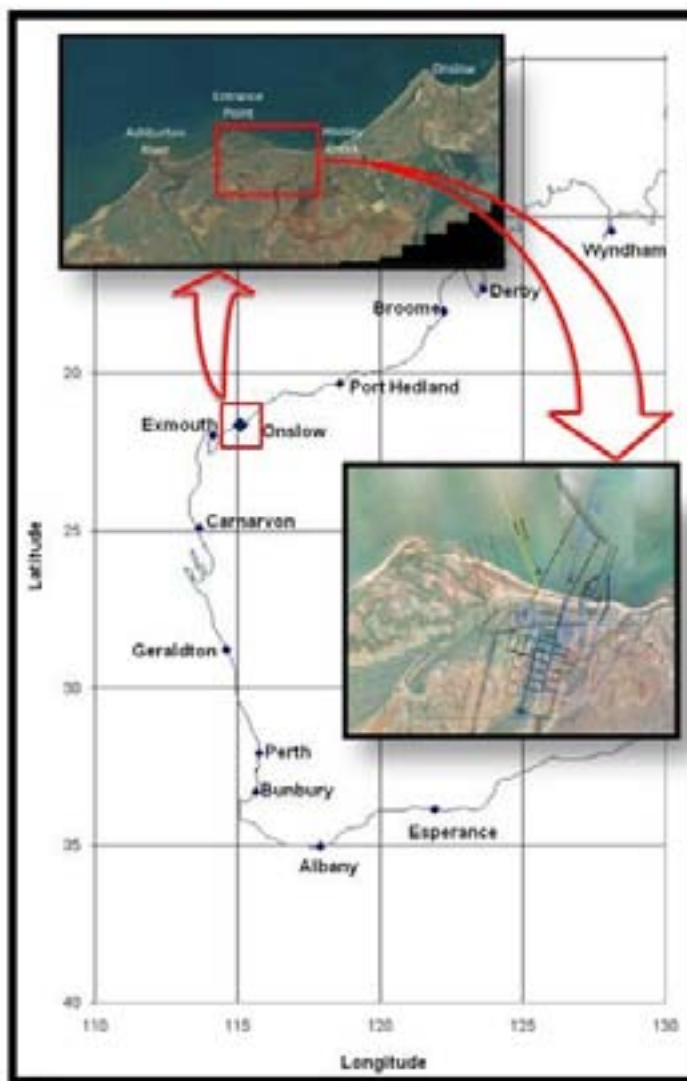


Figure 1-1: Location and Preliminary Nearshore Infrastructure Layout

1.2. METHODOLOGY

The survey area for examination and reconnaissance survey of the geomorphology of the Ashburton Delta and adjoining coastal area of the proposed Project site is illustrated in Figure 1-2. Evidence-based interpretation of the Ashburton delta morphology has been undertaken through a combination of desktop analysis and field inspection. Preliminary analysis of aerial photography and satellite imagery was undertaken to formulate working propositions for examination in the field.

1.2.1. Fieldwork

Field inspection was undertaken from 4th to 9th May 2009 using a combination of off-road vehicle access and one day visits to less accessible sites via helicopter. The focus of inspection varied between terrestrial and coastal locations, in accordance with expected processes and relative dynamics. At each site, photographs were taken to help identify key landforms and existing vegetation.

Terrestrial sites are identified in Figure 1-2, with landform, sediments and surface geology identified at each location. Shallow core samples were extracted at selected locations to obtain stratigraphic evidence. These are the numbered Core Sites shown in Figure 1-2.



Figure 1-2: Shallow Core Sample Sites and On-ground Photograph Locations

At coastal sites identified in Figure 1-3 surface sediments were collected for particle size analysis. Beach profiles and grades were measured using dumpy level and hand tools, with the presence of vegetation and structurally significant rock features identified and logged by photograph.



Figure 1-3: Beach Monitoring Sites



1.2.2. Aerial Image Interpretation

Aerial photographs of the region have been collated previously by DHI (2008). Currently available data is summarised in Table 1-1.

Table 1-1: Historic Aerial Photography – Onslow Region

Date	Scale	WANO	Comment
Sep-63	1:20,000	WA828	B&W plate
Jul-73	1:25,000	WA1471	B&W plate, photo 5351
May-86			B&W plate
Sep-93	1:50,000	WA3269	B&W plate, photo 5015
Sep-01			Digital rectified image
Aug-04			Digital rectified image
Oct-05			SPOT Satellite image
Feb-06			SPOT Satellite image
Oct-06			SPOT Satellite image
Feb-07			SPOT Satellite image
Aug-07			Digital image
Jun-08			SPOT Satellite image
Jan-09			SPOT Satellite image
Feb-09			IKONOS Satellite image

Available imagery from 1963, 1973, 1986, 1993, 2001, 2004, 2007 and 2009 has been used to develop coastline movement plots for the Project area. These drawings extend along approximately 25km of coastline from the Ashburton entrance to Beadon Creek (Whelans dwg 13776 series).



1.2.3. Coastal Chronology

Wright (1985) pointed out that

'No attempt at generalizing, no matter how detailed, can adequately convey the reality of natural deltas: each has its own individual attributes that set it apart from the others' (Wright 1985: 53)

The Ashburton River delta is no exception to this statement. River deltas develop as a result of sediment transport and deposition in response to complex interactions amongst fluctuations in sea level, change in the wave regime and variation in river discharge. The interactions commonly occur within an inherited and fixed geological framework, as occurs between Tubrigi Point and Coolgra Point. Within these constraining headlands, the Ashburton River is active and the river channel has changed position on several occasions during the past 6,000 years. This has been due to channel avulsion, and likely in response to extreme events such as river flooding and/or surge inundation. Over a longer period, and particularly during the past 500,000 years of the Pleistocene, the delta appears to have been subject to recession in response to marine transgression with the onset of interglacial periods, progradation at a time of falling sea levels and reworking of the land surface by aeolian and terrestrial processes between the times of extreme climate and sea level. The resulting morphology matches the process interactions in complexity. Between Urala Creek near Locker Point and Beadon Creek, the upper deltaic plain is a mosaic of sand dunes, flood plains, palaeochannels, active river channel, and saltflats, on an apparently dissected calcarenite limestone pavement that outcrops irregularly on the plains. Closer to the coast, the upper deltaic plain merges with the low coastal plain and includes an assemblage of coastal dunes, cheniers, spits, tidal creeks, palaeochannels, mudflats lagoons and overbank basins.

The form of the delta is transitional between the wave and tide dominated forms described in the literature, for example those by Suter (1994), with considerable modification by tides and the formation of tidal creeks. It has morphologic similarities with the Burdekin and Jaba deltas described by Wright (1985). Overall the delta of the Ashburton River has been produced by the interaction of low to intermediate wave energy, strong littoral drift, micro- to meso-tidal fluctuations and modally low to moderate fluvial discharge; all of which may be overwhelmed by extreme conditions during tropical cyclones. The active deltaic plain is highly dynamic. Although small in comparison to the full extent of the delta with its upland flood plains there is historical evidence of change in its location from Entrance Point to the present day river mouth. This is essentially a transition from deposition covering and flanking a lithified chenier plain to development of a wholly unconsolidated landform. It 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.

Radiocarbon and uranium series dating of shell and coral was used to estimate the ages of some of the sediments and land surfaces comprising the active delta in order to provide a first order separation of its landforms. This was done to provide an indication of areas of potential change that would yield sediment and impact on the proposed development area and further downstream. Samples were taken from shallow coring on the active delta (Figure 1-2), as well as surface samples along the shore and samples taken from deep cores collected by Coffey International. The sample locations are shown in Figure 5-3 and described in Section 5.3.



2. Regional Setting

2.1. REGIONAL GEOLOGY

A complex geologic framework of lithified Pleistocene and older landforms determines the coastal geomorphology of the western Pilbara Region, as it does around much of Western Australia (Sanderson 2000) and elsewhere (Cleary *et al.* 1996; M^cNinch 2004). The western Pilbara sub-region lies north of the Gascoyne Sub-basin and on the Peedamullah Shelf (GSWA 1975). Its superficial (surface) geology and geomorphic components have been reviewed and described by Semeniuk (1993; 1996). Apart from its intrinsic values including geoheritage values, the geology is significant as potential foundation for the proposed Projects coastal infrastructure through identification of its clastic and non-clastic components, and for its influence on the stability and development of the coast. In the latter context it determines the form and extent of foreshore and nearshore habitats and ultimately their bioproductivity, as well as the likely impacts of environmental change on, and potentially as a result of, the proposed development.

Partially lithified and unconsolidated alluvial sediments, mainly red sands, dominate the terrestrial landscape in the vicinity of the proposed Project, the area of immediate interest (Figure 1-1). Close to shore these are overlain in places by sediments of marine origin, including mainly shelly sands and reworked alluvial sands. Some of the sands are of recent Holocene origin. Mixed with reworked alluvial material these abut and overlie older Pleistocene sedimentary structures, particularly along the beach and in the nearshore waters. Further seaward the inner continental shelf landwards of the 20 m isobath supports two major structural features.

First, the Mangrove Islands, extensive sand shoals in the vicinity of the islands and Barrow Island form an extensive ridge trending approximately north-northeast off the mouth of the Cane River to water over 20 m deep. The ridge and North West Cape provide topographic controls shaping the arcuate shelf and its surface structures between Tubridgi Point and Cape Preston. The ridge and cape contribute to formation of a discrete sediment compartment extending along the coast and in the nearshore waters from Tubridgi Point to Coolgra Point. The sandy shores and nearshore morphology of the compartment differs in geological structure, sediment constitution, coastal processes and morphology from adjoining compartments; the extensive tidal flats of the Yannarie Coast within Exmouth Gulf and the muddy shores of the Robe and Fortescue River deltas to the east.

Second, chains of islands and shoals form lines approximately parallel to the shore between the mouth of Exmouth Gulf and Barrow Island. One line occurs in shallow waters, close to the 5 m isobath. The other is located closer to the 20 m isobath and includes more substantial islands such as the Muiron, Serrurier, Bessieres and Thevenard islands. The distribution of the islands is consistent with Holocene and earlier transgressions of the inner continental shelf and breaching of lithified coastal barriers during periods of rise to a high sea level. Their presence also has ramifications for wave diffraction, water-current patterns and sediment movement in the nearshore environment.



2.2. THE GEOLOGICAL FRAMEWORK

Between the mouths of the Ashburton River and Beadon Creek the geologic framework is comprised of at least two deltaic complexes comprised of coalescing limestone structures; one crossed by the Ashburton River, the other forming the undulating pavement supporting the catchments of Hooley Creek and Four Mile Creek (Semeniuk 1996). Both delta formations appear to be related to ancestral channels of the Ashburton River. Although eroded and reworked by marine process along the coast, it is highly likely the lithified surface morphology of the deltas is present offshore, including all landforms apparent in the terrestrial environment. It is anticipated lithified forms of antecedent shorelines, beach ramps, fringing coral reefs, rock platforms, palaeo-river channels, overbank basins and topographic rises would provide the framework structure of the shoreface. Following Cowell *et al.* (1999: 39), the shoreface is the transition zone between the active surf zone and the inner continental shelf. For convenience herein, the shoreface in the vicinity of the Ashburton River is part of the inner continental shelf and is defined as the area between the present day beach and the steep slope from the 20m to 50m isobath. It includes the most-active wave-dominated part of the coastal system, and is an area in which the mobile sands of the nearshore beaches and unconsolidated sediments of the shoreface proper overlie and are markedly affected by the geological framework.

From an examination of the influence of hard bottom topography on the shoreface morphology of Onslow Beach in North Carolina Cleary *et al.* (1996: 250-251) pointed out:

The shoreface geologic framework defines:

- I. *The compositional character of the sediment blanket;*
- II. *The role of hard bottoms in shaping the shoreface profile in determining the patterns of erosion on adjacent beaches; and*
- III. *The rates and process of degradation of hard-bottom habitats by natural physical and biological processes that contribute a significant amount of new sediment*

Their observations are pertinent to the marine environment of the Ashburton coastal compartment, at several levels, especially in terms of the time scales at which geomorphic changes are occurring close to shore.

2.3. COASTAL CONTEXT

At a regional scale the Project site is in the West Pilbara Region and is located in a primary (large) coastal compartment extending from Tubridgi Point to Cape Preston. Coastal compartments are identifiable from the plan form of the coastline and related to structural control by the regional geology. They are secondarily dependent on coastal aspect and large coastal landforms such as deltas and cusped forelands visible at a scale of 1:250,000. Each compartment is comprised of a complex array of physical landforms and coastal processes in which the state of the environment is highly dynamic, varying over space and time. Some of the landforms occurring within the compartment are described in Section 4.

Three distinct secondary compartments are discernable along this reach of coast. Starting from Locker Point at the mouth of Exmouth Gulf they extend to Coolgra Point; from Coolgra Point to the longitude of Passage Island; and from there to Cape Preston, after which the geology of the coast changes significantly. The secondary compartment is of immediate interest and is referred to here as the Ashburton compartment. It is a single sediment cell extending over 70 km from approximately Tubridgi Point to Coolgra Point. Distinguishing geomorphological features of the compartment include the active delta and tidal creeks of the Ashburton River, long sandy beaches and dunes as well as the island chains running approximately parallel to the shore. The western boundary of the compartment, a lithified chenier, marks a change from the WNW facing shore of Exmouth Gulf to the NNW facing coast of the west Pilbara Region.



There is also a change from the extensive saltflat, mudflat and tidal creek complex of eastern Exmouth Gulf to the partially lithified and unconsolidated sandy landscapes of the Ashburton compartment. Within the Ashburton compartment the geomorphology changes with distance eastwards. Saltflats and mudflats increase in extent east of Beadon Point. Alongshore, the sandy beaches and dunes of the Ashburton compartment gradually give way to saltflats and mudflats associated with the active deltas of Robe River and Fortescue River east of Coolgra Point. Offshore, the thin cover of sandy sediments over the pavement of the inner continental shelf appears to have been moved along and offshore to merge with the sandy shoals and islands abutting the Barrow Island ridge.

Functioning of the Ashburton compartment as a sediment cell is especially relevant to marine and coastal management because disruption of one part of the cell is highly likely to affect the stability of the coast downstream. As defined in the literature (Komar 1996; Patsch & Griggs 2006), a sediment cell is a reach of coast, including the nearshore terrestrial and marine environments, within which movement of sediment is readily identifiable if not largely self-contained. Sediment cells are segments of the coast in which sediments being or derived from a common origin or source can be traced along transport paths to a sink where they are temporarily or permanently lost to the coast. The cell has two sectors; the shore west of the mouth of the Ashburton River between Tubridgi Point and Entrance Point and the eastern shore from the river mouth to Coolgra Point. Although reversible with easterly winds dominant from time to time the net sediment movement is easterly. As a result, sediment in the western sector is reworked by erosional processes and littoral drift along the shore. In contrast to this, sediment in the eastern sector is largely of fluvial origin and 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 mudflats 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; and bioproduction and reworking of material from the inner continental shelf. The major transport path in the cell is along the shore, at the beachface, with much of the material being supplied as littoral drift along spits fed from the Ashburton River. There is also some evidence of sediment movement along slope breaks on the inner shelf and perhaps across the shelf pavement, although these are not as substantial as the littoral pathway. Sediment sinks include long chenier spits, coastal dunes and inshore shoals as well as deposition on mudflats by tidal creeks.

At a more detailed scale, the role of the tidal creeks in exchanging sediment between the terrestrial and marine environments warrants scrutiny since this process is likely to affect and be affected by the proposed development. Sediment is exchanged between the coastal wetlands (salt flats and mud flats) and inshore waters via the tidal creeks. The dominant sediment transport mechanism apparently switches between two key processes, which to some extent act in reverse. Both processes have implications for the bioproductivity of nearshore waters. First, inundation of the coastal wetlands by fluvial run off 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 to erosion is apparent as gullying at the headwaters of the tidal creeks, with tributary streams feeding into the active tidal channel. Erosion patterns of this kind are apparent in parts of the Ashburton delta and the western margin of the Onslow salt flats, where the creeks are becoming entrenched in the swales between recently formed cheniers. Second, in places where the flood-tide flows are dominant and/or fluvial run-off is hindered, the tidal creeks may deposit silty sands and mud on the mudflats. The 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, settling of the salt flats or diversion of the fluvial run-off in the area where they occur.



2.4. COASTAL TOPOGRAPHY & BATHYMETRY

2.4.1. Shelf-scale Bathymetry

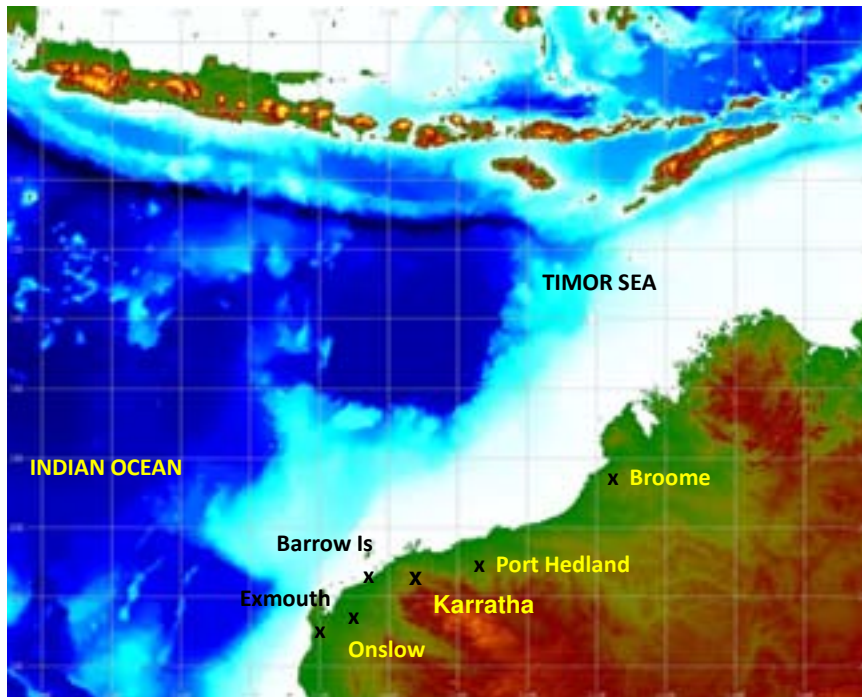


Figure 2-1 Timor Sea Bathymetry (from GEBCO database)

Onslow is located on towards the western end of the North West Shelf. The continental shelf narrows towards the west and it is roughly 35 km to the shelf boundary offshore from the development site (Figure 2-1). This position is generally sheltered, with southwest Indian Ocean swells diffracted around North West Cape and easterly swells from Timor Sea restricted by relatively shallow depths and limited fetch length.

The coastal margin of the Pilbara is generally low lying floodplain, interspersed with rocky headlands such as the Burrup Peninsula or Cape Preston that are oceanward extensions of the rugged upland.

2.4.2. Regional

The proposed Project site is located to the eastern end of a 40 km long section of coast between Tubridgi Point and Entrance Point that is almost linear, facing to the northwest. Coastal dunes from 3 to 8 metres high are present along the shore, underlain by coastal limestone that emerges above the inter-tidal zone irregularly, but provides the general linear structure of the coast. Significant shoreline control is provided by the extended rock ridge which includes Tubridgi Point.

To the east of the Entrance Point, the coast is defined by a series of arcuate beaches, extending more than 30 km to Coolgra Point (Figure 2-2 and Figure 2-3). Underlying rock platforms control the down drift (eastern) end of these beaches rather than rocky headlands which are more typically associated with arcuate beaches. Coastal dunes are present along most of the shore. These are perforated by tidal creek networks and in the vicinity of the mouth of Hooley Creek show evidence of localised washover likely to have occurred during tropical cyclonic flooding. These systems provide partial connection to extensive mudflats landwards of the dunes. The mudflats are subject to seawater inflow during very high tides or cyclonic coastal flooding.



The most significant difference between the coastal morphology in either direction from Entrance Point is considered to be the availability of sediment, although the Ashburton River is the major source of sediment to both sections of the 70 km long sediment cell. As with the coast between Entrance Point and Coolgra Point, a substantial amount of sediment east of Entrance Point has been derived from the Holocene transgression of the inner continental shelf and contemporary reworking of dune sediments by beach erosion and tidal creeks as well as from river discharge. The disparity between the two reaches of coast is associated with the dominance of easterly littoral transport from the river and the alongshore migration of large slugs of sediment, such as that comprising the active chenier spit immediately west of the Project site.



Figure 2-2 Coastal Plan-form near Proposed Project Site



Figure 2-3 Bathymetry near Proposed Project Site
Extract from AUS Chart 743



Some explanation of the “two-peaked” deltaic structure for Ashburton River is suggested by the local bathymetric features (Figure 2-3). Sheltering provided by Curlew Bank provides enhanced coastal stability, and encourages the formation of a coastal salient, following Silvester & Hsu (1996). As the capacity of offshore features to retain sediment is limited to their proximity to shore, there are two possible “stable” configurations, depending upon the influence of the bank. The Saddle Hill dune ridge, which marks the southern limit of the deltaic complex is consistent with the “alternative” configuration, where structural control is provided by rock outcropping at the shore near the proposed MOF site.

2.4.3. Shoreface Topography & Bathymetry

At the time of writing little detail describing the topography of the shoreface between Entrance Point and Beadon Creek was available. However, the area is currently subject to investigation of its bathymetry and marine habitats. It is anticipated the shoreface topography will contain seaward extension of many of features observed in the terrestrial coastal environment, and that these will provide the geologic framework controlling the effect of ocean process in a manner similar to affects described from elsewhere by Cleary *et al.* (1996), Mc Ninch (2004) and Valvo *et al.* (2006). The major topographic features of the shoreface are likely to include the beach (intertidal and subtidal), rock pavement reef (submarine platform), erosional bluffs associated with shorelines formed at lower sea levels, palaeochannels, gorges and topographic rises. Because undulations in the submarine topography on the shoreface affect wave refraction and water circulation they should be considered in any modelling of sediment transport. For example, although the greatest volume of alongshore sediment transport apparently occurs as littoral transport along the beaches some takes place along the slope breaks occurring on the pavement, with the pavement being swept clean of sediment. The relative contribution of each of these components to the sediment budget, and hence their potential impacts on development are under assessment. Also it is likely offshore topography provides the anchor point for development of the Entrance Point foreland and other promontories along the coast. How the stability of these features is likely to change with projected sea level rise is a moot point.

Limited interpretation has been undertaken of the bathymetric features evident from high density soundings (Figure 2-4). Hydrographic surveys have been undertaken for the purpose of engineering, and only cover the area between Entrance Point and Hooley Creek. The presence of several rocky features is suggested, including a nearshore rise, offshore bed features, channels linked to the Hooley Creek system and a 700m long and 100m wide rock ridge, which runs at approximately 60° to the shore. Offshore, the bathymetric contours are generally parallel to regional structure, which causes steepening and sharp curvature towards Entrance Point.

Features comprised of rock or low mobility sediments, such as the gravel bank identified offshore from the MOF site (Figure 2-3) may have a significant influence upon sediment transport patterns. First, they provide an area of lowered sediment transport, simply due to the less mobile nature of their material. Second, they may provide zones of sheltering in their wake, due to wave friction, breaking and scattering. It is common for less mobile features to be present in zones of relatively greater hydrodynamic stress. Finer sediments are stripped away from underlying rock, or winnowed out from the surface material, leaving only coarse gravels. Zonation of sediment mobility is considered likely to be related to relative stress: this is indicated in a broad on-shelf to off-shelf comparison by Margvelashvili *et al.* (2005) and has been identified at a smaller scale in the Port Hedland region related to the offshore focusing of tidal currents (GEMS 2009 *draft report*).

Evaluation of seabed types and materials is considered a key parameter for the estimate of sediment transport rates.

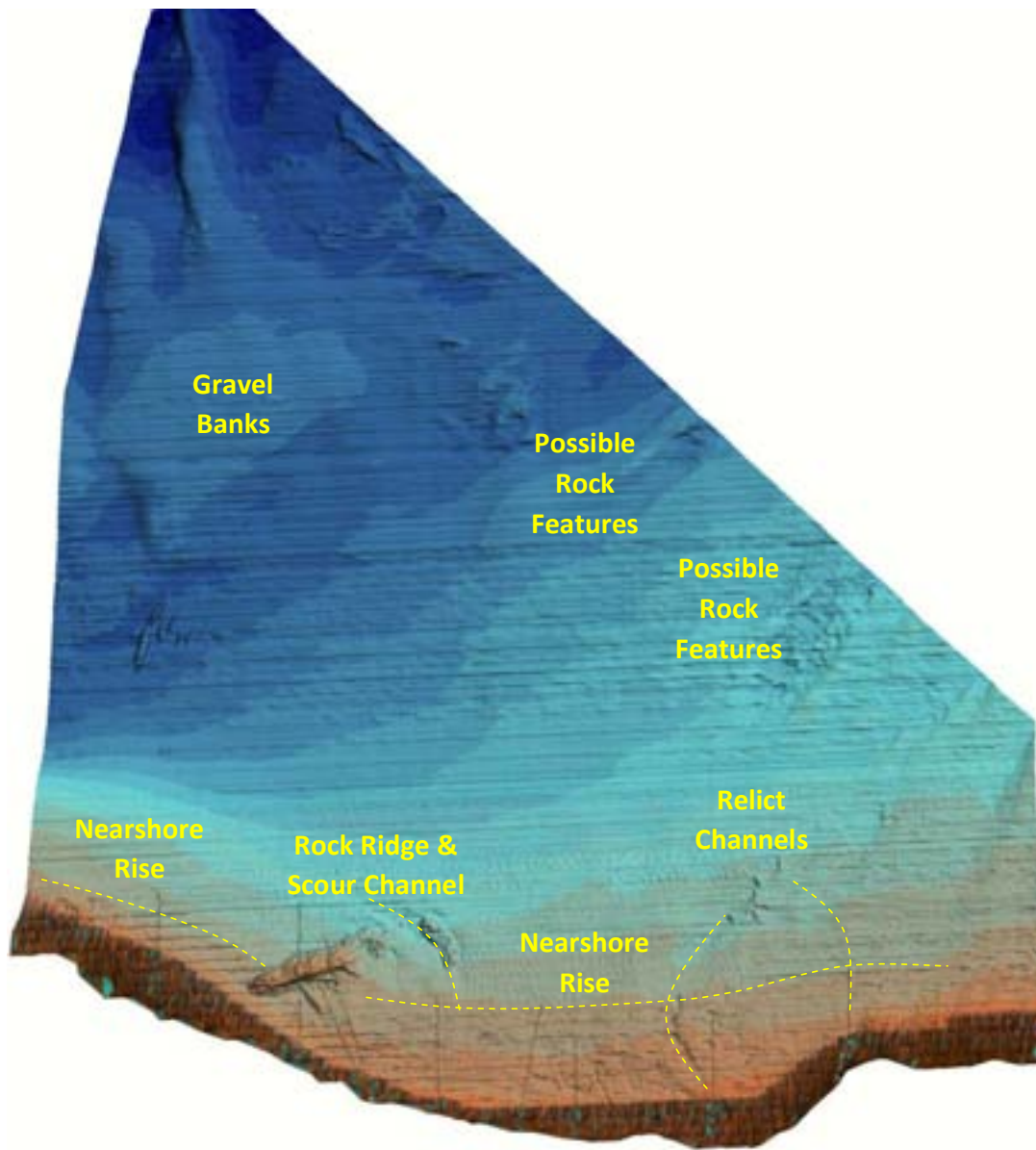


Figure 2-4 Bathymetry North of the Proposed Site

3. Metocean Drivers

3.1. WEATHER SYSTEMS

Onslow is located towards the western end of the North West Shelf, experiencing an arid sub-tropical (sub-monsoonal) climate. The weather is affected by latitudinal shift of the extra-tropical ridge, in combination with the summer continental heat trough (Gentilli 1971). This produces a distinct seasonal cycle of temperature and wind speed (Figure 3-1). Weather systems affecting Onslow are predominantly extra-tropical in character, with occasional influence of tropical and mid-latitude systems. This weather is similar to that affecting Exmouth Gulf (Steedman & Russell 1986).

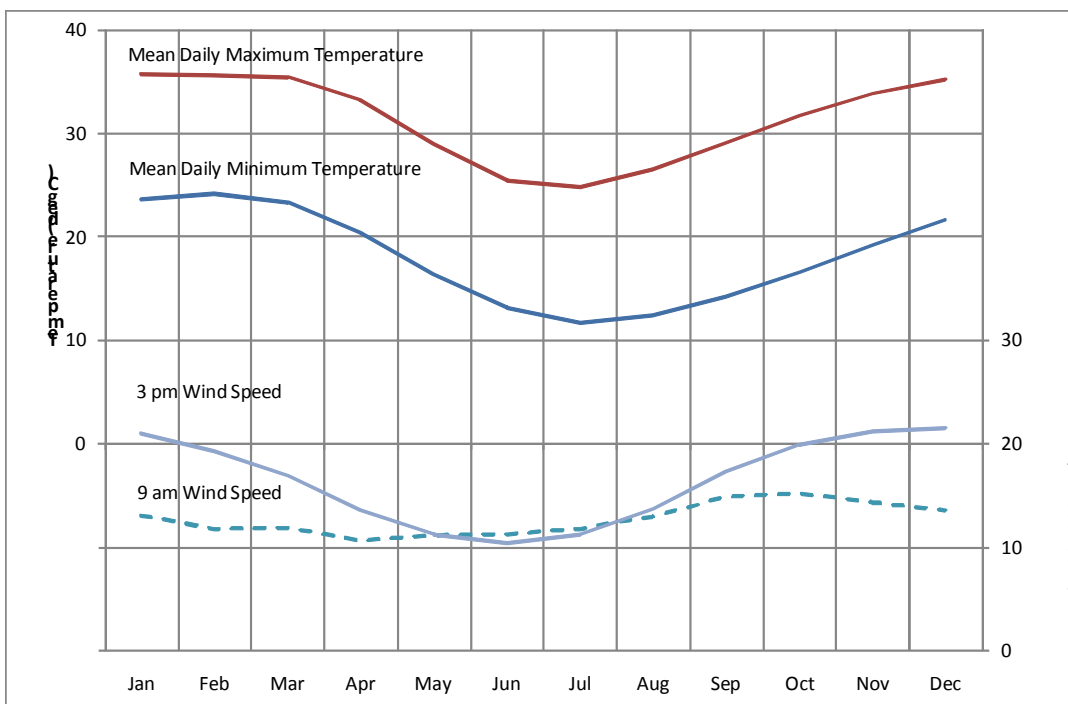


Figure 3-1 Monthly Wind and Temperature Summary (Data from BOM website)

Typical synoptic conditions during summer are illustrated by Figure 3-2, which shows a weak trough across northern Australia, associated with continental heating. This synoptic structure is a key feature of the Australian monsoon, and encourages movement of tropical air towards the central north of Australia. This effect declines towards the west, such that the Pilbara climate is typically arid year-round, rather than the wet-dry cycle experienced in the Kimberley. The majority of weather systems are extra-tropical in origin, although occasional tropical cyclones are clearly associated with all the most severe wind observations on record. During summer months, rainfall mainly occurs from thunderstorms, with a highly variable contribution from tropical cyclones.

At Onslow, the influence of the heat trough produces prevailing westerly winds during summer, which are modulated by a local land-sea breeze cycle, to typically produce southwest winds in the morning, and northwest winds in the afternoon. Prevailing wind conditions may be disturbed for several weeks during the passage and aftermath of tropical cyclones, or for longer periods associated with destabilisation of the heat trough, albeit with much milder influence.

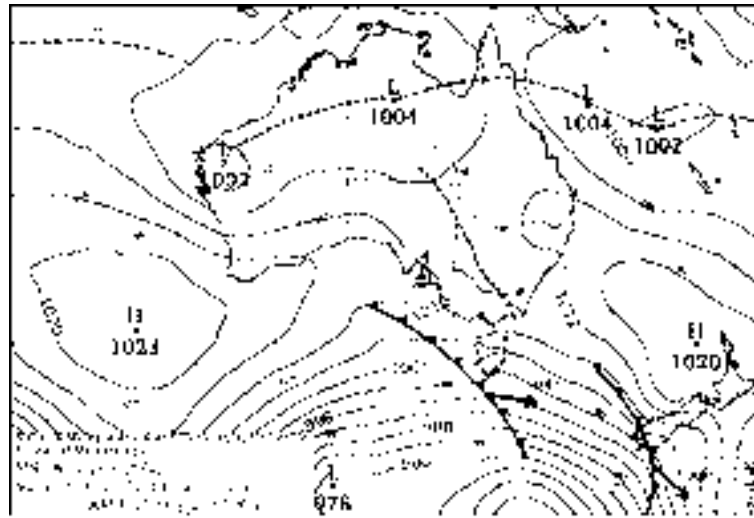


Figure 3-2 Common Summer Synoptic Conditions

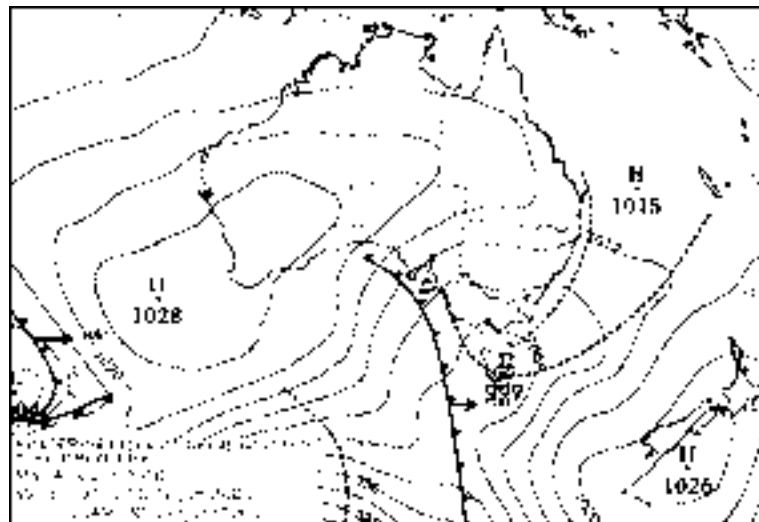


Figure 3-3 Common Winter Synoptic Conditions

During winter, a high pressure ridge typically dominates the mid-latitudes, which promotes weak easterly winds and dry conditions (Figure 3-3). Winds are highly modulated by the land-sea breeze cycle, which commonly produces a diurnal rotation from west to southwest in the early hours of the morning, through southerly and easterly to northerly or northeast winds in the evening. The northern reaches of mid-latitude synoptic systems, including the effect of pre-frontal troughs (Figure 3-4), occasionally influence the region, producing westerly winds and bringing rainfall.

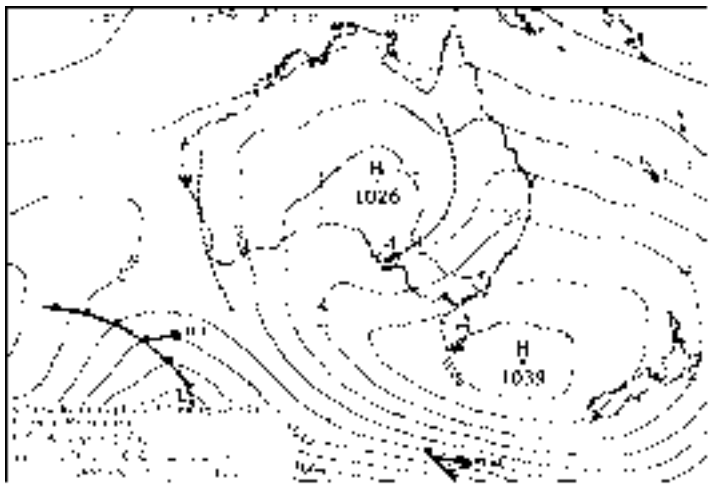


Figure 3-4 Synoptic Chart Showing Pre-frontal Trough

On average summer and winter events contribute a similar quantity of rainfall, with approximately 11 rainy days either season (Figure 3-5). Winter rainfall, although it is quite variable, is more consistent than summer rainfall, such that there have been a number of years in which negligible summer rainfall occurred, but there have also been occasions when a single day’s rainfall exceeded the annual average of 277mm (median 241mm).

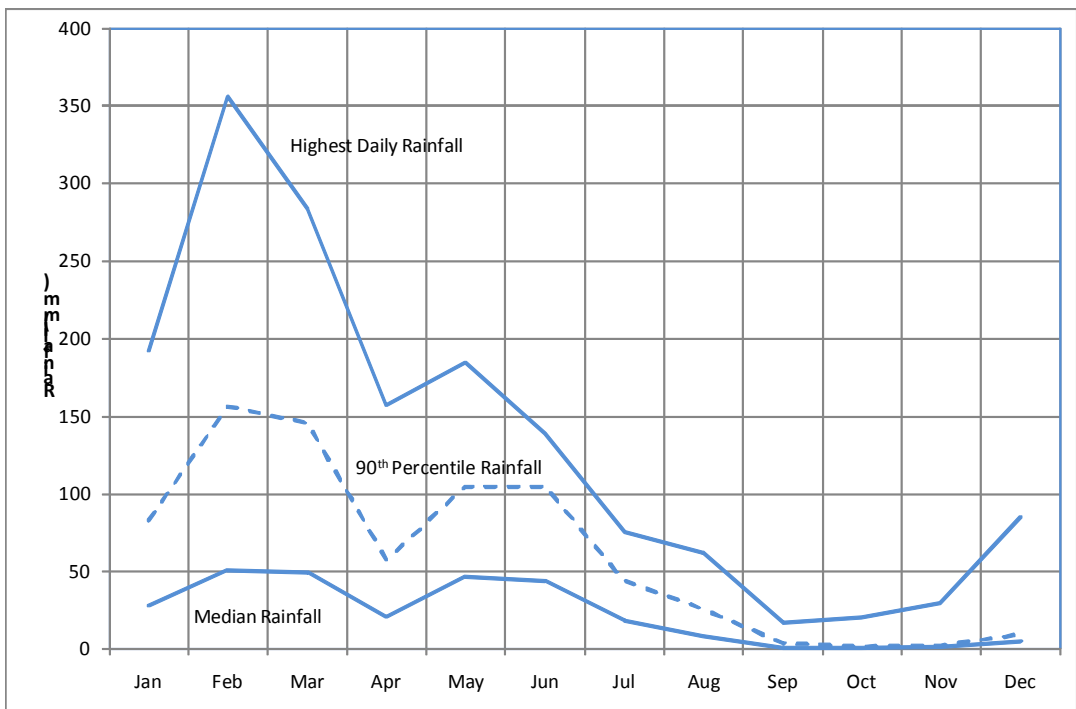


Figure 3-5 Monthly Rainfall Statistics (Data from BOM website)



3.2. ONSLOW WIND RECORD

3.2.1. Ambient Wind Conditions

Two long-term weather stations have recorded wind, at Onslow Jetty from 1957 (BOM site 5016) and Onslow Airport from 1940-1975 and 1998 onwards (BOM site 5017). Observations have been made with variable frequency, with the Onslow Jetty data from 9am and 3pm only. Data from Onslow Airport is 3 hourly, but largely only during daylight hours for the period 1940-1975.

Comparison of the wind speed exceedance suggests that Onslow Jetty observations are normally weaker than those at Onslow Airport (Figure 3-6). Median wind speed is 11.2 km/hr for Onslow Jetty and 18.4 km/hr for Onslow Airport. The marked difference between the two sites is likely to be due to the height and timing of the wind measurements, rather than suggesting an increase from over water wind speeds at the Jetty to those over land at the Airport. Its key implication is that there are factors which require careful interpretation if the locally observed winds are to be used for the validation of regional wind fields such as the NOAA or MesoLAPS data sets.

Although the general pattern is consistent between the two sites, with prevailing westerlies and a weak northerly component, a further discrepancy is revealed by the wind direction-frequency plots. Onslow Jetty winds (Figure 3-7) are effectively unimodal, although broadly spread, with the majority of winds from the south to west quadrant. The Onslow Airport plot (Figure 3-8) suggests a bimodal distribution, with southerly and westerly winds prevailing.

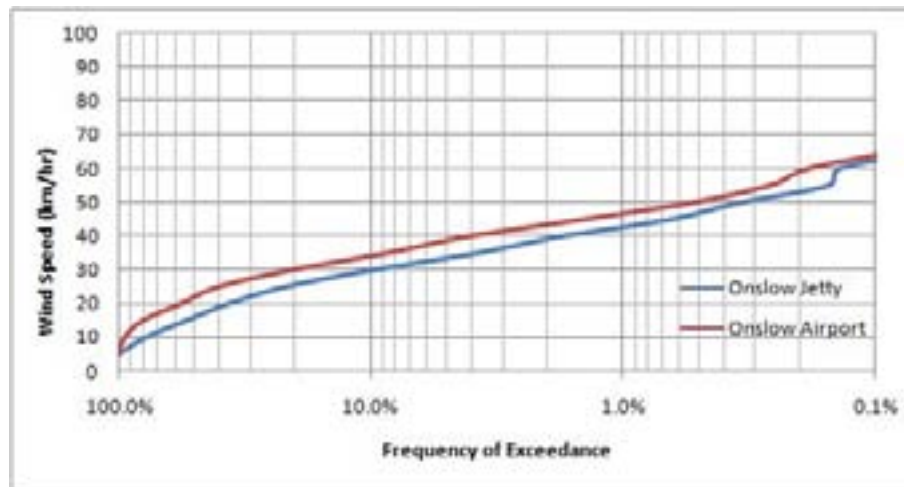


Figure 3-6 Onslow Wind Speed Exceedance

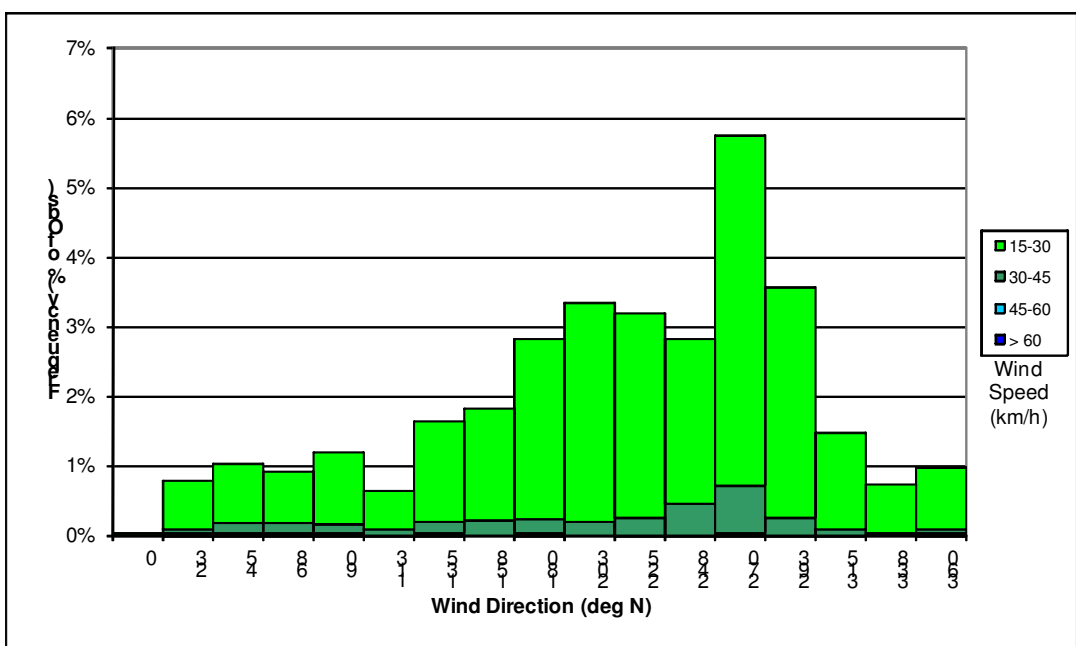


Figure 3-7 Onslow Jetty Wind Distribution

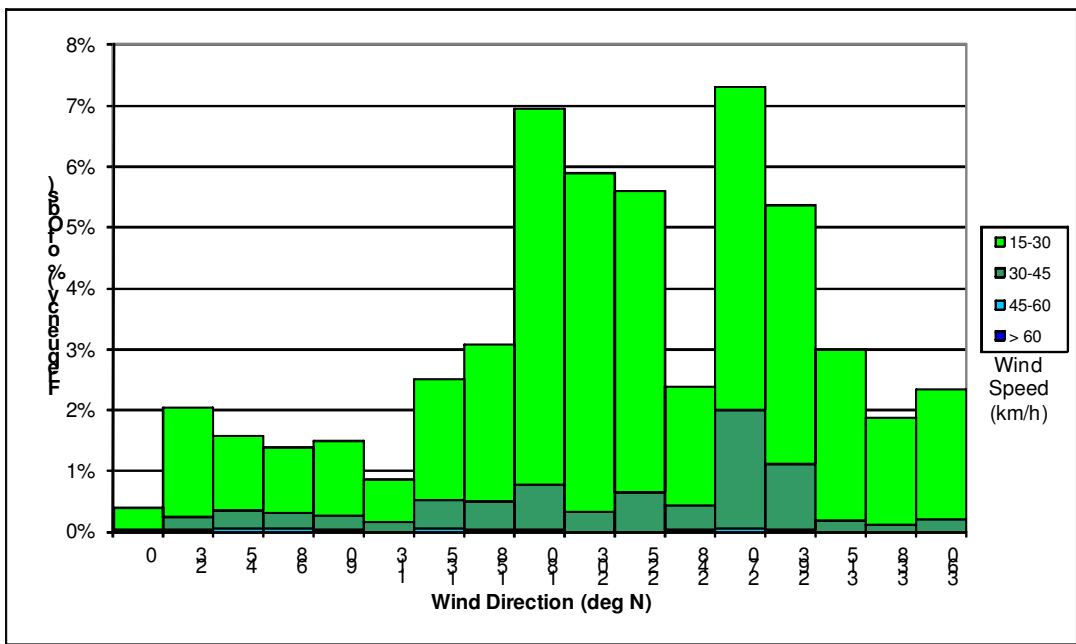


Figure 3-8 Onslow Airport Wind Distribution

3.2.2. Land-Sea Breeze Cycle

Differential heating between the land and ocean commonly causes formation of a local thermal cell structure, which modulates the direction and strength of coastal winds (Hsu 1988; Masselink & Pattiaratchi 2001). Wind direction frequencies have been determined for each 3-hour interval that observations have been made at Onslow Airport to identify the role of the land-sea breeze cycle. This analysis identifies the diurnal pattern of clockwise rotation occurring during both summer (Table 3-1) and winter (Table 3-2).

Local winds, being developed over spatial scales of tens of kilometres (Hsu 1988) are poorly represented by global wind field models. This creates potential misinterpretation when using coastal winds for the validation of modelled or gridded wind data sets, and provides local modulation to nearshore waves and currents that is difficult to represent accurately using numerical modelling. The significance of local winds upon nearshore waves and currents has not been assessed at the development site through the metocean instrumentation program (Metocean Engineers 2008).

Table 3-1: Percentage frequency of winds, showing summer diurnal cycle

December to January		Hour of Day							
		0	3	6	9	12	15	18	21
NE	22.5 to 45°	1.14	1.40	1.54	3.23	1.84	0.11	0.47	0.79
	45 to 67.5°	1.49	1.05	0.82	2.56	1.16	0.34	0.80	1.03
E	67.5 to 90°	0.90	0.71	1.54	4.40	1.26	0.68	0.24	0.91
	90 to 112.5°	0.80	1.99	3.07	4.07	1.26	0.68	0.46	0.91
SE	112.5 to 135°	1.25	1.63	1.65	4.38	1.96	0.00	0.81	0.46
	135 to 157.5°	2.20	2.24	3.07	8.71	3.90	0.68	0.34	0.80
S	157.5 to 180°	1.03	2.69	3.56	9.24	6.83	1.03	0.70	1.13
	180 to 202.5°	4.84	9.31	15.33	20.75	6.93	2.31	1.86	1.74
SW	202.5 to 225°	18.45	26.33	26.09	16.31	6.47	1.74	1.17	4.00
	225 to 247.5°	30.64	21.74	20.19	7.88	2.75	0.92	4.34	26.51
W	247.5 to 270°	13.46	11.34	8.79	1.88	0.23	1.61	8.29	21.71
	270 to 292.5°	9.93	6.53	4.05	4.79	14.74	40.97	50.00	22.60
NW	292.5 to 315°	5.17	4.58	2.03	2.78	18.39	25.19	17.78	7.59
	315 to 337.5°	3.35	2.13	1.89	2.87	12.31	13.38	6.96	4.70
N	337.5 to 360°	3.08	3.18	2.60	3.13	10.26	7.28	4.28	3.30
	0 to 22.5°	2.28	3.16	3.78	3.00	9.71	3.08	1.49	1.83

During summer the land-sea breeze cycle normally causes a change in wind direction during late morning, shifting from southerly to northwest (Table 3-1). Wind speed increases during this shift, and gradually declines towards late evening. After the land to sea breeze transition, the wind rotates gradually around through the westerly half of the compass.

The land-sea breeze cycle is less defined during winter months (Table 3-2). Although a change in wind direction frequently occurs during late morning or early afternoon, occasionally southerly winds remain persistent throughout the day. Where a change in direction occurs, the wind switches from easterly to northerly and weakens, rotating in the late evening across the westerly half, to southerly by early morning. Clockwise rotation continues to occur until the land-sea breeze transition.



Table 3-2: Percentage frequency of winds, showing winter diurnal cycle

June to August		Hour of Day							
		0	3	6	9	12	15	18	21
NE	22.5 to 45°	2.68	1.65	1.11	1.34	24.95	6.35	4.13	4.24
	45 to 67.5°	3.83	3.01	5.00	4.96	9.78	1.02	1.12	2.70
E	67.5 to 90°	2.57	5.47	8.51	19.38	10.68	0.68	0.33	0.67
	90 to 112.5°	4.29	7.48	11.89	14.43	4.36	0.56	0.45	1.12
SE	112.5 to 135°	4.70	8.61	14.62	13.06	3.77	0.78	0.67	0.78
	135 to 157.5°	6.21	11.54	10.79	20.46	13.03	6.34	1.97	2.57
S	157.5 to 180°	12.25	15.98	18.09	16.21	9.40	6.02	5.44	6.36
	180 to 202.5°	20.93	24.82	21.47	7.35	6.76	5.20	7.75	15.03
SW	202.5 to 225°	18.30	12.18	5.85	1.00	2.77	2.56	3.75	11.13
	225 to 247.5°	9.94	3.62	1.10	0.22	1.33	2.88	1.55	17.59
W	247.5 to 270°	3.96	1.10	0.11	0.00	0.55	0.89	6.88	11.06
	270 to 292.5°	1.66	0.54	0.33	0.00	0.99	6.66	24.35	6.19
NW	292.5 to 315°	0.77	0.11	0.00	0.22	1.76	8.21	7.95	3.66
	315 to 337.5°	0.78	0.66	0.22	0.46	1.79	10.49	8.54	3.45
N	337.5 to 360°	1.43	0.33	0.22	0.23	1.88	20.45	15.58	4.64
	0 to 22.5°	5.70	2.90	0.67	0.68	6.19	20.90	9.53	8.81

3.2.3. Occurrence of Strong Winds

Although median wind speeds are not great, Onslow has historically experienced very strong winds, and is classified within Category D in the Australian wind code, which represents the most severe wind conditions (Standards Australia 2002). Comparison of the strong wind record against the Bureau of Meteorology tropical cyclone database suggests that effectively all wind events above 60 km/hr may be attributed to tropical cyclones (Figure 3-9).

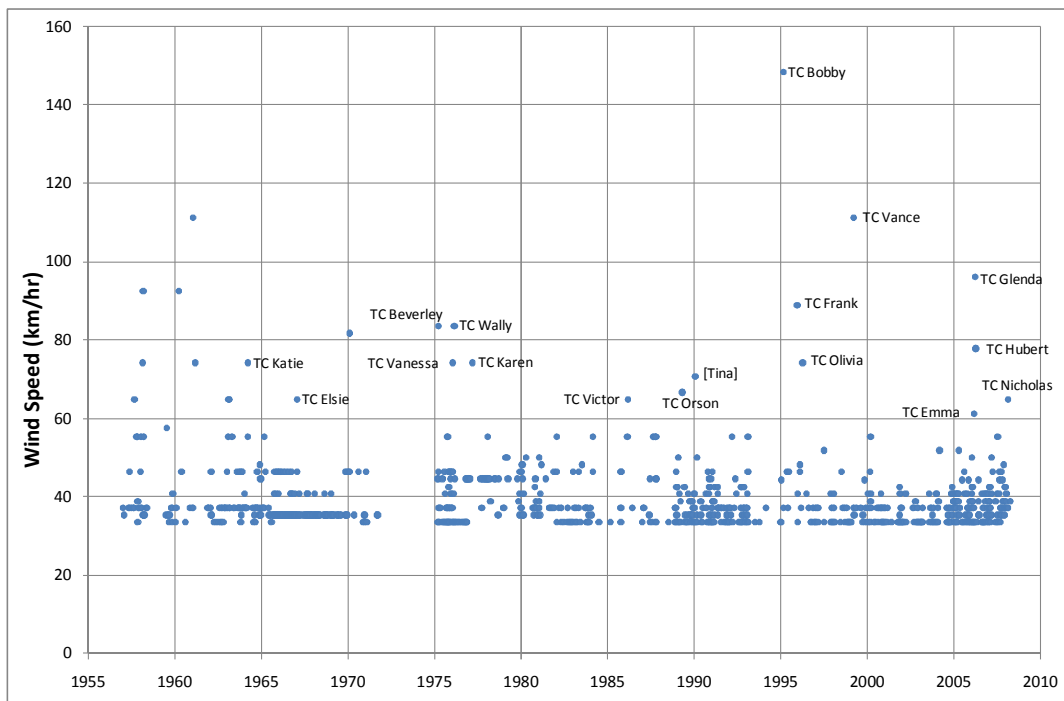


Figure 3-9: Strong Winds Coincident With Tropical Cyclones



As with the ambient wind record, differences between the two weather stations are reflected in the observed frequency of strong wind events (Figure 3-10 and Figure 3-11). It is recognised that this is biased by the frequency of wind observations, such that 3-hourly wind observations at Onslow Airport will identify a larger number of strong wind events than the twice-daily observations from Onslow Jetty. A key implication of this disparity is that the wind records may not provide a wholly reliable measure of historic stressors at the site.

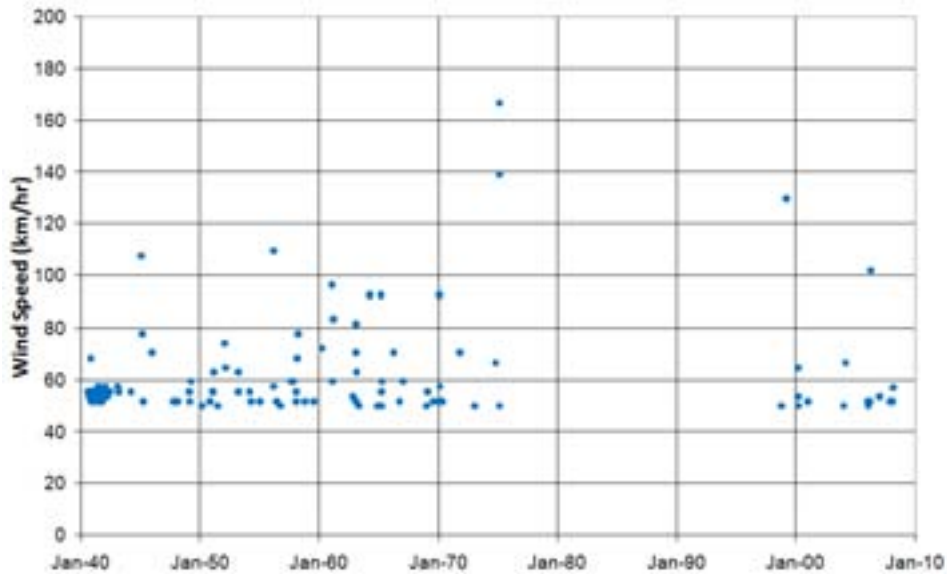


Figure 3-10: Wind Events above 50 km/hr from Onslow Airport

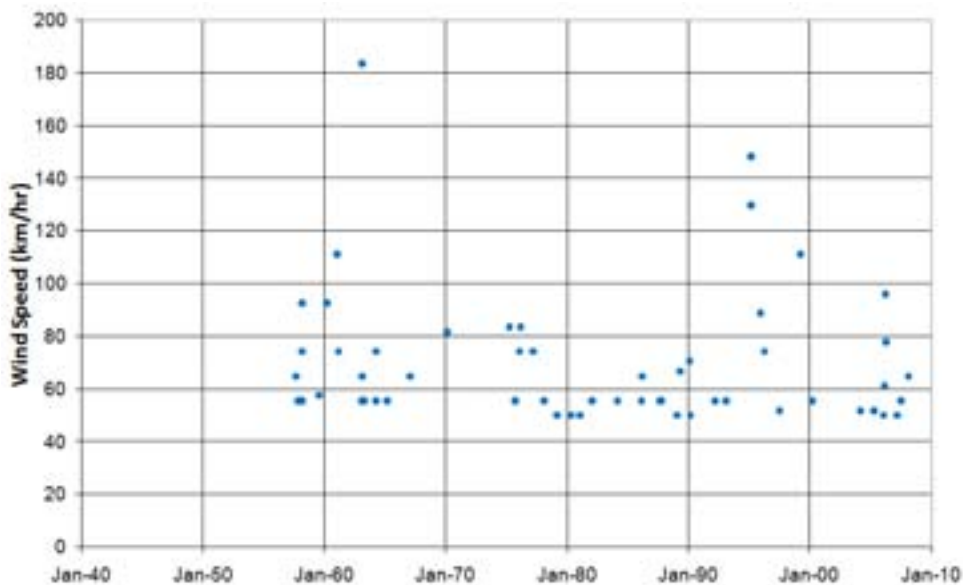


Figure 3-11: Wind Events above 50 km/hr from Onslow Jetty

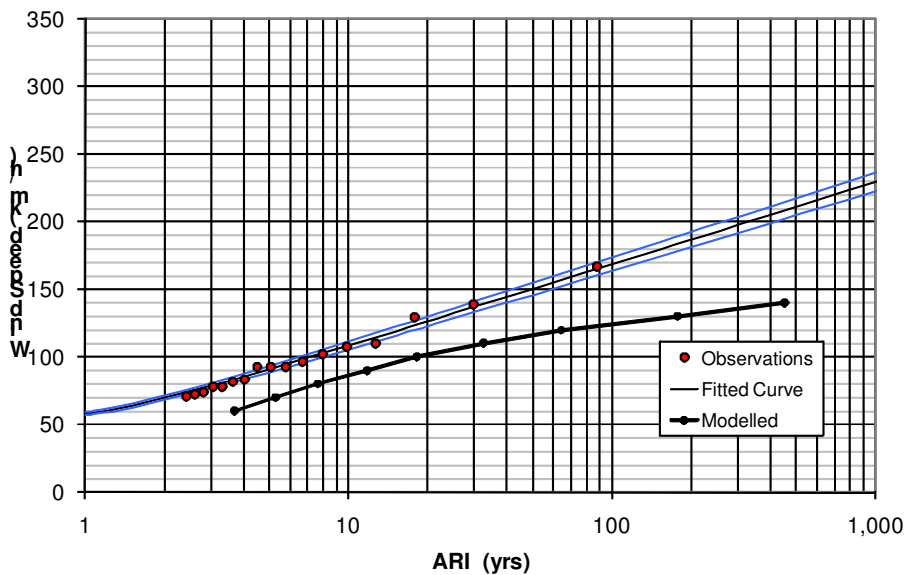


Figure 3-12: Extreme Wind Speed Distribution from Onslow Airport data

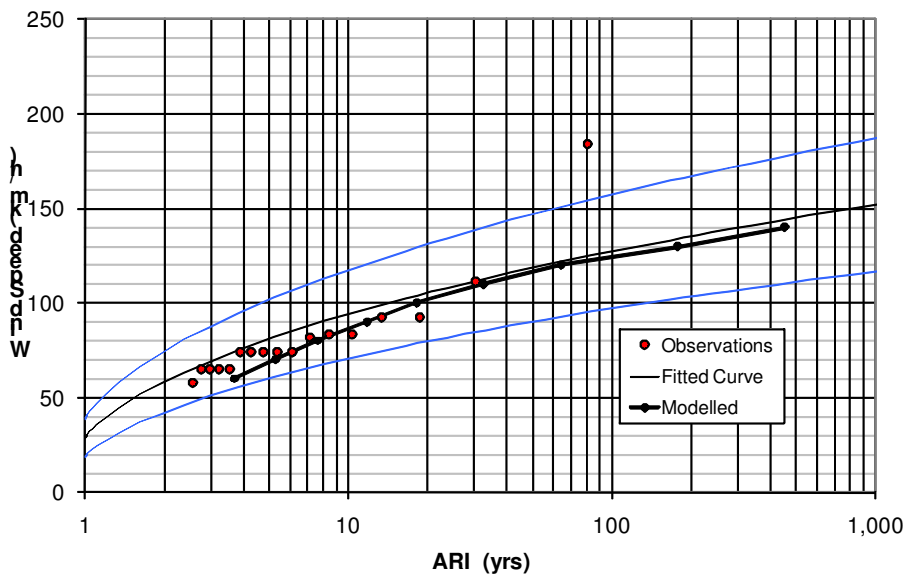


Figure 3-13: Extreme Wind Speed Distribution from Onslow Jetty data



Extreme distributions derived from the two data sets are understandably different, with 100-year average recurrence intervals of 170 km/hr from Onslow Airport (Figure 3-12) and 130 km/hr from Onslow Jetty (Figure 3-13). Comparison of the observed distributions with a parametric model, based upon tropical cyclone intensity distribution suggests a good relationship for the Onslow Jetty data, and requires factoring by approximately 20% for Onslow Airport (Damara WA 2009).

Analysis of the directions associated with strong winds at Onslow Airport indicates they most frequently occur from the northeast quadrant (Figure 3-14). However, this bias is not reflected in the distribution of winds stronger than 75 km/h, which have occurred from a wider range of directions. A relative absence of strong and extreme winds occurs from the southeast to south, which is likely to be caused by overland frictional loss.

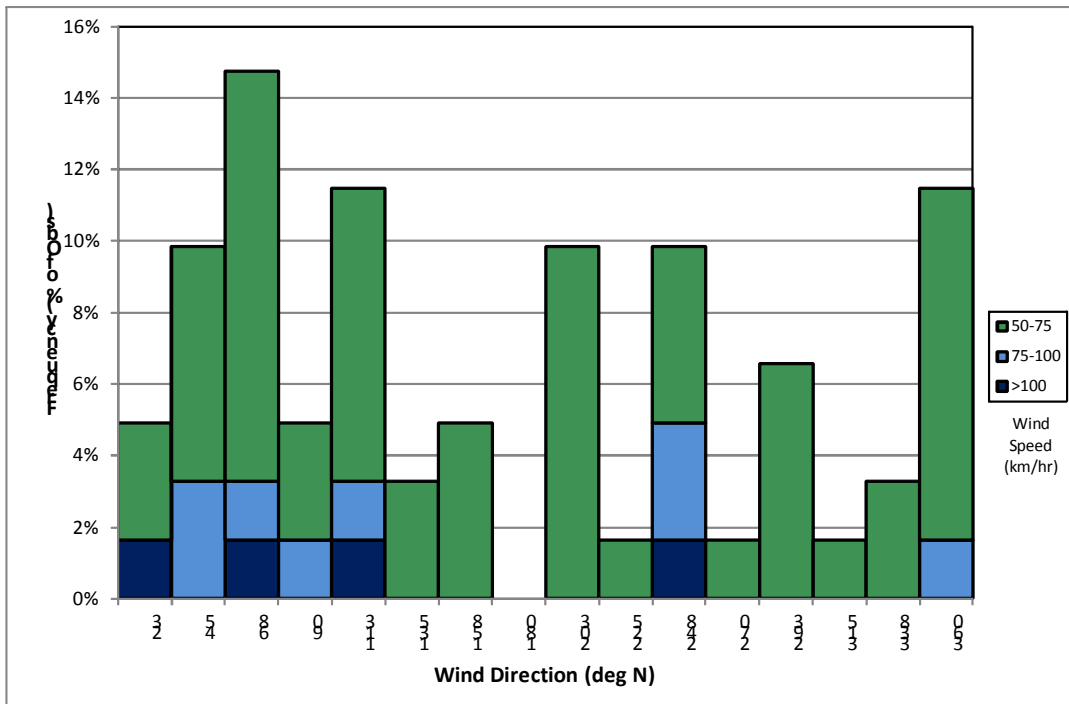


Figure 3-14: Directional distribution of strong winds (>50 km/h)



3.2.4. Inter-annual Wind Variability

Variation of the wind conditions over inter-annual and inter-decadal time scales has implications for the relative stability of coastal sedimentary features, as changes in the regional wind regime affects the direction and persistence of nearshore waves and currents.

The Bureau of Meteorology wind record from Onslow Jetty has been examined using cumulative summation analyses on an annual basis, derived from 9 am and 3 pm winds (Appendix B). These analyses confirm marked inter-annual variability of the trade winds, which is typically coherent for 5-6 years periods. This behaviour is consistent with, and intricately linked to inter-annual variability of the Australian monsoon (Holland 1986; Webster *et al.* 1998; Kullgren & Kim 2006). Climate analyses suggest relatively complex relationships between regional climate indices and the monsoon, with the Southern Oscillation and Madden-Julian Oscillations affecting the onset, intensity and termination of the monsoon period, as measured by winds and rainfall (Kim *et al.* 2006).

Inter-annual variability of the prevailing wind systems is illustrated by the cumulative summations of westerly and northerly wind components from 9 am and 3 pm over each year. The range of conditions is shown by Figure 3-15, with three markedly different years:

- During 1979, strong westerly winds occurred over the two periods at the start and end of the year, resulting in a net westerly influence over the year. Southerlies were prevalent for 9 am observations throughout the year and strongest from April to October. Increased northerly influence from November and December was reflected in both 9 am and 3 pm observations;
- Commonly occurring conditions were recorded during 1991, with a gradual westerly drift during warmer months at the start and end of the year. Southerlies were prevalent for 9 am observations throughout the year, but strongest from September to December;
- Over 1982, very strong easterlies occurred from April to August for 9 am observations. Weaker westerly conditions were generally observed throughout the year for 3 pm observations. Westerlies normally prevalent during the warmer months were weak. The meridional components of observed winds, which are southerly at 9 am and northerly at 3 pm, were generally weak although they remained prevalent throughout the year.

Differences between these three years can only partly be ascribed to global climate variations, as 1979 represents a neutral year, 1982 a strong El Nino year and 1991 a moderate El Nino year. Conditions experienced during strong La Nina years (1973, 1975, 1988, 1998) fell within the range represented by the three selected years.

As Onslow is sub-monsoonal, the relationship between wind and rainfall variation is weaker than the tropical regions. However comparison of annual cumulative summation winds against the Ashburton River flow record from Nanutarra (Figure 3-37) suggests a period of weaker easterly trades from 1996 to 2002 corresponded to a spike in runoff. It is relevant to note that this also coincides with a period of enhanced tropical cyclone activity (Table 3-4).

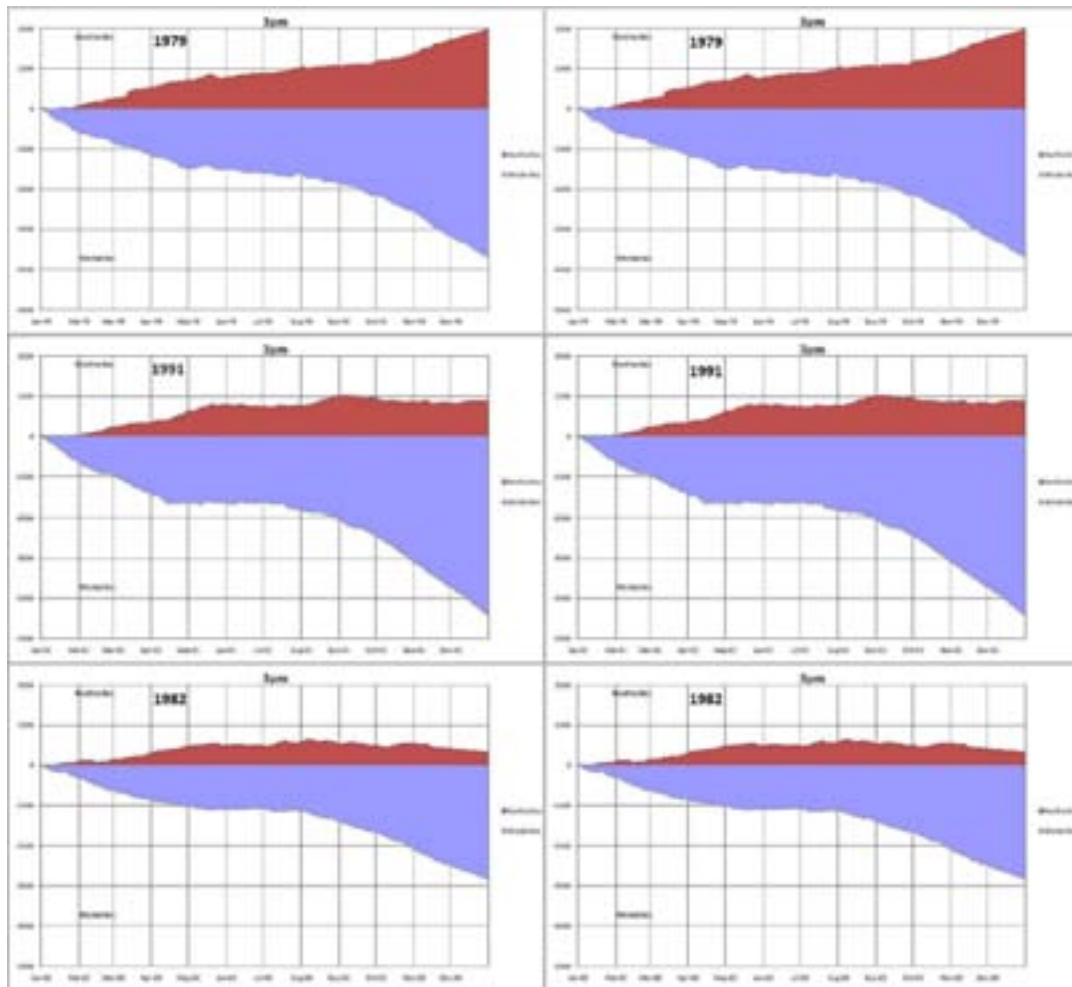


Figure 3-15: Cumulative Wind Summaries for Selected Years

The complete set of cumulative summation diagrams is included in Appendix B.

Behaviour over the longer-term record can be inferred from the net annual wind drift, which is the “final position” of the cumulative wind summation for each year. Onslow Jetty data over the period 1957-2007 from 9 am has been examined, and is shown relative to north-south and east-west components. Missing data affects interpretation of the data, although the record is largely continuous over the two periods 1957-1970 and 1974-2007. The net annual wind drift exhibits a trend-break pattern, where a sustained trend is disrupted by a large jump, after which the trend recommences. However, breakpoints are not wholly consistent between the northerly and easterly components, and there are sections of the record that exhibit cyclic behaviour (i.e. reversing trends) rather than trend-break behaviour. The overall pattern of the easterly wind drift, which is the more important factor for alongshore sediment transport, is similar to the corresponding inter-annual variation of rainfall (Figure 3-36) implying wetter conditions (on a decadal scale!) are generally associated with a stronger easterly drift. However, this proposition is not wholly demonstrable and has not been fully assessed.

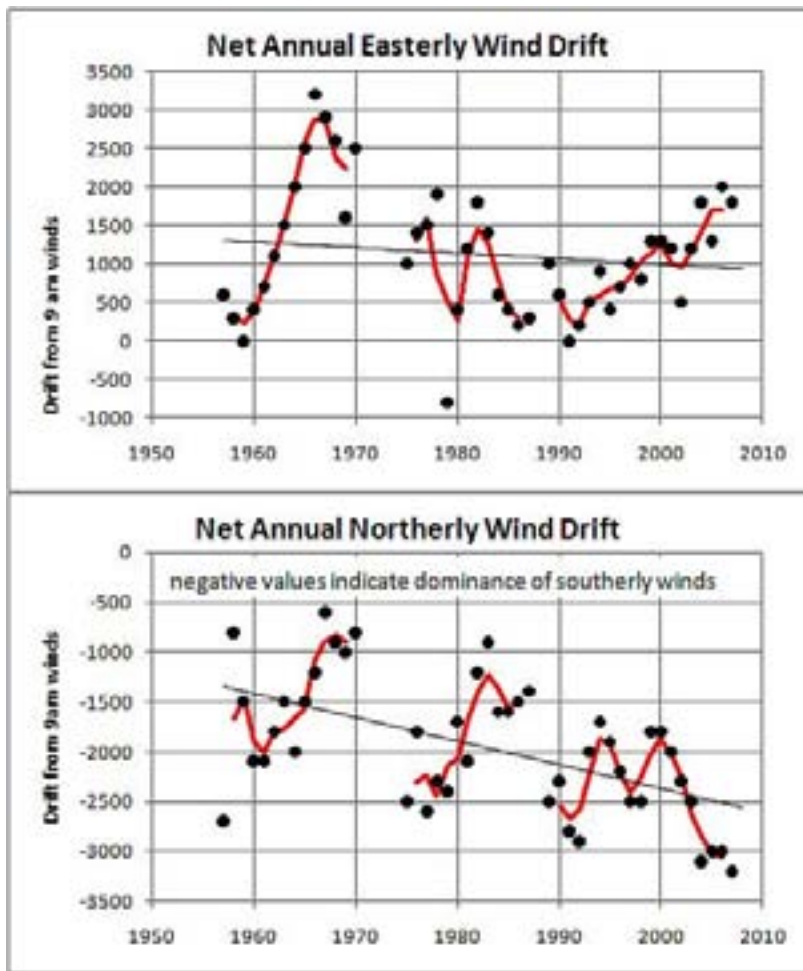


Figure 3-16: Inter-annual variability illustrated by net annual wind drift (9am winds)

Net annual drifts are derived from the cumulative summation diagrams included in Appendix B.



3.3. CYCLONES

A tropical cyclone has been defined as a non-frontal synoptic scale, cyclonic rotational, low pressure system of tropical origin, in which ten minute mean winds of at least gale force (63 km/hr) occur, the belt of maximum winds being in the vicinity of the system's centre

(Bureau of Meteorology 1978; in Lourensz 1981)

Tropical Cyclones are intense tropical depressions, causing wind speeds of gale force or greater (Lourensz 1981). Originating in the lower latitudes, these systems are highly mobile and are capable of travelling extensive distances. Due to the intense nature of tropical cyclones, very strong wind speeds may occur, creating potential devastation both on land and at sea. Tropical cyclones have been identified as the most severe synoptic weather system affecting the Northwest Shelf region, capable of producing extreme winds, waves, currents and coastal surges (Hopley & Harvey 1976; Silvester & Mitchell 1977; Hearn & Holloway 1990; Nott 2006; Hemer *et al.* 2008).

On average, five tropical cyclones pass through the Western Australian region each year, although this may be highly variable on a year-to-year basis. Cyclones are typically generated offshore from the Kimberley, although they may be generated across a broader range of longitudes under suitable conditions. Although Onslow is to the southwest of the zone with the highest frequency of cyclone events (Figure 3-17), it may still experience significant winds, as previously identified (Figure 3-6) and is classified within Region D of the Australian wind loading code (Standards Australia 2002). This region frequently experiences intense tropical cyclones (Figure 3-19) with cyclones causing gusts above 90 km/hr at Onslow approximately once every two years (Bureau of Meteorology, website

www.bom.gov.au/weather/wa/cyclone/about/onslow/index.shtml).

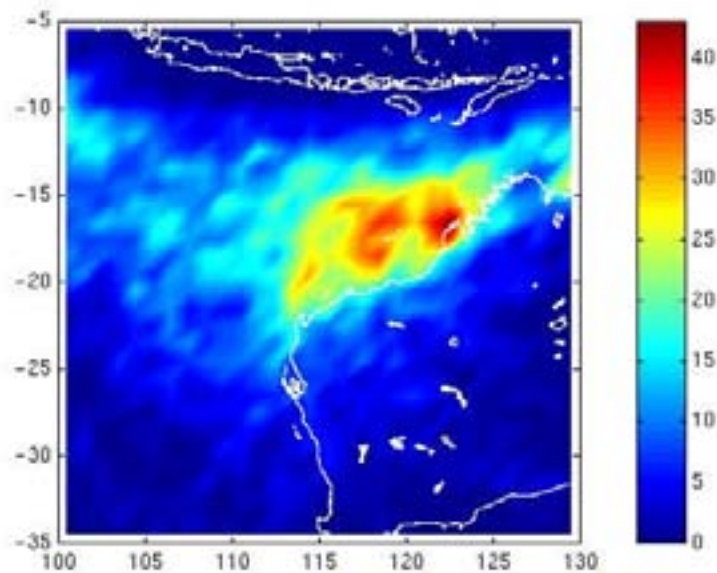


Figure 3-17: Occurrence of Tropical Cyclones in 1° lat-long cells 1970-1999

The Bureau of Meteorology tropical cyclone database captures available cyclone records from 1906 to 2007 (BOM, website: <http://www.bom.gov.au/weather/cyclone/tc-history.shtml>).



Tropical cyclones affecting the Western Australian region are observed and analysed by the Commonwealth Bureau of Meteorology (BOM). A database of observed and interpreted characteristics is maintained by the Bureau following initial development by Coleman (1972) and Lourenz (1981). Irregularities within the database were noted by Lourenz (1981), who suggested that much of the apparent ‘trend-like’ behaviour of the tropical cyclone record was a clear result of changing capacity, coverage and monitoring frequency of the observing systems. Despite this early warning, trends in the historic record have been used to describe ‘cyclone climate trends’, with varying acknowledgement of the limits of the database (Landsea 2000; Qi *et al.* 2008). Although the exact period varies between agencies and regions, it is generally considered that the database provides a suitable measure of cyclone parameters (such as radius or cyclone central pressure) for the period from 1970 onwards.

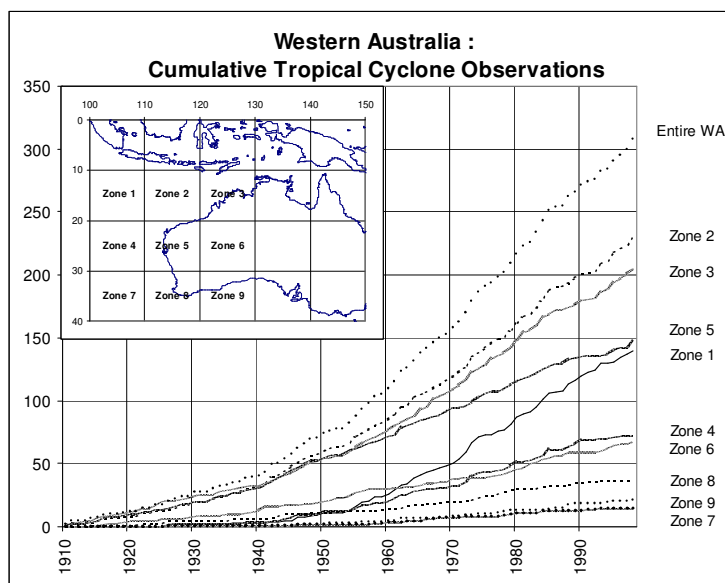


Figure 3-18: Regional Trends of Cyclone Observations
Strongly affected by Observation techniques

Analysis of the tropical cyclone database has previously been undertaken by Damara WA, for the purpose of characterising cyclone climatology. Information presented here has previously been presented to the Department for Planning & Infrastructure within Damara WA (2006) *Tropical Cyclone Climatology of Western Australia* and Damara WA (2008) *Tropical Cyclone Surges. Western Australian Tide Gauge Observations*.

The most critical cyclone parameter affecting the resulting metocean conditions is cyclone intensity, commonly described by the cyclone central pressure (Holland 1980). This has been used as the primary descriptor of the cyclone data set, although it is recognised that other parameters may be significant, including:

- System scale;
- Cyclone forward speed and direction;
- System structure, such as described by Holland β -parameter (Holland 1983);



The relationship between cyclone intensity and location has been examined by comparing intensity distributions according to a 5° latitude-longitude grid (Damara WA 2008). For each grid square, the distribution is approximately exponential, although there is a distinct difference in the frequency of tropical cyclones according to location. Cyclone intensity generally decreases with latitude (south of 20°S) and across land, corresponding to the findings of Lourensz (1981). The tendency for early season cyclones to remain at northerly latitudes and late season cyclones to travel further south corresponds to analyses by Broadbridge & Hanstrum (1998). Fitting of extreme distributions to the most intense tropical cyclones has also been conducted on a 5° latitude-longitude grid, providing an estimate of the likelihood of severe cyclone events. This is presented in Figure 3-19 for the coastal regions along Western Australia.

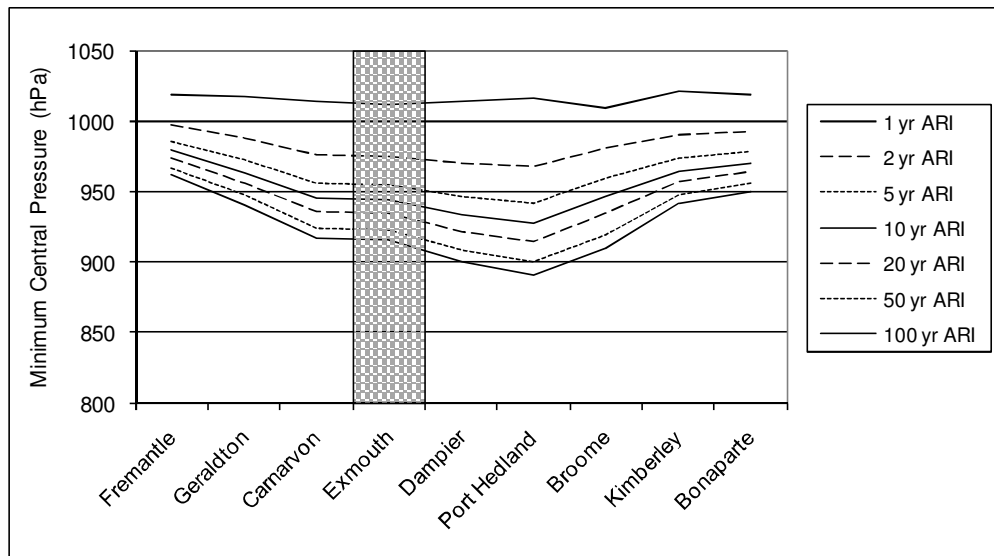


Figure 3-19: Tropical Cyclone Intensity along the Western Australian coast (1970-2003)
Onslow falls within the “Exmouth” Region

The Bureau of Meteorology database indicates that the radius of maximum winds, estimated by the eye diameter, is largely independent of cyclone intensity, which corresponds with cyclone descriptions by Callaghan & Smith (1998). Observations obtained from the Western Australian region have shown cyclone eye diameters ranging from 4 to 90km, with a mean of 30km. The distribution appears to have an approximate exponential distribution, with a very weak tendency for smaller intense cyclones and larger weak cyclones.

