Appendix 4

Studies of the offshore marine environment

REPORT

Ichthys Gas Field Development Project

Studies of the Offshore Marine Environment

Prepared for

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1.1 Background

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field in the Browse Basin at the western edge of the Timor Sea about 200 km off Western Australia's Kimberley coast. The field is about 850 km west south west of Darwin in the Northern Territory (Figure 1-1). The field encompasses an area of approximately 800 km^2 (out of the 3041 km^2 in the permit area) with water depths ranging from 235 to 275 m (Figure 1-2).

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 MMbbl (million barrels) of condensate. INPEX will process the gas and condensate to produce liquefied natural gas (LNG), liquefied petroleum gas (LPG) and condensate for export to overseas markets.

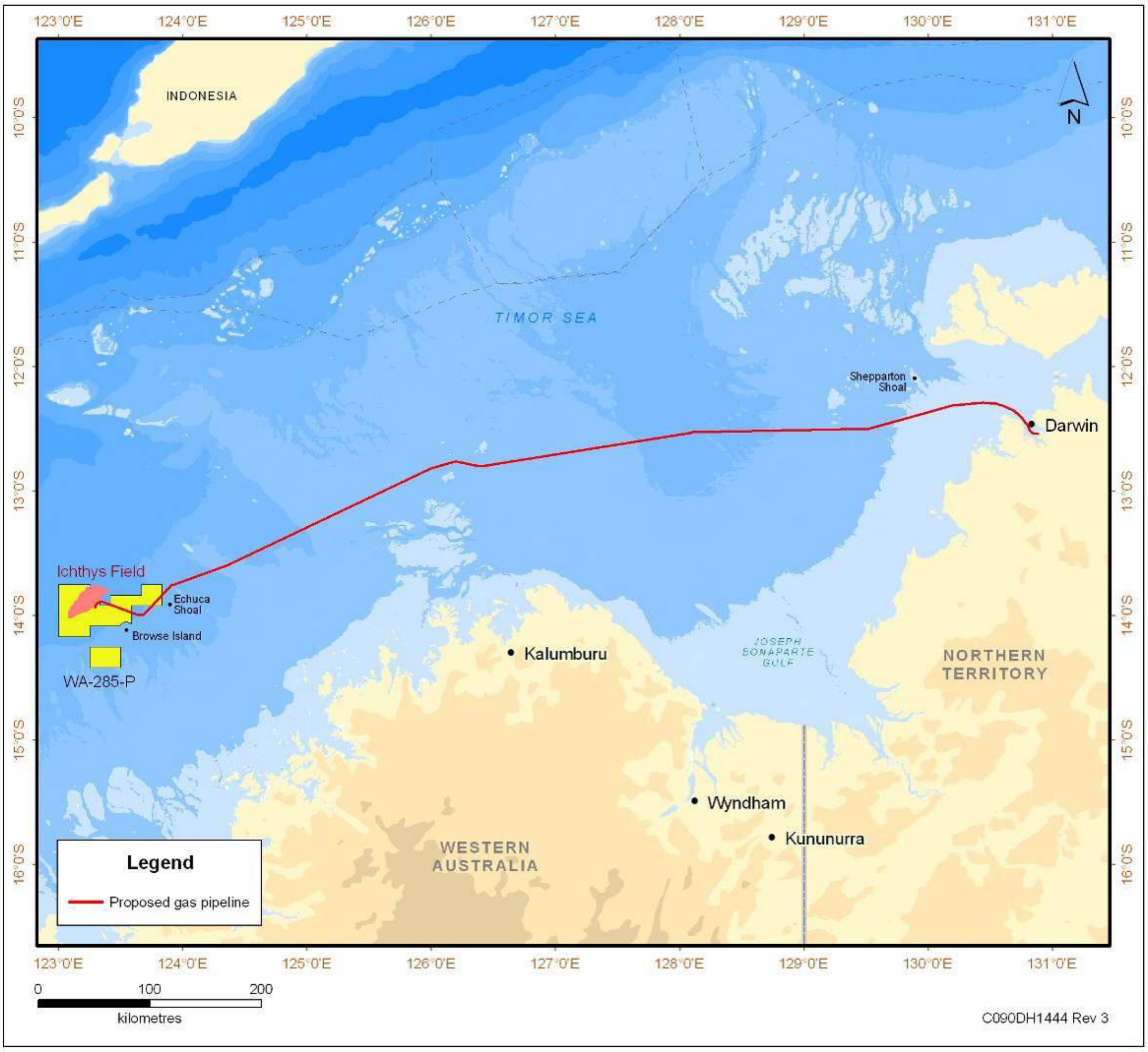


Figure 1-1 Position of the Ichthys Field in the Browse Basin

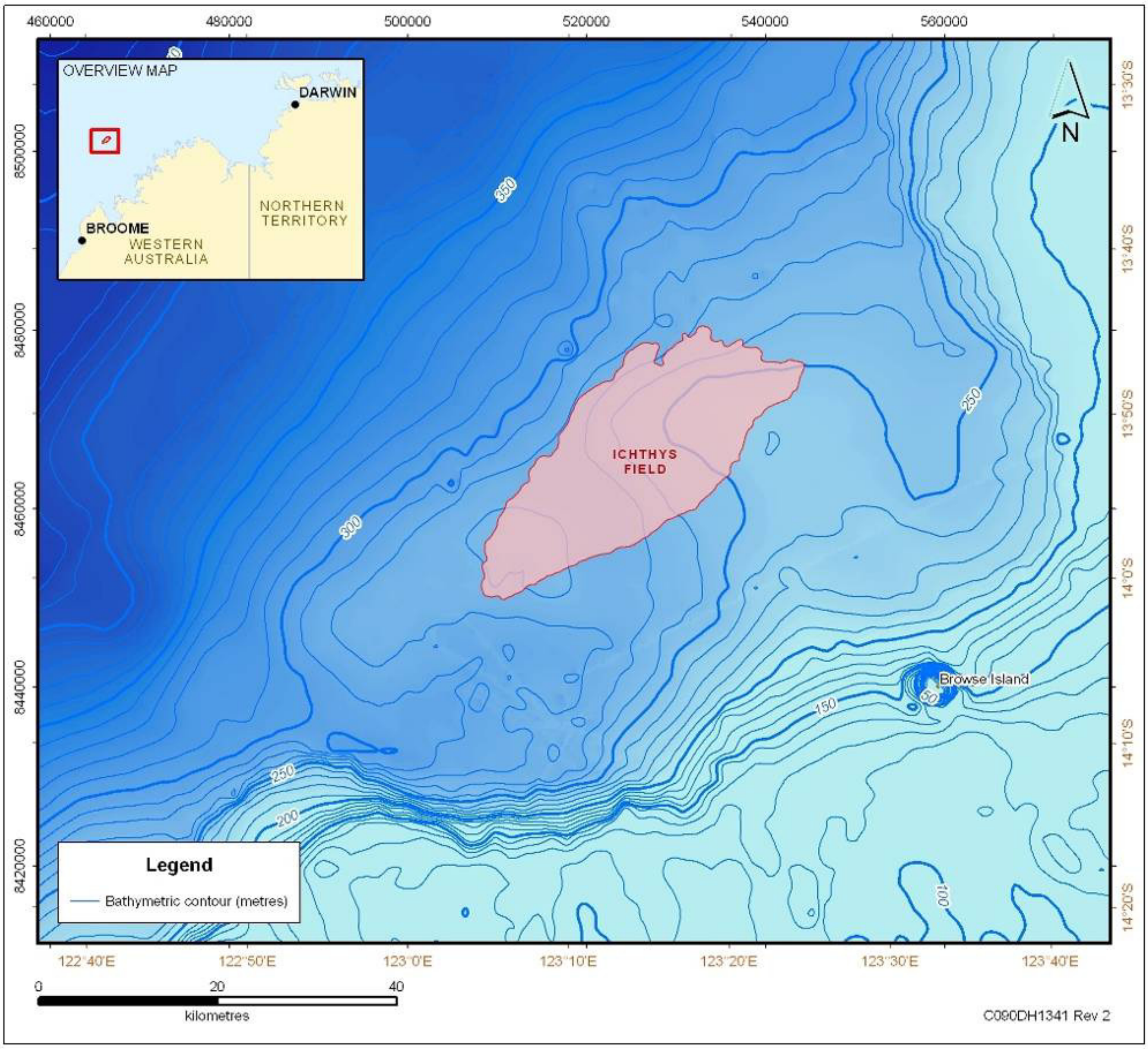


Figure 1-2 Bathymetric chart of the Ichthys Field and the Browse Basin area

For the Ichthys Gas Field Development Project (the Project), the company plans to install offshore facilities for the extraction of the natural gas and condensate at the Ichthys Field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour in the Northern Territory. A two train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site zoned for development on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

In May 2008 INPEX referred its proposal to develop the Ichthys Field to the Commonwealth's Department of the Environment, Water, Heritage and the Arts and the Northern Territory's Department of Natural Resources, Environment and the Arts. The Commonwealth and Northern Territory ministers responsible for environmental matters both determined that the Project should be formally assessed at the environmental impact statement (EIS) level to ensure that potential impacts associated with the Project are identified and appropriately addressed.

Assessment will be undertaken in accordance with the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) and the *Environmental Assessment Act* (NT) (EA Act). It was agreed that INPEX should submit a single EIS document to the two responsible government departments for assessment.

1.2 Preparation of the offshore appendix

A broad range of targeted environmental studies was undertaken by INPEX and its consultants to characterise the baseline conditions within the offshore Project area. These studies included consideration of the physical and biological environment within and around the Project area. The complete list of studies undertaken is presented in Table 1-1. The environmental studies support Chapter 3 *Existing Natural, Social and Economic Environment* of the *Draft environmental impact statement* (Draft EIS).

Table 1-1 Offshore studies conducted for the environmental impact assessment of the Project

Section	Study	Organisation	Study period
2	Meteorological conditions	RPS Environment	Field studies: February 2004–March 2005
3	Marine ecology	RPS Environment University of Western Australia	Field studies: September 2005 October–November 2006 March–April 2007
4	Ichthys Darwin pipeline	URS Australia Pty Ltd (URS)	Field studies: December 2008
5	Sediment quality	RPS Environment Marine and Freshwater Research Laboratory Murdoch University CSIRO Laboratories	Field studies: September 2005 May 2007
5	Water quality		Field studies: March and September 2005 October and December 2006 May and June 2007
6	Cetaceans and megafauna	Centre for Whale Research Centre for Marine Science and Technology RPS Environment	Field studies: August–October 2006 August 2007

2.1 Introduction

A meteorological conditions study for the Ichthys Field in the Browse Basin was conducted by RPS (2008a) with a focus to assemble and analyse as many numerous long-term historical meteorological data sets as were available for the Browse Basin region, in order to come up with the best meteorological data/criteria for the Ichthys Field. As a result, some statistics (ambient and/or extreme) or information on the following meteorological parameters were calculated and provided as part of the study.

- Extreme design conditions—1- to 200-year return period values were calculated and provided for the Ichthys Field for rainfall intensities, air temperature, barometric pressure rate of change, wind and gust speeds (i.e. cyclonic, non-cyclonic monsoonal and convective).
- Ambient or operational conditions—statistical presentations/tables were assembled and/or produced for winds (mean and gusts), rainfall, air temperature, relative humidity, solar radiation, evaporation, barometric pressure, dew point, cloud cover and thunder/ lightning for numerous Browse Basin locations.
- Tropical cyclone occurrence, intensity, movement and approach details were calculated for all storms that passed within a 500-km radius of the Ichthys Field over the 36 year period 1968/69 to 2003/04.
- The latest IPCC report on Global Warming and Climate Changes was reviewed and summarised.

In addition to analysis of historical data sets, a full year of field measurements (February 2004—March 2005) using an instrumented meteorological buoy (metbuoy) deployed at the Ichthys Field was undertaken by RPS (RPS 2008a). Unfortunately, from the full year of measurements at the Ichthys Field only about eight months of good meteorological data (mostly over the summer months) was returned. The meteorological parameters available from the Ichthys Field metbuoy consisted of: wind speed and direction (U10), gust speed (Ug), air temperature (AT) and barometric pressure (BP) (RPS 2008a).

2.2 Climatological review

2.2.1 Synoptic meteorology

The climate of northern Australia shows two distinct seasons, ‘winter’ or ‘dry’ from April to September and ‘summer’ or ‘wet’ from October to March, with very rapid transition seasons, generally in April and September/October, between the two main seasons. This is a result of two major atmospheric pressure systems affecting the north of Australia: the subtropical ridge of high pressure cells (highs or anticyclones), and a broad tropical low pressure region called the monsoon trough (RPS 2008a).

The subtropical highs move from west to east across southern Australia in winter, and further south in summer, usually separated by low pressure troughs or cold fronts. The highs provide the driving force behind the south-east trade winds, which dominate northern Australia’s weather in the winter months (RPS 2008a).

The monsoon trough or intertropical convergence zone is a broad area of low atmospheric pressure running east-west through the tropics in the summer months. It follows the sun, shifting north and south between the hemispheres with the seasons. In the southern hemisphere it is the meeting place of the dry east to south-east winds generated by the subtropical highs, and the moisture laden north westerly monsoon winds. During the summer it lies for lengthy periods over northern Australia, and is the source of much rainfall (RPS 2008a).

Winter season

The 'dry' season (April—September) is characterised by steady north-east to south east winds of 5 to 12 m/s driven by the South East Trade Winds over Australia. The prevailing south-easterlies bring predominantly fine conditions throughout the north of Australia. Rainfall in the north is low to nonexistent in most areas, although light showers are common about the north-west coast and occasionally develop elsewhere over northern Australia (RPS 2008a).

Summer season

The 'wet' season (October—March) is the period of the predominant North West Monsoon. It is characterised by north-west to south-west winds of 5 m/s for periods of 5 to 10 days with surges in the airflow of 8 to 12 m/s for periods of 1 to 3 days.

The 'wet' season weather in the north is largely determined by the position of the monsoon trough, which can be in either an 'active' or an 'inactive' phase. The active phase is usually associated with broad areas of cloud and rain, with sustained moderate to fresh north-westerly winds on the north side of the trough. Widespread heavy rainfall can result if the trough is close to, or over land. An inactive or 'break' period occurs when the monsoon trough temporarily weakens or retreats north of Australia; it is characterised by light winds, isolated shower and thunderstorm activity, sometimes with gusty squall lines (RPS 2008a).

Tropical cyclones can develop off the coast in the wet season, usually forming within an active monsoon trough. Heavy rain and strong winds, sometimes of destructive strength, can be experienced along the coast within several hundred kilometres of the centre of a cyclone (RPS 2008a).

Transition seasons

The September/October transition season is characterised by the development of a low pressure system over central Australia. This low pressure system tends to be displaced from time to time when large anticyclones (high pressure cells) travel over the southern regions of Australia. While the low is present, surface winds at the Ichthys Field should possess a westerly component. At other times, the synoptic easterlies may persist. The winds tend to be light, frequently less than 5 m/s (RPS 2008a).

In the April transition season, the North West Monsoon retreats northward and the subtropical ridge also moves northward. Thus the winds can be south-easterly for a period, but brief returns of the north-west airflow are common. By the end of April the dry easterly airflow of the winter period is usually well established (RPS 2008a).

2.2.2 Extreme wind conditions

There are five storm types that may occur in the area. Table 2-1 presents general summary information on the months of occurrence, typical wind speeds, wind directions and durations.

Most storms occur during the months of December to April with the odd distant storm occurring in November. Within 500 km of the Ichthys Field, >20 storms occur each month during December to March. However, the most severe cyclones will most often occur in the months of December and March/April, when sea surface temperatures typically reach a peak. In the Browse Basin area, most of the storms are tropical lows/depressions or developing storms, with most of them passing either to the north or south of the Ichthys Field. However, the storms can be fully developed at this latitude (RPS 2008a).

Table 2-1 Storms, principal months of occurrence and typical wind speeds, directions and durations. Source: RPS 2008a

Storm Type	Principle months of occurrence	Typical wind speed and duration[1]	Typical extreme wind speeds[1]	Typical wind direction[2]
Tropical cyclone	November–April	10–30 m/s 24 h	24-45 m/s	All directions (dependent on eye location)
Monsoon Surge	December–April	12–20 m/s 24–72 h	20-25 m/s	West, north-west and south-west
Squalls	October–April	15–20 m/s 1-6 h	30-40 m/s	All directions
Trad winds surge	April–October	10–15 m/s 24–72 h	15-22 m/s	South, south-east and east
Tornadoes and water spouts	December–April	Unknown, but say 40 m/s 1–5 h	Unknown	All directions

Note: 1 Wind speed values in the above table are not to be used for design. 2 Directions are from which the winds approach.

Statistical data for the durations and forward speeds of storms within 100, 300 and 500 km of the Ichthys Field are presented in Table 2-2.

Table 2-2 Residence times and forward speeds of storms within 100, 300 and 500 km radius of the Ichthys Field

		All storms			Tropical Cyclone			Severe Tropical Cyclone		
Intensity (kPa)		**1010**	**1010**	**1010**	**992**	**992**	**992**	**960**	**960**	**960**
Radii (km)		**500**	**300**	**100**	**500**	**300**	**100**	**500**	**300**	**100**
Duration (hours)	Average	50.2	29.8	10.7	37.6	27.6	11	22.6	33.3	16.5
	Max	197.5	92.3	29.7	197.5	92.3	28.8	99.8	84.3	20.7
	Std Dev	30.2	18.5	6.2	31	18.8	6.7	26.9	27.8	4.4
Speed (m/s)	Average	4.2	4.6	5.3	3.9	4.3	4.9	3.5	3.4	3.4
	Max	11.1	12.4	14.1	8.7	8.6	8.4	6.6	5	4
	Std Dev	1.8	2.1	2.6	1.7	1.9	1.9	1.3	1.3	0.5

Wind speeds and return periods for 5 and 200 years for the Ichthys Field are presented in Table 2-3. Maximum air pressure rates of change were determined for each storm using the Holland Wind Field Model. The results showed that the maximum air pressure rate of change due to tropical cyclones over the 35 year period was 20.9 hPa/h during Severe Tropical Cyclone Fay in 2004 (RPS 2008a).

Table 2-3 Extreme wind speeds at return periods of 5 and 200 years for the Ichthys Field

	Mean wind speed	Return Period (years)	
		5	200
Tropical cyclone	10 min	26.3 m/s	52.0 m/s
Non-cyclonic (summer)	10 min	16.4 m/s	23.8 m/s
Non-cyclonic (winter)	10 min	15.3 m/s	16.8 m/s
Convective squall	10 min (gust)	20.6 m/s	24.8 m/s
	3 sec (gust)	31.1 m/s	36.0 m/s

Tropical cyclones

Tropical cyclone is the general term for a cyclone that originates over the tropical oceans. At maturity, the tropical cyclone is one of the most intense storms of the world; winds exceeding 50 m/s are possible with mature storms. Torrential rainfall is associated with the storms (RPS 2008a).

Tropical cyclones form in the area generally south of the equator in the eastern Indian Ocean area, and the Timor and Arafura seas. Most of the storms pass through the area heading in a west or south-west direction before turning southward (RPS 2008a).

Tropical cyclone occurrence and intensity as a function of the Southern Oscillation Index (SOI) indicate that more intense storms (lower central pressure) will occur during a La-Nina event (Table 2-4). Excluding the fact that more Neutral events occur than La-Nina and El-Nino events, it is apparent that a greater number of storms occur during La-Nina events compared to El-Nino events (RPS 2008a).

Table 2-4 Tropical cyclone occurrence and intensity as a function of the Southern Oscillation Index (SOI)

Central Pressure	El-Nino	Neutral	La-Nina	Total
1010	27	53	36	116
992	22	43	30	95
960	4	5	9	18

Monsoonal surge

Regular surges in the monsoonal flow occur throughout the summer period. These surges are associated with synoptic scale changes in the tropical circulation, and result in winds increasing typically to 8 to 12 m/s for periods of 1 to 3 days. Occasionally, surges may attain speeds of 20 m/s (RPS 2008a).

Squalls

These are associated with the thunderstorms occurring in the North West Monsoon over the period October to April. The squalls result from strong downdrafts in the cumulonimbus cloud. They are of relatively short duration and are usually accompanied by heavy rain, an air temperature drop of 2–6 ˚C and frequently, lightning and thunder. In some cases, squalls are associated with cumulonimbus clouds of only a few miles in diameter. In such cases, the strong winds are usually 12 to 25 m/s and of approximately one half hour duration. In other, less frequent cases, the cumulonimbus clouds may cover a considerably greater area, occasionally forming into lines of 200 to 600 km in length and 40 to 60 km in width. In these cases, the winds associated with the squalls may be in excess of 20 m/s for several hours, and in extreme cases may reach 25 m/s with instantaneous gusts to 30–40 m/s (RPS 2008a).