The scale for any particular cyclone will tend to vary over the course of cyclone generation, transit and decay. Most typically, the radius of maximum winds decreases during intensification. During transit, cyclone radius will normally increase as the system moves into the mid-latitudes, along with an increase in speed and a change in cloud cover (Callaghan 2002; Harr 2004).

Due to the vortex structure of tropical cyclones, and the relatively small spatial scale over which the wind field decays, the relative path of the cyclone is critical to the direction of winds, and consequently the resulting metocean conditions. For any tropical cyclone that passes nearby, the winds will experience nearly 180° change in direction (Table 3-3).

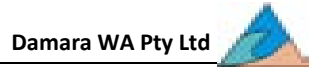


Table 3-3: Wind direction change according to system passage

Cyclone Path	Leading → Peak → Lagging
System passes westward to the North (30%)	S → SE → E → NE → N
System passes westward to the South (13%)	S → SW → W → NW → N
System passes southward to the East (36%)	E → SE → S → SW → W
System passes southward to the West (21%)	E → NE → N → NW → W

Changes to wind direction are not directly related to the potential for cyclonic events to generate alongshore transport, as there is a need for sustained wind and over-water fetch to generate wave action, and wave influence is further affected by coastal orientation. In order to provide a preliminary assessment of historic events prior to numerical modelling of cyclone events by others, a simple analysis has been conducted by looking at cyclone paths. Due to the need for over-water fetch to generate wave action, only cyclones to the north of the coast have been considered.

Cyclones have been classified as passing through the northwest or northeast quadrants (Figure 3-20):

- Cyclones in the northwest quadrant generally curve from westwards to southerly as they round North West Cape. Although they may produce strong easterly winds, initial winds have an offshore component, limiting the capacity of these winds to generate waves. As the cyclone path swings, subsequent sustained northwest winds provide waves producing an overall eastwards sediment transport.
- Cyclones in the northeast quadrant produce easterly winds during initial phases, but produce offshore winds towards land-crossing, resulting in low wave conditions, and an expected overall mild westwards sediment transport.

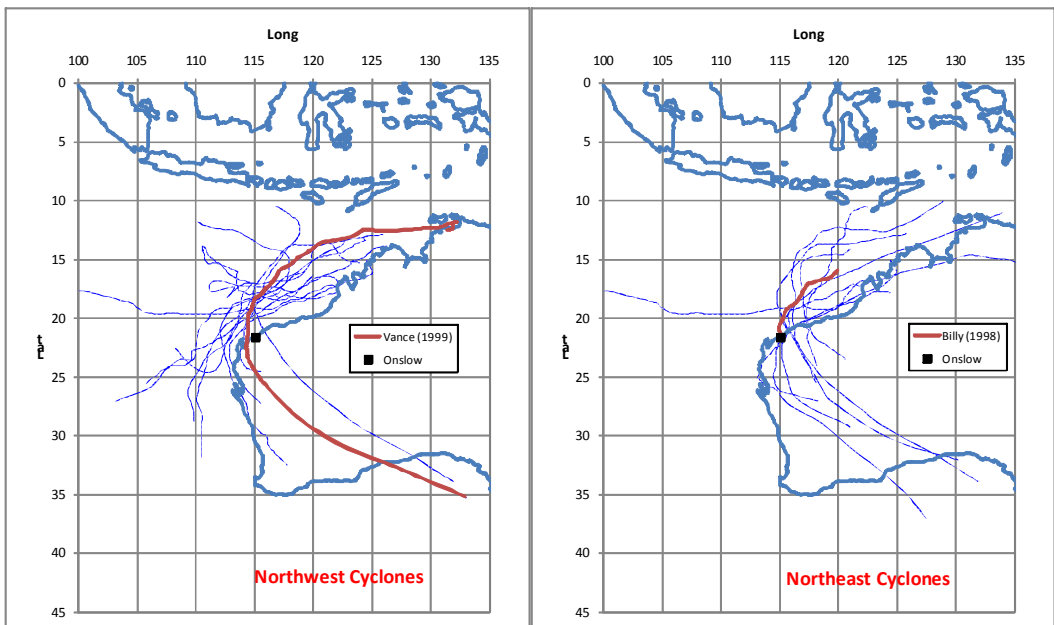


Figure 3-20: Historic NW and NE Cyclones



It is apparent from Figure 3-20 that tropical cyclones passing to the northwest are more frequent, particularly systems that track parallel to the North West Shelf. This suggests that tropical cyclones will typically reinforce the eastwards sediment transport, with occasional reversal of transport. TC Billy (1998) passed most closely to the east of Onslow, although it was not a very severe system.

The severity of tropical cyclone impacts has been evaluated for wind, surge and river flow based upon available data sets (Table 3-4). Comparison of the cyclone paths associated with high river flow (Figure 3-21), strong winds (Figure 3-22) or high surges (Figure 3-23) indicate that different design cyclones may need to be considered for the extremes of each environmental parameter.

- High river flow is largely associated with tropical cyclones that recurve towards the southeast, passing over the Ashburton catchment in the southern Pilbara;
- Strong winds have principally been recorded when Onslow is on the leading left quadrant of the cyclone system, matching expected behaviour (Holland 1983). Consequently, the majority of strong wind events have been associated with tropical cyclones that pass to the north of Onslow;
- The most extreme observed surges are associated with extreme onshore wind events, caused by tropical cyclones passing nearby to the west of Onslow (GEMS 2000). However, more frequent moderate surges may also be generated by tropical cyclones travelling parallel to the coast. It is understood that this is likely to be a result of shelf wave formation, when winds are shelf-parallel (Fandry & Steedman 1994).

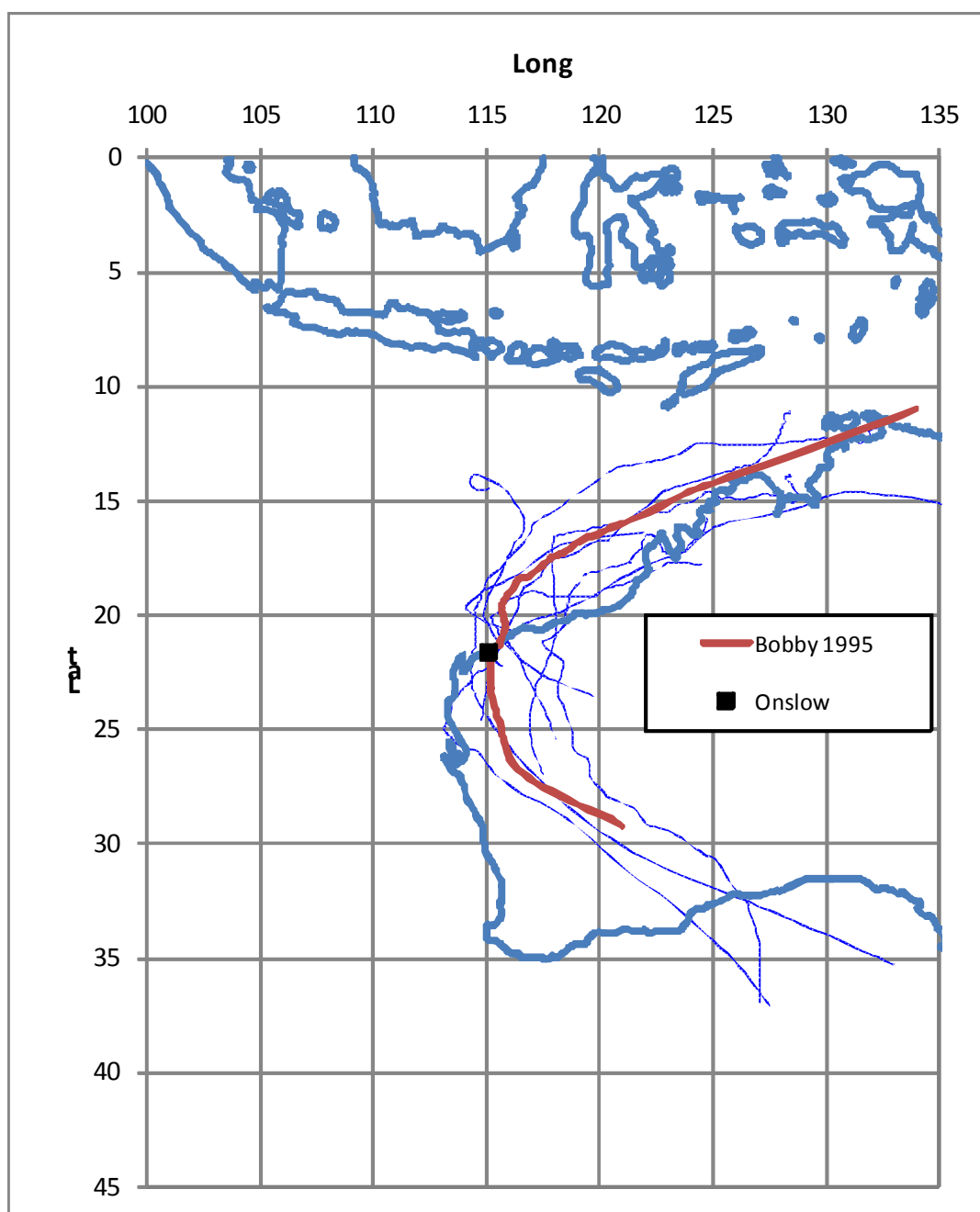


Figure 3-21: Cyclone Paths associated with High River Flows

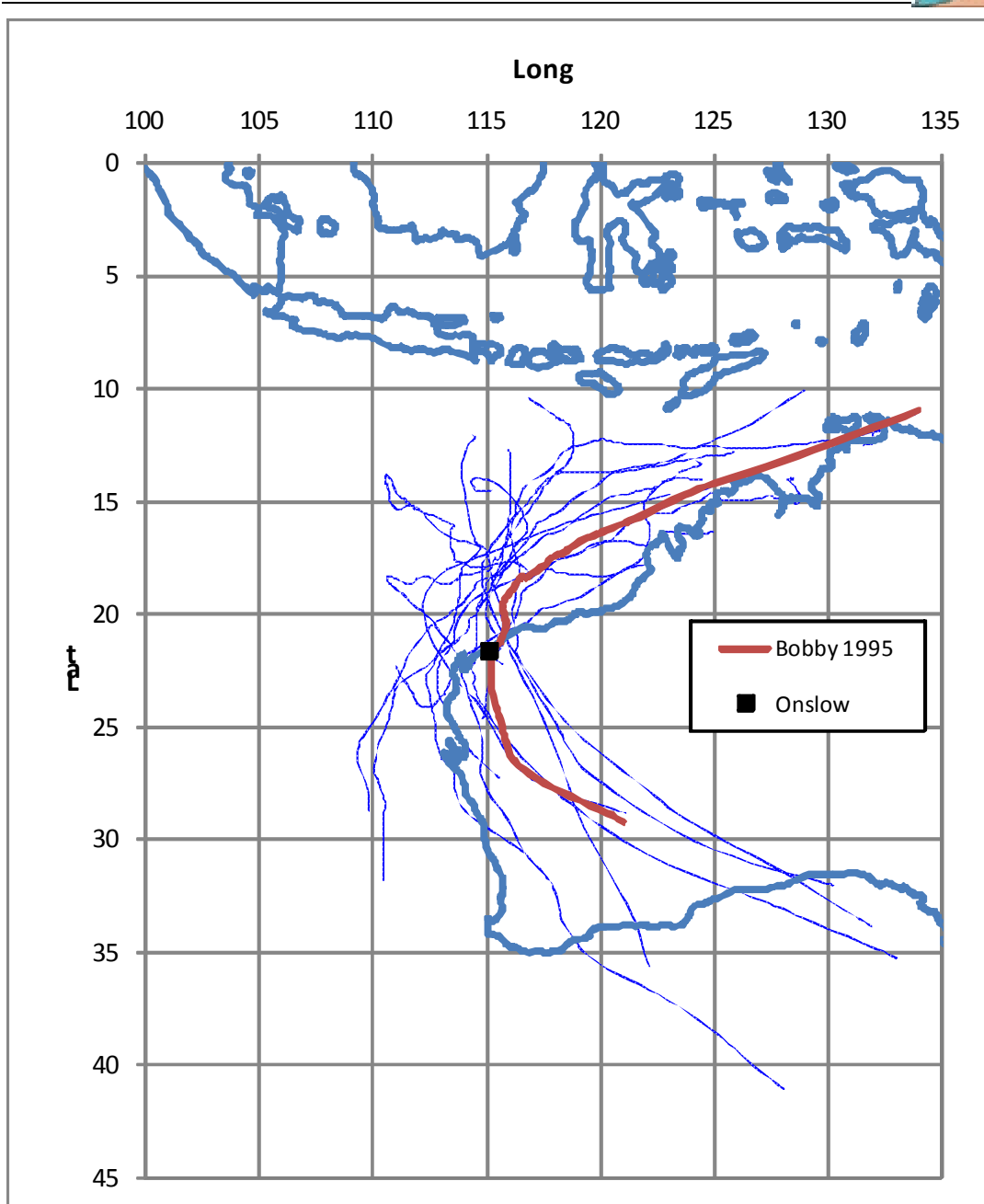


Figure 3-22: Cyclone Paths associated with Strong Winds

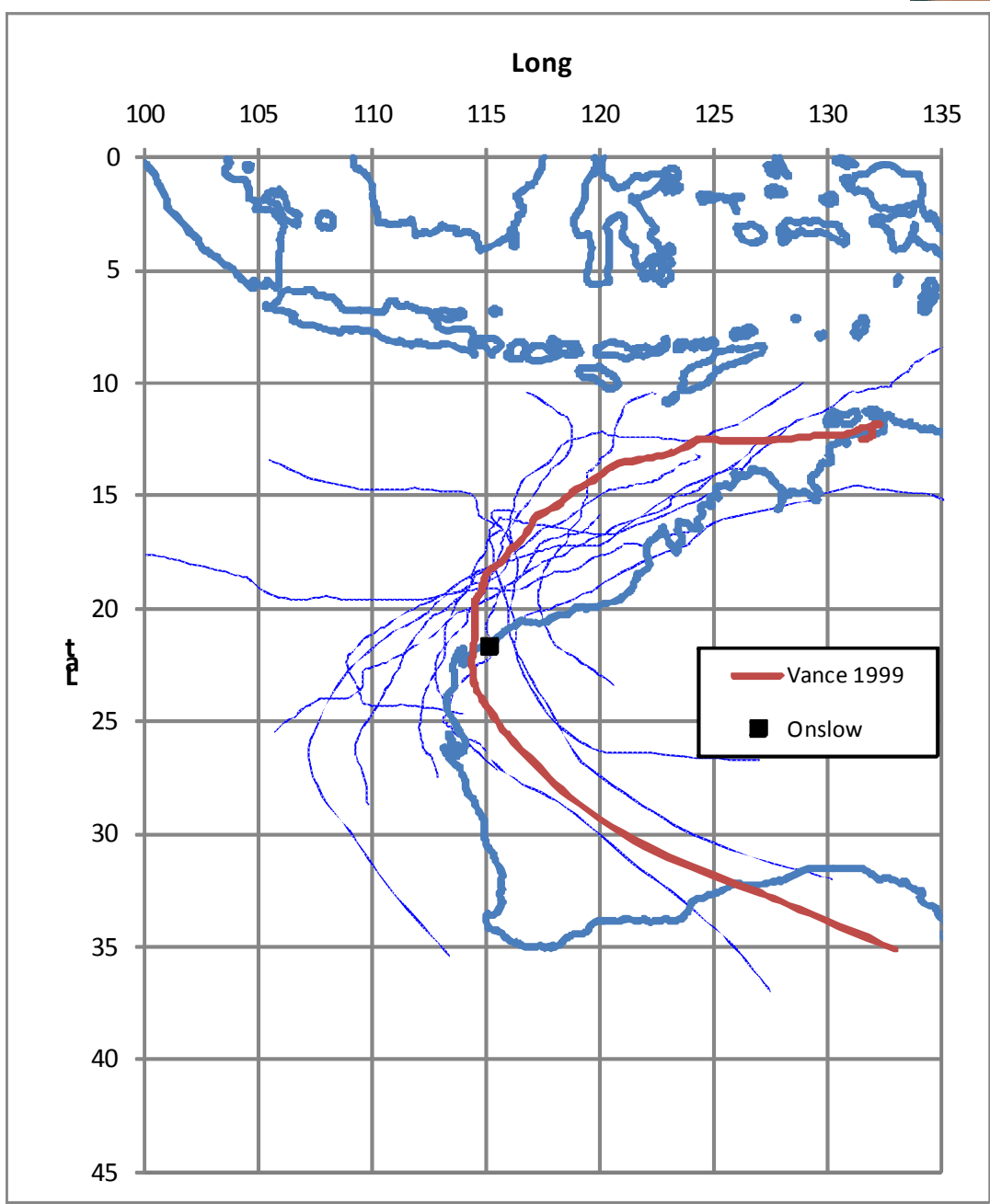


Figure 3-23: Cyclone Paths associated with High Surge



Table 3-4: Tropical Cyclones developing severe winds, surge or river flow

Season	Name	Date	Min CP (hPa)	Nearest Dist (km)	Bearing (deg N)	Near CP (hPa)	Max Runoff (m ³ /s)	Max wind (km/h)	Surge (m)
1955/56	1955/12	2/03/1956	960	67.3	213.1	970	NR	109.4*	NR
1957/58	1957/10	4/03/1958	960	14.7	143.9	960	NR	92.5	NR
	1957/12	15/03/1958	950	29.9	23.5	950	NR	55.4	NR
1960/61	1960/5	24/01/1961	920	24.6	273.6	920	NR	111.2	NR
	1960/12	2/03/1961	950	59.1	129.7	960	NR	74.2	NR
1962/63	1962/19	7/02/1963	940	24.1	142.7	940	NR	183.6	NR
1964/65	JOAN	10/03/1965	965	88.5	63.5	965	2608		
1966/67	ELSIE	20/01/1967	965	206.7	245.2	965		64.8	NR
1974/75	TRIXIE	19/02/1975	925	18.1	156.3	935		NR	
	BEVERLEY	30/03/1975	929	143.1	253.3	969		83.5	NR
1975/76	JOAN	8/12/1975	915	261.2	116.2	981	2,608		NR
	VANESSA	25/01/1976	950	208.4	299.3	972		74.2	NR
	WALLY	25/02/1976	973	176.4	285.4	976		83.5	NR
1976/77	KAREN	7/03/1977	970	51.8	317.7	978		74.2	NR
1985/86	RHONDA	19/02/1986	968	200.2	270.5	974			0.34
	VICTOR	6/03/1986	930	266.3	319.4	955		64.8	
1986/87	CONNIE	19/01/1987	950	250.5	78.3	965	1,735		
1987/88									
1988/89	ILONA	17/12/1988	960	110.7	86.7	965			0.30
	ORSON	23/04/1989	905	122	97.4	950		66.6	0.29
1989/90	[TINA]	28/01/1990	972	143		972		70.6	0.78
1994/95	BOBBY	24/02/1995	925	9	127.5	945	5,824	148.3	
1995/96	FRANK	10/12/1995	950	150.2	313.6	965		88.9	0.63
	JACOB	4/02/1996	955	204.6	340.5	960			0.50
	OLIVIA	10/04/1996	925	94.1	72.4	930		74.2	0.26
1997/98	TIFFANY	27/01/1998	940	277.6	11.8	950			0.28
1998/99	BILLY	6/12/1998	965	28.3	78.2	1000			0.26
	VANCE	22/03/1999	910	71	292.1	920	1,667	111.2	NR
1999/00	JOHN	15/12/1999	915	272.9	69.6	950			0.29
	STEVE	6/03/2000	975	32.4	120.3	980	3,887		0.36
2000/01	ALISTAIR	20/04/2001	975	323	322.7	990			0.22
2002/03	HARRIET	7/03/2003	985	300.2	333.8	990			0.20
2003/04	MONTY	1/03/2004	935	96.2	29.8	955	24,66		
2005/06	CLARE	9/01/2006	960	117.3	70.2	968			
	EMMA	28/02/2006	988	88.5	63.5	990		61.2	NR
	GLENDA	30/03/2006	910	24.1	45.8	962	2,660	96.1	NR
	HUBERT	8/04/2006	980	32.4	120.3	996	1,860	77.8	NR
2007/08	NICHOLAS						3,657	64.8	NR
2008/09	DOMINIC						??		NR
	GLENDA	30/03/2006	910	24.1	45.8	962	2,660	96.1	NR
	HUBERT	8/04/2006	980	32.4	120.3	996	1,860	77.8	NR



3.4. WAVES

Wave conditions at the Project site are presently being measured through a dedicated metocean monitoring program, offshore from the project site by RPS Metocean on behalf of Chevron. Two acoustic wave and current meters (AWACs) and a directional wave rider buoy have been deployed (Metocean Engineers 2008). The time series of wave conditions from January to September 2009 are shown for the offshore waverider buoy by Figure 3-24 and for the inshore AWAC by Figure 3-25.

Metocean observations made from January to September 2009 show moderate wave conditions at the offshore waverider buoy site (52m depth) and generally mild wave conditions at the inshore AWAC site (8m depth). The median wave conditions are 0.89m significant wave height and 11s period, from 270° at the directional waverider buoy, with the corresponding conditions of 0.22m wave height and 7.8s period, from 300° at the inshore AWAC. The significant change between the two locations indicates the degree of sheltering, including the effects of friction, diffraction and refraction from outside Thevenard and Bessieres Islands through to the nearshore region. The large change of modal direction clearly indicates the role of refraction.

Elevated wave conditions were experienced at both offshore and inshore instruments during the influence of northerly winds produced by TC Dominic and TC Freddy (Figure 3-26). Other energetic conditions similarly occurred due to low pressure systems located to the west of Onslow, producing onshore winds, such as occurred on 16 February 2009. This behaviour is consistent with other observations from the North West Shelf region for similar periods.

Strong westerly wave conditions were identified in the offshore waverider buoy record from July 2009. However, as the inshore AWAC was out of service at the time, it is not possible to compare the difference in relative transmission between the more northerly events during summer and westerly events during winter.

Further comparison between offshore and inshore conditions is given by the cross-plots of significant wave height (Hs) against peak spectral wave period (Tp) and mean direction (θm) at each location. Figure 3-27 shows the Hs-Tp plot for the directional wave rider, which shows four distinct wave bands, being locally generated (< 6s), regionally generated swells during summer (~10s), regionally generated swells during winter (~15s) and distant long-period waves (~20s). The locally generated waves, which include the highest recorded, are clearly affected by wave steepness, forming the linear “front” of the Hs-Tp plot.

The inshore AWAC, shows lower wave energy, with only three distinct wave bands (Figure 3-28). The absence of a distinct band corresponding to the winter swell suggests that it is significantly damped, likely through refraction, such that it is no longer apparent as a separate peak. The effect of wave steepness is significantly less distinct for the inshore AWAC than the offshore measurements.

Figure 3-29 show the Hs-θm plots for the offshore waverider. The offshore direction is dominated by a relatively narrow directional band from the west, understood to be related to Indian Ocean swells. Higher waves were recorded from the northeast, with the highest waves apparently (and possibly spuriously) from the southerly quadrant.

Analysis of the wave direction record from the inshore AWAC deployment shows a broad directional range, with the median wave direction from the north-northwest (Figure 3-30). As with the directional wave rider, high waves were recorded from the north-northeast corresponding to tropical cyclones Dominic and Freddy. High waves from the southerly quadrant may potentially be explained by the capacity for AWAC processing software to reverse wave direction, although this error should not be repeated for the directional waverider.

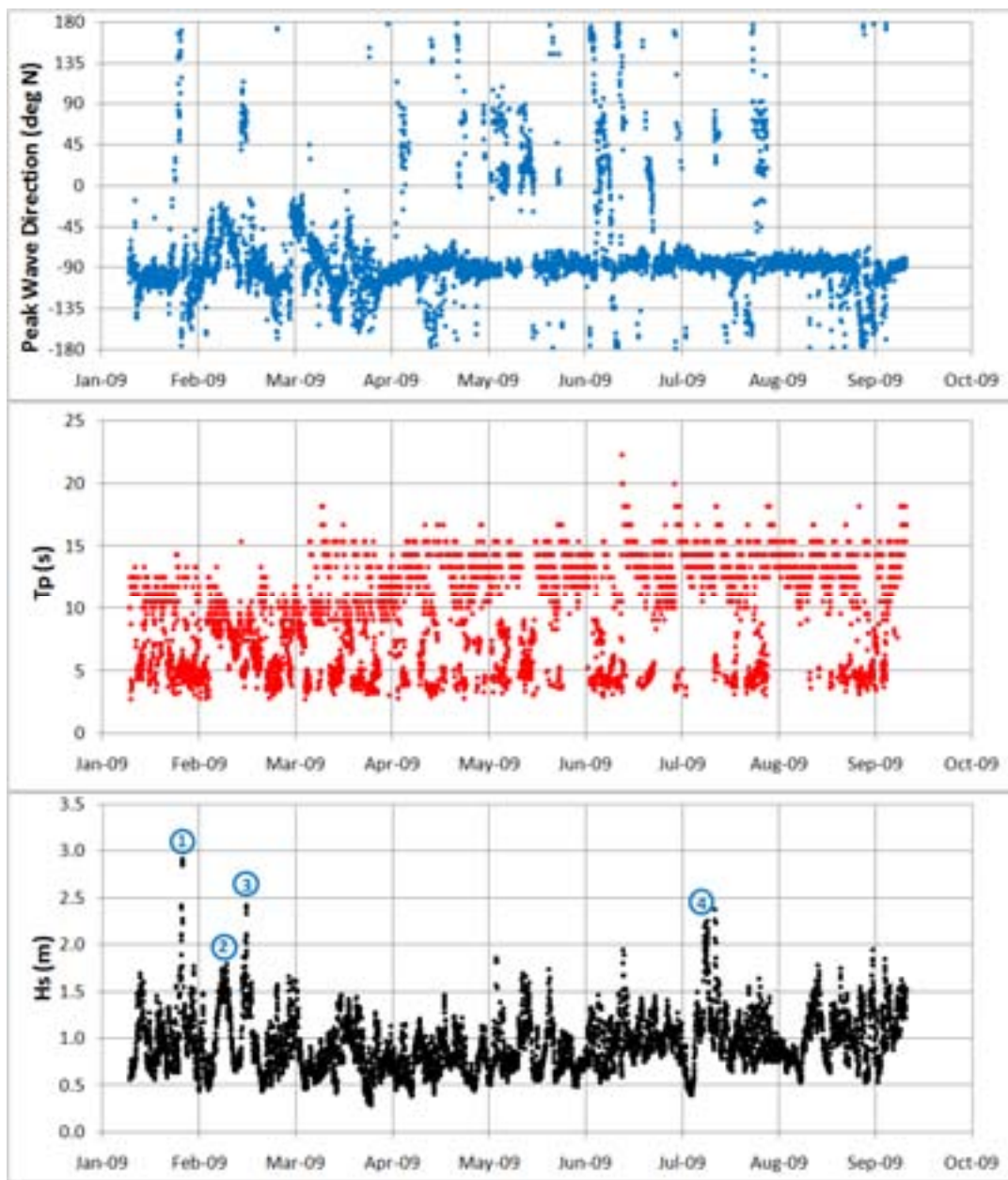


Figure 3-24: Wave Record from Directional Waverider Buoy

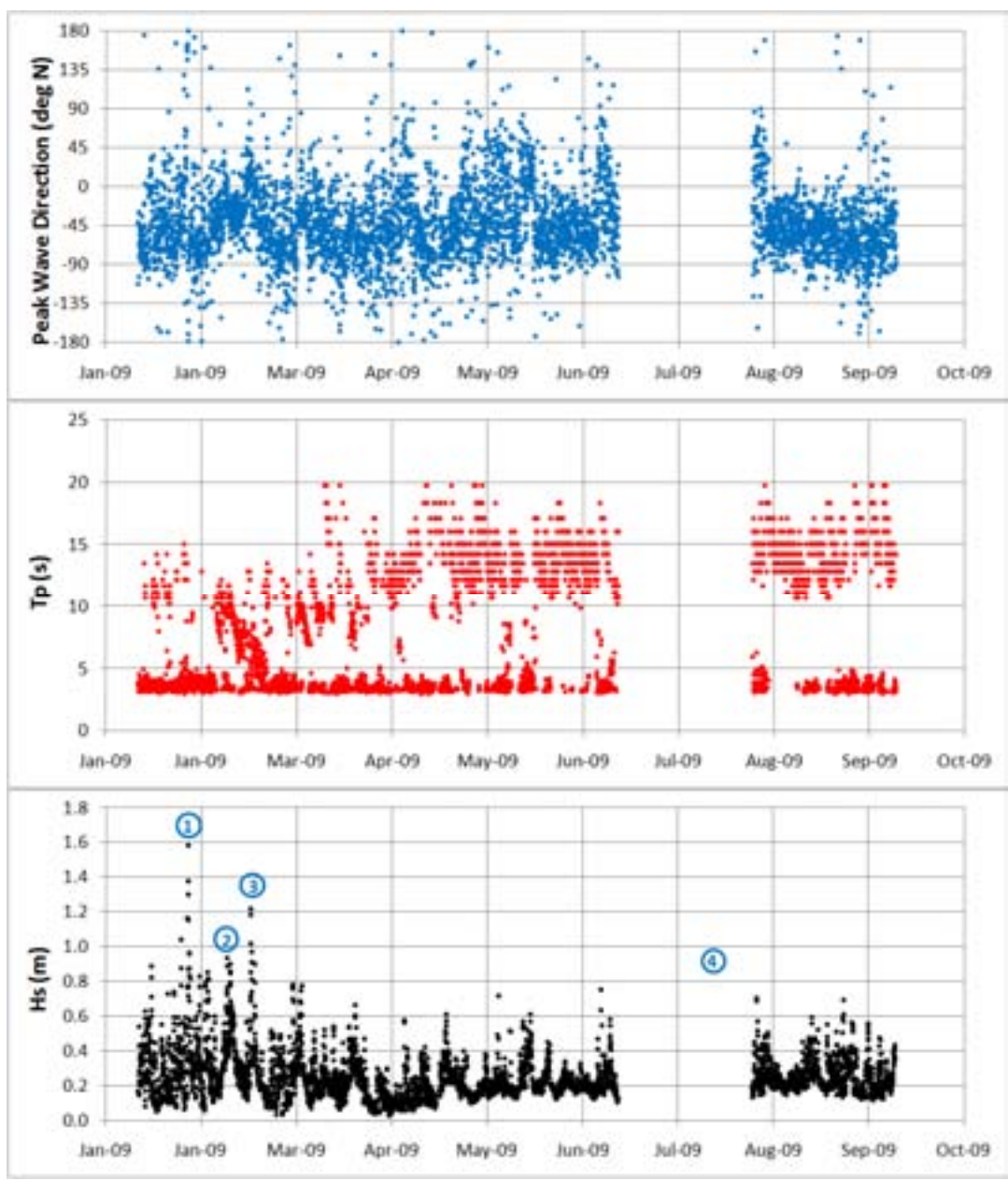


Figure 3-25: Inshore wave record from PLF AWAC

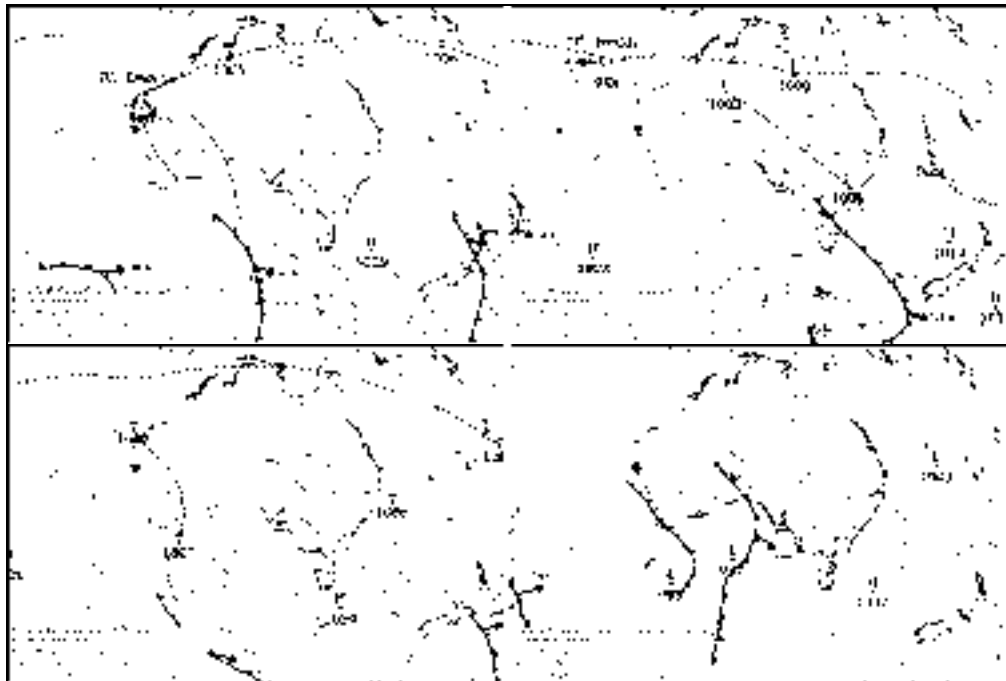


Figure 3-26: Synoptic charts associated with high offshore waves

Although the complete annual cycle has not yet been recorded, the transition from “summer” to “winter” conditions is evident at both sites (Table 3-5). The most significant feature is the relative increase in swell wave activity, resulting in longer wave periods during winter. The mild increase in offshore wave height does not carry through to the inshore site, as it is effectively counteracted by the increased refraction developed by the more westerly wave direction.

Table 3-5: Seasonal transition of observed wave conditions

Instrument	“Summer” Conditions	“Winter” Conditions
Offshore DWR (52 m depth)	Maximum Wave Height, Hs = 2.8 m Median Wave Height, Hs = 0.89 m Median Wave Period, Tp = 8.0 s Modal Periods, Tp = 4, 10 s Median Wave Direction, 270° Direction Spread, 240° to 345°	Maximum Wave Height, Hs = 2.4 m Median Wave Height, Hs = 0.95 m Median Wave Period, Tp = 13.3 s Modal Periods, Tp = 4, 15 s Median Wave Direction, 265° Modal Directions, 60°, 270°
Inshore AWAC (8 m depth)	Maximum Wave Height, Hs = 1.6 m Median Wave Height, Hs = 0.24 m Median Wave Period, Tp = 3.9 s Modal Periods, Tp = 4, 10 s Median Wave Direction, 300° Direction Spread, 255° to 30°	Maximum Wave Height, Hs = 0.8 m Median Wave Height, Hs = 0.21 m Median Wave Period, Tp = 12.8 s Modal Periods, Tp = 4, 13 s Median Wave Direction, 300° Direction Spread, 270° to 60°

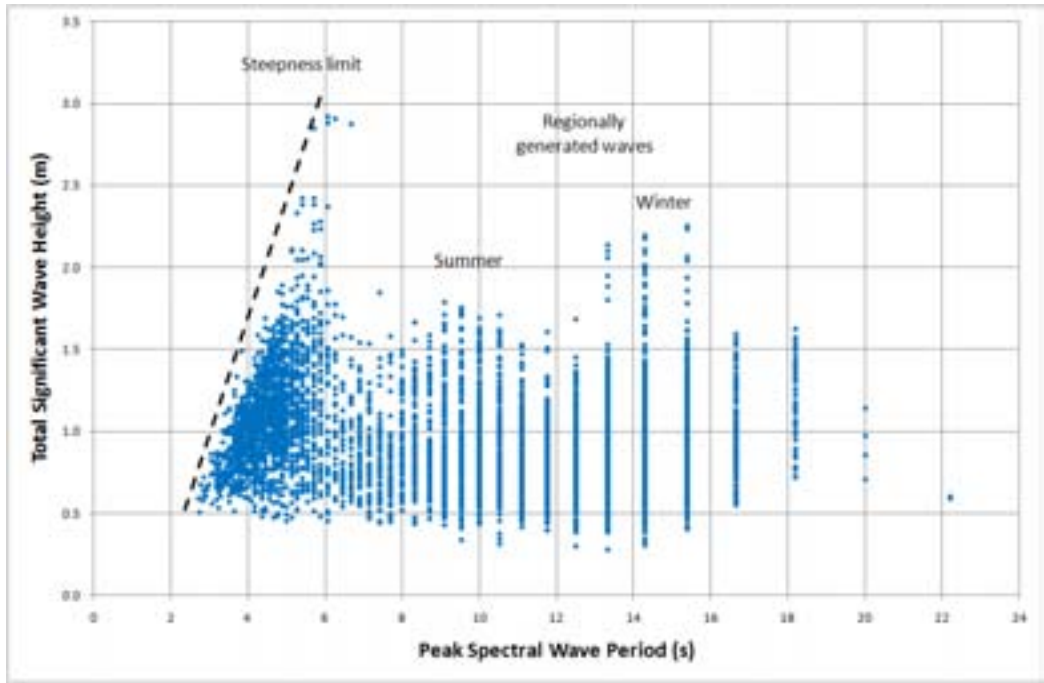


Figure 3-27: Wave height versus spectral wave period crossplot (Directional Waverider Buoy)

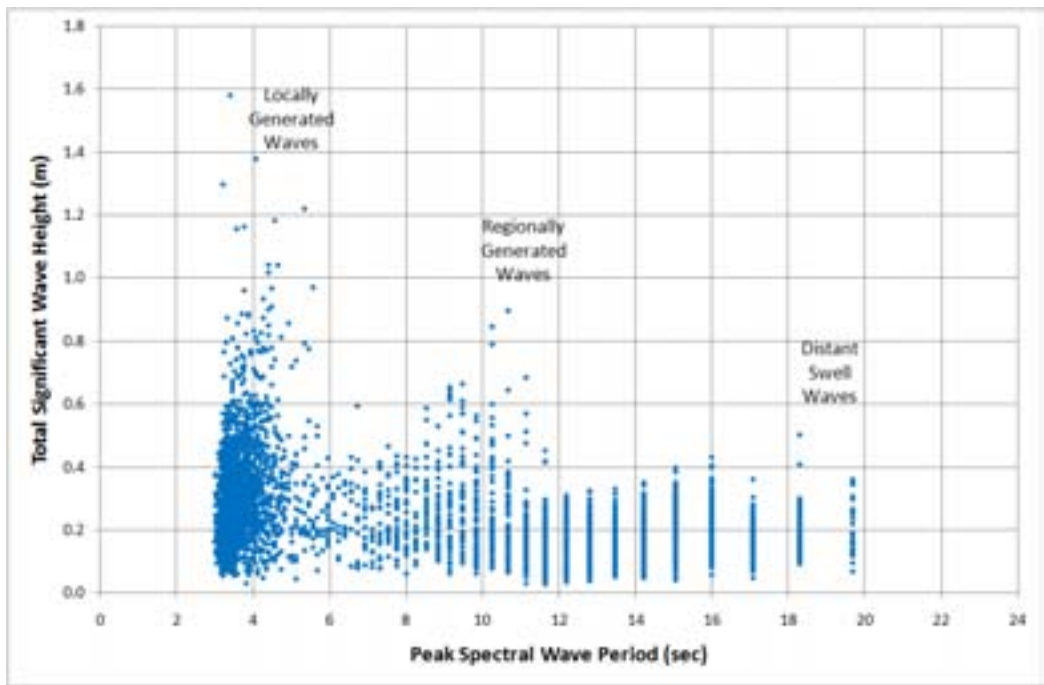


Figure 3-28: Wave height versus spectral wave period crossplot (PLF AWAC)



An indication of the regional wave climate is available from other studies across the Northwest Shelf (Pearce *et al.* 2003; Metocean Engineers 2004; GEMS 2008a & 2008b). Wave measurements along the Northwest Shelf are mainly measured by RPS Metocean, on behalf of a range of resource development agencies, including Apache, BHP-Billiton, Rio-Tinto and Woodside Energy Limited (Hamilton 1997). Although in many cases instruments are deployed for relatively short project-based periods, the combination of measurements enables a description of the overall wave climate of the Northwest Shelf, which varies spatially from Onslow to Port Hedland. The nearest permanent wave recording station to Onslow is located offshore from North West Cape (Exmouth Waverider Buoy), which has been in place from October 2006, and is managed by the Department for Transport. Long-term measurements have also been made at North Rankin A, on behalf of Woodside Energy Limited (Buchan *et al.* 1998), but this data is not generally available to other resource agencies.

Waves along for the North West Shelf have been identified (Pearce *et al.* 2003; Metocean Engineers 2004) as coming from four sources:

- Southern and Indian Ocean swells, propagating past North West Cape
- Winter easterly swell generated across the Timor Sea
- Locally generated wind waves
- Wind waves generated by tropical cyclones

Comparison of wave observations along the Northwest Shelf suggests that the role of Indian Ocean swells increases towards the west, such that southwest swells provide the prevailing wave conditions for the ocean offshore from Onslow, which is supported by the offshore waverider buoy record (Figure 3-29). However, due to sheltering from the continental landmass, these swell waves have reduced influence closer to shore. Similarly, Barrow Island and the shoals of the Lowendal and Monte Bello Islands provide shelter from Timor Sea swells. Consequently the nearshore wave climate is strongly influenced by locally generated wind waves and occasional tropical cyclones.

Due to the limited size of the data set, it is unlikely that the observations cover the full range of synoptic conditions, particularly the potential for cyclonic winds from a range of directions. Consequently, interpretation of the wave height-direction distribution is limited, and preliminary in nature:

The bimodal peak of the wave distribution suggests that there is a separation between locally generated waves and those that are regionally or distantly generated, which are believed to be mainly swell waves from the west. This suggests that the pathway for greatest wave generation under cyclonic conditions brings waves in from the north-northeast.

The behaviour of non-cyclonic waves should be confirmed using a record that extends for at least one year. Interpretation of the distribution should be considered, say using a long-term hindcast, for direction-critical facilities due to the large degree of inter-annual variability identified within the wind record.

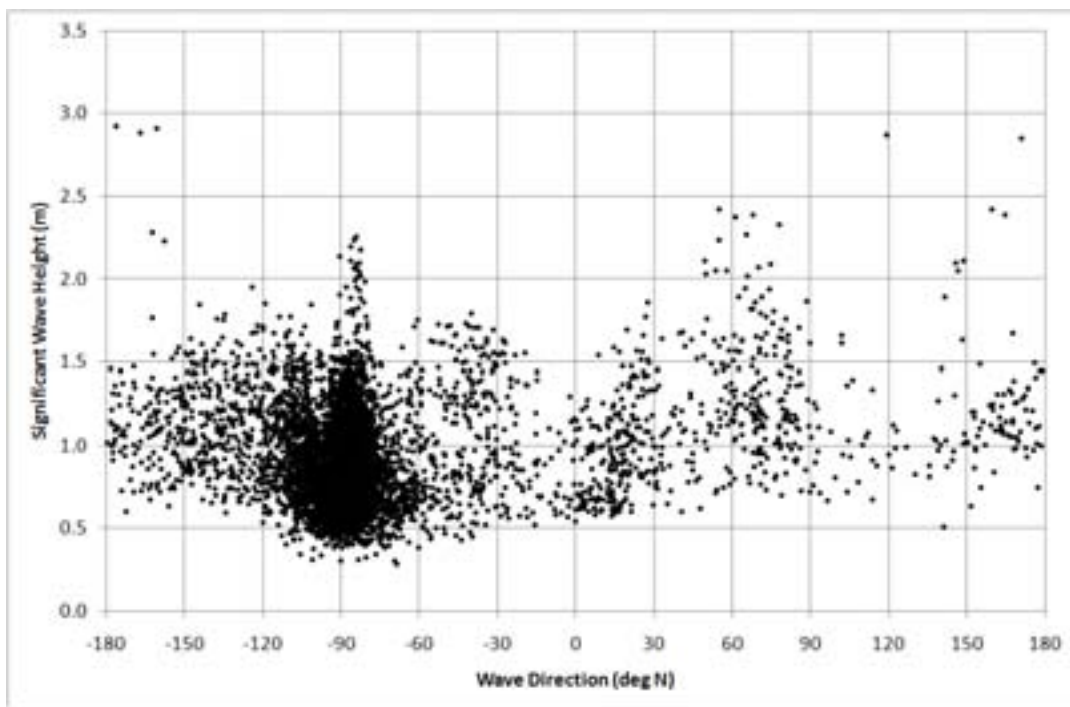


Figure 3-29: Wave height versus direction crossplot (Directional Waverider Buoy)

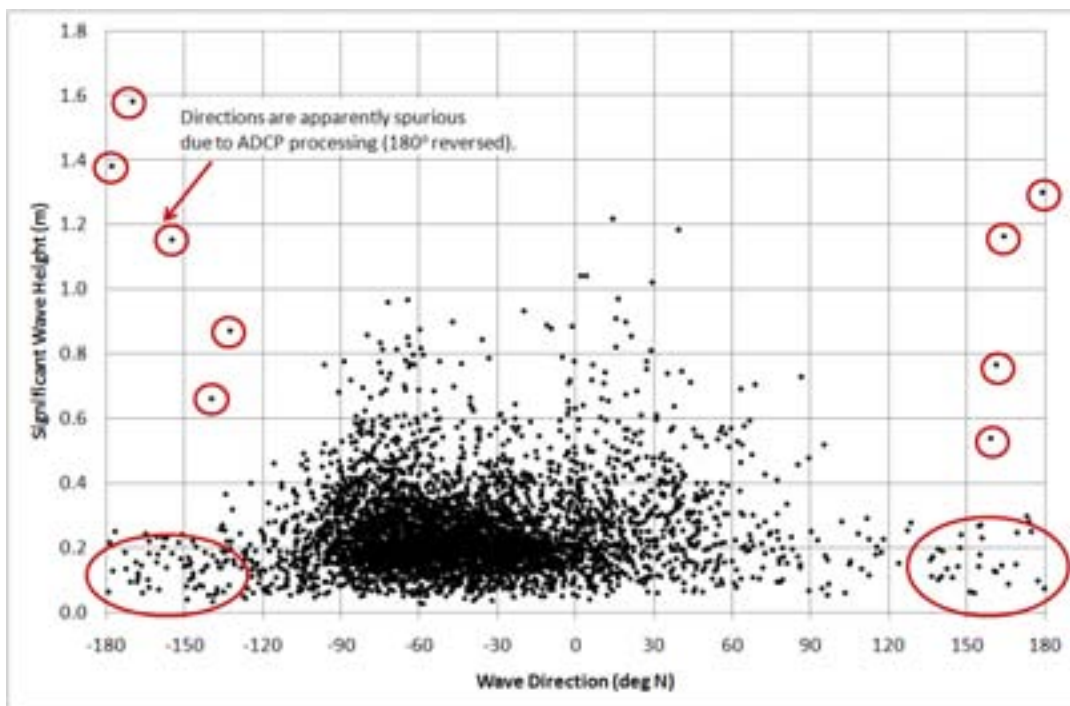


Figure 3-30: Wave height versus direction crossplot (PLF AWAC)



3.5. WATER LEVELS

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 mixed, mainly semi-diurnal tides are mesotidal with a spring tide range of 1.9m. Tidal planes are summarised in the Australian National Tide Tables (Table 3-6). Water level observations are available since 1985.

Table 3-6: Onslow Tidal Planes (Department of Defence 2008)

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

Key water level processes affecting Onslow include tides, cyclonic surges, seasonal ranging and inter-annual mean sea level variations (National Tidal Facility 2000). 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, a 4.4 year cycle developed from lunar elliptic motion and a 19.6 year cycle developed from lunar nodical motion (Damara WA 2008).

Table 3-7: Water Level Processes at Onslow Tide Gauge (1985-2008)

Water Level Process	Time Frame	Scale	Derivation of Scale
Tides			
Semi-diurnal Tides	12 hrs	1.3m average	Average 12-hr range
Spring-Neap Ranging	2 weeks	0.1-2.4m	12-hr range
Bi-Annual Cycle	6 months	0.15m	Diff of monthly max
Lunar Perigee Sub-harmonic	4.4 years	0.15m	Diff of annual max
Mean Sea Level			
Seasonal Ranging	12 months	0.15-0.30m	Range of monthly avg
Inter-annual Variability	3-8 years	up to 0.25m	Range of annual peaks
Surges			
Non-cyclonic (short)	3 hours	0.25m	Avg once per year
Non-cyclonic (medium)	1 day	0.2m	Avg once per year
Non-cyclonic (long)	7 days	0.03m	Avg once per year
Cyclonic		up to 0.8m*	Highest hourly peak

* Surge estimates at Onslow Tide gauge (Beadon Creek) are filtered by the gauge stilling well



The resulting water level climate shows a distinctly tidal character, with perturbations brought about by mean sea level variations (Figure 3-31). The standout non-tidal event over the period of tide recording was in February 1990, when a very large scale tropical low pressure system produced a surge of approximately 0.8m. This event was originally listed as TC Tina, but as the system failed to reach gale force winds, it was later downgraded to a tropical low.

Notably, the influence of TC Bobby and TC Vance were not recorded in the tide gauge record. It is understood that surges much larger than that occurring during “TC” Tina were observed, based upon debris lines (Nott & Hubbert 2005).

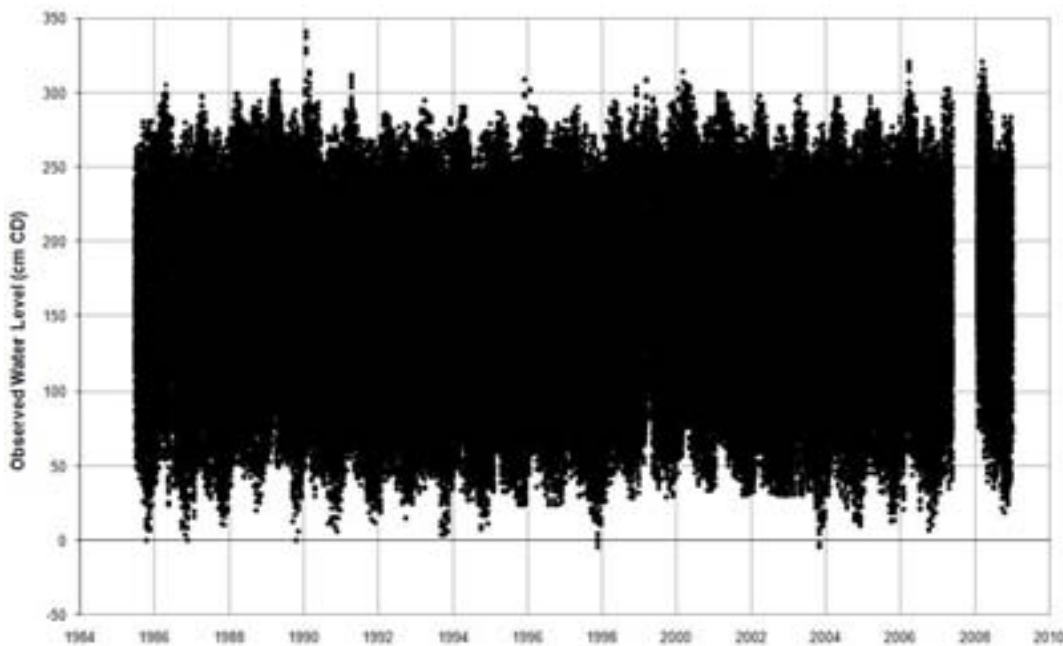


Figure 3-31: Observed Water Levels from Onslow Tide Gauge (1985-2008)

The seasonal variations of tides, surges and mean sea level are generally not in phase (Figure 3-32):

- 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 (>2.8m CD) over the majority of the year. The relative timing of the tidal and mean sea level peaks provides increased potential for extreme water level events to occur as a result of late season tropical cyclones, in March or April.

Modelling of extreme cyclonic water levels for the Onslow town site and Onslow Salt (GEMS 1999, 2000; Nott & Hubbert 2005) has estimated the 100-year ARI water level as 4.7m AHD (6.2m CD), including allowance for wave setup. Observed tide gauge levels are much lower due to the sheltered position of the tide gauge, damping due to the gauge stilling well and the discrete nature (in time and space) of the gauge.

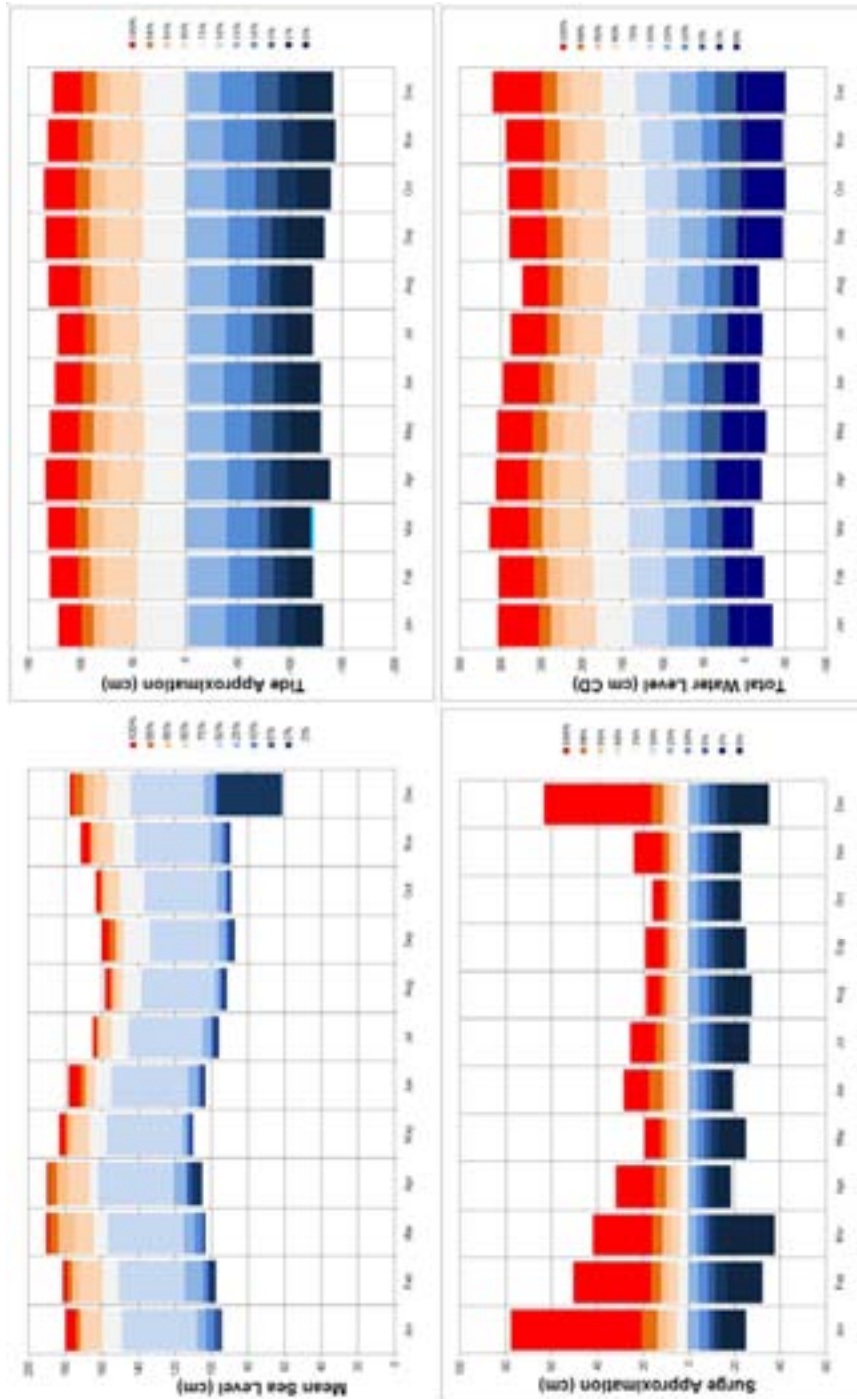


Figure 3-32: Seasonal variation of water level components

3.6. CURRENTS

Limited information has been collected regarding currents in the Ashburton region. In theory, the four principal current drivers are oceanographic (steric gradients and weather systems), tidal, wind-driven (local winds) and wave driven, each of which is likely to be dominant in a different zone relative to the coast. Consequently, there is a theoretical sequence of currents moving seawards that relates to the relative strength of the forcing mechanisms (Figure 3-33).

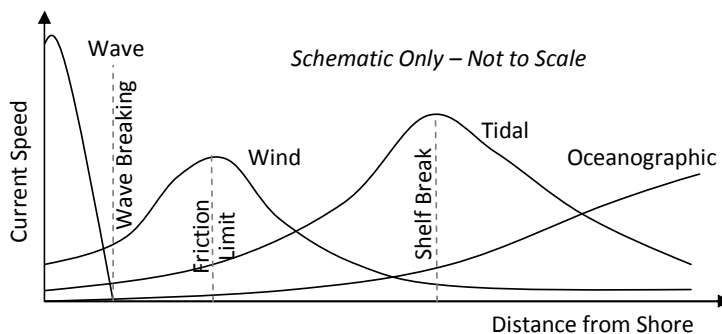


Figure 3-33: Schematic Spatial Distribution of Currents

Nearshore, the boundary effect of the coast causes all currents to run nearly shore parallel. In general, further offshore, the direction more closely follows the direction of forcing, with the notable exception of tide, which becomes more shore-normal near the shelf break.

Observation of bottom and surface currents at the proposed dredge material placement site, in 51m depth, shows direct response to weather systems (Figure 3-34). Background drift is not apparent within the record from January to April.

The nearly shore parallel nature of currents and the strong tidal signature is shown at the inshore AWAC location, in 8m depth (Figure 3-35).

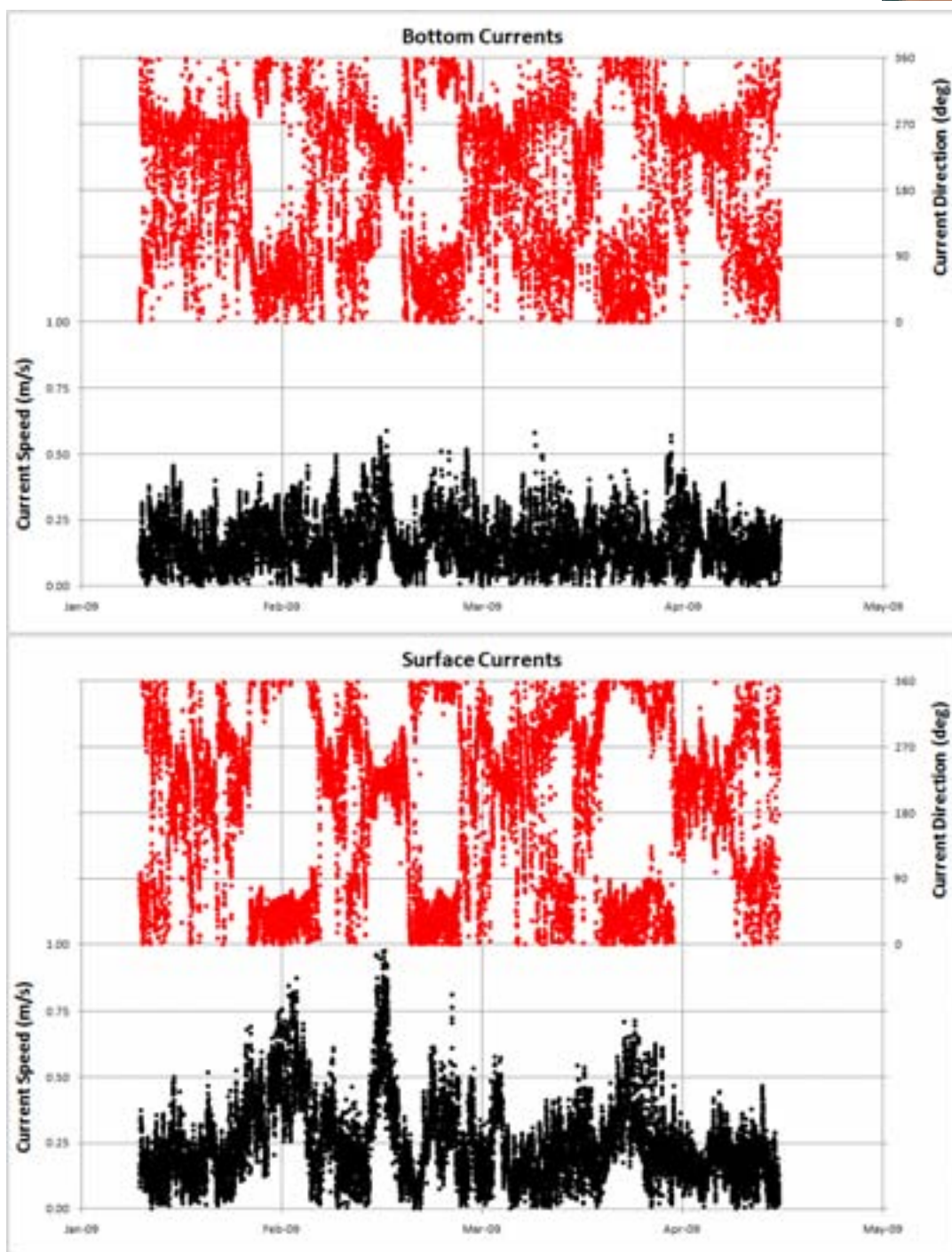


Figure 3-34: Observed Currents at Dredge Material Placement Site (51m depth)

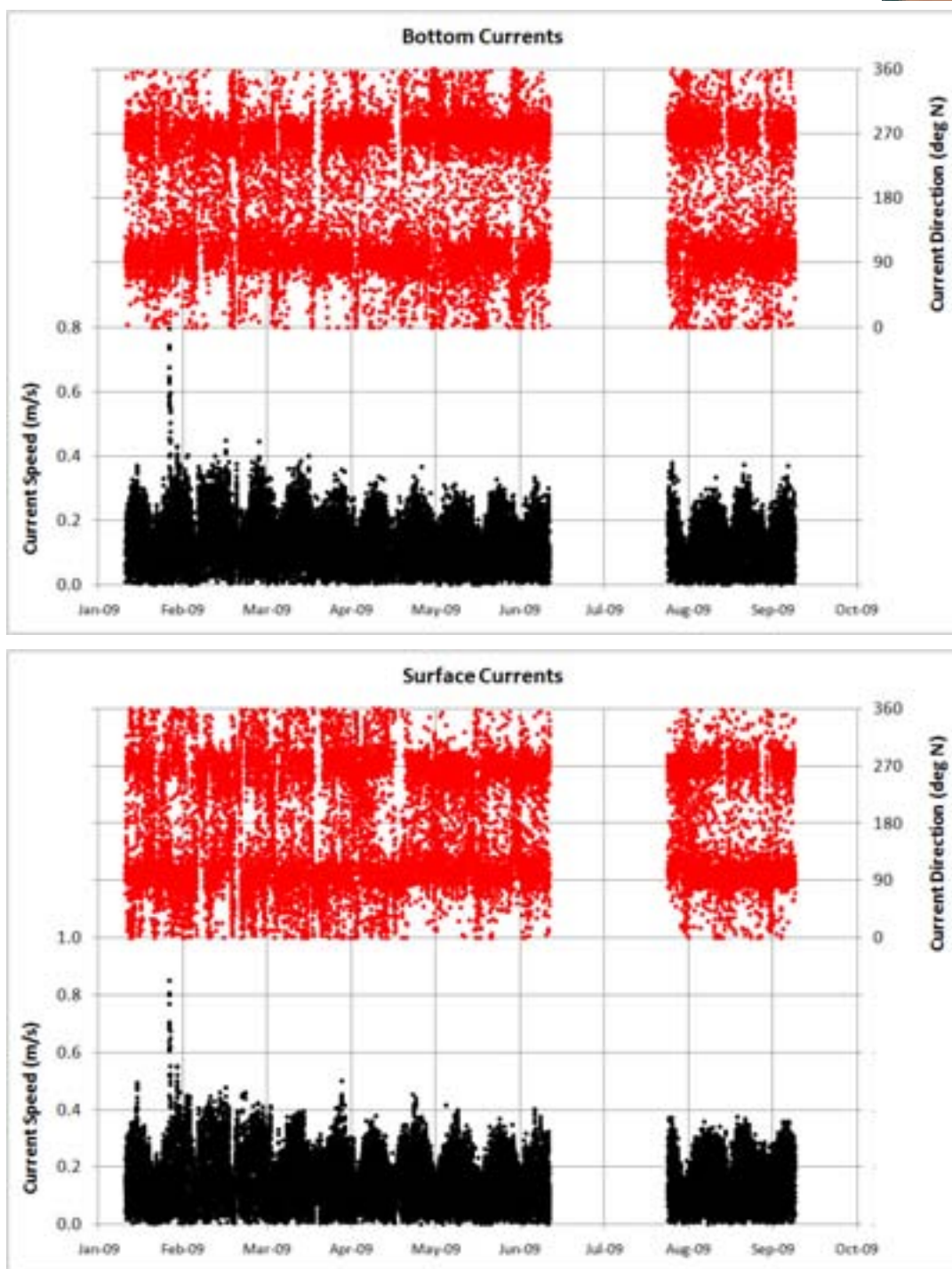


Figure 3-35: Observed Currents at PLF (8m)



3.7. RAINFALL & RUNOFF

The Ashburton River catchment lies in the arid Pilbara region, which is on the fringe of both tropical and extra-tropical rainfall influences (Gentilli 1971; Semeniuk 1996; Bureau of Meteorology 1998). As a result, rainfall may occur during either summer or winter months (Figure 3-5) but there is capacity for extended periods of sustained drought (Figure 3-36). As a consequence, the Ashburton River is subject to highly variable flow conditions, with extended periods of low flow and short periods of intense flow, generally associated, although not always, with extreme rainfall due to tropical cyclones (Figure 3-37).

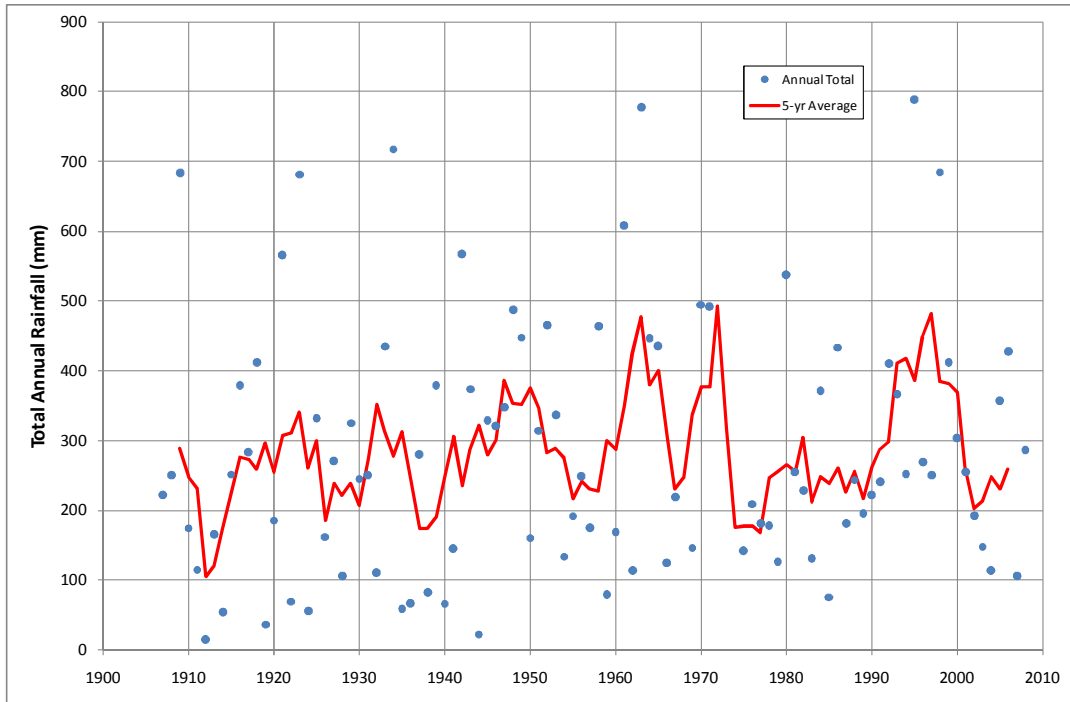


Figure 3-36: Onslow Annual Rainfall Summary

The runoff record suggests a dramatic increase in the magnitude of flood events over the period 1995 to 2000, compared with the preceding period from 1972 to 1995. However, this apparent secular change is put in context when compared with the longer rainfall record from Onslow, which suggests that similar decadal scale fluctuations have occurred previously.

A major implication of the highly variable river flow regime is the capacity for the Ashburton River to episodically release massive sediment loads. Some indication of sediment carrying capacity is suggested by the very high associated turbidity (Ruprecht & Ivanescu 2000). It is notable that the estimate of mean annual sediment load from the Ashburton river quoted by Margvelashvili *et al.* (2005) was obtained from an earlier version of Ruprecht & Ivanescu (1996 *unpublished*) which calculated sediment loads almost exclusively during lower flow conditions from 1972 to 1995.

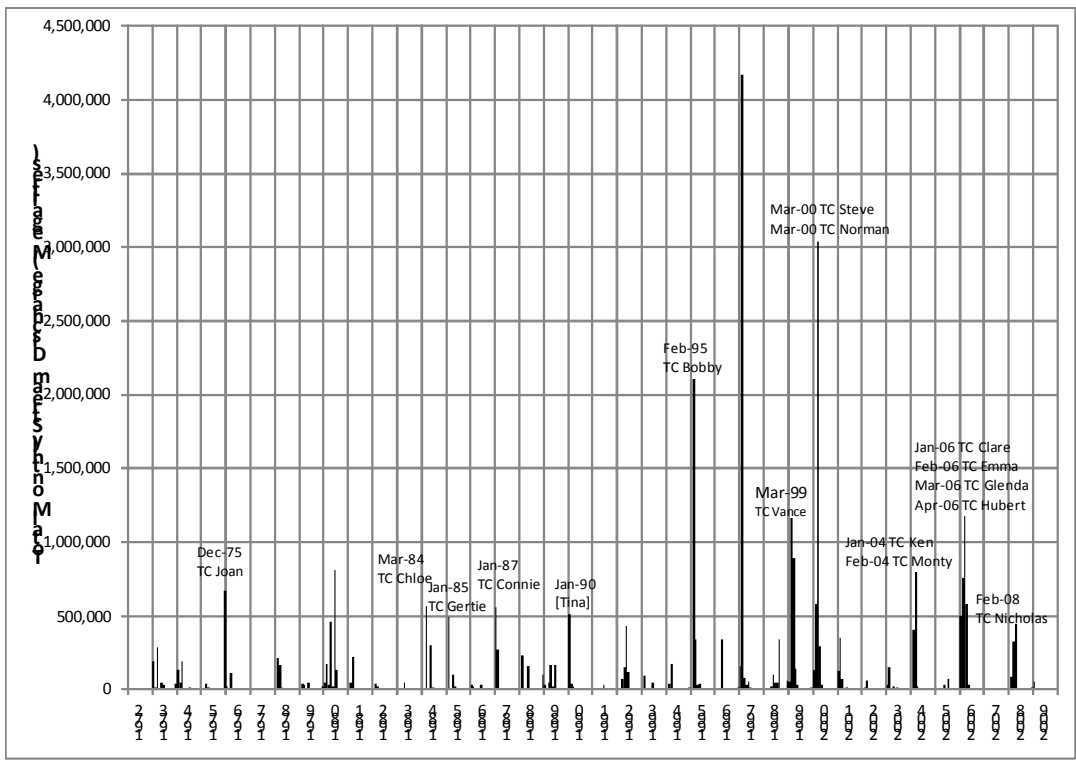


Figure 3-37: Ashburton River Discharge (Nanutarra)

3.8. TSUNAMI

The potential for tsunami to affect Northwest Australia was highlighted by the 2004 Boxing Day tsunami in the Sumatra region. However, such events are not isolated, and there is a long record of earthquakes or volcanic eruptions across the Indonesian Archipelago capable of producing tsunami. Available information for Western Australia is limited and largely interpretive in nature (Bryant & Nott 2001; Nott 2004) but suggests that large tsunami occurred around 350-400 years ago and 900 years ago.

Modern observations of tsunami in the Northwest have included:

- 2004 Boxing Day tsunami, observed along entire WA coast
- June 1994 – propagating to 4m above sea level in Exmouth Gulf
- 1977 tsunami – propagating to 7m above sea level near Cape Leveque

The relative scale of such tsunami, despite their relative rarity has prompted detailed hazard assessment and modelling (Middelmann 2007). Recent detailed modelling of tsunami propagation along the southern arc of the Indonesian Archipelago has indicated that the Onslow region is a natural focal point for impacts (Pattiaratchi 2005; Leggett 2006, see Figure 3-38).

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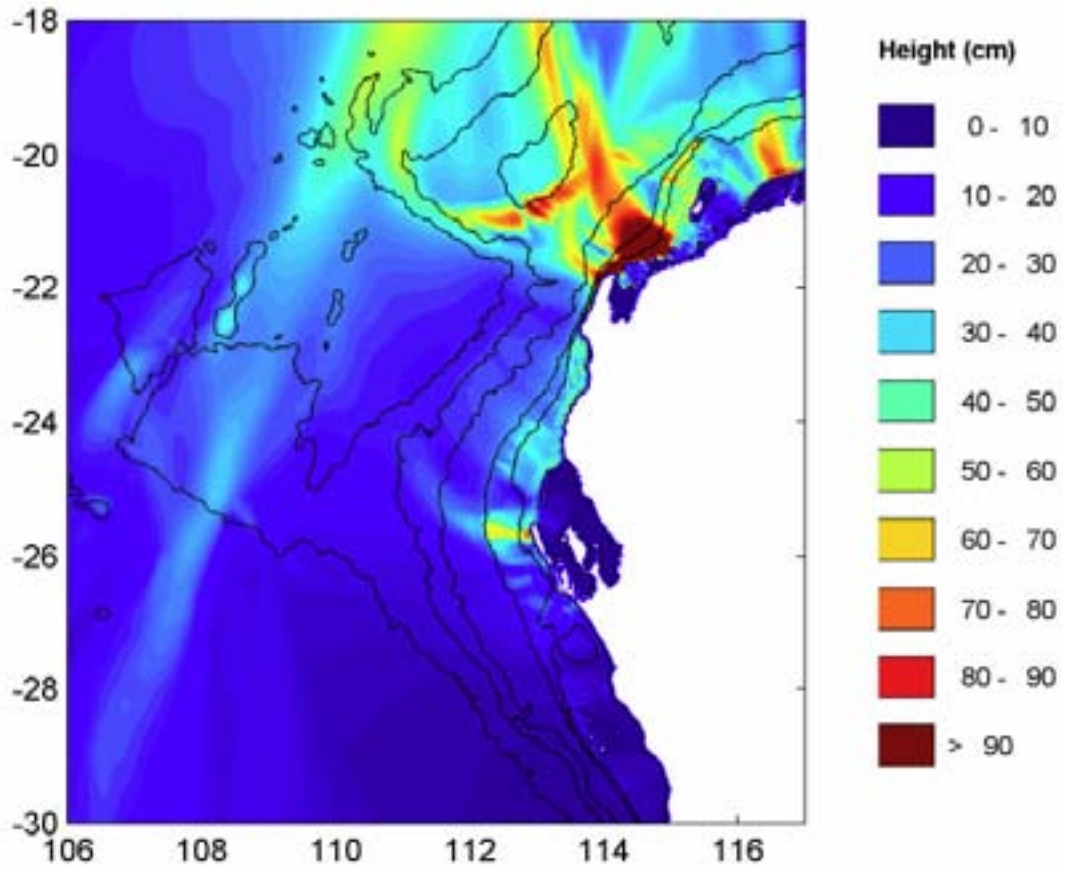


Figure 3-38: Modelled Tsunami Propagation from Bali Region (Leggett 2006)



4. Landform Components

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

Four sets of landforms comprise the coastal area of the wider Ashburton River delta. These include the active deltaic complex of the Ashburton River, the Saddle Hill dune ridge and back-barrier flats, the Onslow mudflats and tidal creeks, and the active sandy beaches and associated coastal dunes. Each is described below in terms of its components and potential likelihood to impact on or be impacted by the proposed development. In addition to these units, the shoreface topography provides the geologic framework supporting local landforms and processes comprising the active foreshore and nearshore components of the coast. Whilst the structure of the shoreface is being considered separately as a component of the marine investigations for the project and is not described in detail herein, it is important to consider linkages between the shoreface topography and beach stability in assessing the potential impacts on the development site. The distribution of rock outcrops along the beach, between Casugrina Point, at the eastern margin of the Ashburton Delta, and Four Mile Creek is described for this reason. It provides the local geologic framework and explains some of the variation in unconsolidated sedimentary landforms along the coast.

4.1. ASHBURTON RIVER DELTA & BEACHES

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

Throughout the Quaternary at least, the shifting Ashburton River has built a suite of coalescing deltas with the deltaic plain consisting of overlapping and inter-fingering delta lobes against a NW trending rocky shore. The switching pattern has commonly resulted from channel avulsion with one of the few distributaries present at any time carrying the majority of water and sediment discharge. Judging by the formation of recorded changes to Entrance Point, the active channel rapidly progrades seaward while secondary channels are clearly less active and may be blocked by deposition from the main channel. In several places, particularly where the channel has been driven parallel to shore, presumably under the influence of winds and waves from the W and flowing in a NE direction, the delta is asymmetrical with the river feeding chenier spits on the eastern side of its mouth (Figure 4-2). This is a feature of coastal environments subject to strong littoral transport along the lower swash zone of sandy beaches.

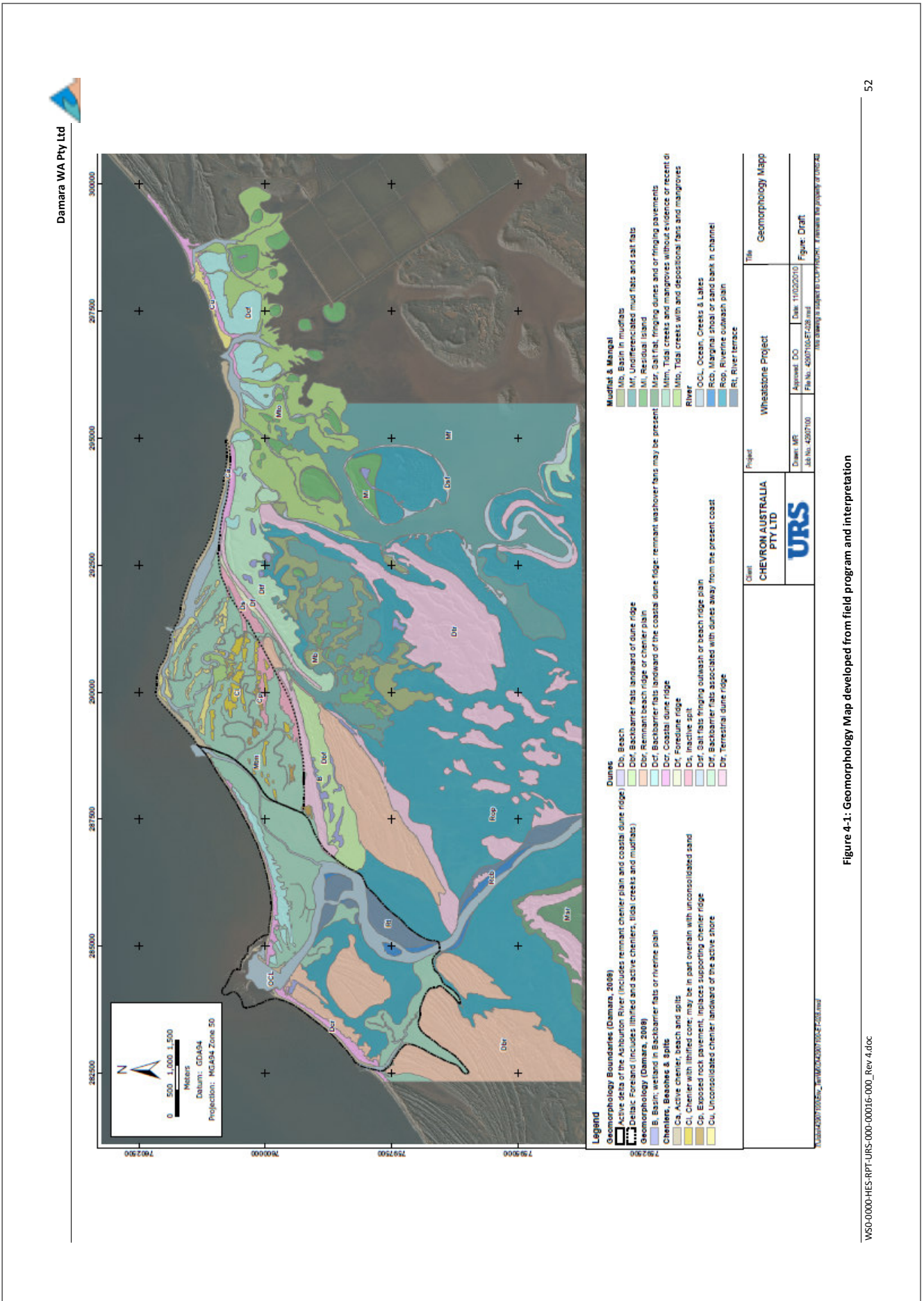


Figure 4-1: Geomorphology Map developed from field program and interpretation



Figure 4-2: Geomorphology of Ashburton River Deltaic Complex



Figure 4-3: Ashburton River Palaeochannels



Presently, the main channel is approximately 7 km west of Entrance Point and its delta has a more symmetrical form than that present in the early 1900's. This is a very recent change of channel position. It resulted from main river mouth switching from Entrance Point to its present position after siltation of the channel in the vicinity of the Old Wharf, which was abandoned in 1921. Channel avulsion, the change in channel position associated with extreme flood events, is typically associated with river systems bearing a high sediment load, under relatively low wave and tide conditions (Coleman & Wright 1975). At the site of the active channel, a local salient and shoal structure commonly occurs, which may be rapidly destabilized if the river flow subsequently switches to an alternate channel. This feature is locally apparent at the existing Ashburton Channel entrance, with only residual shoals remaining at Entrance Point. Such changes have occurred in the geologic past, throughout the Holocene in particular. Changes in channel position are apparent as palaeochannels on the floodplains (Figure 4-3), forming elongate depressions that may carry fluvial flood waters, contain tidal creeks along part of their length, or form billabongs in wet seasons. The channels may be reactivated by tidal creek incursion or avulsion of the main river channel. Shoals at the abandoned river mouths are rapidly reworked by ocean processes and moved into the littoral transport system to form beaches, chenier spits and foredune ridges as is currently occurring at Entrance Point.

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

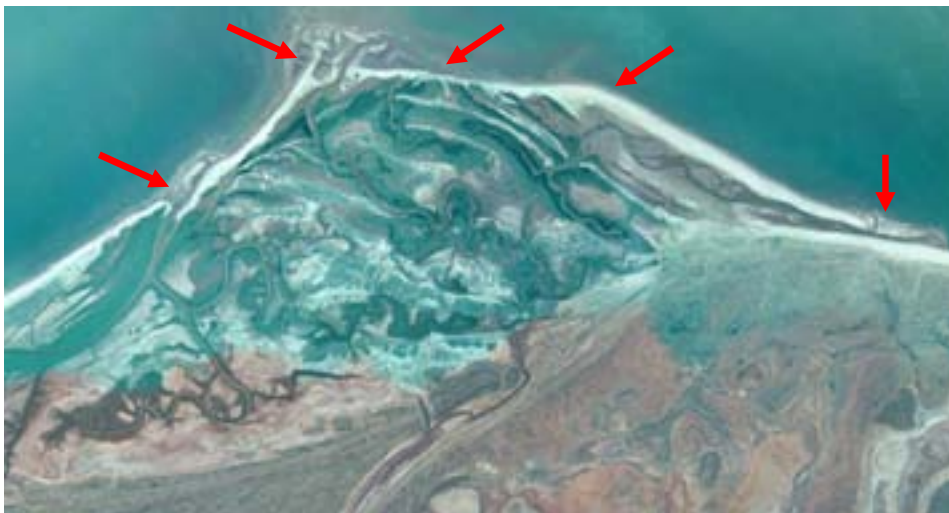


Figure 4-4: Sedimentation blocking the mouths of tidal creeks



4.1.1. Ashburton Entrance West

The coastline west of the Ashburton river entrance is a relatively flat, sandy beach backed by wide, high dunes. The coastline faces northwest and is relatively exposed to antecedent westerly winds. The dune field includes a sparsely vegetated, wide primary dune and higher thickly vegetated secondary dune. A shell debris line in the swale at the toe of the secondary dune is likely to represent a 10-year old inundation line from Cyclone Vance. Figure 4-5 corresponds to beach monitoring site BS01 (Figure 1-3).



Figure 4-5: Ashburton Entrance West

4.1.2. Ashburton Entrance East

East of the Ashburton entrance the coastline is a barrier island within the active Ashburton delta. The sandy coastline extends for 4.5km from the Ashburton Entrance eastwards to a smaller secondary entrance, which is understood to have been the historic navigable entrance. The beach is backed by a thickly vegetated, shore parallel dune field up to 10m high, which reduces in height towards the entrances. The coastline has a north-northwest aspect, which is exposed to westerly winds that prevail during summer months. The beach profile is flat with establishing primary dunes in many areas. Figure 4-6 corresponds to beach monitoring site BS02 (Figure 1-3).



Figure 4-6: Ashburton Entrance East

4.1.3. Entrance Point West

The shore from the secondary entrance to Entrance Point is also a coastal barrier structure within the Ashburton delta complex. The island is composed of a vegetated dune field of modest height in the west (for about 1.2km) transitioning abruptly to a low relief, sandy spit. The unvegetated spit is about 1.5km in length with an elevation in the order of 3mCD and a width, at the time of inspection, of about 50m. Figure 4-7 corresponds to beach monitoring site BS03 (Figure 1-3).



The vegetated dunes to the west have an elevation in the order of 5mCD with a relatively steep face on the ocean side and irregularly spaced swales that could be breached during high water level events. The ocean beach faces northwest and is relatively narrow whilst colonizing mangroves are evident on the estuary side.

The morphology of the sandy spit is a 'dogleg' shape, with the coastal orientation transitioning relatively abruptly from northwest around to the north. The cross-shore profile is higher on the ocean side, slowly falling away towards the estuary, characteristic of washover. This spit is a dynamic feature that would be vulnerable to breaching during high water level events.



Figure 4-7: Entrance Point west

4.1.4. Entrance Point East

East of Entrance Point, a second sandy spit extends eastwards for approximately 3.2km until it joins the coastline beyond the eastern extremity of the Ashburton delta. The spit is built of sandy sediments transported eastward from the active Ashburton River delta. Its cross-shore profile is similar to the western spit although the coastline faces northeast. Figure 4-8 corresponds to beach monitoring site BS04 (Figure 1-3).

The ocean beach at the western extremity of the spit has a moderate beach slope (1:8) with a berm at about the highest astronomic tide level (in the order of 3m 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 mangrove covering. Breaking waves were evident on the delta shoals at the entrance although the extent of these shoals was difficult to ascertain due to high water levels and muddy waters.



Figure 4-8: Entrance Point East



4.2. WEST SADDLE HILL DUNE COMPLEX & BEACHES

Geomorphologically, the West Saddle Hill dune complex, the uplands west of Saddle Hill proper, (Figure 4-9) gives an indication of the manner in which the coast developed. It provides landform evidence for avulsion of the Ashburton River channel and reversal of the littoral drift direction along the shore. Several distinct landscapes form the complex: From east to west they include two ridges trending approximately SW to NE, The ridges are linked by dunes along the coast and separated by backbarrier flats and a riverine plain to landward.

The longer, eastern ridge rises as upland of low networked dunes in the vicinity of the junction between from the Urala Road turn-off to Old Onslow Road and extends over 10 km to the coast. The upland becomes a single, 5 to 10m high ridge approximately 6km from the junction and extends NNE for another 4km, until it joins or has been truncated by the coastal dunes. This long ridge has formed on one of several Pleistocene shorelines apparent on the deltaic plain. The Onslow Mudflats lie to the east of the dune ridge.

A low, undulating riverine plain at an elevation similar to the Onslow Mudflats lies to the immediate west of the dune ridge. This is the area of interest for development. In its central area the plain supports a complex network of palaeochannels and overbank basins (Figure 4-3) that hold water after inundation from the Ashburton River and, perhaps to a lesser extent, the Onslow Mudflats or some combination of the two. Further west and to the north the plain rises and merges with backbarrier flats, a second NNE trending ridge and the coastal dunes. The western ridge is apparently comprised of parallel coastal dunes built on a chenier complex with recurved spits extending onto the riverine plain from the main body of the dune ridge as well as from its seaward margins.

Water from the riverine plain drains seaward onto the deltaic foreland through a series of palaeochannels transecting the dunes and riverine plains. To the west, some of the palaeochannels are occupied by active tidal creeks (Figure 4-1 and Figure 4-3). The potential effect of river flooding and storm surge inundation through the tidal creeks on the proposed development site is open to question and depends on factors such as storm recurrence and the prior wetness of coastal soils. However, there may be scope to use the palaeochannels to drain the development site as part of any measures for flood minimisation or mitigation.

Reversal of the dominant littoral drift from an easterly to westerly flow is indicated by the recurved spits at the seaward and landward limits of western margin of the coastal dunes (Figure 4-1 and Figure 4-9). The most recently formed spits are apparently those close to the coast, where lobes of sediment abut the western ridge and spill onto the active delta of the Ashburton River. The size of the spits indicates a need to consider the potential reversal of littoral drift in any modelling of sediment transport along the coast.

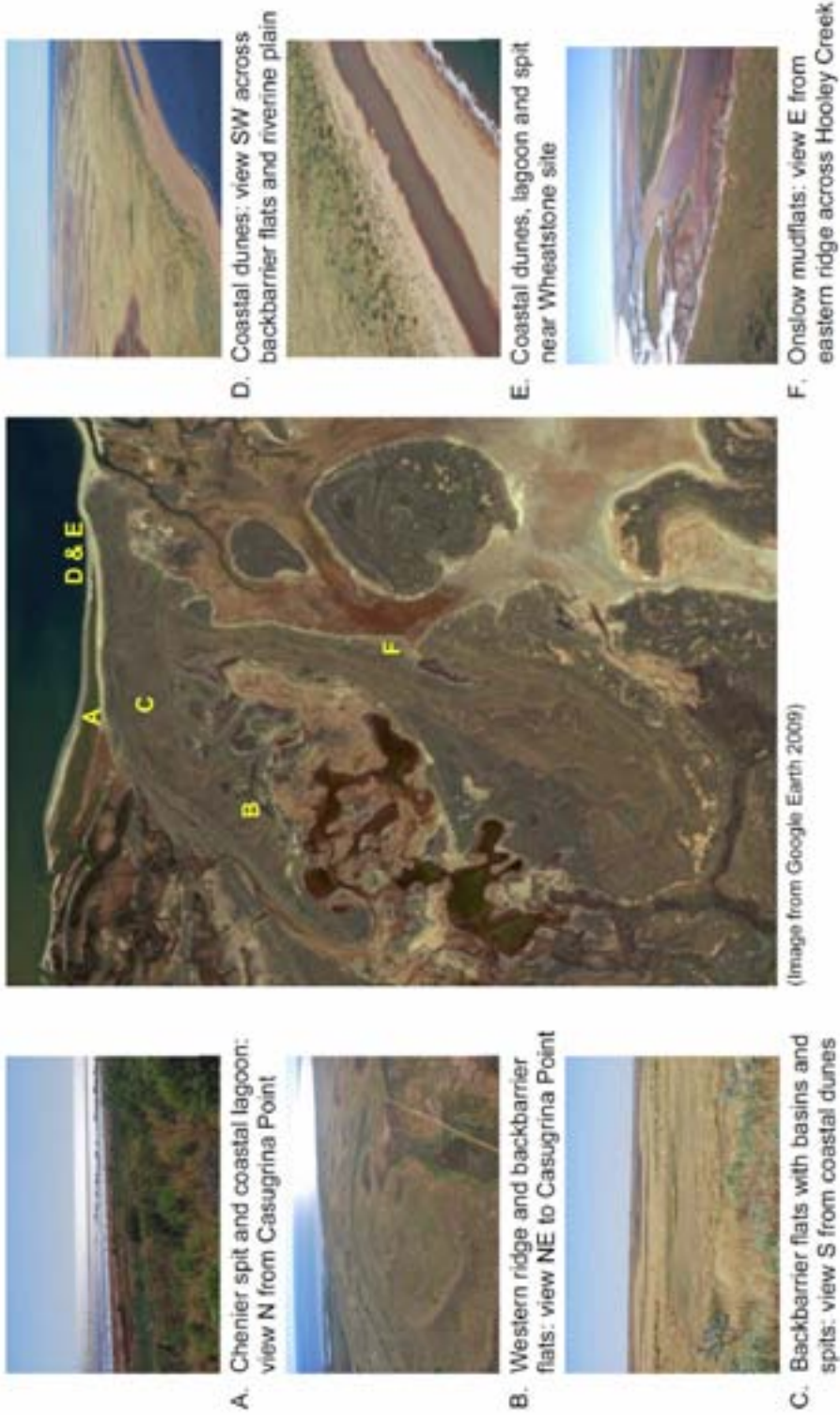


Figure 4-9: Saddle Hill Dune Complex Morphology



4.2.1. The Spit Beach

A beach profile was taken midway along the Entrance Point eastern spit at a lower tide. The beach slope becomes flatter (1:11) and the spit marginally wider. The spit impounds a shallow lagoon which is approximately 50m 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 3m CD. Figure 4-10 corresponds to beach monitoring site BS05 (Figure 1-3).

This site is understood to be near the location of an ocean jetty for Old Onslow in the early 1900s. The site was being drilled by Coffey Geotechnics at the time of inspection.



Figure 4-10: Spit

4.2.2. Spit Weld

The eastern spit of Entrance Point welds to the beach approximately 500m west of a prominent salient. The coastline faces due north at this location and the beach is more than 100m wide. Beach slope west of the salient is about 1:13 with a berm level in the order of 3m CD and a wide, overwashed beach in the order of 100m wide. There is a sparsely vegetated low spinifex foredune backed by high primary dunes. Figure 4-11 corresponds to beach monitoring site BS06 (Figure 1-3).

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 2.5m CD and appear to fall away between the spit weld and the salient, resurfacing in isolated areas at the salient.



Figure 4-11: Spit Weld

4.2.3. Plant Site (Salient)

A small salient, apparently controlled by rock outcrop, forms a slight re-curve of the coastline between the spit weld and Hooley Creek. The beach here is relatively wide and backed by high dunes that rapidly decline in height to the east. Figure 4-12 corresponds to beach monitoring site BS07 (Figure 1-3).

The emergent rock is about 0.5m above the sand level at about 3.5mCD. At the time of inspection about half a dozen outcrops were evident along the vegetation line, approximately 30 to 40m from the water line.

A submerged beach ramp and rock platform was also evident at the toe of the beach to the east of the salient. The elevation of this platform would be in the order of 0.5m CD. It is exposed at lower water levels.



Figure 4-12: Plant Site – Salient

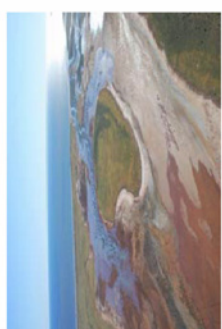
4.3. ONSLOW MUDFLATS & TIDAL CREEKS

Palaeochannels, tidal creeks, mudflats and residual mounds or islands comprise the natural landforms of the Onslow Mudflats (Figure 4-13). Water flow through the tidal creeks provides the major exchange of sediment between the nearshore marine and terrestrial areas. With river flooding, it is a process affecting floodplain development through raising or lowering the elevation of mudflats and saltflats (Winn *et al.* 2006). Extreme flows occur when ebb flows are reinforced by fluvial run off and when flood flows are linked to higher than average sea level and arid conditions. Dominance of ebb and flood run-off produces channel extension, landward incursion of mangroves and gulying of the channel headwaters (Cobb *et al.* 2000). After flooding has subsided the gulying is apparent at the channel headwaters as a network of tributaries flowing into an eroded depression and ultimately the main channel of the tidal creek (Figure 4-14a). Conversely, when flood tides are dominant overbank flooding occurs as the tide reaches its peak and distributary fans form in the channel headwaters (Figure 4-14b).

The headwaters of tidal creeks between the western arm of Hooley Creek and Four Mile Creek display morphologies ranging from erosional to depositional. The variation may be due to natural causes such as



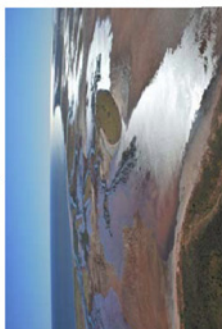
different coastal aspect, the underlying geologic framework, changes in entrance configuration or recent flood run-off patterns. Alternatively it could be due to modification of run-out of flood water across the saltflats resulting from construction of the Onslow Salt ponds and diversion of the flood waters away from the eastern creeks. Regardless of cause, which remains to be established for individual creeks, the change is from headwater gullying and erosion in the west to headwater fans and deposition in the east. If the variation is long-lasting rather than a response to seasonal or inter-annual fluctuation in metocean processes, it has ramifications for potential impacts on the development site, particularly for MOF development. Further constraint on floodwater discharge, particularly its restriction to a single discharge outlet adjacent to the development area, may result in channel entrenchment and enhanced erosion of the floodplain landward of the existing saltflats. It is also possible for this to be intensified by avulsion of the main channel of Ashburton River in association with extreme flooding events if tidal creek incursion reactivates a palaeochannel. While these are matters for consideration in site design and environmental management, flood discharge from a reduced number of tidal creeks also will affect littoral sediment transport processes.



C. Flood tide inundation of Hooley Creek East & mudflats



B. View NE across Saddle Hill to mouth of Hooley Creek complex



A. Coastal lowlands: view NE to Hooley Creek



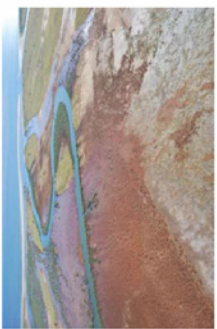
IKONOS, February 2009
Hooley Creek and East Creek mudflats.



G. Four Mile Creek with Salt Ponds



D. Flood tide inundation of Hooley Creek with overbank deposition



E. Detail of flood tide inundation & storm surge overbank deposits



F. View NE across Hooley Creek mudflats, palaeochannel & dunes

Figure 4-13: Hooley Creek Morphology



**Figure 4-14: Morphodynamics within the Hooley Creek Mudflat Complex
Erosional and depositional headwaters of tidal creeks**

4.3.1. Hooley Creek

Hooley Creek is a tidal creek immediately east of the salient with three distinct tidal channels; Hooley Creek East, Hooley Creek West and Eastern Creek. These tidal channels currently have a single inlet adjacent to Eastern Creek. A 1.2km long sandy spit extends eastwards across the entrance. Figure 4-15 corresponds to beach monitoring site BS08 (Figure 1-3).

The spit originates adjacent to Hooley Creek west, where high dunes to the west fall away to low-lying dunes. The spit is about 100m wide at its origin with a wide beach on the seaward side and mangroves and mudflats on the creek side.

The spit is unvegetated for 600m until the entrance to Hooley Creek east. At this site, midway along the spit, there is evidence of debris and large shell deposits that are likely to be overwash deposits. This spit appears to be marginally lower at its midpoint, which is also the western edge of the ebb delta.



The seawards beach in the lee of the relatively large, emergent ebb delta is sinuous for a further 600m until the end of the spit. The spit is relatively wide (~200m) at its eastern extremity and there is some colonizing vegetation on the creek side of the spit. The elevation of the spit is estimated to be in the order of 3m to 4mCD.

Tidal creek vegetation is evident of the inland side of the creeks at the origin of the spit whilst coastal dune vegetation becomes evident midway along the spit, suggesting this coastline has been directly exposed to the ocean in the past.



Figure 4-15: Hooley Creek



4.4. THE EASTERN BEACHES & DUNES

The Ashburton River and its offshore shoals are the major sources of sediment moved eastwards along the beaches to the offshore shoals in the vicinity of the Mangrove Islands and Barrow Island. Disruption of the littoral pathway through MOF construction is therefore likely to have downstream effects on the coast, especially the stability of Sunset Beach and Beadon Point. Conversely, the littoral drift is reversible during extreme cyclonic events driving strong onshore winds and high seas from the N to NW, and this is likely affect sedimentation in the vicinity of shore crossing engineered works. Beaches at and east of Four Mile Creek have been examined for these reasons, as well as for their potential indication of coastal change.

4.4.1. Four Mile Creek

The entrance to Four Mile creek is about 2.0km east of the current entrance to Hooley Creek and Eastern Creek (and about 4 miles west of Onslow). Relatively high coastal dunes back this coastline. The orientation of the coastline becomes more northwest towards the Onslow Salt Jetty and Beadon Point. Figure 4-16 corresponds to beach monitoring site BS09 (Figure 1-3).

Dunes at the entrance to Four Mile Creek were reportedly eroded during Cyclone Vance and new dunes of modest relief and colonized by spinifex are evident at the site. Dunes further east towards Beadon Point are high and wide with established vegetation. There are large shell deposits along the active beach face at least to a depth of 0.2m on the beach to the east of the entrance. Beach material is visibly coarser than beaches to the east.

The creek entrance is orientated to the west with a wide entrance shoal on the eastern shore and a spit in the order of 200m length.



Figure 4-16: Four Mile Creek

4.4.2. Beadon Point

Beadon Point is immediately west of Onslow and the site of the most recent ocean timber jetty, since dilapidated. The Onslow Salt Jetty is immediately west of the Point. Figure 4-17 corresponds to beach monitoring site BS10 (Figure 1-3).

Beadon Point is backed by high dunes fronted by a deep swale and lower primary dune. The beach to the south east of the Point is very narrow and appears to be eroding, with small rock groynes apparent. Onslow townsite is protected from erosion by a long revetment seawall and adjacent beach however the depth of the toe of this seawall is uncertain. The section of the seawall closest to the Point, protecting the local memorial, is in poor condition with rubble apparent along the toe.

Wide subtidal shoals and possibly reef are evident offshore at lower tides but were largely inundated at the time of inspection.



Figure 4-17: Beach Southeast of Beadon Point

4.4.3. Beadon Creek

Beadon Creek is about 2.5km southeast of Beadon Point at the site of the local boat harbour. A 500m long breakwater trains the western side of the creek. The eastern side of the creek remains untrained with an entrance bar encroaching westward. There is a north facing concave sandy beach with modest relief dunes between Onslow townsite and Beadon Creek. Figure 4-18 corresponds to beach monitoring site BS11 (Figure 1-3).

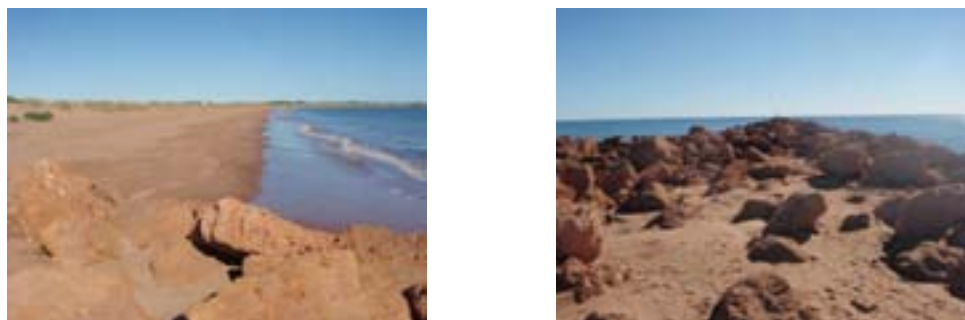


Figure 4-18: Beadon Creek

4.5. SEDIMENT SIZE DISTRIBUTIONS

Sediment samples were collected from the beaches between Ashburton River and Beadon Creek for particle size analysis (Figure 4-19). The results of the analyses are included within Appendix D. The majority of beach sediments collected had a narrow size range, with a median of 0.24 to 0.28 mm (Figure 4-20). Slightly coarser sediments were observed at locations more exposed to wave action west of Beadon and Entrance Points, where winnowing of sediments is likely to have occurred.

Sediments exhibited a relatively narrow, unimodal range, except for the sample near Onslow Salt Jetty (SS15), which showed a broad, bimodal character. It is theorised that this is a mixture of coarse winnowed sediments with a fraction of finer material bypassed *westward* around Beadon Point. If this is the case, the presence of finer sediments is likely to be ephemeral.



Figure 4-19: Sediment sample locations

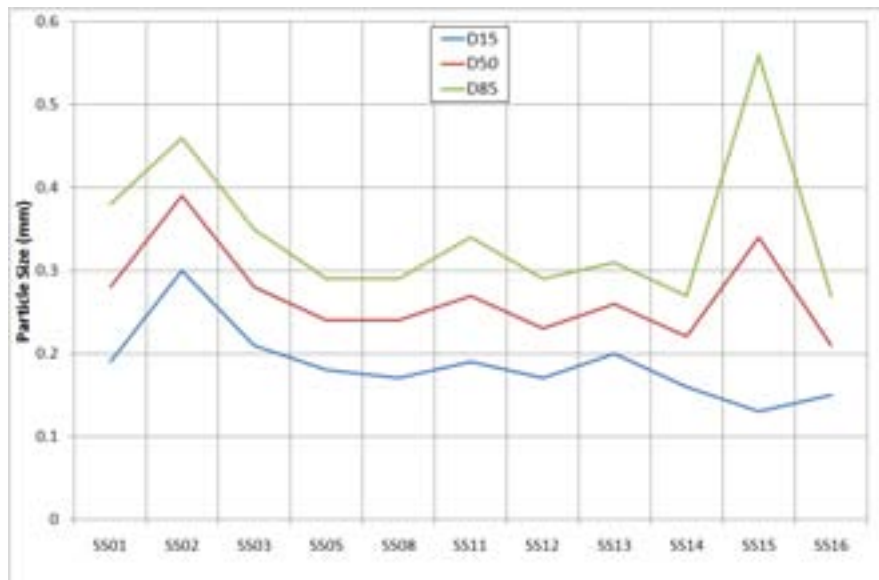


Figure 4-20: Particle size measurements from swash samples only

4.6. LOCATION OF ROCKY SHORE

Limestone outcrops discontinuously along the coast between Casugrina Point and Beadon Creek. The outcrops include low eolianite bluffs at the seaward margin off the frontal dunes; platform and bluff along the southern shore of the lagoon near the Project site and in the vicinity of Four Mile Creek, where it joins a beachrock ramp sloping seaward onto a subtidal pavement. The distribution of the outcrops is illustrated in Figure 4-21. They form the geologic framework for local beach response to fluctuations in coastal processes, particularly changes in sea level and the intensity of wave regime. Several affects are apparent. First, the low bluff along the shore of the lagoon inhibits, but does not prevent development of a sandy beach along the shore. It thus contributes to the formation and maintenance of the lagoon between Entrance Point and the salient at the Project site where the chenier spit merges with the shore. Second,

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breaks between rock outcrops are areas of potential coastal instability, areas where erosion is most likely to occur under prolonged storm conditions and/or rising sea level, as has been demonstrated for discontinuous rocky shore (McNinch 2004; Brunel & Sabatier 2007). Third, away from Casugrina Point, the updrift, eastern margin of breaks between outcrops commonly have frontal dunes which are higher than those landward of the adjacent outcrops.



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Figure 4-21: Observed Location of Exposed Rock during Field Inspection

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5. Coastal Change

5.1. GENERAL FRAMEWORK FOR ASSESSMENT OF CHANGE

Coastal change occurs over a wide range of temporal and spatial scales. The general framework adopted for this study to assess historic changes in the Ashburton delta and adjacent coastal areas is outlined below. Observed change has been assessed assuming that different spatial scales will be dominated by processes acting over corresponding time scales (de Vriend *et al.* 1993 a & b). For instance, although rapidly varying processes may cause dramatic fluctuations, their net effect when considered over an extended period is often reduced. In contrast, slowly varying processes, which are considered extrinsic over the short-term, are dominant over longer time frames due to their sustained nature. The philosophy behind this framework has been used to justify four distinct concepts when describing coastal change over different time scales:

- At the largest (geological) scales, coastal change is dominated by eustasy (sea level movements), isostasy, tectonics, lithification and occasionally vulcanology (van de Plaasche 1986). These processes determine the presence of rock, and through movement of relative sea level, may relate to large movements of the coast;
- At moderate (geomorphic) scales, coastal evolution is determined by the production of mobile sediments, transfer via metocean forcing, and accumulation in zones of relative shelter. This suggests simulation of coastal change using sediment sources or sinks, and prompts the concept of equilibrium coastal alignment;
- Over short (planning and engineering) scales, large scale sinks and sources of material may be considered constant and the shoreline fluctuations caused by storm erosion-recovery cycles may be considered almost in balance. Coastal change may be described largely by alongshore sediment transport and its variability, including spatial variation developed through changes in coastal aspect, and year-to-year metocean variations;
- Over very short (coastal management) scales, dramatic coastal change occurs in response to weather cycles. This is most commonly represented by cross-shore transport associated with storm events and subsequent recovery during lower energy conditions (van der Meer 1988).

It should be noted that change may be active over all time scales simultaneously. Care is required to ensure that the process of change is not inappropriately identified due to confined use of one or two concepts of change. For this study, the following hierarchy of geomorphic features, based upon spatial and temporal variability, has been used to help identify active processes (Figure 5-1).

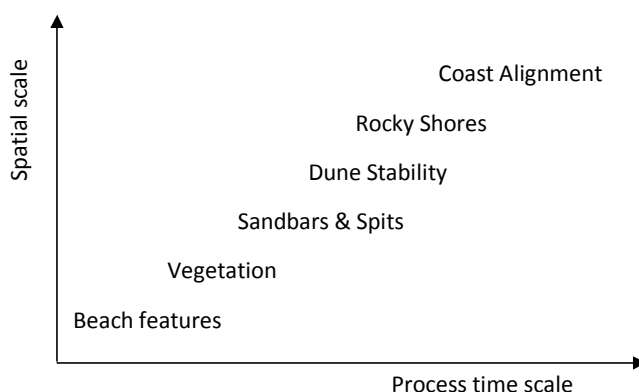


Figure 5-1: Hierarchy of Geomorphic Features



5.2. NATURE OF THE PILBARA COAST

The Pilbara coast has been identified as a significant floodplain system, subject to highly variable river flows, which may contribute large quantities of fluvial sediments to the coastal region for relatively brief periods of time (Semeniuk 1996). This material is transported along the coast through the combined effect of waves and tidal currents. Despite highly variable sediment supply, the Pilbara coast remains relatively slowly varying, due to the extensive presence of coastal rock features that act as strong controls upon coastal structure.

As with other parts of Western Australia, the North West Shelf demonstrates the effect of several eras of different sea levels, including periods above and below the present day level. Coastal induration has developed significant bands of limestone along parts of the coast that were stable in some previous era, which result in bands of rock reefs, islands and coastal ridges that are resistant to erosion. The most recent era, following the last glacial maxima, has experienced coastal recession associated with rising sea levels. Where sediment supply was unable to keep pace with sea level change, low lying sections of coastal floodplain have drowned, in many cases leaving a residual rocky coastal barrier, or chenier system.

Where breaches occur through the coastal barriers, tidal creek networks commonly occur. Over the longer-term, these systems generally provide a pathway for the import of sediment to the floodplain (i.e. export of sediment from the coast to land) as a result of ongoing sea level rise (Ryan *et al.* 2003). However, over shorter time scales, this behaviour may be reversed, particularly if the tidal creek networks act as a runoff pathway.

Net alongshore sediment transport from Onslow to Dampier is generally considered to be from west to east, based upon offshore wave climate, prevailing winds, the orientation of tidal creek entrances, accretive features on the west side of rocky headlands and the drift paths of modelled circulation across the North West Shelf (Pearce *et al.* 2003). Transport reversal during winter, or under cyclonic action is expected, and the quantum of potential transport may vary significantly due to inter-annual variability of the trade winds and land-sea breezes. It is noted that offshore suspended sediment transport is generally in the opposite direction to alongshore transport, moving from east to west (Margvelashvili *et al.* 2006).

Aeolian transport along the Pilbara coast is, in general terms only, largely limited to beach and foredune development. The majority of primary dunes are old in geomorphic terms. Under extreme cyclonic conditions, some local Aeolian transport may occur on primary and secondary dunes, such as deflation of the upper surface.

5.3. GEOCHRONOLOGY

A broad indication of the geologically Recent (<50,000 years before present) development of coastal landforms has been made through radiometric dating, particularly those in the highly-active chenier foreland plain comprising the eastern delta of the Ashburton River. This was done to establish a broad context for analysis of historical records and interpretation of available aerial photography as well as to provide indication of which components of the chenier foreland may contribute to the volume of material transported along the coast if the landforms were destabilised.

5.3.1. Chronology methods

Radiocarbon and uranium series dating was used to estimate the ages of coral embedded on a rock platform near Hooley Creek; shell from a wrack line along a high foredune near Cosigny Point; and to date the transition from marine to terrestrial conditions along the corridor between the mouth of the Ashburton River and Hooley Creek. Wrack lines were present on many dune faces and these are assumed to result from either high sea-level stands or high magnitude storm or tsunami events.



The rock platform has well preserved coral heads, sometimes cemented into limestone pavement. Several samples of coral were collected in the mid to upper Hooley Creek region (Figure 5-2). These were transported to Sydney where heavy elements in the Uranium series were extracted and deposited on a platinum wire for heat ablation on a Thermal Ionisation Mass Spectrometer (TIMS) machine to count the abundance of key elements in uranium decay series. Since these have known decay rates they can be used to estimate the age of the corals.



**Figure 5-2: Coral heads cemented into limestone pavement
Located on the northern side of an island in the mudflats near Hooley Creek**

It is well-known that marine systems have ‘old carbon’ reservoir which may be incorporated into animal shells because of their living environment. True age estimates require the size of the reservoir to be accounted for, which in this case has been done by measuring radiocarbon activity in recently living shells. The effect of the ‘old carbon’ reservoir may be anything from zero to several thousands of years depending on the location.

The age of most recent marine conditions across the landscape was estimated from shells collected in sediment sections obtained by Coffey International and from shallow cores taken across the chenier sequence forming the eastern delta of the Ashburton River. Complete shells which could be identified were preferred for the radiocarbon analyses. In other cases fragments of shell were employed. In general shells of *Anadara crebricostata* were used but they were not available in all cases. Shell identifications were performed by Dr Barry Wilson. In one case, where no shell was available, a date was obtained from charcoal in mangrove mud. No marine reservoir effect needs to be applied to such a sample.

Shell samples were cleaned of adhering soil and limestone encrustations and then treated with acid to liberate carbon dioxide which was captured in a cold trap and converted to graphite. Stable carbon isotope measurements on the samples were carried out to help estimate the size and therefore account for any fractionation effect between ¹⁴C and ¹²C in calculating the ages. The samples were measured in the STAR Accelerator at the Australian Nuclear Science and Technology Organisation. That process also involves frequent measuring standards to ensure quality control of the final ages. Dates are then presented as calibrated ages using the internationally accepted calibration program from the University of Cologne (Reimer *et al.* 2004).



5.3.2. Radiocarbon and Uranium Series Results

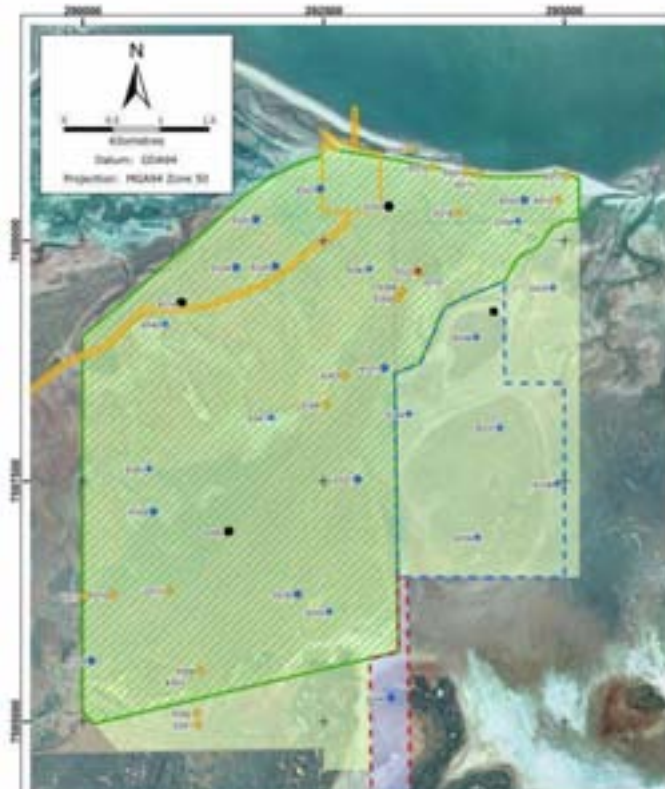
Radiocarbon results are shown for the eastern Ashburton delta in Table 5-2, the elevated foredune wrack line in Table 5-3 and from deep cores across the mudflats and west Ashburton delta in Table 5-1. Following Reimer *et al.* (2004), radiocarbon ages from the analyses have been converted to calendar ages. Here the effects of 'old carbon' reservoir were determined on samples of *Anadara crebricostata* and a juvenile Mytilid shell collected from the modern beach. These were found to be consistent with modern radiocarbon percentages, and this suggests that it is a reasonable assumption that no significant radiocarbon age correction needed to be applied to marine shell.

A coral dominated platform in the mudflats of Hooley Creek tidal complex at 21°41.47'S and 115°00.78'E had uranium/thorium dates estimated from three coral samples. The corals were surprisingly enriched in uranium, suggesting they were in locations relatively open to ocean water inundation (and continuing enrichment in uranium). Once these are isolated from the ocean they begin to accumulate thorium from uranium decay. The samples had about 30 pico-curies of thorium which is consistent with last interglacial ages, that is within the range of about 105-125 thousand years before present. However these should be regarded as minimum ages.

Several shells were collected from bore samples within the wider Project site. These samples were taken from MB and EO series of bores and were collected on our behalf by Coffey International (Figure 5-3). The samples included *Anadara granosa*, *A. crebricostata* and other shells. Samples from approximately 4.5 to 6.5m below the modern surface returned radiocarbon ages of about 43,000 or more. They may in fact be close to, or beyond, background ages of 50,000 or more, and are thus Late Pleistocene in age. These results together with the coral dates are consistent with an interpretation of relatively stable surfaces occurring between about 120,000 and perhaps 50,000 years ago, and being formed in essentially marine conditions with a higher than present relative sea level.

Core samples from the EO and MB series at approximately 3m depth have ages between 35,000 and about 22,000 years before present (Table 5-1). These approximately correspond to the beginning of the last glacial maximum and coincide with the end of a period of rapid global sea level fall, and thus probably mark a phase corresponding to the lowest of influence of marine conditions and inundation at the site. These results suggest the site was sensitive to sea level variations that were occurring in many parts of the world at this time. Modern sea levels established after about 6000 years before present (Figure 5-4).

Shallow core samples from the eastern delta of the Ashburton region (Figure 5-3) gave dating that varied from modern to approximately 7500 years, which is consistent with development of the modern delta surface over the late Holocene standstill. Lithified strata underlying much of the eastern delta, and emergent in parts, is considered likely to be older, probably Pleistocene, but has not yet been dated.



Above:
Shallow core sites on the eastern delta of the Ashburton River

Legend
 ● Push Core Locations
 □ Terrestrial Ecology Survey Area (REV1)

Below (Left):
Deep core sites from which samples were dated and the coral sampling site

● Radiometric dating site
 ■ Coral samples from surface of limestone pavement

Figure 5-3: Location of Samples used for dating



**Table 5-1: Radiocarbon results from Mudflats and Western Ashburton River Delta
Deep cores from Coffee Pty Ltd MB & EO series**

Identification	Depth	Location	ANSTO Code	Sample Type	Calendar Age Years
MB 5A	2.75 – 2.85m	7596954.00 mN 291482.00 mE	OZL973	<i>Anadara granosa</i>	20,150 BC
MB 5A	3.2 - 6.25m	7596954.00 mN 291482.00 mE	OZL974	<i>Venerid shell</i>	NDFB
MB 15A	4.5 - 4.95m	7596347.00 mN 290894.00 mE	OZL975	Shell fragment	(45,950)
MB 5C	2.8 - 2.9m	7596954.00 mN 291482.00 mE	OZL976	<i>Anadara granosa</i>	(44,760)
MB 5C	3.1 - 3.2m	7596954.00 mN 291482.00 mE	OZL977	Bivalve	27,020 BC *
MB 5D	4.8 - 4.9m	7596954.00 mN 291482.00 mE	OZL978	Shell	NDFB
EO 14A	ca. 5.4m		OZL979	Shell	(49,400)
EO 14B	6.2 - 6.3m		OZL980	Shell	NDFB
EO 33A	6.4m		OZL981	<i>Anadara crebicosata</i>	(43,610)
EO 33A	6.5 - 6.95m		OZL982	Indurated fine carbonate shell	(43,710)
BRW 1 Depth: Surface			OZL983	<i>Anadara granosa</i>	1,935 BC
BRW 2 Depth: Surface			OZL984	Snails	32,940 BC *
BRW 3 Depth: Surface			OZL985	<i>Spondylus sp</i>	1215 AD
BRW 4a Depth: Surface		Pleistocene surface on Urala Station	OZL 986	2 Bivalves	32,630 BC *

NDFB = Not Distinguishable From Background

Numbers in parentheses = Radiocarbon ages of about 43,000 or more be close to, or beyond, background ages of 50,000 or more.

* = Uncorrected radiocarbon ages beyond the Reimer et al (2004) calibration.

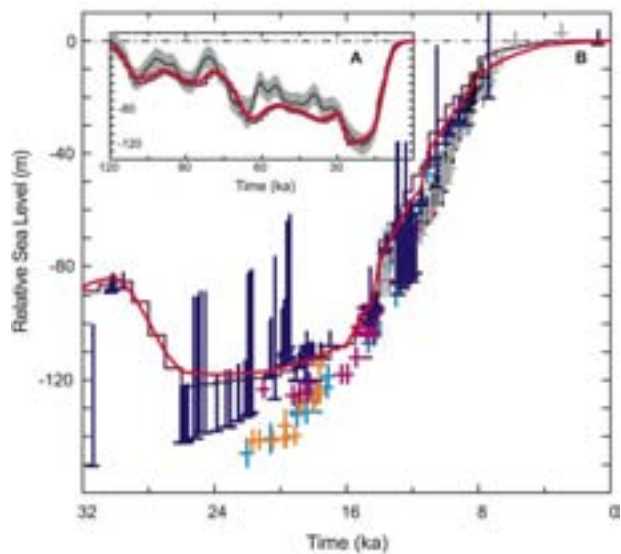


Figure 5-4: Relative sea level during the past 120,000 and 10,000 years before present. From Lambeck & Chappell, 2001

There are some age inversions (older material overlying younger material) in the shallow core samples from the eastern delta of the Ashburton River (Table 5-2), consistent with relatively modern marine conditions represented within the upper metre of sediments. The inversions indicate some mixing and/or turnover of sediments occurred after 1000 BC; and on the evidence we have the degree of mixing has not been substantial in terms of the depth of sediment affected. Muddy sediments derived from the Ashburton River have tended to overwhelm marine influence, as marked by the upper levels of marine shells which occur below about 0.5 m depth in the chenier sequence.

Table 5-2: Radiocarbon results from the Eastern Ashburton River delta and chenier plain

Identification	Depth	Location	ANSTO Code	Sample Type	Calendar Age Years
Site 1 – Eastern Delta	89-91cm	21° 41.51' S 114° 58.22' E	OZL987	Shell	1080 AD
Site 1 – Eastern Delta	56-60cm	21° 41.51' S 114° 58.22' E	OZL988	Shell Fragment	750 BC
Site 2 – Eastern Delta	19-23cm	21° 41.43' S 114° 58.16' E	OZL989	Shell	5630 BC
Site 2 - Eastern Delta	40-42cm	21° 41.43' S 114° 58.16' E	OZL990	Shell	1330 AD
Site 5 – Eastern Delta	53-55cm	21° 41.23 S 114° 58.23' E	OZL991	Organic roots	Modern
Site 7 - Eastern Delta	47-49cm	21° 40.72' S 114° 58.51 E	OZL993	Wood fragments	Modern



Two ages were determined on samples from a deposit of shells in a wrack line which was noted to be common on dunes across the region (Table 5-3) although its exact distribution is not known. The beach wrack assemblages comprise mollusc shells, corals and remains of other organisms representing a shallow subtidal community of benthic filter-feeding invertebrates that occurs on pavement seabed of the inner shelf in the west Pilbara. It is characterised by sponges, alcyonarians and other soft-bodied epifaunal filter-feeders, a few species of scleractinian corals (*e.g. Turbinaria* sp.), and shallow-burrowing or epifaunal bivalves (*e.g. the twisted arc Trisidos semitorta, Anadara crebricostata*, and a large unidentified oyster, Ostreidae). This community is vulnerable to episodic destruction by storm surge when large quantities of heavier, calcareous shells and corals may be thrown up high on the beach slope. It is likely that the dense contemporary assemblages of such shells and corals on the supra-tidal beaches may be reworked accumulations of material from successive storm events.

Table 5-3: Radiocarbon results from the surface wrack line on elevated foredune

Identification	Depth	Location	ANSTO Code	Sample Type	Calendar Age Years
Beach - NW Coastal Dune	Surface of modern beach	Approximately 1 km W of mouth of Hooley Creek	OZL808	Mytilid Shell	Modern
Foredune - NW Coastal Dune	Raised wrack line	21° 41.16' S 114° 59.46' E	OZL809	Shell <i>A1 Anadara crebricostata</i>	1350 AD
Foredune - NW Coastal Dune	Raised wrack line	21° 41.16' S 114° 59.46' E	OZL810	Shell <i>A2 Anadara crebricostata</i>	1350 AD
Beach - NW Coastal Dune	Surface of modern beach	Mouth of Hooley Creek	OZL811	Shell <i>Anadara crebricostata</i>	Modern

In some places the wrack lines appeared to have two separate levels on the foredunes, and in others only one was evident. The samples here were collected at Site 1 (near 21° 41.16'S and 114° 59.46'E), at about 5m and 13m above present mean sea level. The shells were both samples of *Anadara crebricostata*. The ages were indistinguishable at 680 years BP (calendar ages 1350 AD) (Table 1). We interpret these as having been deposited from either an extremely severe cyclone or a tsunami, at around 1350 AD.

The nature of the deposited material is suggestive of tsunami transport, as such events cause a combination of emergence and inundation, allowing exposure of the shoreface followed by rapid inland transport of shell and coral fragments. This proposition is further supported by the record of high levels of volcanic activity in the Indonesian archipelago during this period. However, despite this circumstantial evidence, it is not presently possible to rule out the origin as cyclonic, for corresponding high level coral debris deposition has been historically observed elsewhere in the world, albeit more commonly on atolls (Baines & McLean 1976; Maragos et al. 1983; Fitchett 1987; Bayliss-Smith 1988). Either way this is evidence of the low-frequency high-magnitude events affecting the Ashburton River delta.



5.3.3. Ramifications for Site Development

There is a series of sediments aged between 35,000 and about 22,000 years before present, which correspond to a lowstand with relative stability in relation to global sea level changes. There is then a gap in dated material ages until the mid to late Holocene, as global sea levels returned to near present conditions. The stratigraphic structure from the observed cores, and corresponding dating from different material types suggests that the rate of sedimentation increased significantly from about 2000 years ago and accretion rates of up to a few centimetres per decade have occurred since. These are dominated by a mix of Ashburton deltaic sediments and mangrove mud accumulations.

True bedrock is generally 25 metres or more below the modern land surface and is apparently of Tertiary age (Semeniuk 1993). Substantial site development may occur on unconsolidated material, although stable (lithified) geologic features of Pleistocene age may provide a basement platform for the site. These outcrop within 6 metres of the surface south of a discontinuous line trending approximately WSW from Four Mile Creek onto Urala Station. The Pleistocene surface is variable in elevation, presumably due to differences in environments of deposition from the Late Pleistocene onwards as well as changes in the position of the Ashburton River which has cut channels through the platform. There are outcrops of older material north of this line, including dune features of undetermined age and some rock pavements.

Most of the surface material north of the line and those areas associated with the Hooley Creek and Four Mile Creek systems is subject to redistribution during extreme events associated with river flooding and storm surge inundation. In places modern shell beds interfinger older marine sediments and fluvial mud in the surficial 3m of sediment. These provide a contrast with the older surfaces found over 2km from the highly dynamic shore. Interfingering of the old and modern marine material is evidence of high magnitude events occurring in the past 3000 years. This appears to be unmatched in the past 100,000 years.

5.3.4. Geoheritage

Geoheritage relates to geological and geomorphological areas or features listed for conservation under land management decisions as set out in the Australian Natural Heritage Charter (Environment Australia 1997). The features are listed according to their level of geological significance, with particular reference to those of international and national importance.

The following comments from Brocx (2008) indicate the geoheritage values of the Ashburton region.

- *The Pilbara coast in north-western Australia is the most arid coast in Australia, and globally it is one of the few arid coasts that consists of wide riverine lowlands fronting Precambrian uplands in a non-tectonic setting (Semeniuk 1993).*
- *Semeniuk (1996) emphasized that the Pilbara Coast is special in comparison to other coasts in Australia and worldwide. This is because the Pilbara Coast portrays distinctive coastal forms, chemical products and stratigraphy, all of which reflect a Pleistocene to Holocene history of sedimentation, aridity, and frequent cyclonic storms. As a result, the coastal zone is distinguished by a range of features such as construction of arid-zone deltas, delta destruction and sediment redistribution during times of sediment depletion, cyclone-induced erosion and sedimentation, growth of mangroves and their associated deposits, evolution of coastal groundwater hypersalinity, and cementation to form beachrock, high-tidal crusts and gypsum precipitates, amongst others.*
- *In this context, Semeniuk (1996) considers that the Pilbara Coast provides a globally important model or classroom, unparalleled elsewhere in the world, for the development of a range of megascale landforms through to microscale geomorphic, sedimentary and stratigraphic products that develop within a coastal alluvial plain in an arid climate, and also provides for the Earth*



Sciences an important and unique global model of arid zone coastal sedimentation, diagenesis, and stratigraphic evolution.

The fossil coral outcrops and shore platform identified at Casugrina Point are unusual features for their age and completeness of structure. However, the degree to which they are of geoheritage significance is a function of the geographic distribution of similar forms and remains open to question even within the region. Although Interglacial features have been described from the Ningaloo Coast (Tezer Esat – pers. comm.) the assemblage of shorelines and islands along the Ashburton Coast are very different and are likely to be of international significance.

The significance of the deltaic complex of the Ashburton River including the suite of geologic features and landforms comprising the shoreface, coastal dunes, chenier plains, mudflats, upper deltaic floodplains and palaeochannels relates to the degree to which the landforms: (a) collectively and individually provide essential life services; and/or (b), are recognised by experts within the geological disciplines for inclusion within the Register of the National Estate (Australian Heritage Commission 1990).

Examples which would attract interest include:

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

In combination, these elements have considerable conservation significance on the basis of geoheritage.

5.4. INTERPRETATION OF LATE HOLOCENE DYNAMICS

Rapid sea level rise associated with the post-glacial transgression (Figure 5-4) causes a break point in coastal evolution, with modern geomorphic coastal features typically having an age of less than 6000 years. These features overlie an older coastal structure developed during the Pleistocene relative sea level highstand. Pleistocene features can typically be distinguished from modern formations by their lithified nature, although indurated beach rock structures may be comparably modern.



Figure 5-5: Apparent Planform Formations

The presence of lithified cheniers within the Ashburton eastern and western deltas confirms that the deltaic complex is comprised of both modern and older formations. Available dating, historical nautical records and more recent aerial imagery allow approximate distinction of four formations, corresponding to different eras of development (Figure 5-5). The relative accretion rate suggested by each of these formations has been estimating using rough estimates of accumulation depth based upon existing adjacent bathymetry and indicative depth to underlying rock.

Table 5-4: Estimated Accretion Rates for Planform Formations

Formation	Age	Area	Est. Depth	Accretion
Holocene Delta	c. 6000 yrs	860 ha	1-3 m	1,500-4,500 m ³ p.a.
Eastern Delta	c. 1000 yrs	360 ha	1-3 m	3,500-10,000 m ³ p.a.
River Mouth	c. 100 yrs	180 ha	2-8 m	50-200,000 m ³ p.a.



5.5. HISTORIC COASTLINE MOVEMENTS

Shoreline movements in the vicinity of the proposed development site have been examined using photogrammetric analysis of historic aerial imagery from 1963, 1973, 1986, 1993, 2001, 2004, 2007 and 2009 (Appendix E). Despite very high variability of forcing conditions, historic photographs show that the Ashburton coast has generally maintained a similar shoreline position for decades, with only local features experiencing significant change, including the deltas, cheniers and spits at the mouths of tidal creeks. Observed coastal movements between Ashburton River entrance and Hooley Creek suggest discrete coastal components that have persisted from 1963 to 2009, but have each evolved in different ways.

The characteristic behaviour of constrained dynamic zones is developed by the geologic framework underpinning much of the Pilbara coast, with rocky features providing strong structural control over shoreline position (Semeniuk 1996). In this situation, coastal dynamics are appropriately interpreted using sediment cell concepts in which sediment sources, transport pathways, and sediment sinks (loss areas) are identified. This conceptual framework is applicable to a largely controlled or engineered coast.

5.5.1. Ashburton Delta

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

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

Channel switching is typically associated with river systems bearing a high sediment load, under relatively low wave and tide conditions (Coleman & Wright 1975). At the site of the active channel, a local salient and shoal structure commonly occurs, which may be rapidly destabilized subsequently if the river flow switches to an alternate channel. This feature is locally apparent at the existing Ashburton Channel entrance, with only residual shoals remaining at Entrance Point.



Figure 5-6: Coastal Components near Ashburton River Entrance

The northwest facing coastline between Ashburton River entrance and Entrance Point (BS02) appears to have receded by 50m between 1973 and 2004. Imagery from 1993 and 2001 shows a reasonably consistent trend of shoreline erosion in the order of 1.5 m/yr. Concurrent accretion of a barrier spit occurred on the coast eastwards of Entrance Point, which gradually elongated, before eventually welding to the coast in 2005. This behaviour is consistent with an eastwards migration of the delta sediments.

The 2009 site inspection identified two creek entrances east of the main Ashburton River entrance. Historic imagery shows there are three historic creek entrance sites that intermittently migrate, close up and break open. These sites are summarised in Table 5-5.

Table 5-5: Position of Ashburton Delta Creek Entrances

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

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

- Ashburton East entrance closed between 2001 and 2004. There were no significant flow events during this period and it is assumed the littoral drift overwhelmed the tidal flow.
- The Entrance Point western spit, evident in 2009, has historically been the site of a reasonably complex entrance bar complex, with the bar configuration suggesting eastwards littoral drift. This spit migrated eastward by about 700m since 2004.
- The Entrance Point western spit was located 300m offshore of the 2004 coastline in 1973.



- The Entrance point eastern spit migrated eastwards by about 2.2km between 1973 and 2009. The rate of eastward migration since 1993 has been in the order of 100m/yr. This spit welded to the coastline after 2004, about the time when the current entrance to the west appears to have opened. The entrance spit is welded to the shore about 500m west of the Plant Site. The present rates of eastward migration are uncertain however historic rates have been very high.
- The coastline at the salient has been relatively stable but remains vulnerable to the influence of the eastward migration of the Ashburton delta.



Figure 5-7: Entrance Point looking East



Figure 5-8: Entrance Point looking West toward Plant site



Figure 5-9: Coastline adjacent to Entrance point Eastern Spit in 1990 (top) and 2009 (bottom) showing build-up of sand (Source: Anthony Bougher, URS)



Figure 5-10: Aerial Photograph of Ashburton Delta August 2003. Note absence of barrier spit. (Source: Oceanica)



5.5.2. Hooley Creek Complex



Figure 5-11: Features near Hooley Creek tidal complex

The entrance bar at Hooley Creek was estimated to be about 1.2km in length during the 2009 field inspection. The entrance bar configuration in 1993 was similar to 2009 configuration but had deflated and progressively rebuilt during this period, most likely as a result of Tropical Cyclone Vance in 1999. The 2001 photography shows deflation of the entrance bar with isolated, disconnected sub aerial bars evident in the entrance. The western spit of Hooley Creek had re-established in 2004 and elongated by about 700m between 2004 and 2009. The eastward migration of sand is expected under typical conditions.

In 1973, the entrance was located further west towards the centre of the three tidal creeks. There were two spits in the order of 1.0km length on both sides of the entrance with the western spit further offshore.

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



Figure 5-12: Hooley Creek Entrance Bar and Creek System

5.5.3. Interpretation of Coastal Movements

Photogrammetric interpretation of aerial imagery between 1963 and 2009 has been undertaken to provide an estimate of sediment transport rates at the Project site. Both the vegetation line and the shoreline at the time of photography were tracked. In general, interpretation of shorelines must be undertaken with care, as they will “move” according to the tide at the time the images were captured. The vegetation line, in contrast, within meso-tidal regions and mangrove coasts, limits the perception of change, as considerable volumes of sand may be stored or eroded from the beach face without affecting the vegetation line. In this case, the general trends of the vegetation lines and shorelines were consistent, suggesting that the shoreline is likely to provide a fair representation of the coastal dynamics.

In order to interpret volumetric change in terms of areal changes, a suite of assumptions were applied, based upon field inspection and survey of existing conditions (Table 5-6). Change has been assumed to be intertidal and supratidal only.

The resulting accretion and erosion rates between Ashburton River and Beadon Creek are summarised graphically in Figure 5-13 and in tabular form by Table 5-7. By assuming that these two boundaries represent the start and end of a largely closed sediment cell, the erosion and accretion patterns has been used to estimate *minimum* net transport rates.

Comparison between net sediment transport rates derived from shoreline movement plans and those developed through wave modelling suggests good agreement at Hooley Creek spit, and along Sunset Beach (Table 5-8). Discrepancy along Ashburton eastern chenier is possibly due to a relative absence of cyclonic transport in the model, or representation of transport due to waves approaching at an acute angle to the shore.



Table 5-6: Assumptions Used for Estimate of Accretion / Erosion Rates

Site	Observed Sediment Capture	Assumptions
Entrance Point Spit	30,000m ³ /yr	Based on eastward migration of sand spit by 700m between 2004 and 2009. Assumed width of bar is 50m. Assumed accumulation between +3.0m CD and -1.0m CD.
East Ashburton Spit	15,000m ³ /yr to 30,000m ³ /yr	<ul style="list-style-type: none"> a) Linear spit growth from 1963 to 1973. 700m growth in 10 years. Assumed width of 100m. Growth between +3.0m CD and -1.0 m CD (~30,000m³/yr). b) Based on eastward migration of sand spit by 300m between 2001 and 2004. Assumed width of bar is 50 m. Assumed accumulation between +3.0m CD and 0.0m CD (~15,000m³/yr). c) Beach infill at MOF site following 2005 spit weld. 70m accretion of water line over 700m length. Assumed accretion between +3.0mCD and rock platform at +0.5m CD (~25,000m³/yr)
Hooley Creek Spit	45,000m ³ /yr to 65,000m ³ /yr.	<ul style="list-style-type: none"> a. Based on eastward migration of sand spit by 700m between 2001 and 2004. Assumed width of bar is 100m. Assumed accumulation between +3.0m CD and +1.0m CD (45,000m³/yr). b. Accumulation of spit between Dec 2008 Lidar survey and Jan 2010 field survey (65,000m³ above +1.5m CD).



Figure 5-13: Erosion, Accretion and Net Transport Rates
 Derived from aerial photos 1963-2009¹. Quantities are m³/yr.

¹ Based on Whelans 13776 drawing series (February 2010)



**Table 5-7: Erosion, Accretion and Net Transport Rates
Derived from aerial photos 1963-2009².**

Zone	Change	Cumulative Rate (W) This is the net transport rate which must be occurring, to enable observed accretion patterns	Cumulative Rate (E) This is how much sand must be supplied from Ashburton, to enable observed accretion patterns
Beadon Creek & Onslow Town Beach	5 to 10k Accretion Some is dredge material.	5 to 10k	45 to 110k
Beadon Point	0 to 20k Accretion* This appears mostly recovery from foredune deflation rather than volumetric change	5 to 30k	40 to 100k
Sunset Beach	Net balanced	5 to 30k	40 to 80k
Four Mile to Hooley Creek	10 k Accretion	15 to 40k	40 to 80k
Hooley Creek Spit	20 to 30k Accretion	35 to 70k	30 to 70k
Minor Rock Headland	5k Accretion	40 to 75k	10 to 40k
Ashburton Eastern Chenier	20 to 30k Accretion	60 to 105k	5 to 35k
Ashburton East Delta	30k Migration Net balanced	60 to 105k+30k local variation	-15 to 5k+30k local variation
Entrance Point West	15k Erosion	45 to 90k	-15 to 5k
Barrier Beach & Dune	Net balanced	45 to 90k	0 to 20k
Ashburton Delta East	0 to 5k Accretion	45 to 95k	0 to 20k
Ashburton Delta West	15k Accretion	60 to 110k	15k

Table 5-8 Comparison of Derived Sediment Transport Rates

Location	Derived from Shorelines (Damara)	Derived from Modelling (DHI 2010)	Comment
Ashburton East Chenier	60 to 105k m ³ /yr	40k m ³ /yr (50k m ³ /yr gross)	Low model transport maybe due to absence of cyclonic transport or transport due to waves at acute angle to the shore
Hooley Creek Spit	35 to 70k m ³ /yr	45k m ³ /yr (75k m ³ /yr gross)	Good match
Sunset Beach	5 to 30k m ³ /yr	20k m ³ /yr (65k m ³ /yr gross)	Good match

² Based on Whelans 13776 drawing series (February 2010)



For environmental management purposes, it is conservative to apply the larger sediment transport rates derived from shoreline movement plans. Hence, the assumed average net transport rates are:

- Supply to the west of the Project site 60,000 to 105,000 m³/yr
- Loss from the east of the Project site 35,000 to 70,000 m³/yr

Note that the range of figures represents the uncertainty associated with the means of estimation. Considerable variability may be expected on a year-to-year basis due to episodic supply from the Ashburton River, variable cyclone effects and the potential for inter-annual and seasonal variability in the magnitude and direction of transport.



5.6. HISTORIC COASTAL INFRASTRUCTURE & MANAGEMENT

5.6.1. Timber Jetties

Maritime facilities were constructed more than 115 years ago in the Ashburton Delta area, west of Onslow. The location of these historic wharves and jetties, since demolished, are shown in Figure 5-14. The design, construction and serviceability of these facilities provide some information on coastal processes in the area prior to the earliest dates of aerial photography.

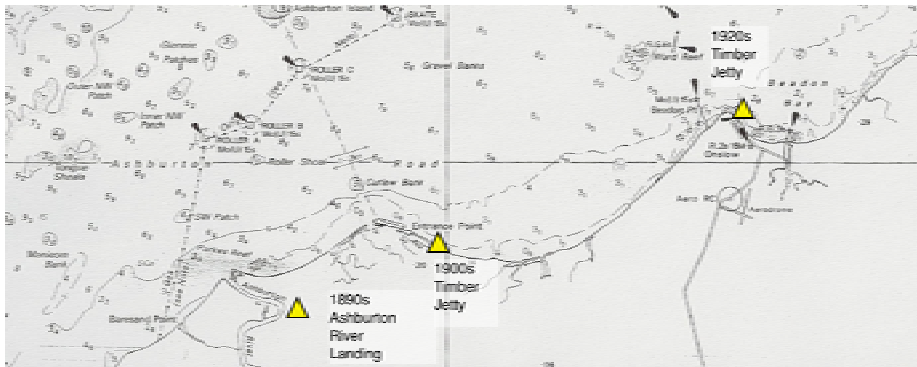


Figure 5-14: Historic Maritime Facilities for Onslow

5.6.1.1. 1890s Ashburton River Landing

Onslow was originally located at the Ashburton River mouth, the site of the historic buildings of ‘Old Onslow’. This site was proclaimed a town in 1883 and a riverside wharf augmented a small lighter landing, along the Ashburton River, in 1885. Construction to double the length of the landing to 70 ft commenced in 1893, however a cyclone on 27 February 1893 swept the new timber for the river landing down the creek and it was lost. The works were eventually completed in mid-1893. (Le Page 1986)

These original port facilities for Onslow were four miles upstream of the entrance bar to the Ashburton River in a deep pool of water. It has been noted that negotiating the bar at the river mouth could be extremely hazardous at times and floods in October 1894 worsened the situation. The Australian Pilot from 1923 notes:

“Ashburton or Curlew River, from one to 2 cables wide, with mangrove banks, is navigable for small craft, of not more than 4 foot (1.2m) draught, for a distance of 3 miles, to the landing place abreast the township of Onslow”

The Australian Pilot notes that location of the entrance to the Ashburton is Entrance Point (Lat 21° 41’ S, Long 114° 57’ E) which is east of the current entrance.

5.6.1.2. 1900s Timber Jetty

The hazardous entry to the Ashburton River and vulnerability of the landing to river floods resulted in the construction of a new maritime facility for Old Onslow in the 1900s. Designs for constructing a 2760ft sea jetty, in a north easterly direction from the coastline east of the estuary, were tendered by Public Works in 1896.



Construction of this new jetty was nearly completed in Dec-1897 when a violent Boxing Day storm lifted almost all the decking of the new jetty and many of the piles were loosened by wave uplift.

A newly proposed structure had its deck level raised to 15ft above high water, was 960ft long and 14 ft wide neck. There was a 124ft long and 30ft wide berthing head, a platform at the shore end and rail line to Onslow. The jetty was completed in 1900 with a low water depth of only eight feet (Le Page 1986).

An undated photograph was sourced from the Battye library, labelled Onslow Jetty, but undated (Figure 5-15). This is expected to be the 1900s timber jetty.



Figure 5-15: Timber Jetty at Onslow

The 1922 Australian Pilot notes the following, which provide some description of the coastal geomorphology of the delta area prior to the 1920s:

“There is a pier 1,120 feet (341.4m) long, with a 2-ton crane, at 1½ miles eastward of the river entrance, and 3 miles from the town, with a depth of 8 feet (2.4m) at the end. It is connected to Onslow by a light tramway, and is used for shipping stock and landing general cargoes. There is a light at the end of the pier”

“Buoy – A black buoy, with staff and cage, lies near the edge of the 3-fathom (5.5m) line, at 8 cables northward of the pier”

“The eastern side of the entrance is all mangrove swamp, extending to a distance of 1¼/10 miles northward of Saddle hill; a sand-spit, covered at high water, extends about 6 cables northward of the swamp, leaving a narrow passage between it and the sand spit, which extends 2½ cables south eastwards of the western point of the entrance”



A comparison with the recent chart of the area, (AUS 743 c1992), suggests the depth of water at the 'black buoy', almost 200m offshore, remains in the order of 5m. Similarly, the depth of water at the end of the pier, about 350m offshore, is shown in 1992 as being in the order of 2m. However, the existence of sand spits east of the entrance, observed in the 1920s, and more recently, indicate the dynamic nature of the nearshore coastal area east of the entrance.

Le Page (1986) also noted that silt travelling down the Ashburton River would eventually reduce the depth of water at the head of this jetty. This ultimately resulted in the construction of the timber jetty at Beadon Point in the 1920s and, combined with flooding, caused the relocation of Onslow to its present location (Figure 5-14).

5.6.2. Dredged Navigation Channels

Dredged navigation channels are present at Onslow Salt Jetty, and the entrance of Beadon Creek, which is trained with a rock wall on its western side. Due to the distance from the proposed MOF facility and differences in scale and coastal structure, sedimentation of the proposed navigation channel is likely to differ markedly to these channels. In this context, the behaviour observed at each channel is indicative of sediment transport processes rather than expected rates of sedimentation.

Onslow Salt channel is approximately 12m sounding, extending from 5m deep natural surface at the jetty to roughly 10km offshore. Anecdotally, the channel has not required maintenance dredging since its initial excavation, although subsequent capital dredging may have accounted for some accretion. Preliminary difference plots developed on behalf of the Project engineering team suggest that limited accretion has occurred over the period 2000 to 2008, except for a narrow section, approximately corresponding to a local rise in seabed gradient, which acts as a minor pathway for shore parallel sediment transport. The channel does not extend to shore, and is considered unlikely to influence the majority of alongshore sediment transport. A shallow coastal convexity to the west of the jetty and a concavity to the east suggest that shelter from the jetty acts to trap a small quantity of sand.

Beadon Creek navigation channel is maintained regularly by the Department for Transport, with approximately 5,000 m³ per annum of sediment dredged since excavation of the navigation channel in 1968 (Crawford 1995). The channel is trained with a rock wall on its western side, with a tidal spit on the eastern side acting to provide "natural training". The navigation channel is connected to a tidal creek network, which links to a large area of inundated mudflats during extreme tides, high storm surges or high runoff drainage. Following the approach of Bruun (1978) for an inter-tidal area of 33.8 ha, the channel is estimated to have a capacity to naturally bypass 5,000-10,000 m³ of alongshore drift.

Considerable sedimentation has also been observed at either side of the navigation channel. Accumulation to the west of the training wall is estimated to be in the order of 15,000-30,000 m³ per annum. Sedimentation within the tidal creek network is estimated at 10,000-40,000 m³ per annum, based on a rise of 0.1-0.5 m, which is related to inflow during extreme spring tides and cyclonic flooding. Combined with the observed rate of sedimentation and natural bypassing, a net eastwards littoral transport rate of 35,000-85,000 m³ per annum is estimated.



5.6.3. Town of Onslow Coastal Stability & Management

The township of Onslow was relocated to its present site in the 1920s, between Beadon Point and Beadon Creek, fronted by a broad sandy beach. Subsequent to construction of an 800 m long training wall on the western side of Beadon Creek in 1968, the beach has gradually eroded, with corresponding accumulation on the western side of the training wall. In part, this has exposed the coastal rock that underlies much of the coast from Beadon Point eastwards 15 km towards Consigny Point.

Concern regarding the stability of the shoreline, and potential cyclone impacts on the township resulted in the construction of a seawall in front of the town. This structure was damaged during TC Vance in 1999, with an upgraded 900 m seawall completed in 2002.

Presently there is a narrow, low beach in front of the seawall, which provides a limited buffer to wave impacts, or to a reduced sediment supply to this part of the coast. It is unknown whether there is potential for enhanced sediment transport in front of the seawall.

5.7. SHOREFACE SEDIMENT TRANSPORT

5.7.1. Effect of Prevailing Conditions upon Nearshore Transport

The Ashburton coast is comprised of a sequence of arcuate beaches, terminating in locations controlled by rock formations. This plan form provides the maximum stability for a given wave climate, by orienting the beach towards minimal transport, at both updrift and downdrift ends.

Structurally controlled beach forms have two significant characteristics:

- Controls may hold a discrete quantity of sediment, with any additional material rapidly bypassed;
- Controls reduce the capacity for sediment transport reversals to occur, effectively causing a uni-directional transport regime.

The environmental conditions and the orientation of the coast suggest a net eastward transport of sediment. Although there is occasional capacity for transport reversal, the effect of structural controls will largely constrain the effects of reversal within the beach plan form. Internal adjustment of the beach occurs through beach rotation, profile adjustment and formation of nearshore bar features (Gordon 1987; Prats 2003).

A simplified interpretation of the shoreline plan form is summarised by Figure 5-16. Wave driven alongshore sediment transport reduces for shore aspect both perpendicular and parallel to the wave approach. Inclination of the beach alignment to these positions suggests active alongshore sediment transport, with a maximum occurring at around 45°. Applying this principle, the alongshore transport rate towards Beadon Point is minimal, with relatively high transport east of Entrance Point. The coastal orientation at the mouth of the Ashburton suggests local reversal of sediment transport, which is consistent with the Ashburton acting as an ongoing sediment source. Comparison of indicative transport rates suggests that erosion is likely to occur near Entrance Point and the mouth of the Ashburton, with deposition occurring near Four Mile Creek and the barrier dune west of Entrance Creek. The variable influence of tidal creeks on the sediment transport patterns is noted.



Figure 5-16: Geometric Interpretation of Plan Form (Schematic)

5.7.2. Cyclonic Conditions

Sedimentation may potentially be enhanced under cyclonic conditions, due to the following factors:

- Higher mobilisation due to stronger waves and currents;
- Release of sediment due to a change in the prevailing direction of stress, destabilising seabed features such as ripples, or accumulations in the lee of rocky features. The direction of stress undergoes rotation during the cyclone passage;
- A sustained prevailing direction of currents for several days, allowing transport from a far greater distance than occurs on each tidal current cycle;
- Exposure of sediments previously not winnowed (i.e. erosion may be deeper than the zone normally subject to bioturbation);
- Significant release of fluvial sediments due to cyclonic rainfall and runoff (Margvelashvili *et al.* 2006).

These processes may be active over several different spatial (and hence also temporal) scales:

- In the immediate vicinity of the channel, the dramatic change in depth, and slope of the channel banks, provides a local discontinuity in the bedload transport rate, allowing material to be deposited in the channel. This is essentially a local effect, within hundreds of metres of the channel, as further away, the rate of “outgoing” transport is almost in balance with “incoming transport”. This process is most active during high metocean stresses, which last for a number of hours to several days;
- The effect of enhanced regional stresses during a cyclone is commonly to release a quantity of material from sediment structures that were otherwise in balance with prevailing weather and tidal forcing, which notably includes terrestrial material



mobilised by runoff flooding. Subsequent to the cyclone, prevailing conditions become active, pushing any “out of place” material. The most commonly recognised patterns of transport are “post-storm” onshore beach recovery, and enhanced alongshore transport, such as formation of spits. This process is most commonly active for several weeks to months following a cyclone event, until the excess unrestrained sediment is captured by geomorphic features;

- Under extreme situations, tropical cyclones may cause the movement, disruption or formation of coastal or offshore geomorphic features, including sand bars, tidal creek systems and barrier spits. Destabilisation of such features may enhance the quantity of available sediment, for a matter of months or years.

5.7.3. Active Chenier Dynamics

The Ashburton eastern delta is partially surrounded by a chenier structure, understood to have developed subsequent to TC Vance in 1999, which holds a narrow coastal lagoon. The lagoon is connected to tidal creek systems in the eastern delta, and forms part of the tidal network, with an entrance at its western end, held open by tidal flows. The balance between littoral transport and tidal exchange is affected by variability of both mechanisms.

The chenier is low lying, with signs of overwash occurring, characteristic of a “barrier lagoon” system (Stutz & Pilkey 2002). Typical evolution of such barriers is to progressively migrate landwards through overtopping, and migration or switching of the entrance channel (Fagherazzi *et al.* 2003; Andrade *et al.* 2004; Masetti *et al.* 2008). Although the alignment of the chenier is likely to cause a relatively low rate of alongshore sediment transport, the ephemeral nature (*in decadal time scales*) of the formation is suggested by the loss of an earlier spit at Entrance Point between 1973 and 1993 (Appendix E).



5.8. FLOODPLAIN EVOLUTION

The Ashburton coast is dominated by floodplain, which although ultimately fluvial in origin, has progressively compartmentalised into distinct modern tidal and river dominated sections, being the Ashburton deltaic complex and the extensive tidal creek and mudflat complex connected to Hooley Creek, East Creek, Four Mile Creek and Beadon Creek. The two sections are not actively connected, but readily identified palaeochannels and upland breakouts indicate that discharge under high flood conditions may pass across the mudflat complex, draining through the existing tidal creek systems.

Deltaic form and evolution is determined by the sedimentary processes developed by river flow, tides and waves, interacting with the existing topography, and underlying geology (Perillo 1995; Sanchez-Arcilla & Jimenez 1997). The Ashburton delta has been classified by Geoscience Australia as a wave dominated delta (Harris *et al.* 2002) using a simplified ternary classification scheme derived from Dalrymple *et al.* (1992). The corresponding long-term conceptual model for sedimentation suggests that the majority of material deposits outside the river mouth, with occasional deposition across the floodplain during high flow events (Ryan *et al.* 2003). The prograding nature of the Ashburton shoreline suggests that the average rate of sediment supply exceeds the mean capacity of the wave climate to transport material away from the entrance. In the shorter-term, seasonal or inter-annual shifting between “wet” and “dry” conditions causes a tendency for relative sediment import to or export, respectively, from the estuary (Eyre 1998).

A characteristic of the Ashburton sedimentation pattern that is not described by the Ryan *et al.* (2003) conceptual model is the formation of multiple flood channels and switching of the primary flow path over time. This structure is described by Wright (1985) as symptomatic of very high sediment load, with a sequence of channel choking, overbank breaching and subsequent bank deposition. The process of switching assists with the deposition of sediment across the floodplain. It is considered likely that the rock structure underlying the Ashburton delta increases the capacity for mobility, as the channel depth is constrained. As a further consequence, there is an inherent preference for flow paths to adopt the relict structure of the palaeochannels (Woodroffe *et al.* 1993; Perillo 1995).

The tidal creeks between Hooley Creek and Beadon Creek are separated from the mudflats and lagoons under moderate tidal conditions, with flow into and out of the lagoons occurring under high tides, during elevated ocean water levels, or when heavy runoff causes super-elevation of the lagoon. Variation of these conditions over seasonal or inter-annual time scales may cause a switching between deposition and erosion phases for the tidal creeks, as described for Hooley Creek in Section 4.3.

The stability of the tidal creeks is ultimately determined by the tidal catchment area and the littoral sediment influx (Bruun 1978; Jarrett 1976; USACE 1991). However, episodic flow events may scour the tidal channels, connecting the lagoon to the ocean, and dramatically increasing the available tidal prism. If sufficiently opened, connection to the lagoon may remain open for an extended period of time, until coincidence of high littoral transport and low tidal phases causes the tidal channel to become choked again. This mechanism allows irregular sedimentation of the floodplain, and where sufficient connection occurs, may provide some capacity of the coast to respond to sea level rise (Semeniuk 1994).



5.9. POTENTIAL IMPACTS OF ENVIRONMENTAL CHANGE ON THE DEVELOPMENT

5.9.1. Existing Variability

Historic climate records of cyclone events, wind, water level, rainfall and river flow all suggest that the Ashburton region is subject to very high levels of environmental variability. Interpretation of potential impacts should consider this variability and define appropriate scenarios for coastal management associated with the development. In particular:

- Ongoing progradation of the Ashburton delta system should be recognised, and an understanding of the likely delta expansion over the facility lifetime should be developed;
- The impact of a suite of tropical cyclones should be considered, including those capable of either enhancing or reversing the ongoing easterly sediment transport;
- The effects of significant variations in flow and sediment supply associated with varying runoff from the Ashburton River should be acknowledged;
- Inter-annual sea level and wind climate variations should be catered for within the design conditions, including their effects on wave conditions. This may be achieved by modelling over sufficiently long time scales, or by applying sensitivity analyses to the coastal modelling.

5.9.2. Sea Level Rise

The influence of Greenhouse gas induced climate change is projected to result in global sea level rise (IPCC 2001, 2007; CSIRO 2007). Projected changes are based upon a raft of models and a suite of alternative scenarios for emissions, population growth and technology change. Projected global sea level rises range from 0.18 to 0.85 m by 2100, with regional corrections (CSIRO 2007) and historic tide gauge observations (Mitchell *et al.* 2000) suggesting that conditions for northwest Australia are likely to be near the global mean behaviour.

Although there is considerable uncertainty in the assumptions and method to project sea level rise, it is relevant to note that Western Australian tide gauge records show 0.15m sea level rise over the 20th Century, with 0.06m rise for Northwest stations over 1985-2003. Although inter-annual variability contributes to the recent rise, if this rate continued, the mid-range projections of sea level rise due to climate change would be achieved.

The effects of sea level rise should be incorporated into design parameters adopted for the development, with an understanding and acceptance of the appropriate level of risk.

Sea level rise will cause a range of coastal dynamics that may affect the development. Specifically:

- Erosion related to re-adjustment of the shore profile is likely to occur where sediment supply is low, or lagged. This effect is likely to be strongly mitigated by the fluvial sediment supply from the Ashburton River;
- The capacity for emergent rock platforms to control the position of the shore is minimally affected, providing relative shoreline stability;
- The capacity for Curlew Shoal to provide shelter through friction and refraction is reduced, and will increase the rate at which ephemeral spit structures at Entrance



Point erode. Some shoreline erosion is likely, but is limited by the presence of underlying rock;

- The potential mobility of tidal channels is enhanced, including avulsion of the main Ashburton flow path and connection of tidal creeks through to the lagoon and mudflats (van Rijn 1998; van Goor *et al.* 2003);
- Drowning of the Ashburton deltaic complex is a potential outcome of rapid sea level rise. However, the high sediment supply, and the capacity for redistribution through tidal creeks or channel avulsion make this scenario unlikely, based upon geomorphic interpretation of the early Holocene transgressive phase on coastal mangrove communities (Semeniuk 1994).

5.9.3. Change to Cyclone Climatology

Projected increases in ocean temperatures as a result of Greenhouse gas induced climate change are considered likely to modify the historically observed cyclone climatology (IPCC 2001, 2007). Interpretations of what these potential changes may be remains a topic of considerable ongoing research, with fundamental questions of meteorological science and the corresponding techniques of cyclone modelling still to be addressed (Damara WA 2009). The most comprehensive available statement regarding the likely interaction between cyclones and climate change is available from the World Meteorological Organisation, which suggests a general increase in the occurrence of severe tropical cyclones (WMO 2006).

Theoretical modelling of projected climate change at a global scale has suggested that a 3-10% increase of tropical cyclone intensity is likely in most ocean basins for a 2.2-2.7% increase of sea surface temperature, with an approximate 6hPa decrease of MPI for the South Indian Ocean region (Knutson & Tuleya 2001).

The most recent efforts to understand the behaviour of tropical cyclones off Western Australia have suggested that regional behaviour is markedly different to that occurring off Eastern Australia. Modelling of climate change effects upon cyclone climatology relevant to the Pilbara region have shown that the outcome may be significantly affected by the methodology.

Results for Australian region tropical cyclone modelling are described in CSIRO (2007):

*Three recent studies have produced projections for tropical cyclone changes in the Australian region. Two suggest that there will be no significant change in tropical cyclone numbers off the east coast of Australia to the middle of the 21st century (Walsh *et al.* 2004; Leslie *et al.* 2007). The third study, based on the CSIRO simulations (Abbs *et al.* 2006), shows a significant decrease in tropical cyclone numbers for the Australian region especially off the coastline of Western Australia.*

And further:

*Each of the above studies finds a marked increase in the severe Category 3-5 storms. An increase of 60% and 140% in the **intensity*** of the most extreme storms for 2030 and 2070, respectively, was found using a model with a 15 km grid spacing (Abbs *et al.* 2006). Walsh *et al.* (2004) found an increase of 56% by 2050 using a 30 km model. Leslie *et al.* (2007) used a 50 km model and reported an increase of 22% by 2050, and a change in the latitudinal extent of tropical cyclones, with more storms forming closer*



to both the equator and the poles; a poleward extension of tropical cyclone tracks; and a poleward shift of over 2 degrees of latitude in the tropical cyclone genesis region. A poleward shift of 0.7 degrees of latitude (around 70 km) in the average tropical cyclone genesis region on both coastlines and a shift of almost 3 degrees latitude in the average decay location for east Australian cyclones were found for the year 2070 (Abbs et al. 2006).

* Damara review of Abbs *et al.* (2006) suggests that these figures refer to frequency rather than intensity. Abbs *et al.* (2006) report simulation of tropical cyclone-like vortices, suggesting a net reduction in the frequency of events, but an increase of intensity, with a mean decrease of 6hPa. Furthermore, the parameterisation developed by Abbs *et al.* (2006) shows a reasonable prediction for east-coast Australia, but clearly underestimates the frequency of cyclones for Western Australia. Consequently, studies grouping the Australian region as a whole may be inclined towards providing a relatively poor representation.

Notably, each of the studies for the Western Australian region has been 'tweaked' such that the historic period is 'calibrated' in terms of cyclone numbers, which has been shown to be significantly biased by the observations methods (Lourensz 1981; Landsea 2000; Qi *et al.* 2008). Performance of the models with respect to cyclogenesis and re-creation of observed events is moderate.

The potential unreliability of tropical cyclone projections obscures the ability to resolve the effects of different climate change scenarios. Hence, for the purpose of assessing potential climate change impacts on cyclonic conditions, a conservative approach may be to consider an increase of both tropical cyclone intensity and frequency in the order of 10% by 2050 and 20% by 2100 for Category 3 of stronger events, noting that existing models provide less support for increased frequency. Conditions previously applied for parametric modelling across the Pilbara region included a 15% increase of intensity and a 10% increase of frequency (Damara WA 2009).



5.10. POTENTIAL ENVIRONMENTAL IMPACTS FROM PROPOSED DEVELOPMENT

5.10.1. Sedimentation and Erosion

The proposed MOF breakwaters, shipping basin and dredged navigation channel provide an interruption to shoreface sediment transport patterns, particularly in close to the coast.

1. Construction of the proposed MOF basin and breakwaters will cause a “near-field” impact, developed through sedimentation within the capture zones of the proposed facility. Some accretion is likely to occur on either side of the MOF, with a greater volume accreting on the western side, estimated to be capable of capturing from 100,000 to 400,000 m³. This accretion will be more rapid than long-term rates of littoral drift, and is counterbalanced in the short-term by erosion from the adjacent coast, which is likely to cause destabilisation of the outer chenier adjacent to the Ashburton eastern delta.

As noted in Section 5.7.3, the outer chenier is an unstable feature due to its low level. Using LIDAR data, the volume of the spit above 0.0m AHD has been estimated as 270,000 m³. The relative volume of the trap to the chenier suggests that near-field erosion may be significant, and requires careful management during construction and for several months following. The likely pattern of change is for general loss from the front of the chenier, although it is possible that up to one third of the eastern end of the chenier would be “cut off”.