The metbuoy wind measurement at the Ichthys Field recorded the occurrence of convective squall wind, very severe, sudden, transient gusts associated with convective downbursts in thunderstorms. These convective events all occurred in the summer North West Monsoon months of November—March. Each downburst was characterised by gusts rising almost instantaneously to over 20 m/s, with an associated sudden dip in air temperature (RPS 2008a).

Trade wind surge

Surges in the easterly Trade Winds occur during winter. The steady 5 m/s winds strengthen to about 12 m/s as an intense high pressure cell in the subtropical high pressure belt passes eastwards over Western Australia. Typically, these surges last 3 to 5 days (RPS 2008a).

Tornadoes and water spouts

Tornadoes and water spouts may occur in the area associated with the thunderstorm activity and tropical cyclones of the summer monsoon season. No reported information exists on their frequency of occurrence or intensity. In general, very high winds could be expected (RPS 2008a).

2.3 Meteorological parameters

2.3.1 Rainfall

No rainfall data are available from the Ichthys Field or from the very nearby (~57 km to the south-east) Browse Island BoM Meteorological Station. There were only several sporadic months of rainfall data (from the early 1990s) available in the entire 19 year data set. It is expected that the rainfall amount received at the more distant Troughton Island (i.e. ~315 km due east of Ichthys) will still be quite similar to that at the Ichthys Field during the summer months, and during non-tropical cyclone events (RPS 2008a).

The highest mean (>40 mm) and maximum (>200 mm) rainfall occurs in the summer months of December to March and in the early winter month of May for Troughton Island (BOM 2009). The months of December—March are also the most active months for tropical cyclones.

The 5-year and 200-year return period rainfall intensity values for one hour duration for the Ichthys Field are 99.2 mm and 138.5 mm, respectively.

It is expected that the most extreme rainfall events will be associated with tropical cyclones or their precursor disturbances. The return period rainfall amounts will be a function of the number of tropical cyclones to affect the area and the severity. The frequency of tropical cyclones at the Ichthys Field compared to the nearby mainland shows considerably more tropical cyclones at the Ichthys Field for radii of 100 km and 50 km but a very similar number for a radius of 200 km. For all of the radii the storms are typically more intense at the Ichthys Field (RPS 2008a).

2.3.2 Air temperature, relative humidity and barometric pressure

Air temperature and barometric pressure along with wind data (U10, Ug and direction) were measured at the Ichthys Field using the metbuoy. No moisture or relative humidity information is available for the Ichthys Field (RPS 2008a).

In general, air temperatures at the Ichthys Field will remain warm throughout the year with mean and maximum air temperatures ranging from 26 to 30 ˚C, respectively. The maximum air temperature from Browse Island was 36 ˚C and the minimum was 19 ˚C. Similarly, the maximum air temperature from Troughton Island was 35 ˚C and the minimum was 18.2 ˚C. Mean RH at the Ichthys Field will likely range from 60 to 80% throughout all months of the year. RH will be highest during the summer months (RPS 2008a).

2.3.3 Evaporation

The closest measured pan evaporation data to the Ichthys Field are from the BoM meteorological station on Koolan Island, located approximately 225 km south of the Ichthys Field. Overall, the mean annual daily pan evaporation rates for Koolan Island (March 1982—September 2007) was 7.6 mm per day and the maximum reported was 19.8 mm per day. The lowest monthly mean was 6.6 mm per day in March, reaching a peak monthly mean value of 8.5 mm per day in September (RPS 2008a).

2.3.4 Solar radiation

The North Maret Island solar radiation data are the closest measured to the Ichthys Field. Unfortunately the dataset does not cover an entire year. In the months covered by the measured data, the monthly maximum solar radiation occurred in March (1073 Wm^{-2}) and the highest mean value (297.85 Wm^{-2}) occurred in November. A highest daily average of 28.2 MJ/m^2 occurred in November and a lowest daily average of 15.2 MJ/m^2 occurred in July (RPS 2008a).

3.1 Introduction

The Ichthys Field is approximately 220 km from the mainland and lies in 200–280 m of water. The benthic communities at the Ichthys Field were characterised using side-scan sonar and bathymetric surveys, remotely operated vehicle (ROV) surveys and sampling of infauna and epibenthic fauna by RPS in September 2005, October—November 2006 and March—April 2007 (RPS 2008b). Intertidal and subtidal habitats at Echuca Shoal and Browse Island were also surveyed as they are the closest shallow water habitats to the offshore development area that could potentially be impacted by unplanned discharges.

The studies conducted at Browse Island, Echuca Shoal and Ichthys Field included:

- Intertidal surveys to investigate the physical characteristics, and the species composition and abundance of taxa in benthic habitats at four sites at Browse Island (Figure 3-1).
- Subtidal habitat investigations using an underwater video camera towed behind the survey vessel along transects at selected locations.
- Video surveys of subtidal benthic habitats using an ROV at Echuca Shoal (Figure 3-2) and Ichthys Field.
- Epibenthic communities on non-reefal substrates using a benthic sledge.
- Sediment samples to examine the infauna community in the marine sediments at selected locations within the Ichthys Field.
- Sampling of reef platform rock pools for fish on Browse Island.
- Coral spawning at Browse Island.

3.2 Methods and materials

3.2.1 Tow camera surveys

Subtidal habitats were described using an underwater video camera towed behind the survey vessel along transects at selected locations. The video camera assembly comprised a Mako housing equipped with a low light camera. The transmitted images were delivered through an umbilical cable to a control and recording station on the vessel. The live images were displayed on monitors and recorded simultaneously to DVDs with mini DV back-up. Qualitative descriptions of benthic habitats and assemblages were recorded, and positions along the survey route were recorded using a Garmin GPS receiver. Positional and habitat information were recorded directly to files using ArcPad GIS software (RPS 2008b).

Video surveys targeted seabed features identified from aerial photography or acoustic remote sensing imagery. Deep water surveys were designed to ground-truth different habitat/seabed features identified using remote sources, such as side-scan sonar or swathe bathymetry. The video data were used to compile habitat maps for all proposed development areas and adjacent areas of seabed (RPS 2008b).

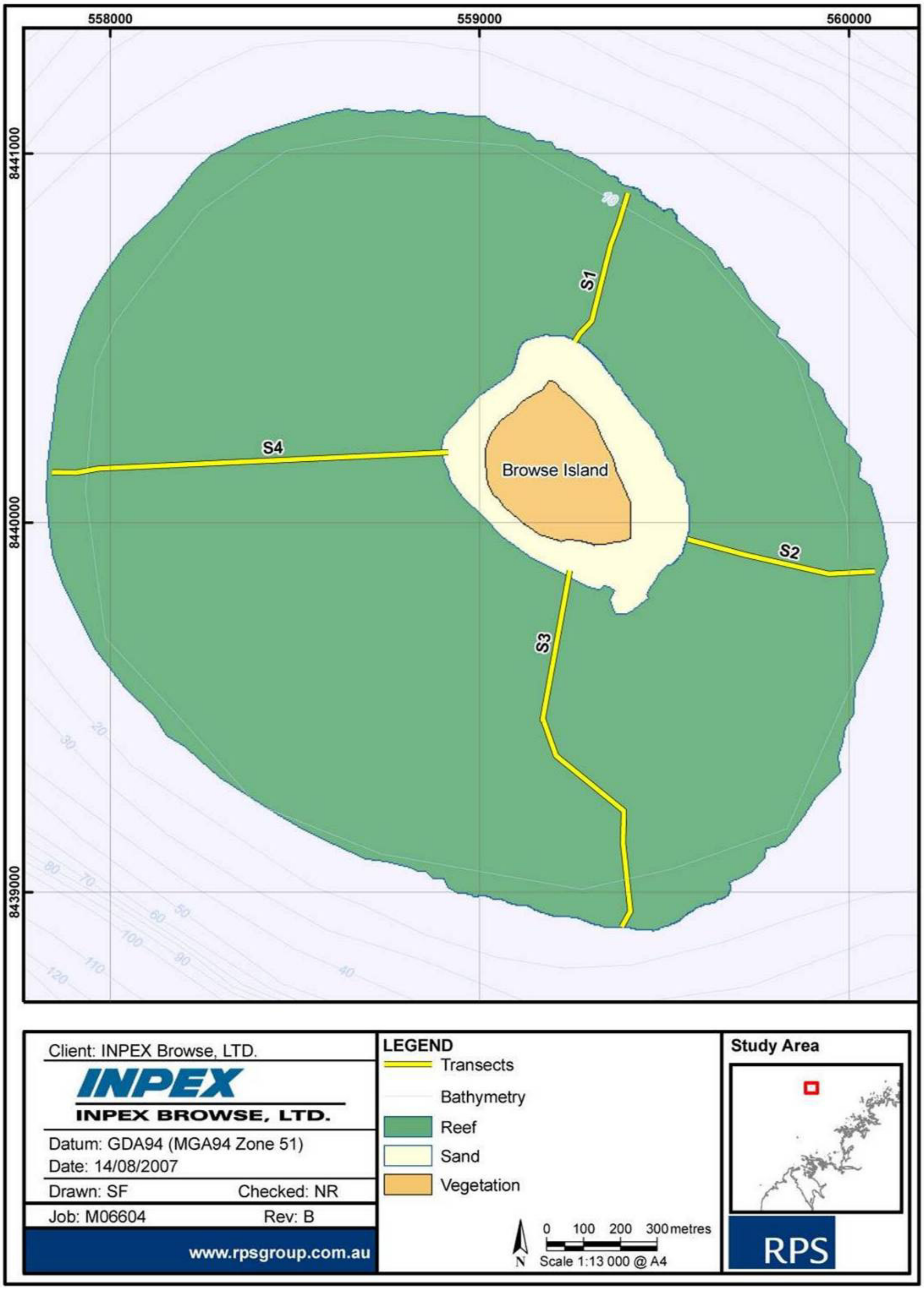


Figure 3-1 Intertidal survey sites at Browse Island

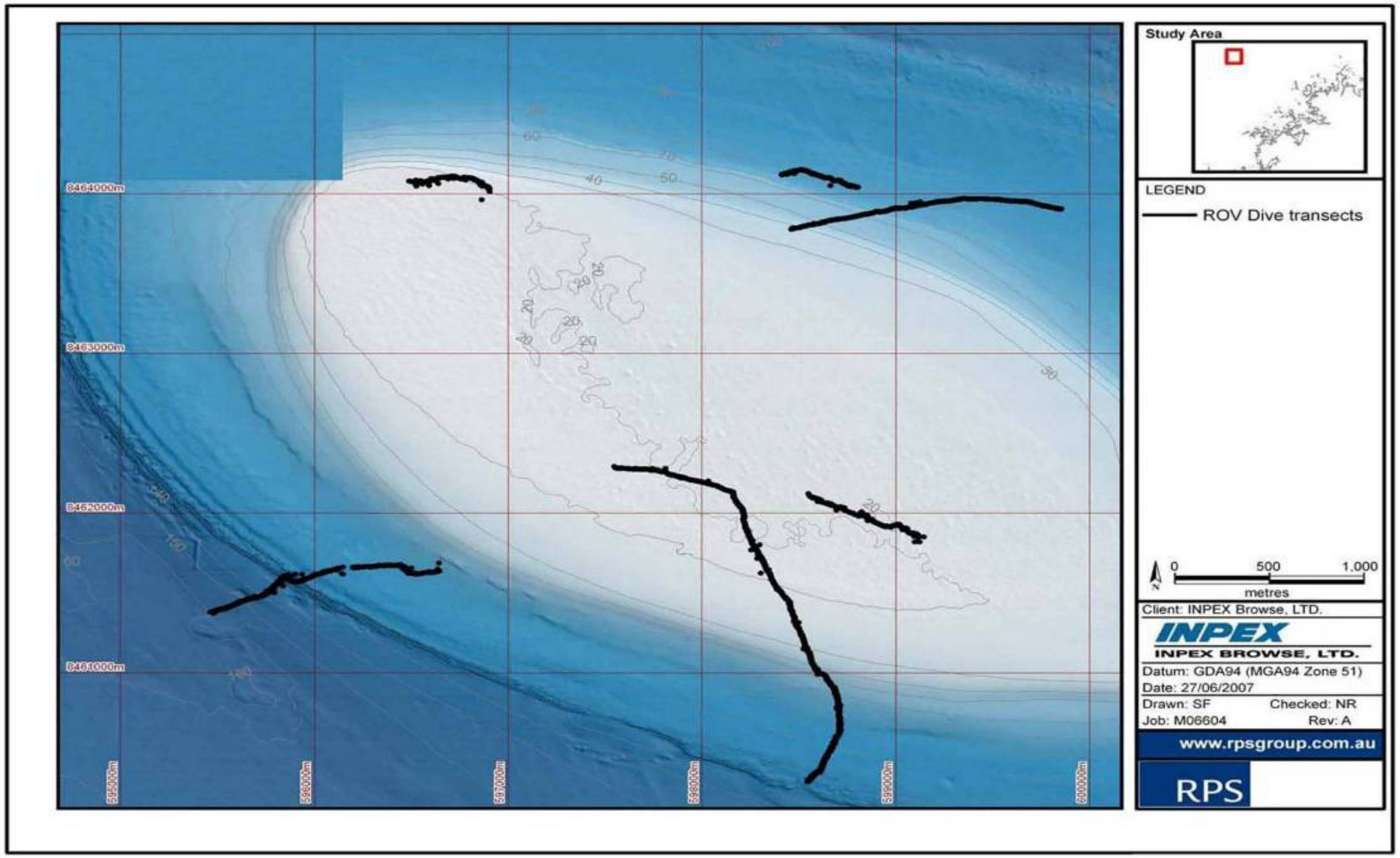


Figure 3-2 ROV transects at Echuca Shoal

3.2.2 ROV surveys

Visual inspections of the seafloor were conducted using a 20 hp Seapup Observation Class ROV at Echuca Shoal and the Ichthys Field. The ROV was fitted with digital video cameras, and was operated by Fugro Survey. The ROV transmitted live video images to a control station aboard the survey vessel where they were recorded to a digital hard-drive and later recorded onto DVD (RPS 2008b).

3.2.3 Sledge sampling

The epibenthic communities on non-reefal substrates were sampled using a benthic sledge. The sledge was an Ockelmann design, comprising a rectangular box collector, 1.5 m long, with a 0.5 m gape. A pair of nets was attached to the box section to collect the samples that were dislodged by the sledge. The smaller of the two nets had a mesh size of 1 cm, generally limiting the samples to macro-organisms. The on-seabed tows were standardised to five minutes at the vessel's minimum speed (approximately 2 knots), roughly equating to a tow distance of 500 m. The samples were sorted and described in the field, with digital photographs taken of all taxa collected. Representative samples of all taxa were collected and frozen for later identification (RPS 2008b).

3.2.4 Benthic infauna

Sediment samples were collected to describe the infauna community in the marine sediments at selected locations within the Ichthys Field.

Samples were collected using a 0.25 m^2 stainless steel Van Veen grab operated with the assistance of a pneumatic winch. Upon recovery, the sediment samples were reduced to a standard surface area of 0.15 m^2 using a graduated divider. Three replicates were collected at each site and the standardised portion was segregated for the extraction and subsequent analysis of infauna (RPS 2007a).

Following standardisation of the surface area of the retained sediment, infauna samples were washed through a 1 mm sieve with seawater and material retained on the sieve was placed in a labelled calico bag. The samples were drained of free water and placed in 10% formalin in seawater buffered with borax (sodium tetraborate) (RPS 2007a).

The preserved infauna samples were analysed by scientists at the Zoology Department, University of Western Australia (UWA), under the supervision of Dr Jane Prince. The sediment samples containing the infauna were washed and the infauna extracted by elutriation. The remaining sediments were stained with Rose Bengal (a protein stain) and then examined for fauna that were too heavy to be efficiently extracted by elutriation, e.g. bivalves and ostracods (RPS 2007a).

Infauna were sorted under a binocular dissecting microscope and identified to the lowest practicable taxonomic level. Taxonomic resolution varied among phyla, but the most abundant taxa were generally identified to nominal species within families or sub-orders (RPS 2007a).

Patterns in species richness (numbers of species) and abundance of infauna between sites were analysed using non-metric MDS. For this analysis, data from all three replicates at each site was pooled to give total number of individuals and total species richness of the various infauna phyla at each site. These data were analysed by non-metric MDS using PRIMER v5 software. Prior to these analyses, the number of individuals and number of species of the various infauna phyla were log-transformed and the Bray-Curtis similarity measure used to construct the similarity matrix.

ANOSIM was used to determine whether the composition of the infauna community differed between sampling locations (inshore, pipeline or offshore). R-statistic values of pair-wise comparisons provided by ANOSIM were used to describe the degree to which groups were dissimilar. Similarity Percentages (SIMPER) was used to determine which taxa contributed the most to any dissimilarity between locations (RPS 2007a).

3.2.5 Fish surveys

An assessment of fish communities was carried out in a randomly selected intertidal rock pool on Browse Island (14º 6' 13.98" S 123º 32' 49.26" E) during a series of spring low tide surveys which were conducted between October 2006 and March 2007. The dry powder ichthyocide, rotenone, was first mixed with water to allow easy application, and then applied at a concentration of approximately 200 g of original dry-weight per 10 m^2 of pool area. Barriers were erected when necessary to contain the rotenone in the selected rock pool, to ensure that neighbouring pools did not become contaminated. The sampled pools ranged between 6 and 60 m^2 in area, and between 0.3 m and 0.7 m deep. Fish became narcotised within approximately ten minutes of application of the rotenone, allowing collection with a 5.0 mm mesh scoop net. Samples of fish were stored in 70% ethanol, or 10% formalin in seawater (RPS 2008b).

The fish were identified by fish taxonomists and selected taxa were archived for scientific record. Data collected during the spring low tide surveys were used to provide a 'snap shot' of species abundance of the intertidal communities of the island. Although widely distributed throughout Western Australia, little is known of the distribution of EPBC-listed pipefish and seahorses (Syngnathids) in the Kimberley region (RPS 2008b).

3.2.6 Coral spawning investigations

The reproductive state of some corals (e.g. *Acropora* spp.) can be gauged easily by breaking off a branch below the expected sterile zone and noting the presence or absence of visible eggs. Mature eggs in *Acropora* are large enough to be visible to the naked eye and are pigmented, usually pink, red or peach in colour. Mature eggs in some faviids are also visible to the naked eye (albeit significantly smaller than *Acropora* eggs), and are also pigmented, usually red, but can also be blue, green or purple. The colonies that contain pigmented eggs are likely to spawn on the neap tide following the next full moon; colonies that have visible, non-pigmented eggs are likely to spawn within one to three months, and colonies with no visible eggs are either unlikely to spawn for at least three months, or have already spawned (RPS 2008b).

In October 2006, only corals of the genus *Acropora* were examined, due the ease of sampling this genus. In March 2007, *Acropora* were sampled, together with a small number of faviids. In October 2007, mainly *Acropora*, but a number of other genera, were sampled, including *Hydnophora*, *Montipora, Goniastrea, Platygyra, Favites* and *Merulina* (RPS 2008b).

The sampling procedure involved removing small individual branches of *Acropora*, or a small piece of the colony from faviids, and noting the presence or absence of pigmented/unpigmented eggs. The October 2006 investigations were preliminary to the later studies; those corals with eggs were collected for later identification. This method facilitated the examination of a large number of colonies in the short period that was available for the survey (RPS 2008b).

3.2.7 Limitations

The limitations of the study, and this document, relate mainly to the logistics of working in such a remote location, and the relatively short period in which completion of the study was required (RPS 2008b).

The safety issues associated with operations in very remote waters potentially containing crocodiles, stinging jellyfish, and sharks, made diving operations and therefore close up examinations of coral assemblages impracticable. The risks to divers could not be minimised to As Low as Reasonably Practicable (ALARP) levels without significant cost and effort inputs. For this reason investigations of coral communities were undertaken using tow camera and ROV surveys. While these allowed a broad-level assessment of biotic assemblages in the subtidal environment, these methods do not allow scientists to identify most corals and other taxa to species level (RPS 2008b).

Fish surveys were only conducted in pools in the intertidal zone and only during one season. As a result, the limited sampling regime simply provides a ‘snapshot’ of species abundance at Browse Island.