2. Interruption of ongoing littoral drift is likely to cause updrift accretion on the western side and downdrift erosion on the eastern side of the MOF, modulated by seasonal, inter-annual and episodic fluctuations in the direction of sediment transport. This may be partially mitigated through bypassing works, although the discrete nature of such works, either spatially or temporally, is likely to affect the coastal dynamics, and increase local shoreline variability.
3. The effect of wave sheltering adjacent to Hooley Creek tidal spit will produce a local imbalance in sediment transport and is likely to cause erosion of the spit. Marginal increase in the water level exchange through to Hooley Creek West is anticipated due to the more open entrance, including exposure to greater wave action.
4. Deeper waters provided by the dredged navigation channel and shipping basin will provide a trap for any sediment bedload transport passing in either direction. This accumulation may be managed by incorporating siltation allowances and sediment traps to the basin design and undertaking maintenance dredging.

The preliminary breakwater layout suggests capture of up to 100,000 m³ may occur within the sand trap to the west, after which an increasing proportion of bedload is likely to bypass the trap. Considerable further accretion may occur until the breakwater will be wholly saturated, with up to 400,000 m³ held to the west.

Using the estimated net sand transport rates described in Section 5.5.3, if the sand trap alone were used for management, then excavation would be required every 1-2 years, with the remaining 300,000 m³ capacity of the breakwaters available to cater for cyclonic events.



Figure 5-17: Shoreline Effects Caused by Breakwaters

5.10.2. Hooley Creek Activation

Construction and operation of the proposed terrestrial facilities will modify the catchment properties of the Hooley Creek lagoon. The ultimate effects of terrestrial operations will be determined by changes to the runoff and surge catchment areas of the lagoon. Filling of the mudflats reduces the effect of the lagoon to act as a compensation basin, increasing the super-elevation during a flood event and potentially enhancing the capacity of the Hooley Creek tidal channel to erode, connecting to the lagoon to the ocean. The possibility of the lagoon-ocean connection expanding is also increased by the interruption to littoral transport caused by the MOF breakwaters and the consequent destabilisation of the Hooley Creek spit due to downdrift erosion.

Expanded 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. Whilst remote, the capacity for increased channelization of Hooley Creek west provides potential for re-activation of the palaeochannel identified from the Ashburton River towards the Hooley Creek tidal creek complex (Figure 4-3). Such re-activation would require an extreme flood event, and therefore whilst considered remote, may occur without a corresponding progressive expansion of the tidal creek structure.



6. References

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7. Appendices

7.1. APPENDIX A PHOTO LOGS

Site	Location	Lat	Long	Date
BS01	Ashburton Entrance west	21° 42.10S	114° 54.32E	7/05/2009 11:20
Photo number	Description	Comment		
All		All BS01 photos		
0	Aerial	Ashburton Entrance looking West		
8	Aerial	Ashburton Entrance looking East		
9	Beach	Beach site looking east		
11	Beach	Beach site looking west		
16	Dune	On top of dune looking towards ocean		
BS02	Ashburton Entrance east	21° 41.44S	114° 56.37E	7/05/2009 11:50
Photo number	Description	Comment		
All		All BS02 photos		
1	Aerial	East of Ashburton looking west		
12	Aerial	East of Ashburton looking east		
13	Aerial	Ashburton delta looking east		
2	Beach	Looking east		
3	Beach	Looking west		
5	Dune	Looking east		
9	Dune	Turtle hole		
BS03	Entrance Point West	21° 40.40S	114° 58.15E	7/05/2009 10:40
Photo number	Description	Comment		
All		All BS03 photos		
1	Aerial	Entrance Point looking west		
8	Spit	Seaward side of spit looking east		
21	Aerial	Entrance point looking east		
6	Spit	From spit looking at the lagoon		
10	Spit	Lagoon side of the spit looking east		
12	Spit	Vegetation at western end of spit		
18	Spit	Lagoon side of vegetation		



BS04	Entrance Point Eastern Spit	21° 40.65S	114° 59.04E	7/05/2009 10:00
Photo number	Description	Comment		
All		All BS04 photos		
2	Aerial	Spit looking west		
24	Aerial	Western tip of spit (veg covered)		
27	Aerial	Spit looking east		
34	Aerial	Entrance looking north from land		
35	Aerial	Spit looking east from land		
20	Spit	Seaward side of spit looking east		
22	Spit	Seaward side of spit looking west		
5	Spit	Looking east from the middle of the spit		
15	Spit	Lagoon side of spit looking east		
9	Spit	Vegetation on lagoon side of western tip of spit		
BS05	Spit	21° 41.03S	115° 00.08E	6/05/2009 16:15
Photo number	Description	Comment		
All	Spit	All BS05 photos		
35	Aerial	Spit looking east from land		
1	Spit	Seaward side of spit looking east		
6	Spit	Lagoon side of spit looking west (cusps)		
7	Spit	Lagoon side of spit looking east		
9	Spit	Lagoon		
2	Spit	Spit looking west		
BS06	Spit Weld	21° 41.12S	115° 00.79E	8/05/2009 8:50
Photo number	Description	Comment		
All		All BS06 photos		
1	Beach	Looking west at dune 9 at rocks along lagoon		
2	Beach	Looking east at dune 9 along lagoon		
10	Beach	Beach at weld looking east		
14	Dune	Shell deposits over 1 st dune		
15	Lagoon	Lagoon looking west		
16	Beach	Looking east from eastern end of lagoon		
18	Aerial	From land side of weld looking east		
21	Aerial	Weld looking west		
28	Rock	Exposed rock close up		
30	Dune	Rock over 1 st dune		
31	Dune	Looking south from beach at dunes		
32	Beach	Beach looking west from east of the weld		
4	Lagoon/weld	Lagoon and spit from landward side of lagoon		
9	Spit	Beachface of spit looking west from weld		



Photo number	Description	Comment
BS07 Plant Site / Salient 21° 41.16S 115° 00.99E 8/05/2009 12:35		
All		All BS07
0	Beach	Beachface looking west
1	Dune	Dune looking from beach
10	Beach	From dune looking west towards weld
11	Beach	From dune looking east towards Hooley Creek
13	Beach	Looking at beach in front from dune
2	Beach	Beachface looking east
4	Aerial	Looking east towards plant site
9	Rock	Exposed rock at salient
BS08 Hooley Creek West 21° 41.18S 115° 01.60E 6/05/2009 15:00		
All		All BS08 photos
1	Spit	Start of Hooley Creek spit looking east
10	Beach	Beachface at start of spit looking west
11	Beach	Beachface at start of spit looking east
13	Spit	Intertidal flats looking east
18	Salient	Looking seawards at salient
23	Spit	Hooley Creek side of spit looking west
24	Spit	Hooley Creek side of spit looking east
21	Spit	Intertidal flats at end of Hooley Creek spit
27	Aerial	Hooley Creek spit looking east
30	Aerial	End of spit
26	Spit	Hooley Creek side looking east
3	Hooley Creek	Hooley Creek at start of spit looking west
BS09 4-mile Creek 21° 40.70S 115° 03.31E 9/05/2009 7:30		
All		All BS09 photos
0	Aerial	Looking west at 4 Mile
8	Dune	Looking seaward from dune
14	Shells	Shell deposits at back of beach
15	Beach	Beachface looking west towards entrance
16	Shells	Shell deposits on beachface
20	Creek	Looking seaward from edge of 4 mile creek
3	Aerial	4 mile entrance
5	Aerial	Looking east towards Hooley Creek from 4 mile
9	Dune	From dune looking towards 4 mile entrance



Photo number	Description	Comment		
BS10 Beadon Point 21° 38.08S 115° 06.61E 9/05/2009 8:20				
All		All BS10 photos		
10	Lookout	Remnants of old jetty looking from lookout		
1	Lookout	Onslow Salt Jetty with ship about to dock		
17	Beach	Series of low profile rock groynes		
14	Beach	Seawall looking east		
16	Beach	Seawall looking west		
18	Beach	Seawall looking east		
21	Beach	Close up of rock groyne and remnant jetty		
25	Beach	Rocks at Beadon Point shoreline		
BS11 Beadon Creek 21° 38.56S 115° 07.77E 9/05/2009 9:00				
Photo number	Description	Comment		
All		All BS11 photos		
0	Creek	Looking inland along Beadon Creek		
1	Creek	Looking seaward along western breakwater		
3	Beach	Eastern side of Beadon Creek		
4	Beach	Shoreline looking west of Beadon Creek		

7.2. APPENDIX B WIND DISTRIBUTIONS

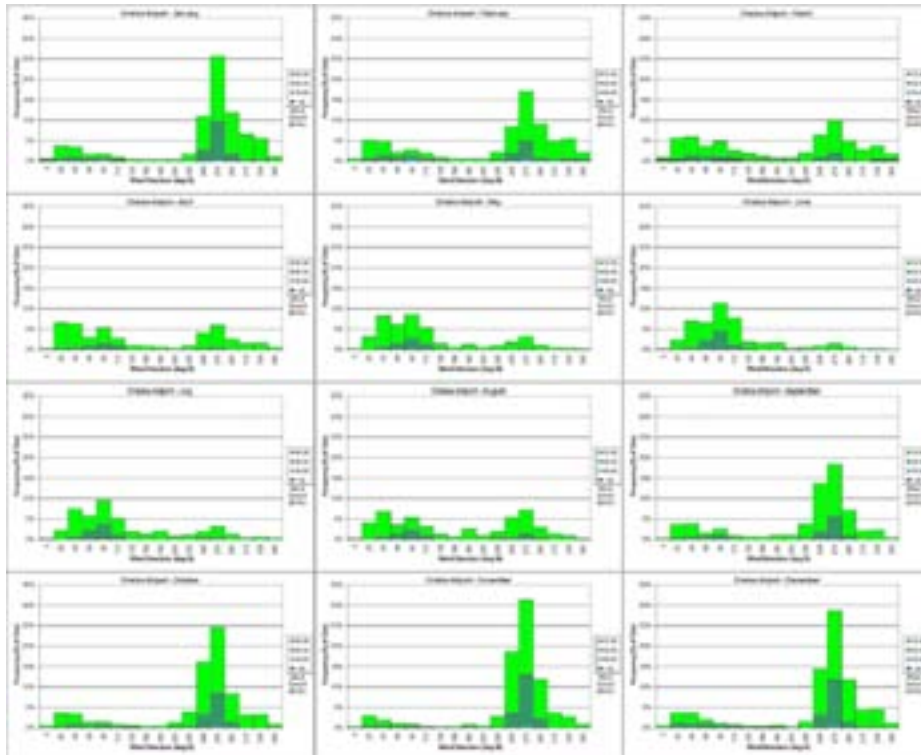


Figure B1: Onslow Airport Wind Distribution

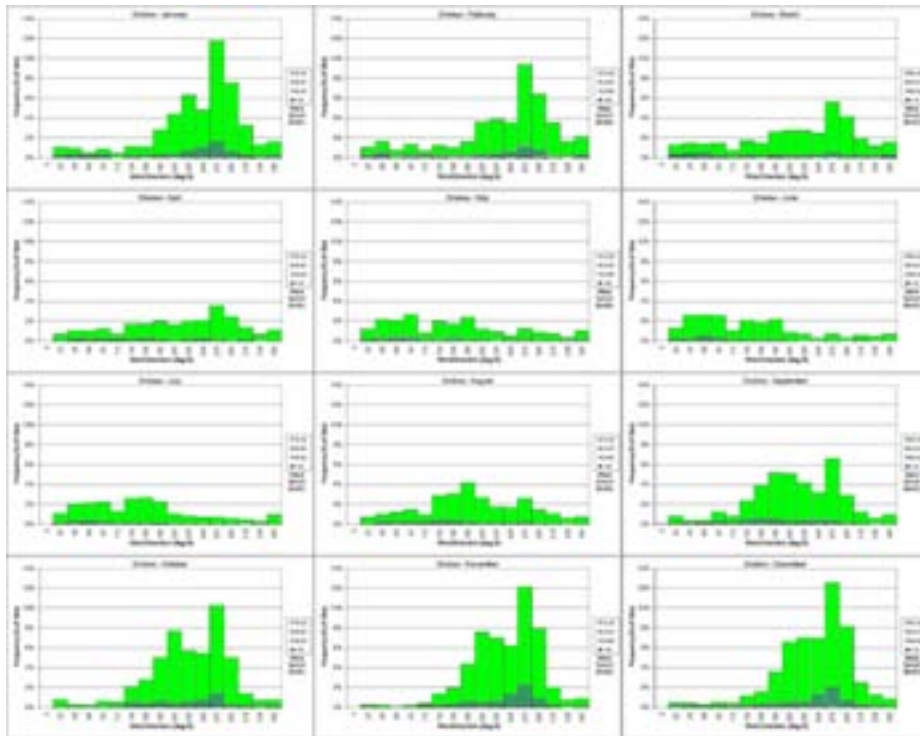


Figure B2: Onslow Jetty Wind Distribution



Damara WA Pty Ltd

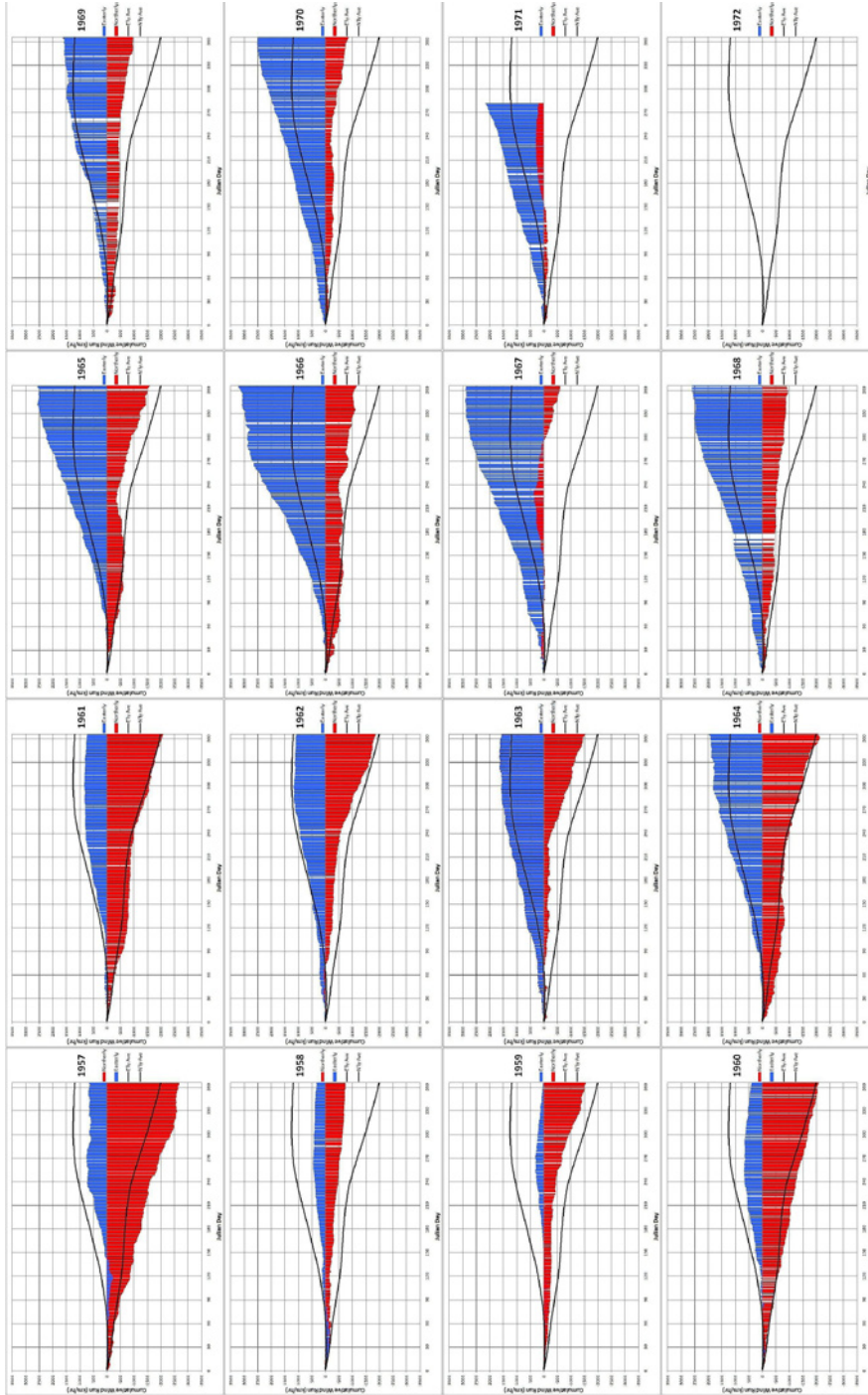


Figure B3: Annual Cumulative Summation Winds 1957-1972



Damara WA Pty Ltd

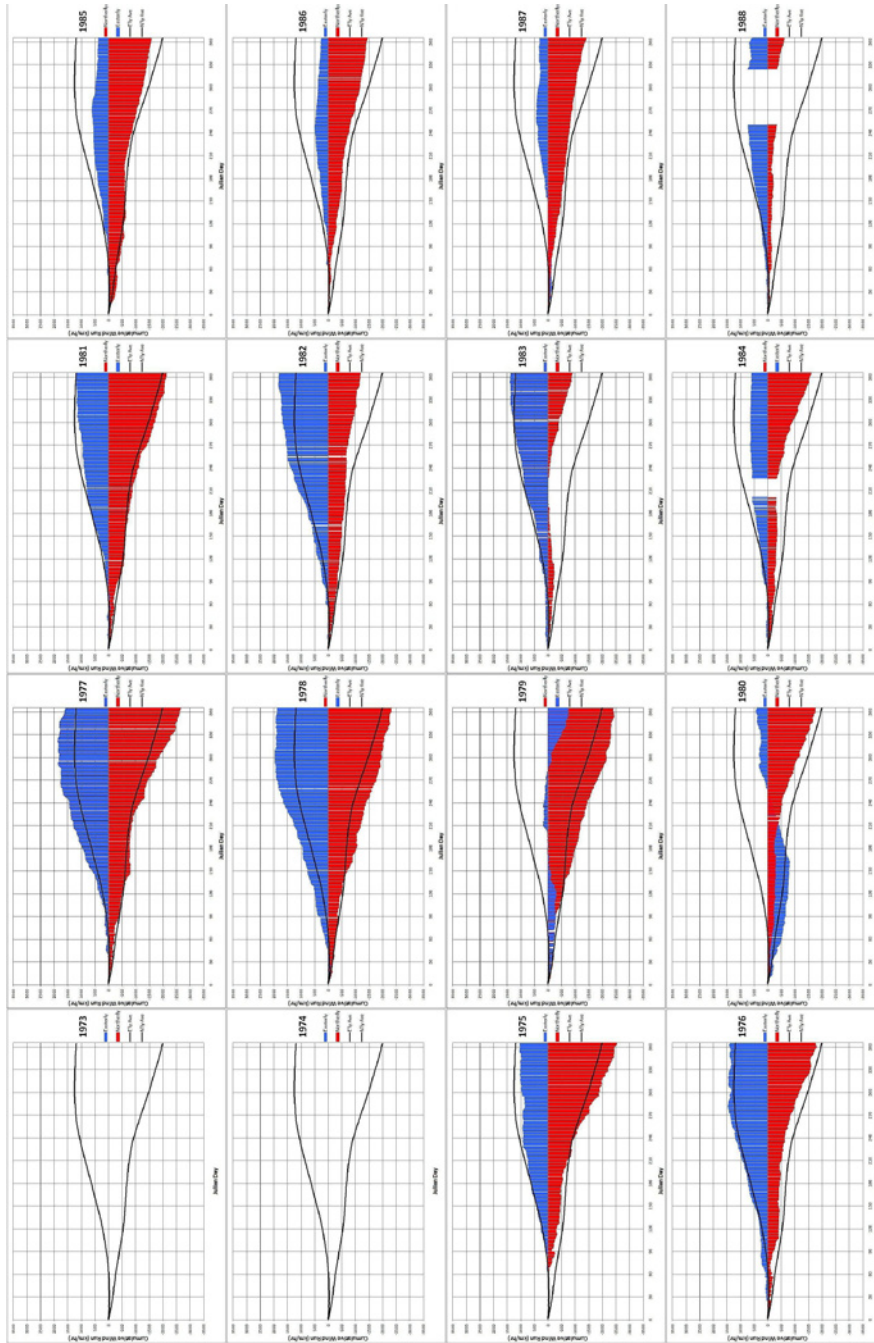


Figure B4: Annual Cumulative Summation Winds 1973-1988



Damara WA Pty Ltd

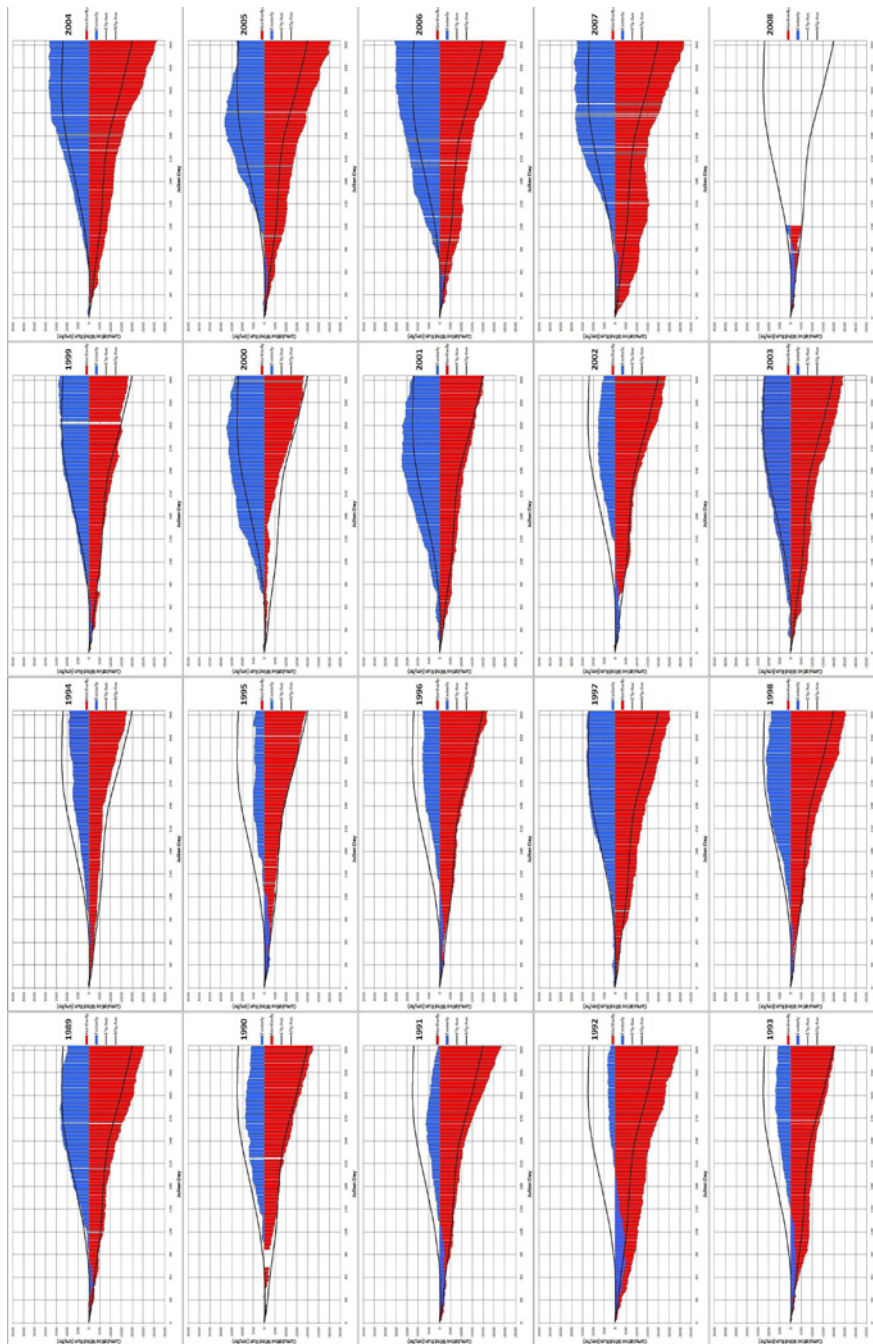


Figure B5: Annual Cumulative Summation Winds 1989-2008

7.3. APPENDIX C TROPICAL CYCLONE CHARACTERISTICS

Extract from Damara WA (2006) *Tropical Cyclone Climatology of Western Australia*

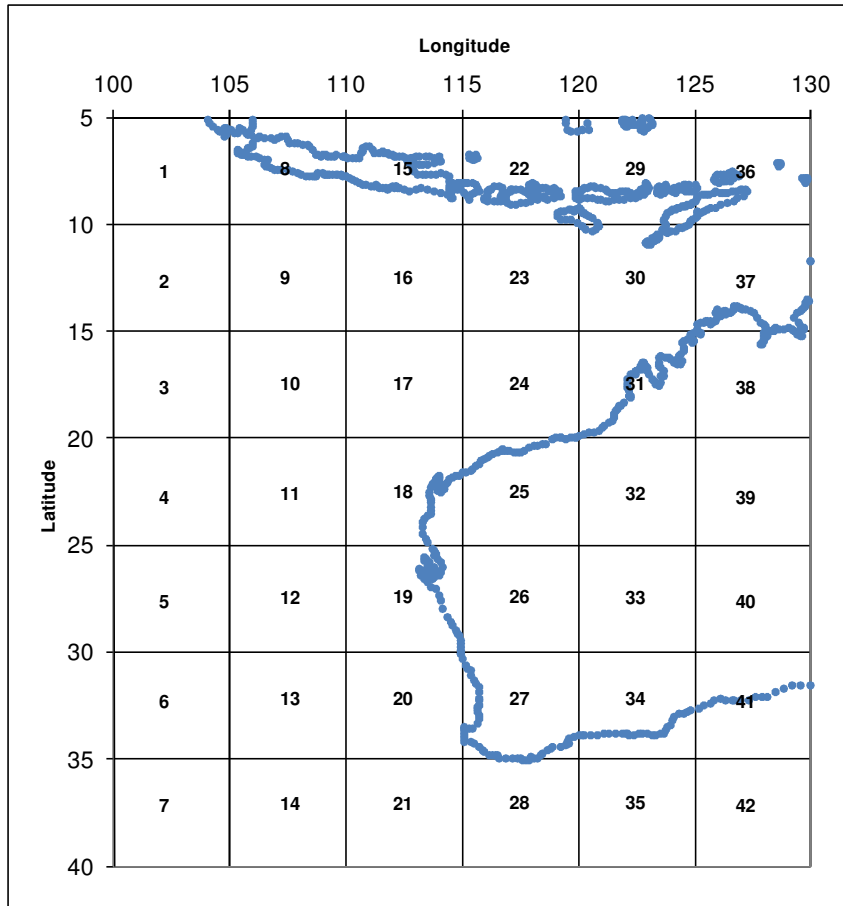


Figure C1: Zones Used for Tropical Cyclone Analysis

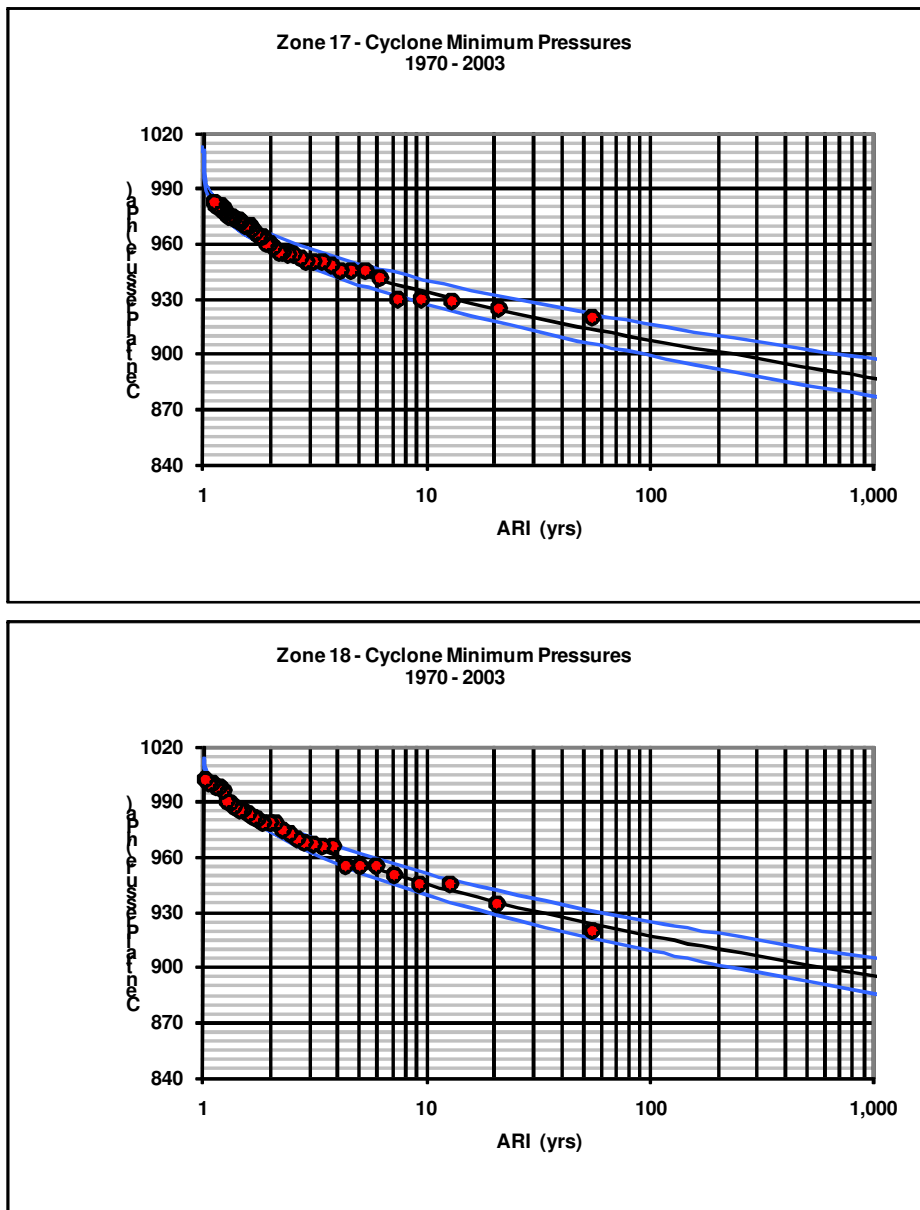
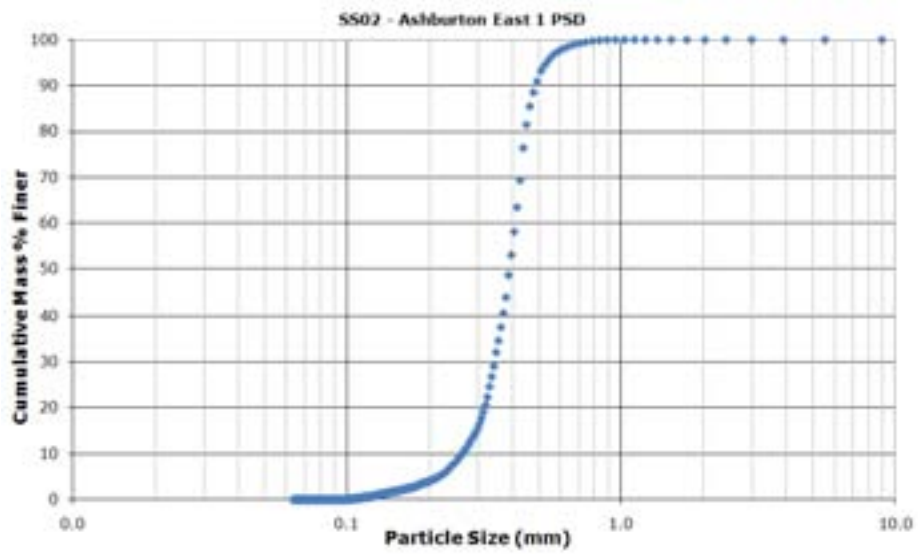
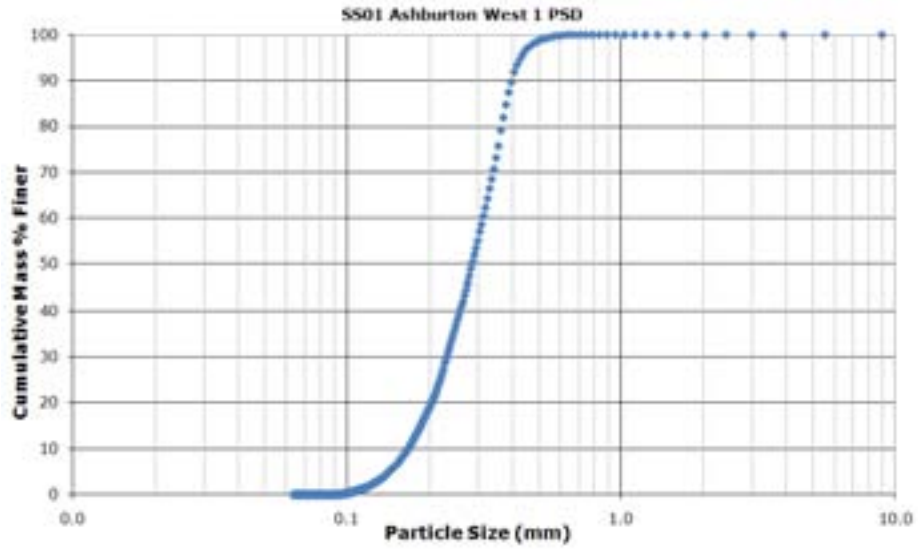
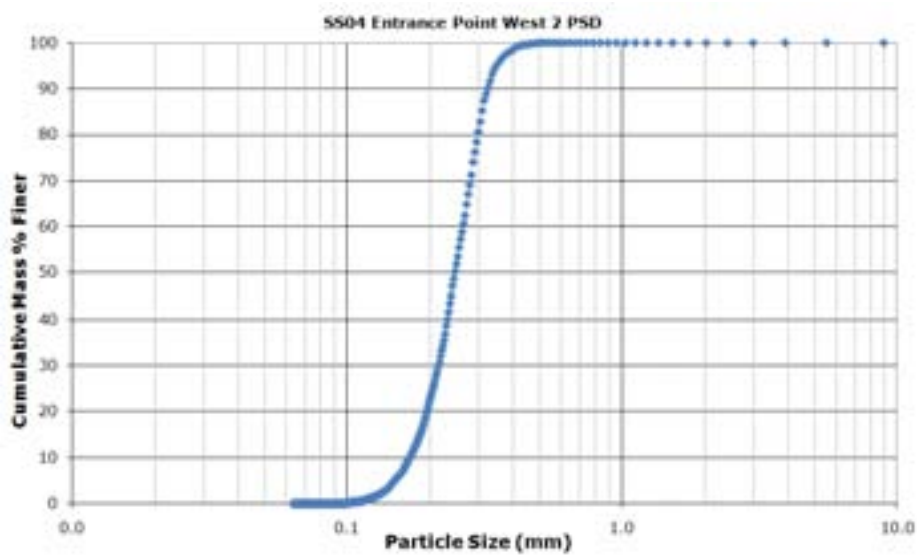
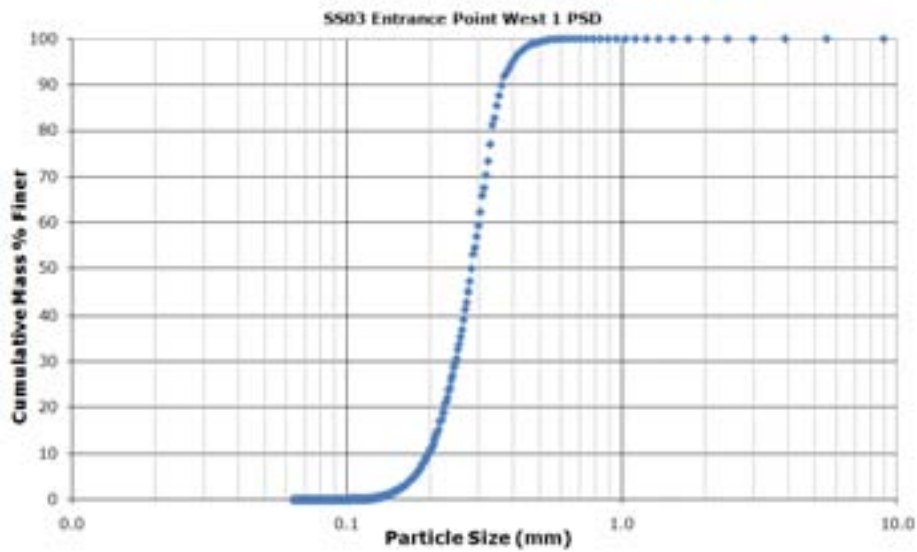
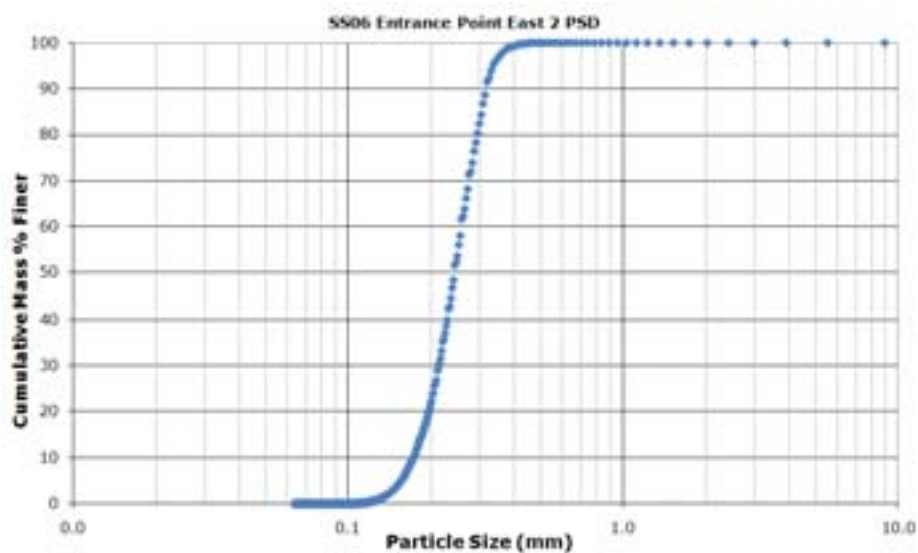
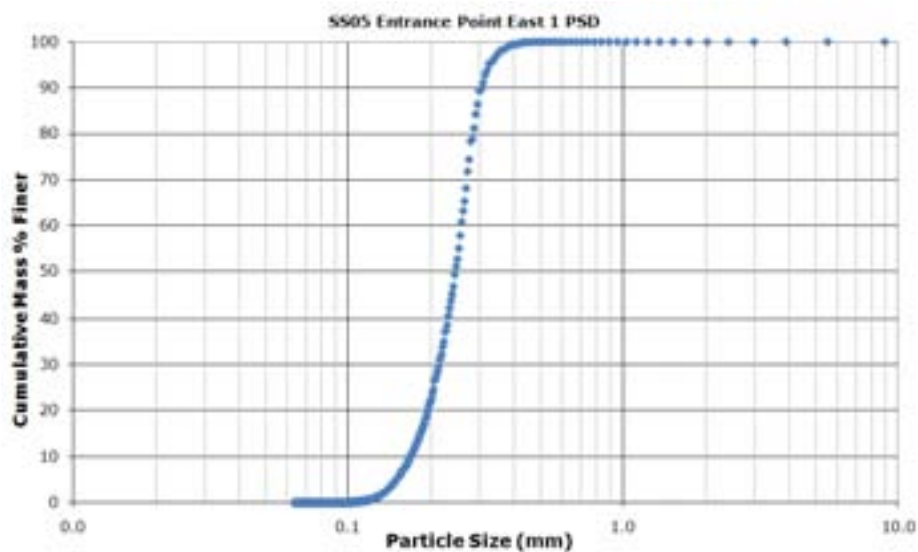


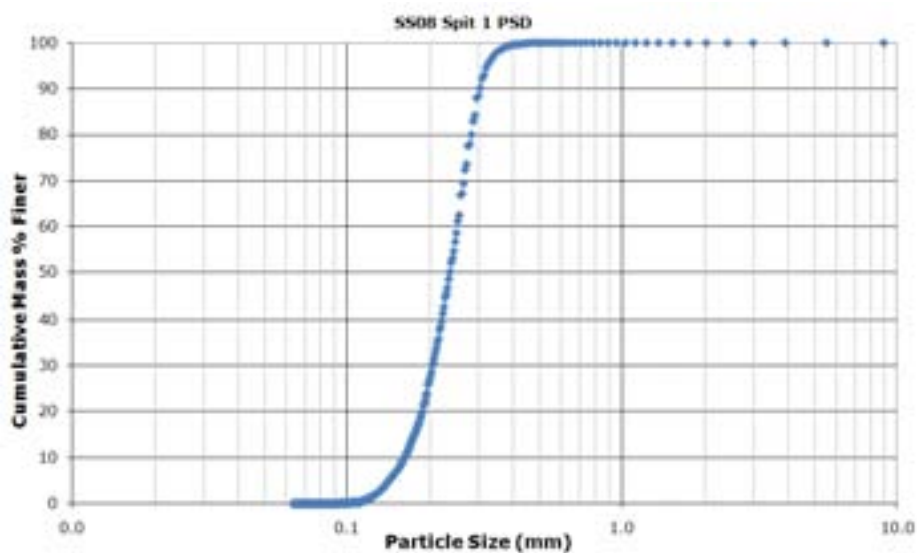
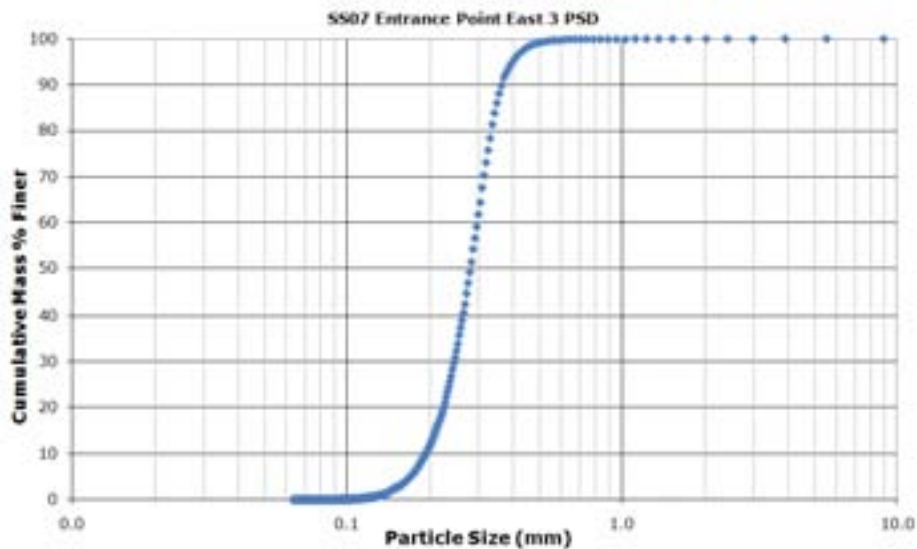
Figure C2: Tropical Cyclone Minimum Central Pressure Distributions

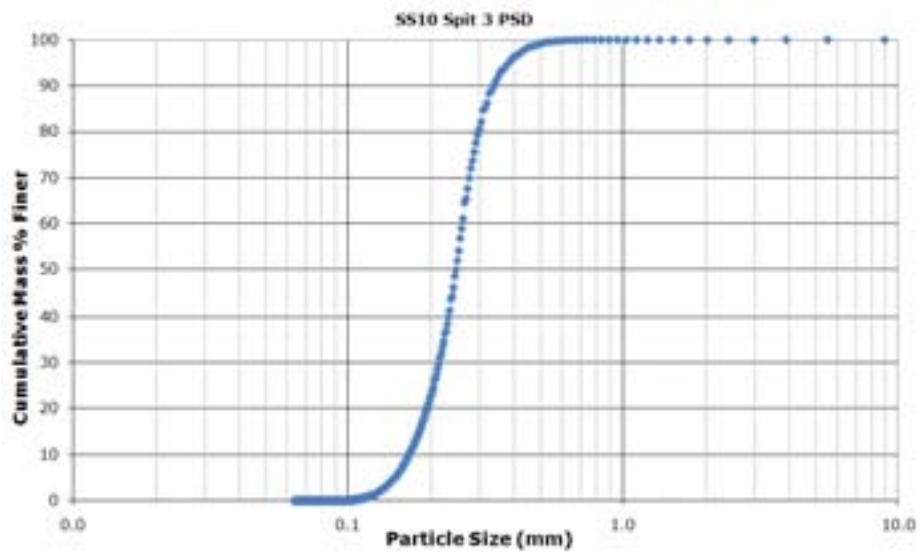
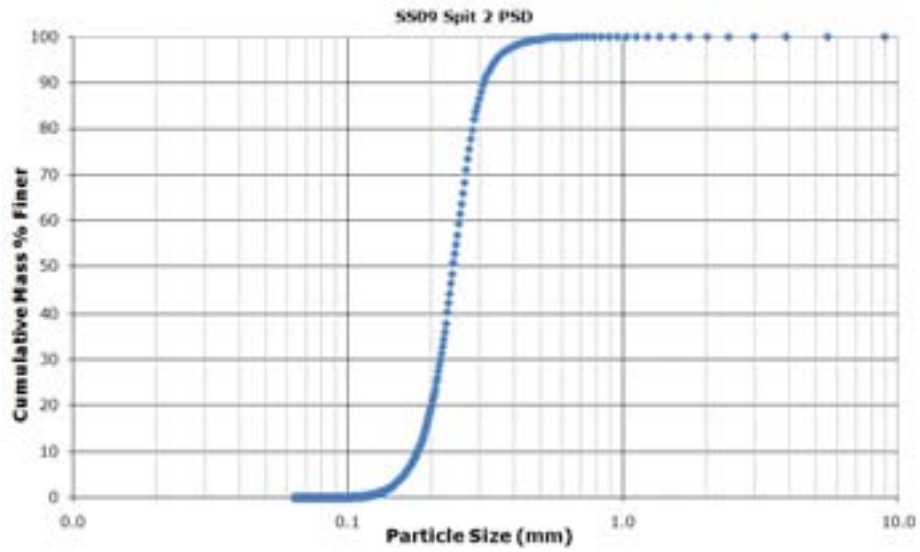
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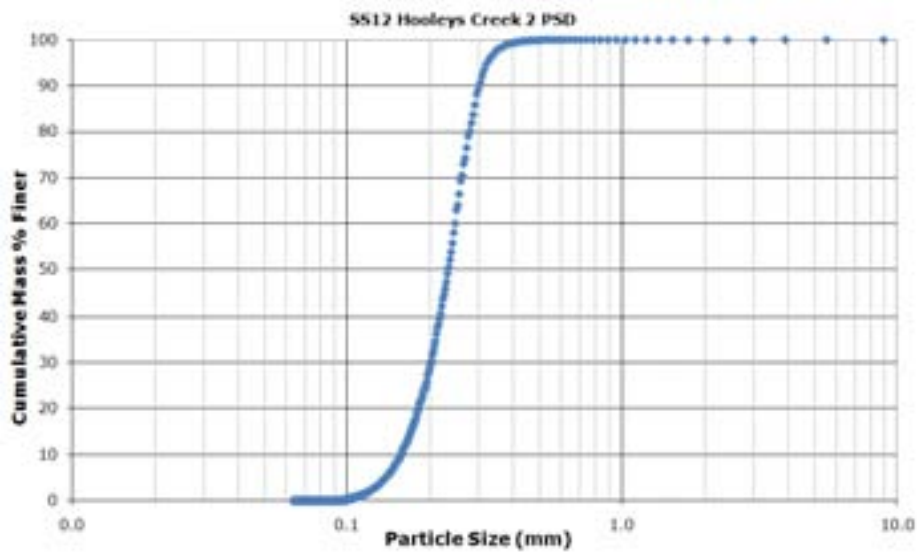
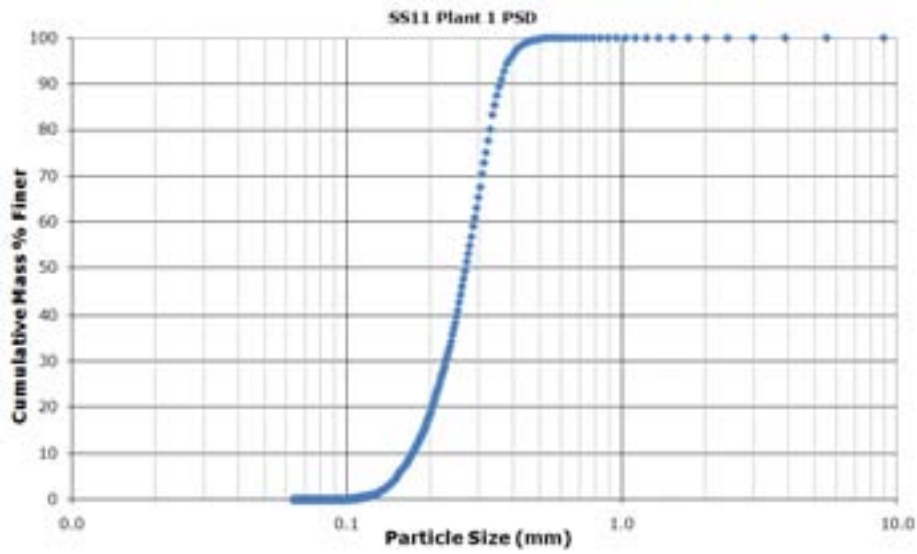


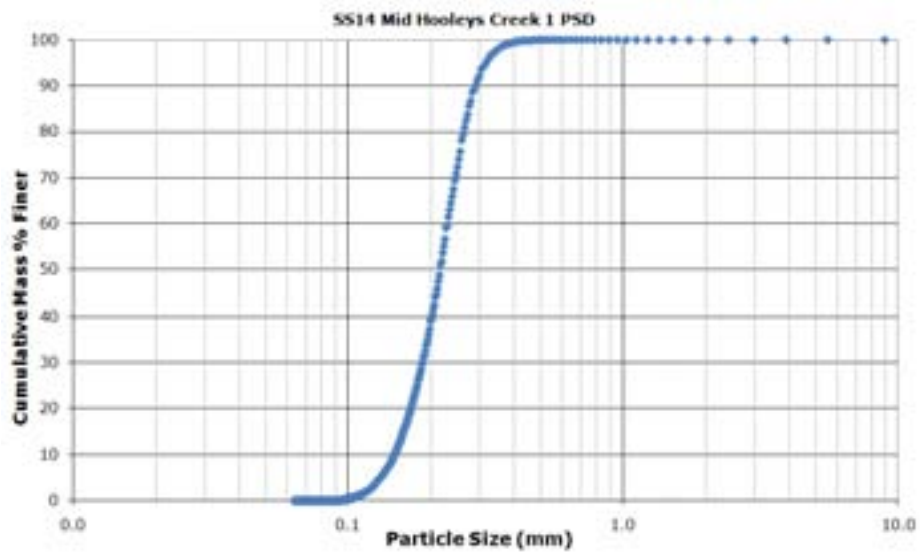
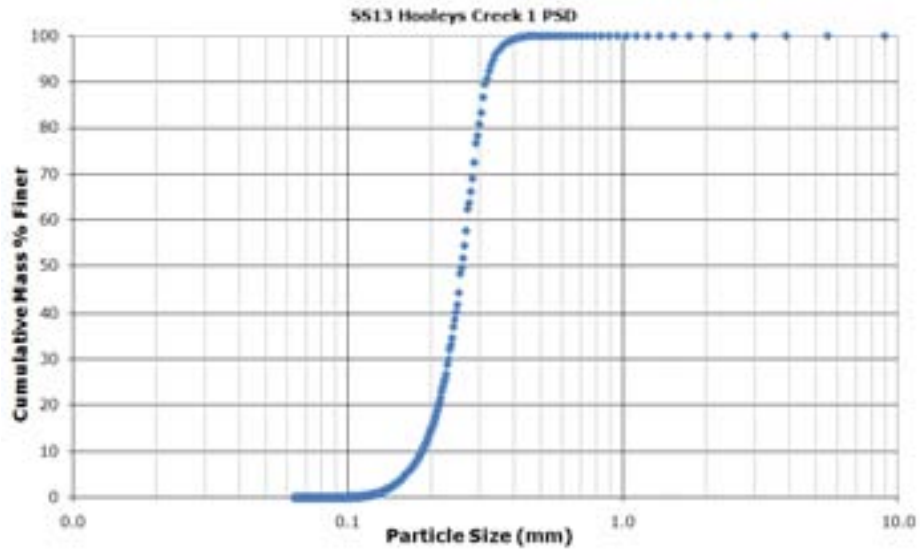


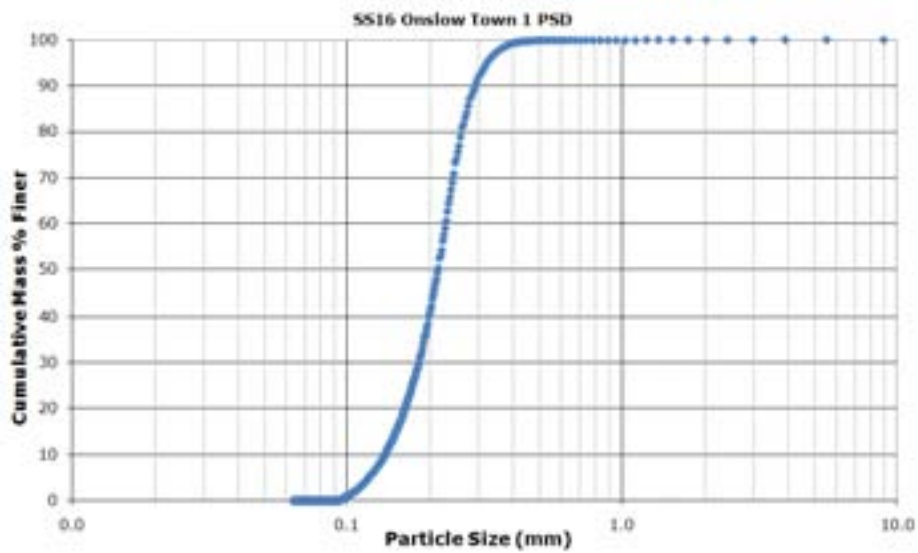
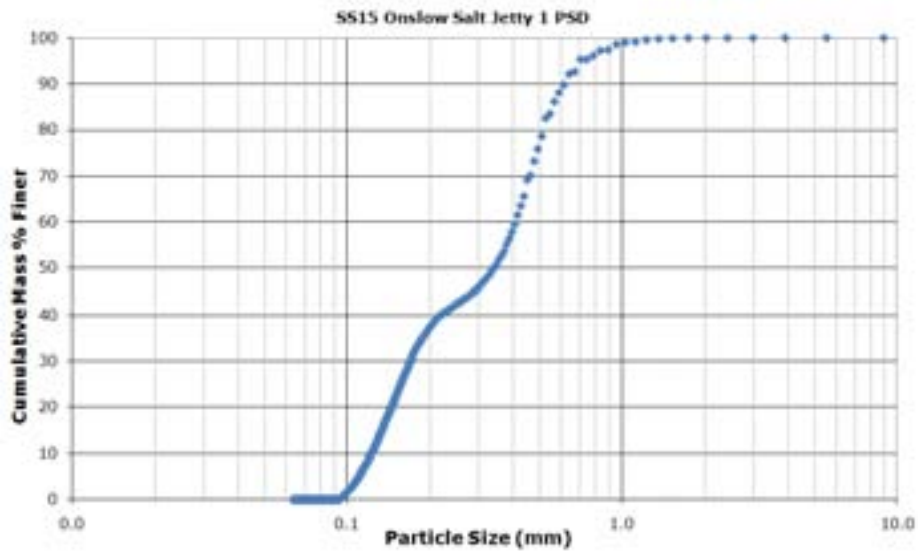












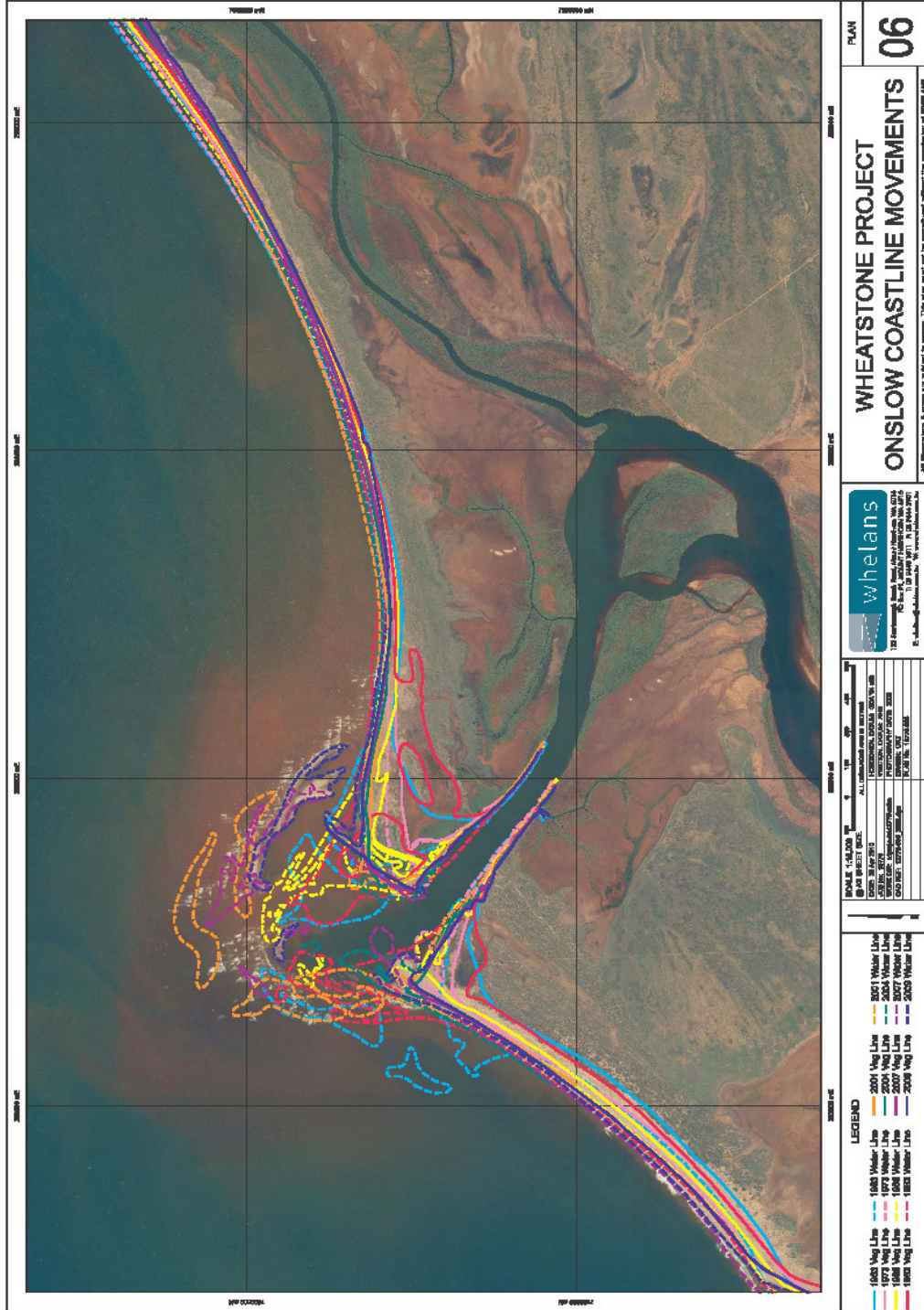


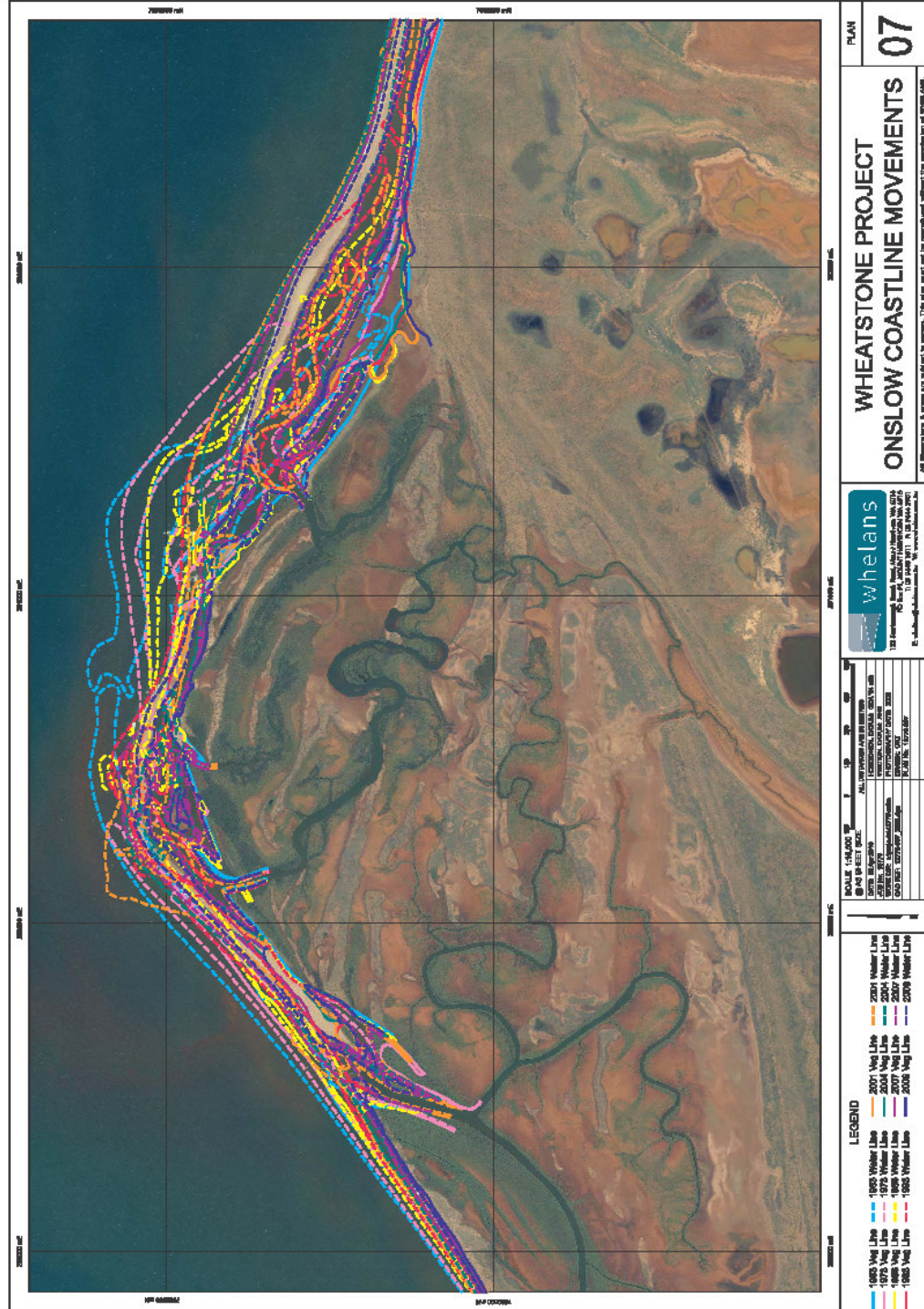
7.5. APPENDIX E COASTAL MOVEMENT PLANS

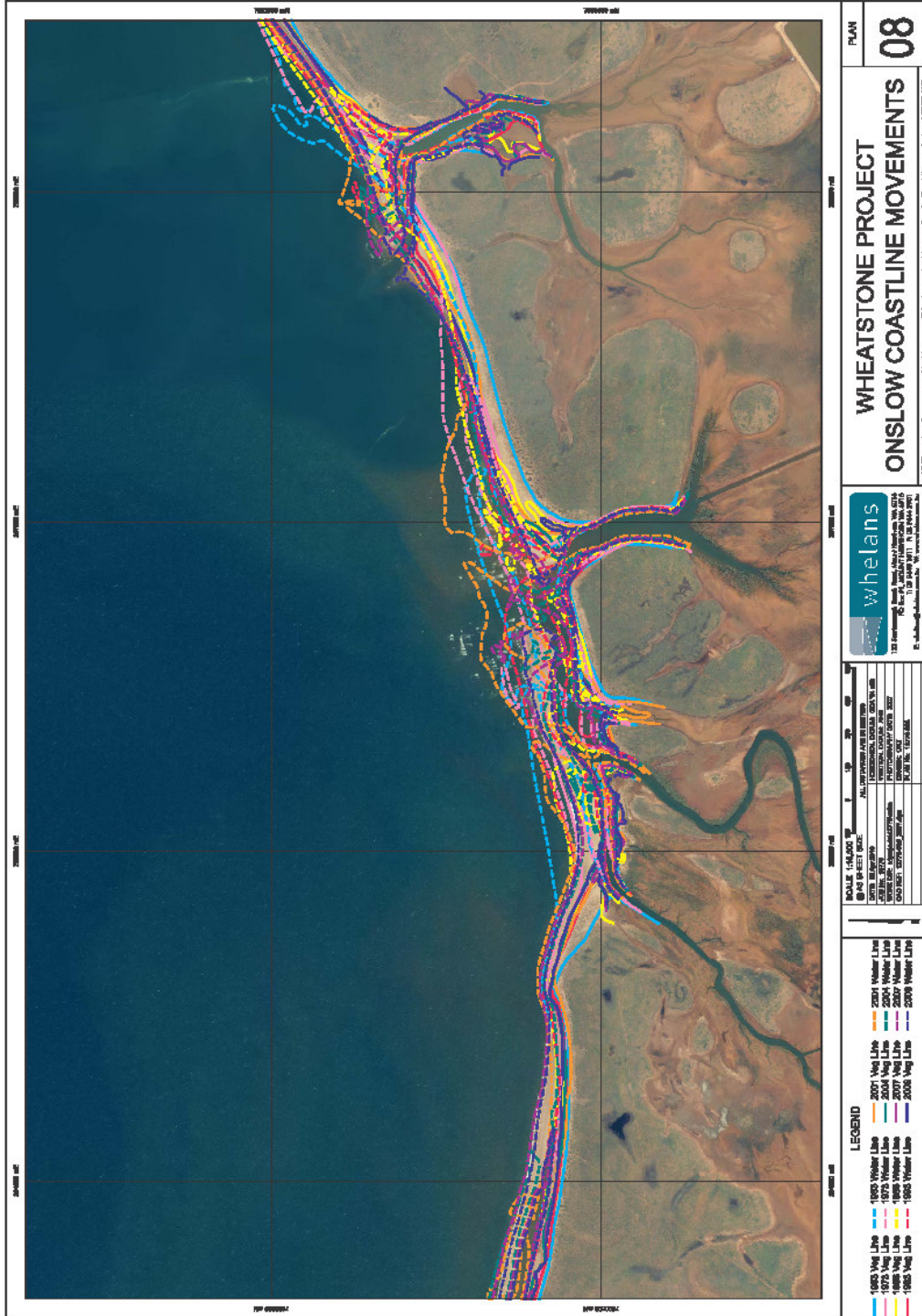
Coastal movement plans have been developed from imagery captured in the years 1963, 1973, 1986, 1993, 2001, 2004, 2007 and 2009.

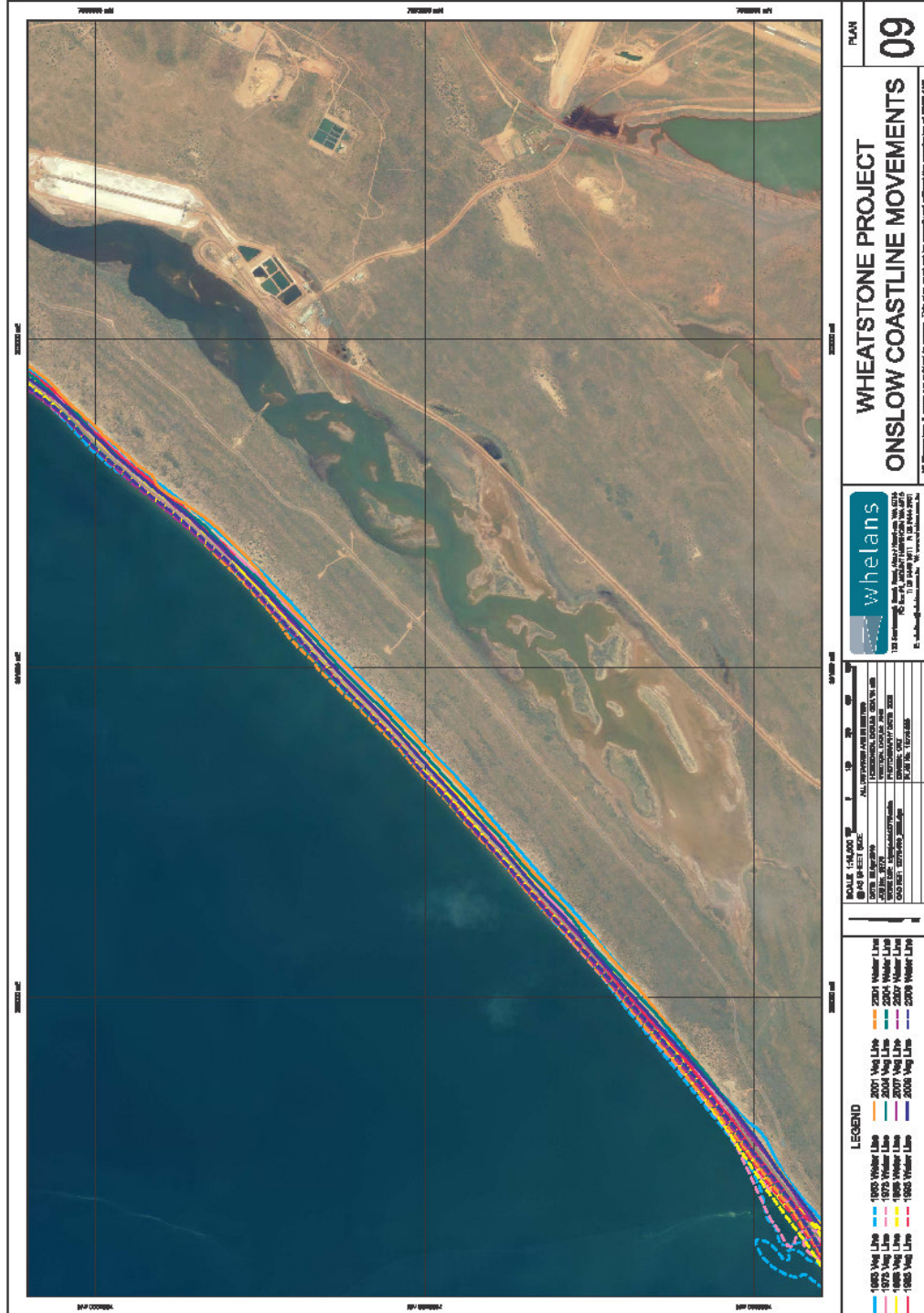
Two-dimensional photogrammetry has been used to capture the vegetation line and the shoreline at the time of the photography. Care must be taken to interpret perceived shoreline changes as these may be affected by tides.

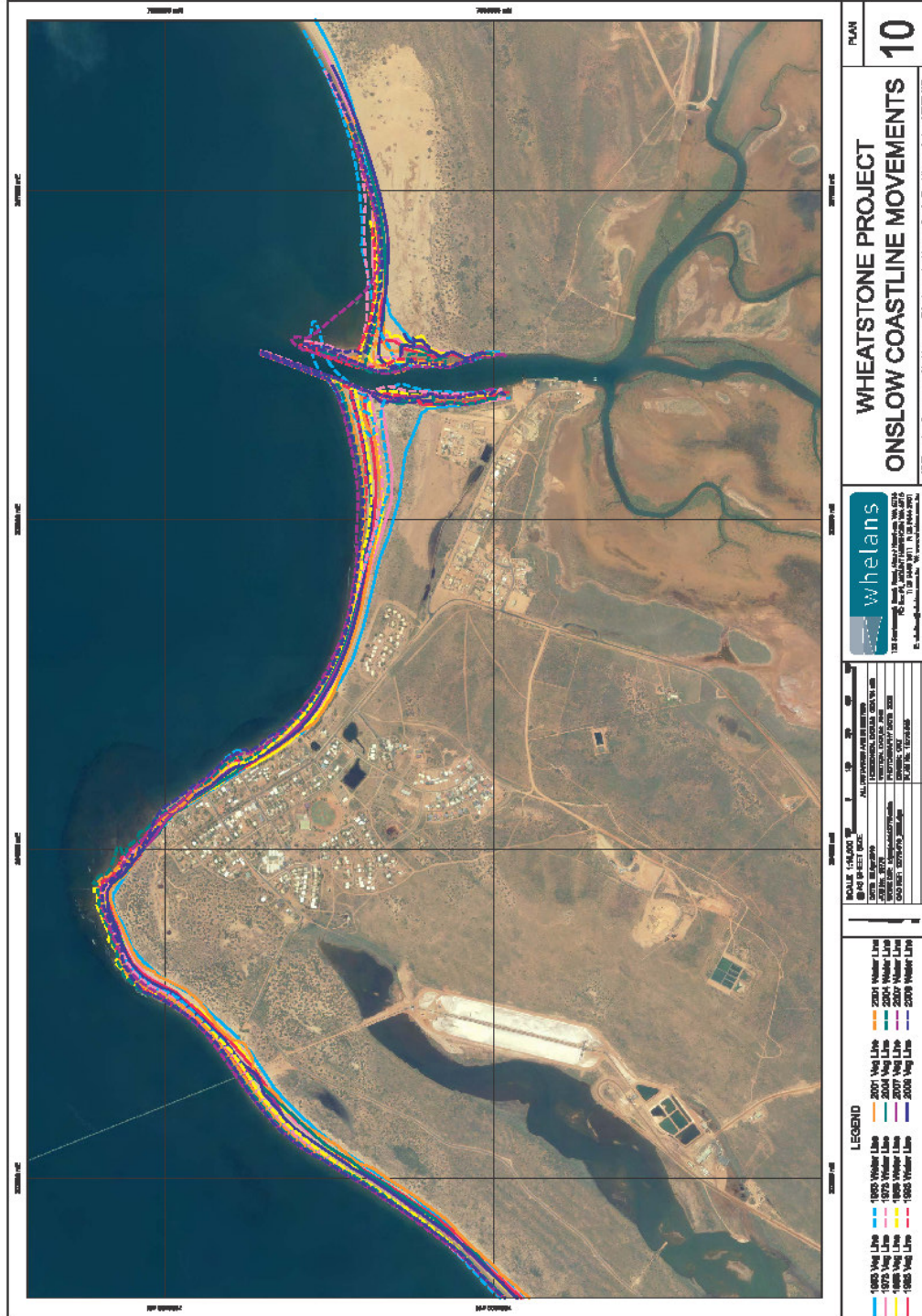
Drawing Number	Coverage
13776-001	Ashburton Delta (Main)
13776-002	Ashburton East Delta
13776-003	Hooley Creek
13776-004	Sunset Beach
13776-005	Beadon Point













7.6. APPENDIX F PROJECT SCOPE

1.0 Geomorphic Mapping

- 1.1 Existing information will be reviewed to identify landform assemblages and major geomorphic components
- 1.2 Geomorphic mapping based upon available aerial photographs, satellite imagery and landscape photography
- 1.3 Plan and execute field survey to ground truth geomorphic interpretation
- 1.4 Radiometric dating of material from cores obtained by the geotechnical drilling program

2.0 Coastal Process Assessment

- 2.1 Collate available meteorologic, oceanographic, bathymetric and sediment information relevant to the assessment of sediment transport processes and shoreline movement
- 2.2 Interpret field observations for indicators of recently active coastal processes (e.g. shoreline scarping or headward migration of tidal creeks)
- 2.3 Review historical aerial photographs, aerial reconnaissance and information from other associated development studies to inform assessment of recent and ongoing coastal development processes
- 2.4 Assess bathymetric surveys to identify seabed features characteristic of sediment transport processes

3.0 Stratigraphic & Chronologic Investigation

- 3.1 Advise on sampling locations to determine the stratigraphy and chronology of (a) the chenier sequence forming the cusate foreland at Entrance Point; and (b) the Hooley Creek mudflat. It is anticipated that this sampling will be completed as part of the geotechnical drilling program
- 3.2 Should offshore cores be taken, advise on suitable sampling locations. These would be appropriate on the seaward margin of any sharp breaks on the shelf pavement structure
- 3.3 Laboratory inspection of cores obtained from the drilling program to obtain samples suitable for radiometric dating, and to describe the stratigraphy of the major features (ANSTO)
- 3.4 Radiometric dating of relevant samples (ANSTO)
- 3.5 Collation of geomorphic, stratigraphic and chronologic data to develop a conceptual model of coastal and deltaic development through the late Holocene



8. Glossary

Arcuate Shore: a shore with an arc-shaped, concave plan form, often comprised of a sandy beach between two erosion resistant features which provide structural control (e.g. rocky headlands).

Avulsion: rapid abandonment of a river channel and the formation of a new river channel. Avulsion usually occurs during flood conditions where river or channel banks are breached, and the hydraulic resistance of the new channel is less than the previous channel. The 'new' channel may actually be an old river channel that was previously abandoned (cf: *palaeo-channel*). This commonly produces delta switching when avulsion occurs in a deltaic landscape.

Back-barrier flats: the flat area, often marshy and populated with low vegetation, on the bay or lagoon side of a barrier island (USACE).

Barrier Island: a detached portion of a barrier beach between two inlets. It commonly has dunes, vegetated areas and swampy terrain extending from the beach into the lagoon.

Beach Ramp: Sloping platform of beach rock, formed by induration (cementation) at the seawater-groundwater interface.

Berm: A nearly horizontal part of the beach or backshore formed by the deposit of material from wave action. Some beaches have no berm, others have one or several, typically related to different tidal or storm surge levels. (USACE)

Bi-modal: the data set has two modes, or two equally most common values.

Chenier: a discrete, elongated, vegetated marine beach ridge, comprised of sand or shell, which is stranded on a coastal mudflat or marsh, roughly parallel to a prograding shoreline. When cheniers are distributed across a wide plain, that feature is called a 'chenier plain' (OzCoasts)

Chenier Spit: a chenier that is joined to the mainland on one end but not the other, thus forming a spit.

Coalescing River Deltas: Two or more river deltas that are fused or joined together to form one delta.

Cuspate Foreland: (or cusped spit) the coastal convexity (in plan form) developed in the lee of a shoal or offshore feature by waves that are diffracted and/or refracted around both sides of the offshore feature. Elongated features may be referred to as cusped spits. If the foreland links the feature to the mainland reaches, it is a tombolo.

Delta (river): a landform comprised of branched or interleaved channels and alluvial deposits occurring at the mouth of a river, due to high riverine sediment supply.

Delta Switching: relocation of the primary deposition zone of a river delta which occurs through rapid change of deltaic channels close to river mouth. Commonly this involves narrowing of the primary channel and expansion of a secondary (smaller) channel. Delta switching may be related to response to flood flows, channel avulsion or delta migration.

Distributary Fans: Fan shaped deposits of sediments protruding from the ends of a tidal channel. Deposits protrude from the mouth if sediment transport is outward or ebb



dominated, whereas the deposits may intrude from the upper reaches of the tidal creek if sediment transport is inward or flood dominated.

Fetch: Length of water over which wind stress acts to create seas and swell. In general, the longer the fetch distance, the greater the potential to create larger waves.

Gorge: A deep channel cut into underlying bed material by the erosional action of a river or tidal channel.

Induration: The process of becoming hard. In geomorphic terms, this is generally associated with the calcification of marine sediments to form cohesive or sedimentary rock deposits.

Isostasy: Vertical movement of the earth's crust, creating regional relative sea level rise or fall.

Lithified Chenier: a chenier that has become cemented through a combination of induration and compaction.

Littoral drift (littoral transport): movement of beach sediments in the littoral zone by waves and currents. It is generally dominated by movement parallel to the shore (longshore drift) although it may sometimes have a cross-shore component.

Littoral zone: A general term for the coastal zone influenced by wave action.

Madden-Julian Oscillation: this is a periodic enhancement of rainfall over the Australian tropics, which progresses across tropical latitudes roughly every 30-50 days, associated with eastward movement of large-scale atmospheric circulations near the equator. Satellite cloud loops and atmospheric pressure changes can signal passage of the wave over Australia, signalling a burst in monsoon (rainfall) activity during the tropical wet season (BOM website).

Mode: In a data set, the mode is the most common value.

Overbank Basin: An area outside the stable river banks that may be filled with water when the river overtops its banks, and retains water when most other floodwaters have receded.

Palaeochannels (palaeo river channels): channels where the river previously flowed prior to the present flow path.

Recurved Spit: a spit structure that curves shoreward at its end.

Rock pavement reef (submarine platform): an extended area of near surface rock, commonly limestone, with a horizontal or gradually inclined upper surface. They are usually beach rock pavements that were formed during periods of lower sea level.

Salient: a bulge in the coastline projecting towards an offshore island, breakwater, reef or shoal, but not connected to it as in the case of a tombolo. Developed by a local slowing of longshore drift caused by wave diffraction and refraction.

Shoal: a detached mound of any material (except rock or coral), typically composed of sand, silt or small pebbles that has a relatively shallow depth. Similar continental or insular shelf features of greater depths are usually termed banks. Shoals may develop from a detached portion of a deltaic or tidal spit.

Sinuuous: Curved or curving in and out; a 'wavy' line.



Slope breaks: A sudden change in the slope of the continental shelf.

Southern Oscillation: An oscillation in air pressure between the tropical eastern and western Pacific Ocean waters. The strength of the oscillation is measured by the Southern Oscillation Index (SOI), which is computed from fluctuations in the surface air pressure difference between Tahiti and Darwin. The oscillation does not have a specific period, but episodes (sustained longer than 5 months) occur every three to eight years and lasts nine months to two years. The oscillation is related to changes in ocean temperatures and the intensity of trade winds.

El Niño episodes are associated with negative values of the SOI, meaning that the pressure at Tahiti is relatively low compared to Darwin. Low atmospheric pressure tends to occur over warm water and high pressure occurs over cold water, in part because deep convection over the warm water acts to transport air. El Niño episodes are defined as sustained warming of the central and eastern tropical Pacific Ocean. This results in a decrease in the strength of the Pacific trade winds, and a reduction in rainfall over eastern and northern Australia. Conversely, La Niña episodes are associated with *positive values* of the SOI and are accompanied by stronger Pacific trade winds and warmer sea temperatures to the north of Australia. Waters in the central and eastern tropical Pacific Ocean become cooler during this time.

Sub-monsoonal (or arid sub-tropical): the climatic region found adjacent to the tropics, generally distinguished by rainfall, and considered to be beyond the normal extent of monsoonal rain systems.

Surge: The water level above normal expected tide levels for that point in time, usually due to a combination of pressure, wind and wave setup during a storm or cyclone.

Unimodal: In a data set, there is only one mode, or one most common value.

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Appendix P2

Coastal Impacts Modelling

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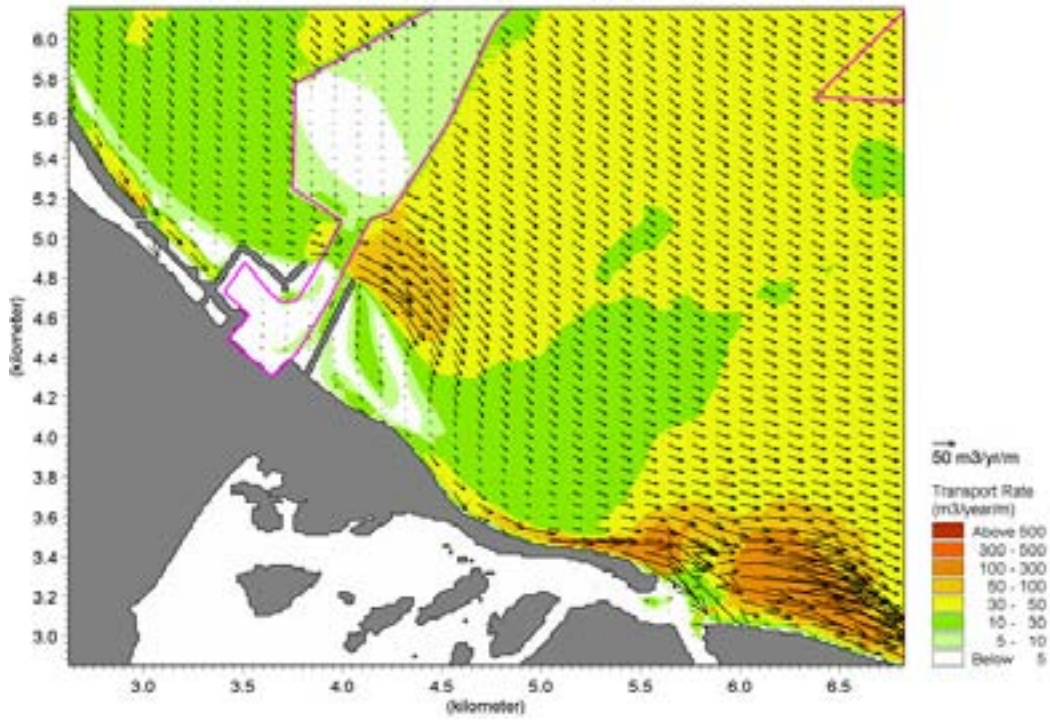
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Wheatstone Project

Coastal Impacts Modelling



Chevron Australia Pty Ltd

May 2010



Wheatstone Project
Coastal Impacts Modelling

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1.0 INTRODUCTION

1.1 Project Description

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 Wheatstone Project is referred to as “the Project” and the Ashburton North Strategic Industrial Area (Ashburton North SIA) is the proposed site for the LNG and Domgas plants. The Project will require the installation of gas gathering, export and processing facilities in Commonwealth and State Waters and on land. The LNG plant will have a maximum capacity of 25 million tonnes per annum (MTPA) of LNG.

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

1.2 Document Flow

A large number of documents and reports are produced for the Environmental Assessment of the Wheatstone Project. Key documents produced for the modelling and dredge plume and coastal impacts assessments are listed below:

- Dredge Spoil Modelling (DHI 2010a)
- Tolerance Limits Report (DHI 2010b)
- Dredge Plume Impact Assessment (DHI 2010c)
- Coastal Modelling and Impact Assessment (DHI 2010d)

The present assessment (highlighted) documents the modelling carried out in support of the coastal assessment. The main coastal assessment report was completed by Damara WA (2010).

1.3 Purpose of Present Document

The Project involves dredging of approximately 40 million m³ of material for installation of berths and turning basins at an inshore materials offloading facility (MOF) and a product loading facility (PLF) as well as access to these through an approximately 15 km long navigation channel. The potential coastal impacts have been rated as a key environmental risk for the project.

Numerical modelling of the coastal processes is a key component in the assessment and quantification of existing conditions and potential impacts. The present document reports the findings of the model study with an initial morphological impact assessment. This provides input to the overall coastal impact assessment.

A range of models, including wave, current and sediment transport models for both littoral sediment transport and two dimensional (2D) transport processes have been established for the site. A data assessment and detailed description of the geomorphology is provided in the coastal assessment report (Damara WA 2010). Further model related data assessment as well as the base model performance was documented in DHI (2010a), and only additional modelling for the coastal assessment is documented in the present report.



1.4 Study Scope

The numerical study for the coastal processes and impact assessments addresses several aspects related to both direct/indirect and short/longer term impacts on the coastal morphology and the lagoon systems.

Key components covered in the assessment include:

- Overall sediment budget including direct impacts by the MOF on the littoral transport and adjacent coastal morphology
- Impacts to the Hooley Creek entrance
 - Due to the MOF
 - Due to reclamation and impacts to tidal prism and tidal flushing



2.0 SITE OVERVIEW & PROBLEM ASSESSMENT

A detailed description of the coastal geomorphology is provided in Damara WA (2010), while descriptions of bathymetry, met-ocean and other relevant data are provided in Global Environmental Modelling Systems (GEMS) (2010) and Damara WA (2010). This section provides a brief overview of the site, with focus on the local morphology and potential impacts of the Project, on the existing morphology. The overview establishes the background for the assessment of modelling requirements for the coastal impact assessment.

2.1 Site Overview

The Project is located along a generally north northwest facing section of the Pilbara coastline between the North West Cape and the Dampier Peninsula (Figure 2.1; Figure 2.5).

2.1.1 Wave Exposure

Waves are the fundamental driver for coastal sediment transport and morphology. Establishing wave field characteristics for a given site is therefore often a prerequisite in the understanding of the coastal morphology of the site. On a regional scale, the area is exposed to the Indian Ocean with a fetch of more than a 1000 km towards Java and the other southern islands of the Indonesian Archipelago to the north, and several thousand kilometres towards the northwest to southwest, (Figure 2.1) The long fetches towards open ocean areas potentially allow large/long waves to reach the shelf break off the site.



Figure 2.1 Google image illustrating Wheatstone site exposure on an ocean scale.

The off-shore wave climate off the site is seen to be dominated by south-westerly and westerly swell from the Southern Indian Ocean and south-westerly wind generated waves (example of



annual wave rose off the North West Cape, Figure 2.3). A less pronounced swell component is observed from the Timor Sea during winter (Figure 2.4). The dominant offshore wave directions are largely parallel to the overall coastline orientation and near-shore depth contours, and the offshore waves thus have to undergo significant refraction before reaching the coastline.

A shallow area with water depths of less than 20 m stretches in the order of 30-50 km perpendicular to the coast at the site. At the Montebello Island group to the north of Barrow Island the shallow waters stretches up to almost 100 km from the mainland coast (Figure 2.5). Numerous small islands, fringing reefs and shoals are found in this shallow area, and the sheltering effect of these combined with large scale refraction and impacts of bottom friction leads to a relatively benign wave climate along the coastline for normal conditions (annual wave rose at the nearshore PLF, Figure 2.6).

Significantly larger waves can be encountered during cyclones, although the shallow area and sheltering effects significantly reduce the wave impacts along the coastline, also during cyclones.

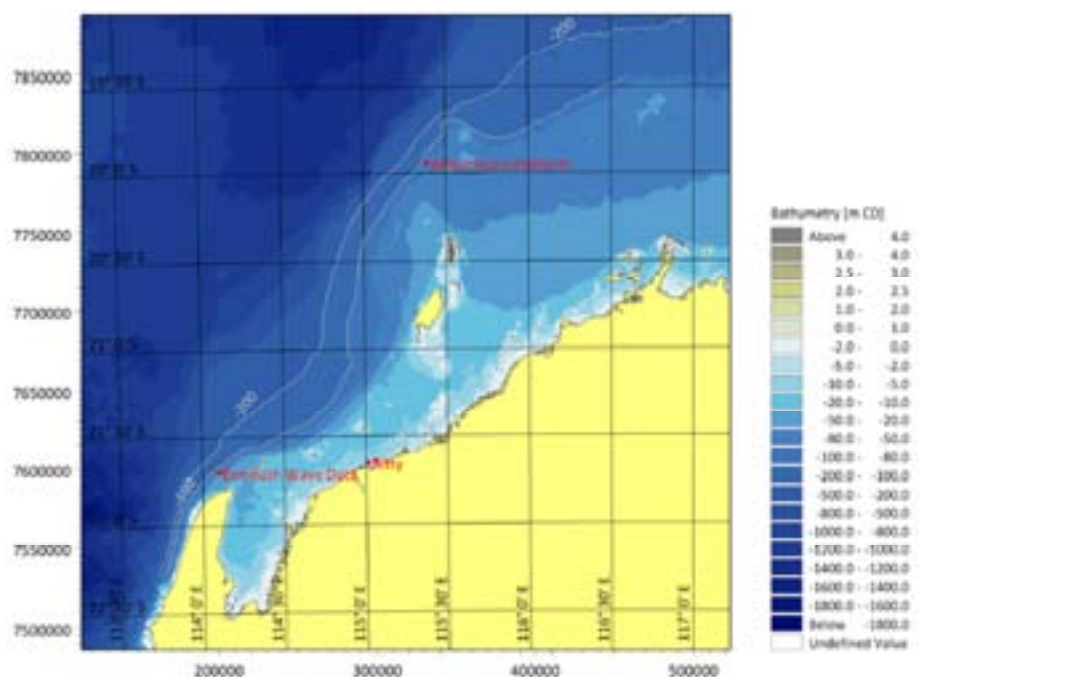


Figure 2.2 Locations of available off-shore wave data off Northwest Cape, Exmouth and at Wheatstone Platform and near-shore data at PLF.

2-3

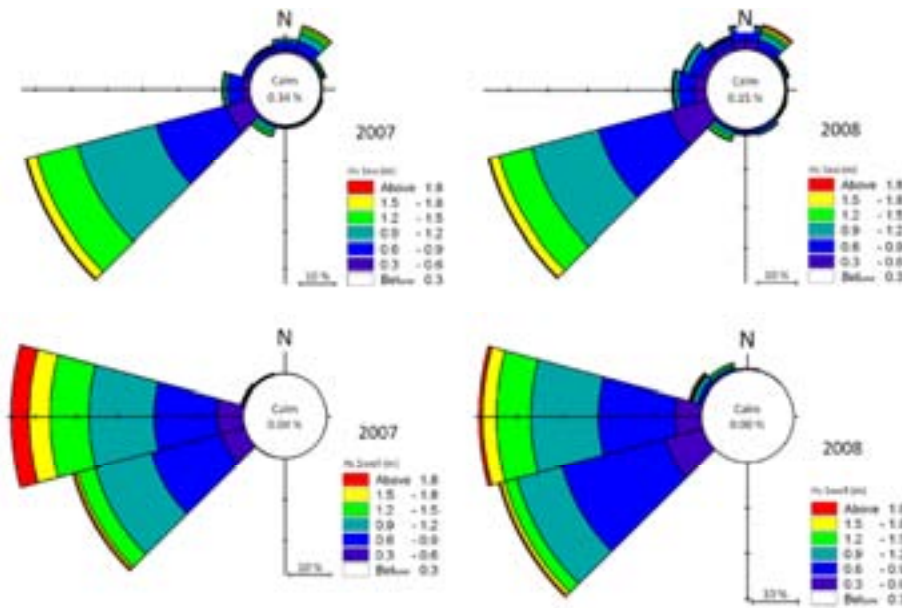


Figure 2.3 Annual wave roses for sea and swell components for 2007 and 2008 based on data acquired from the Department of Transport, Government of Western Australia from the buoy off Northwest Cape, Exmouth, see Figure 2.2 for location.

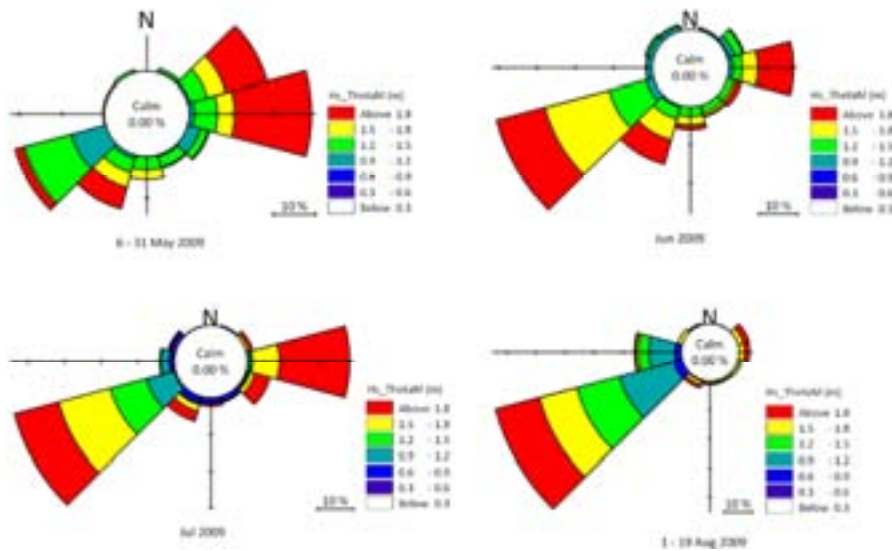


Figure 2.4 Monthly wave roses for data available from Wheatstone Platform, see Figure 2.2 for location. Note that primarily winter months are represented. Significant wave heights for combined sea and swell waves.



Figure 2.5 Sketch of project site along North-northwest facing section of Pilbara Coastline. Light blue coloration indicates depths less than 30m CD. Green areas indicate reefs and rocks drying out at low tide.

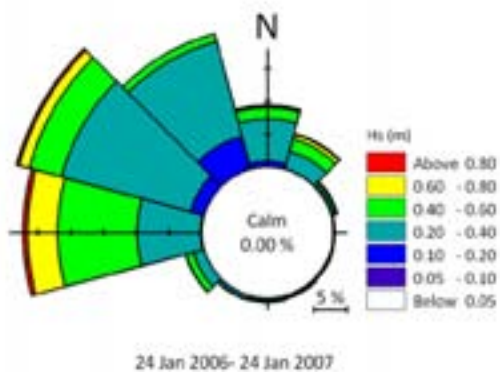


Figure 2.6 Annual wave rose for nearshore data at PLF location, see Figure 2.2. Note different scale compared to off-shore wave roses.

2.1.2 Current Patterns

Currents affecting the site are described in GEMS (2010) and patterns are described further in Section 2.7, based on the detailed modelling. Important notes include:

- The influence of oceanographic currents is insignificant over the shallow nearshore area where tidal and local wind driven currents dominate.
- Spring tidal currents are sufficiently strong to mobilise sediments over a larger area.
- Seasonal winds generate north-easterly directed net current along the coast during summer, and south-westerly directed net currents during winter.



- Wave-driven currents will dominate within the surf zone and determine the morphology of the coastline.
- Tidal currents are maintaining the inlets to the tidal flats open.

2.1.3 Morphology and Sediment Transport

A detailed description of the coastal geomorphology is provided in Damara WA (2010), and only a brief overview of the main transport mechanisms working in the short to medium term is provided here as a background for the model interpretation and assessment.

As described in GEMS (2010), the site is situated along the Pilbara coastline in a coastal cell stretching from Tubridgi Point to Cape Preston (Figure 2.5), with a sub-cell from Tubridgi to Coolgra Point.

The main sediment supplier to the littoral sediment budget along this part of the Pilbara coastline is the Ashburton River, which discharges large quantities of fluvial sediments when in flood. This has shaped the coastline to the southwest of the site with delta formations both at the present river mouth and at the Entrance Point, which is a former discharge location for the Ashburton.

2.1.3.1 Hooley Creek Entrance

The current entrance to the Hooley Creek tidal flats is located in the order of 2 km to the east of the eastern breakwater of the proposed MOF. The outlet location is dynamic as changes in the littoral sediment transport and sediment balance may cause the outlet to shift location over an approximately 1.5 km stretch between the area where the western arm of the Hooley Creek approaches the coastline and up to about the outlet point of Middle Creek. A typical sequence would be that the outlet migrates eastward as the sandspit in front of the entrance grows eastward due to the net eastward littoral transport.

This gradually increases the resistance in the river system as the river channel is extended eastward. A breach of the sandspit and the formation of a new entrance location may occur either due to periodic erosion of the sandspit or a flood event in the creek (or a combination). If the flow resistance through the new entrance is lower than that of the old entrance, then the old entrance will likely rapidly close up.

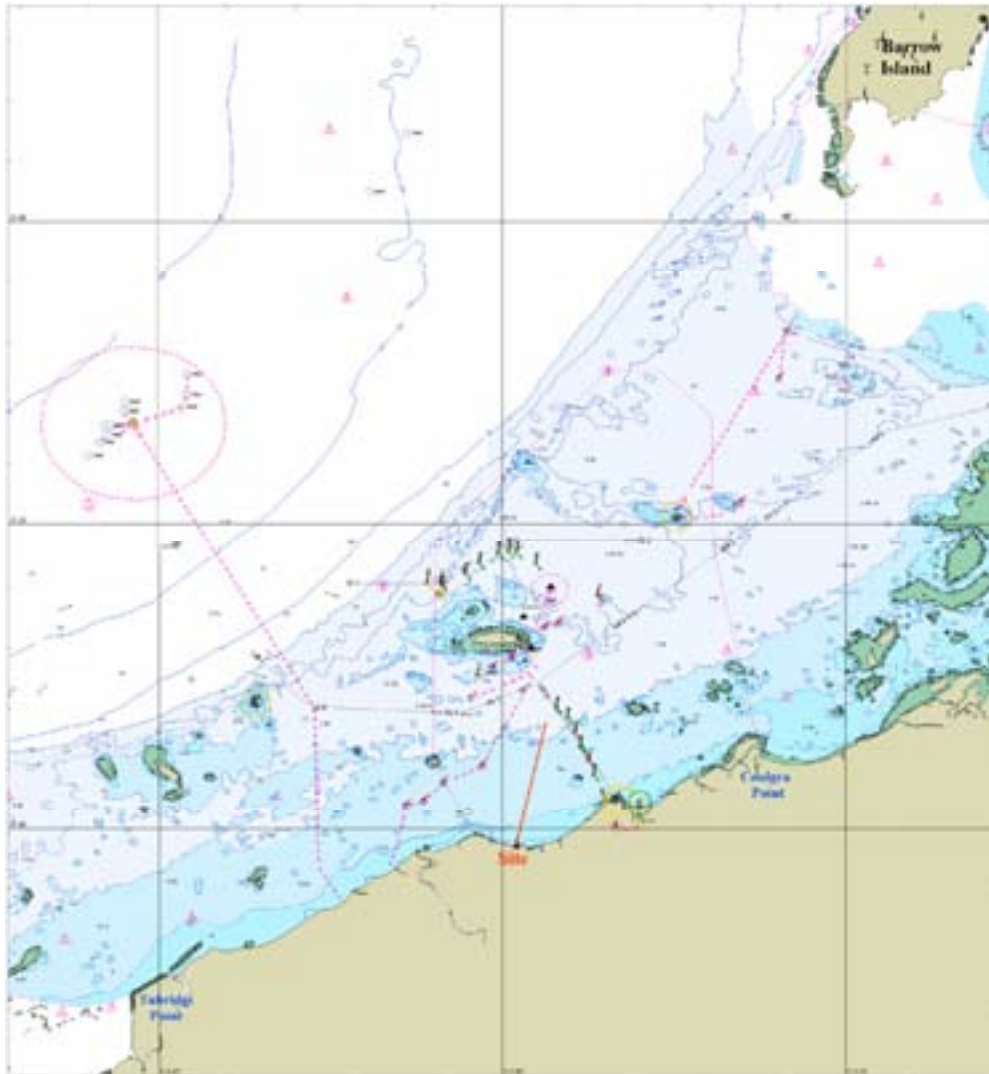


Figure 2.7 Sketch of project site along North-northwest facing section of Pilbara Coastline. Site is located in the coastal sub-cell stretching from Tubridgi Point to Coolgra Point.



Figure 2.8 Google satellite image (June 2006) of coastline to the east of the site with tidal inlets.

2.2 Problem Assessment & Methodology

As described in the previous section, littoral transport takes place in a relatively narrow zone along the coastline with the overall coastline shape and spit formation pointing to a net easterly transport of sand along the coastline.

2.2.1 Coastal Impacts

The MOF will block this transport, which will lead to coastal impacts. The magnitude and rate of the morphological response depends on the magnitude of the littoral transport. The distribution of any impacts along the coastline further depends on the spatial and temporal transport patterns. Key results from the modelling to address the direct morphological impact include quantification of the littoral transport, both in terms of average annual net and gross transport rates, its cross-shore distribution and the intra-annual variations to address the potential impacts on the coastlines on both sides of the MOF. The potential natural sand bypassing of the MOF by littoral sediments needs to be addressed to establish the overall impacts to the existing littoral sediment budget.

2.2.2 Hooley Creek Entrance

The existing entrance to the Hooley Creek tidal area is dynamic in nature as described in Section 2.1.3.1 and documented in Damara WA (2010). The Project may affect the entrance configuration in several ways, with the more direct impact outlined below:

- Changes to the local wave, current and sediment transport patterns caused by the MOF and dredged navigation channel may directly impact the sandspit and entrance stability.



- Changes in the sediment supply caused by the MOF and dredged navigation channel may gradually destabilise the sandspit at the entrance and the entrance delta.
- Reduction in the tidal prism of the Hooley Creek tidal system due to construction of onshore infrastructure. This can reduce the tidal flushing of the western arm and entrance and lead to reduced depths through the entrance.
- Changes to the drainage patterns within the tidal creek system may affect flows within the creek system and through the entrance.

The potential changes to the sediment transport patterns at the entrance location will be assessed through the detailed 2D transport simulations, while the overall changes to the sediment budget will be assessed through the quantification of the annual sediment transport capacities.

An assessment of the impacts of reduction in the tidal prism has been included in the simulations of the detailed flow through the inlet.

Changes to the drainage patterns have not been part of the present scope.



3.0 MODELLING OVERVIEW

The same modelling is used in several component of the overall assessment. This section provides an overview of the coastal modelling components and presentation of sample results, while the main assessments are provided in following Sections.

3.1 Waves

Waves are a key component for the sediment transport in shallow water. Waves are required for:

- Longer time series of waves at selected locations along the coastline to drive the littoral transport model. This should include several years of wave data to provide the temporal distribution over the year as well as the inter-annual variations in waves and littoral sediment transport.
- Shorter scenarios for detailed 2D sediment transport to address potential sediment bypass of the MOF as well as the sediment influx to the dredged channel.

For the longer term time series of waves, the waves are extracted outside the surf zone along the coast, and the model is thus not required to resolve the surf zone in great detail. It is noted that due to the irregular bathymetry and the off-shore waves being almost parallel to (or even directed off-shore compared to the local coastline orientation) the waves undergo considerable transformation to reach the surf zone. As this process is not well represented in the one-line littoral transport model, it is important to extract the waves close to the surf zone.

3.1.1 Model Setup

The numerical wave transformation modelling has been carried out using DHI's MIKE 21 Spectral Wave (SW) model with its fully spectral formulation. The fully spectral formulation is based on the wave action conservation equation as described in Komen *et al.* (1994) and Young (1999), where the directional-frequency wave action spectrum is the dependent variable. The model includes the phenomena of shoaling, refraction, bottom dissipation, wave breaking, wind generation and directional spreading.

3.1.2 Unstructured Mesh

The wave model has a variable resolution and has been established with progressively finer grid resolution closer to the shore and around island and shoals where the impacts of local bathymetrical features need to be resolved (Figure 3.1; Figure 3.2). The mesh was established based on the extensive bathymetry data base established for the project as reported in GEMS (2010).

Figure 3.3 shows the unstructured mesh applied for the offshore wave transformation in finest resolution for both existing and "layout 1" based on the CUCA 3.2c layout of the MOF and dredged areas. It is noted that the mesh is extended landward to ensure that all water areas are included at high tide.

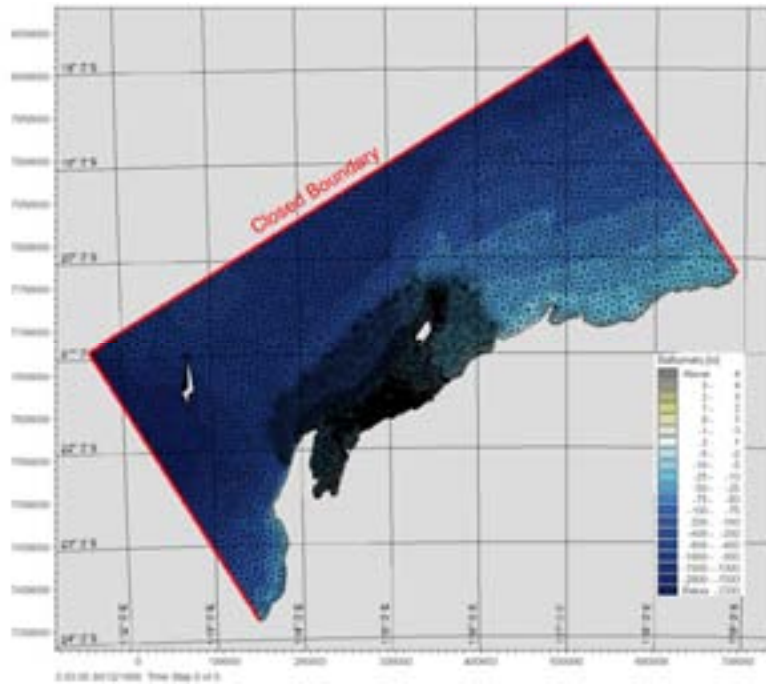


Figure 3.1 Unstructured mesh established for wave transformation; The mesh resolution increases when moving towards main features that will play a role in terms of sheltering. (e.g. Islands, shoals) as well as in the vicinity of the study area.

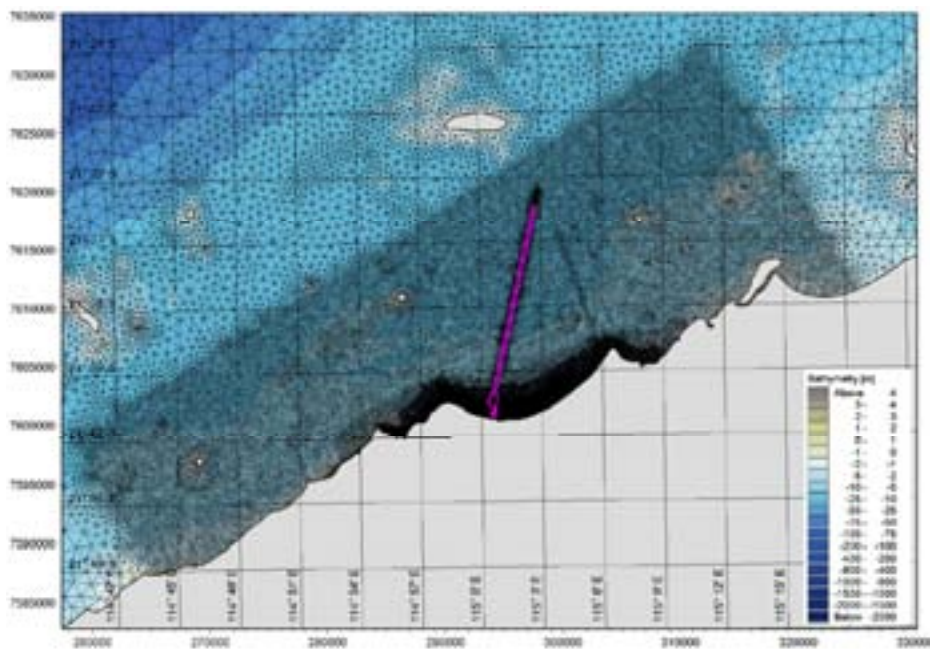


Figure 3.2 Zoomed-in view of mesh in the vicinity of the site with the location of the dredged channel.

3-3

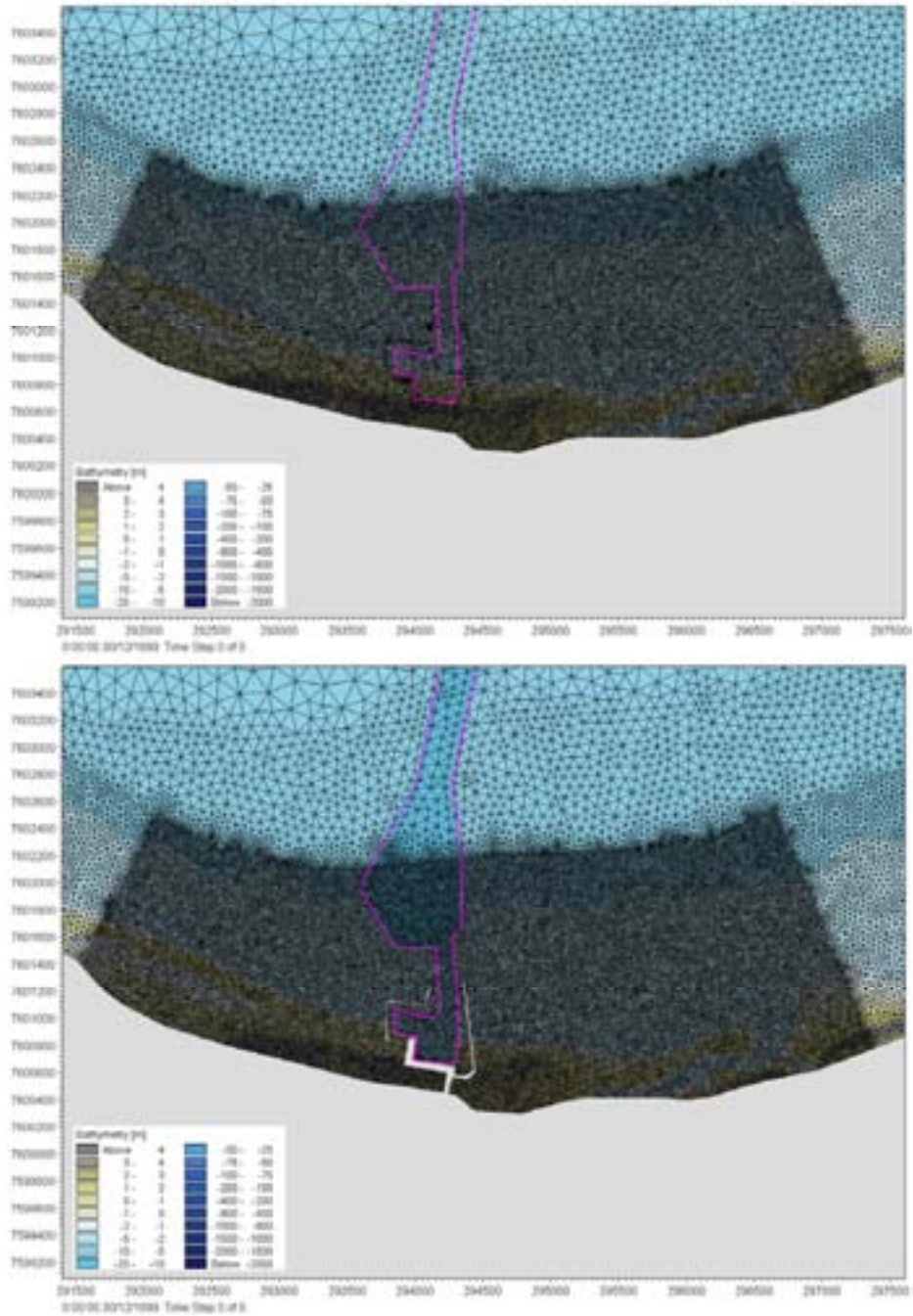


Figure 3.3 Detailed view of finest mesh resolution for the existing (top) and proposed breakwater and channel configuration according to CUCA 3.2c (bottom)



3.1.3 Wind-generated Waves

As waves propagate from the offshore region towards the site, they lose energy through dissipation over offshore shoals, strings of coral reefs located near the site and through large-scale wave refraction within the shallow waters. Consequently, energy input from the wind becomes increasingly important. Therefore, for sea waves, it is important to include wind in the nearshore wave simulations.

The Project area has dominant summer and winter conditions. Due to the variable climatic component, a number of scenarios with best estimates of “representative” and “strong” conditions are required. Based on this, two wave conditions have been modelled, as per outlined in Table 3-1.

Table 3-1 Climatic scenarios

Condition Period	Period
Summer	17 th – 27 th January 2007
Winter	9 th – 19 th June 2007

3.1.4 Water Levels

The water level becomes important for the transformation of wave conditions to nearshore areas as higher water levels result in less wave energy dissipation due to depth-dependency of bottom friction and wave breaking. Water levels derived through tidal predictions from a tidal station nearest to the study area (predicted water levels at Onslow) has been applied in the SW model. The tidal range at this station is shown in Figure 3.4 for a period of one year.

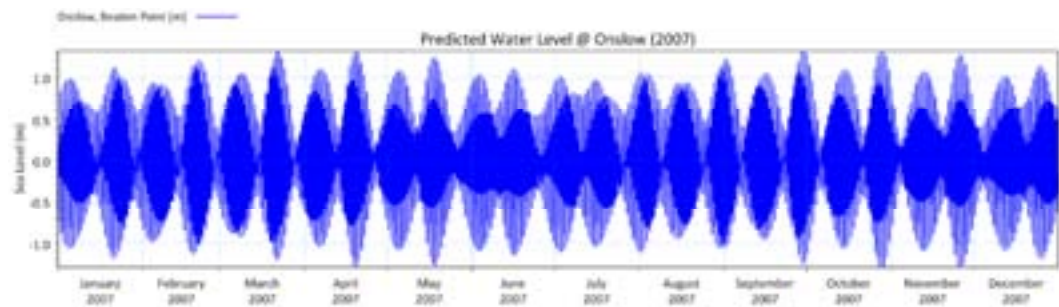


Figure 3.4 Predicted water level from Onslow, Beadon Point

3.1.5 Wave Model Results

The shallow water depths in the vicinity of the site restrict the propagation of waves. For similar offshore waves, the waves at the site vary with the water levels over a tidal cycle. This effect is included in the simulations as the waves are modelled as a time series with the water level varying according to the tide. This is illustrated in Figure 3.5 and Figure 3.6 which shows regional wave fields for high water levels and low water levels. Regional wave fields are shown for both summer and winter conditions.

Figure 3.7 to Figure 3.10 shows detailed close up views for the same events at the site.

The simulation of representative summer and winter conditions are based on the setup outlined in GEMS (2010) and are described in Section 5 with further refinement of nearshore areas to capture and resolve surf zone processes. Comparisons of wave conditions during summer with and without

3-5



Project infrastructure in place are shown in Figure 3.11 (for high tides) and Figure 3.12 (for low tides). The following main impacts are noted:

- Water levels have a marked influence on the wave conditions with more wave energy penetrating to the nearshore area during high tide conditions.
- The MOF has a significant sheltering effect to the east of the MOF during typical summer conditions.
- The dredged navigation channel and PLF basin further adds to the sheltering effect east of the MOF by “trapping”, refracting and reflecting waves.

The total affected sheltering zone stretches in the order of 1.5 km to the east of the eastern MOF breakwater during summer conditions.

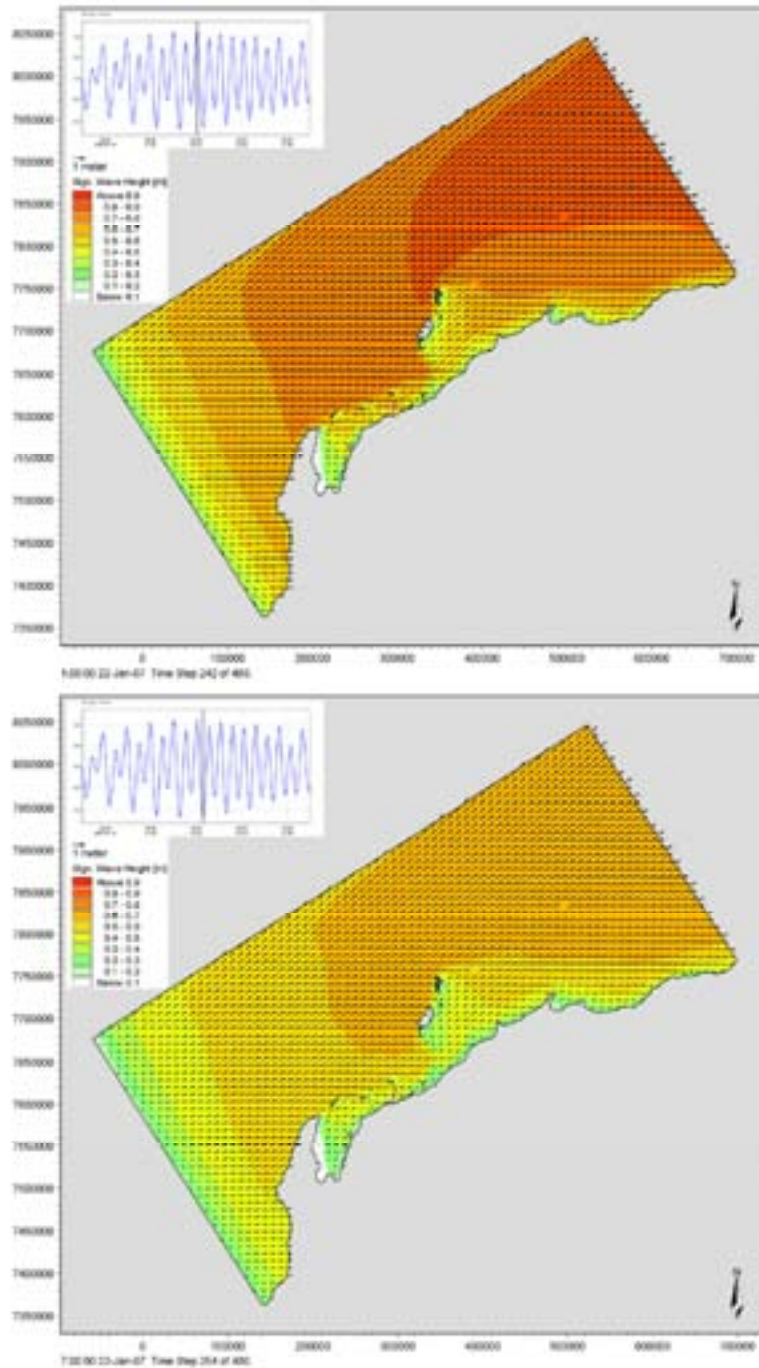


Figure 3.5 Overview of instantaneous simulated wave field during summer high tide (top) and low tide (bottom).

3-7

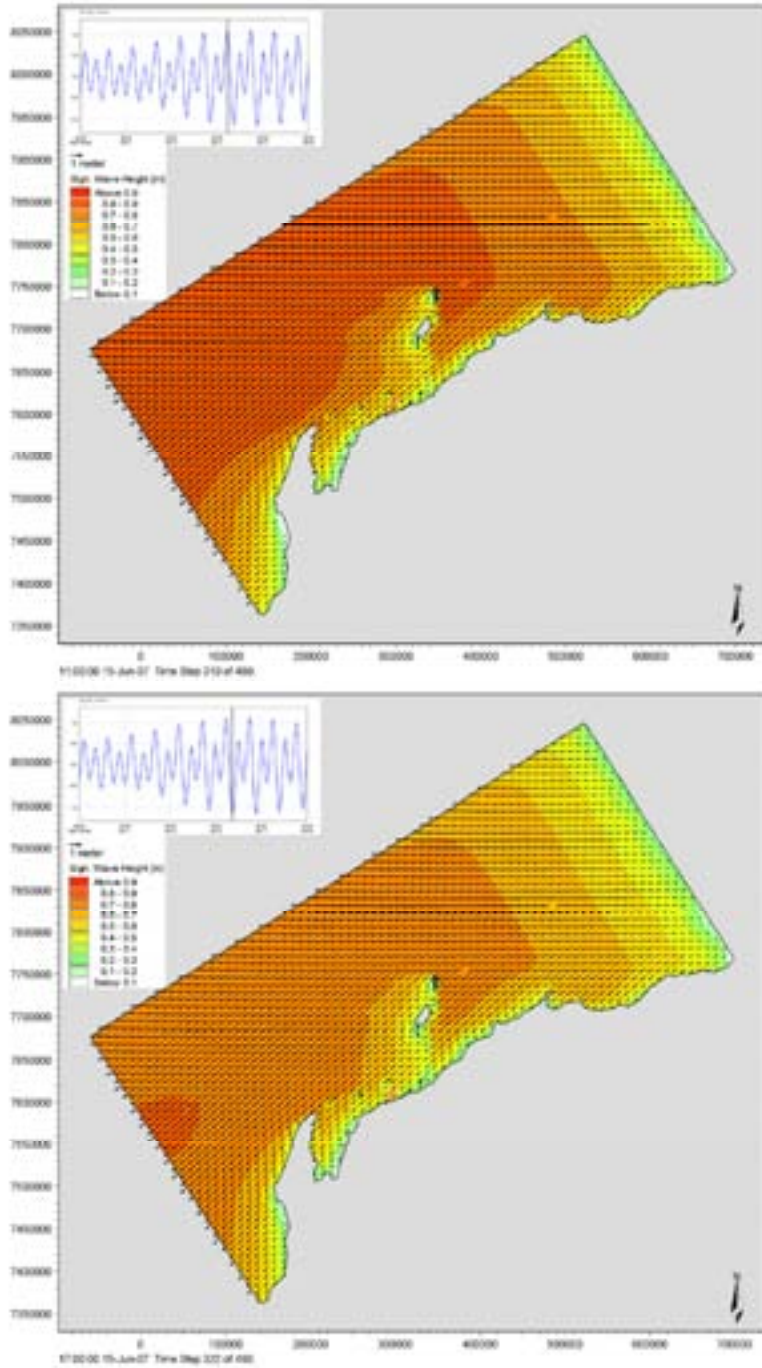


Figure 3.6 Overview of instantaneous simulated wave field during winter high tide (top) and low tide (bottom).

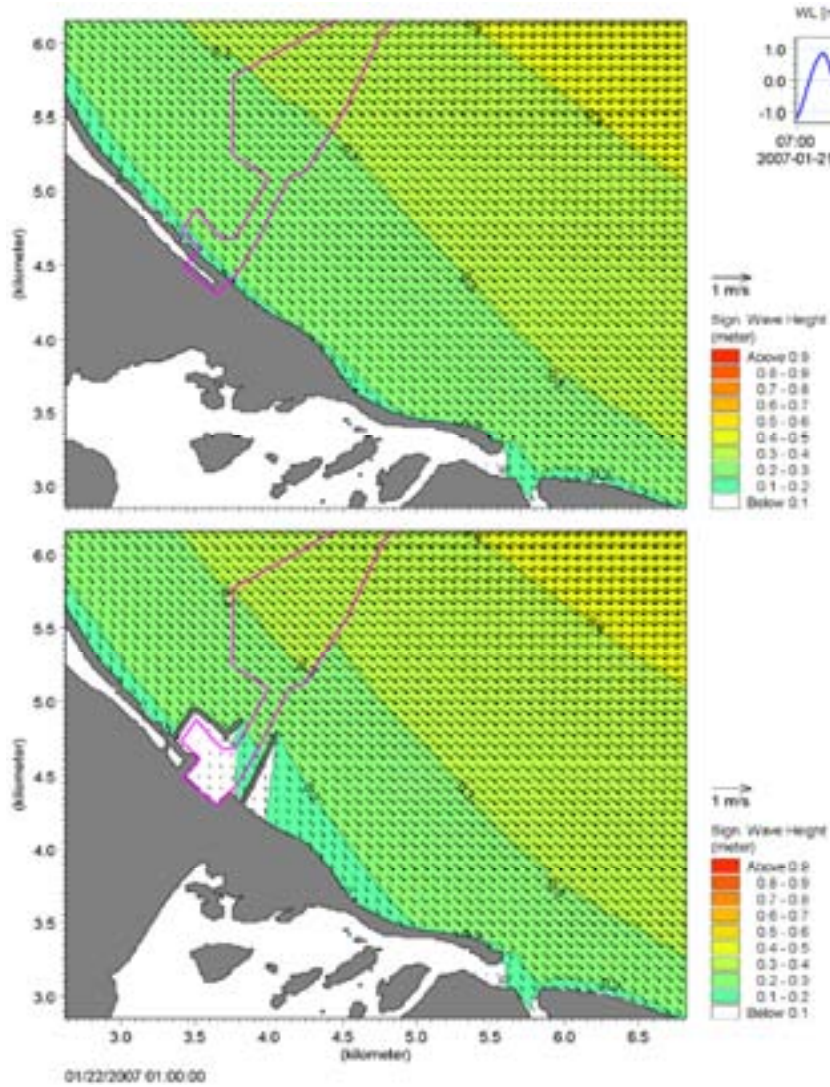


Figure 3.7 Detailed nearshore wave field during summer high tide for existing (top) and proposed layout (bottom).

3-9

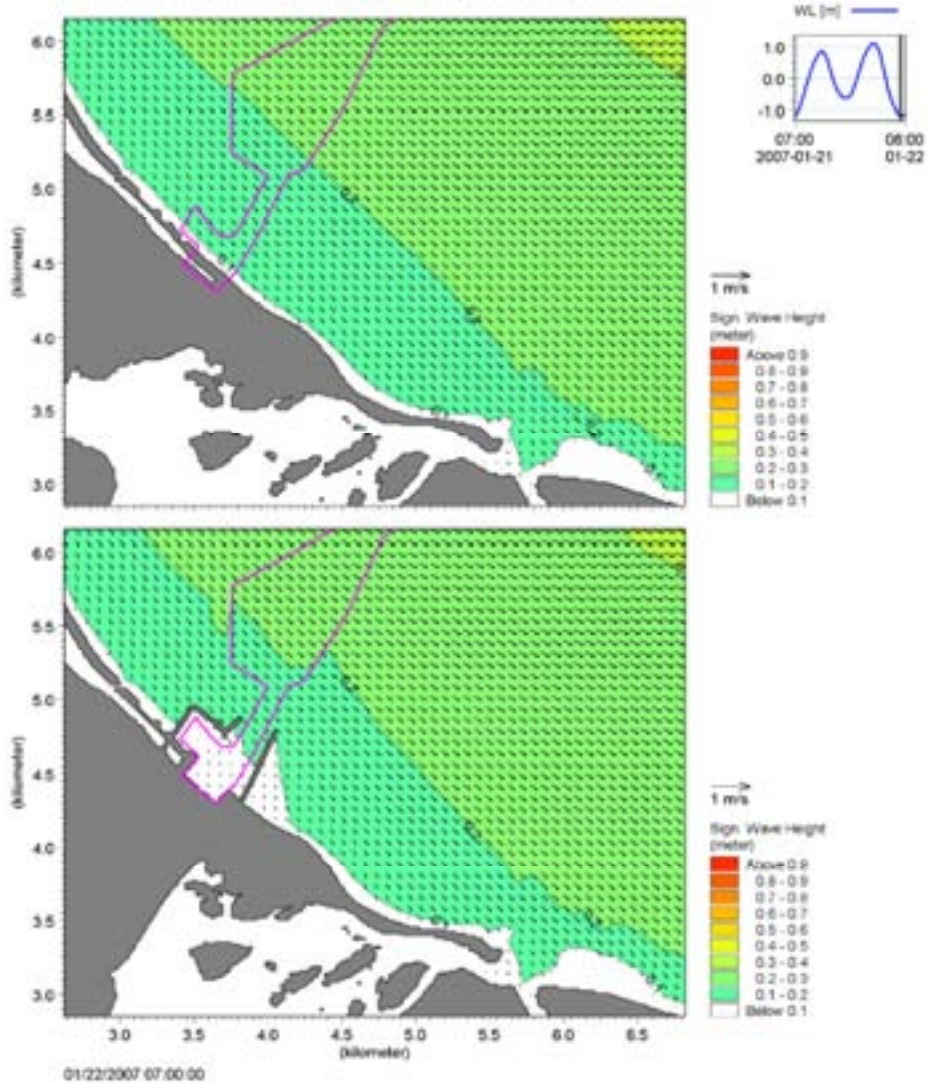


Figure 3.8 Detailed nearshore wave field during summer low tide for existing (top) and proposed layout (bottom).

3-10

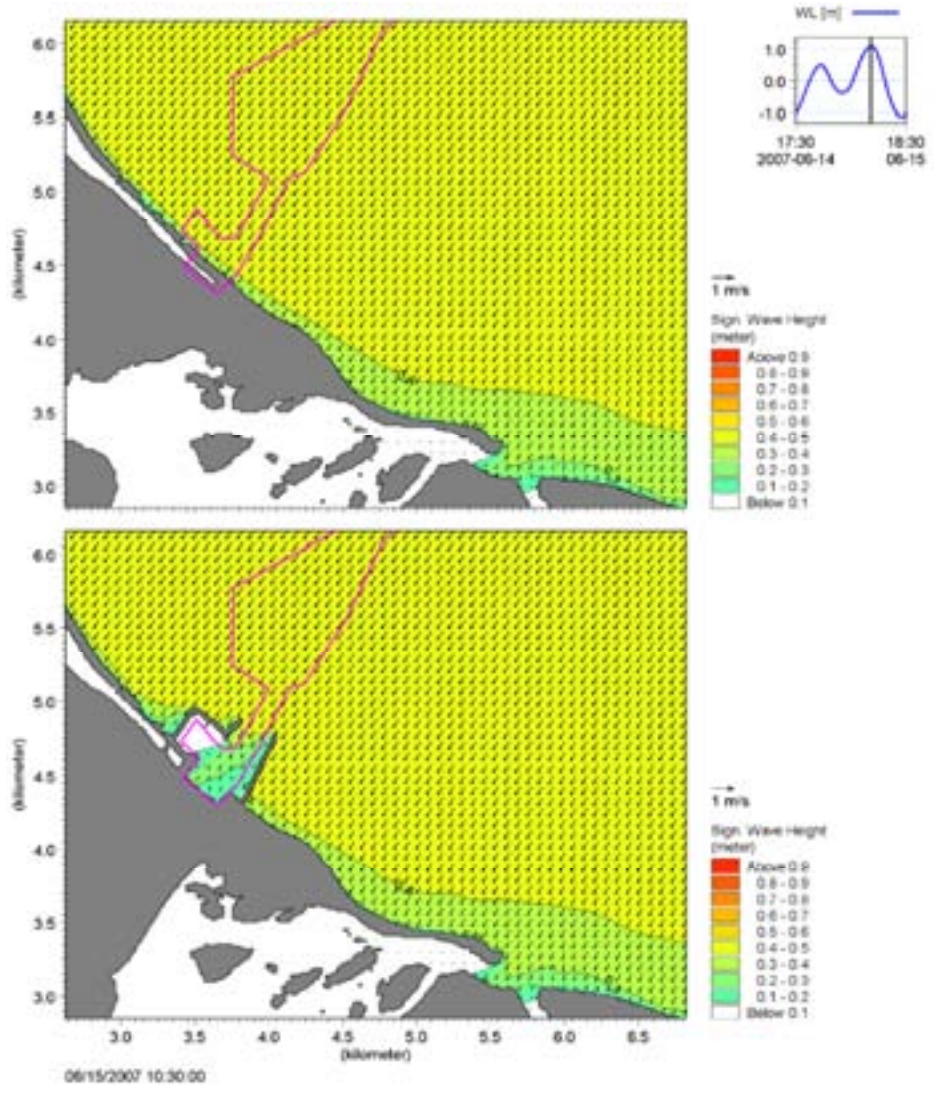


Figure 3.9 Detailed nearshore wave field during winter high tide for existing (top) and proposed layout (bottom).

3-11

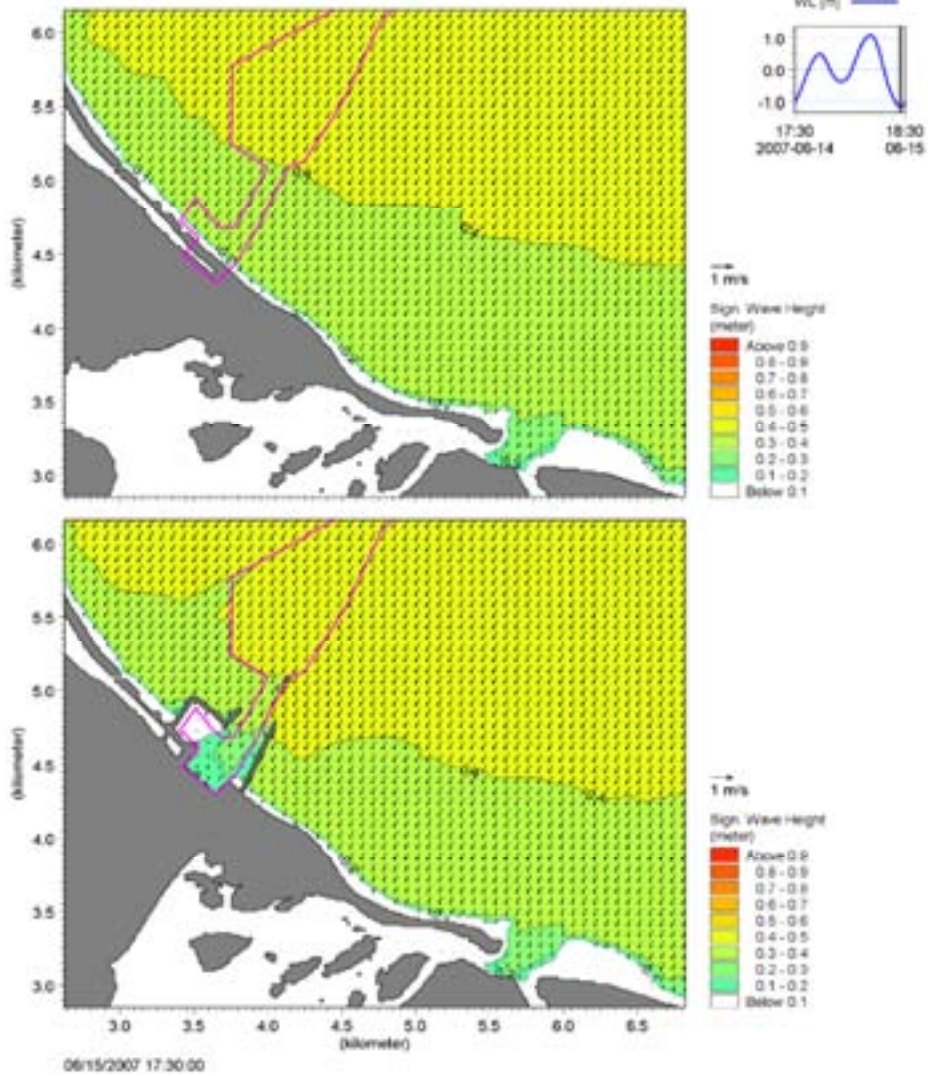


Figure 3.10 Detailed nearshore wave field during winter low tide for existing (top) and proposed layout (bottom).

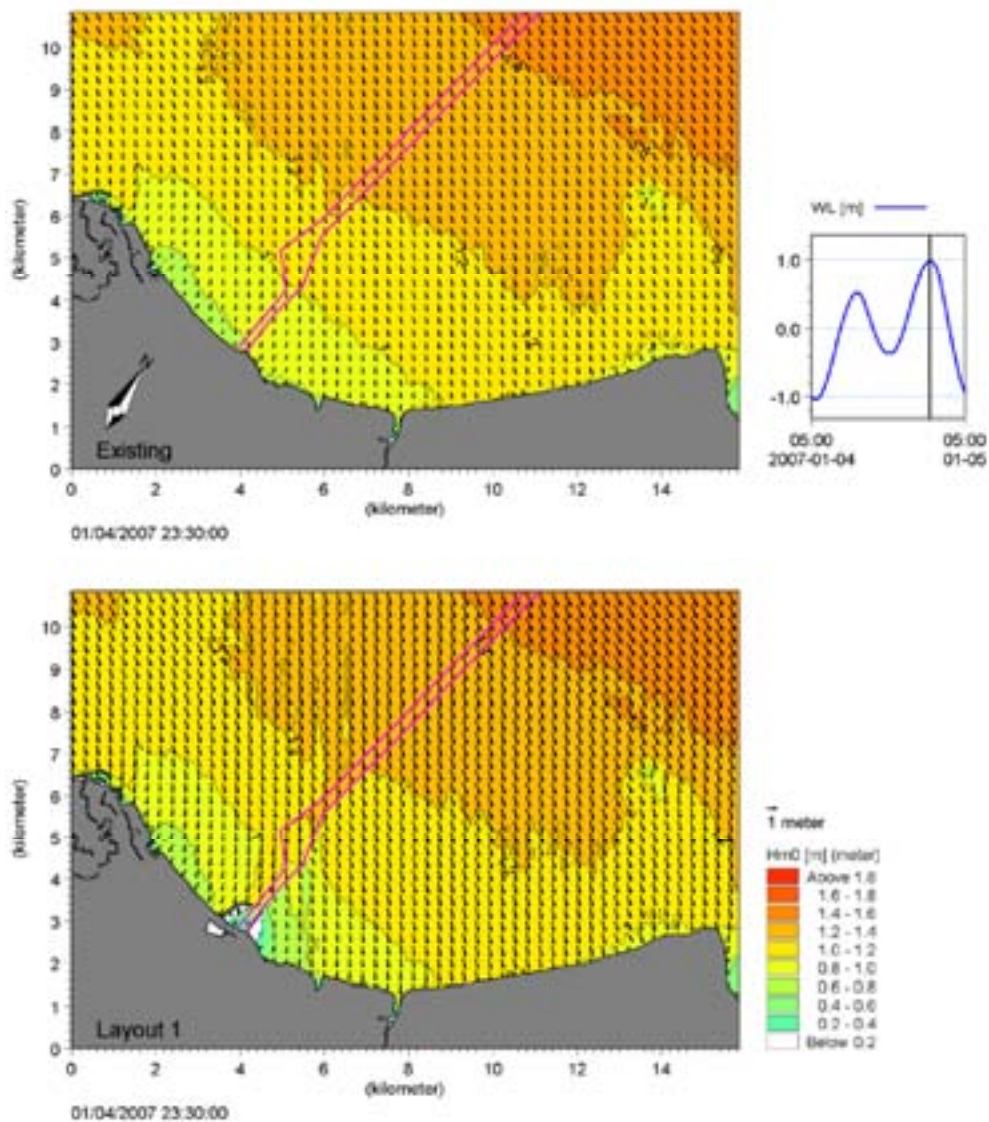


Figure 3.11 Comparison of wave fields at high tide during summer for existing conditions (top) and with the proposed MOF and dredged PLF basin and PLF approach channel in place (bottom) for rougher summer wave conditions.

3-13

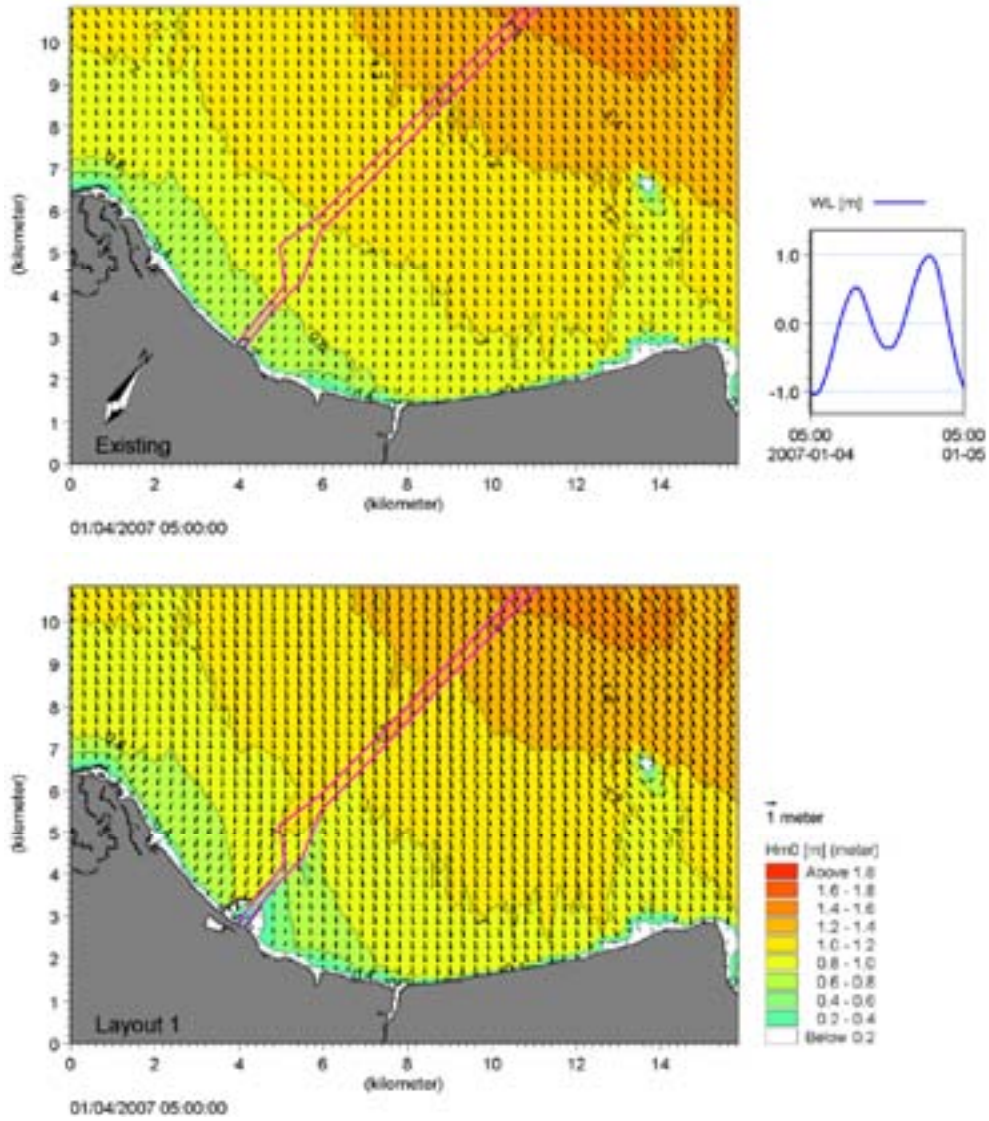


Figure 3.12 Comparison of wave fields at low tide during summer for existing conditions (top) and with the proposed MOF and dredged PLF basin and PLF approach channel in place (bottom) for rougher summer wave conditions.



3.2 Hydraulic Modelling

All hydraulic modelling is carried out based on the Regional Model Complex established for the modelling of dredge material. This model complex has been extensively calibrated and verified regionally and close to the site. Model setup, calibration and validation is documented in GEMS (2010).

3.2.1 Regional Model Complex

The Regional Model Complex has been extensively documented in GEMS (2010), and only a very brief overview will be provided here for reference.

3.2.1.1 Boundary Conditions

The regional model is driven by water levels on the open boundaries shown in yellow lines in Figure 3.13. Time series of water levels varying along the boundaries have been derived from the global tide model (KMS¹).

Using the KMS data has the big advantage over using local tide constituents that the variations along the boundaries can be included in the boundary conditions. Predictions from local tidal constituents have been used for model verification.



Figure 3.13 Open boundaries for the Regional 2D modelling derived from the KMS global tide model.

¹ The global tide model data representing the major diurnal (K1, O1, P1 and Q1) and semidiurnal tidal constituents (M2, S2, N2 and K2) with a spatial resolution of 0.25° × 0.25° based on TOPEX/POSEIDON altimetry data. For more information see e.g. Ole Baltazar Andersen (1995), Global ocean tides from ERS 1 and TOPEX/POSEIDON altimetry, J. of Geophys. Res., 100, C12, p. 25249-25260. Please note that the data is mainly applicable in relatively deep water, say, depths greater than 20 meter.



3.2.1.2 Model Calibration and Validation

For calibration of the regional hydrodynamic model, comparison of water levels has been performed using predicted water levels at the 16 primary tidal stations located within the model domain at the locations shown in Figure 3.14. The model has been set up without wind to reproduce the pure tidal signals obtained from predictions based on tidal constituents (Admiralty Tide Tables 2004).

This is the initial phase to ensure the basic boundary conditions of the model domain are sound and performing well. Figure 3.15 to Figure 3.17 show comparisons between simulated and predicted water levels (based on constituents) at the various stations.

The model generally performs very well throughout the area with only very minor differences in amplitude. This shows that the basic tidal boundaries derived from the KMS model provide a good representation of the dominant tidal constituents, and that the model can resolve the progression of the tidal wave throughout the model domain. It is noted that there are significant changes in tidal amplitude within the model domain, and these variations are reproduced accurately by the model.

Comprehensive verification against available current meter stations have been carried out with a few examples from the stations close to the site (see Figure 3.18) shown in Figure 3.19 to Figure 3.27. There are times and areas with some discrepancies between simulated and measured current speeds and directions, but considering the complexity of the mixed tidal and wind generated current fields, the model performs very well and the calibration is considered fully adequate for the intended applications.

RMS errors for all stations are less than 0.1 m/s as specified by the standard set in Foundation for Water Research (1993).

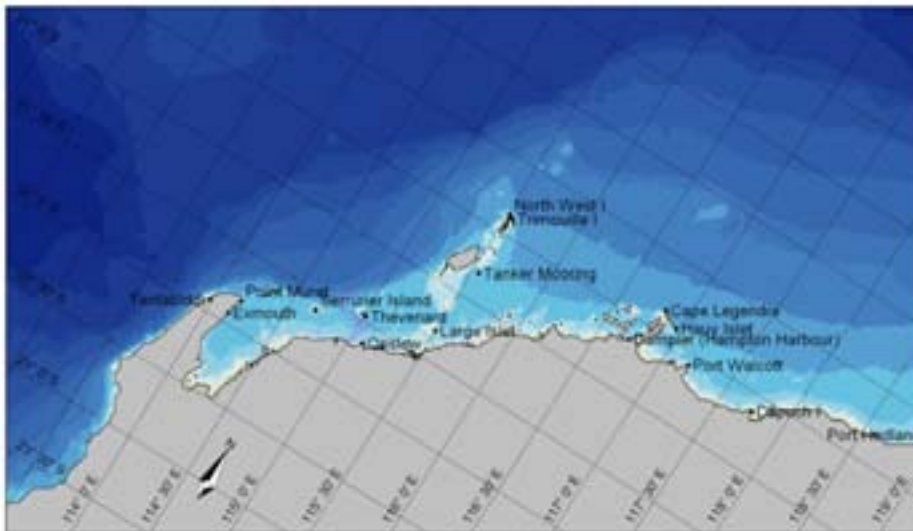


Figure 3.14 Locations of tidal stations used for model calibration and validation.

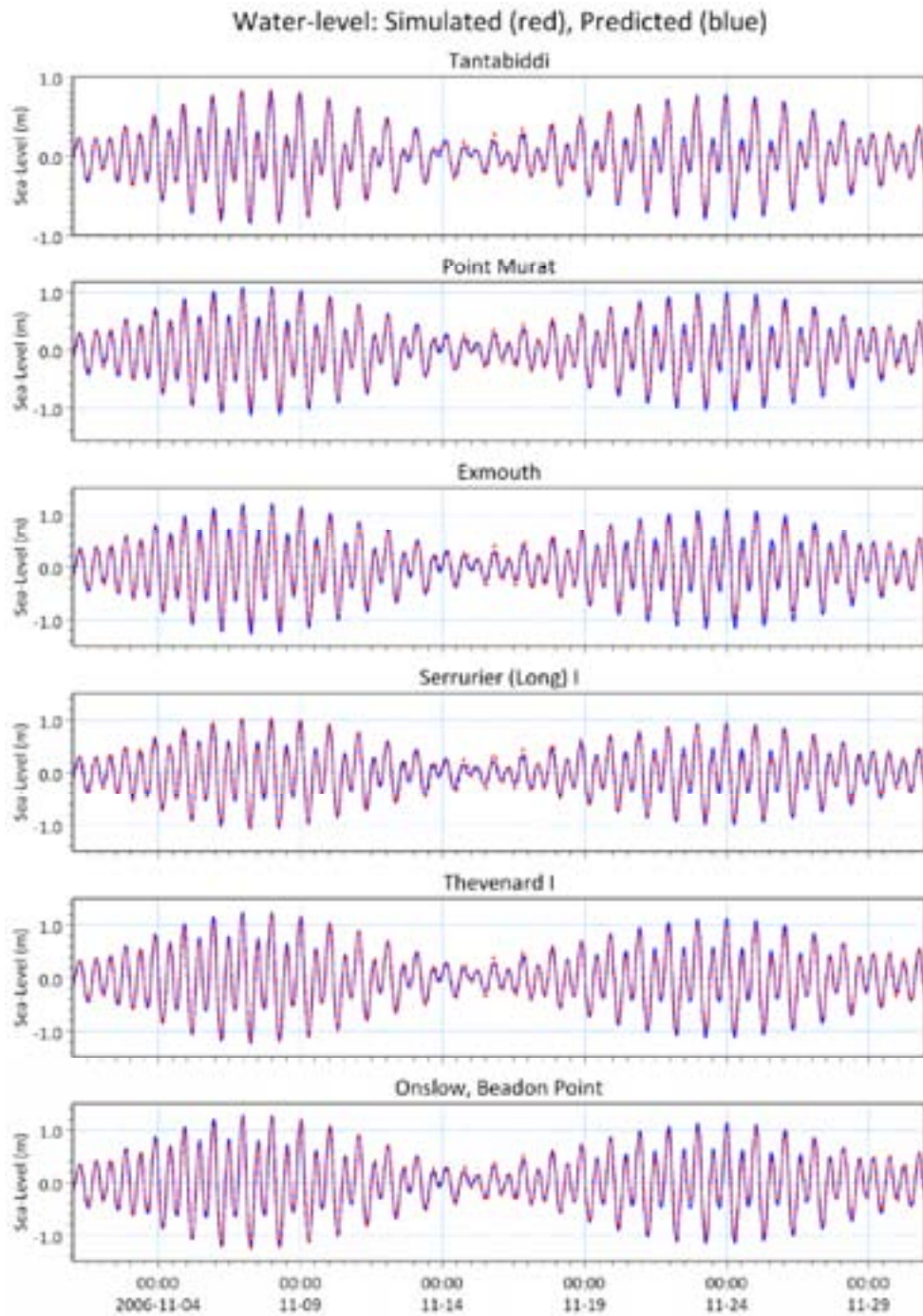


Figure 3.15 Comparison of simulated and predicted water levels at the selected tidal stations during typical period in November 2006. Simulated elevations in red and predicted elevations in blue.

3-17

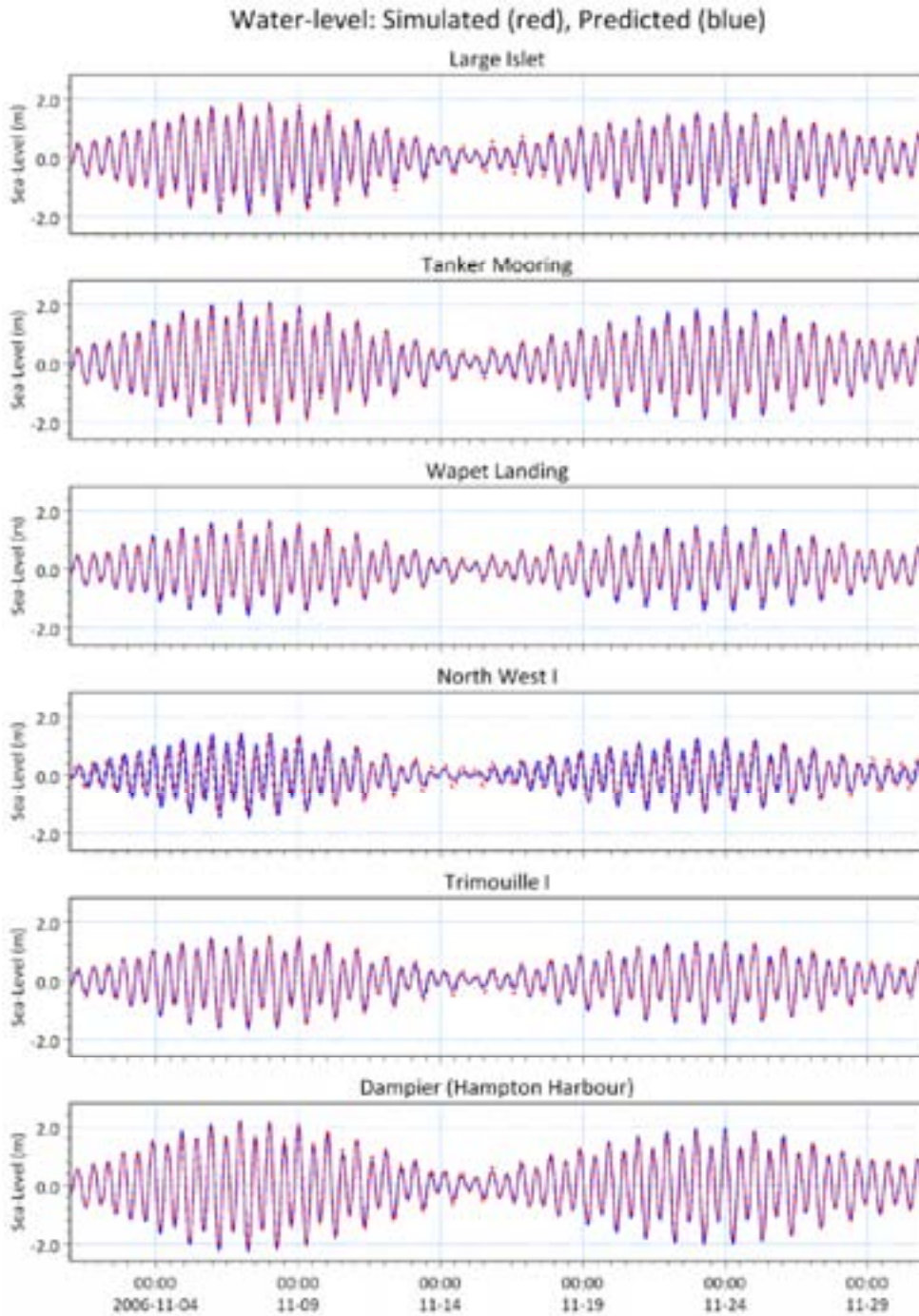


Figure 3.16 Comparison of simulated and predicted water levels at the selected tidal stations during typical period in November 2006 (continued) Simulated elevations in red and predicted elevations in blue.

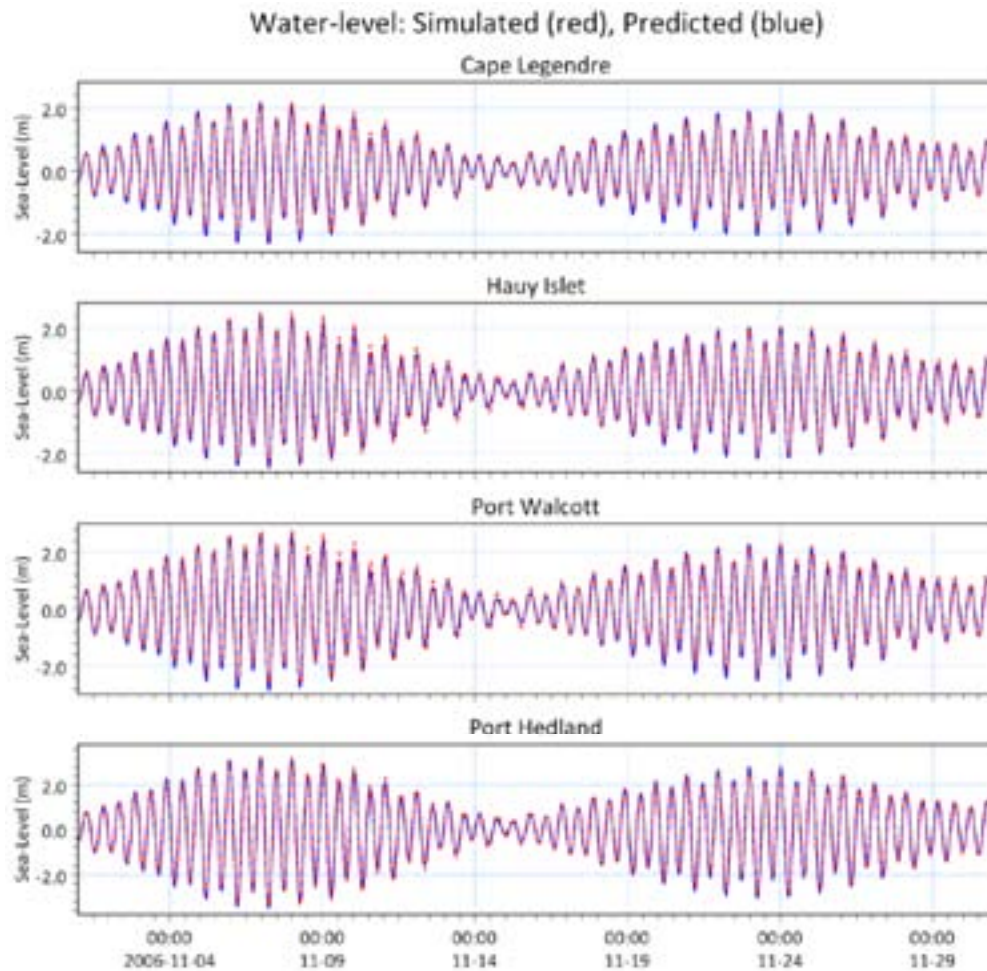


Figure 3.17 Comparison of simulated and predicted water levels at the selected tidal stations during typical period in November 2006 (continued) Simulated elevations in red and predicted elevations in blue.