Micro-molluscs were not considered in the intertidal or subtidal components of this study. Molluscs of that size were not recorded in the surveys and, for that reason, the inventory of molluscs presented is not comprehensive, but probably includes most of the intertidal macro-species of shelled gastropods and bivalves present in the study areas (RPS 2008b).

Tropical marine and intertidal environments are subject to high water temperatures and periodic disturbance from cyclone activity. The high water temperatures promote high growth rates of benthic organisms and, when extreme, can cause coral bleaching and death. Cyclones can cause periodic catastrophic impacts on benthic communities, although Cyclone George traversed the area without causing obvious damage. The study provides a detailed short-term record of the current condition of the regional marine and intertidal environments, but does not include temporal information that captures the dynamic processes that act over larger timescales (RPS 2008b).

3.3 Results

3.3.1 Ichthys Field

ROV and towed video investigations were conducted in areas of the Ichthys Field that were selected based on information provided by earlier geophysical investigations. ROV investigations encountered bare substrates, with heavily rippled sand, suggestive of strong near-seabed currents and mobile sediments that do not favour the development of diverse epibenthic communities. Few epibenthic organisms were recorded, limited to an anemone, a galatheid crab and an olive-tailed flathead (RPS 2008b).

The towed video surveys encountered a range of benthic communities, the composition of which was determined by substrate-type, water depth, and probably current regime. The deeper areas, between approximately 150 m and 220 m, generally supported very sparse benthic communities. The seabed substrates included muds, rippled sands, low semi-exposed pavements, and upstanding reefal features. The soft substrates supported very few species in a sparse suite of epibenthic organisms, primarily small gorgonians, sponges, and tube worms. The hard substrates were colonised by a more diverse assemblage, with the density increasing with decreasing depth. The more common epibenthic organisms included small sea whips, sponges, gorgonians, crinoids, and black corals, in low-to-medium densities. Species density also appeared to relate to sediment movement and seabed profile, with higher-profile features supporting significantly more abundant communities than the flatter pavements (RPS 2008b).

The homogeneity of the seabed habitats in the Ichthys Field area, and the absence of features such as high profile reefs that may support spatially restricted and diverse biotic assemblages, indicate the proposed offshore development area is of low conservation significance for benthic biota. The areas of mud and fine sand on the seabed in the Ichthys Field area indicate it is a depositional area where fine sediments and detritus accumulate. Soft substrates are typical of deep continental shelf seabeds and this habitat type is very widely distributed in the deeper parts of the North West Shelf. This habitat generally supports a diverse infaunal assemblage dominated by polychaetes and crustaceans which are widely distributed in the region (RPS 2008b).

The large sand waves in parts of the Ichthys Field area indicate that there are strong seabed currents in the area. The sand waves are likely to move in response to seasonal changes in the currents and the substrate instability is expected to limit the development of infaunal communities in this habitat (RPS 2008b).

3.3.2 Echuca Shoal

ROV surveys at Echuca Shoal were limited to transects where the ROV could maintain direction, and where the research vessel could maintain safe position, in the prevailing currents. The transects traversed the top of the shoal, dropping down the slope to a depth of 120 m (Figure 3-2).

The ROV surveys generally encountered an environment characterised by high currents, and seabed substrates dominated by coral rubble. Relatively small colonies of *Porites* were common, but the community was low in both species richness and abundance. The presence of occasional large rocky outcrops, generally supporting sponges, suggests that larger coral structures have occurred previously, and may still occur elsewhere on the shoal (RPS 2008b).

The dominant substrate in the shallower areas was coarse sand and coral rubble, with small patches of exposed pavement. The benthic community comprised a sparse assemblage, dominated by occasional hard corals and soft corals, sponges, crinoids, hydroids and turfing algae. Small *Porites* colonies were the most common of the hard corals, with faviids and acroporids less common. All of these taxa are common in tropical Western Australian reefal habitats. The largest features observed in the shallows were the remains of large coral colonies, heavily eroded and covered in encrusting and boring sponges. Soft corals included *Junceela, Sarcophyton, Dendronephthya, Sinularia, Tubipora* and the black coral, *Antipathes* (RPS 2008b).

Isolated areas of exposed rock and sheer drop-offs on the slope supported a diverse and abundant filter-feeding community, mainly sponges, soft corals, hydroids and crinoids. These isolated areas of hard substrate and associated fauna were encountered on two of the three slope surveys, in depths of between 55 m and 65 m (RPS 2008b).

3.3.3 Infauna

September 2005

One hundred and eighty six individuals representing 117 nominal species from ten phyla were collected in September 2005 from the 13 sites around the Echuca Shoal and Ichthys Field. Polychaete worms (Annelida) and crustaceans (Arthropoda) were the most species-rich and numerically dominant phyla, contributing 72% of the individual fauna species and 75% of the total number of animals between them (RPS 2007a).

Polychaetes were represented by 51 species from 17 families, and accounted for 44.5% of the total individuals collected. The abundance of individuals was distributed relatively evenly across the identified families, with no dominant taxa. The samples collected included tube-dwelling deposit feeders from the Ampharetidae, Terebellidae, Magelonidae and Spionidae families and members of the surface deposit-feeding Captellidae family.

The crustacean assemblage comprised 31 nominal species from at least 13 families. Gammarid amphipods and tanaids were the most abundant taxa, accounting for 25 of the 54 individuals collected (RPS 2007a).

May 2007

In total, 419 individuals from nine phyla and at least 94 nominal species were collected from the eight offshore locations in May 2007. Arthropoda and Annelida were the most species rich and numerically dominant, together contributing more than 70% of the species identified and individuals counted (Table 3-1). This result is similar to that obtained in September 2005 (RPS 2007a).

Differences in the composition of the infauna between sites appear to be related, at least in part, to both sediment particle size distribution and water depth. In some cases, sites with similar particle size distributions had very similar infaunal community compositions (RPS 2007a).

Table 3-1 Ranking, numbers and percentage contributions of each phylum to the number of taxa and number of individuals collected from sediment samples at offshore locations in May 2007. Source: RPS (2007a)

Phylum	Species			Abundance		
	Rank	Number	% of total	Rank	Number	% of total
Arthropoda	1	44	46.8	2	148	35.3
Annelida	2	>22	23.4	1	183	43.7
Mollusca	3	10	10.6	4	14	3.3
Echinodermata	4	7	7.4	3	58	13.8
Sipunculida	5	5	5.3	5	9	2.1
Cnidaria	6	3	3.2	7	3	0.7
Bryozoa	7	1	1.1	9	1	0.2
Chordata	7	1	1.1	10	1	0.2
Nematoda	7	1	1.1	6	2	0.5

Water depth is likely to be a major influence on the diversity and composition of the infaunal assemblage. At water depths of 20–80 m, low oxygen levels in water become stressful to benthic life. At offshore locations, dissolved oxygen decreased consistently with water depth below the thermocline to as low as 60% saturation at the maximum depth measured (approximately 90 m). This decrease in the concentration of oxygen would presumably preclude the existence of many infauna species in the sediments of the offshore locations (RPS 2007a).

The relationship between water depth and species richness and total number of individuals was apparent in this study, with both species diversity and abundance decreasing with increasing water depth. Species richness and abundance could also be influenced by a numbers of other factors, including oceanographic conditions, productivity rates, availability and range of food sources and habitats, and sediment grain-size composition (RPS 2007a).

3.3.4 Browse Island

Browse Island is an isolated sandy cay surrounded by an intertidal reef platform and shallow fringing reef. The natural resources of the island and platform include beaches, a fringing coral reef, and various shallow lagoon micro habitats. The Browse Island reef complex is an outer-shelf, biohermic structure rising from a depth of approximately 200 m. It is a flat-topped, oval-shaped, platform reef, the largest diameter being about 2.2 km. The island is a triangular, vegetated sandy cay, standing just a few metres above high tide level, and measures approximately 700 m by 400 m (Figure 3-3) (RPS 2008b).

Reef habitats at Browse Island are not diverse. Rocky shore habitat is represented only by exposed beach rock, and there are no intertidal sand flats. The lagoon habitat is poorly developed, with poor water circulation, and shows evidence of recent in-fill and high mortality. The reef platform, especially on the western side, is high and conspicuously barren in many places. Only the reef crest and seaward ramp habitats around the edge of the reef support moderately rich assemblages of molluscs. The shallow subtidal zone is narrow, and supports relatively small areas of well-developed coral assemblages (RPS 2008b).

Intertidal habitats of Browse Reef

The habitat and flora and fauna assemblages in the intertidal zones at Browse Island are described below and are shown in Figure 3-3.

Beach sand (upper littoral)

There is a sandy zone between the vegetation and the high tide mark, widest on the northern and eastern sides of the island, where turtles nest. There is a steep upper littoral beach of coarse coral sand on those sides while, on the western and southern sides, the upper littoral zone is mostly beach rock, with only a narrow zone of beach between the rock and the island vegetation (Figure 3-3).

The mobile, coarse coral sand of the island's beaches did not appear to provide a suitable habitat for invertebrates, and the suite of bivalves and gastropods that occupies this habitat at other localities was missing (RPS 2008b).

Beach rock (upper littoral)

The exposure of beach rock around the western and southern shore of the island was interpreted as an indication that the island has moved nearly 100 m northwards in geologically recent times. It is unclear whether development of a sandy beach on the northern side and exposure of the south-eastern beach rock are seasonal features, a result of recent storm events, or long-term trend. The upper part of the beach rock zone was devoid of visible life, and not even the two species of littorinid that would normally be expected in this habitat were observed (RPS 2008b).

Section 3 Marine Ecology

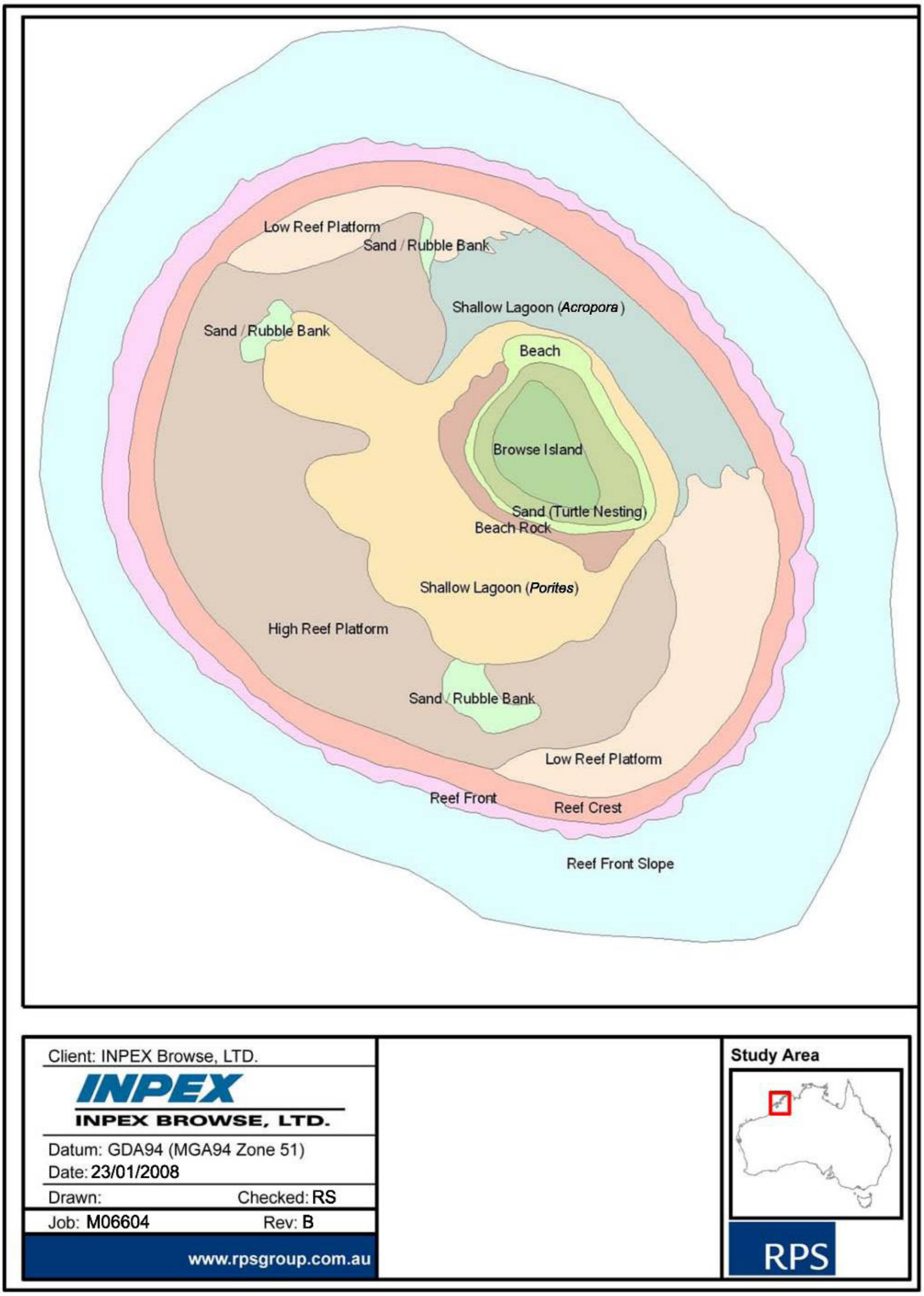


Figure 3-3 Habitat map of Browse Reef

The lower part of the beach rock habitat along the western and southern shores of the island supported a modest invertebrate fauna. However, there were few barnacles and no rock-oysters or byssal-attached, filter feeding bivalves on the rock surfaces, and no boring mytilid bivalves (lithophagines) were observed. Although some algal turf was observed on the rock surfaces in this part of the zone, the grazing and detritus-feeding molluscs characteristic of the habitat were either missing, or only present in very low numbers. There were no chitons or limpets and, of the marine snails, only juvenile *Nerita polita* and a single specimen of *N. albicilla* were seen (RPS 2008b).

Lagoon

There is a shallow central lagoon (0.5–1 m at low tide) separating the shore from a high midlittoral reef platform on the south-western side of the island. The lagoon has a sandy floor, several metres thick, overlaying hard platform, with extensive coral growth (especially *Porites* and other massive corals). In places it shows evidence of in-filling, with dead corals still in place, partly covered by sand and rubble. It is unclear whether this is the result of a recent storm event, e.g. Cyclone Fay in 2004, or geomorphic progression (RPS 2008b).

Adjacent to the beach on the north-eastern and eastern sides of Browse Island, the lagoon is narrower and shallower than that on the south-western side (<0.5 m at low tide). In the area around Site 1 (Figure 3-1) there is no midlittoral reef platform, and the reef crest passes directly into the shallow lagoon that has two distinct zones. The wider, outer part was dominated by *Acropora*, much of it dead but still in place. The narrow, inner part of the lagoon was dominated by *Porites*. Further towards the south-east, in the vicinity of Site 2, there is a reef platform behind the reef crest, and the *Acropora* lagoon is missing. A narrow band of what may be a continuation of the inner *Porites* zone was found near the shore (RPS 2008b).

The lagoonal substrates were generally composed of sand and coral rubble supporting macroalgae and live corals. The outer part of the lagoon was rich in coral cover, but low in diversity. The commonest corals in this zone were from the families Poritidae, Acroporidae, Helioporidae, Pocilloporidae and Faviidae, the Acroporidae being the most prolific. *Acropora palifera* was particularly important as a reef building coral. The other branching *Acropora* species formed mixed-species thickets in the lagoon (RPS 2008b).

The lagoons typical of fringing reefs and atolls that usually provide sand habitats and support a characteristic assemblage of burrowing bivalves and gastropods was virtually absent from the Browse Island reef; and none of the usual sand-burrowing bivalves was present. Of the gastropods usually occurring in this habitat, no cerithiids, olivids, or mitrids were seen (RPS 2008b).

Reef platform

The midlittoral reef platform is widest on the western and southern sides (approximately 1 km), and narrowest on the north-eastern side (approximately 450 m). Most of the platform is exposed at low tide, and the midlittoral platform on western and southern sides appeared to be slightly higher than the eastern platform, which is covered first by the incoming tide (RPS 2008b).

The last areas to be covered by an incoming tide are two rubble banks at the centre of the high platform, one in the north-west and the other in the south. At the north western and south-eastern ends of the island, there are drainage gutters, approximately 10 m wide, between the shore and adjacent high sections of the midlittoral reef platform; they appear to be continuations of the inner

Porites lagoon but their contents were not investigated. As the tide floods, the lower eastern platform is covered first, and strong currents flow westwards around the island, through these gutters into the south-western lagoon, with the high western platform flooding last from the back, rather than from the seaward side (RPS 2008b).

The reef platform at Browse Island was dominated by large areas of sand and coral rubble, with some exposed limestone supporting sparse algal turf, and many barren shallow pools. The common corals were similar to those found in the lagoon. Few of the predatory and grazing gastropods normally common in this habitat were observed (RPS 2008b).

On the western, swell-affected side of the island (Site 4, Figure 3-1), the lower littoral seaward ramp is about 60 m wide and noticeably sloped (estimated to be about 2 degrees). There is a wide, high reef crest in the outer midlittoral zone, with a well-developed zone of dead coral boulders (up to 1.5 m high) and little live coral (RPS 2008b).

The seaward ramp is narrower and less sloping on the leeward eastern side (Sites 1 and 2); the seaward ramp is lower and narrower, and the boulder zone is poorly developed with a moderate live coral fauna (RPS 2008b).

A mobile sandy beach at the northern end of the island appears to be growing north-westwards, possibly due to the tidal flow pattern. On the south-eastern corner of the island, a wide area of low beach rock appeared to have been uncovered recently (RPS 2008b).

Reef crest

Although relatively elevated, this zone was regularly swept by waves, except during the lowest of tides, and there were usually numerous pools and loose stones, as well as frequent slabs of limestone, large faviids, and some upstanding boulders (not a typical boulder zone). The reef crest supported the highest diversity of molluscs of all the zones, both surface-dwelling and cryptic species. On the southern side of the island (Site 3, Figure 3-1), there was a very wide but relatively low reef crest without a zone of dead coral boulders. Instead, there was a band of coral of relatively high species richness and abundance (80% cover), dominated by *Goniastrea* (RPS 2008b).

Seaward ramp

There is a narrow reef-front slope in the sublittoral zone around the reef platform before a steep drop-off into deep water. The reef edge is virtually uninterrupted (continuous around the entire structure), although there are narrow drainage gutters across the seaward ramp on the south-western side (RPS 2008b).

There is significant variation in the form of the reef margin, especially in the width of the reef crest and the development of a boulder zone. The seaward margin of the reef is wave-swept, except during brief periods at extreme low tide. The seaward ramp generally has a ragged edge, and consists of pavement with crustose algal cover and a low algal turf. Live coral cover was variable (10–15%), but coral species richness was low, with mainly encrusting forms and small colonies of the same families as found in the lagoon, and on the reef platform and crest. The seaward ramp supported a moderately rich molluscan fauna, primarily species that live in crevices and in the algal turf (RPS 2008b).

Subtidal habitats of Browse Reef

The shallow (<20 m) subtidal zone outside the reef at Browse Island generally ranges from 50 m to 200 m in width. The morphology of the seabed in the shallows outside the reef reflected the energy regime of the different locations. The majority of the oceanic swell appears to impact the island from a north to south-west direction. The shallow seabed to seaward of the reef platform in this area was mainly bare limestone, with very minor corals of mostly encrusting or low massive morphologies (RPS 2008b).

A more diverse range of substrates and community-types was encountered in the remaining shallows surrounding the island, with substrates including broad areas of coarse sand, low profile pavements, rubble zones, and small, raised coral reefs. Coral communities included some large monospecific thickets of branching *Hydnophora rigida*, tabular *Acropora*, and occasional large *Porites* colonies. Some parts of the edge of the reef flat comprised near vertical drop-offs to 10–12 m, supporting more diverse and abundant coral communities, including *Acropora, Goniopora, Platygyra, Goniastrea, Seriatopora, Pocillopora, Montipora* and *Coeloseris* (RPS 2008b).

Some large areas of coral rubble were found outside the reef, mostly adjacent to the reef platform on the southern side of the island. This was mainly derived from branching *Acropora*, and appeared to be the remains of extensive coral growths, possibly fragmented by a past storm event (RPS 2008b).

Fish surveys

An intertidal pool, approximately 19 m^2 and 0.7 m deep, on the north-east reef crest of Browse Island was sampled during the spring low tide survey. Of the 32 species identified, *Abudefduf vaigiensis* (Family Pomacanthidae), *Ecsenius oculus* and *Cirripectus filamentosus* (Family Blennidae), and *Gymnothorax* spp. (Family Muraenidae) were the most abundant. *Acanthurus nigrofuscus* (Family Acanthuridae), *Thalassoma hardwickei* and *Thalassoma janseni* (Family Labridae) were among the least common (Table 3-2). All of the species found are common in the Indo-Pacific region; no members of the protected Family Syngnathidae were recorded (RPS 2008b).