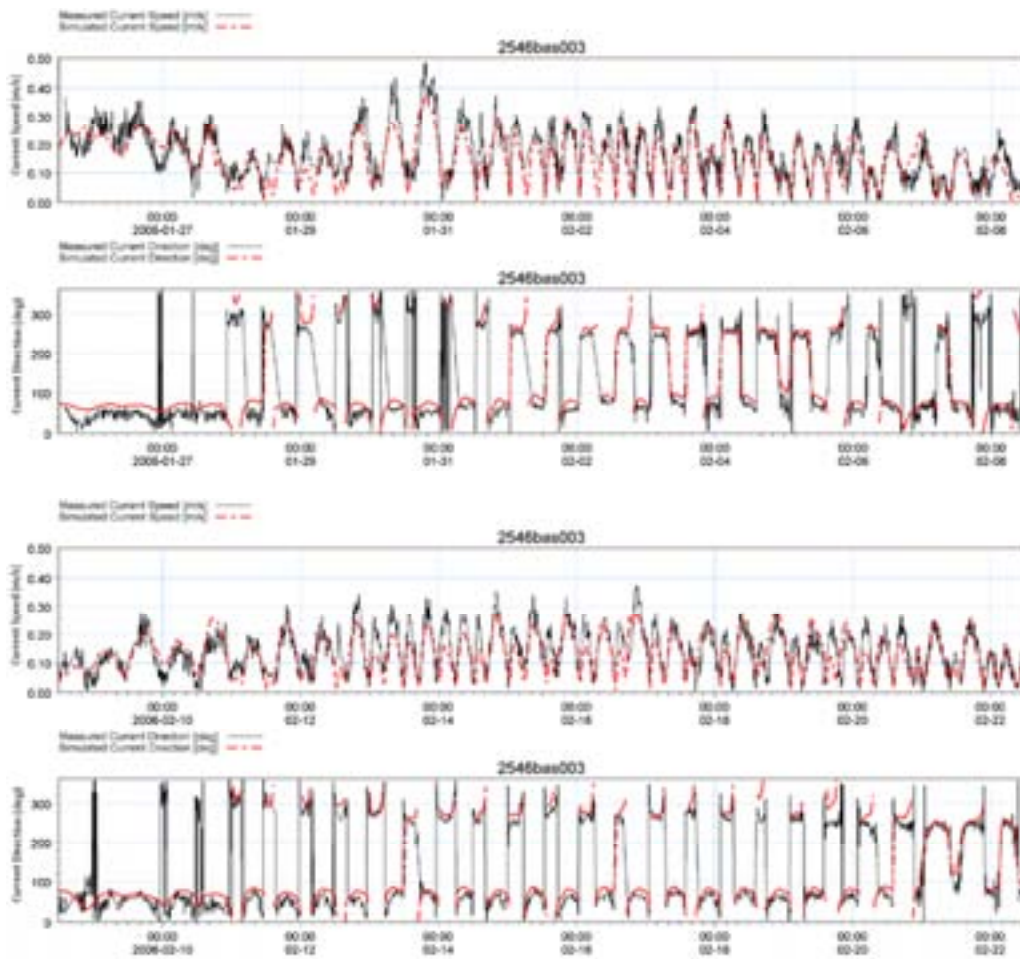


Figure 3.19 Time series of measured and simulated current speed and direction at P3

3-21

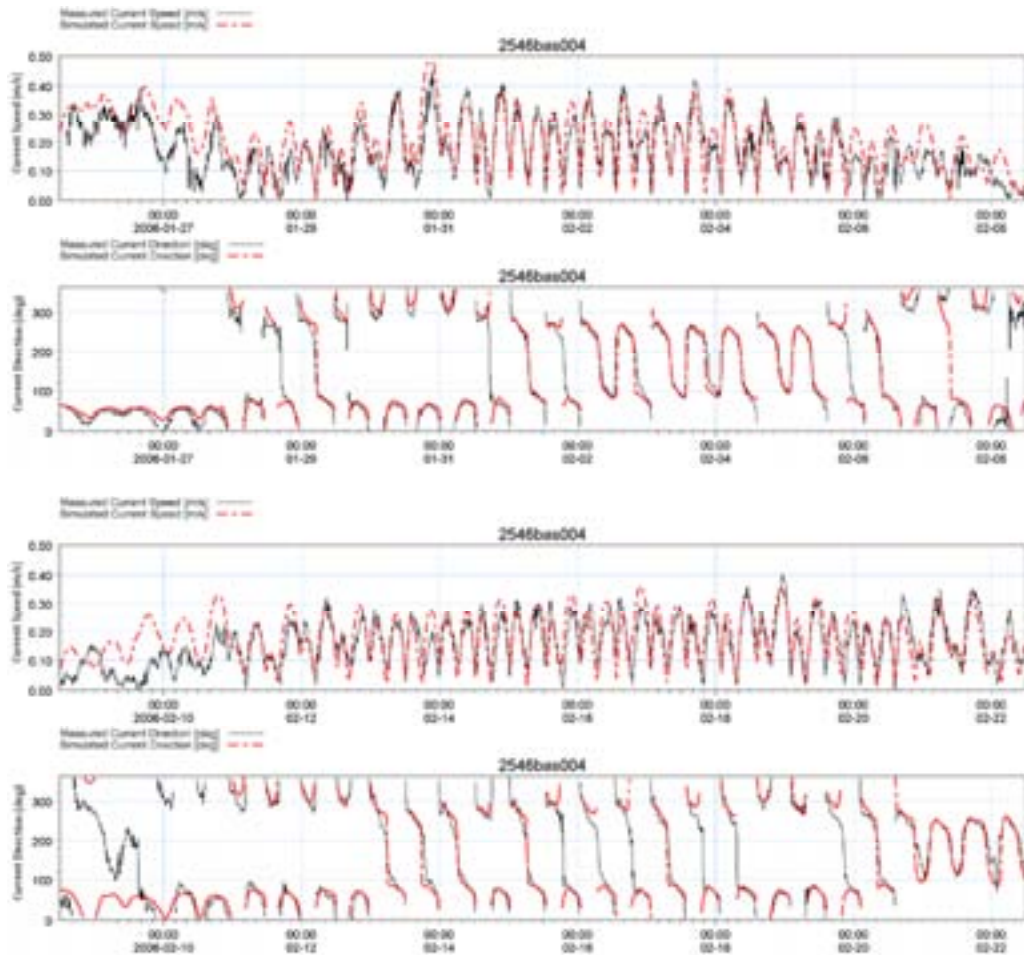


Figure 3.20 Time series of measured and simulated current speed and direction at P4

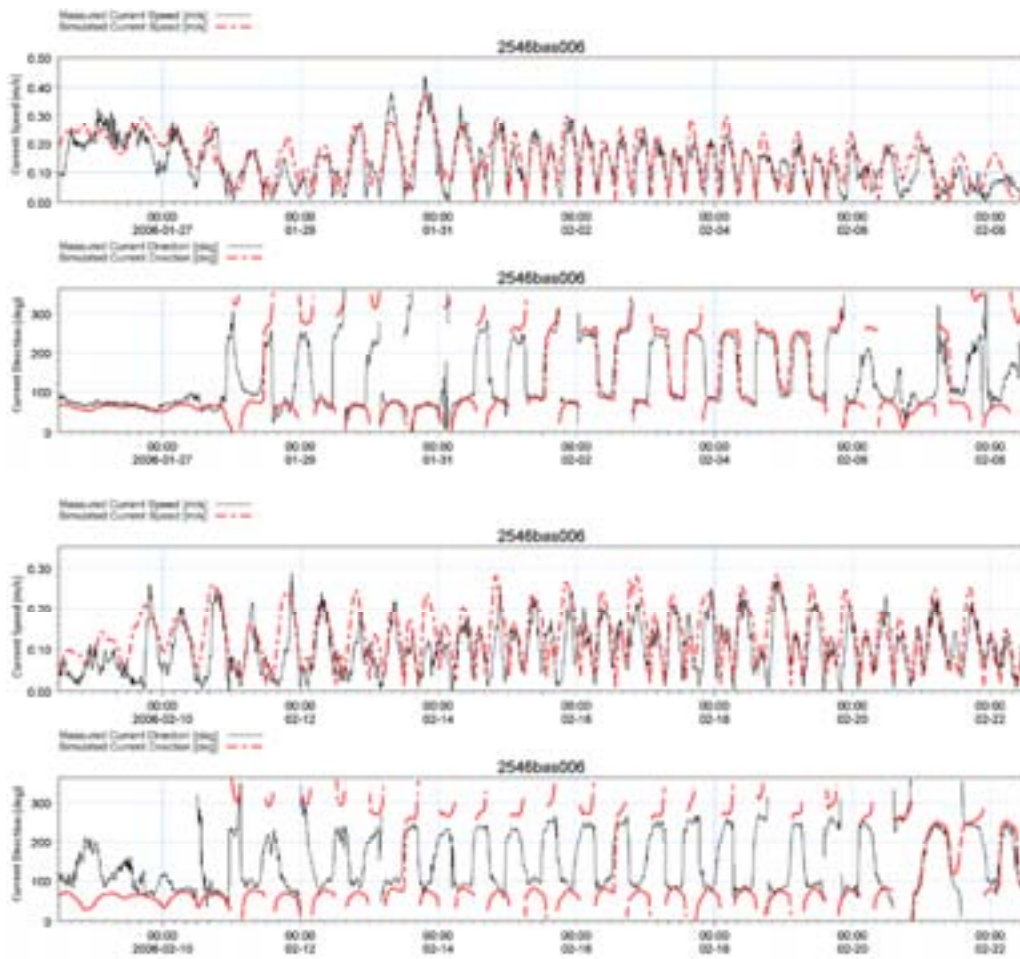


Figure 3.21 Time series of measured and simulated current speed and direction at P6

3-23

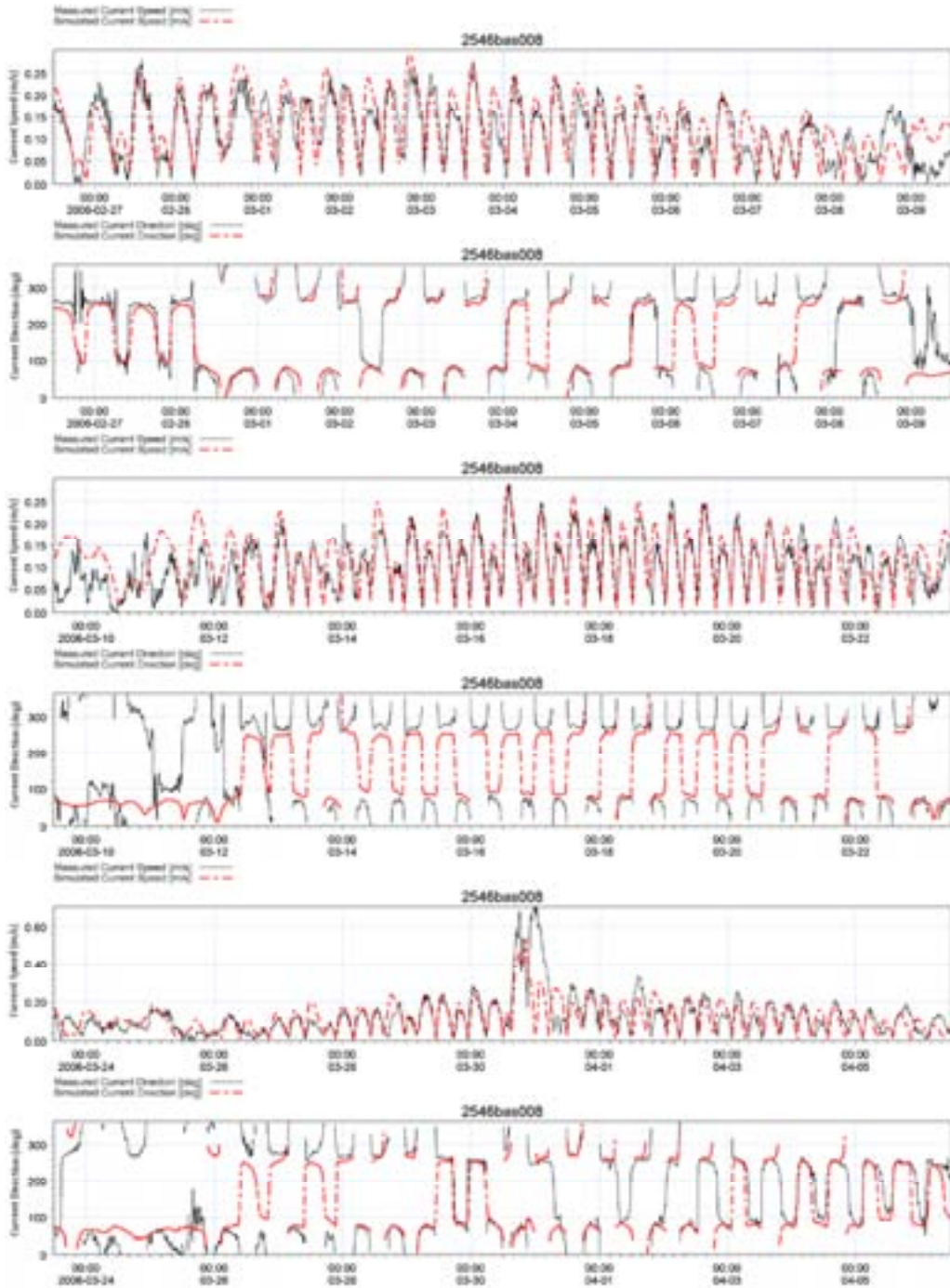


Figure 3.22 Time series of measured and simulated current speed and direction at P8

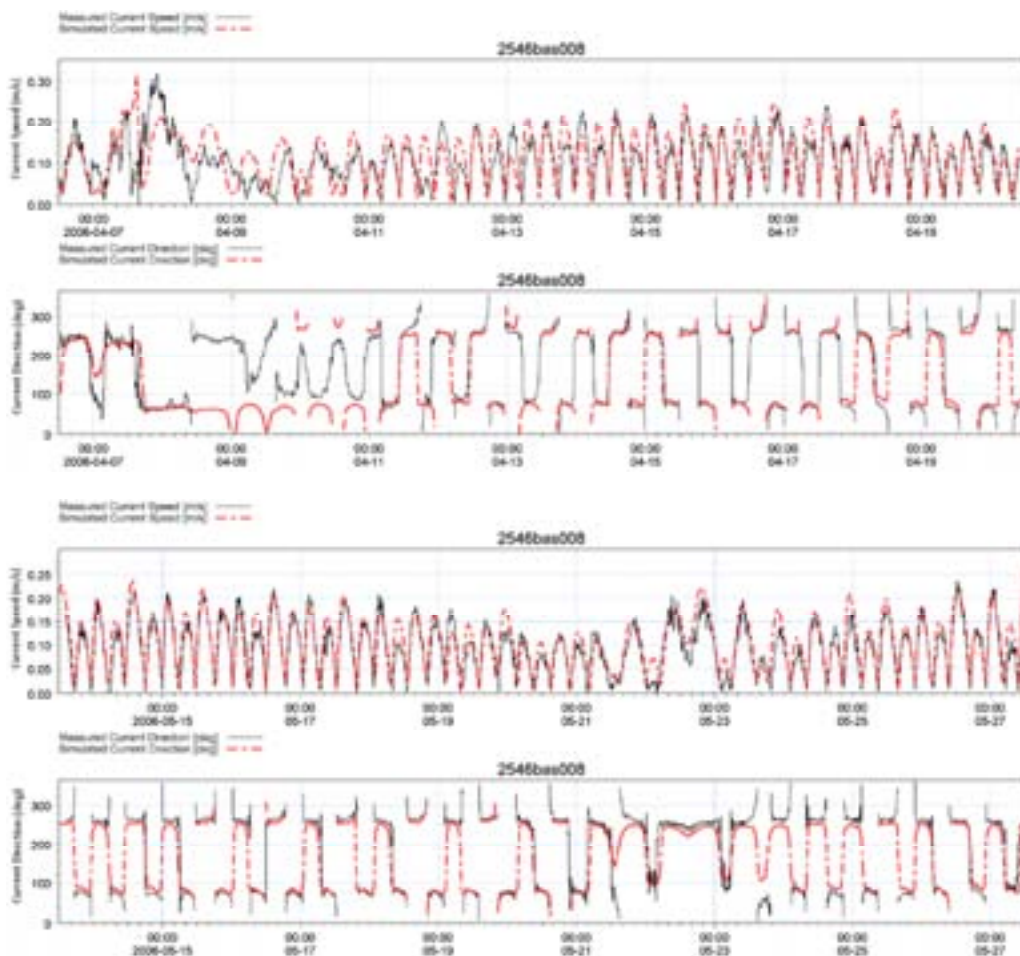


Figure 3.23 Time series of measured and simulated current speed and direction at P8 (continued)

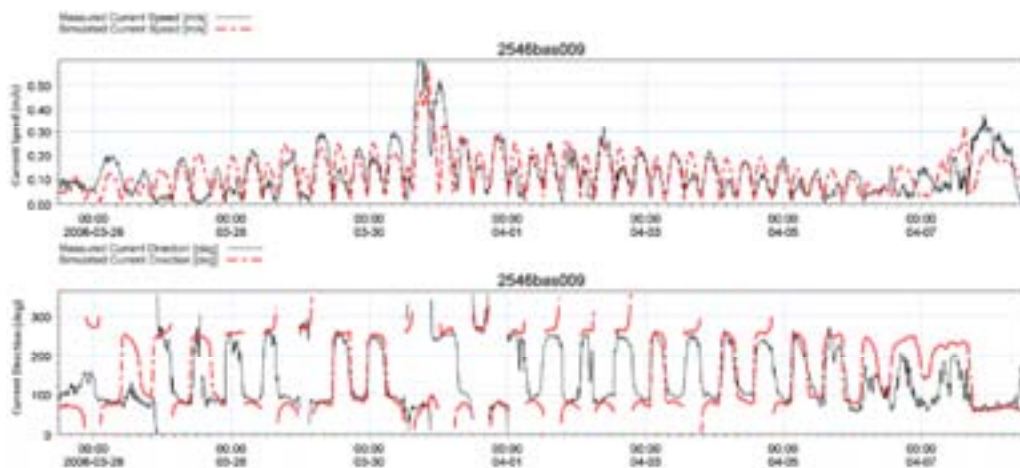


Figure 3.24 Time series of measured and simulated current speed and direction at P9

3-25

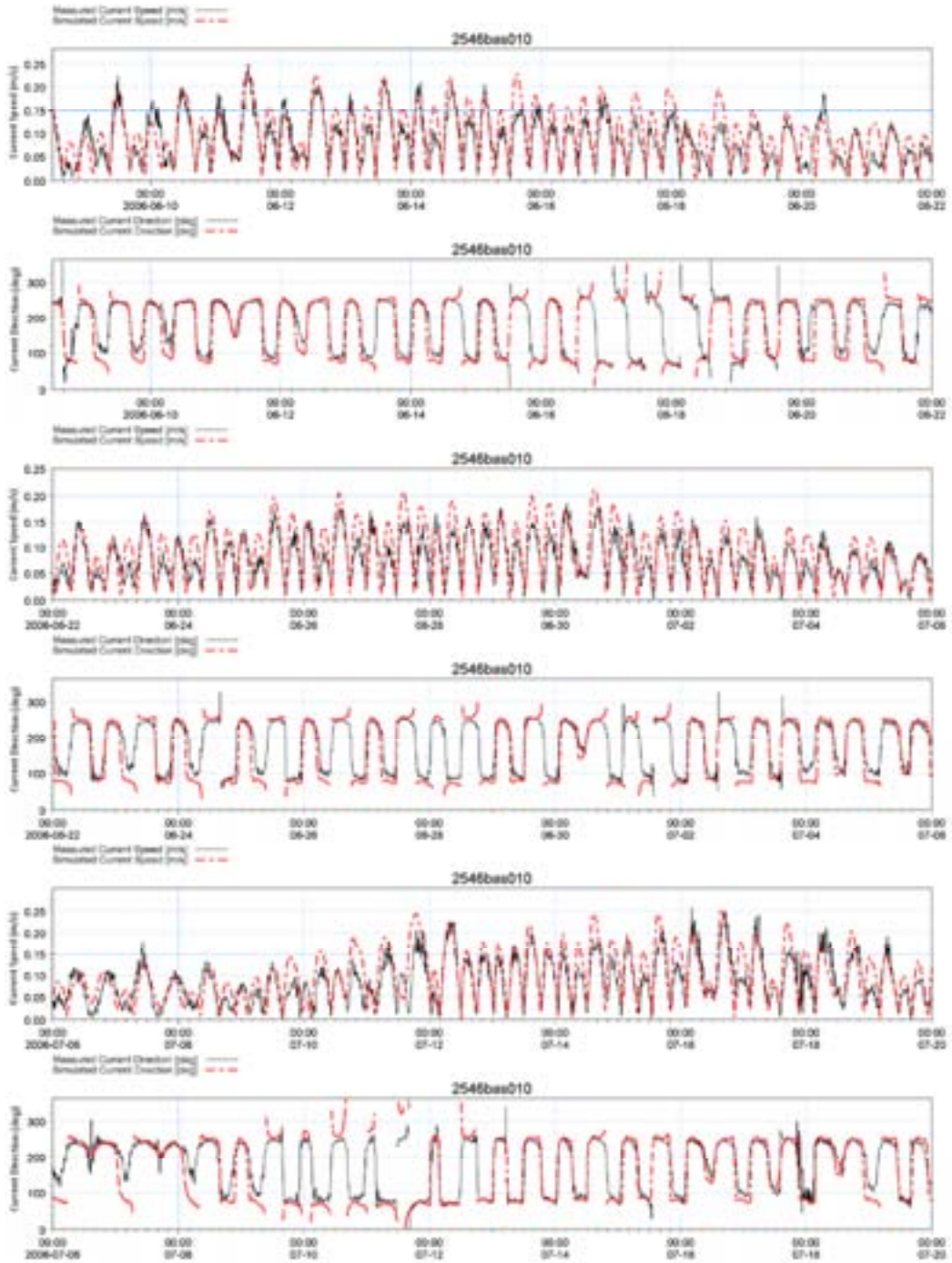


Figure 3.25 Time series of measured and simulated current speed and direction at P10

3-26

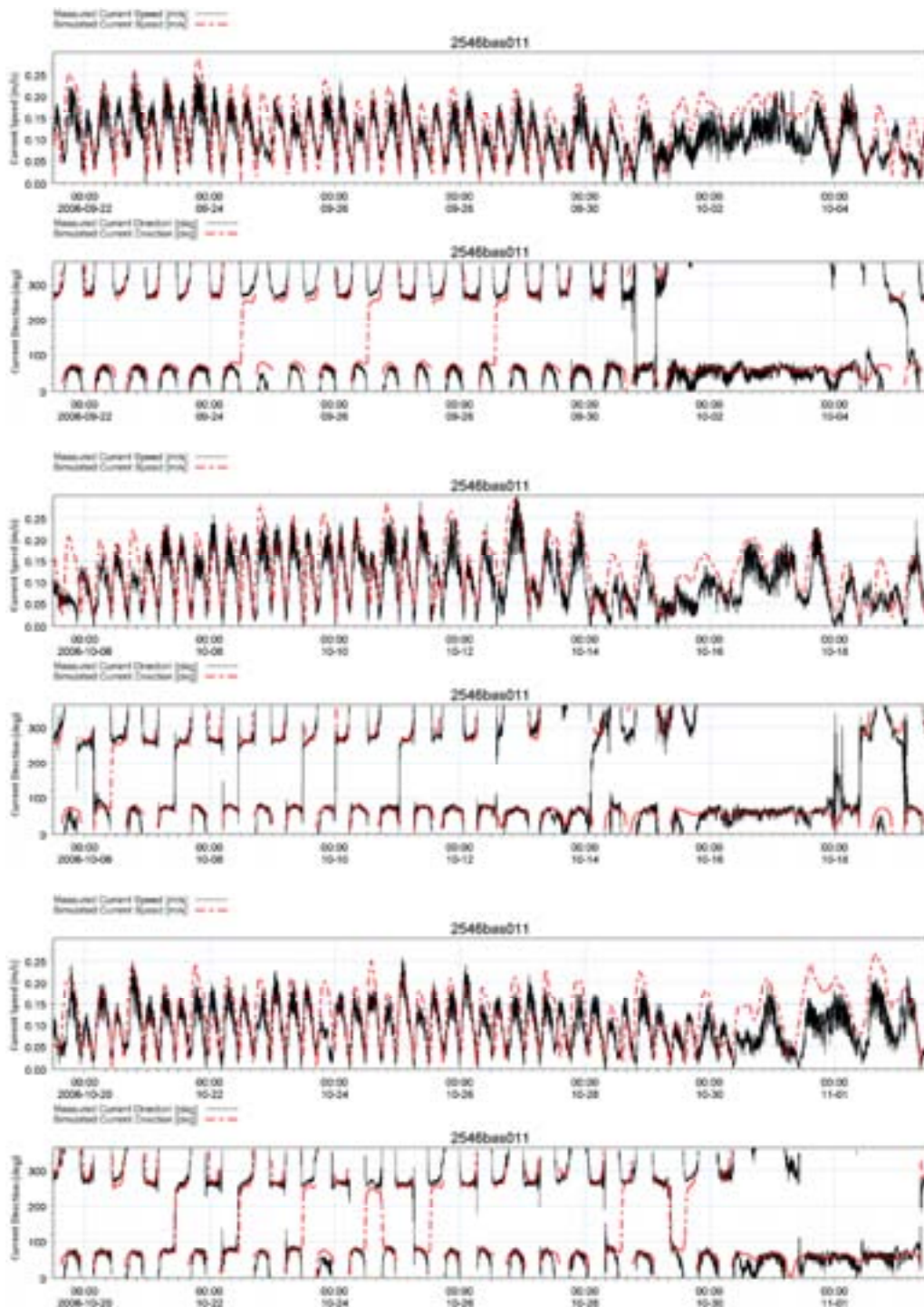


Figure 3.26 Time series of measured and simulated current speed and direction at P11

3-27

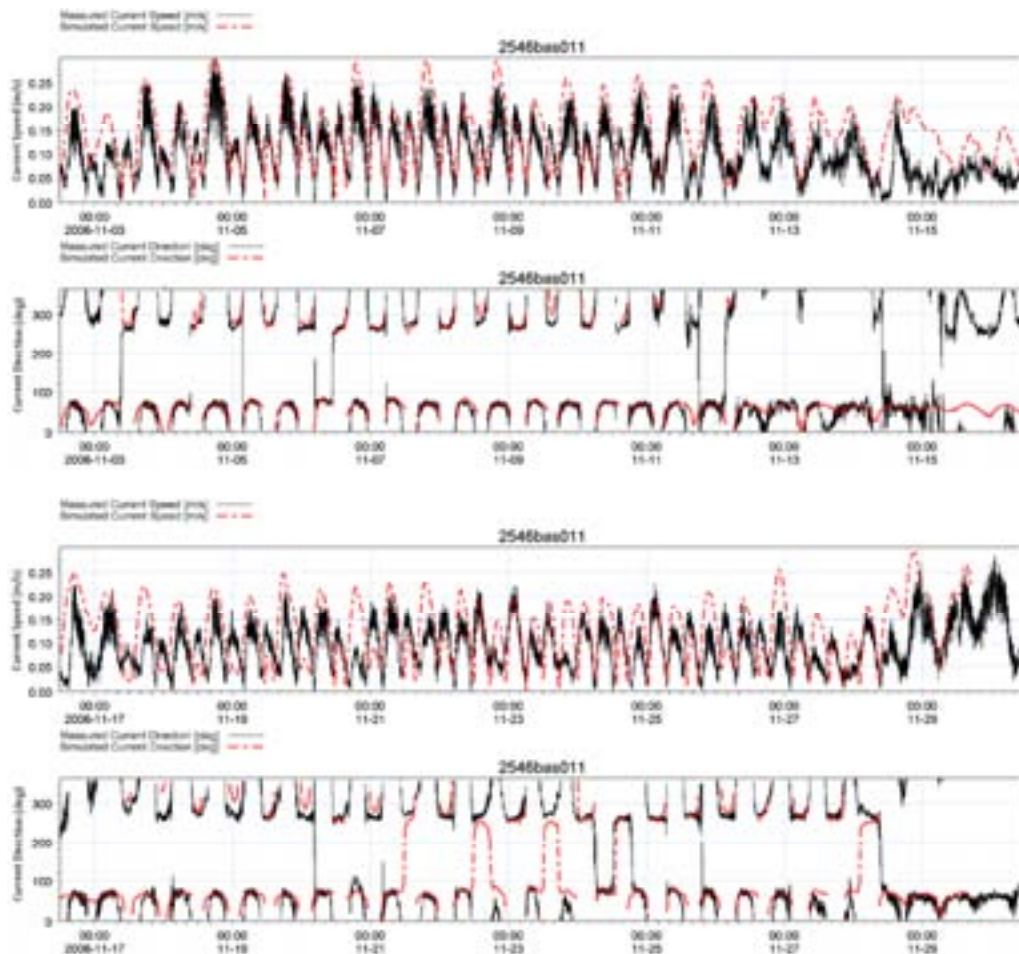


Figure 3.27 Time series of measured and simulated current speed and direction at P11 (continued)

3.2.2 Coastal Model Complex

Much higher resolution of the coastline and surf zone is required for the coastal modelling complex than for the setup for modelling of dredged material. The coastal model complex is based on the same regional 3645 m, 1215 m and 405 m coverage as the model complex for the dredge material modelling, while a new 135 m grid extended along the coastline has been included, supplemented further by 45 m and 15 m grids.

Potential changes to the Hooley Creek entrance as well as tail-water discharges into the Hooley Creek system from onshore dredge material placement have been identified as key risks to the coastal system. To resolve this in the model, the Hooley Creek tidal prism needs to be included in the model setup. This was established based on Lidar data for the area (Figure 3.28). The Lidar data covers the entire Hooley Creek tidal prism under normal and king tide conditions.

The 405 m grid bathymetry with the location of the extended 135 m grid is shown in Figure 3.29. Details of nesting and grid coverage is shown in Figure 3.30. The model complex has been established for two conditions: existing conditions based on the best available bathymetry data and with the proposed layout of the marine facilities including dredged channel, MOF and onshore



infrastructure within the Hooley Creek system included. The corresponding 45 m and 15 m grids are shown in Figure 3.31 and Figure 3.32, respectively.

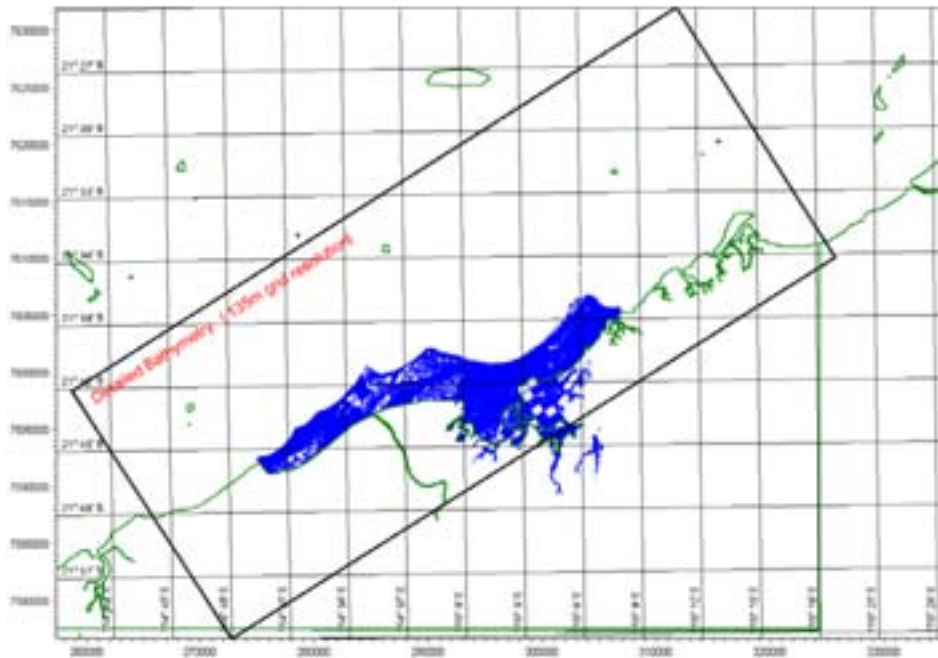


Figure 3.28 Coverage of extended 135m grid for the Coastal Model Complex with coverage of Lidar data applied for the Hooley Creek tidal prism definition.

3-29

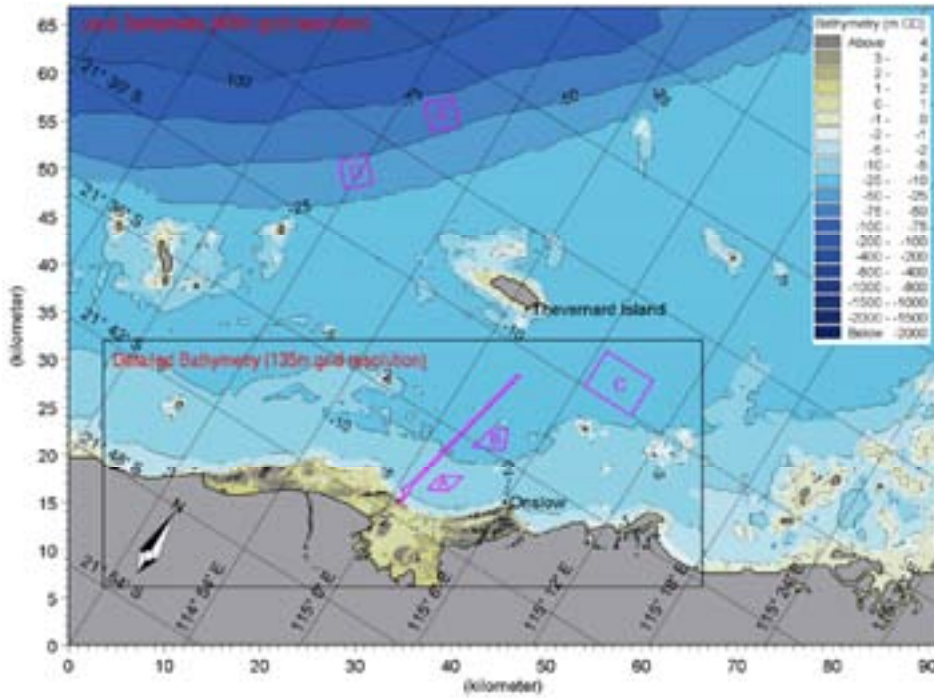


Figure 3.29 405m grid with location of extended 135m grid for the coastal modelling.

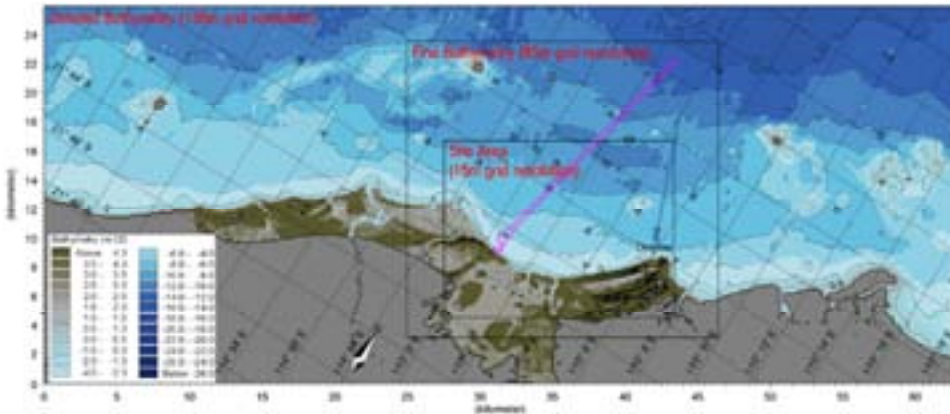


Figure 3.30 135m model bathymetry showing extent of the various nested grids (45m and 15m grids)

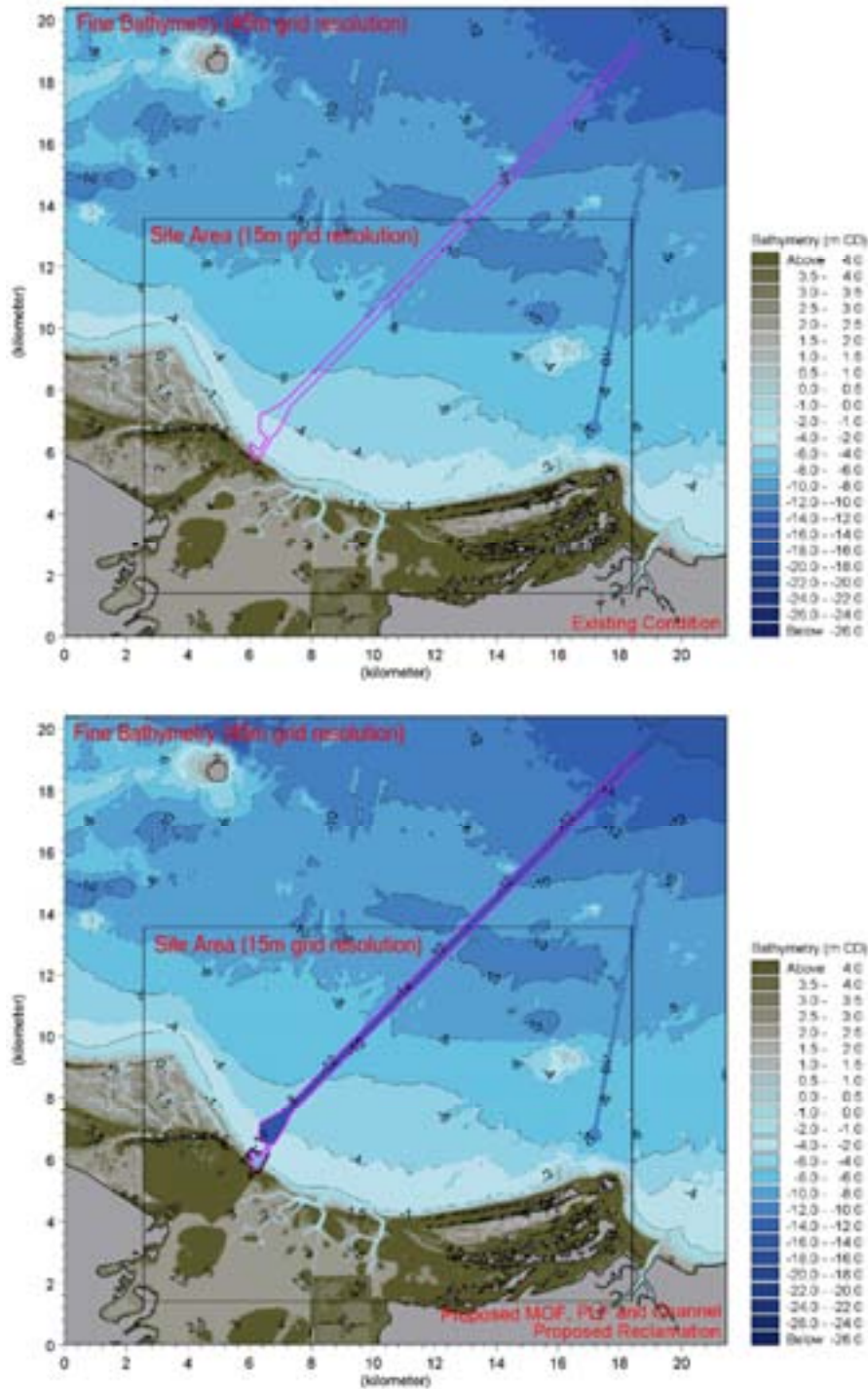


Figure 3.31 45m grid bathymetry showing extent of the 15m grids for existing conditions (top) and with proposed Wheatstone Project included (bottom).

3-31

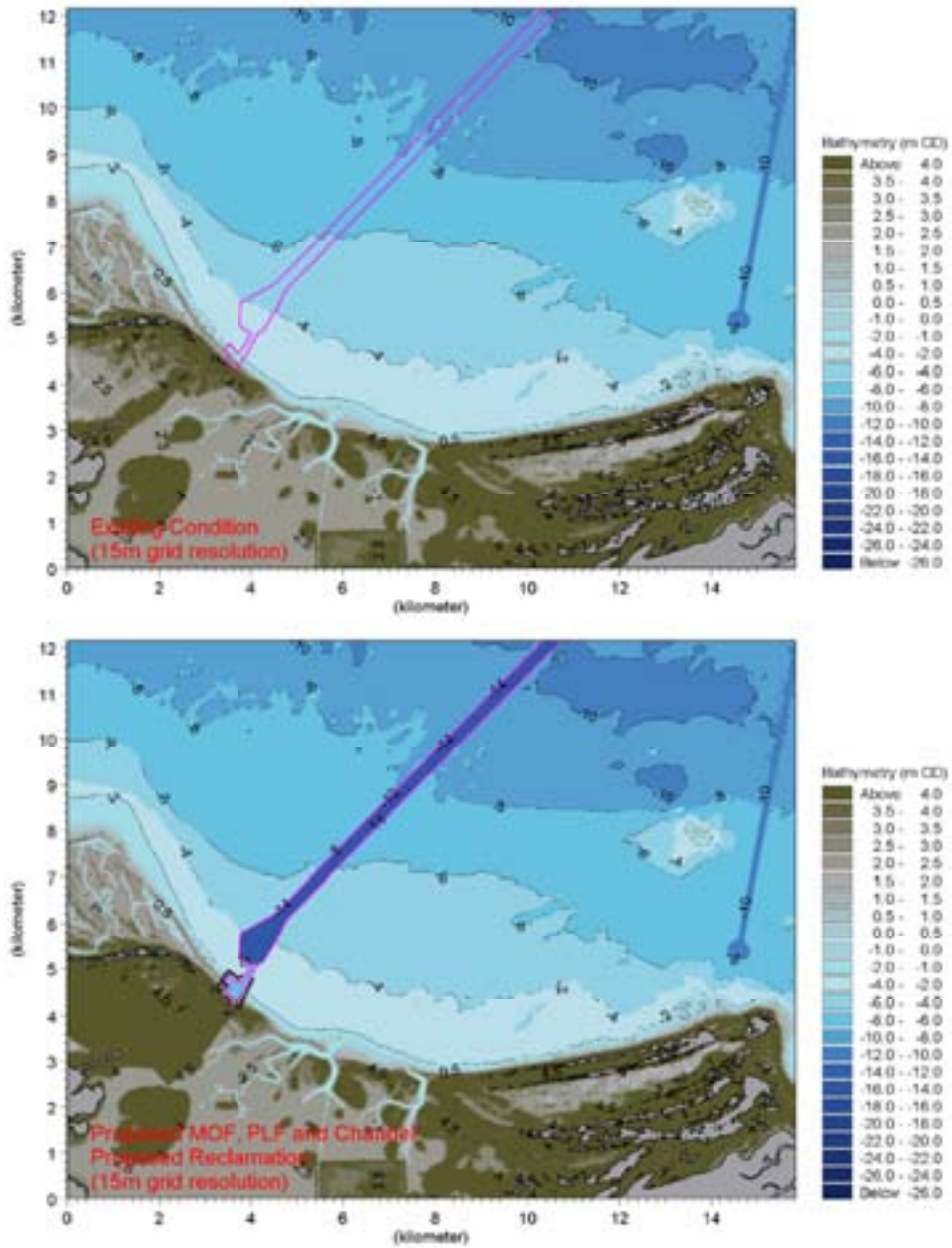


Figure 3.32 Details of 15m grid resolution with existing conditions (top) and with the project included (bottom).



3.2.3 Simulation Period

The model has been run for spring/neap tidal cycles for the coastal assessment. A summer and a winter period have been simulated.

There are significant differences in the spring tidal amplitudes from cycle to cycle (Figure 3.33) which shows one year predicted water levels at Onslow. To capture the full impacts of the reduction in tidal prism within the Hooley Creek tidal system, for example, a sub-set with a high tidal amplitude has been selected for the base modelling for the Hooley Creek tidal system (Figure 3.34).

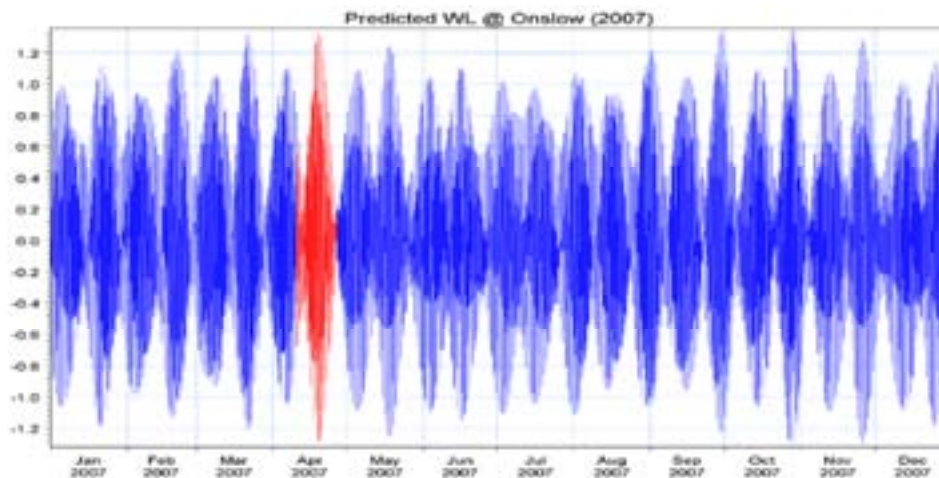


Figure 3.33 Predicted tidal water levels at Onslow for year 2007, red series mark the selected model simulation period

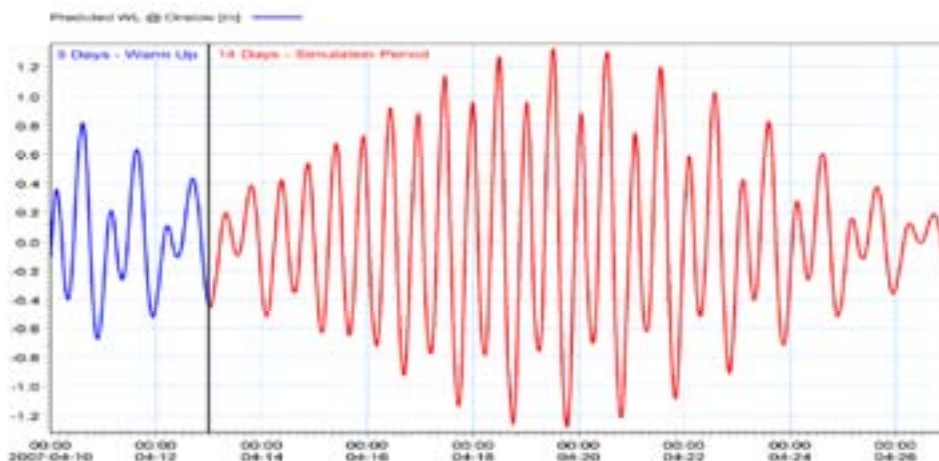


Figure 3.34 17 days simulation period for hydrodynamic simulations, with 3 days warm up outlined in blue.



3.2.4 Wave driven currents

In addition to the wave parameters such as wave heights, periods, mean directions and directional spreading, the wave simulations also provide output of the so-called radiation stresses, which are included in the HD modelling together with the “normal” driving forces for tides and winds to include the wave driven currents and water levels. The models thus simulated the combined wind-, wave- and tidal driven water level and current fields.

The waves were simulated based on the MesoLAPS winds as previously documented in Section 3.1.

3.2.5 Sample Model Results

Figure 3.35 to Figure 3.42 show sample current patterns with and without the development in place for flood-, high-, ebb- and low spring tide for representative summer conditions. Figure 3.43 to Figure 3.50 showing similar plots for winter conditions.

Some notable points include:

- Peak tidal currents are moderate with the strongest currents in the vicinity of the flowing around the coastal protrusions at the entrance point and at Beadon Point. This correlates with coarser sediments in these areas (Gravel Banks).
- Shallow areas such as Ward Reef also lead to higher currents locally.
- Tidal and wind driven currents are weaker in the shallow area along the coastline
- The winds cause flood tide currents (easterly directed) to be stronger than ebb tide currents (westerly directed) during summer, with the reverse effect during winter
- Wave generated currents are relatively weak (due to the generally benign wave conditions as well as the angle of the incoming waves relative to the coastline).
- The flooded areas within the Hooley Creek system have limited extent during normal tidal conditions.
- On easterly currents, a large-scale eddy structure is formed to the east of the eastern breakwater towards the entrance to Hooley Creek.
- On weaker westerly flow, the formation of large-scale eddy to the west of the western breakwater is less pronounced due to the shape of the western breakwater.
- On strong westerly flow, a large-scale eddy is pushed seaward by the MOF and affects the PLF basin (Figure 3.48).

In addition to the “representative” summer and winter conditions with time series of waves during average summer and winter conditions, a summer period with peak wave conditions has also been tested to investigate the current patterns and potential sediment bypass of the MOF structures during more extreme events.

Figure 3.51 to Figure 3.54 show currents patterns at two scales for flood, high, ebb and low tide conditions for the rough wave conditions. From these it is noted that:

- The wave driven currents are much stronger than for average conditions and dominate the current patterns along the coastline in the surf zone for all tidal conditions.
- A distinct flow pathway past the MOF is noted for all tidal conditions except ebb tide where the tidal currents balance the wave driven currents.

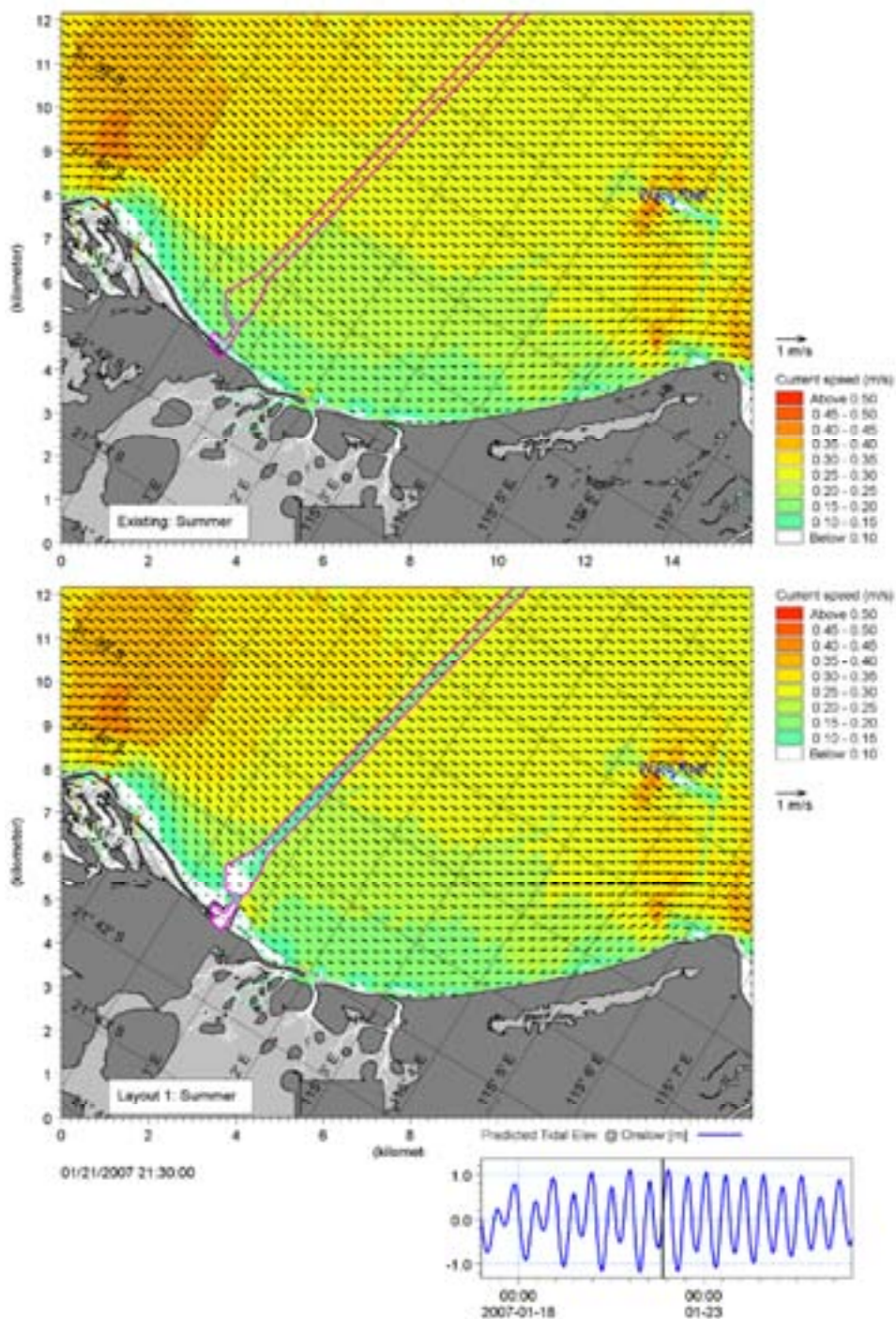


Figure 3.35 Example of current fields for existing conditions (top) and layout 1 (bottom) for flood tide for summer conditions.

3-35

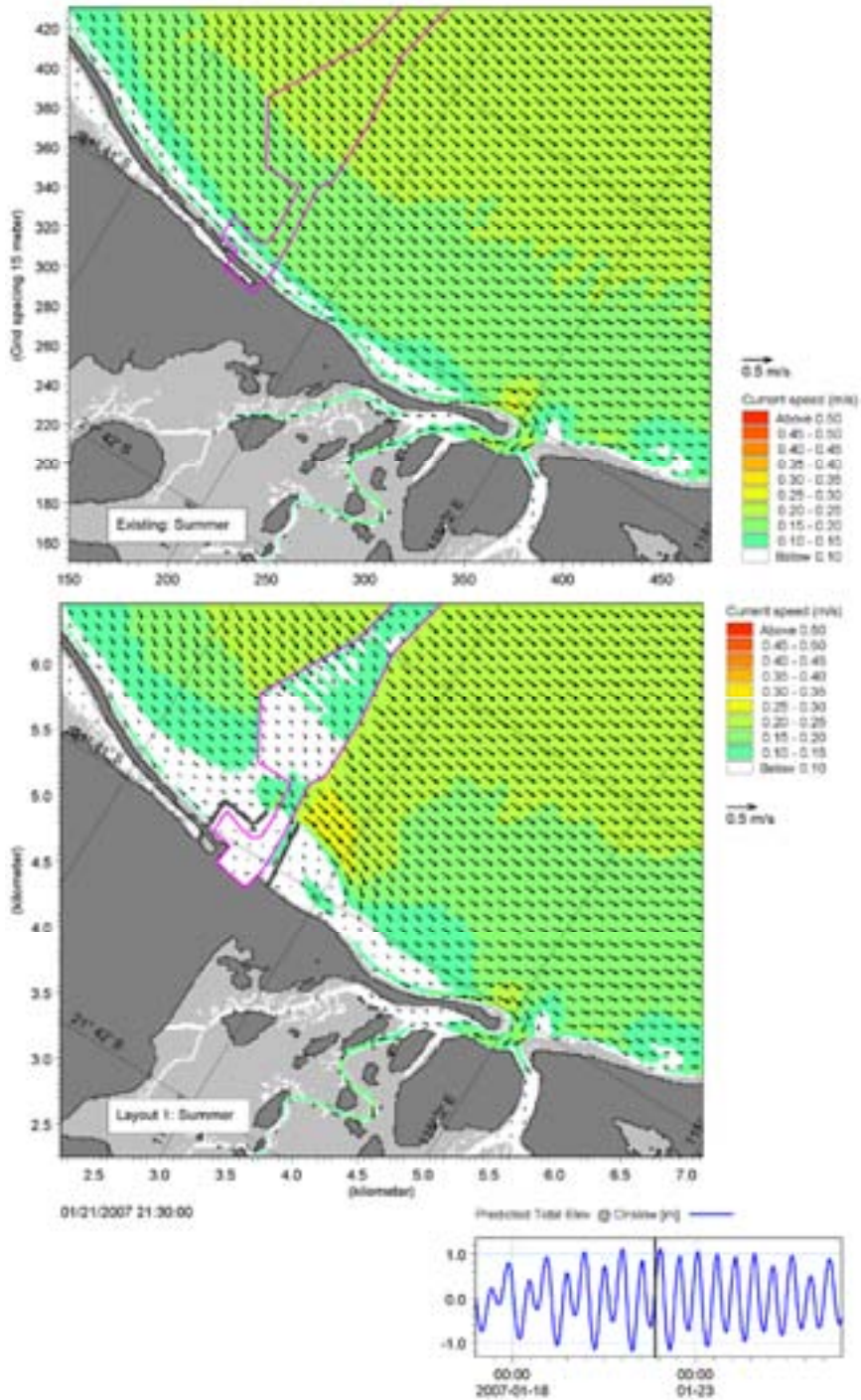


Figure 3.36 Details of current fields at MOF and Hooley Creek entrance for existing conditions (top) and layout 1 (bottom) for flood tide for summer conditions.

3-36

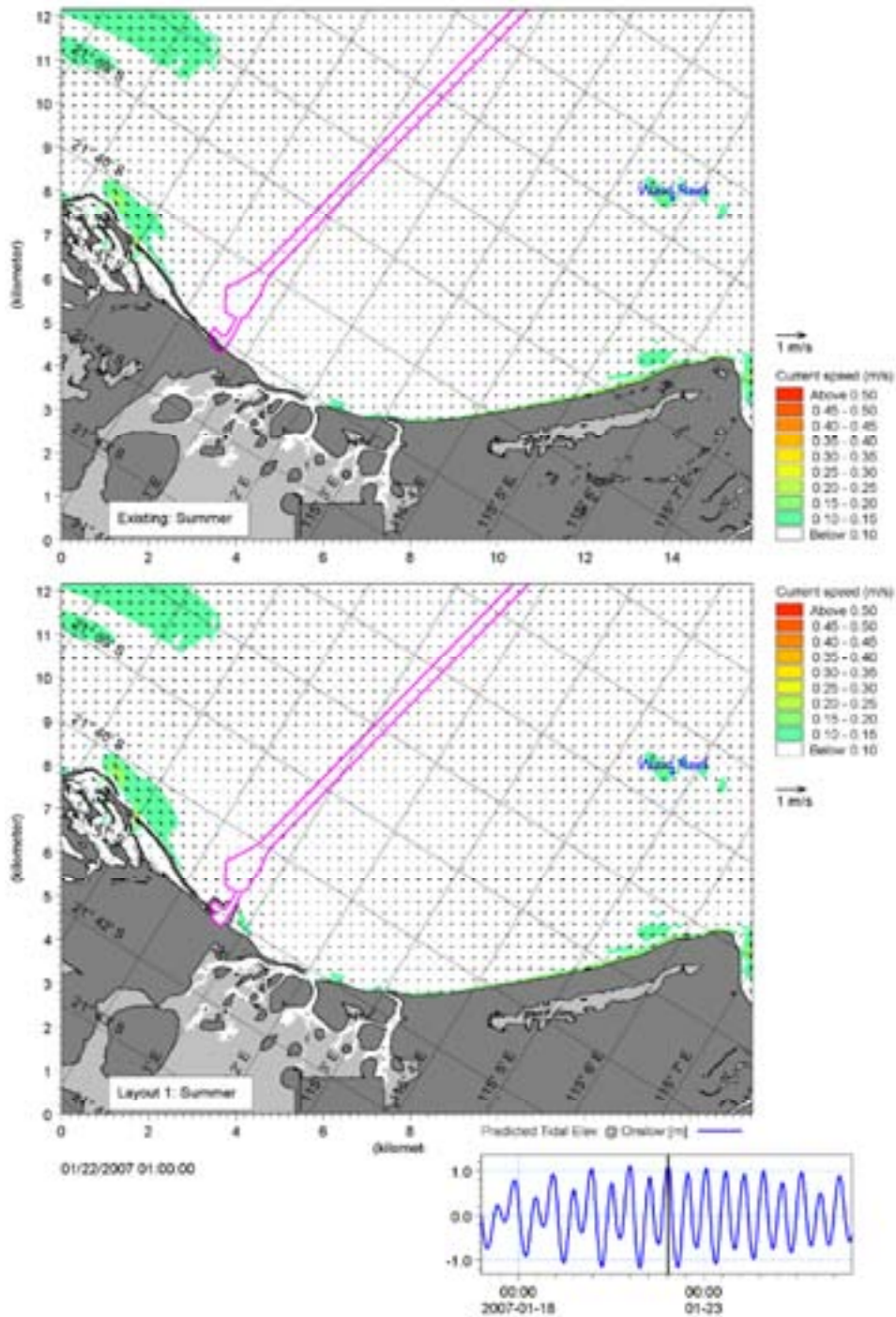


Figure 3.37 Example of current fields for existing conditions (top) and layout 1 (bottom) for high tide for summer conditions.

3-37

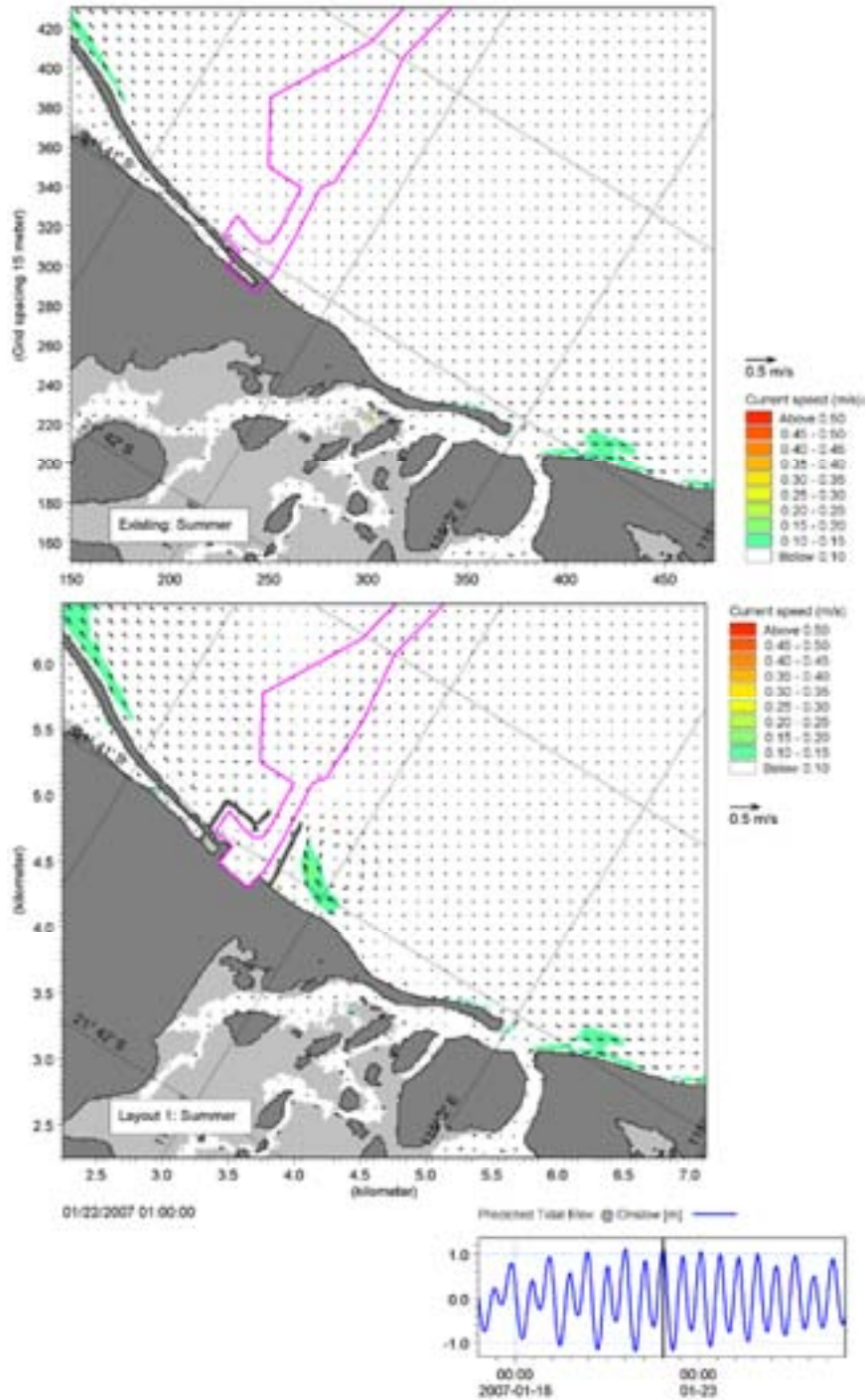


Figure 3.38 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for high tide for summer conditions

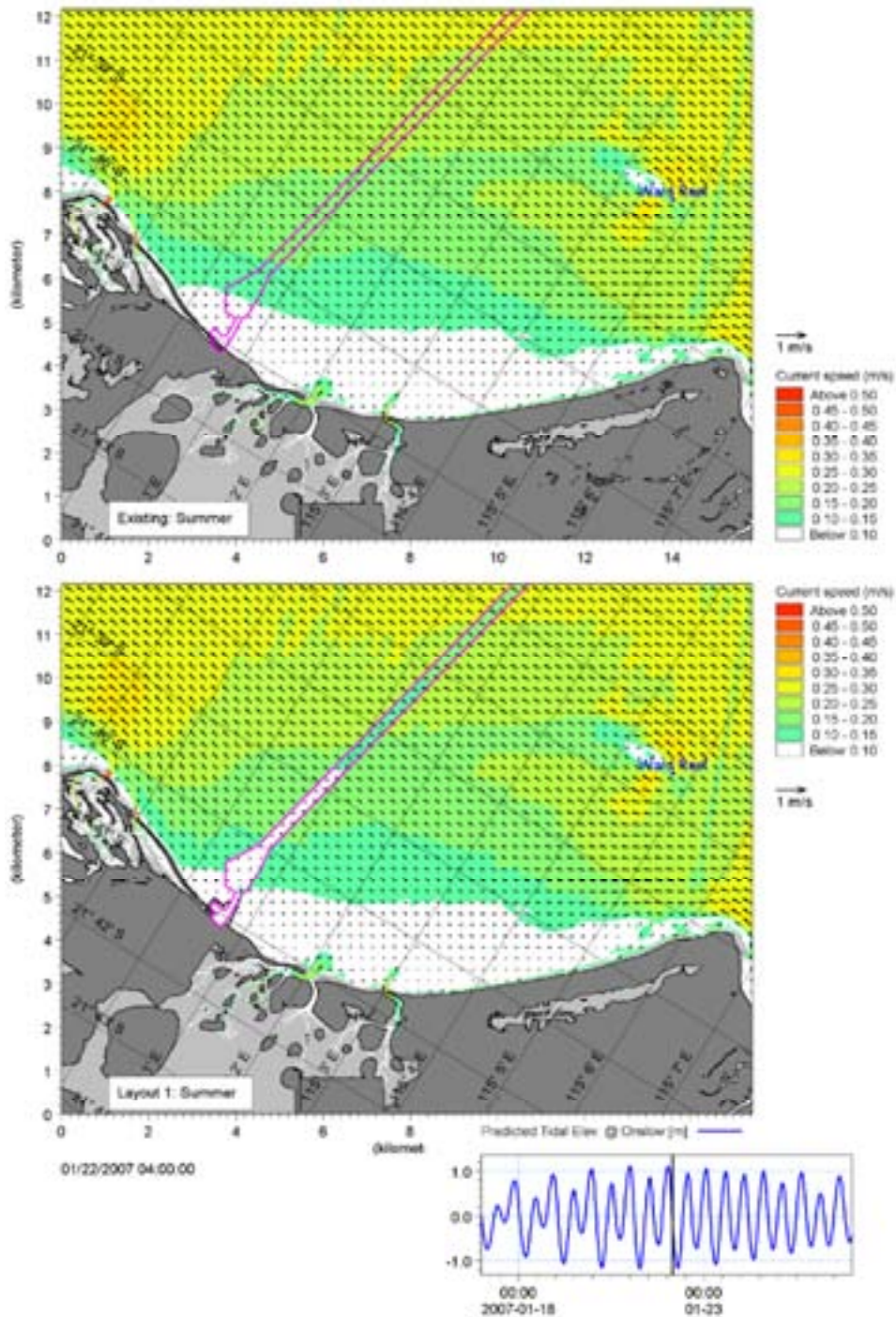


Figure 3.39 Example of current fields for existing conditions (top) and layout 1 (bottom) for ebb tide for summer conditions

3-39

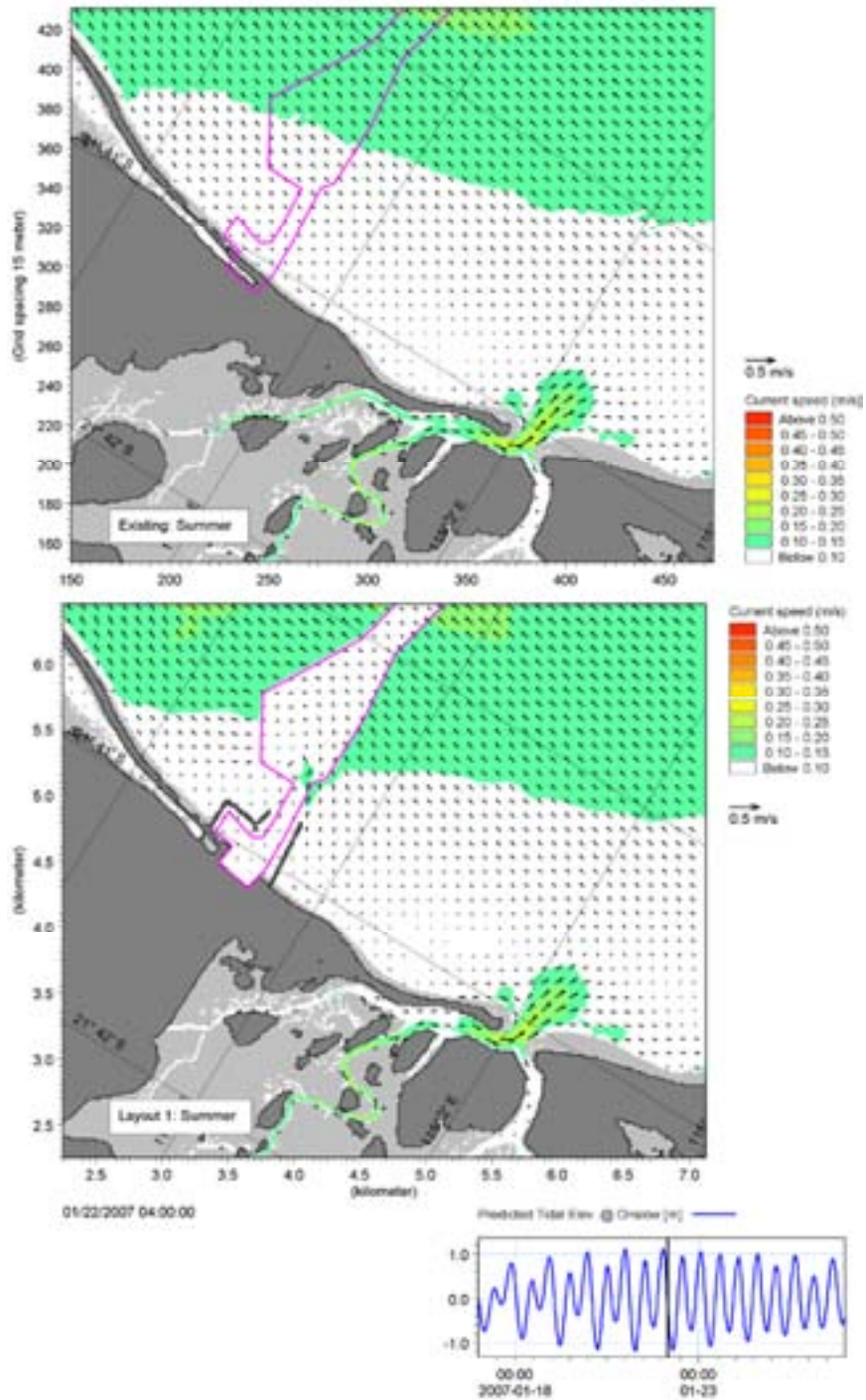


Figure 3.40 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for ebb tide for summer conditions

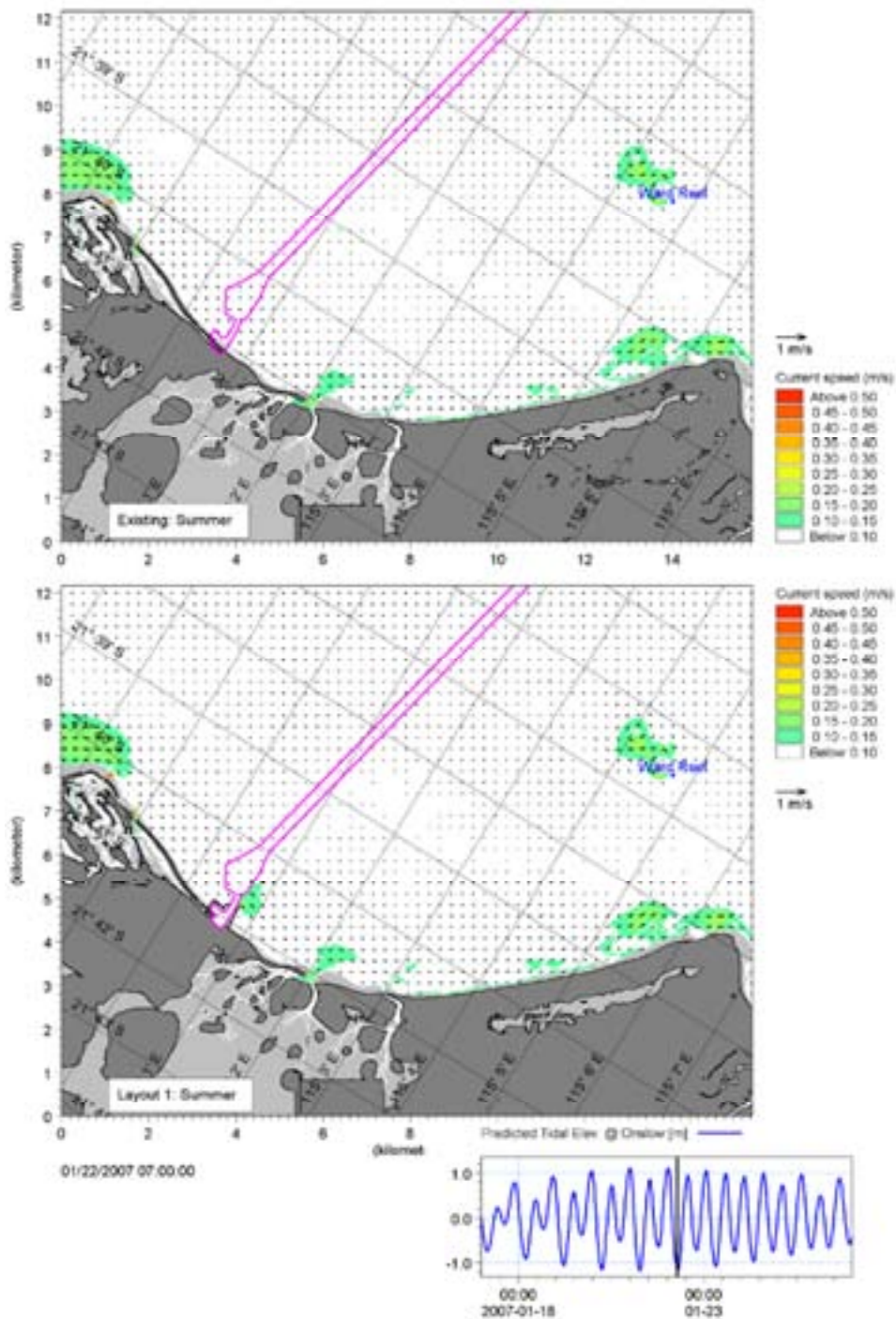


Figure 3.41 Example of current fields for existing conditions (top) and layout 1 (bottom) for low tide for summer conditions

3-41

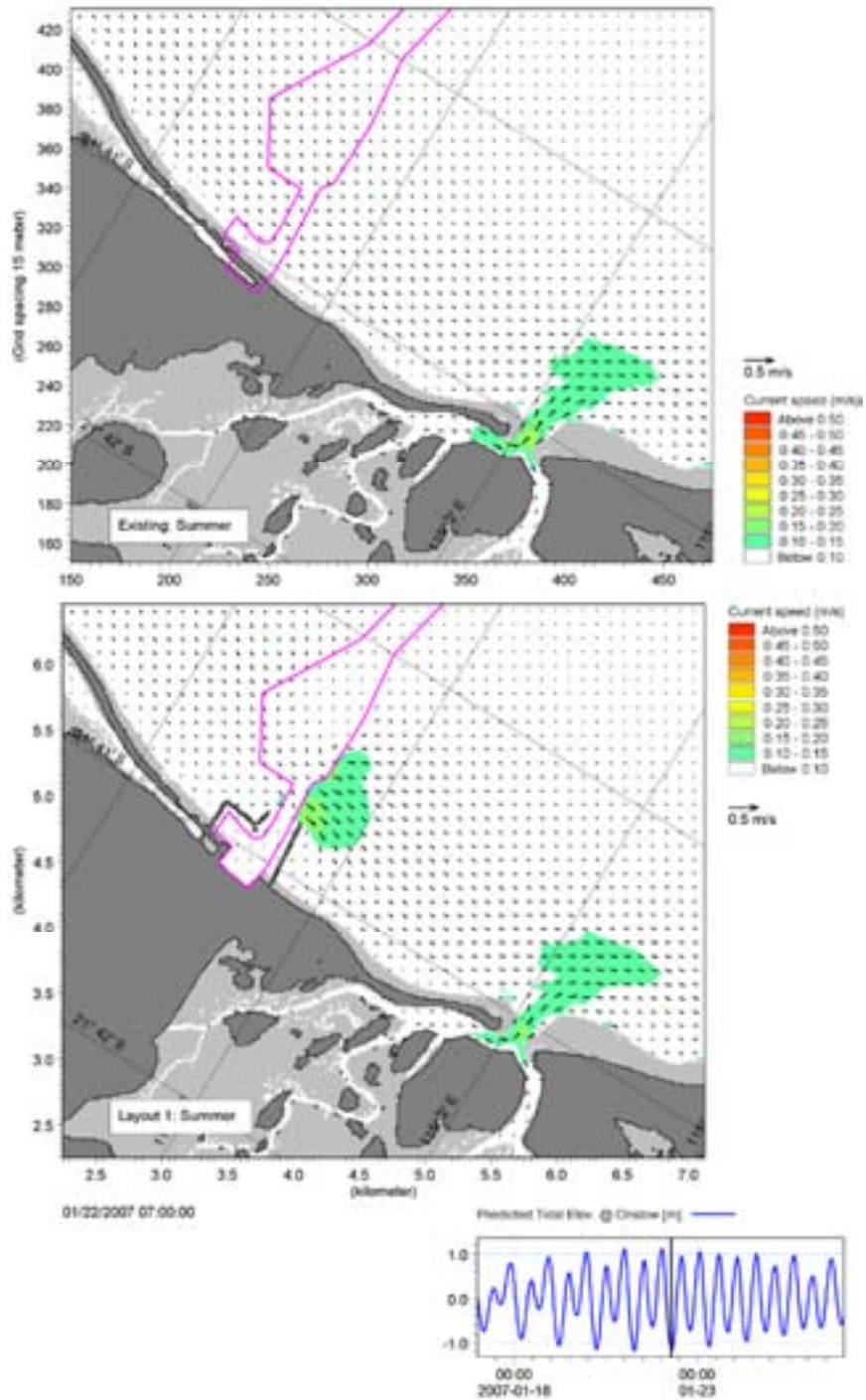


Figure 3.42 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for low tide for summer conditions.

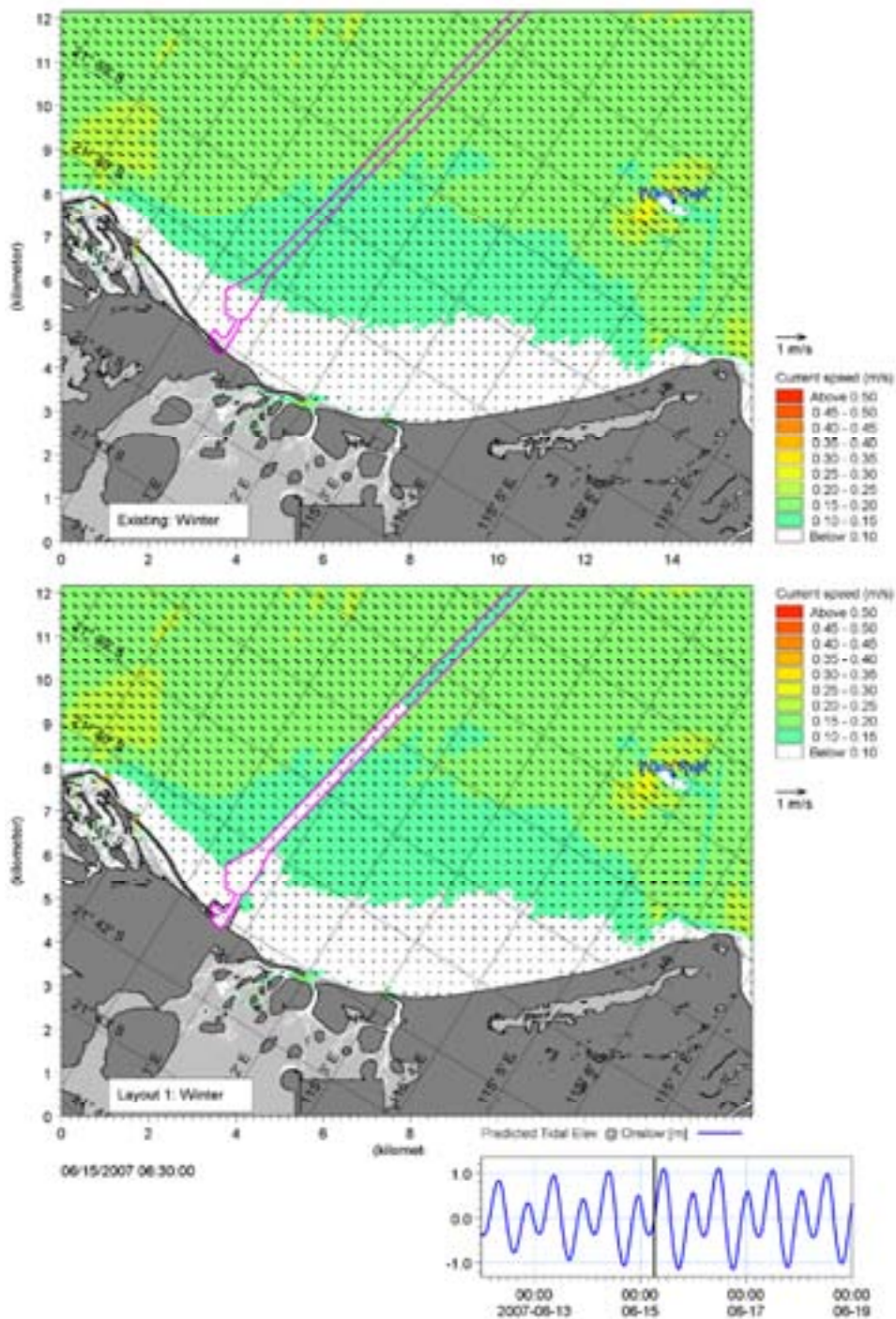


Figure 3.43 Example of current fields for existing conditions (top) and layout 1 (bottom) for flood tide for winter conditions.

3-43

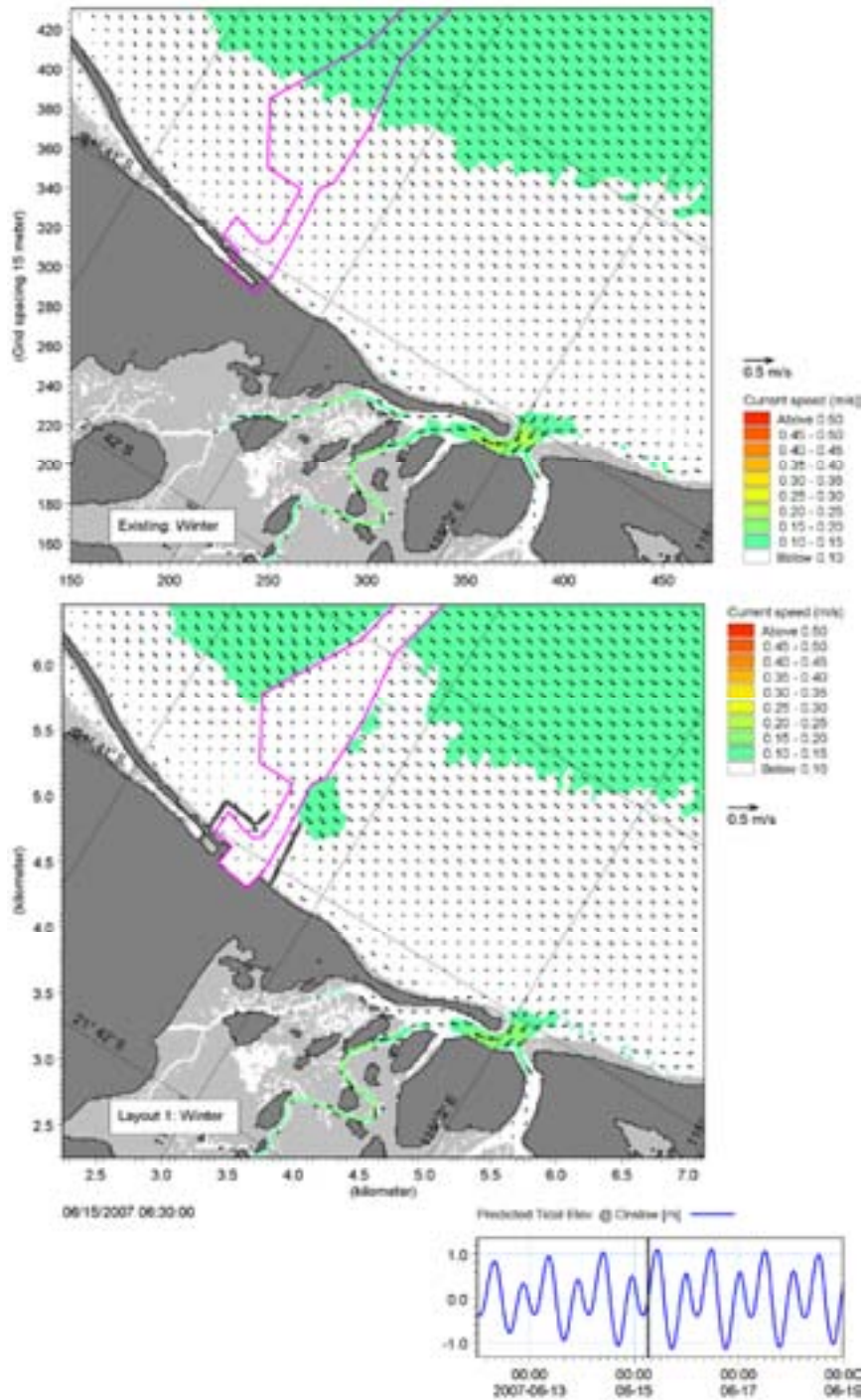


Figure 3.44 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for flood tide for winter conditions.