Table 3-2 Numbers of individuals of each fish species sampled by rotenone in an intertidal pool on the NE reef crest of Browse Island. Source: RPS (2008b)

Browse Island	No. of fish	Browse Island	No. of fish
Abudefduf vaigiensis	19	*Lutjanus decussatus*	8
Acanthurus nigrofuscus	1	*Nemipterus* sp. A	1
Acanthurus sp.	1	*Ogilbia* sp.	1
Balistoides viridescens	1	*Ophidion muraenolepis*	2
Cephalopholis argus	2	*Parupeneus bifasciatus*	2
Chaetodon lunula	2	*Plectroglyphidodon leucozona*	3
Cirripectes filamentosus	12	*Pseudochromis punctatus*	2
Cirripectes sebae	7	*Pseudochromis* sp.	4
Diodon liturosus	1	*Pseudochromis tapeinosoma*	4
Ecsenius oculus	19	*Pufferfish* sp.	1
Grammistes sexlineatus	1	*Scorpaenopsis diabolos*	3
Gurnard 3 spp.	3	*Suggrundus japonica*	2
Gymnothorax sp.	12	*Thalassoma hardwickei*	3
Halichoeres margaritaceous	3	*Thalassoma janseni*	1
Halichoeres marginatus	3	*Leatherjacket* sp.	1
Halichoeres nebulose	4	*Istiblennius periophthalmus*	8
		Total	**137**

Coral spawning

The investigations conducted in early October 2006 found nine species of *Acropora* containing pigmented eggs. Although not confirmed it was estimated that the corals spawned between 10 and 15 October 2006; this period coinciding with neap tides following the full moon on 7 October 2006 (RPS 2008b).

Further investigations between 18 and 20 March 2007, based on predicted coral spawning period for reefs further south in Western Australia (Ningaloo Reef and Dampier) being 9-12 April 2007, sampled the reefs approximately three weeks prior to that date. These investigations observed eggs in *Acropora* and a number of faviids. Eggs observed in *Acropora* supported the conclusion that most species of *Acropora* would have spawned during the predicted April mass spawning event. However many observed eggs in the faviid colonies were more pigmented than was expected for corals that were expected to spawn in approximately three weeks. This could mean that many of the faviids spawned during the neap tide following the new moon (i.e. within about a week), as has been observed in some species at Ningaloo Reef, rather than about three weeks later, during the full moon which is more typical (RPS 2008b).

The most comprehensive of these coral spawning surveys was conducted at Berthier, Turbin and Albert islands in October 2007. Four hundred and twenty-nine coral colonies were sampled, comprising 63 species from 17 genera. Sixteen species (25%) from two genera, *Acropora* and *Hydnophora*, contained pigmented eggs. The dates over which the coral spawning took place is unknown, but it is estimated that all colonies containing pigmented eggs spawned between 2 and 6 November, during the neap tide following the full moon on 26 October 2007 (RPS 2008b).

Significantly the investigations also found that some colonies of many species did not contain any visible eggs, indicating that not all colonies of all species were due to spawn during the imminent spawning period (RPS 2008b).

Regional context

The benthic habitats and biotic assemblages at Browse Island are characteristic of coral platform reefs throughout the Indo-West Pacific region. Geomorphically and biologically, it most closely resembles Cartier Reef, which is approximately 200 km further north, near Ashmore Reef. However, the small area of intertidal habitat at Browse Island, the elevation of the reef flat and the limited shallow subtidal area, appears to have limited the development of benthic communities on the island (RPS 2008b).

The elevation of the reef platform appears to have restricted the development of coral communities on the reef flat. Coral diversity was greater on the reef faces and in the shallow lagoons, but these areas are of very limited extent. The molluscan assemblage was limited and strongly dominated by widespread Indo-West Pacific species that do not occur on the inshore reefs of the Bonaparte Archipelago. It appeared that long-term harvesting of reef animals by Indonesian fishermen has depleted the stocks of target species such as cowries, *Trochus* spp. and holothurians (RPS 2008b).

Macrophytes such as seagrasses and the macroalga *Sargassum*, which are abundant in inshore areas, do not appear to occur in intertidal or shallow subtidal areas at Browse Island. The macrophyte assemblage at Scott Reef is similarly depauperate (RPS 2008b).

The coral reefs, habitats and biota of Browse Island were typical of the outer shelf atolls, banks and platform reefs that characterise the Oceanic Shoal Bioregion and differed markedly from those around the islands of the Bonaparte Archipelago, which are representative of the more turbid, macrotidal, fringing nearshore reefs and rocky shores that characterise the Kimberley Bioregion. Although the general characteristics of the two bioregions have been known for some time, the information obtained by the present study has confirmed that the two bioregions are ecologically distinct (RPS 2008b).

4.1 Background

INPEX proposes to construct a 42-inch, 885 km long sub-sea pipeline to transport dehydrated gas from Ichthys Field in the Browse Basin to a proposed onshore LNG plant at Blaydin Point in Darwin Harbour. This section presents the results of a seabed survey conducted in December 2008 by URS along the proposed pipeline alignment (URS 2008).

The overall survey programme was conducted as five sequential activities highlighted below:

- Desktop review of available survey information to enable selection of appropriate and representative sampling locations along the route.
- Design of field survey programme.
- Conduct of field survey using a drop camera.
- Reduction, analysis and interpretation of photographic and video data.
- Production of this field survey report.

4.2 Methods and materials

4.2.1 Information review and site selection

Prior to commencement of the field survey, an interpretation of data was undertaken of the geophysical and geotechnical survey of the pipeline route carried out by Neptune Geomatics (2009), on behalf of INPEX. The survey utilised a hull-mounted Reson 8101 Multibeam Echo Sounder to record bathymetry, an EdgeTech 2000DSS 670-CD towfish sidescan sonar to identify seabed features, and an Applied Acoustics AA301 Boomer Sub Bottom Profiler and an EdgeTech 2000DSS 670-CD combined chirp and sidescan sonar system to obtain shallow, high-resolution seismic data for interpretation of shallow geology. The survey was conducted between July and November 2008, with the objective of establishing a suitable pipeline route, covering the shortest possible distance while taking account of the seabed morphology, sediment types and sub-soil to ensure the minimum risk to the pipeline during installation and throughout its life cycle (Neptune Geomatics 2009).

These data, showing the seabed profile and seabed characteristics, allowed for a more targeted habitat survey identifying areas of potential ecological interest or areas representative of the seabed along the proposed pipeline route. As a result, eighteen survey stations were selected to enable characterisation of the epibenthic faunal communities along the proposed pipeline route and to ‘ground truth’ the side scan sonar data (Figure 4-1) (URS 2008).

Section 4 Pipeline Habitat Survey

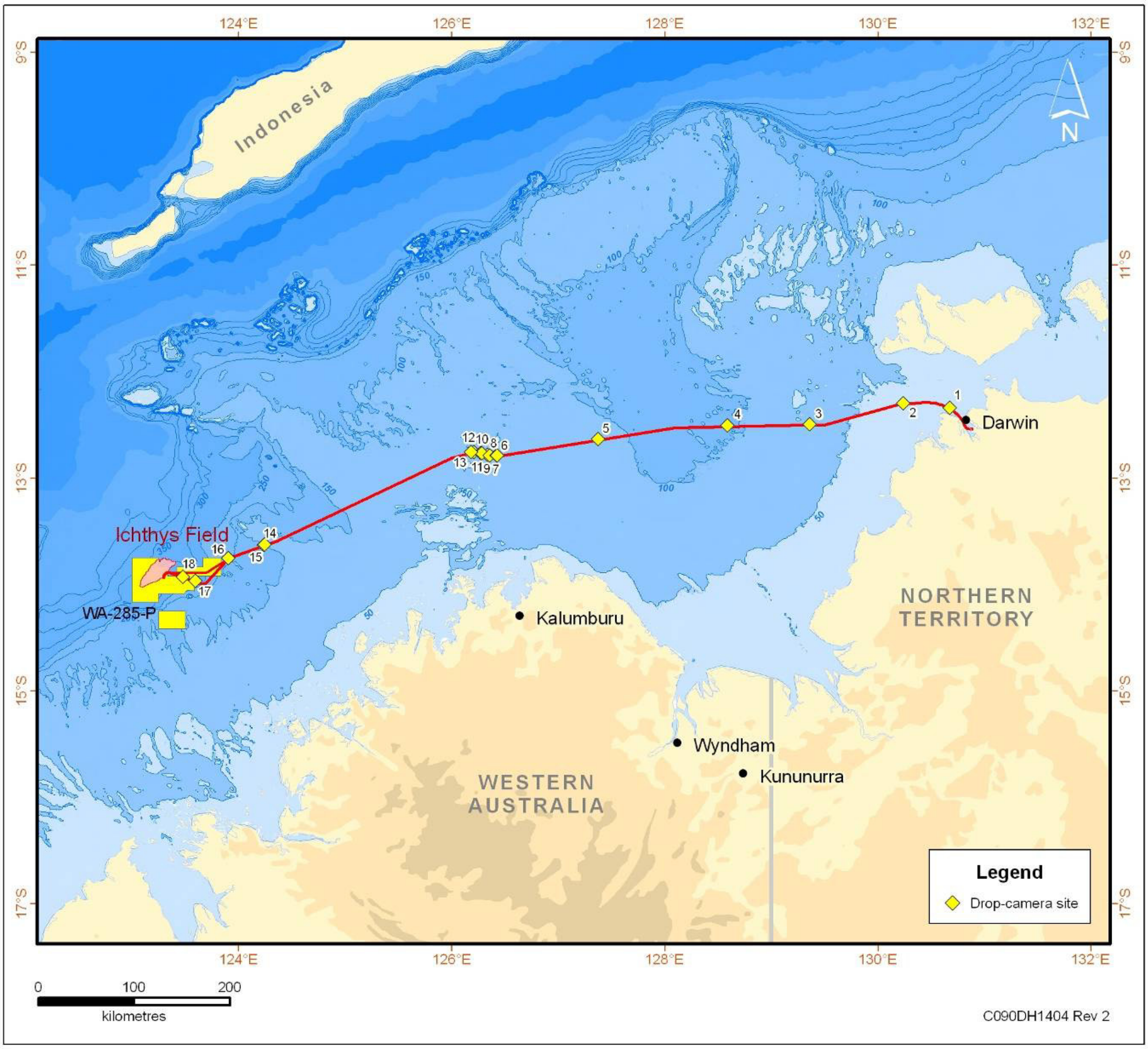


Figure 4-1 Proposed pipeline route with survey locations highlighted

4.2.2 Drop camera survey

The survey of the seabed at the selected stations was undertaken using a drop camera (Figure 4-2), operated by Gardline Marine Sciences, with the digital camera relaying live images to monitors aboard the Gardline survey vessel Ocean Endeavour. In addition to general photographic observations, the camera recorded video of the seabed at the station. At each station, the camera was deployed over the side of the vessel and approximately 10–15 photographs of the seabed and representative epibenthic fauna were taken.

While the drop camera returned high quality images, it had some limitations:

- It was not possible to ascertain the accurate position of the drop camera on the seabed, as the depth of operation and currents through the water profile most probably offset the camera position from the vessel position.
- As it had no means of propulsion, it could not be used to search for discrete seabed features (e.g. individual outcrops), especially as there would be a risk of entanglement of the camera with such features.
- The restricted field of view of the camera, coupled with turbid water, limited the ability of the camera to capture some of the larger-scale features (e.g. sand waves, channel slopes) present at some stations.

Notwithstanding the above, the camera was effective for recording general seabed characteristics across a broad area as it was partially raised and redeployed a number of times at each location.

As the survey did not entail photographing the seabed along transect lines, the relative abundance of habitats or species identified were expressed qualitatively as far as possible. Epibenthic fauna were initially identified by a URS environmental scientist in the field, with additional identification and interpretation of the survey data undertaken at URS' offices in Perth (URS 2008).

Figure 4-2 Drop camera set-up used for the survey

4.3 Results

4.3.1 Information review and survey design

Classes of seabed characteristics, as interpreted by Neptune Geomatics (2009) from side scan sonar data, are described in Table 4-1.

Table 4-1 Seabed characteristic lasses. Source: Neptune Geomatics (2009)

Class	Seabed Classes	General Description
1	Clay/Silt	Very soft to soft silts, sandy silts and very loose to loose silty fine to medium sands, often with some shell content.
2	Silt/Sand	Sandy silts and silty fine to coarse sands, slightly higher sand or shell content than Class 1.
3	Fine/Coarse Sand	Gravely fine to coarse sands and sandy gravels with minimal silt content.
4	Low relief subcrop	Cemented carbonate (calcarenite) subcrop.
5	Moderate to higher relief outcrop	Outcrop of calcarenite or relict reef (coralline limestone).
6	Pockmarks	Pockmarks (5-10 m diameter) thought to be related to the emission of interstitial pore water or biogenic gas derived from underlying decaying carbonate sediments.
7	Sand waves	Sand waves >2 m high.

The following is a summary of seafloor characteristics along the pipeline route, drawn from the Neptune Geomatics (2009) geophysical and geotechnical survey. The kilometre point (KP) values relate to the distance along the pipeline route from the Ichthys Field (KP 0). The summary description terminates at Darwin Port Limits (KP 862.77).

The majority of the proposed pipeline route (>98%) encompasses featureless, unconsolidated clay/silty sands with the most dominant seabed features being areas of pockmarks and sand waves. The only substantial areas of subcrop are between KP 361–374.5 and KP 482–513. Exposed outcrop is very rare along the route with only small areas encountered at KP 36.5, KP 187, between KP 360–372 and KP 378–382 (URS 2008).

KP 0 to KP 97.5

The majority of the gently upward sloping seabed (250–136 m deep) between these points is comprised of rippled fine to coarse sands with an occasional gravely matrix existing as a veneer overlying more consolidated cemented calcarenite. Areas of megaripples, up to 5 m high, are present in this zone. A single calcarenite outcrop (3 m high, approximately 600 m long and 200 m wide) at KP 36.5 is the only notable hard substrate area recorded within this section (URS 2008).

KP 97.5 to KP 213

The seabed along this section of the route is dominated by fine to coarse sands with both low (≤10 per 10 000 m^2) and high (≥10 per 10 000 m^2) density pockmarks (5–10 m in diameter). An isolated area of megaripples (0.15 m crest height and 9 m wavelength) is present between KP 112–120, with some relatively small patches (1 km) of low relief subcrop evident. An area of subcrop, with small outcrops in the shallower parts (106–112 m), is present around KP 187. Overall, the seabed slopes gently upwards from a depth of 136 m to 84 m (URS 2008).

KP 213 to KP 331.5

The seabed along this section of the route is characterised by featureless fine to coarse sands with occasional patches of a gravely matrix and dense (≥10 per 10 000 m^2) pockmarks. No substantial areas of outcrops or hard substrate are present (URS 2008).

KP 331.5 to KP 481

The seabed along this section of the route is typically comprised of gently sloping, featureless fine to coarse sands with occasional areas of ridged calcarenite subcrop up to 3.4 m high (KP 361–374.5), with scattered outcrops. A scarp slope of cemented outcrop (maximum gradient of 7.2°) around KP 379 forms the western side of a 3 km wide paleochannel, where the water depth reaches nearly 90 m. There are isolated outcrop areas within the paleochannel (URS 2008).

KP 481 to KP 513

Calcarenite subcrop causes the seafloor to be very rugged in places, with a 1 km wide paleochannel between KP 483 and KP 484. Small outcrops are present in the shallower (70–75 m) waters either side of the paleochannel, in which water depths are typically 80–85 m. The subcrop areas are flanked by clay/silt sand, interspersed with sandy gravel patches with a few pockmarks (>5 m diameter) (URS 2008).

KP 513 to KP 706

The seabed along this section of the route is characterised by featureless clay/silt sands dominated by low (≤10 per 10 000 m^2) density pockmarks (5–10 m in diameter). Water depths vary from 110 m to 63 m (URS 2008).

KP 706 to KP 862.77

The seabed along this section of the route is largely characterised by featureless clay/silt sands with areas of megaripples (KP 799–804) and sand waves up to 4.9 m high. Water depths vary from 70 m to 11 m (URS 2008).

4.3.2 Drop camera survey

The camera was deployed at 18 stations (Figure 4-1), with photographic and video records made at each station. Qualitative abundance categories of epibenthic fauna, determined from field observations and validated by further data interpretation are presented in Table 4-2. Brief descriptions of the seabed characteristics and benthic ecology at each station are provided below, with data and photographs from each station presented in figures 4-3 to 4-20 (URS 2008).

Station 1

The geophysical survey indicated that this station would be dominated by large sand waves. Whilst the sand waves were evident on the ship’s echo-sounder, their size was too great to be captured by the drop camera field of view.

The sparse epibenthic fauna present were predominantly colonial hydroids, with some sea pens (Pteroeidae), feather stars (Crinoids) and ascidians also noted (Figure 4-3) (URS 2008).

Station 2

The geophysical survey indicated that this station would be dominated by megarippled sand, with some large sand waves (up to 4.9 m in height). The sand waves were not captured within the field of view of the drop camera, but there were scattered sea pens (Pteroeidae), sea whips (*Junceela*), feather stars (Crinoidea), hydroids, bryozoans and sea stars (Asteroidea) present (Figure 4-4) (URS 2008).

Station 3

The geophysical survey indicated that the seabed at this station would be characterised by a high density of large (>5 m) pockmarks. These features were not evident, due either to their size relative to the drop camera field of view or because the drop camera landed in an area of seabed between pockmarks. Visibility was too low for a panoramic view of the seabed to be captured.

No epibenthic fauna were noted at this station, though the fine sand substrate was peppered with small (up to 5 cm diameter) holes typical of those made by burrowing invertebrates such as bivalves, shrimp and polychaete worms (Figure 4-5) (URS 2008).

Station 4

The geophysical survey indicated that the seabed at this station would be characterised by a high density of smaller (<5 m) pockmarks. As at station 3, these features were not evident, due either to their size relative to the drop camera field of view or because the drop camera landed in an area of seabed between pockmarks.

The substrate was characterised by clay/silt sands (Figure 4-6). Only occasional (two to four individuals) feather stars (Crinoidea) were noted at this site. Additionally, a grinner fish (Sauridae) was noted on the seabed (URS 2008).

Station 5

The geophysical survey indicated that the seabed at this station would be characterised by rock outcrops in an existing paleochannel. Small rocky outcrops were evident, with epibenthic fauna attached to the hard substrate.

The sandy substrate was peppered with small (<5 cm diameter) holes. Sea fans (Gorgonians), sea whips (*Junceela*), feather stars (Crinoidea), tree soft coral (*Dendronephthya*) and sponges were all noted at low abundances at this site (Figure 4-7) (URS 2008).

Station 6

Similar to station 5, the geophysical survey indicated that the seabed at this station would be characterised by rock outcrops in an existing paleochannel. Again, small rocky outcrops were evident, with epibenthic fauna attached to the hard substrate.

Sea pens (Pteroeidae), sea fans (Gorgonians), sea whips (*Junceela*), feather stars (Crinoidea), bryozoans, hydroids, and sponges were all noted at relatively high abundances at this site. The stations were dominated by crinoids, which were the most abundant epibenthic fauna noted during the whole survey (Figure 4-8) (URS 2008).

Station 7

The geophysical survey indicated that the seabed at this station would be characterised by the western rock slope of a paleochannel. However, the rocky substrate at this station was covered with a sand veneer and there was only a very low abundance of epibenthic fauna (sea whips, tree soft coral and hydroids) (Figure 4-9) (URS 2008).

Station 8

The geophysical survey indicated that the seabed at this station would be characterised by low relief subcrop, with sandy substrate overlying rock. Feather stars (Crinoidea) were common at this site, with a ball sponge and tree soft coral (*Dendronephthya*) noted (Figure 4-10) (URS 2008).

Station 9

The geophysical survey indicated that the seabed at this station would be characterised by rocky outcrops. Occasional rocky substrate was recorded by the drop camera. Feather stars (Crinoidea) were common at this site, with bryozoans, urchins, hydroids and sponges also present (Figure 4-11) (URS 2008).

Station 10

The geophysical survey indicated that the seabed at this station would be characterised by outcrops on a north-south ridge. However, the drop camera reached the seafloor between outcrops and only flat sandy substrate was recorded. The visibility was too low, the current too strong and the drop camera insufficiently manoeuvrable, to risk searching the seafloor for the outcrops.

Sea fans (Gorgonians), sea whips (*Junceela*), tree soft coral (*Dendronephthya*), bryozoans, hydroids were all relatively common on the seabed at this station, indicating that the sandy substrate was probably only a thin veneer over rock (Figure 4-12) (URS 2008).

Station 11

The geophysical survey indicated that the seabed at this station would be characterised by outcrops on a north-south ridge. A sandy substrate with occasional rocky outcrops was evident.

Sea fans (Gorgonians), sea whips (*Junceela*), tree soft coral (*Dendronephthya*), sponges, bryozoans and hydroids were all relatively common on the seabed at this station (Figure 4-13) (URS 2008).

Station 12

The geophysical survey indicated that the seabed at this station would be characterised by a sub-crop ridge area. There were no rock outcrops evident and the seabed comprised a flat sandy substrate with shell and coral fragments. Epibenthic fauna were rare at this site, with only occasional sea pens (Pteroeidae) and a sea star (Asteroidea) noted (Figure 4-14) (URS 2008).

Station 13

The geophysical survey indicated that the seabed at this station would be characterised by a sub-crop ridge area. Small rocky outcrops were evident, with epibenthic fauna attached to the hard substrate. Feather stars (Crinoidea) were common at this site, with a few present on tree soft corals (Figure 4-15) (*Dendronephthya*) (URS 2008).

Station 14

The geophysical survey indicated that the seabed at this station would be characterised by a subcrop area. Some small rocky outcrops were evident, with epibenthic fauna attached to the hard substrate. Only sea fans (Gorgonians) and sea whips (*Junceela*) were noted (Figure 4-16) (URS 2008).

Station 15

The geophysical survey indicated that the seabed at this station would be characterised by a subcrop area. Some small rocky outcrops were evident, with epibenthic fauna attached to the hard substrate. Sea fans (Gorgonians), sea whips (*Junceela*), feather stars (Crinoidea), bryozoans, tree soft corals (*Dendronephthya*), sea stars (Asteroidea) and sponges were all noted (Figure 4-17) (URS 2008).

Station 16

The geophysical survey indicated that the seabed at this station would be characterised by clay/silt substrate. A very low density of epibenthic fauna was recorded at this station with only the occasional sea pen (Pteroeidae) noted (Figure 4-18) (URS 2008).

Station 17

The geophysical survey indicated that the seabed at this station would be characterised by a sandy substrate with a distinct single large outcrop (3 m high, approximately 60 m long and 200 m wide). The outcrop was not located and the low visibility, strong currents and low manoeuvrability of the drop camera precluded a search from being undertaken. The silty substrate supported only a very low density of epibenthic fauna—the occasional sea pen (Pteroeidae) and sea whip (*Junceela*) (Figure 4-19) (URS 2008).

Station 18

The geophysical survey indicated that the seabed at this station would be characterised by megarippled sand, with some sand waves up to ~3.5 m high. The drop camera showed the megaripples, though not the larger sand waves (Figure 4-20). No epibenthic fauna were recorded at this site (URS 2008).

SITE 1	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	848.1	12 m	12°20'36.8"S 130°41'44.8"E	A Lambo (URS)	Remote camera	9/12/2008 1634

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Sand waves.

FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Hydroids Feather star (Crinoidea) Sea pens (Pteroeidae)

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS


Hydroid colonies common at this station


Hydroid with a crinoid attached


Bare sandy substrate with shell fragments


Hydroid colonies with crinoid and ascidian colony

Figure 4-3 Pipeline survey—Station 1. Source: URS (2008)

SITE 2	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	799.4	25 m	12°18'18.9"S 130°14'55.2"E	A Lambo (URS)	Remote camera	9/12/2008 1332

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate with small shell fragments	Megarippled sand, with some large sand waves.

FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** Hydroids Sea stars (Asteroidea) Sea pens (Pteroeidae) Sea whips (*Junceela*) Bryozoans

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Hydroid colony

Sandy substrate with possible Anemone (retracted)

Sandy substrate with shell fragments

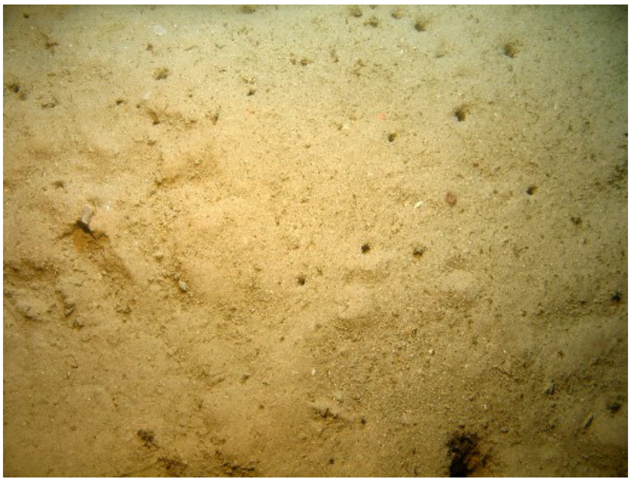
Sandy substrate with shell fragments

Figure 4-4 Pipeline survey—Station 2. Source: URS (2008)

SITE 3	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	701	70 m	12°29'55.3"S 129°21'58.00"E	A Lambo (URS)	Remote camera	9/12/2008 0754

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Bare clay/silty substrate	>5 m diameter pockmarks
FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** No epibenthic fauna evident

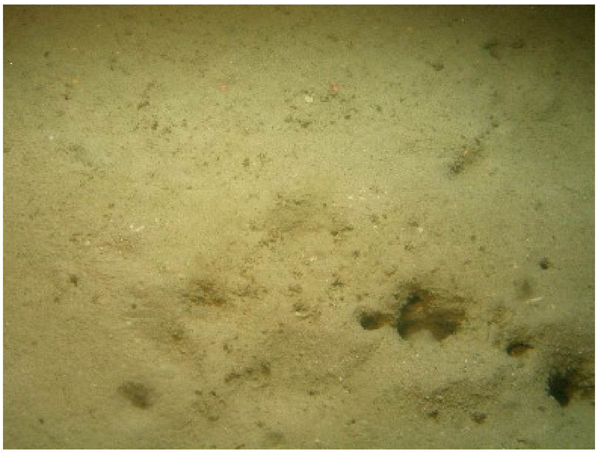
REPRESENTATIVE SUBSTRATE PHOTOGRAPHS



Fine sandy substrate with small burrows

Fine sandy substrate with small burrows

Fine sandy substrate with small burrows



Fine sandy substrate with small burrows

Figure 4-5 Pipeline survey—Station 3. Source: URS (2008)

SITE 4	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	617	100 m	12°30'47.5"S 128°35'28.0"E	A Lambo (URS)	Remote camera	9/12/2008 0239

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Clay/silty substrate with high density of small burrows	>5 m diameter pockmarks

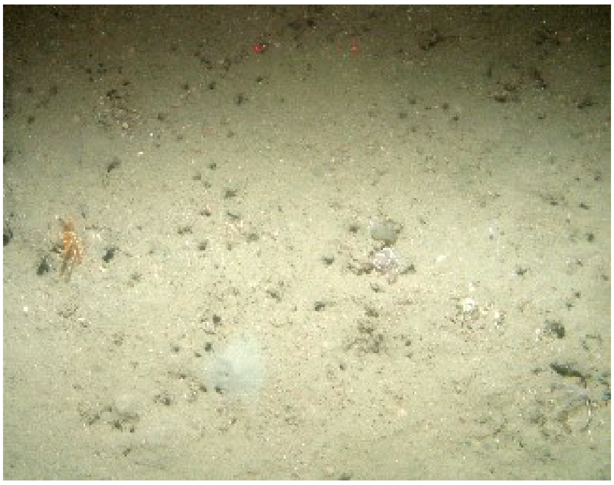
FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
Sauridae spp.	Feather star (Crinoidea) Basket star

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Fine sandy substrate with crinoid in a burrow

Fine sandy substrate with small burrows



Fine sandy substrate with small burrows

Demersal fish (*Sauridae* spp.) on sandy substrate

Figure 4-6 Pipeline survey—Station 4. Source: URS (2008)

SITE 5	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	483.9	71 m	12°38'16.2"S 127°22'40.4"E	A Lambo (URS)	Remote camera	8/12/2008 1837

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Bioturbated sandy substrate	Outcrop adjacent to paleochannel

FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Sea fan (Gorgonians) Feather star (Crinoidea) Basket star Tree soft coral (Dendronephthya) Sea whips (*Junceela*) Sponge

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Sea fans (Gorgonians)

Crinoid and tree soft coral

Sandy substrate dominant at this station

Sponge with colonial hydroids

Figure 4-7 Pipeline survey—Station 5. Source: URS (2008)

SITE 6	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	379.5	75 m	12°47'32.8"S 126°25'43.4"E	A Lambo (URS)	Remote camera	8/12/2008 1301

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Rock outcrop within paleochannel.

FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Sea pens (Pteroeidae) Sea fans (Gorgonians) Bryozoans Sea whips (*Junceela*) Hydroids Feather star (Crinoidea) Sponges

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS


Crinoids abundant at this station


Sandy substrate with shell fragments


Gorgonian, Crinoids and Bryozoan


Crinoid and fan sponge

Figure 4-8 Pipeline survey—Station 6. Source: URS (2008)

SITE 7	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	378.85	75-82m	12°47'46.6"S 126°25'27.1"E	A Lambo (URS)	Remote camera	8/12/2008 1136

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Western rock slope of paleochannel.

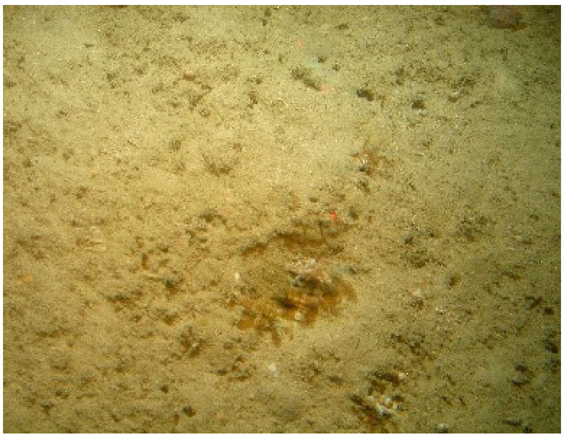
FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Sea whips (*Junceela*) Tree soft coral (*Dendronephthya*) Hydroids

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Sandy substrate dominant at this station

Sandy substrate with burrows



Sandy substrate dominant at this station

Sandy substrate dominant at this station

Figure 4-9 Pipeline survey—Station 7. Source: URS (2008)

SITE 8	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	371.8	70-75m	12°47'29.5"S 126°21'37.1"E	Ade Lambo	Remote Camera	8/12/2008 1048

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Rock slope of paleochannel ~5 m high.

FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** Feather star (Crinoidea) Sponge (*Oceanapia* sp. and *Callyspongia* sp.) Tree soft coral (*Dendronephthya*)

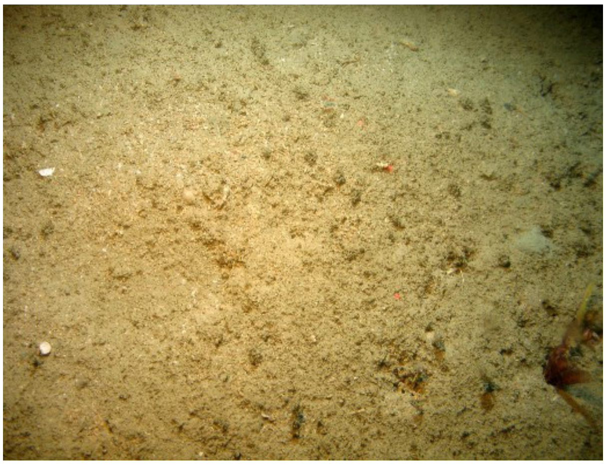
REPRESENTATIVE SUBSTRATE PHOTOGRAPHS	
 Sandy substrate dominant at this station	 Sandy substrate dominant at this station
 Ball sponge	 Crinoids

Figure 4-10 Pipeline survey—Station 8. Source: URS (2008)

SITE 9	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	369.35	70 m	12°47'11.4"S 126°20'16.9"E	A Lambo (URS)	Remote camera	8/12/2008 1015

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Rocky outcrops
FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** Sea whips (*Junceela*) Sea fan (Gorgonians) Feather star (Crinoidea) Sea stars (Asteroidea) Urchin Sponges (unknown) Bryozoan

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Crinoids common at this station

Bryozoan, hydroids and sponges

Sea Urchin (Cidaridae)

Bryozoan colony

Figure 4-11 Pipeline survey—Station 9. Source: URS (2008)

SITE 10	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	363.49	52 m	12°46' 26.1"S 126°17' 8.2"E	A Lambo (URS)	Remote camera	8/12/2008 0926

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Outcrops on north-south ridge. Similar seabed structure to Station 9 but at shallower depth

FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** Sea whips (*Junceela*) Sea fan (Gorgonians) Bryozoans Tree soft coral (*Dendronephthya*) Hydroids

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Sandy substrate

Bryozoan, tree soft coral and hydroid

Brittle star

Sea whip and tree soft coral

Figure 4-12 Pipeline survey—Station 10. Source: URS (2008)

SITE 11	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	362.4	60 m	12°46'30.7"S 126°16'32.8"E	A Lambo (URS)	Remote camera	8/12/2008 0859

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate with occasional rocky outcrops	Outcrops on north-south ridge. Similar seabed structure to Station 9 and 10, but at intermediate depth.

FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** Sea pens (Pteroeidae) Sea fan (Gorgonians) Sea whips (*Junceela*) Black coral (*Antipatharia*) Sponges (*Oceanapia* spp.) Tree soft coral (*Dendronephthya*) Hydroids

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS	
 Sea whip (*Junceela*) and sponges	 Sea fan (Gorgonian) and tree soft coral
 Vase sponge	 Hydroid colony and sea fan (Gorgonian)

Figure 4-13 Pipeline survey—Station 11. Source: URS (2008)

SITE 12	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	355/6	~60 m	S12° 45' 38.0" E126° 12' 41.8"	A Lambo (URS)	Remote camera	8/12/2008 0807

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate	Subcrop ridge area
FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** Sea pens (Pteroeidae) Sea stars (Asteroidea) Gastropod – *Murex* sp
REPRESENTATIVE SUBSTRATE PHOTOGRAPHS	
 Sandy substrate with shell and coral fragments	 Sea star
 Sandy substrate with shell and coral fragments	 Sandy substrate with shell and coral fragments

Figure 4-14 Pipeline survey—Station 12. Source: URS (2008)

SITE 13	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	352/3	66 m	S13° 45' 48.6" E126° 11' 05.2"	A Lambo (URS)	Remote camera	8/12/2008 0631

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Sandy substrate ridge with rocky outcrops	Subcrop ridge area

FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Tree soft coral (*Dendronephthya*) Feather star (Crinoidea) Anemone

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Sandy substrate

Crinoids (retracted) on rocky substrate

Crinoids on sandy substrate

Crinoids (retracted) on sandy substrate

Figure 4-15 Pipeline survey—Station 13. Source: URS (2008)

SITE 14	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	120/1	97 m	S13° 37' 51.0" E124° 14' 53.2"	A Lambo (URS)	Remote camera	7/12/2008 1610

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Fine bioturbated sand with occasional rocky outcrops	Outcrop

FAUNA RECORDED AT SITE	
Fauna Large pod (>20) of false killer whales with calves	**Sessile Fauna** Sea fan (Gorgonians) Sea whips (*Junceela*)

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Sand waves

Sea whips (*Junceela*) and hydroids

Bare sandy substrate

Sand waves

Figure 4-16 Pipeline survey—Station 14. Source: URS (2008)

SITE 15	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	120/1	100 m	S13° 37' 57.2" E124° 14' 28.7"	A Lambo (URS)	Remote camera	7/12/2008 1516

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Fine bioturbated sand with occasional rocky outcrops	Subcrop

FAUNA RECORDED AT SITE

Fauna	Sessile Fauna
Large pod (>20) of false killer whales with calves.	Sea pens (Pteroeidae) Sea fan (Gorgonians) Sea whips (*Junceela*) Bryozoans Tree soft coral (*Dendronephthya*) Sea stars (Asteroidea)

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Sandy substrate with sea whip (*Junceela*)

Bryozoan colony

Tree soft coral with sea stars

Sea fan (Gorgonian)

Figure 4-17 Pipeline survey—Station 15. Source: URS (2008)

SITE 16	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	81/2	147 m	S13° 45' 23.1" E123° 54' 28.5"	A Lambo (URS)	Remote camera	7/12/2008 1141

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Fine sand with burrows	Shoal south-east of pipeline corridor

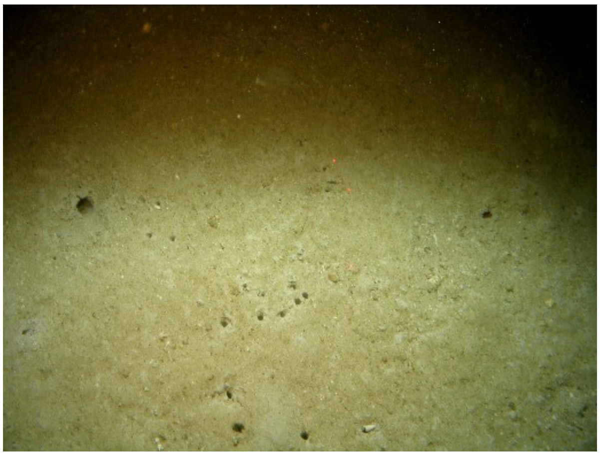
FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Sea pens (Pteroeidae)

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Bare sandy substrate

Bare sandy substrate with burrows



Bare sandy substrate with burrows

Bare sandy substrate

Figure 4-18 Pipeline survey—Station 16. Source: URS (2008)

SITE 17	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	36.5	222 m	S13° 58' 33.6" E123° 35' 45.1"	A Lambo (URS)	Remote camera	7/12/2008 0838

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Fine sand overlying a clay/silt substrate	Outcrop

FAUNA RECORDED AT SITE

Other Fauna	Sessile Fauna
None	Sea pens (Pteroeidae) Sea whips (*Junceela*)

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Thin veneer of sand overlying a silt substrate

Thin veneer of sand overlying a silt substrate

Thin veneer of sand overlying a silt substrate

Thin veneer of sand overlying a silt substrate

Figure 4-19 Pipeline survey—Station 17. Source: URS (2008)

SITE 18	KP	DEPTH	GPS LOCATION (GDA datum, Zone 52, hr°min'ss.ss")	NOTED BY	METHOD	DATE/TIME
	23	230 m	13°55'42.5"S 123°28'23.7"E	A Lambo (URS)	Remote camera	7/12/2008 0637

SUBSTRATE RECORDED	SUBSTRATE ANTICIPATED BY GEOPHYSICAL SURVEY
Coarse sand with ripples and shell fragments	Sand with mega-ripples (~3.5 m high)
FAUNA RECORDED AT SITE	
Other Fauna None	**Sessile Fauna** No sessile fauna evident

REPRESENTATIVE SUBSTRATE PHOTOGRAPHS

Bare sand substrate

Bare sand substrate with sand waves

Bare sand substrate with sand waves

Bare sand substrate with sand waves

Figure 4-20 Pipeline survey—Station 18. Source: URS (2008)

Table 4-2 Qualitative abundance of epibenthic fauna determined using a SAFCOR scale. Source: URS (2008)

Station	Depth (m)	SC	Spo	Hyd	SCo	Gor	Hco	BCo	Ech	Uni	ALL	Comments
1	10	7	nr	C	nr	nr	nr	nr	O	nr	C	5 m high sand waves
2	25	7	nr	O	nr	nr	nr	nr	O	nr	O	Flat bare sand with shell fragments
3	70	2/6	nr	nr	nr	nr	nr	nr	nr	nr	nr	Clay/silt sand
4	100	2/6	nr	nr	nr	nr	nr	nr	R	nr	R	Clay/silt sand
5	71	5	R	nr	R	R	nr	nr	R	nr	R	Low relief subcrop with occasional rock outcrops
6	75	5	nr	C	nr	C	nr	nr	C	nr	C	Low relief subcrop with rock outcrops
7	75-82	5	nr	R	R	nr	nr	nr	nr	nr	R	Flat coarse sand with shell fragments
8	70-75	5	R	nr	O	nr	nr	nr	C	nr	R	Flat coarse sand with shell fragments
9	70	5	nr	R	nr	nr	nr	nr	R	nr	R	Low relief sub crop with rock outcrops
10	52	5	nr	O	O	O	nr	nr	O	nr	O	Flat coarse sand with shell fragments
11	60	5	C	C	C	C	nr	nr	C	nr	C	Flat coarse sand with rock outcrops
12	60	4	nr	nr	nr	nr	nr	nr	R	nr	R	Flat coarse sand with shell fragments
13	66	4	nr	nr	R	nr	nr	nr	C	nr	O	Flat coarse sand with a rock outcrop ridge
14	97	5	nr	nr	R	R	nr	nr	nr	nr	R	Flat coarse sand with low relief subcrop
15	100	5	R	nr	R	R	nr	nr	R	nr	R	Flat coarse sand with low relief subcrop
16	147	5	nr	nr	nr	nr	nr	nr	R	nr	R	Clay/silt sand
17	222	5	nr	nr	R	nr	nr	nr	R	nr	R	Clay/silt sand
18	230	3	nr	nr	nr	nr	nr	nr	nr	nr	nr	Clay/silt sand

C = Common, O = Occasional, R = Rare, nr = none recorded
SCo =Soft coral (Phylum Cnidaria, Order Alcyonacea)
SC = Seabed class (from sonar interpretation, see Table 4 2)
Uni = Unidentified
HCo = Hard coral (Phylum Cnidaria, Order Scleractinia)
Ech = Echinoderm (Phylum Echinodermata)
Gor = Gorgonian fan/whip (Phylum Cnidaria, Order Gorgonacea)
Spo = Sponge (Phylum Porifera)
ALL = Total epibenthic fauna
Hyd = Hydroid (Phylum Cnidaria, Class Hydrozoa)
BCo = Black coral (Phylum Cnidaria, Order Antipatharia)

4.3.3 Comparison of pipeline hard bottom fauna with Echuca Shoals

As described in Section 4.3.2, the seabed along the pipeline route was largely devoid of hard substrate, with only sparse epibenthic fauna noted on the predominantly sandy substrate. However, at some stations (5, 6, 9, 10, 11, 13, 14 and 15) occasional epibenthic fauna (feather stars, gorgonians, bryozoans, sea urchins, hydroids and sponges) were recorded in areas where rocky substrate or outcrops were present.