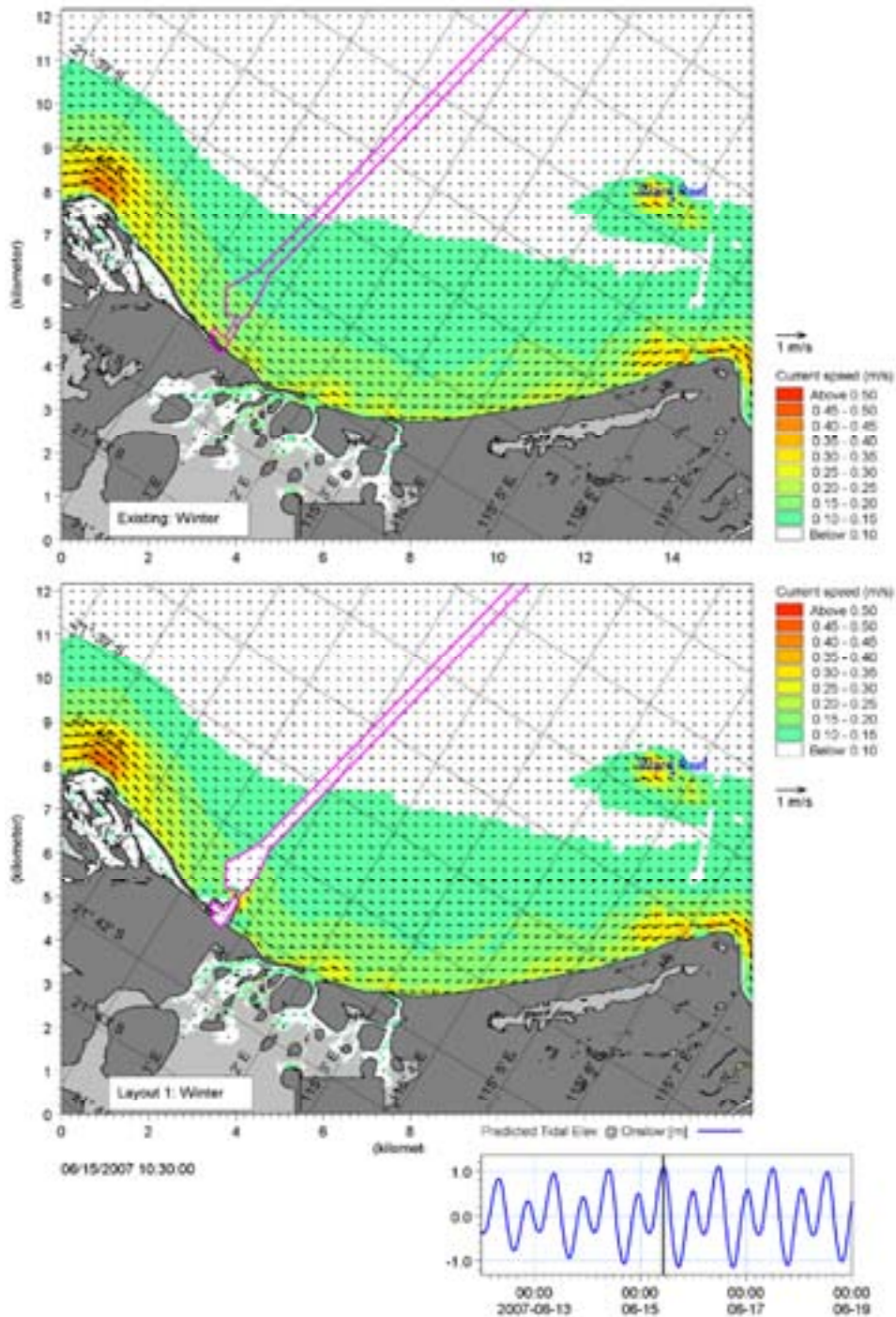


Figure 3.45 Example of current fields for existing conditions (top) and layout 1 (bottom) for high tide for winter conditions.

3-45

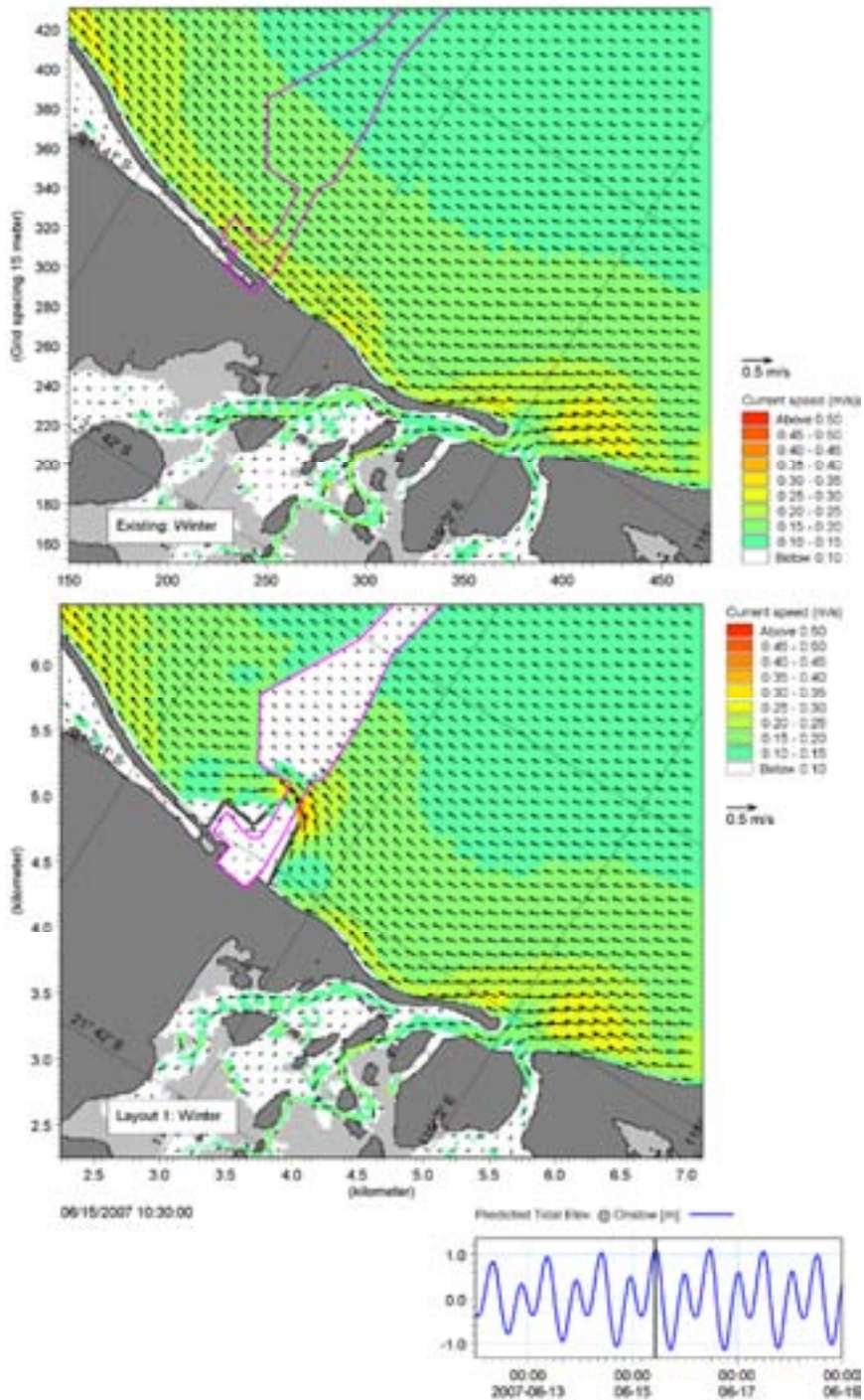


Figure 3.46 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for high tide for winter conditions.

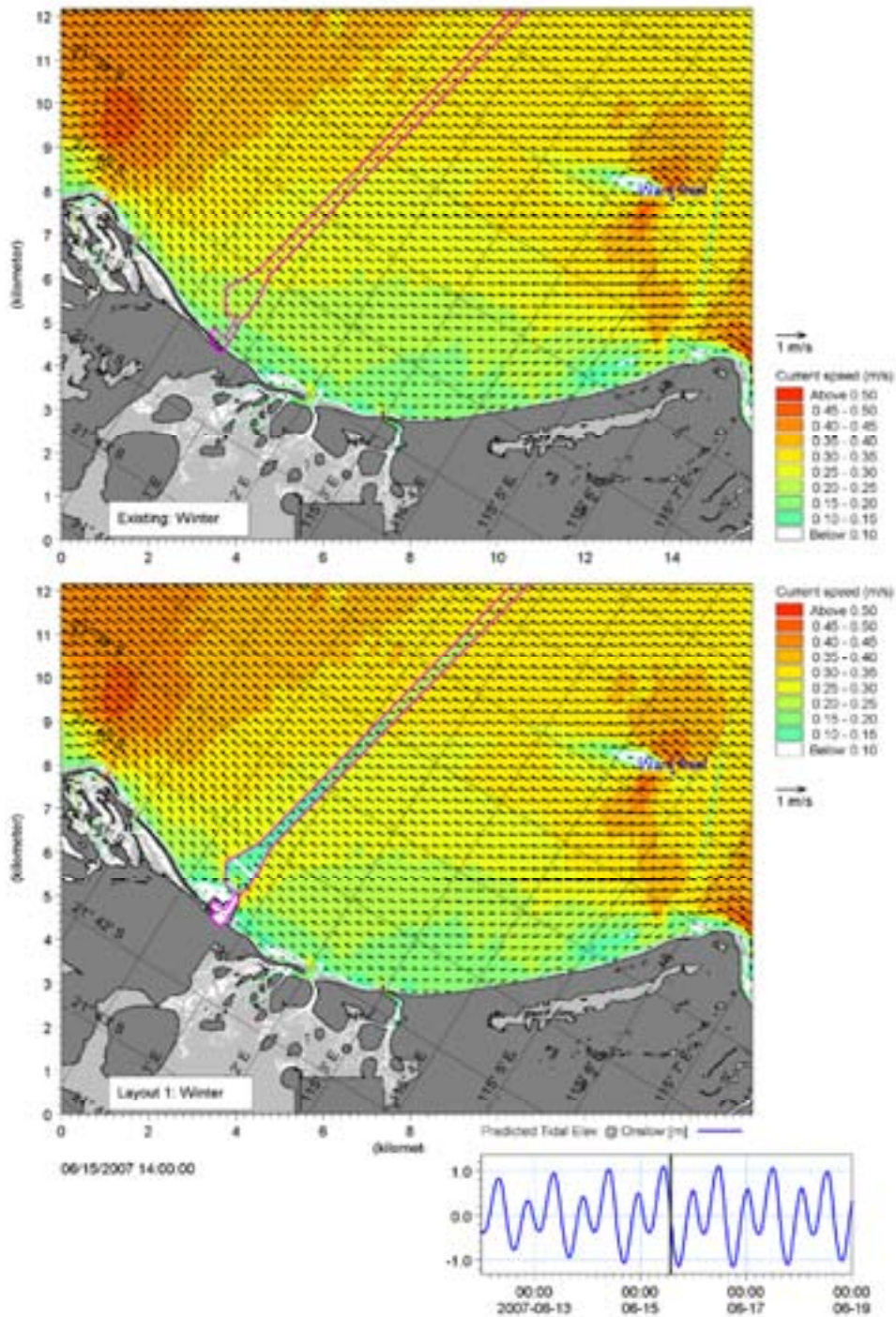


Figure 3.47 Example of current fields for existing conditions (top) and layout 1 (bottom) for ebb tide for winter conditions.

3-47

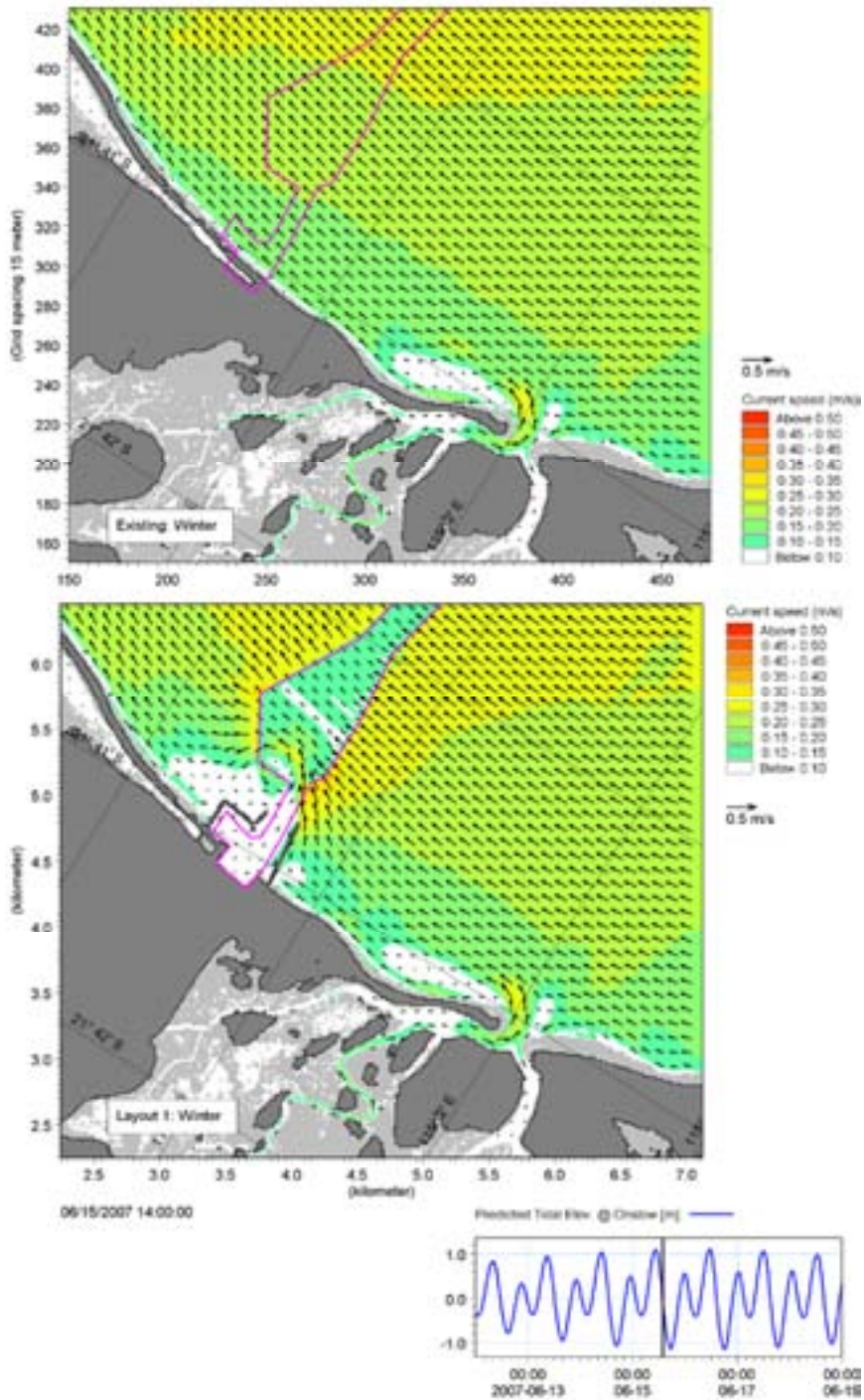


Figure 3.48 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for ebb tide for winter conditions.

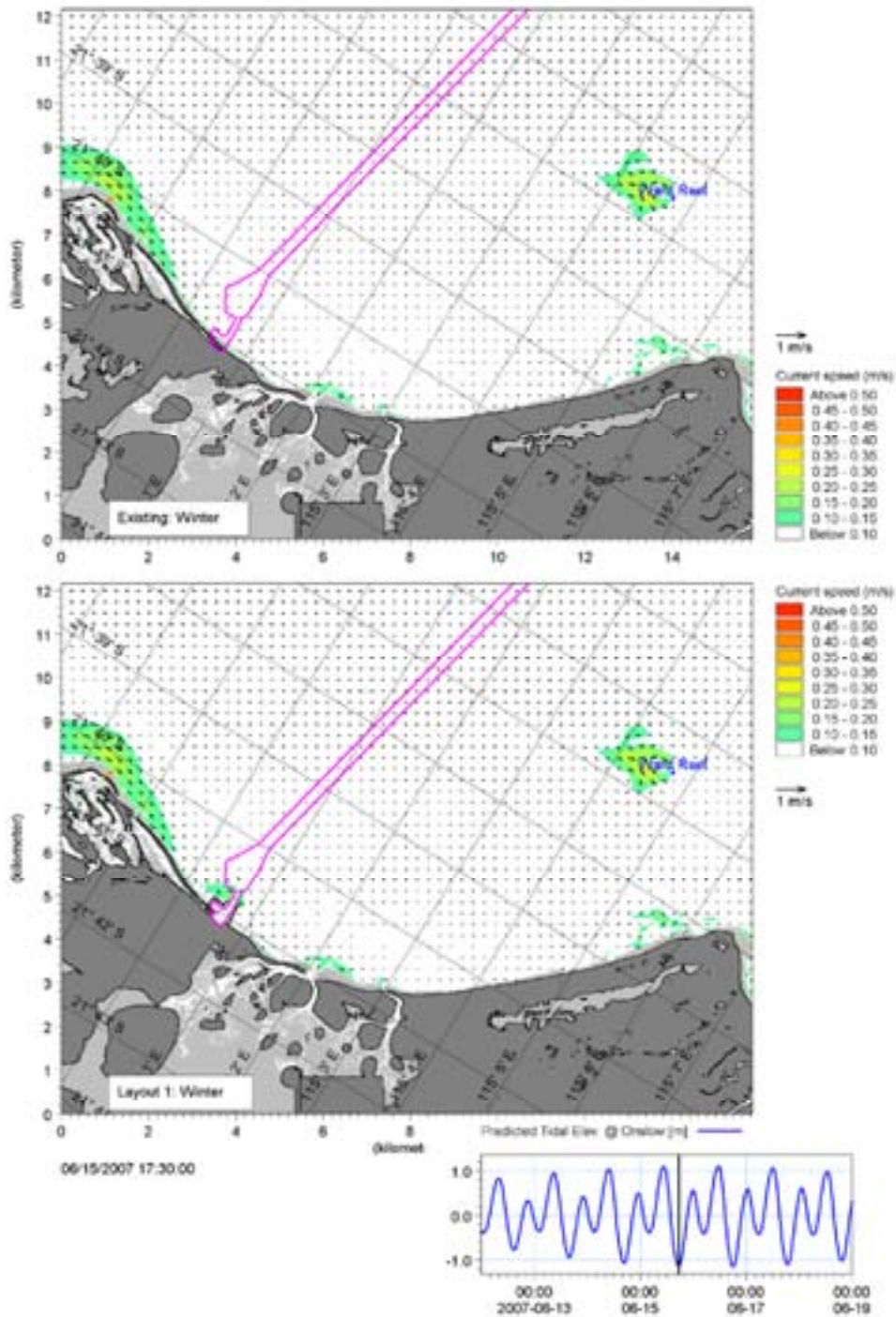


Figure 3.49 Example of current fields for existing conditions (top) and layout 1 (bottom) for low tide for winter conditions.

3-49

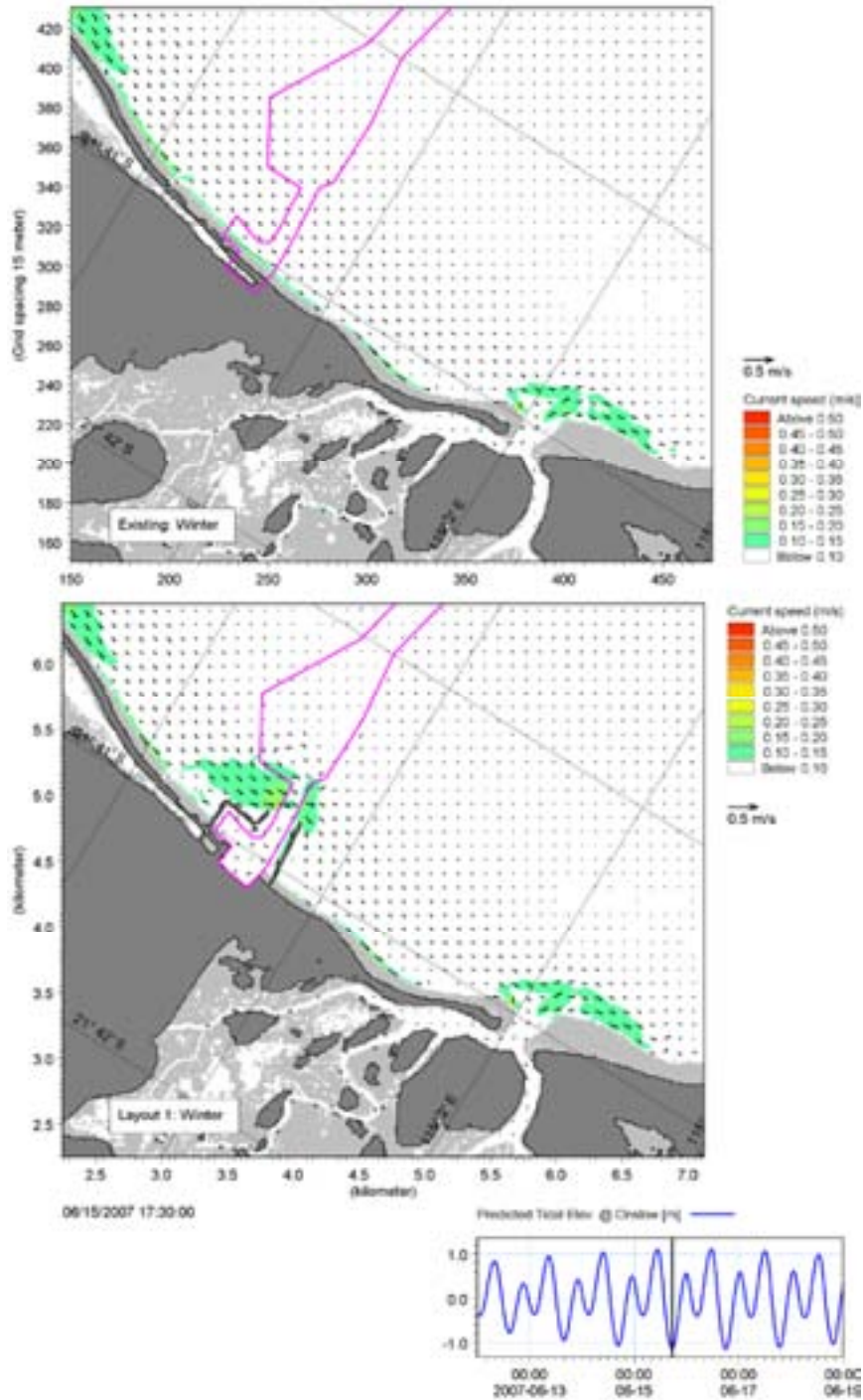


Figure 3.50 Details of current fields at MOF for existing conditions (top) and layout 1 (bottom) for low tide for winter conditions



3.2.5.1 Sample Summer High Wave Event

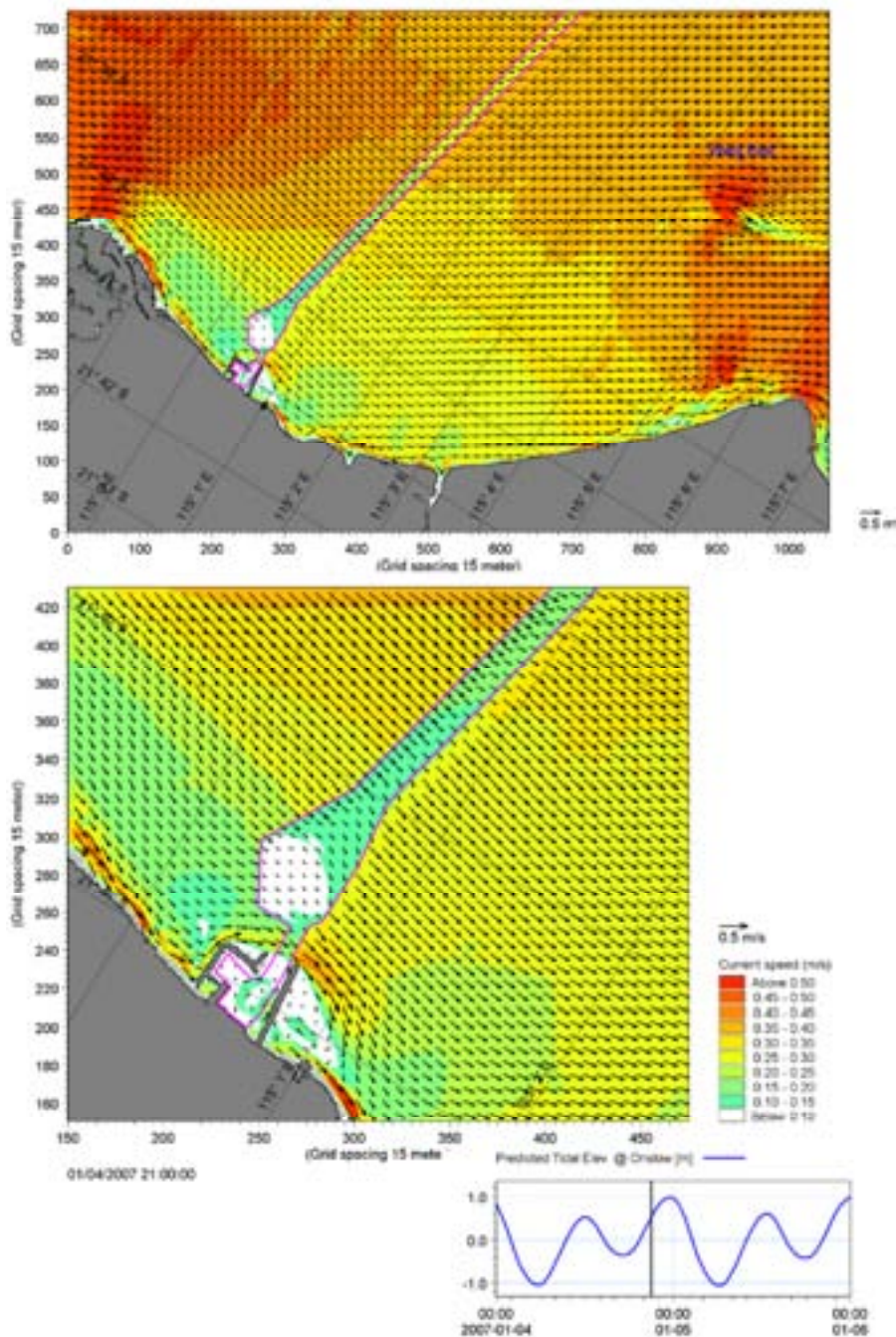


Figure 3.51 Example of flood tide current fields at two scales for "rough" wave conditions during summer.

3-51

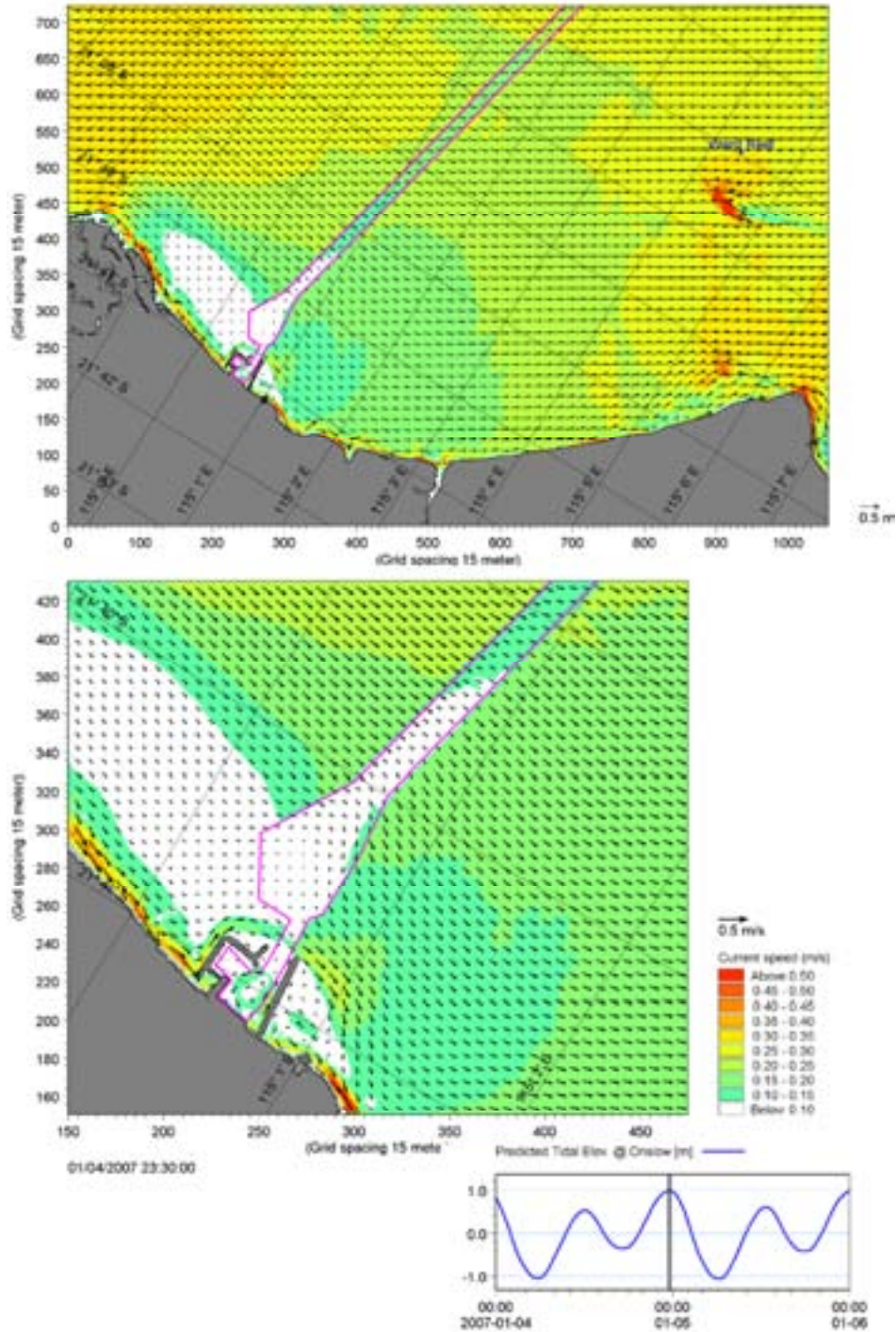


Figure 3.52 Example of high tide current fields at two scales for "rough" wave conditions during summer.

3-52

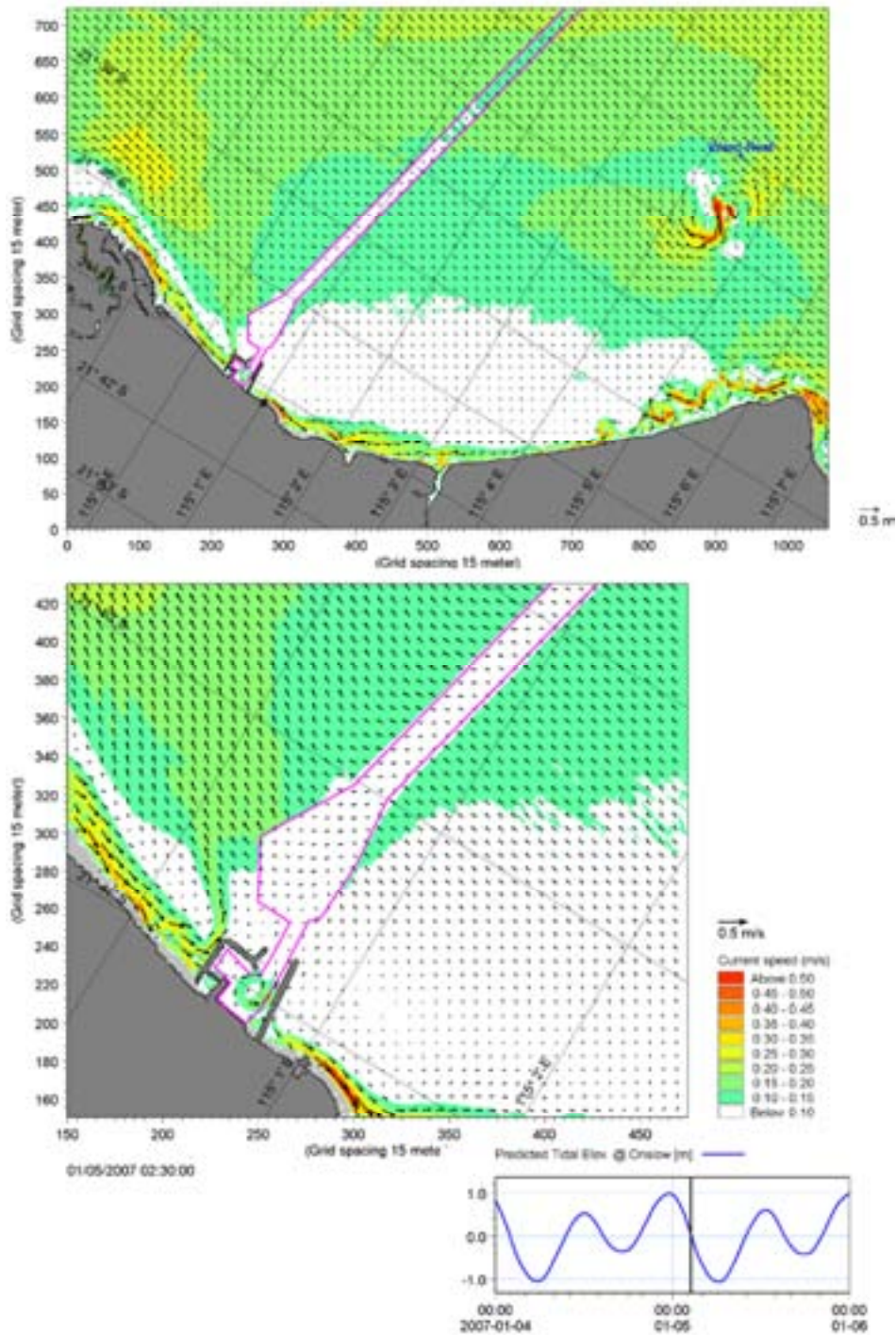


Figure 3.53 Example of ebb tide current fields at two scales for "rough" wave conditions during summer.

3-53

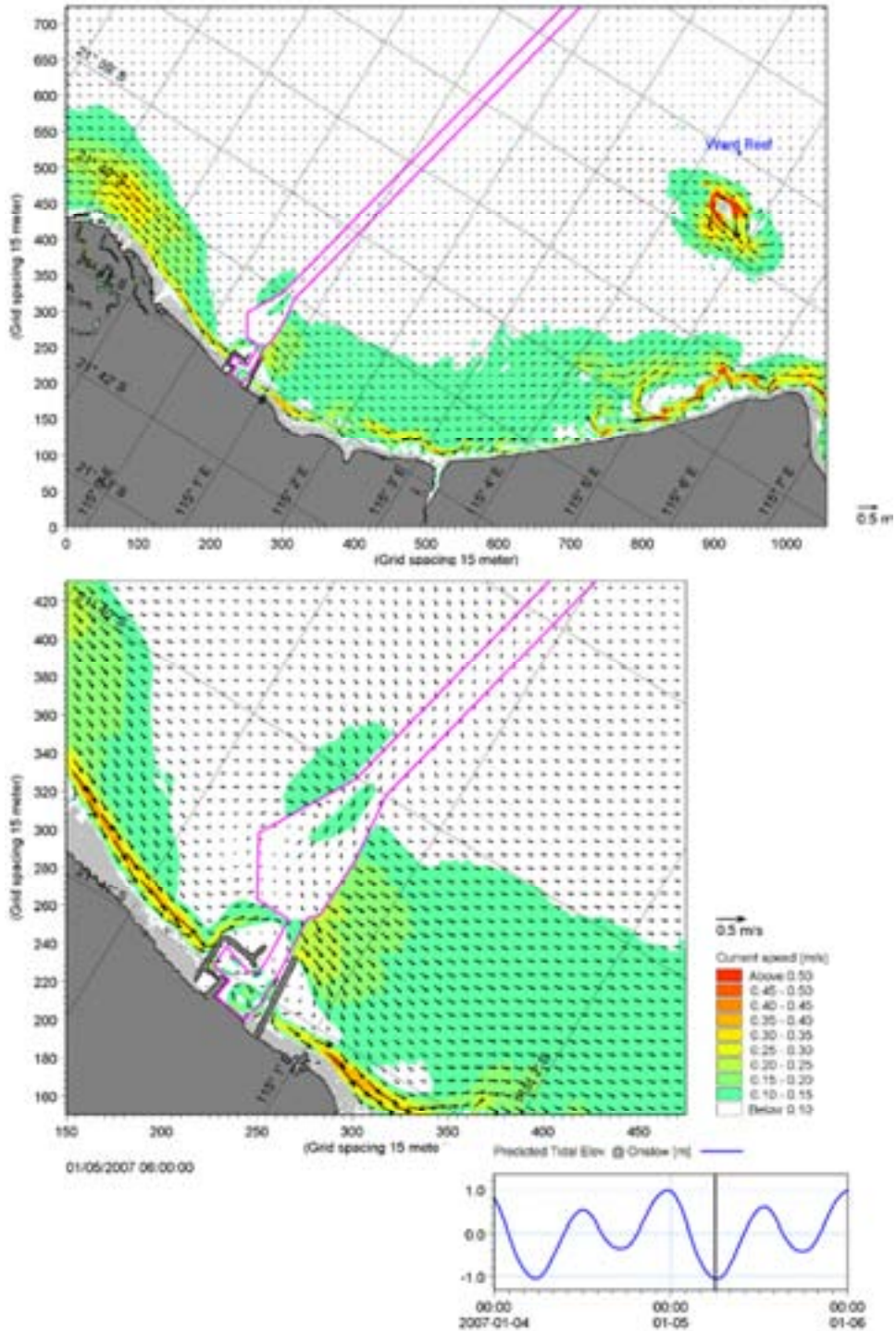


Figure 3.54 Example of low tide current fields at two scales for "rough" wave conditions during summer.



3.3 Two Dimensional Sediment Transport Modelling

3.3.1 Overview

Two dimensional sediment transport simulations have been carried out for representative summer and winter conditions. This is to:

- Provide a clearer picture of the sediment transport patterns and capacities.
- Address impacts of the project (including MOF, dredged navigation channel and PLF)
- Facilitate an assessment of the likely maintenance dredging requirements

Waves are important for two aspects in the modelling of non-cohesive sediment transport:

- Wave driven currents which typically is the main driver for currents in the surf zone
- Wave generated turbulence can stir sediments up and keep it suspended in the water column

The wave driven currents are included through the HD simulations (Section 3.1.5), while the sediment transport model includes the waves in the model and uses a complex formulation for combined waves and currents to derive the bed shear stresses and the amount of sediment in suspended and transported as bed load.

Sediment transport simulations were carried out for the detailed 45 m and 15 m grids, which can resolve the surf zone and the processes in the vicinity of the site.

It is noted that the model simulates transport capacity for the provided sediment maps, and does not take into account whether this sediment is available. In areas of exposed rocks and/or over reefs where the sediment supply is limited, the simulated transport capacities will be higher than the actual transport rates.

Insufficient information is available to establish a detailed map of the surface sediment in the area. Two sediment grain size distributions with mean grain sizes of $d_{50} = 0.1$ mm and 0.2 mm were simulated.

3.3.2 Modelling Results

Figure 3.55 to Figure 3.57 show three zoom levels of sediment transport fields averaged over the simulated spring-neap tidal period for representative summer wave and wind conditions for existing conditions and with layout 1(CUCA 3.2c) for mean grain size of 0.1 mm. Similar plots for a mean grain size of 0.2 mm during summer condition are shown in Figure 3.58 to Figure 3.60.

Winter conditions for $d_{50} = 0.1$ mm and 0.2 mm are shown in Figure 3.61 to Figure 3.66.

Figure 3.67 and Figure 3.68 show averaged transport patterns for $d_{50} = 0.1$ mm and 0.2 mm, respectively, for the simulated high wave case during summer.

The main results are discussed under the various assessments in the following Sections, but some important points to notice include:

- Sediment transport is highly non-linear with current speeds and wave heights (NB: non-linear colour scale).
- The overall current strengths are reflected in the simulated transport capacities with the highest transport capacities generally correlated to the areas with higher current speeds.
- Sediment transport is also highly non-linear with grain sizes. The simulations with constant grain size distribution throughout the area leads to high transport capacities over



the Gravel Banks, at Ward Reef and around Beadon Point. In reality, the coarse and resistant material in these areas will lead to lower transport rates.

- The dredged navigation channel and dredge material placement sites are located in an area with lower transport capacities.
- The transport capacity in the dredged areas is reduced significantly, indicating that most of the sand fractions transported into the dredged areas will be trapped within the dredged areas and cause infill of the channels and basins.
- Summer conditions lead to net easterly directed transport, while winter conditions lead to net westerly directed transport.
- The clear sediment path way in the surf zone is interrupted by the MOF.
- Current contractions around the MOF leads to higher transport rates seaward of the breakwaters, but the rates still drop to low levels within the MOF approach channel between and seaward of the breakwaters, and the sediment bypassing the MOF under normal conditions will be minimal.
- Even during the simulated case with high waves, the simulated coarser (littoral) sediments accumulate in the dredged MOF approach channel, leading to the conclusion that the bypass of littoral sand of the MOF is minimal.
- There is a bypass system over the ebb tide bar at the tidal inlet to Hooley Creek (i.e. not all sediment transported along the sandspit in front of Hooley Creek goes into building up the sandspit).
- Following the current patterns, there is a clear downdrift sheltered zone to the east of the eastern MOF breakwater during summer, while the corresponding zone to the west of the western MOF breakwater during winter is less pronounced.
- For $d_{50} = 0.2$ mm, which is generally representative of the beach material, there is neutral to slight eastward transport in the surf zone between entrance point and the site. This is due to the rotation of the coastline.

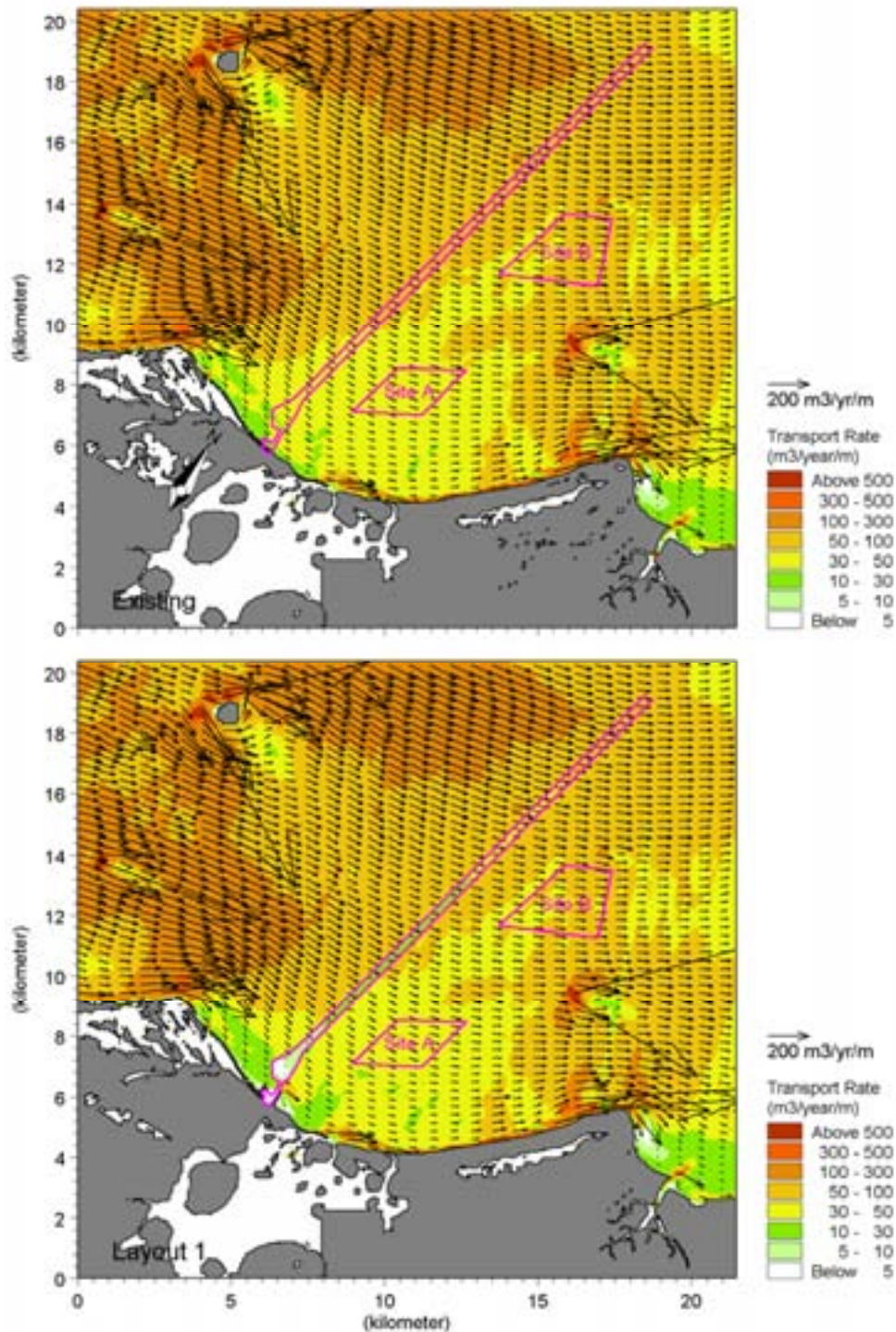


Figure 3.55 Average sediment transport field for mean grain size of 0.1mm during summer condition in 45m grid resolution for existing (top) and layout 1(bottom).

3-57

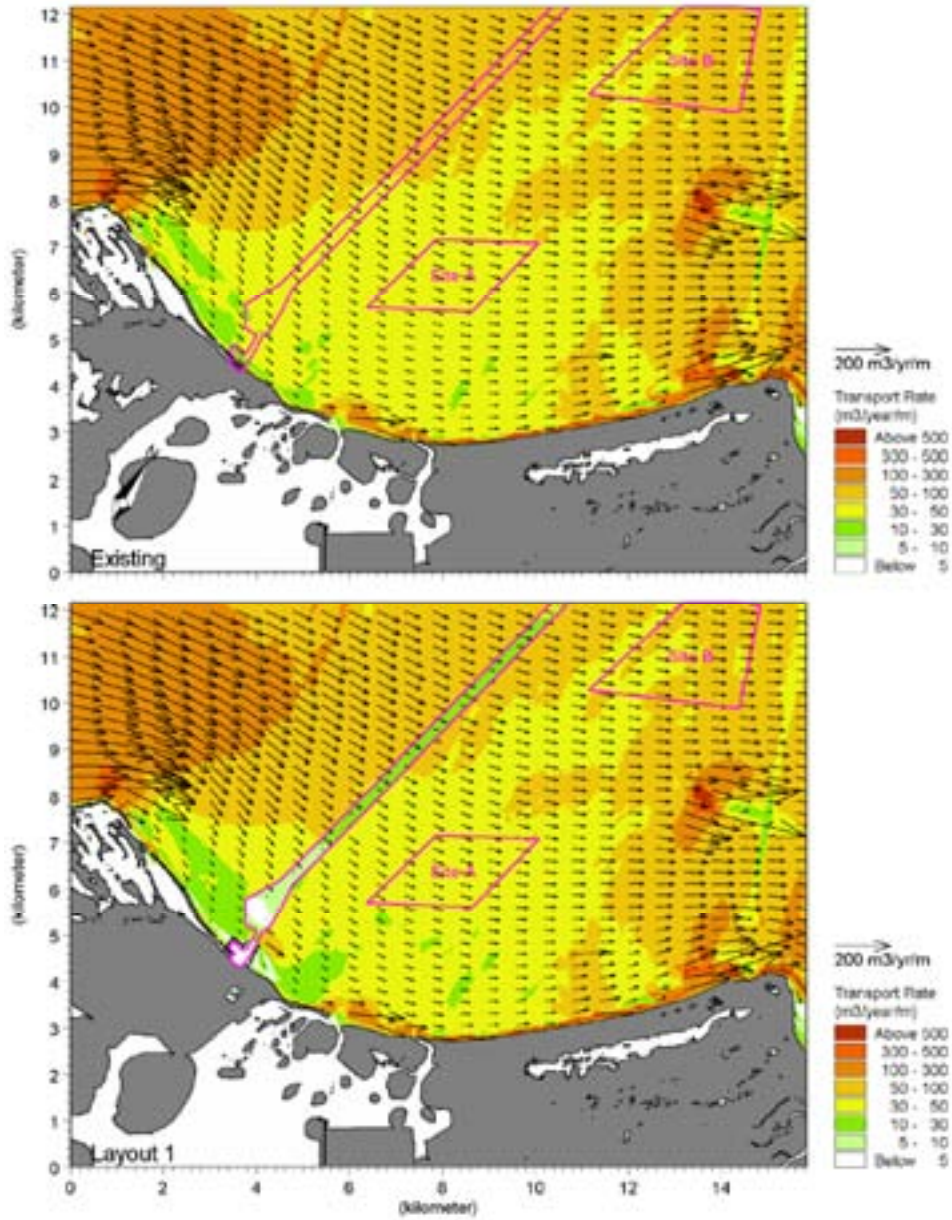


Figure 3.56 Average sediment transport field for mean grain size of 0.1mm during summer condition in 15m grid resolution for existing (top) and layout 1(bottom)

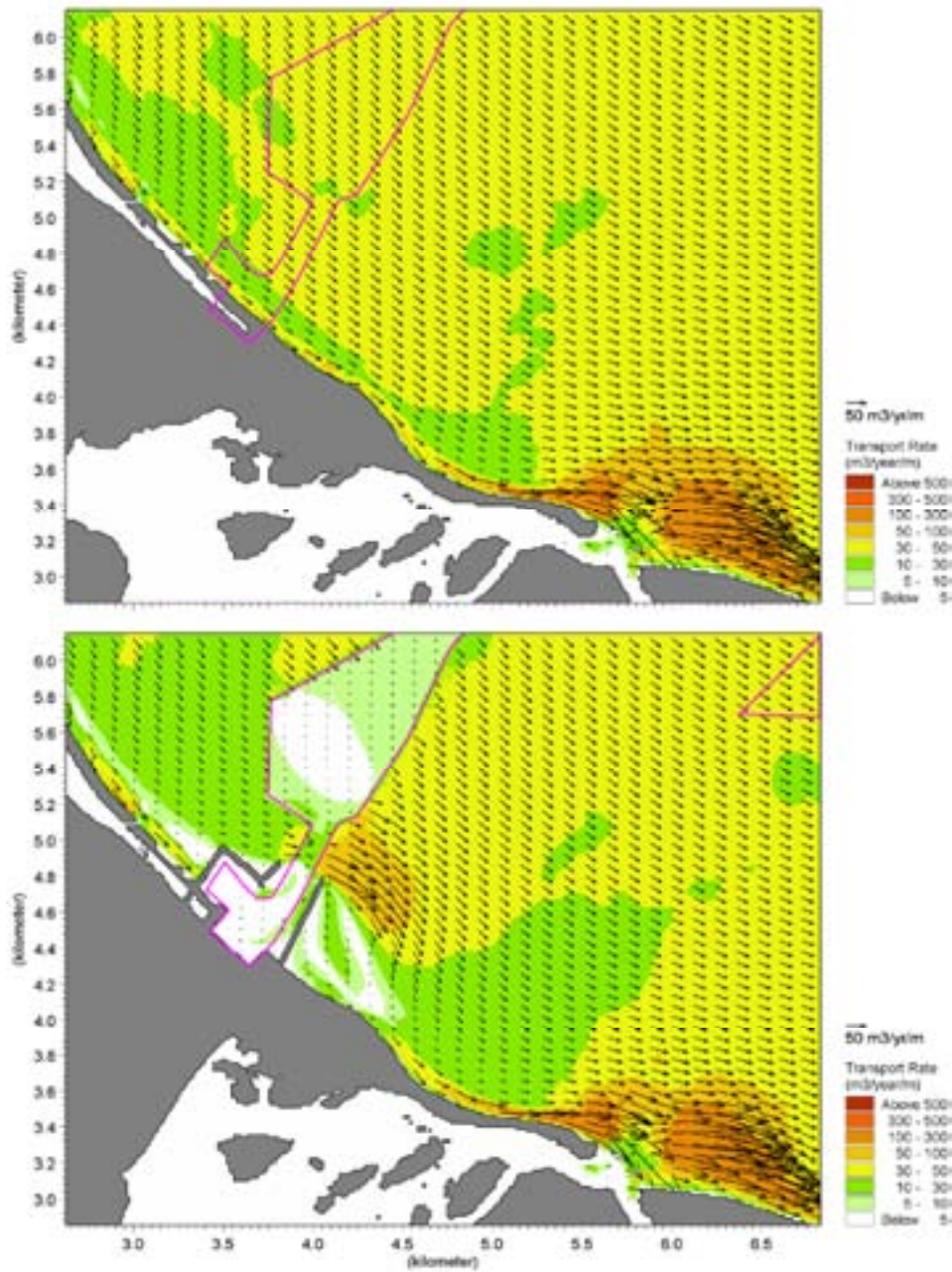


Figure 3.57 Average sediment transport field for mean grain size of 0.1mm during summer condition in detailed view at rivermouth and proposed development site for existing (top) and layout 1(bottom).

3-59

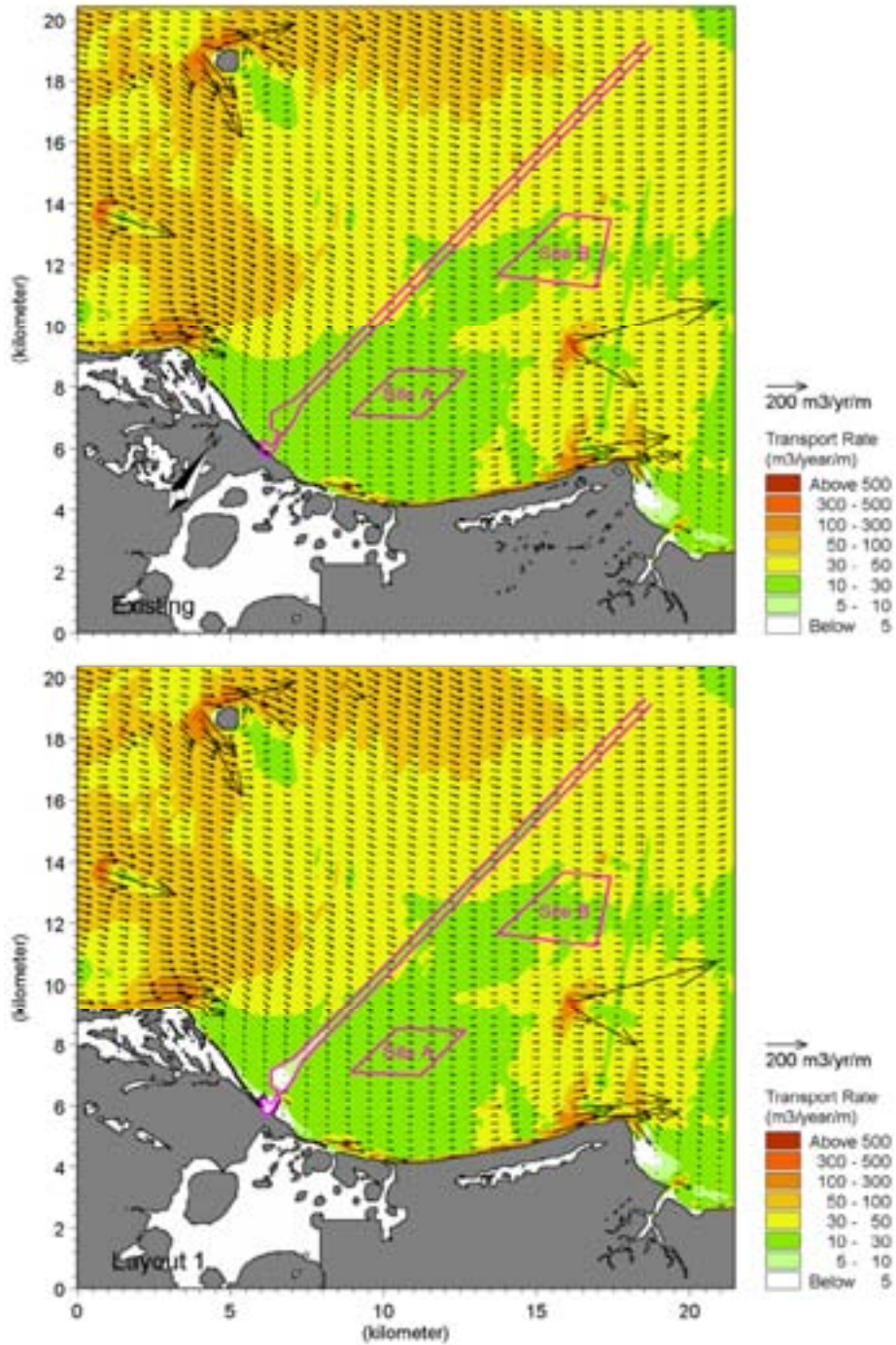


Figure 3.58 Average sediment transport field for mean grain size of 0.2mm during summer condition in 45m grid resolution for existing (top) and layout 1(bottom).

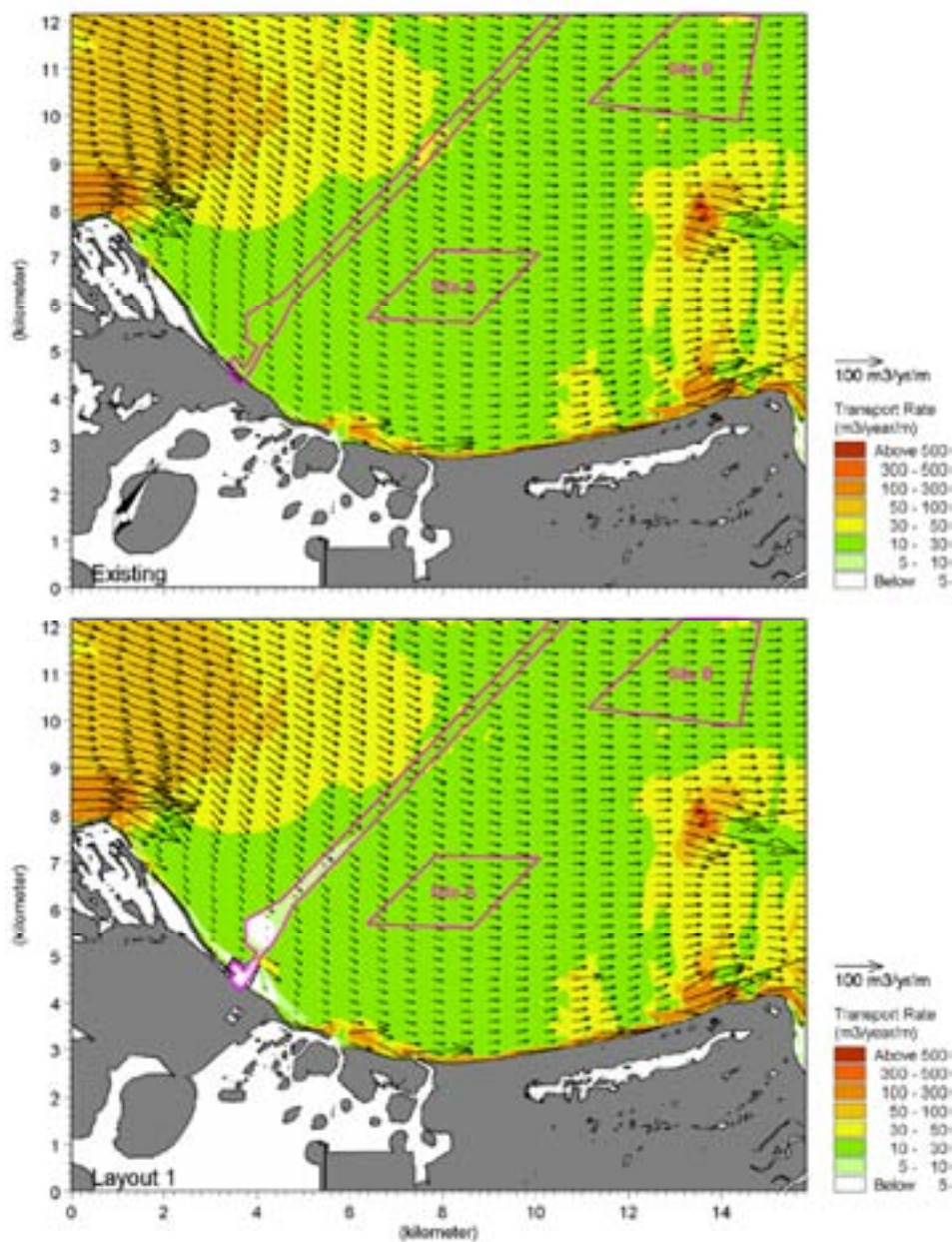


Figure 3.59 Average sediment transport field for mean grain size of 0.2mm during summer condition in 15m grid resolution for existing (top) and layout 1(bottom).

3-61

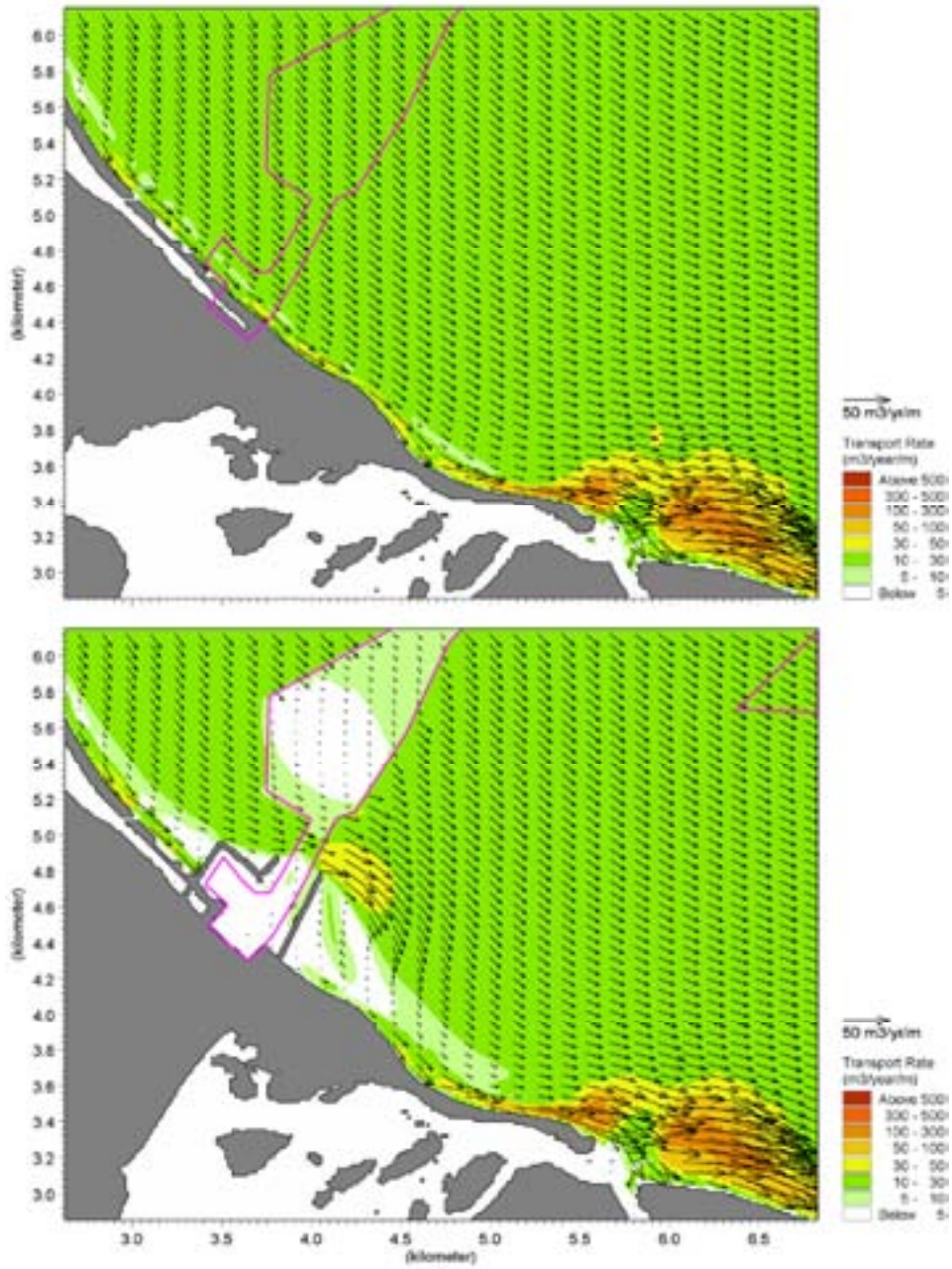


Figure 3.60 Average sediment transport field for mean grain size of 0.2mm during summer condition in detailed view at rivermouth and proposed development site for existing (top) and layout 1(bottom).

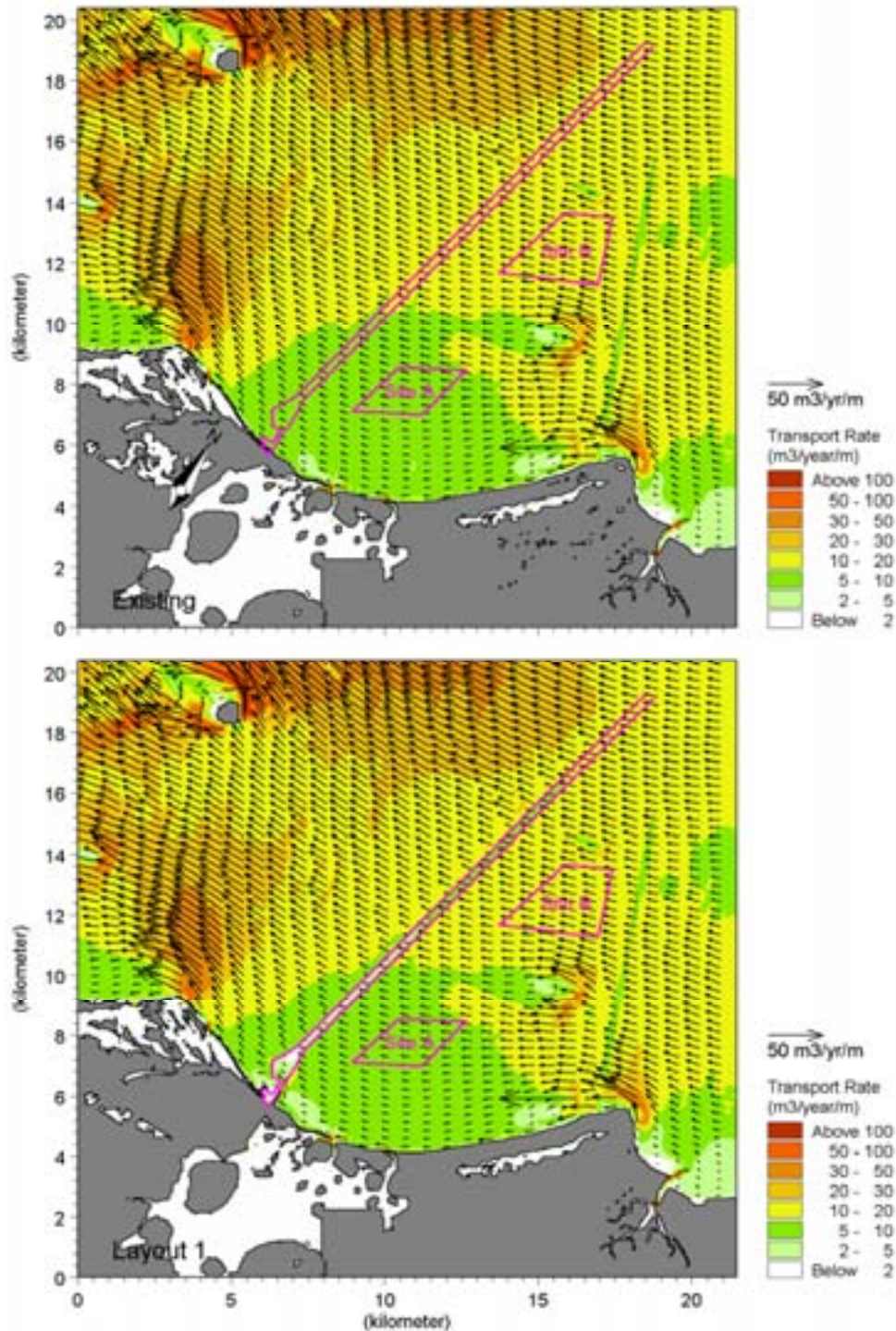


Figure 3.61 Average sediment transport field for mean grain size of 0.1mm during winter condition in 45m grid resolution for existing (top) and layout 1(bottom).

3-63

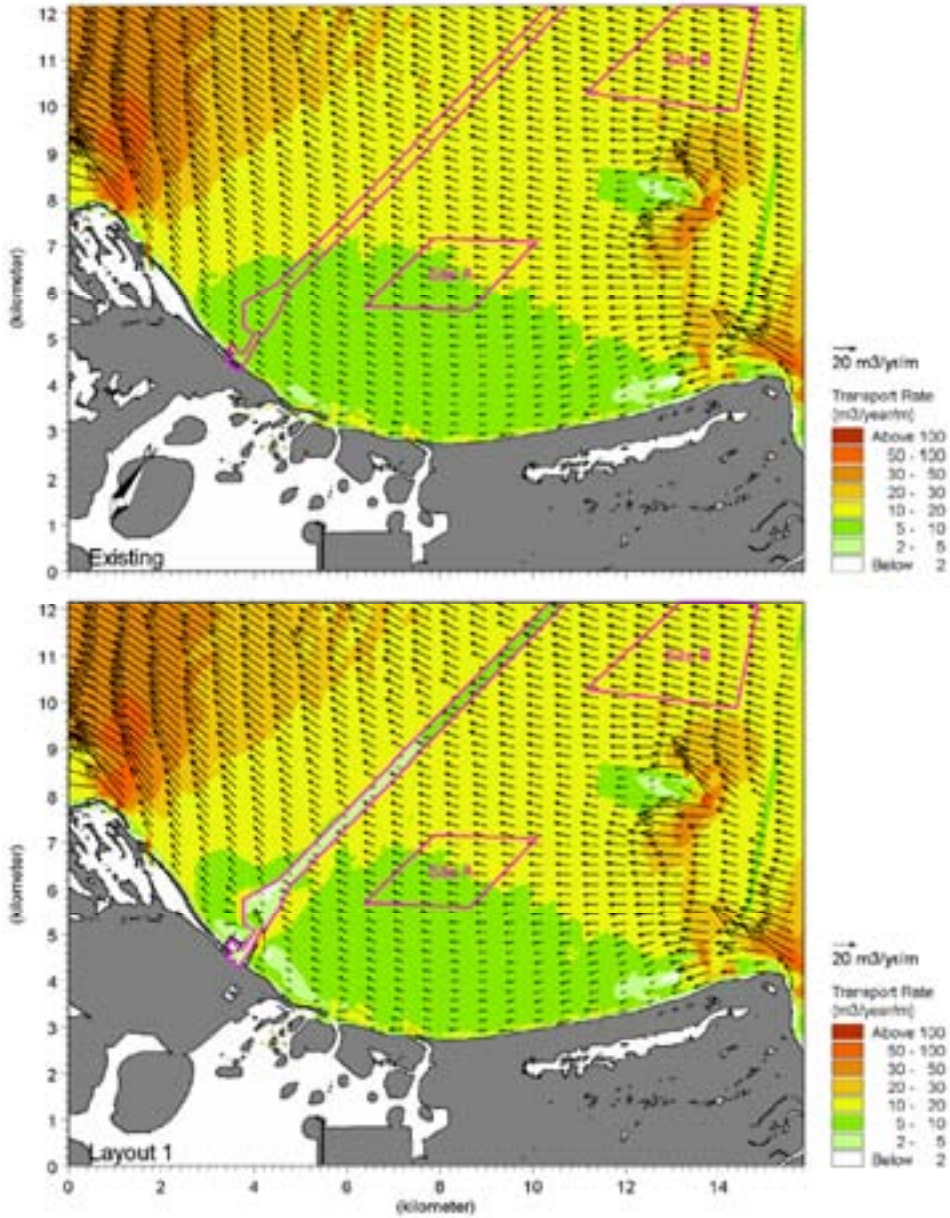


Figure 3.62 Average sediment transport field for mean grain size of 0.1mm during winter condition in 15m grid resolution for existing (top) and layout 1(bottom).

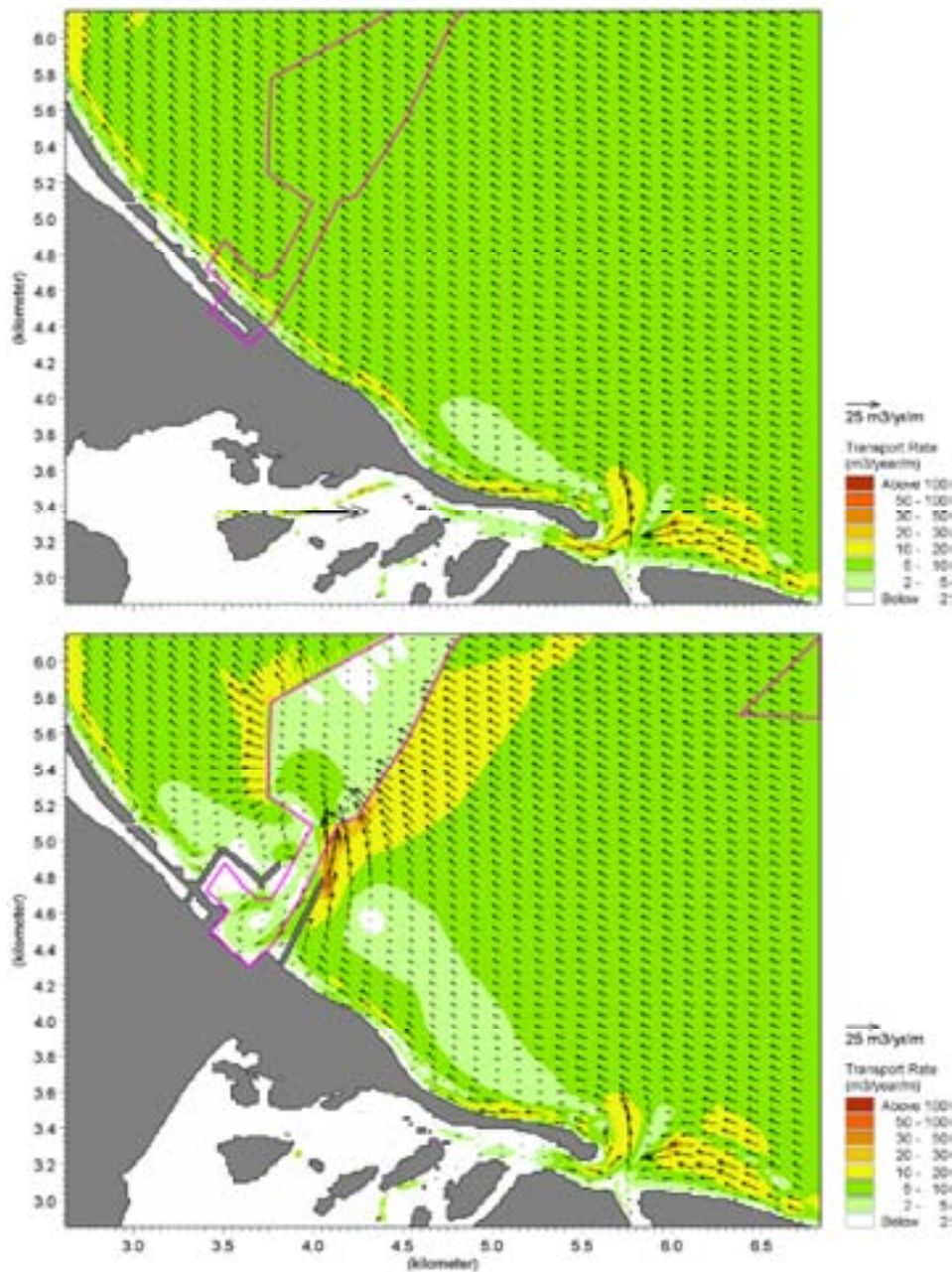


Figure 3.63 Average sediment transport field for mean grain size of 0.1mm during winter condition in detailed view at rivermouth and proposed development site for existing (top) and layout 1(bottom).

3-65

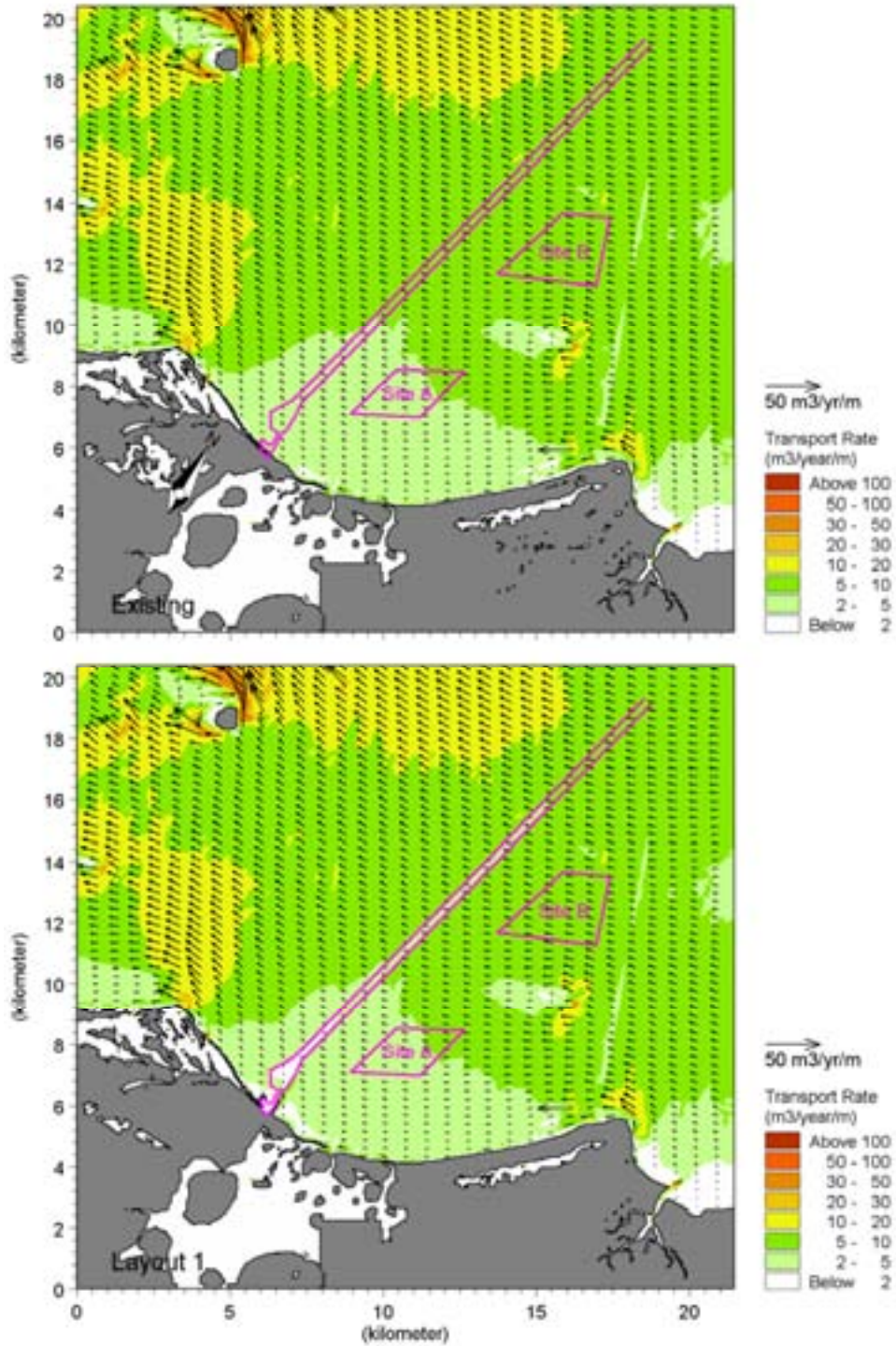


Figure 3.64 Average sediment transport field for mean grain size of 0.2mm during winter condition in 45m grid resolution for existing (top) and layout 1 (bottom).

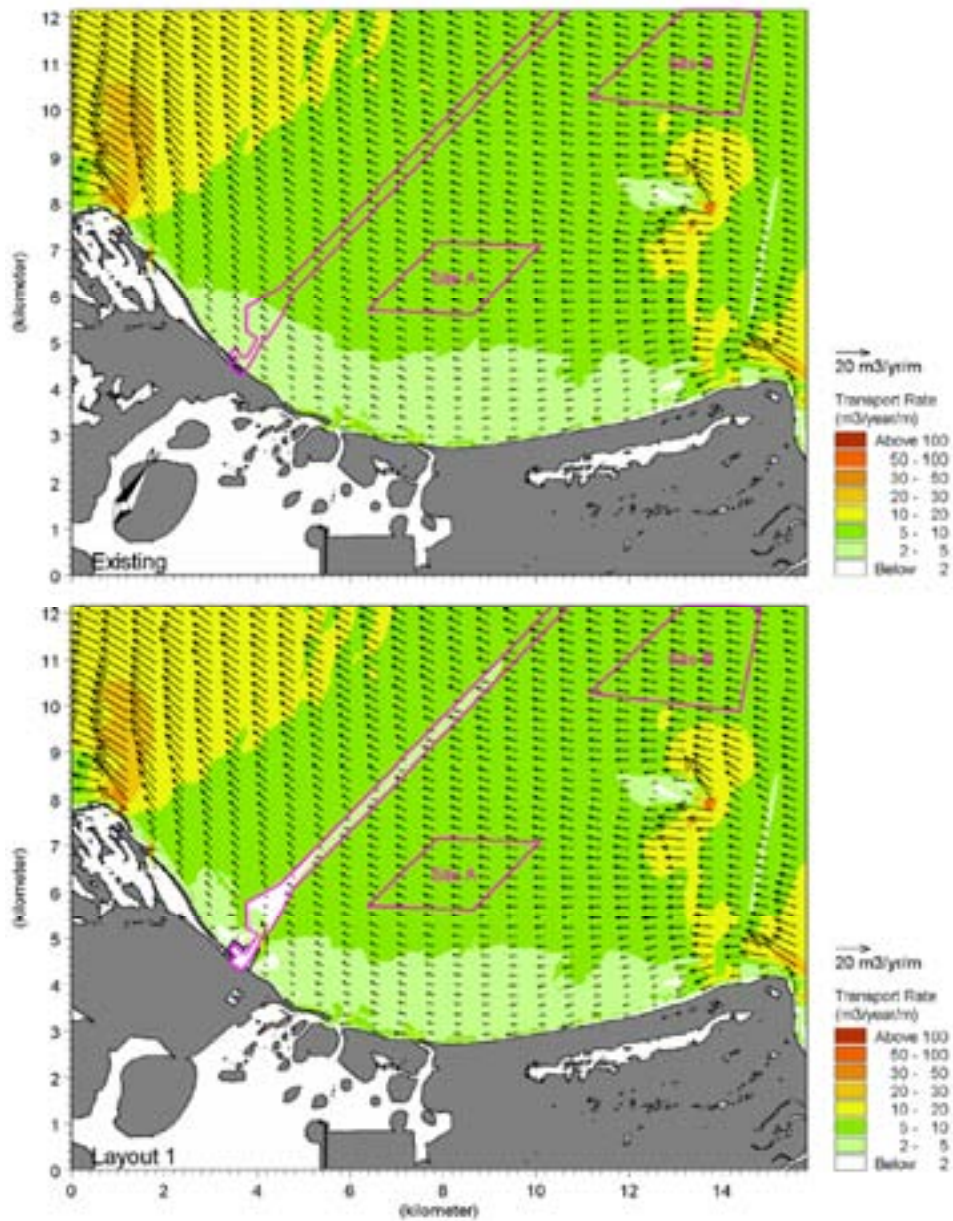


Figure 3.65 Average sediment transport field for mean grain size of 0.1mm during winter condition in 15m grid resolution for existing (top) and layout 1(bottom).