ROV records captured by RPS in September 2005 (RPS 2008b) showed epibenthic fauna on sloping hard substrates at around 200 m water depth to be of low diversity and abundance, primarily comprising gorgonians. These sites were within 20 km of the current proposed pipeline and the sparse communities were similar to those recorded on hard substrates during the present survey.

In contrast, the RPS ROV records show Echuca Shoals (within 10 km of the pipeline route) to have broad areas of hard bottom substrate with substantial epibenthic fauna. The shallow shoal areas were dominated by a flat ‘reef’ platform with hard corals (particularly large *Porites* and *Platygyra* colonies), crinoids, sea whips and soft corals (*Sarcophyton* and *Dendronephthya*) common. With increasing depth (25–80 m), soft corals (particularly *Dendronephthya*) and sponges (particularly barrel sponges, *Xestospongia*) became increasingly dominant, with hard coral abundance limited by decreasing illumination. At a greater depth (80–120 m) the density of epibenthic fauna decreased dramatically, with sea whips (*Junceela*) and sea fans dominant (particularly between 80–100 m). At the drop off (180–200 m) bare sand was the dominant substratum with sponges, crinoids and occasional echinoderms and gorgonians present (RPS 2008b). It is apparent, therefore, that the sparse epibenthic communities present along the pipeline route are well represented, at greater abundance, at Echuca Shoals.

5.1 Regional setting

A small number of broad-scale oceanographic surveys, as well as the use of other remote sensing technologies, have revealed that the oceanography of the Ichthys Field is complex, with the large-scale currents of the Timor and Arafura seas being dominated by the Indonesian Throughflow. This current, which is associated with water movement from the Pacific Ocean to the Indian Ocean between the land masses of Indonesia, Australia and Papua New Guinea, is generally strongest during the south-east monsoon from May to September (RPS 2007a).

In addition to the Indonesian Throughflow, which travels down the Timor Strait (Figure 5-1), the inner Sahul Shelf displays seasonally reversing currents and locally formed water masses. For example, the flow of the surface waters (the upper 20 m of the water column) of the Timor Sea along the Australian continental shelf is north-eastwards from September to January. However, with the transition of the monsoons in March, the current reverses, flowing to the south-west until September. Nearer the Australian coast, the south-westward flow reverses in May. A transition region close to the continental slope and outer shelf is characterised by peak south-westward or northward flows and strong mesoscale variability, causing interleaving and mixing of peripheral water masses. The permit area WA-285-P is located in this transitional region (RPS 2007a). Within the Ichthys Field, ROV observations of cuttings piles from exploratory wells have indicated a slight dominance of seabed currents along a north-east/south-east axis. This has been interpreted as a tidal current signal (Serpent 2009).

The waters surrounding the permit area lie in the North West Shelf biogeographical region. The physicochemical qualities of the waters in this region are typified by persistent thermal stratification in offshore waters, although the strength of the thermocline is likely to vary seasonally. Surface water temperatures in offshore areas are relatively uniform, ranging between approximately 26 and 29°C, while inshore surface water temperatures are known to be locally influenced by upwelling of sub-thermocline waters due to tidal mixing. In shoal areas on the continental slope (<30 m water depth) and inshore waters surrounding the Bonaparte Archipelago, temperatures tend to differ little between the surface and bottom, although this depends on water depth, season and tidal mixing (RPS 2007a).

Relatively low concentrations of nutrients and chlorophyll are common in the surface mixed layer on the North West Shelf. In the mid and outer shelf waters, the concentration of nitrate is high below the thermocline and the phytoplankton biomass tends to be concentrated at this depth and in the benthic mixed layer (RPS 2007a).

Similar to the Timor Sea bioregion, there are differences between inshore and offshore waters in terms of turbidity, nutrients, chlorophyll and phytoplankton communities. Recent modelling studies suggest that productivity on the inner shelf is closely correlated with changes in the optical qualities of the water column that are associated with the spring-neap tidal cycle (RPS 2007a).

Information on the physicochemical characteristics of the marine sediments for the region, particularly that relating to the offshore waters of the Ichthys Field is limited. The most extensive investigations to date have been conducted further to the north in the Timor Sea, 800 to 1000 km north-east of the Ichthys Field. These studies have generally been commissioned in support of offshore oil and gas exploration and development (RPS 2007a).

Section 5 Water Quality and Marine Sediments

The seabed in offshore locations on the continental shelf is generally flat, relatively featureless plains characterised by soft sandy/silt marine sediments that are easily re-suspended. Similarly, the substrate of the Scott Reef—Rowley Shoals Platform, located immediately south-east of the Ichthys Field in depths of 200 to 600 m, was found to be a depositional area with predominantly fine, muddy sediments (RPS 2007a).

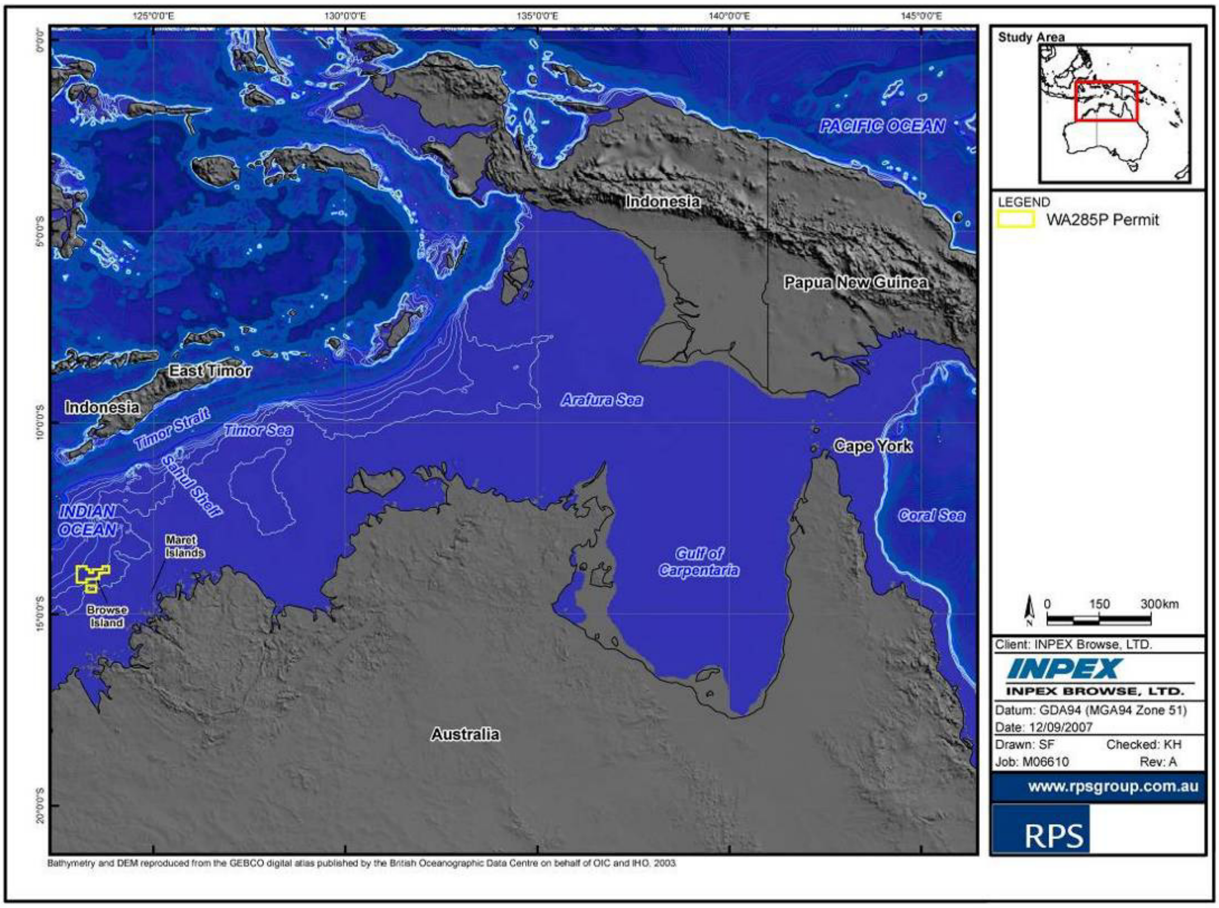


Figure 5-1 Oceanographic features in the waters of northern Australia

5.2 Recent studies

5.2.1 Aims

Sampling of marine sediments and water in the offshore development area was conducted by RPS (2007a) in 2005 and 2007. The aims of the marine sediment and water quality studies were:

- To describe the baseline condition of the sediments and receiving waters in the development areas.
- To determine the relevance of existing sediment and water quality guidelines to the natural characteristics of the development area.
- To measure spatial and temporal changes in water quality associated with natural events.

- To measure natural concentrations of potential contaminants in bioaccumulating organisms.
- To provide water quality data for input into discharge modelling (RPS 2007a).

5.2.2 Study sites

Sediment and/or water quality was measured at a total of ten offshore sites, including the Ichthys Field, Echuca Shoal, and their surrounds (Figure 5-2).

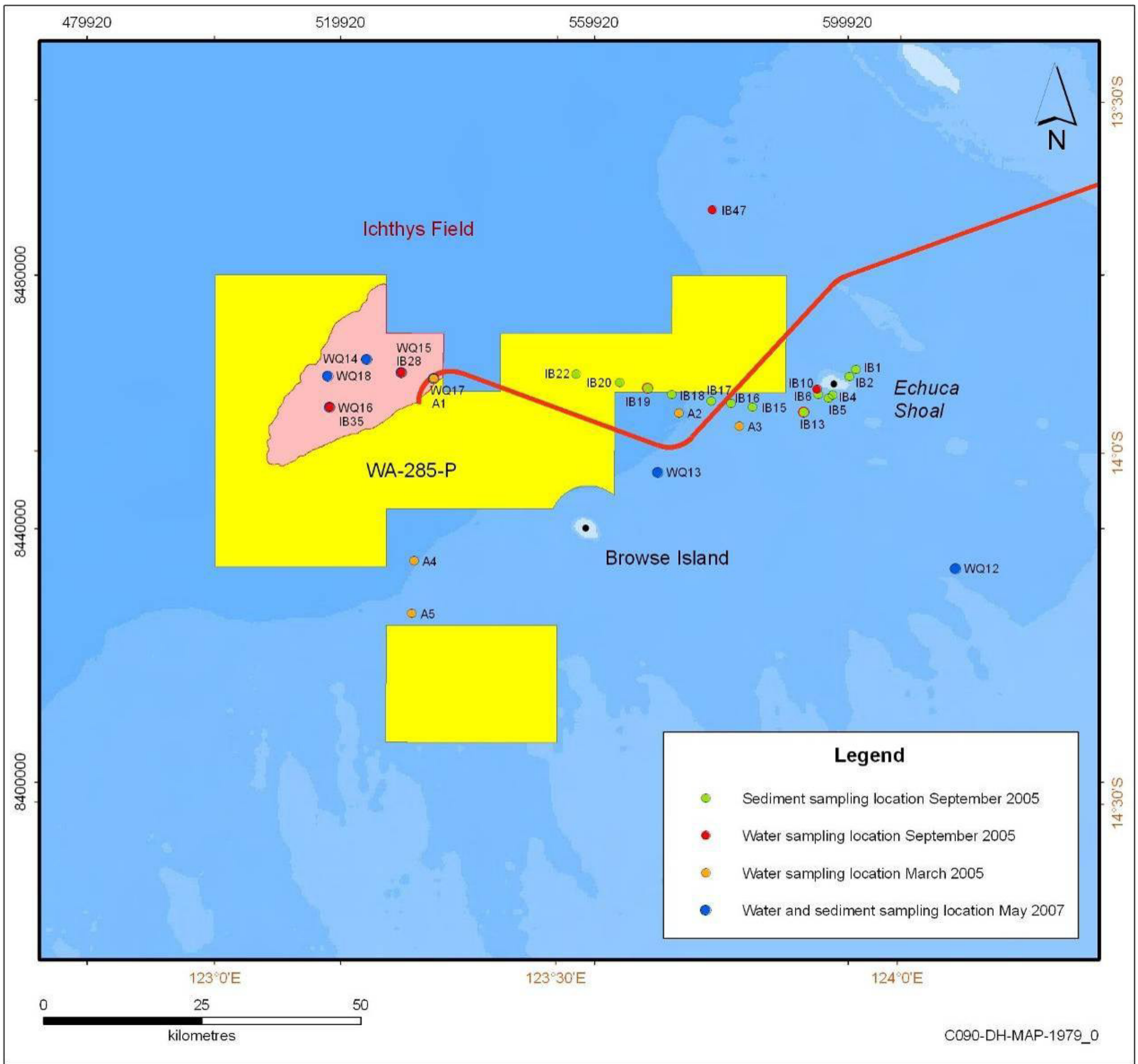


Figure 5-2 Water quality and sediment sampling sites (Adapted from RPS 2007a)

5.2.3 Survey schedule

Field sampling for the marine sediment and water quality studies was undertaken from March 2005–June 2007. This was accomplished using a combination of opportunistic sampling, undertaken during other INPEX studies, and dedicated sampling events. A sampling matrix for each survey is summarised in Table 5-1.

Table 5-1 Summary of sediment and water quality sampling events. Source: RPS (2007a)

Date	Location
March 2005	Water quality sampling
September 2005	Water quality and sediment quality sampling
October 2006	Water quality sampling
December 2006	Water quality sampling
May 2007	Water quality and sediment quality sampling
June 2007	Water quality sampling

5.2.4 Sampling methods and equipment

Water quality

Water quality was measured using in situ instrumentation and laboratory analyses of water samples.

Physiochemical water column profiles

Vertical water quality profiles were obtained in 2005 using a Seabird Electronics SBE19 Seacat Profiler (Seacat) which recorded a suite of water quality parameters at 0.5 second intervals. The Seacat, a precision CTD meter with auxiliary sensors attached, measured conductivity (and derived salinity), temperature, depth, dissolved oxygen (DO), pH, turbidity and photosynthetically active radiation (PAR) to a maximum depth of 93 m. The specifications for the individual sensors are detailed in Table 5-2. The Seacat was fitted with a pump to ensure optimal performance of the DO and conductivity sensors. Data were recorded to an onboard memory bank and subsequently downloaded to a laptop computer, where they were converted to conventional units using instrument-specific software. In May 2007 a different SBE19 Seacat profiler capable of reaching depths of down to 600 m, was used in place of the original instrument. This Seacat was able to measure conductivity (and derived salinity), temperature and depth, but was not fitted with a pump or additional external sensors (RPS 2007a).

Table 5-2 Seabird Electronics SBE19 Seacat profiler specifications. Source: RPS (2007a)

Sensor	Type	Range	Accuracy*
Pressure	Paine strain gauge	0–93 m	0.015% of full range
Oxygen	SBE23Y	0–15 ml/L	0.1 ml/L
pH	SBE18	0–14 pH	0.1 pH
Turbidity	DandA OBS-3	1–1500 NTU	2%
Light (PAR)	LI-193SA / LI-192SA	0.01–10 000 E/s/m^2	1%
Conductivity	Seabird	0-7 s/m	0.0001 s/m
Temperature	Seabird	-5–35 °C	0.001 °C

*Seabird Electronics calibrates the Seacat profiler every two years. All sensors are generally stable for at least two years.

Water sampling

Total suspended solids

TSS encompasses both inorganic solids such as clay, silt and sand, and organic solids such as algae and other biological detritus suspended in the water column. It is a measure of the dry weight of suspended solids, reported in milligrams, per litre of water (mg/L) (RPS 2007a).

Seawater samples for the determination of TSS were obtained near the surface and near the seabed using a 5 L Niskin bottle. Sample water (nominally 3 L) was filtered through pre-dried and weighed 0.8–1.2 µm filter papers. Following sample filtration, the filter papers were rinsed with deionised water to flush off any salt residues that might introduce an error, and then folded before being wrapped in a dry filter paper and placed inside a pre-labelled, protective envelope. The filter papers were then immediately transferred to a freezer for storage prior to being delivered frozen to the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University for analysis (RPS 2007a).

Nutrients

Seawater samples for nutrient analysis were collected near the surface and near the seabed using a Niskin bottle. Water collected for the analysis of dissolved nutrients was filtered through a 0.45 µm membrane and collected in plastic vials; samples for the analysis of total nutrients were collected directly into the sample vessels. All samples were immediately placed in a freezer onboard the survey vessel and transported frozen to the laboratory. Samples were subsequently analysed for:

- ammonium (NH_4^+)
- orthophosphate (PO_4^-)
- nitrate (NO_3^-) and nitrite (NO_2^-) (collectively known as oxides of nitrogen—NO_x)
- total phosphorus (TP)
- total nitrogen (TN)

Phytoplankton

Phytoplankton samples for the analysis of chlorophyll were obtained by filtering 3 L of sample water through 0.8–1.2 µm filter papers. Following filtration, the filter papers were folded and wrapped in a clean, dry filter paper and placed inside a protective envelope. Filter papers were transferred to a freezer for storage prior to being delivered frozen to MAFRL. The samples were processed and analysed for chlorophyll-*a*, -*b* and –*c* (RPS 2007a).

Metals, petroleum hydrocarbons and radionuclides

Seawater samples for the analysis of metals, petroleum hydrocarbons and radionuclides were also collected using a Niskin bottle.

Sub-samples for the analysis of metals (arsenic, cadmium, chromium, cobalt, copper, mercury, lead, nickel, zinc) were collected directly into plastic containers. Sub-samples for the analysis of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and benzene, toluene, ethyl-benzene and xylene, collectively termed BTEX, were collected into amber glass vessels provided by the laboratory. Unfiltered sub-samples for the analysis of radionuclides (radium 226, radium 228, uranium, and thorium) were collected in 1 L pre-cleaned plastic bottles (RPS 2007a).

Upon completion of the field program, samples were transported to the laboratory via freezer or refrigerated trucks, as appropriate.

Ultra-trace level metals

One of the objectives of the water quality surveys is to determine the applicability of existing published guidelines by comparison of measured water quality against them. ANZECC and ARMCANZ (2000) presents trigger values for toxicants at alternative levels of protection, based on the percentage of species likely to be protected at specified concentrations of toxicants (RPS 2007a).

Standard laboratory limits of reporting for metals in marine waters provided by most laboratories are not low enough to enable direct comparison with the 99% species protection level for toxicants in marine waters (Table 3.4.1 in ANZECC and ARMCANZ 2000). In addition, standard laboratory limits of reporting are also not low enough to measure accurately the baseline quality of water in pristine areas that have not been impacted by anthropogenic disturbance (RPS 2007a).

To gain an understanding of the relevance of the guideline trigger values presented in ANZECC and ARMCANZ (2000), water samples were collected and analysed by a specialist laboratory within the CSIRO for ultra-trace levels of metals. Although these analyses are not NATA-accredited, the QA/QC procedures followed by the CSIRO laboratory exceed the existing requirements for NATA accreditation (RPS 2007a).

Near-surface water samples were collected in May 2007 for the analysis of metals at ultra-trace levels of detection. The samples were collected using a Teflon Niskin bottle specifically designed for ultra-trace level sample collection, and rigorous Quality Assurance/Quality Control (QA/QC) measures were adopted to minimise the potential for sample contamination. Sub-samples were collected directly into pre-cleaned containers supplied by the laboratory and immediately transferred to an onboard refrigerator. Upon completion of the field program, samples were delivered to the laboratory by a refrigerated transport service (RPS 2007a).

Sediment quality

Sediment samples for contaminant analysis were extracted by RPS (2007a) from the grab samples collected for benthic fauna analysis (Section 3.2.4).

Sediment samples were collected directly into pre-labelled, pre-cleaned containers. Samples for metals, particle size, nutrients and radionuclide were collected in plastic jars; glass jars were used for samples for TPH analysis. Sediment samples for analysis for organotins were collected in polycarbonate jars (RPS 2007a).

Strict sample hygiene protocols and QA/QC standards were followed for all sediment sampling. Samples were kept cold or frozen in accordance with accepted protocols prior to laboratory analysis.

Sediment samples were analysed for nutrients (TP, total Kjeldahl Nitrogen [TKN]), metals (same suite as for the water samples), plus aluminium, barium and iron), TPH, organotins (tributyl-tin [TBT]), radiounuclides (as for the water samples), total organic carbon (TOC) and particle size.

Sediment samples for the analysis of metals and TPH were delivered to Analytical Reference Laboratory (ARL) or Analytical Laboratory Services (ALS). Particle size analysis (PSA) was conducted by the CSIRO Division of Minerals Particle Analysis Service and Golders Associates. Radionuclide (NORM) analyses were conducted by Western Radiation Services (RPS 2007a).

5.2.5 Quality assurance/quality control

Rigorous QA/QC measures were adopted for each field sampling program, including procedures for:

- organisation of the sampling program
- sampling procedures
- handling, containment and transport of samples
- decontamination procedures
- record keeping procedures
- quality control programs.

The procedures were formulated with reference to the following documents:

- Australia and New Zealand Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand. 2000. Australian Guidelines for Water Quality Monitoring and Reporting.
- Australia and New Zealand Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality.
- Standards Australia. 1998. AS/NZS 5667.1. Water Quality—Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples.
- Standards Australia. 1997. AS 4482.12. Water Quality—Sampling, Part 12: Guidance on sampling of bottom sediments.
- Standards Australia. 1998. AS/NZS 5667.9. Water Quality—Sampling, Part 9: Guidance on sampling from marine waters.

Sampling and analysis plan

Prior to implementing each field program, a sampling and analysis plan (SAP) was developed, which included:

- proposed sampling sites on site maps
- proposed sample analyses
- sampling equipment and associated decontamination requirements
- applicable sample jars

- sample preservation requirements.

Decontamination procedures

All sample collection equipment was subjected to rigorous decontamination procedures to prevent cross-contamination of samples (RPS 2007a).

Water sampling

The Niskin bottle that was used to sample water for the analysis of nutrients, TSS, chlorophyll-*a*, metals at standard levels of detection, and radionuclides, was decontaminated prior to each sampling day. The external and internal surfaces were washed within a phosphate-free oxygen-based detergent solution and thoroughly rinsed in the ocean prior to sampling. All re-useable equipment that came into contact with the sample water (e.g. buckets and funnels) was also decontaminated using the same procedures (RPS 2007a).

A separate Teflon Niskin bottle was used to sample waters for the analysis of metals at ultra-trace levels of detection. This bottle was stored in a sealed container when not in use and was washed in a separate container with an oxygen-based, phosphate-free detergent solution. The cleaned bottle was then immersed in seawater at the sample location for at least 15 minutes prior to sampling (RPS 2007a).

Sediment sampling

Prior to the first deployment each day, the Van Veen grab sampler was decontaminated using a scrubbing brush and an oxygen-based, phosphate-free detergent solution. Prior to each deployment, the grab was thoroughly washed with seawater to remove any adhered sediment (RPS 2007a).

Record keeping

Comprehensive sampling logs were maintained for each survey. Details included:

- container sample identifying marks
- location (and name) of sampling point, with GPS coordinates and other relevant information
- date and time of sampling
- name of sampler
- method of sampling
- general environmental and weather conditions
- record of which samples are quality control samples
- nature of pre-treatment
- preservation procedure
- data gathered in the field
- any other information which might affect the results of the analysis.

All samples submitted for analysis were accompanied by a chain-of-custody form during transport and delivery.

Quality control samples

Quality control samples were collected during the survey programs, which included:

- field blind replicates
- laboratory-split samples (samples split in the laboratory and analysed separately)
- trip blanks (deionised water in the applicable container that travels with the samples during delivery to the laboratory)
- field rinse blanks (final rinse water collected following the decontamination of sampling equipment after sampling).

These samples were used to assess the validity and reproducibility of the results obtained from the laboratory analysis.

Sample analysis

Only National Association of Testing Authorities (NATA) registered laboratories were used to analyse the samples, and analyses were performed in accordance with NATA-certified methods, where applicable (RPS 2007a).

The laboratories implemented a QA/QC program that is endorsed by NATA and meets the following criteria:

- all recovery rates to be between 75% and 125%
- relative percentage differences (RPDs) between original and duplicate laboratory split samples (not field duplicate or field split samples) to be less than 35%
- contaminant concentrations in blanks to be below the nominated limits of detection.

5.2.6 Data assessment

Water quality

The concentrations of potential contaminants in water samples were generally assessed by comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000). These guidelines recommend criteria for assessing levels of contamination, but there is importance placed on the need for site-specific information to enable the development of criteria that are more relevant to the system that is being studied. Therefore, the measured biological and physical water quality parameters were assessed in terms of the recommendations in the guidelines, but with a view to establishing a quantitative baseline dataset against which to assess possible future impacts (RPS 2007a).

Nutrients and total suspended solids

ANZECC and ARMCANZ (2000) provides default trigger values for TN, TP, ammonia, NO_x and orthophosphate in tropical Australia. However, due to the site-specific nature of an ecosystem's response to nutrient enrichment, the interim guidelines are not equally applicable to all circumstances and ANZECC and ARMCANZ (2000) recommended site-specific investigations of nutrient dynamics to determine appropriate low-risk guideline levels for each particular system. Nutrient concentrations have been compared against both the default trigger levels and with data collected previously from the region (RPS 2007a).

Concentrations of TSS have not been compared against any published guidelines because they are dependent on a number of often highly site-specific factors and influenced by seasonally variable climatic and hydrological conditions. Comparisons are mainly made between sampling events (RPS 2007a).

Phytoplankton

Concentrations of photosynthetic pigments in marine water samples are indicative of phytoplankton densities in the water column. Chlorophyll-*a* is the major photosynthetic pigment in phytoplankton, because it is found in all algae. Concentrations of chlorophyll-*a* were assessed against the default trigger level for tropical Australia (ANZECC and ARMCANZ 2000). Chlorophyll-*a* is the only pigment included in these water quality guidelines. Significant changes in the proportions of other photosynthetic pigments may indicate a shift in the phytoplankton assemblage structure (RPS 2007a).

Petroleum hydrocarbons

ANZECC and ARMCANZ (2000) do not include recommended guidelines for most forms of petroleum hydrocarbons. The baseline data presented in RPS (2007a) will provide a dataset against which to assess possible future contamination.

Naturally occurring radioactive material

There are currently no guidelines for the concentration of radionuclides in seawater, but the Southern Metropolitan Coastal Waters Study recommends a maximum total radionuclide concentration of 0.4 Bq/L. Additionally, the Australian Drinking Water Guidelines (ADWG) presents an initial screening level of 0.5 Bq/L for both gross alpha and beta radiation, or a specific guideline level equivalent of 5 Bq/L for radium-226 and 2 Bq/L for radium-228. In the absence of specific environmental standards, the ADWG guidelines form the basis of comparison for data collected during this survey (RPS 2007a).

These screening criteria are only intended as a practical means to ascertain if further consideration of radiological quality of a water supply is needed. They are not intended to represent a guideline value, nor a water quality target. If either of the initial screening concentrations is exceeded, the concentrations of radium-226 and radium-228 should be determined, because these are the most significant naturally occurring radionuclides in Australian drinking water. As such, the screening criteria are broadly relevant to the measured concentration of radium-226 and radium-228 in the waters of the development area, as this will be the source of domestic (including drinking) water supplies for offshore installations and infrastructure (RPS 2007a).

Due in part to the lack of published reference data and the absence of guideline values for radionuclide concentrations in seawater, the data gathered during these studies will augment any future studies in providing a baseline range of natural radionuclide concentrations in the waters of the development area (RPS 2007a).

Further consideration of background concentrations of radionuclides will be given during water quality studies that will be conducted during the development of options for the domestic water supplies. However, it should be noted that various treatments of water, including lime softening, reverse osmosis and ion exchange are all very efficient at removing radium-226 and radium-228 from water (RPS 2007a).

Sediment quality

The results of analysis of metals in sediment samples collected from the survey area have been compared against the lower Interim Sediment Quality Guideline (ISQG-Low) for potentially toxic metals, presented in ANZECC and ARMCANZ (2000). Contaminant concentrations below the ISQG-Low concentration are considered unlikely to have adverse effects on animals in the sediment. Concentrations above ISQG-Low indicate possible biological effects, and concentrations above ISQG-High indicate probable biological effects (RPS 2007a).

5.3 Recent data

5.3.1 Water quality

Physicochemical water column profiles

Water column profiles of offshore locations were undertaken at five sites in March 2005, three sites in December 2006, and three sites in May 2007 (Figure 5-2). In March 2005, the turbidity, pH, salinity and temperature were generally consistent between the sites. Conductivity and temperature profiles in May 2007 were also broadly consistent between sites. However, some variation in PAR values was observed due to different ambient light levels at the time of sampling (RPS 2007a).

Temperature

The maximum temperature recorded was just over 30°C at the surface, and the lowest temperature of 16.5°C was recorded at Site WS14 (Figure 5-2) at approximately 195 m water depth. Major thermoclines were encountered at all sites, with the temperature for the surface 30–40 m being relatively constant. Below this depth, the water temperature decreased at up to 1°C per 10 m (RPS 2007a). For example, at site WS13 the temperature showed similar vertical water profiles for the surface 40 m in both December and May (Figure 5-3 and Figure 5-4). The summer month recorded almost a degree warmer than the winter month. However, both months showed a distinct change in temperature at a depth of 20 m.

The thermoclines were potentially associated with separate sub-surface current streams. Offshore waters of the North West Shelf are usually temperature–stratified, and the depth of the surface mixed layer at the survey sites accords with previous research (RPS 2007a).

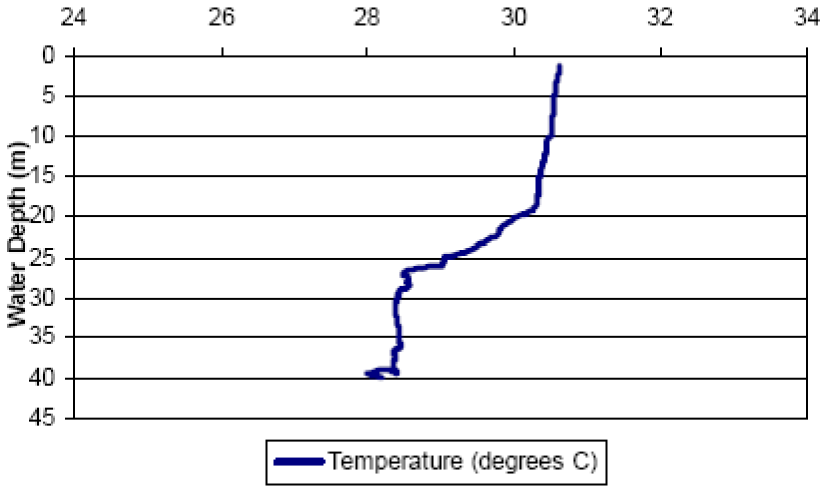


Figure 5-3 Vertical water quality profile at Site WS13, December 2006. Source: RPS (2007a)

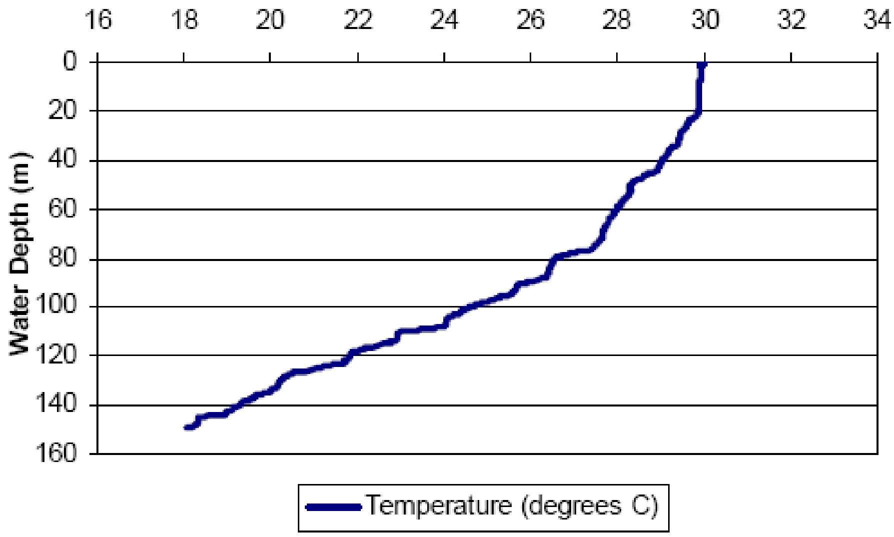


Figure 5-4 Vertical water column profile at Site WQ13, May 2007. Source: RPS (2007a)

Salinity

Salinity was spatially and temporally consistent across all offshore sites, in accordance with expectations for sampling locations that are distant from major freshwater discharges from the terrestrial environment. However, minor variations in the salinity profile associated with the different water layers at depth were recorded at the offshore sites. These variations were most noticeable in the transitional mixing zone at the thermocline with the deeper waters tending to be slightly fresher (RPS 2007a).

Dissolved oxygen

In the March 2005 sampling program, the concentration of DO varied considerably between the surface and sub-surface layers at offshore locations. The surface mixed layer was generally well oxygenated throughout but, below the thermocline, the concentration of DO decreased consistently with depth, to as low as 4.5–5 mg/L at the maximum depths measured (93 m). This indicates that the strong thermal stratification at the offshore locations results in limited oxygen replenishment of sub-surface waters due to the lack of regular mixing between water layers (RPS 2007a). Sampling for DO was not included in the December or May water sampling programs, so the effects of seasonality on this phenomenon are not confirmed.

Turbidity and light attenuation

Turbidity was consistent between the profiles, decreasing marginally at all sites with increasing depth.

PAR is an estimate of the amount of solar light (spectral wavelength range 400 to 700 nm) available for photosynthesis. Measurement of PAR throughout the water column can be used to calculate the vertical light attenuation coefficient (LAC), which represents the rate of reduction of light with depth. LAC ranged from 0.026 to 0.043 in March 2005.

The LAC at offshore sites is within reported 'typical' levels for other regions. For example, the Southern Metropolitan Coastal Waters Study reports light attenuation coefficients for offshore waters of 0.05 (RPS 2007a).

The clarity of water is highly dependent on a number of environmental variables, with metocean conditions being the major influence in the marine environment. This is particularly the case for shallower locations, which are more susceptible to changes in water clarity from re-suspension of sediments (RPS 2007a).

Data from the LTD sensor units suggest that tidal modulation is the major cause of temporal variability in the level of received light at the seabed. Although periods of high suspended sediment have been recorded by the LTD units, these tend to occur at spring low tides, with background concentrations being low. Similarly, measured sediment deposition has been low, in that natural hydrological conditions have been sufficient to resuspend any deposited material within a short time-frame (RPS 2007a).

Nutrients and total suspended solids

Nutrient concentrations in offshore waters in March and September 2005 and May 2007 were generally consistent between sites. Nutrient levels, and dissolved nutrient levels in particular, were generally higher near the seabed than in mid-water or near-surface waters (Table 5-3, Figure 5-5 and Figure 5-6). The exception to this trend was ammonia, which was relatively consistent at all depths, albeit higher than expected for offshore waters (RPS 2007a).

This trend was evident during all three sampling occasions. A similar pattern was evident in data collected by the CSIRO from locations near Scott Reef and approximately 100 km north-east of Browse Island, with nutrients increasing with depth, this phenomenon is also known from the Pilbara region of Western Australia (RPS 2007a).

The source of the high nutrients has not been determined, but the survey area is distant from known anthropogenic inputs. Given the offshore location of the area, the nutrients may be caused by upwelling of nutrient-rich water derived from unknown, distant (deeper) sources, transported by sub-surface currents, tides, wind-driven upwelling and cyclones; this is known to occur elsewhere on the North West Shelf. Alternatively, the nutrients may be derived from the local seabed sediments (RPS 2007a).

ROV investigations in the deeper waters near the Ichthys Field encountered strong tidal currents and current-swept substrates, indicating high near-seabed currents and turbulence. Regardless of the origin, the effects of high nutrients in sub-surface waters are not evident at the surface because the strong thermal stratification in the offshore waters appears to prevent regular mixing between layers (RPS 2007a).

The median concentration of many forms of nutrients in offshore waters approached or exceeded guidelines for slightly disturbed tropical ecosystems in northern Australia (ANZECC and ARMCANZ 2000). Given that the development area shows no signs of any other anthropogenic disturbance, the data show that the default trigger levels are not applicable to the waters of the development area, particularly in relation to sub-surface waters at offshore locations (RPS 2007a).