3-67

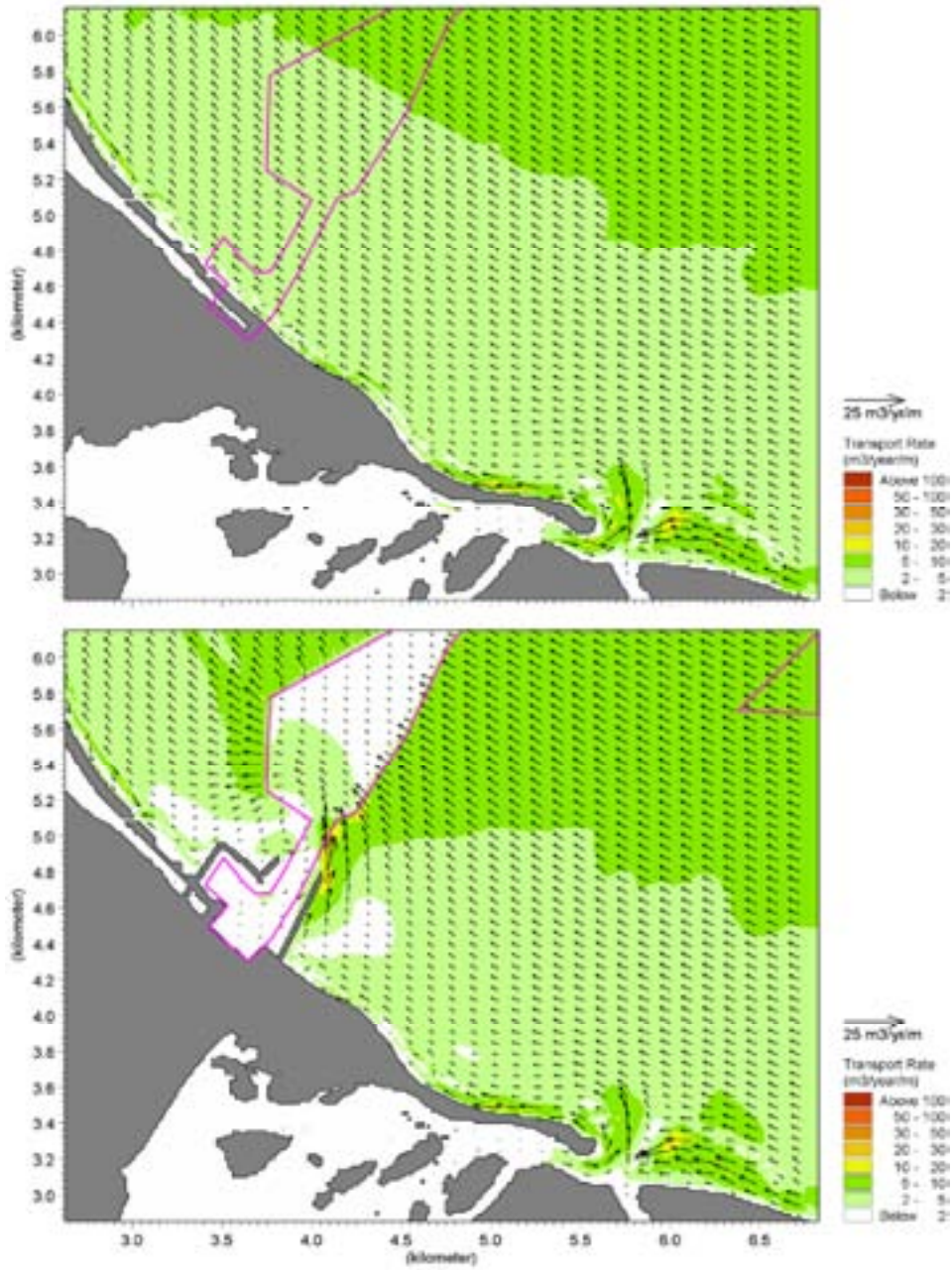


Figure 3.66 Average sediment transport field for mean grain size of 0.2mm during winter condition in detailed view at rivermouth and proposed development site for existing (top) and layout 1(bottom).



3.3.2.1 Sample Transport Patterns for High Wave Event during Summer

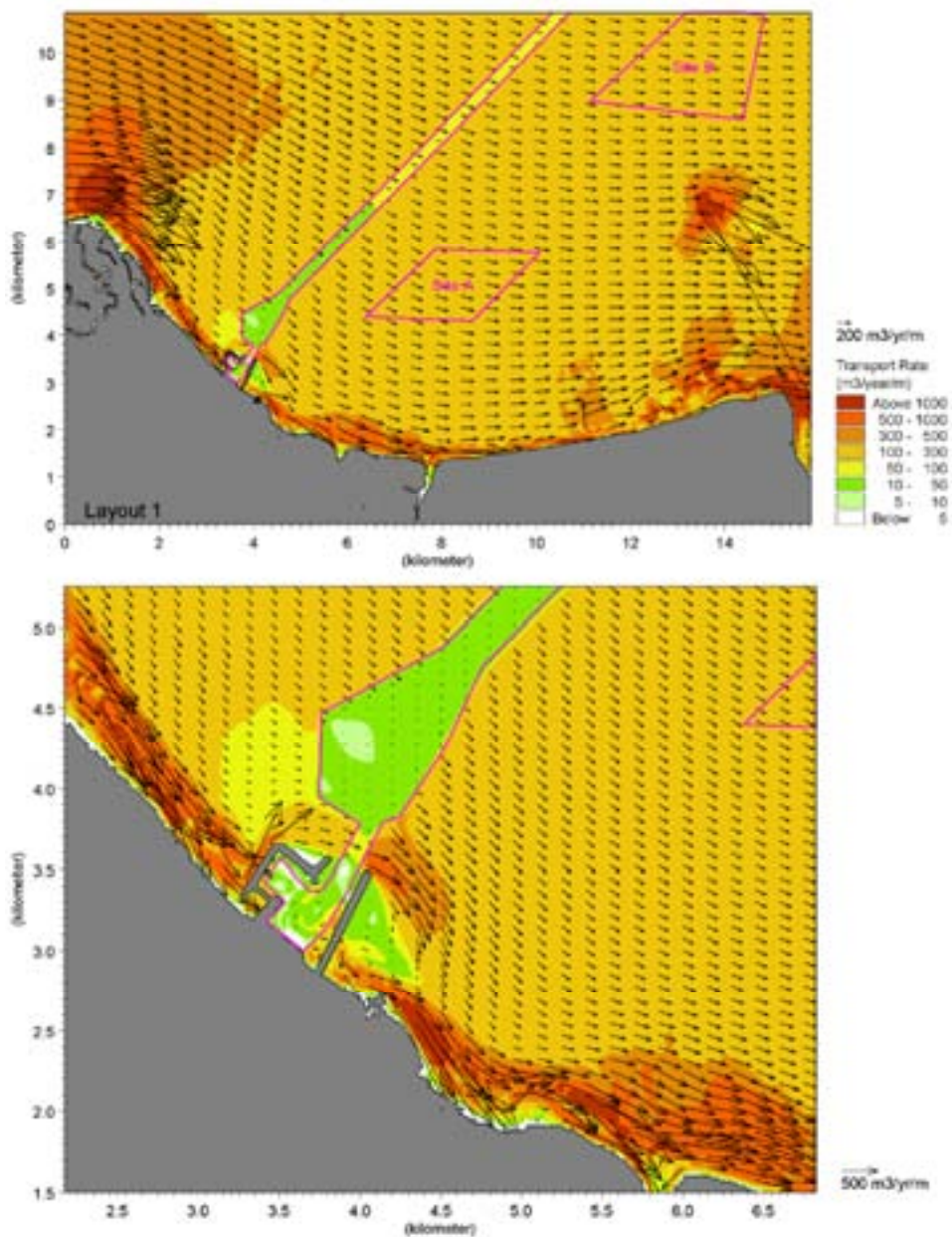


Figure 3.67 Average sediment transport field for mean grain size of 0.1mm during “rough” summer conditions in 15m grid resolution for layout 1(top) and with view at MOF and PLF are (bottom).

3-69

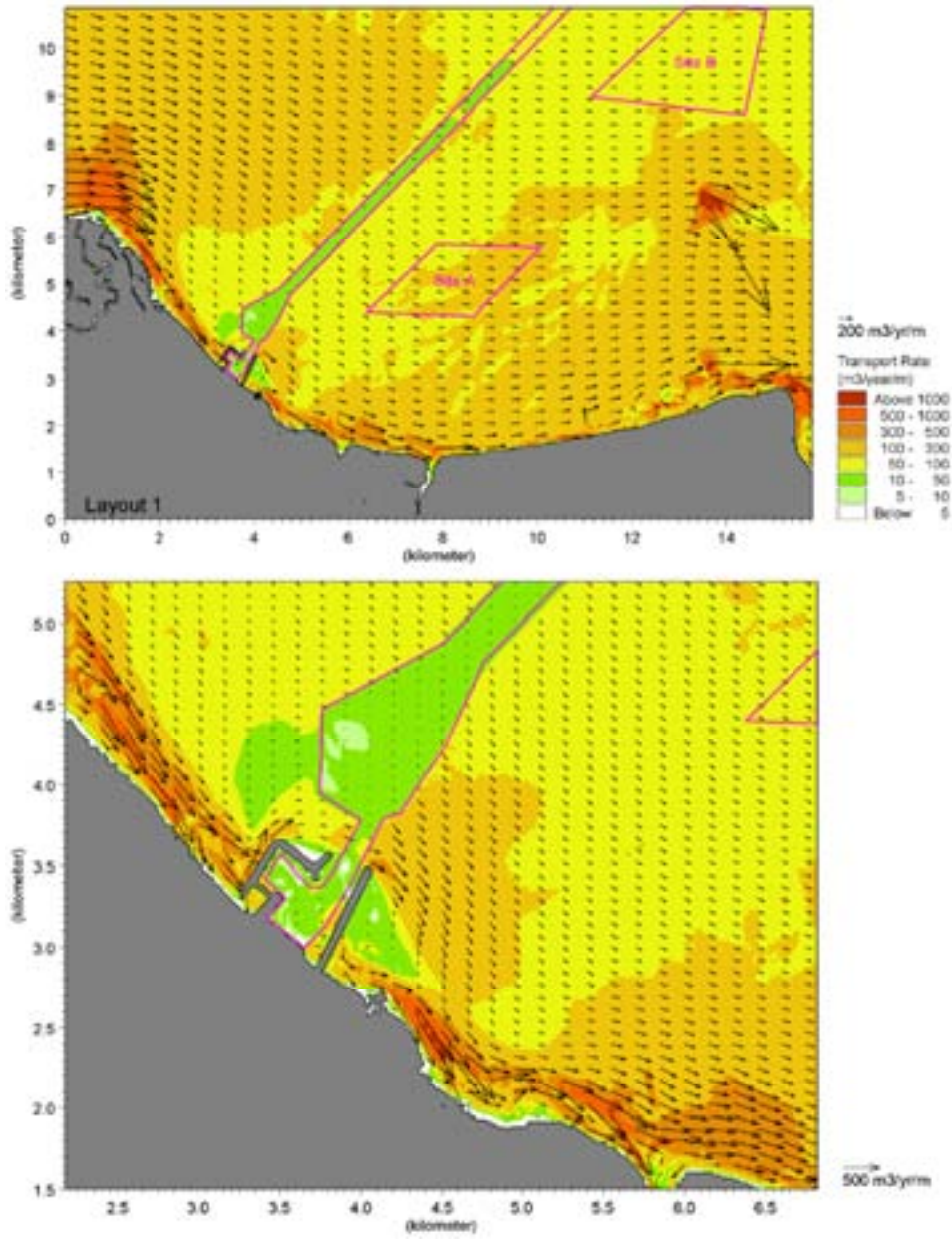


Figure 3.68 Average sediment transport field for mean grain size of 0.2mm during "rough" summer condition in 15m grid resolution for layout 1 (top) and with detailed view at MOF and PLF area (bottom).



3.4 Coastal Sediment Transport and Budget

Quantification of the littoral sediment transport is required to address the potential morphological impacts incurred by the MOF and dredged areas. Whereas the waves at the site generally are small, the littoral sediment transport is primarily driven by the waves. There can be significant variations in transport rates from year to year, and it is therefore desirable to have longer term wave information to investigate inter-annual variations and derive longer term statistics.

Damara WA (2010) used analysis of historical information and satellite images to estimate net transport rates. This is the only available method to directly estimate the transport rates from data, but has significant uncertainties as a number of relatively crude assumptions need to be made.

Littoral transport modelling is a valuable tool to try to derive transport rates based on historical information, but is also subject to significant uncertainties, both in relation to the quality and quantity of data available and the model accuracy. Sediment transport is highly non-linear with the driving forces, and small changes in input parameters and model setup can thus lead to significant changes in results.

3.4.1 Approach and Methodology

Limited nearshore data (1 year) as well as offshore data has been available for the Project. Wave modelling based on winds only to drive the model has, however, shown a reasonably good agreement between measured and simulated wave conditions in the nearshore area. The wave model was thus set up to simulate 10 years of waves based on wave statistics on the offshore boundary and wind fields to drive the model. This enabled the derivation of wave conditions at selected locations along the coastline to drive the littoral drift model.

Whereas the littoral drift model takes wave refraction and shoaling into account, the model is what is called a 1-line model. It assumes in principle straight and parallel depth contours, and these are used to calculate wave refraction and diffraction. For the present site where offshore dominant wave conditions as well as winds are coming almost parallel to the depth contours, 2D refraction is very important. The waves are therefore extracted from the wave model as close to the wave breaking zone as possible without extending into the surf zone. An example of the differences when extracting further nearshore is shown in Figure 3.69 which shows differences between a wave rose extracted at about -6 m and -4 m. Using the waves extracted at -6 m would lead to a significant component of the waves directed off-shore for the coastline between Entrance Point and Hooley Creek, which would underestimate the easterly directed transport.

The littoral sediment transport capacities have been investigated by applying the littoral drift module LITDRIFT, of DHI's LITPACK littoral process modelling system. The module calculates the long-shore currents and sediment transport rates over a (cross-shore) profile of depth. The model has been established for selected profiles along the coastline (Figure 3.70).

Variations in the water levels are included in the model throughout the simulation period. Best-estimate cross-shore variations of the profile and the sediment properties have been included based on the data available.

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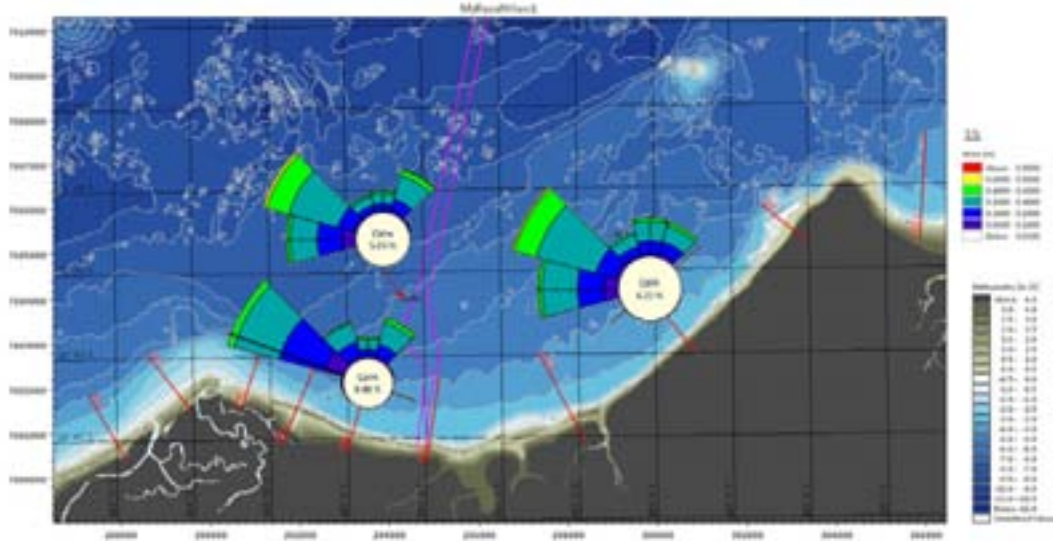


Figure 3.69 Sample of model derived waves roses – the waves undergo significant refraction as the approach the coastline, in particular between Entrance Point and Hooley Creek where the coastline orientation is basically parallel to the dominant wave direction.

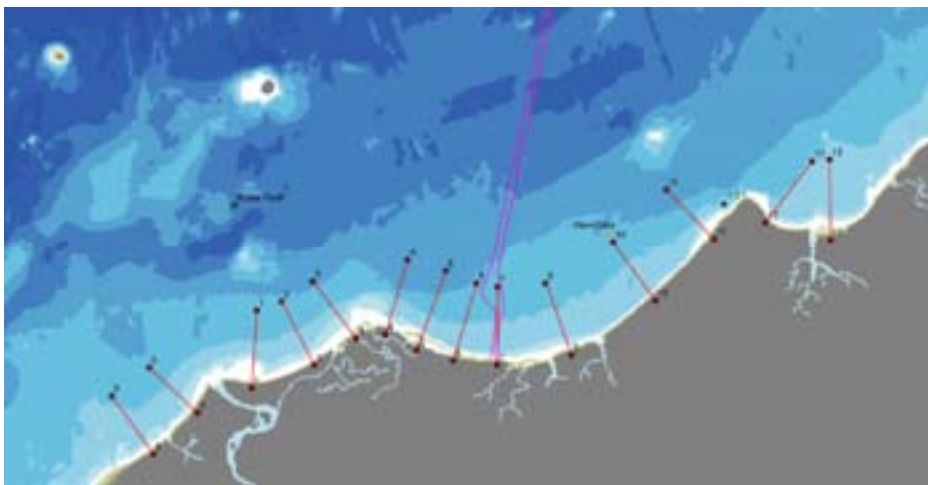


Figure 3.70 Profiles littoral drift modelling.



3.4.2 Results

Examples of simulated cross-shore distributions of annual littoral transport rates are shown in Figure 3.71 for profiles 7 and 11. This illustrates net easterly directed transport rates and a reduction in transport capacity from profile 7 to profile 11. The wave driven littoral transport takes place in a narrow band along the coastline and primarily within the -3 m MSL contour.

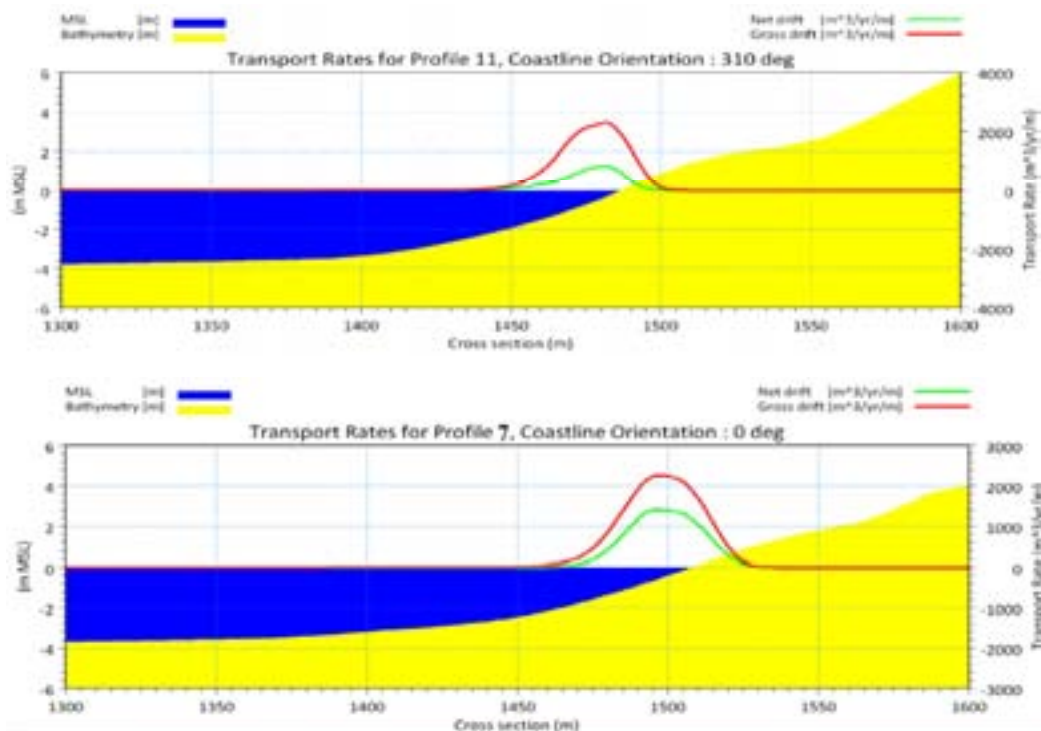


Figure 3.71 Cross-shore distribution of average annual net and gross littoral transport rates. A positive net transport corresponds to easterly directed transport along the coast.

Ten years of simulated wave data has been modelled in the littoral drift model. Annual net littoral transport rates for the 10 years are illustrated for Profile 6 immediately to the west of the site in Figure 3.72. This shows consistent net easterly transport, but more than a factor 3 in the range of magnitudes from less than 20,000 m³/year to more than 60,000 m³/year. The average over the 10 years is in the order of 45,000 m³/year net easterly transport.

This should be compared to an estimated value of 100,000 m³/year based on analysis of the historical coastline evolution by Damara WA (2010). Whereas there is a large difference between the values, the uncertainties for both assessments are, as previously described, significant, and as such they are comparable. A representative net annual transport rate in the order of 50-100,000 m³/year is considered a reasonable estimate of the net annual littoral transport rates.

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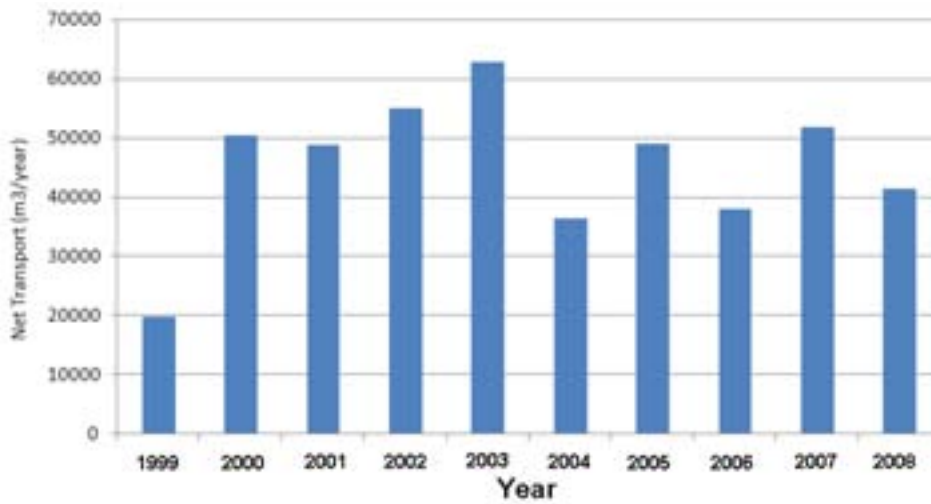


Figure 3.72 Simulated net annual transport rates (m³/year) over 10 years at profile 6 (immediately west of site).

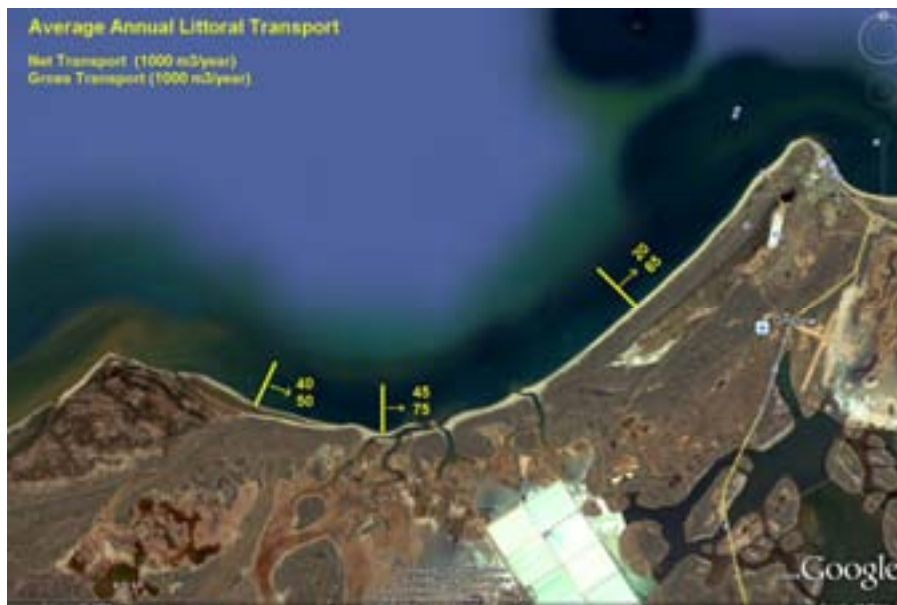


Figure 3.73 Estimated sediment budget in the vicinity of the site based on the littoral drift modelling.

The transport rates obviously vary along the coastline as outlined by Damara WA (2010). Figure 3.73 illustrates transport rates in the vicinity of the site. A moderate, easterly directed, transport takes place along the sandspit between Entrance Point and the site. The net transport is close to the gross transport rates, indicating that the westerly directed transport along this section of coastline is very limited.

Both the net and gross transport increases as the coastline orientation becomes more north-facing at the site. Further to the east of the site towards Beadon Point, the net littoral drift is reduced and becomes much smaller than the gross transport rate, indicating that the coastline orientation is more aligned towards the incoming waves.

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4.0 COASTAL IMPACTS

The net littoral transport at the site was estimated to be in the order of 50-100,000 m³/year easterly on average (Section 3.4.2). The transport at the site is primarily easterly, but there is a smaller westerly directed component during winter conditions.

The 2D sediment transport assessment showed that the MOF essentially block the entire littoral transport. Even for a high wave event, the littoral sediment transport bypassing the MOF breakwaters is trapped in the dredged MOF approach channel (Figure 4.1).

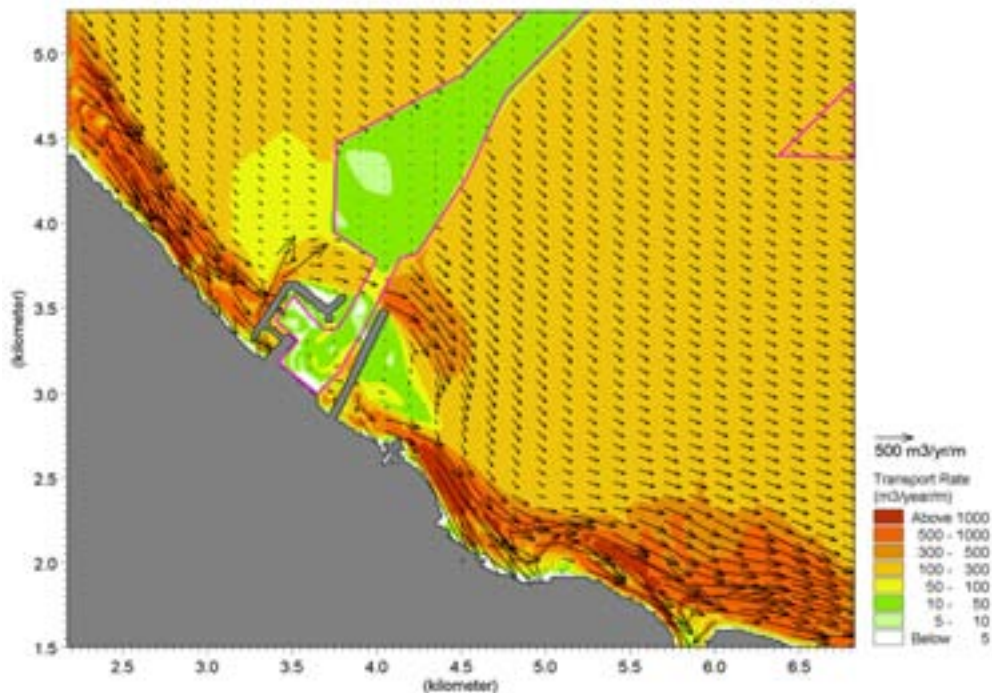


Figure 4.1 Example of average transport rates for rough wave conditions during summer.

4.1 Expected Morphological Impacts West of MOF

Overall, the blockage of the net easterly transport leads to accumulation to the west of the western MOF breakwater and erosion along a section of the coastline to the east of the eastern breakwater, assuming no mitigation measures are taken.

In the longer term, the coastline will build up along the western breakwater, and gradually more sediment will start to bypass the western breakwater. Simulations till date indicate that the sand fractions will be trapped in the dredged MOF approach channel.

Although a long-term build-up of material is expected to the west of the MOF, some erosional impacts cannot be ruled out. During winter conditions, extended periods of westerly transport may occur. This may lead to some erosion to the west of the western breakwater. Figure 4.2 shows simulated average transport patterns for simulated winter conditions. The westerly directed littoral transport is deflected seaward into the MOF approach channel and PLF basin. A circulation cell has developed in front of the breakwater entrance. The littoral transport only re-establishes slowly,



and erosion may occur more than 500 m west of the western MOF breakwater. This may affect and potentially lead to a breach of the sandspit found in this area unless sufficient sediment has accumulated during summer conditions to act as a buffer.

Another risk in the initial phase after construction is the trapping of sediment in the sheltered area close to the western breakwater. This may act as a sediment sink that draws sediment in from the adjacent coastline, which can cause erosion in an area ½ to 1 km to the west of the western breakwater. This may again destabilise the narrow sandspit found in this area.

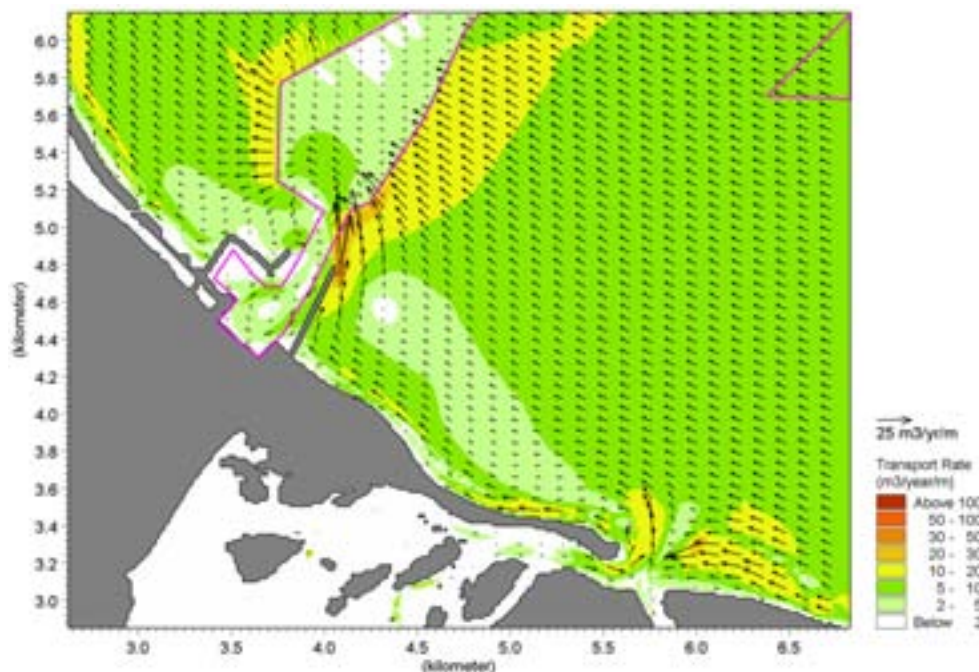


Figure 4.2 Average transport patterns for representative winter conditions for fine sand.

4.2 Expected Morphological Impacts East of MOF

To the east of the MOF, there will be an estimated annual deficit in the order of 50,000 m³ up to 100,000 m³. This will lead to significant morphological impacts if not mitigated.

Figure 4.3 shows simulated average transport patterns for typical summer conditions for fine sand. Due to the large angle of the incoming waves relative to the coastline normal, there is a relatively large sheltered zone and the formation of a large-scale eddy structure which stretches in the order of 500 m east of the eastern breakwater. In addition to the blocked sediment supply from west, the eddy structure will trap additional sediments. The sediment deficit in the area to the east of the eddy structure will thus potentially be significantly larger than the estimated sediment deficit due to the blockage of the littoral drift alone.

Figure 4.3 shows the littoral sediment drift re-establishing from about 600 m to 1 km to the east of the eastern breakwater. The increasing sediment transport capacity in this area will lead to erosion. It is, however, noted that the existing bulge in the coastline in this area is caused by exposed rock which is resistant to erosion. The main erosion is thus expected to move further eastward along the

4-3



sandspit in front of Hooley Creek. Without mitigation, this is likely to lead to breaching of the sandspit.

Without mitigation, the erosion will progressively affect areas further to the east.

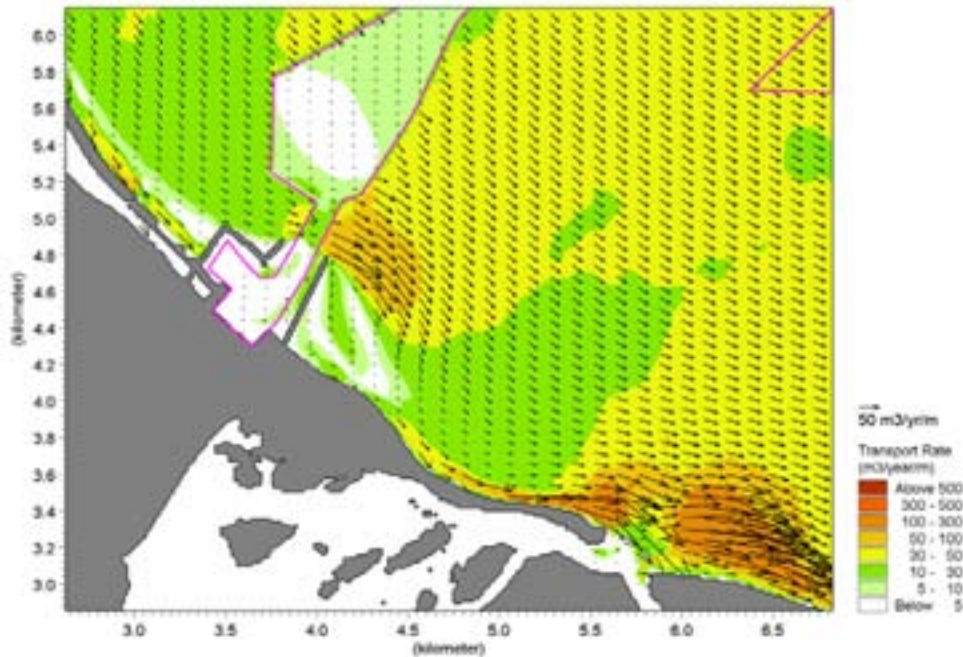


Figure 4.3 Average transport patterns for representative summer conditions for fine sand.

4.3 Erosion Management

Three main options are available to manage erosion:

1. Sacrificial erosion
2. Replacement of the sediment deficit
3. Coastal protection

Sacrificial erosion can be used if it is considered acceptable to let the coastline between the MOF and up to Beadon Point erode. The beach would to some extent change character, but may be maintained as an open, sandy beach, depending on the hinterland and underlying sediments.

The second option involves beach nourishment, either with imported material or through artificial bypass of the sediment (sourcing on the western side of the MOF and placing it to the east of the MOF). Due to the sheltered areas close to the breakwater trapping sand, an initial nourishment with imported material is required to establish a new quasi-equilibrium state which can be maintained through sediment bypassing.

A number of structural options are available for coastal protection. These, however, will only shift the erosion problem further towards the east, and the entire coastline up to Onslow is expected to eventually require protection. This will obviously lead to a major change in the character of the coastline.

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5.0 HOOLEY CREEK ENTRANCE

The existing entrance to the Hooley Creek tidal area is dynamic in nature as described in Section 2.1.3.1 and documented by Damara WA (2010). The Project may affect the entrance configuration in several ways, with the more direct impacts outlined below:

- Changes to the local wave, current and sediment transport patterns caused by the MOF and dredged channel may directly impact the sandspit and entrance stability.
- Changes in the sediment supply caused by the MOF and dredged channel may gradually destabilise the sandspit at the entrance and the entrance delta.
- Reduction in the tidal prism of the Hooley Creek tidal system due to construction of onshore infrastructure. This can reduce the tidal flushing of the western arm and entrance and lead to reduced depths through the entrance.
- Changes to the drainage patterns within the tidal creek system may affect flows within the creek system and through the entrance.

The potential changes to the sediment transport patterns at the entrance location will be assessed through the detailed 2D transport simulations, while the overall changes to the sediment budget will be assessed through the quantification of the annual sediment transport capacities.

The Project will cause some reduction of the Hooley Creek tidal prism. A best estimate of the bund wall location based on available information has been introduced in the model to reduce the tidal prism. An assessment of the impacts of reduction in the tidal prism has been included in the simulations of the detailed flow through the inlet.

Changes to the drainage patterns have not been part of the present scope.

5.1 Changes in Sediment Supply and Local Transport Patterns

The changes in sediment supply and local transport patterns were described in detail in Section 4.2.

During summer, the easterly directed littoral drift is blocked by the MOF, and gradually re-establishes in front of the sandspit. Unless mitigated, the reduction in sediment supply will cause erosion of the sandspit. In the long term, it is also likely to change the stability of the ebb tide delta in front of the Hooley Creek entrance, and thereby change the supply of sediment to the coastline further to the east.

5.2 Effect of Changes in Tidal Prism

The footprint of the Project includes part of the tidal prism of the western arm of Hooley Creek. This leads to a reduction in the tidal prism, and thereby changes in the flow patterns and flushing of the western tidal channel and entrance. The effects of this have been modelled for a spring tidal period by comparing modelled currents for existing conditions to modelled currents with the Project infrastructure in place. The effects of the tidal prism have been isolated by excluding the MOF and dredged navigation channel in the simulations for the developed conditions.

The bathymetry of the tidal prism is established based on detailed Lidar data. This does, however, not penetrate the channels, and the depths of the channels have had to be guessed. A quasi-dynamic equilibrium between flushing capacity and channel cross-section normally exists, and the assumed channel depths have been checked and adjusted to produce “reasonable” current velocities within the channels.



Figure 5.1 to Figure 5.4 compare current fields for existing conditions with the reduced tidal prism on a regional scale for 4 different tidal stages. Figure 5.5 to Figure 5.8 show details around the Hooley Creek entrance and western arm for the same tidal stages. Figure 5.9 compares maximum current speeds derived from the simulations with and without onshore infrastructure throughout the area, while Figure 5.10 shows details around the Hooley Creek entrance. Figure 5.11 shows the differences in maximum current speeds. A positive value means an increase in currents speeds, and a negative values shows the reduction in current speed due to the reclamation.

The simulations show that:

- A large proportion of the Hooley Creek flats only flood on very high tides.
- Ebb current speeds through the tidal inlet are relatively high.
- There is a significant reduction in current speeds in the western arm and through the entrance to the Hooley Creek system due to the reduction in tidal prism on high spring tide conditions.
- Any significant differences in current speed are limited to the western arm of the Hooley Creek and the tidal inlet area.

A dynamic balance exists between the tidal flushing and the cross-section of the entrance. The littoral sediment transport and the eastward growth of the sandspit is constantly trying to fill in the entrance, but this is balanced by the flushing on each tidal cycle. The cross-sectional area is constantly changing in response to the balance between the infilling and the tidal flushing.

A reduction in the tidal prism leads to a reduction in the flushing capacity, and the response will be reduction in the average cross-sectional area, either through a reduction in the depth or the width of the channel. This will affect the western arm as well as the entrance to the sea of the Hooley Creek system. This may affect the navigability of the entrance and the western arm and potentially the flood release during extreme runoff conditions, although this is likely to rapidly scour a larger channel out. A temporary increase in flood levels may be experienced until the entrance is scoured out. This component should be evaluated in conjunction with the potential changes to flow and discharge patterns within the tidal creek system.

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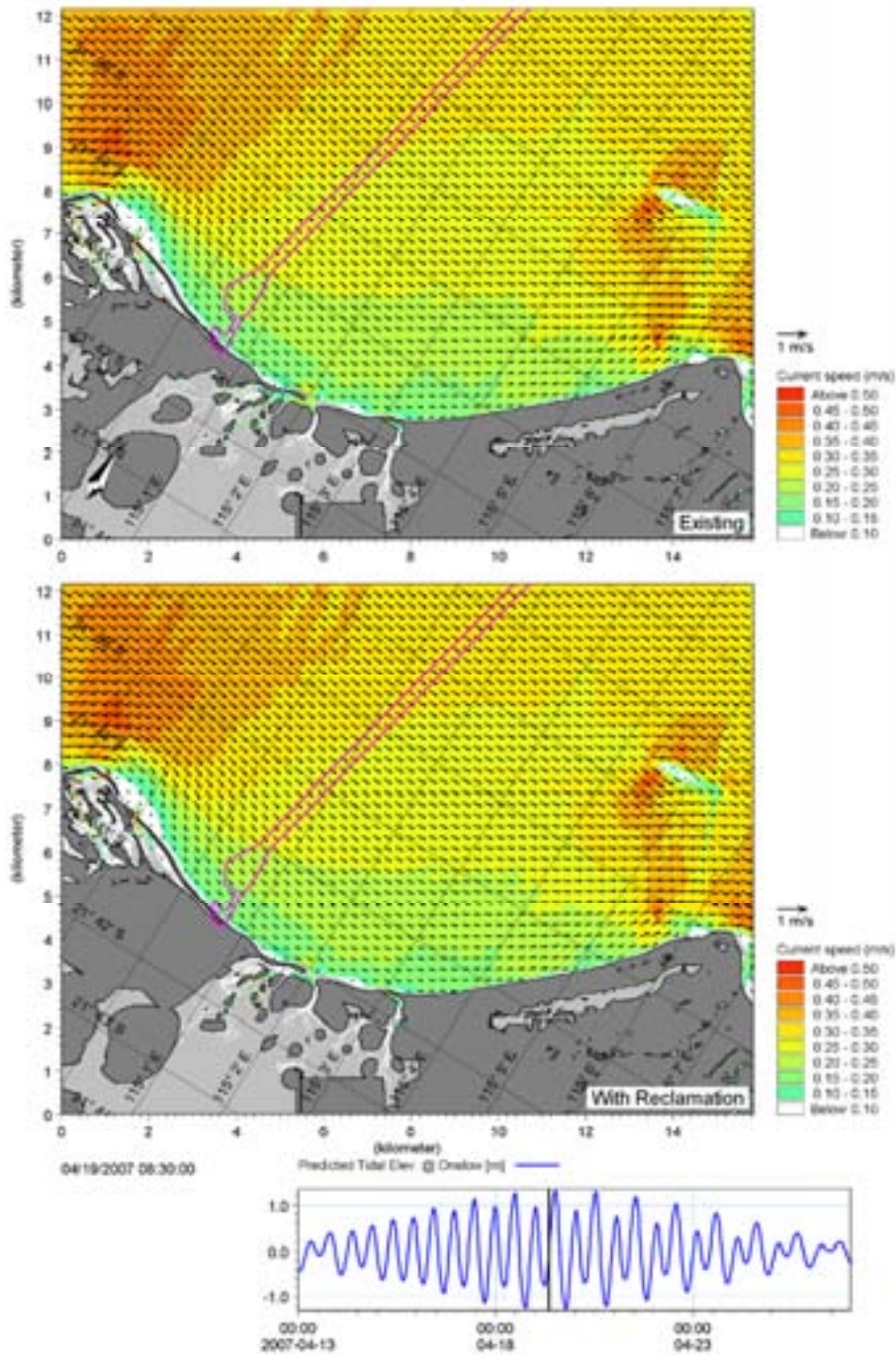


Figure 5.1 Comparison of current patterns for existing conditions (top) and with the proposed reclamation included (bottom) during flood tide in the 15m grid model area.

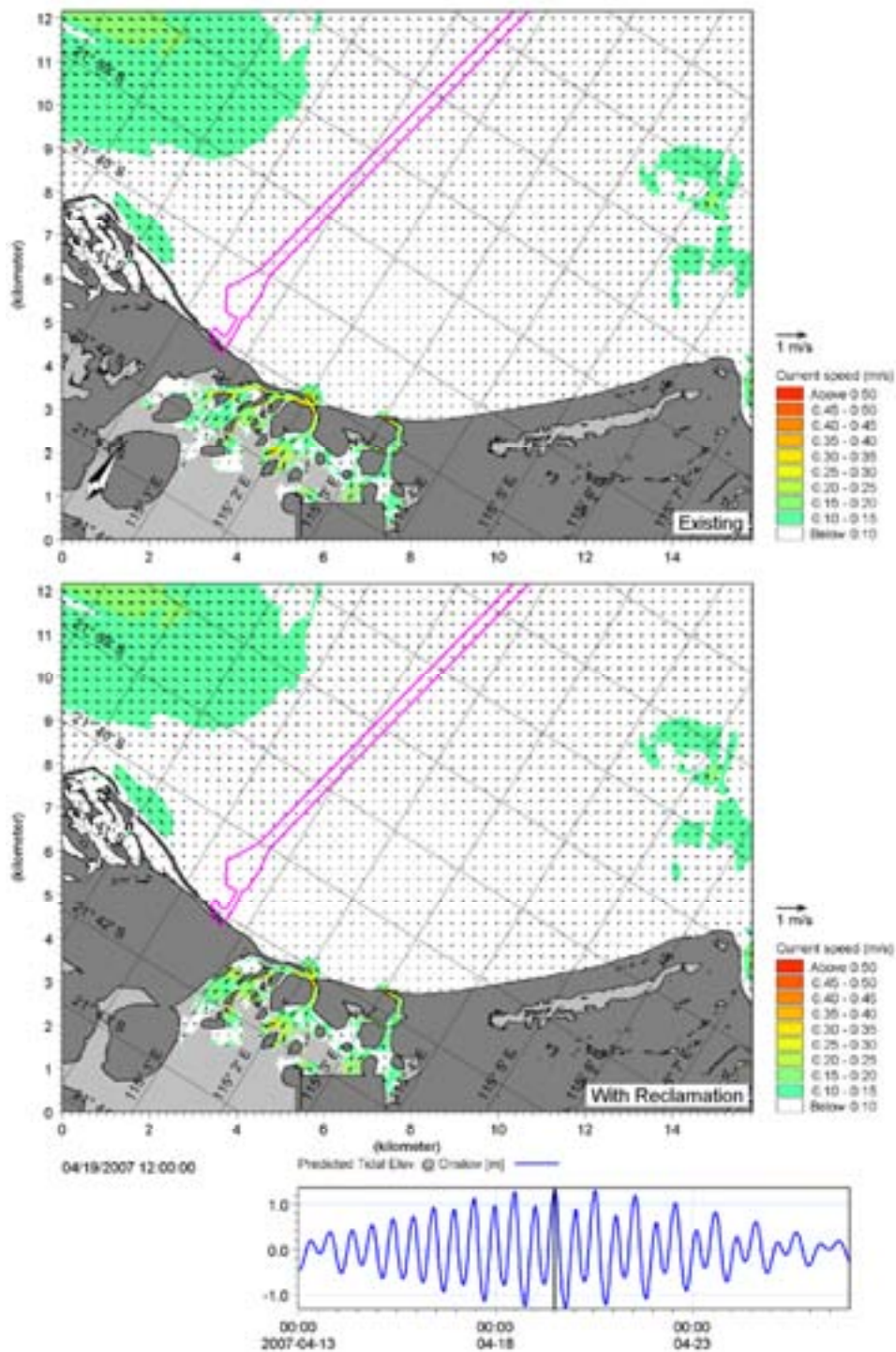


Figure 5.2 Comparison of current patterns for existing conditions (top) and with the proposed reclamation included (bottom) during high tide in the 15m grid model area.

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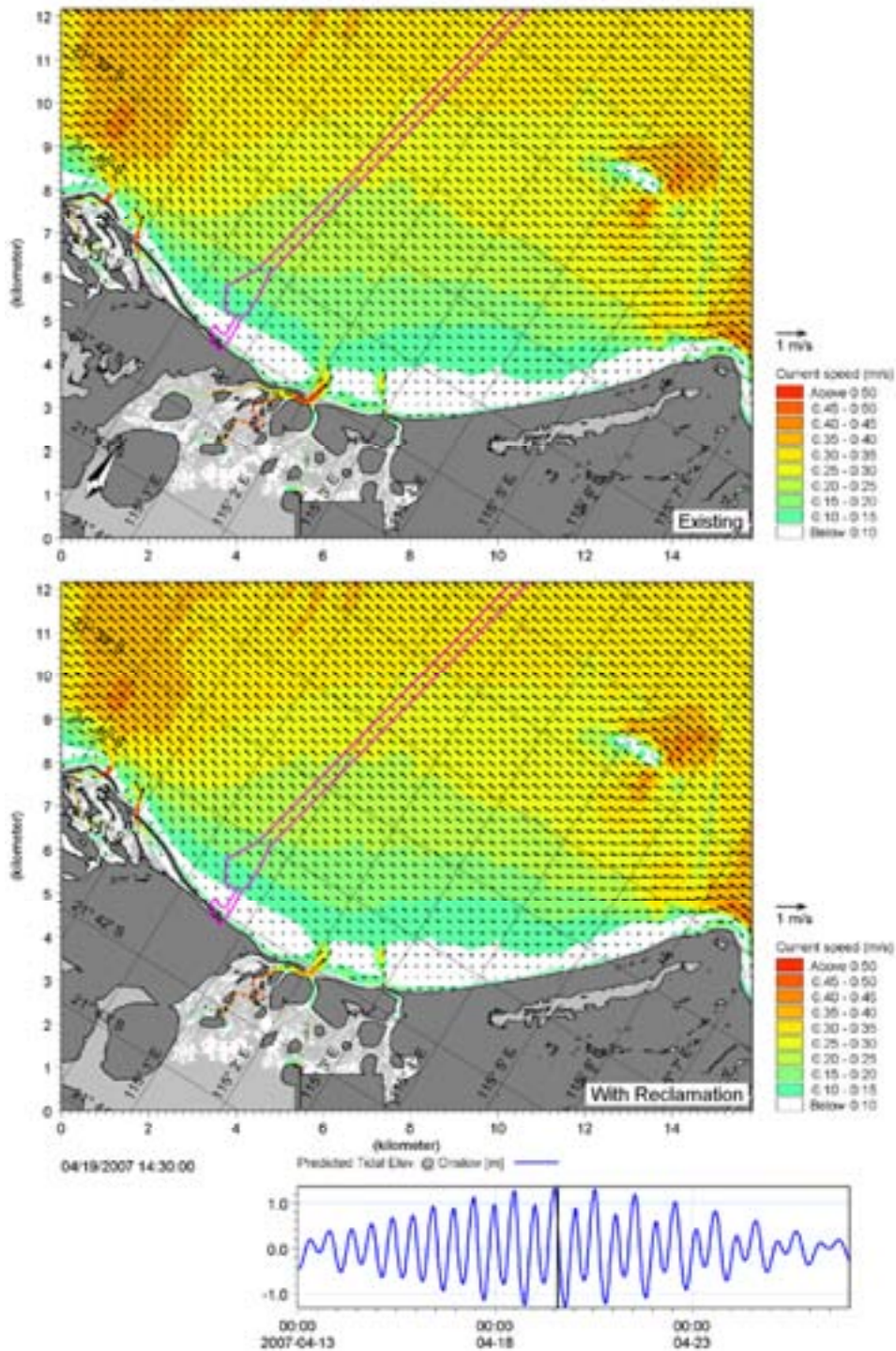


Figure 5.3 Comparison of current patterns for existing conditions (top) and with the proposed reclamation included (bottom) during ebb tide in the 15m grid model area.

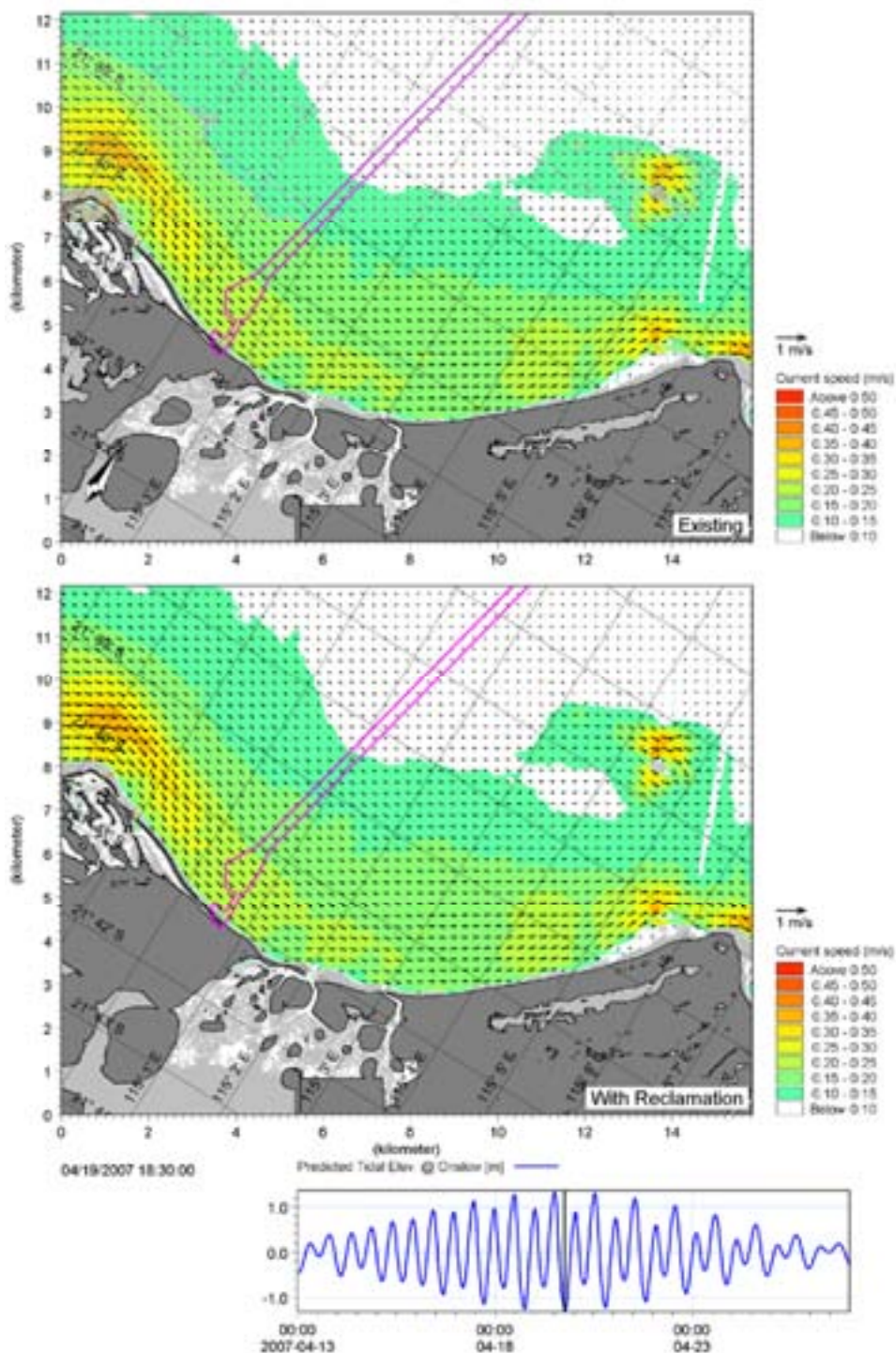


Figure 5.4 Comparison of current patterns for existing conditions (top) and with the proposed reclamation included (bottom) during low tide in the 15m grid model area.

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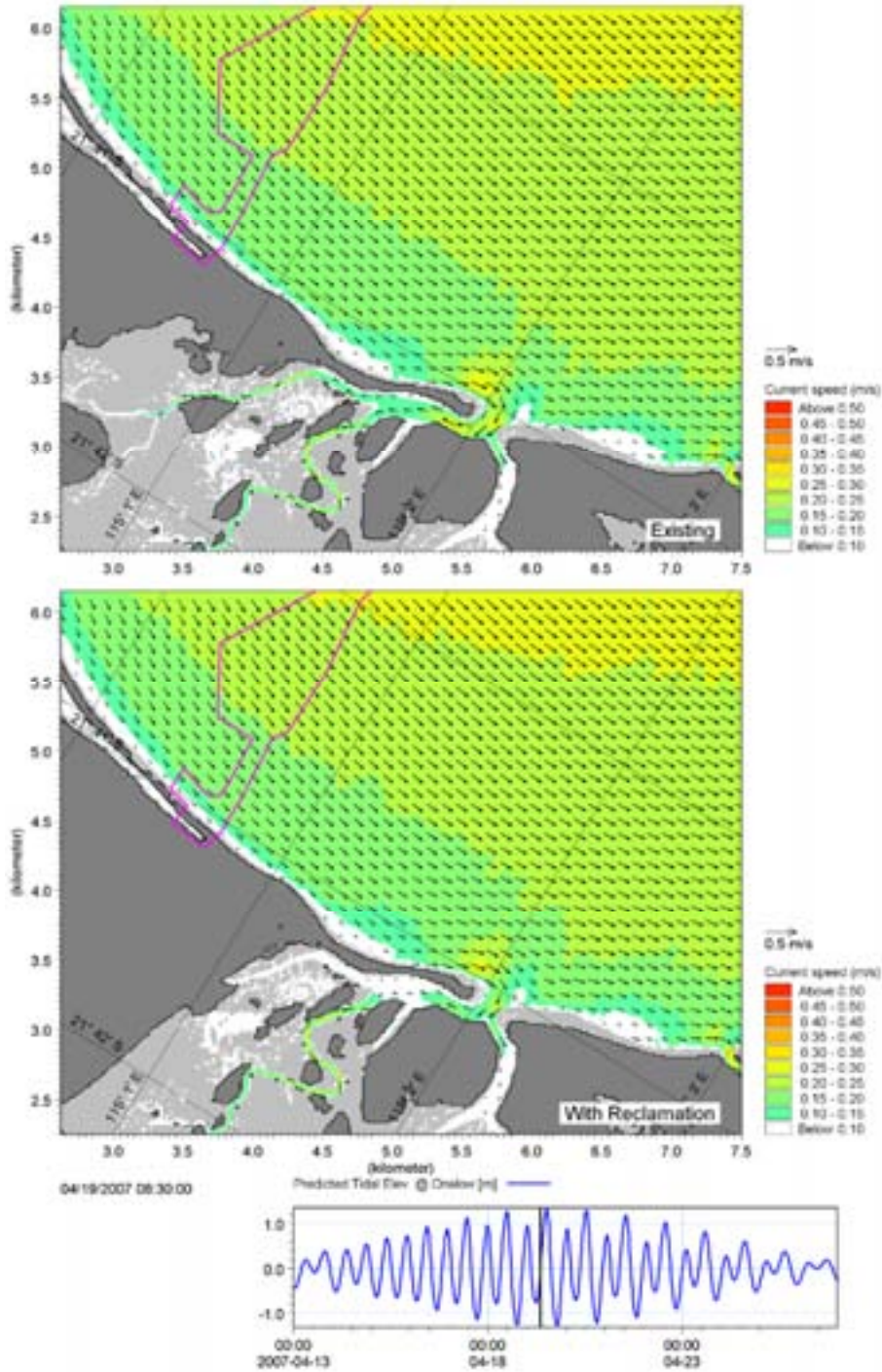


Figure 5.5 Comparison of detailed currents patterns at Hooley Creek inlet and in western arm for existing conditions (top) and with the proposed reclamation included (bottom) during flood tide.

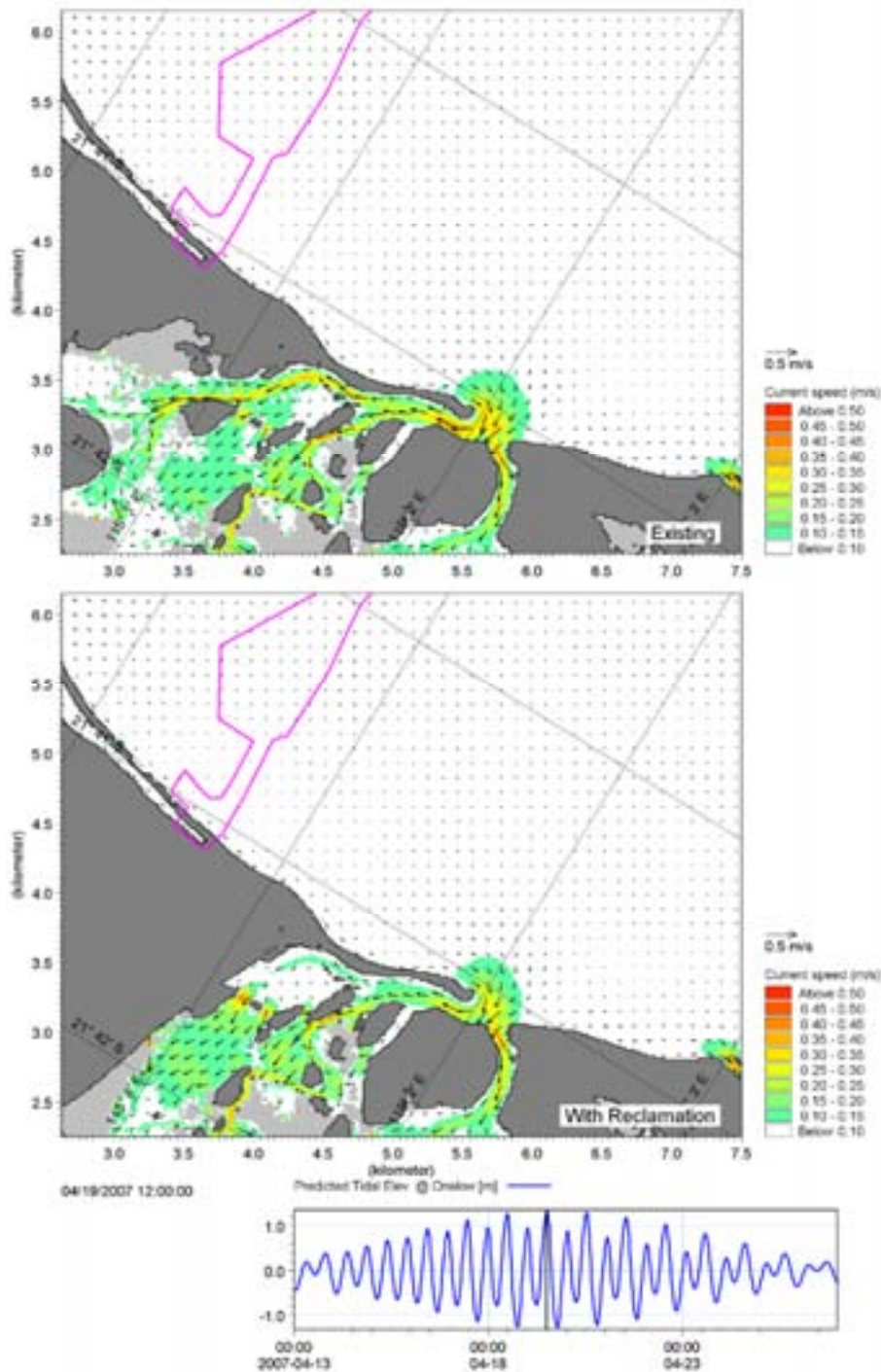


Figure 5.6 Comparison of detailed currents patterns at Hooley Creek inlet and in western arm for existing conditions (top) and with the proposed reclamation included (bottom) during high tide

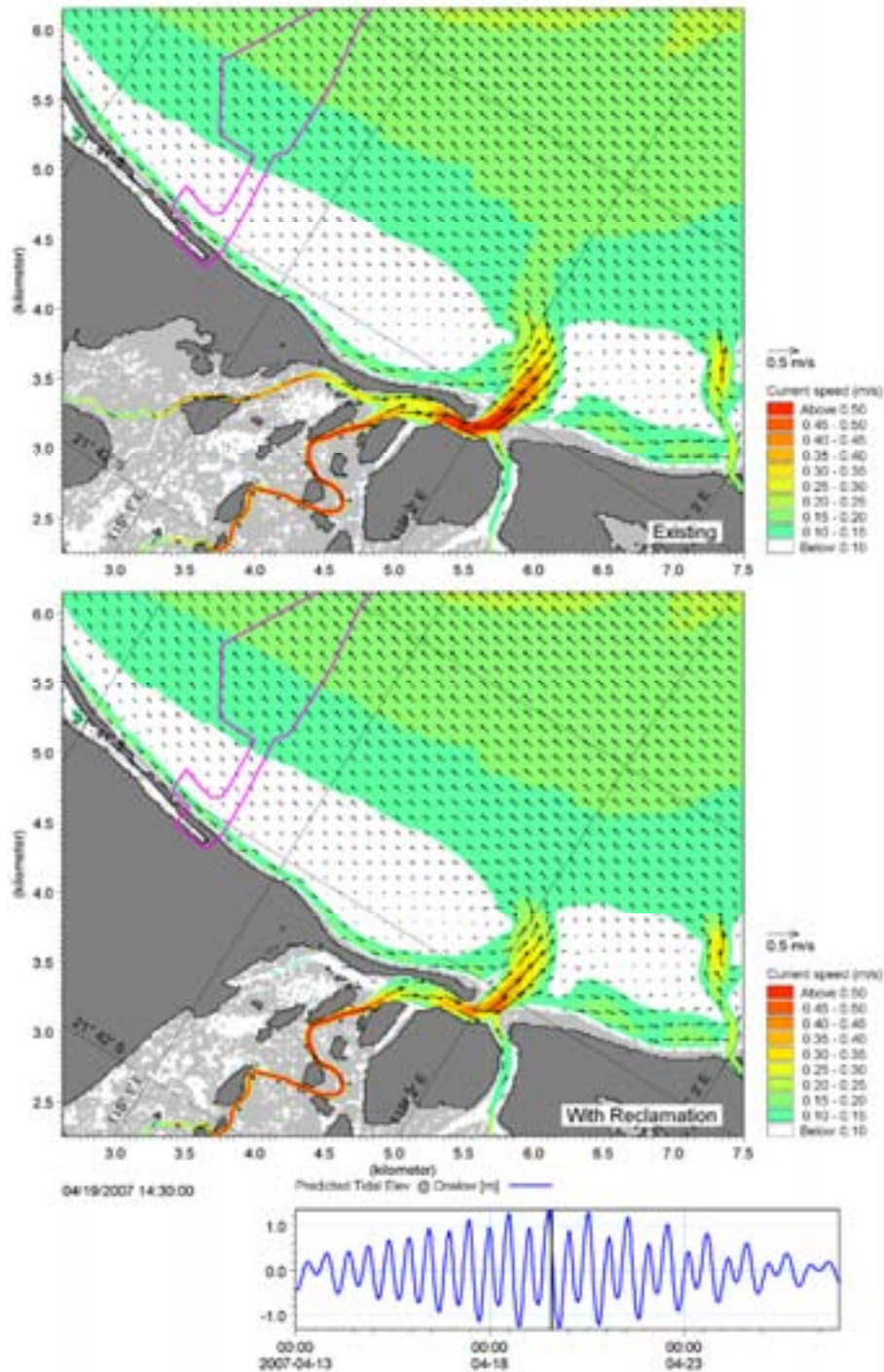


Figure 5.7 Comparison of detailed currents patterns at Hooley Creek inlet and in western arm for existing conditions (top) and with the proposed reclamation included (bottom) during ebb tide

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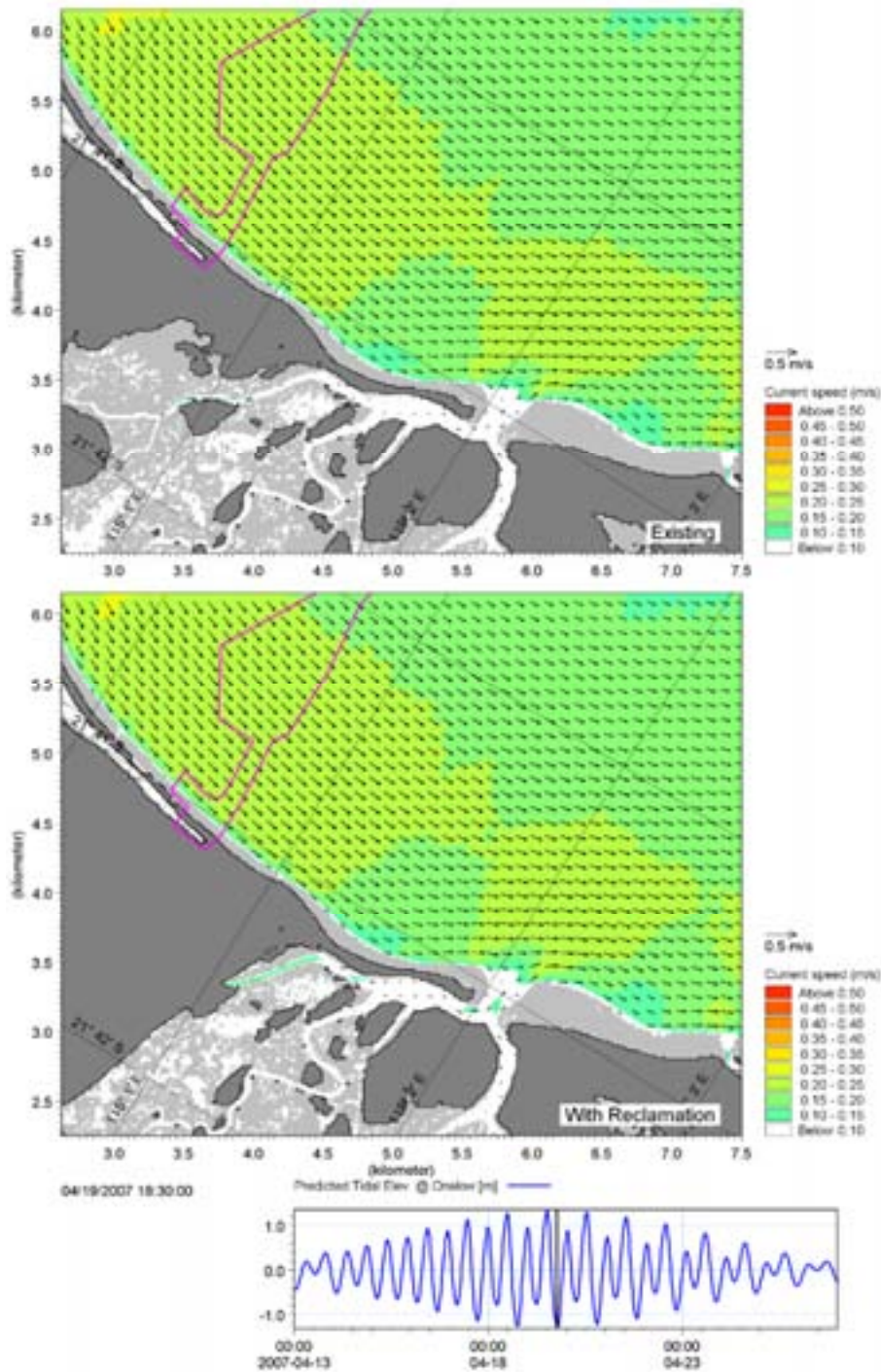


Figure 5.8 Comparison of detailed currents patterns at Hooley Creek inlet and in western arm for existing conditions (top) and with the proposed reclamation included (bottom) during low tide

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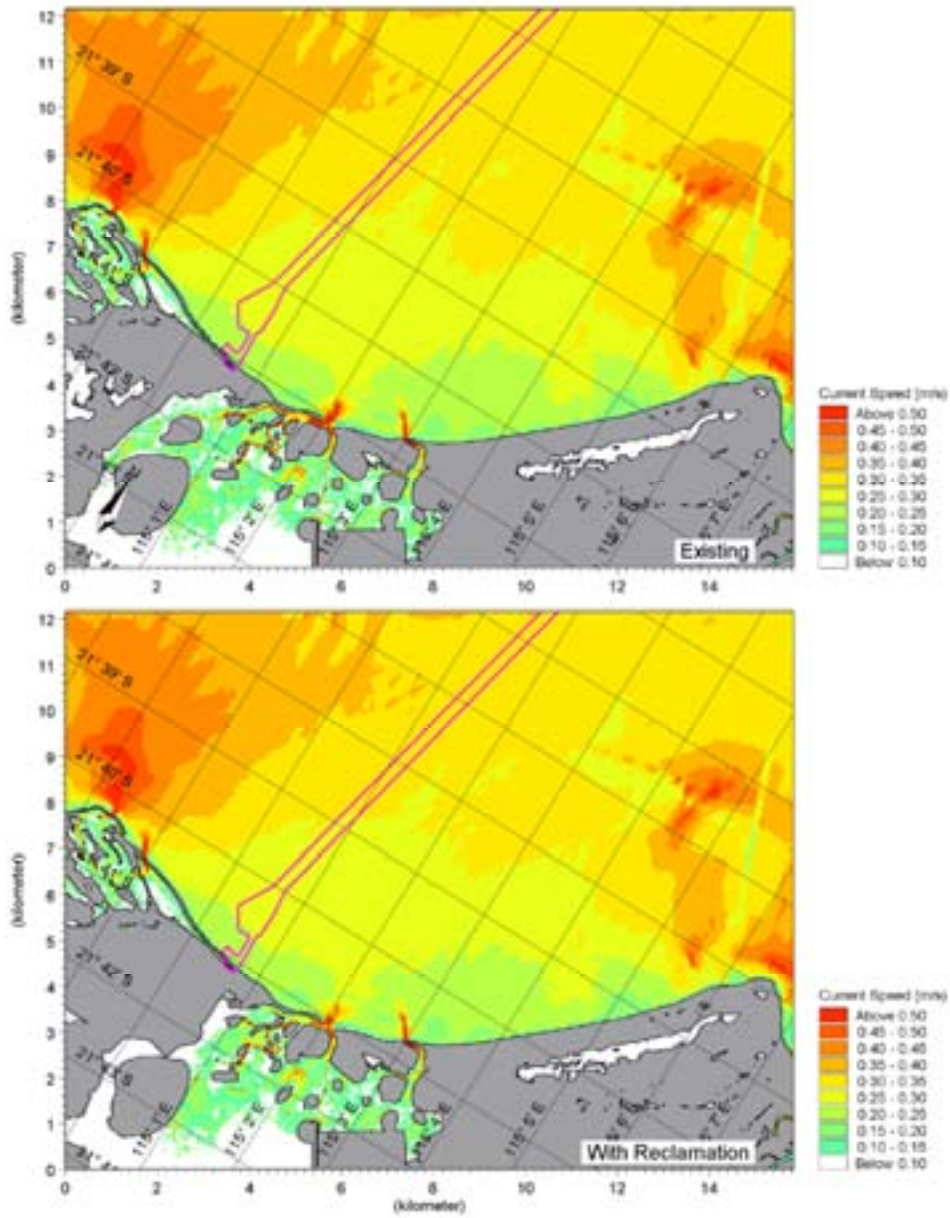


Figure 5.9 Comparison of derived maximum current speeds for the existing conditions (top) and with the reclamation included (bottom) in the 15m grid model.

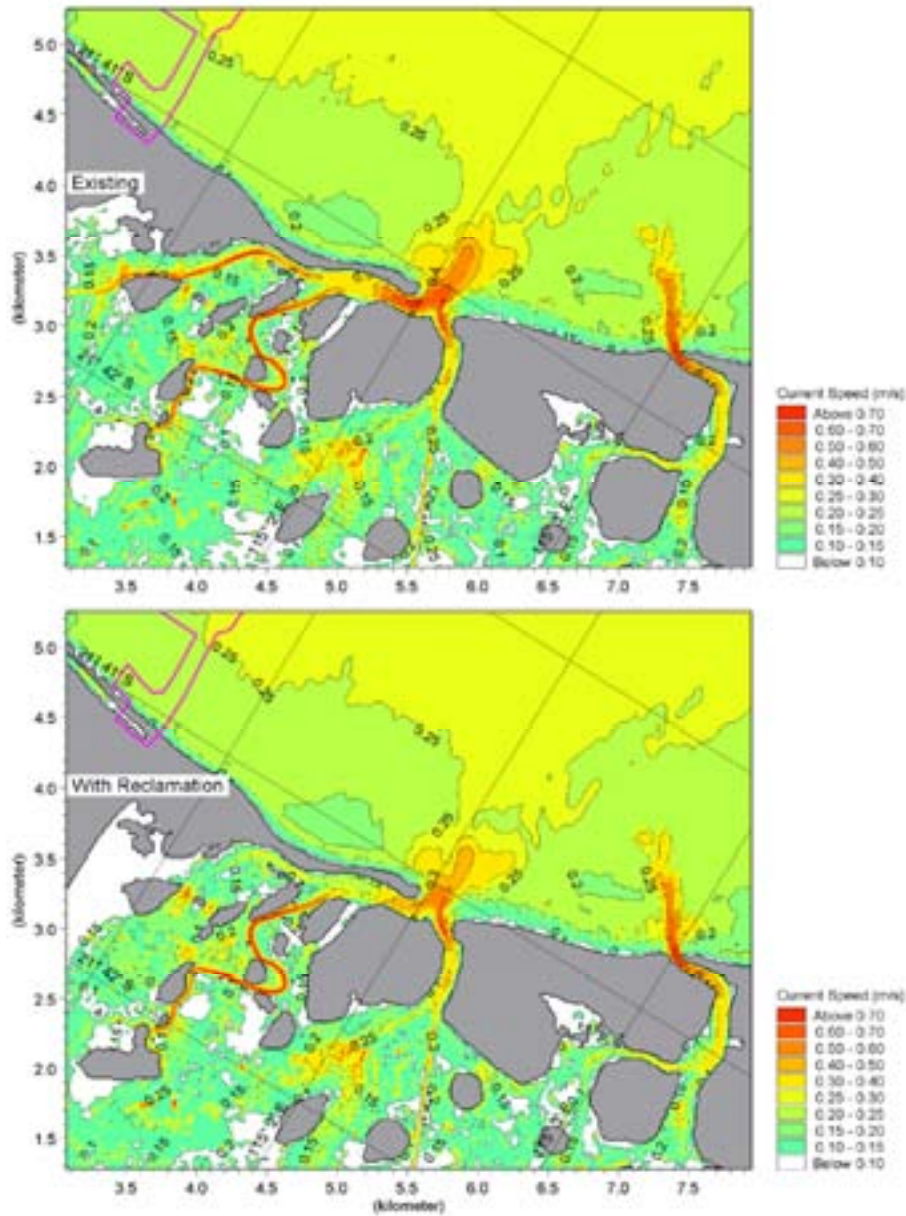


Figure 5.10 Comparison of details at Hooley Creek entrance of derived maximum current speeds for the existing conditions (top) and with the reclamation included (bottom)

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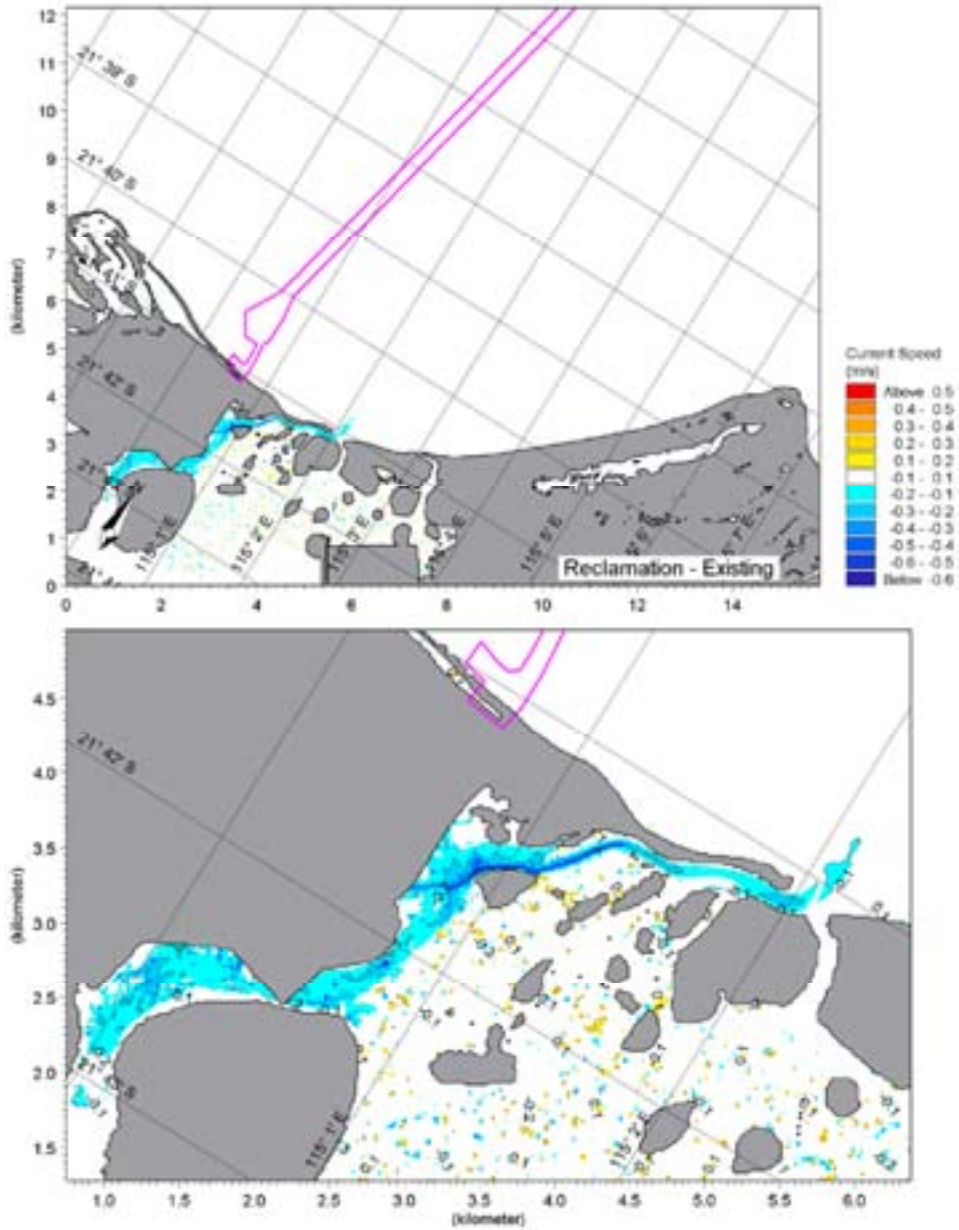


Figure 5.11 Differences in maximum current speeds between the existing condition and layout with reclamation included. Negative means a reduction in max current speeds with the reclamation included.

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