Table 5-3 Summary statistics of nutrients, chlorophyll-*a* and total suspended solids in water samples taken from offshore locations in March and September 2005 and May 2007. Source: RPS (2007a)

Area	Water Depth	Descriptive Statistic	NH_4^+ (ug.N/L)	NOx (ug.N/L)	PO_4^- (ug.N/L)	TN (ug.N/L)	TP (ug.P/L)	chl a (ug/l)	TSS (mg/L)
Offshore Waters	Near Surface	Mean	6.7	6.4	4.9	134.0	10.9	0.1	3.7
		Median	6.0	4.0	5.0	110.0	11.0	0.1	5.0
		Minimum	3.0	2.0	2.0	80.0	6.0	0.1	1.1
		Maximum	13.0	32.0	8.0	270.0	19.0	0.2	5.0
		80%ile	10.2	6.2	6.0	182.0	13.2	0.2	5.0
		95%ile	11.6	21.5	6.6	221.0	15.5	0.2	5.0
	Mid-depth (75-150m)	Mean	8.3	88.6	15.2	207.3	20.4	0.2	5.0
		Median	9.0	100.0	16.0	240.0	21.0	0.2	5.0
		Minimum	3.0	11.0	6.0	100.0	11.0	0.1	5.0
		Maximum	16.0	180.0	26.0	280.0	30.0	0.4	5.0
		80%ile	11.0	120.0	19.0	260.0	23.0	0.3	5.0
		95%ile	13.5	155.0	23.5	275.0	26.5	0.4	5.0
	Near Seabed (150-250m)	Mean	10.1	212.0	30.1	317.3	35.9	0.2	3.8
		Median	8.0	200.0	30.0	330.0	38.0	0.1	5.0
		Minimum	3.0	73.0	13.0	170.0	18.0	0.1	1.1
		Maximum	32.0	320.0	42.0	470.0	54.0	0.3	5.0
		80%ile	14.4	276.0	37.2	372.0	43.2	0.2	5.0
		95%ile	29.2	313.0	42.0	428.0	48.4	0.3	5.0

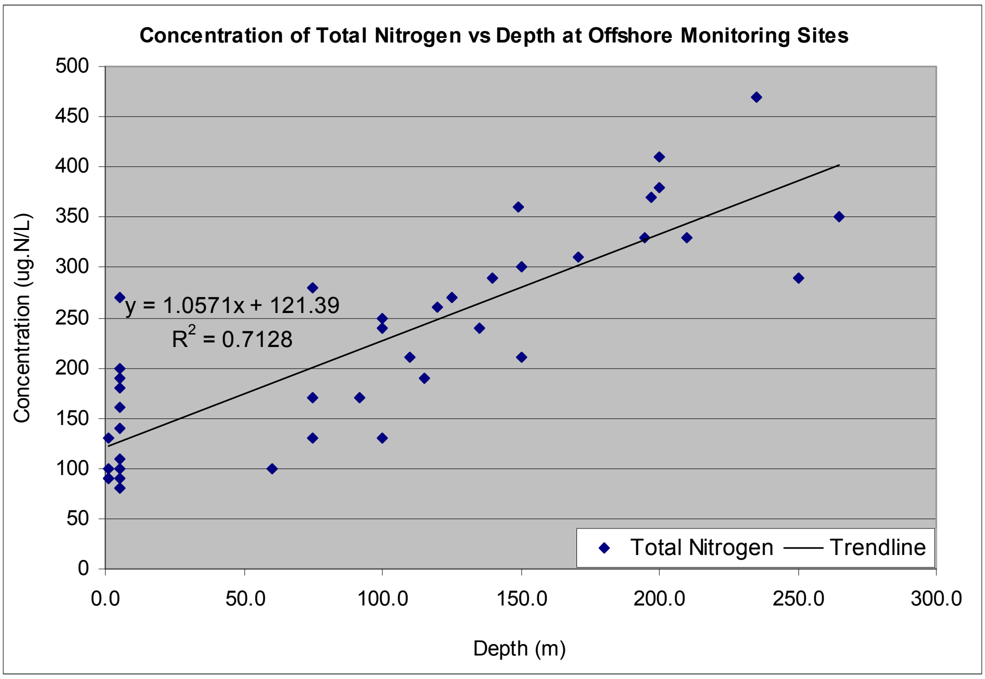


Figure 5-5 Concentration of total nitrogen vs. depth at offshore survey sites. Source: RPS (2007a)

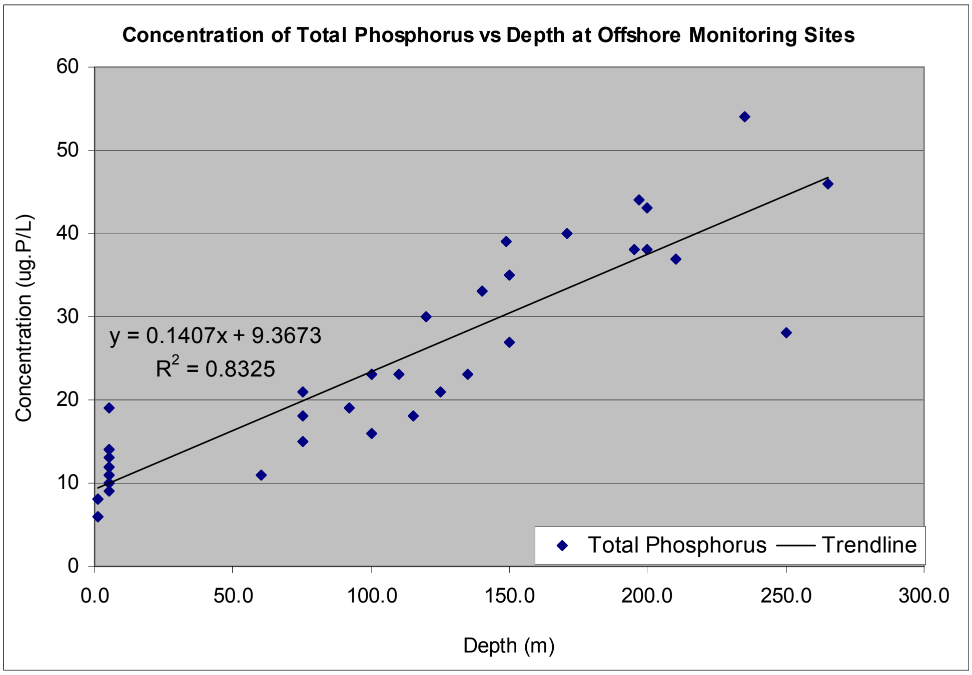


Figure 5-6 Concentration of total phosphorus vs. depth at offshore survey sites. Source: RPS (2007a)

Phytoplankton

The concentrations of chlorophyll-a as an indicator of phytoplankton abundance were low, with many sites below the Laboratory Limit of Reporting (LLR). The maximum recorded concentration was 0.3 µg/L in May 2007 and concentrations were typically similar to those reported for the North West Shelf (RPS 2007a). They were also consistent with seasonal levels for the offshore Kimberley area determined by remote sensing technologies.

The low concentrations indicate lack of enhanced production and probably reflect the trapping of the nutrient-rich waters below the thermocline. It may also be due to the greater dispersion of phytoplankton during winter (when sampling was undertaken), as has been observed in the Pilbara. Additionally, studies on the North West Shelf have shown that, due to the relatively low nitrate levels in the surface waters, the bulk of the phytoplankton lies well beneath the surface at the base of the thermocline, or in the mixed layer near the seafloor where high nitrate levels exist (RPS 2007a).

Petroleum hydrocarbons

Water samples collected from five offshore locations in March 2005 and six offshore locations in September 2005 contained no detectable traces of petroleum hydrocarbons (RPS 2007a).

Radionuclides

The six water samples collected in September 2005 contained concentrations of radium-226 that ranged from below LLR to a high of 0.034 (±0.012) Bq/L. Concentrations of radium-228 were all below LLR except for the mid-depth sample at Site IB1 (0.167 ± 0.128 Bq/L) (Table 5-4). All samples except the mid-depth sample at IB1 were below the ADWG screening criteria of 0.5 Bq/L for both gross-alpha and gross-beta radiation (RPS 2007a).

Table 5-4 Concentration of radionuclides in water samples taken from offshore locations in September 2005 and May 2007. Source: RPS (2007a)

<table>
<tr><th rowspan="3">Survey Date</th><th rowspan="3">Site</th><th rowspan="3">Depth Category</th><th colspan="4">Radionuclides</th></tr>
<tr><th>Ra-226</th><th>Ra-228</th><th>Uranium</th><th>Thorium</th></tr>
<tr><th>Bq/L</th><th>Bq/L</th><th>ug/L</th><th>ug/L</th></tr>
<tr><td rowspan="9">September 2005</td><td rowspan="3">IB1</td><td>near surface</td><td>0.003</td><td>0.1</td><td>-</td><td>-</td></tr>
<tr><td>mid-water</td><td>0.003</td><td>0.167(0.128)</td><td>-</td><td>-</td></tr>
<tr><td>near seabed</td><td>0.003</td><td>0.1</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">IB28</td><td>near surface</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>near seabed</td><td>0.034 (0.012)</td><td>0.1</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">IB35</td><td>near surface</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>near seabed</td><td>0.015 (0.006)</td><td>0.1</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">IB47</td><td>near surface</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>near seabed</td><td>0.010 (0.004)</td><td>0.1</td><td>-</td><td>-</td></tr>
<tr><td rowspan="8">May 2007</td><td rowspan="2">WS12</td><td>near surface</td><td>0.019 (0.009)</td><td>0.436 (0.149)</td><td>5</td><td>5</td></tr>
<tr><td>near seabed</td><td>0.016 (0.0010)</td><td>0.1</td><td>5</td><td>5</td></tr>
<tr><td rowspan="2">WS13</td><td>near surface</td><td>0.010 (0.005)</td><td>0.404 (0.187)</td><td>10</td><td>5</td></tr>
<tr><td>near seabed</td><td>0.021 (.012)</td><td>0.956 (0.232)</td><td>5</td><td>5</td></tr>
<tr><td rowspan="2">WS14</td><td>near surface</td><td>0.003</td><td>0.598 (0.246)</td><td>5</td><td>5</td></tr>
<tr><td>near seabed</td><td>0.003</td><td>0.993 (0.317)</td><td>5</td><td>5</td></tr>
<tr><td rowspan="2">WS16</td><td>near surface</td><td>0.019 (0.011)</td><td>0.586 (0.249)</td><td>5</td><td>5</td></tr>
<tr><td>near seabed</td><td>0.019 (0.010)</td><td>0.344 (0.153)</td><td>5</td><td>5</td></tr>
<tr><td colspan="3">Australian Drinking Water Guidelines (2004)</td><td>0.5</td><td>0.5</td><td>NG</td><td>NG</td></tr>
<tr><td colspan="3">Laboratory Limit of Reporting</td><td>0.003</td><td>0.1</td><td>5</td><td>1</td></tr>
<tr><td colspan="7">denotes below the Laboratory Limit of Reporting
Note:
(Parentheses) denotes the 95% confidence interval for the reported result
Australian Drinking Water Guidelines (2004) values are initial screening criteria for gross alpha (Ra-226) and gross beta (Ra-228) radiation. They are not intended as guidelines or water quality targets
- denotes not tested
NG denotes no guideline</td></tr>
</table>

Metals

Water samples for the analysis of metals were collected in May 2007. The samples for the analysis of total metals at standard detection limits were collected from surface and bottom waters at each sampling site, and the samples for analysis at ultra-trace levels of detection were collected from surface waters only (RPS 2007a).

The results of the analyses for total metals (unfiltered) at both levels of detection are presented in Table 5-5.

Standard laboratory techniques

Mercury, cadmium, chromium, cobalt and copper were not detected above the LLR using standard laboratory techniques. Lead (1.2 µg/L) and zinc (9 µg/L) were each detected above the LLR in one sample–WS13 and WS16, respectively (Table 5-5). However, as the ultra-trace analyses for lead and zinc do not match these data, RPS (2007a) consider that these are likely to be an artefact of the Niskin bottle apparatus used for the samples taken for analysis at standard levels, rather than a reflection of the actual concentration of these metals in the seawater.

The reported concentrations of arsenic were consistent across all sites sampled, with a maximum recorded value of 1.3 µg/L near the seabed at WS12 (RPS 2007a).

Nickel was detected above the LLR in two samples from two separate sites (WS13 and WS14).

For analytes where the LLR was below the 99% species protection level (ANZECC and ARMCANZ 2000), only the concentration of zinc at the surface from WS16 was above the trigger value (RPS 2007a).

Ultra-trace level analysis

Mercury was the only metal with concentrations below the LLR at all of the offshore sites, while cobalt was (marginally) above the LLR at only one site (Table 5-5).

The concentrations of arsenic, nickel, chromium and zinc were consistent across all sites, but the concentrations of cadmium, copper and lead showed greater variability.

Apart from cobalt, the concentrations of all metals at each sampling site were below the 99% species protection level (ANZECC and ARMCANZ 2000).

Table 5-5 Concentration of total metals in water samples taken from offshore locations in May 2007, analysed using standard and ultra-trace levels of detection. Source: RPS (2007a)

Survey Date	Site	Depth Category	Approx. depth (m)	Metals - Standard levels of detection								
				Mercury	Arsenic	Cadmium	Chromium	Cobalt	Copper	Lead	Nickel	Zinc
				ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
May 2007	WS12	near surface	<5	0.1	1.1	0.2	0.5	0.2	1.0	0.2	0.5	5.0
		near seabed	95	0.1	1.3	0.2	0.5	0.2	1.0	0.2	0.5	5.0
	WS13	near surface	<5	0.1	1.0	0.2	0.5	0.2	1.0	1.2	0.5	5.0
		near seabed	150	0.1	1.2	0.2	0.5	0.2	1.0	0.2	0.6	5.0
	WS14	near surface	<5	0.1	1.1	0.2	0.5	0.2	1.0	0.2	0.5	5.0
		near seabed	195	0.1	1.2	0.2	0.5	0.2	1.0	0.2	0.8	5.0
	WS16	near surface	<5	0.1	1.1	0.2	0.5	0.2	1.0	0.2	0.5	9.0
		near seabed	200	0.1	1.2	0.2	0.5	0.2	1.0	0.2	0.5	5.0
	Laboratory Limit of Reporting			0.1	0.5	0.2	0.5	0.2	1.0	0.2	0.5	5.0
				Metals - Ultra-trace levels of detection								
	WS12	near surface	<5	0.0002	1.32	0.0056	0.08	0.017	0.223	0.045	0.244	0.435
	WS13	near surface	<5	0.0002	1.31	0.0015	0.12	0.018	0.254	0.018	0.222	0.376
	WS14	near surface	<5	0.0002	1.31	0.0014	0.10	0.017	0.127	0.038	0.245	0.334
	WS16	near surface	<5	0.0002	1.36	0.0015	0.12	0.017	0.161	0.016	0.252	0.404
99% species protection level				0.1	NG	0.7	7.7*	0.005	0.3	2.2	7.0	7.0
Laboratory Limit of Reporting				0.0002	0.1000	0.0007	0.0500	0.017	0.009	0.016	0.029	0.019

denotes below Laboratory Limit of Reporting
- denotes not sampled
NG denotes no guideline
Note: Chromium measured as Total Chromium, guideline presented is for CrIV

5.3.2 Sediment quality

Metals

Sediment samples collected from two offshore locations during September 2005 and eight offshore locations in May 2007 were analysed for metals. Concentrations of all metals were consistent across the sampling sites and well below ISQG-Low trigger levels (Table 5-6).

Table 5-6 Concentration of metals, metalloids and organometallics in sediment samples collected from offshore locations in September 2005 and May 2007. Source: RPS (2007a)

Survey Date	Site	Metals, Metalloids and Organometallics												
		Aluminium	Arsenic	Barium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Nickel	Zinc	Mercury	TBT
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg Sn/kg
September 2005	IB1	2600	0.66	74	0.2	15	-	4.5	3100	0.6	7.5	15	0.02	-
	IB4	640	0.59	84	0.2	9.4	-	0.7	520	9.7	1.6	3.5	0.02	-
May 2007	WS11	5900	5	10	1	16	3	5	7940	5	8	5	0.1	0.5
	WS12	3260	5	10	1	11	2	5	6350	5	6	5	0.1	0.5
	WS13	1210	5	10	1	7	2	6	2050	5	6	5	0.1	0.5
	WS14	2700	5	20	1	10	2	7	4370	5	7	5	0.1	0.5
	WS15	2190	5	10	1	8	2	6	3940	5	6	5	0.1	0.5
	WS16	1440	5	10	1	8	2	5	4520	5	4	5	0.1	0.5
	WS17	2010	5	10	1	8	2	5	3590	5	5	5	0.1	0.5
	WS18	1840	5	10	1	8	2	6	4480	5	5	5	0.1	0.5
ISQG-Low		NG	20	NG	1.5	80	NG	65	NG	50	21	200	0.15	5
LLR (Sept 07)		1	0.05	1	0.1	0.1	-	0.1	1	0.1	0.1	0.1	0.02	-
LLR (May 07)		50	5	10	1	2	2	5	50	5	2	5	0.1	0.5

LLR denotes Laboratory Limit of Reporting
denotes below Laboratory Limit of Reporting
- denotes not analysed
NG denotes no guidance

ISQG-Low represents the Interim Sediment Quality Guidelines-Low (effects range) trigger value, Table 3.5.1 (ANZECC & ARMCANZ, 2000a)

Petroleum hydrocarbons

Concentrations of petroleum hydrocarbons were below the LLR for each individual alkane, indicating that the sediments at offshore locations are not impacted by natural or anthropogenic hydrocarbon contamination (RPS 2007a).

Radionuclides

Radium-226 was detected at site WS17, but radium isotopes in all other samples were below the LLR. The concentrations of uranium and thorium were reasonably consistent across the sites (Table 5-7).

Table 5-7 Concentration of radionuclides in sediment samples taken from offshore locations in May 2007. Source: RPS (2007a)

Survey Date	Site	Radionuclides			
		Ra-226	Ra-228	U	Th
		mBq/g	mBq/g	ppm	ppm
May 2007	WS11	30	30	2.5	2
	WS12	30	30	3.5	1.5
	WS13	30	30	6.5	0.5
	WS14	30	30	4.5	1
	WS15	30	30	3.5	1.5
	WS16	30	30	3.5	0.5
	WS17	35(5)	30	7.5	1
	WS18	30	30	4	0.5
LLR		30	30	0.5	0.5

denotes below Laboratory Limit of Reporting
- denotes not sampled
(parentheses) for radionuclide analyses denotes the 95% confidence interval

Particle size

Particle size distributions for sediments collected from offshore locations in September 2005 and May 2007 are presented in Figure 5-7 and Figure 5-8. In addition to the particle size analysis results, information gathered during sampling assisted in the description of the surface sediments (RPS 2007a).

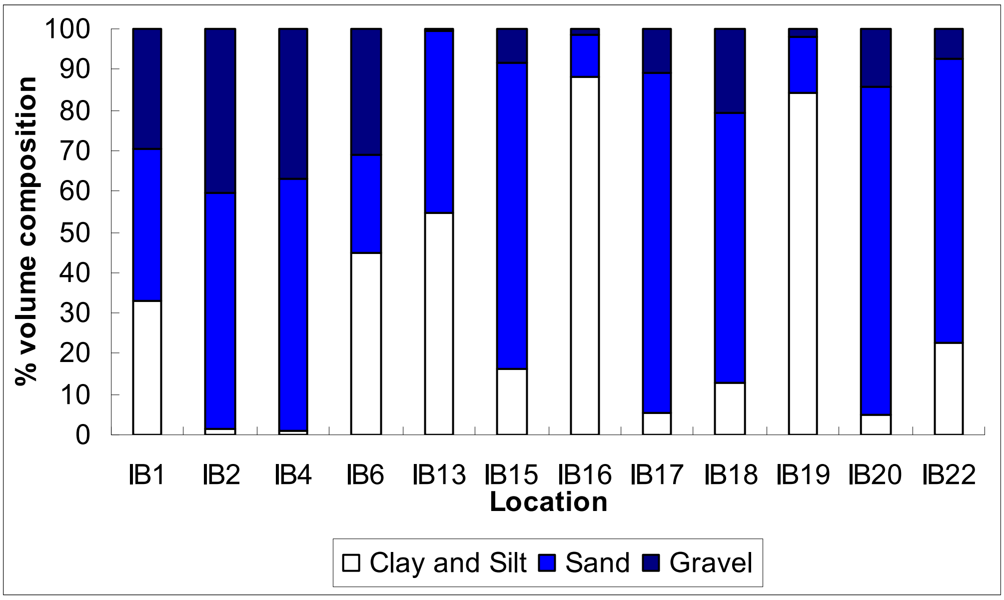


Figure 5-7 Distribution of particle sizes in sediments at offshore locations in September 2005. Source: RPS (2007a)

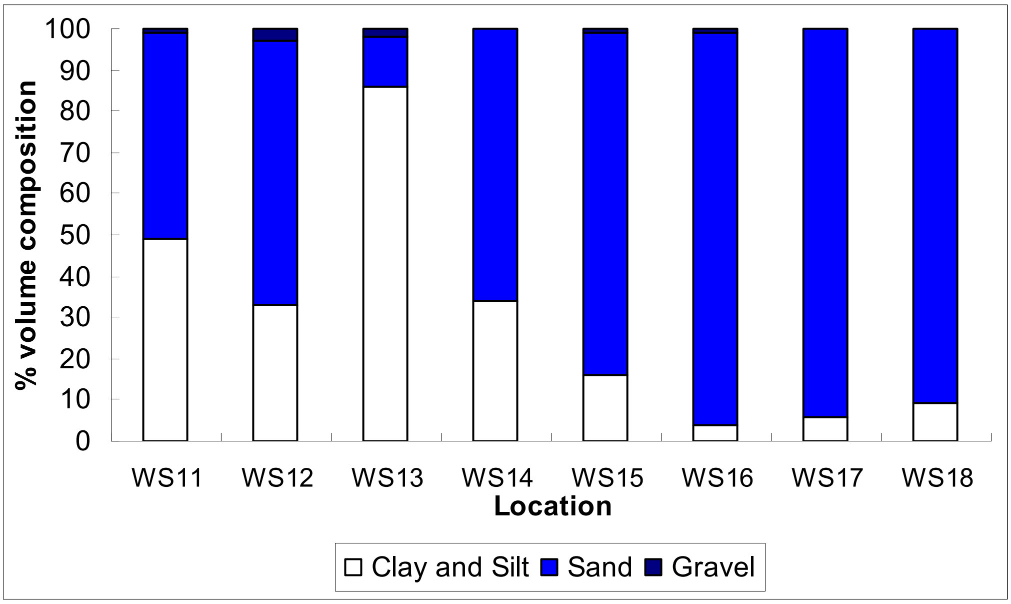


Figure 5-8 Distribution of particle sizes in sediments at offshore locations in May 2007. Source: RPS (2007a)

The composition of sediments varied across the offshore development area but most of the variation was found in the vicinity of the Echuca Shoal where the sediments comprised mainly calcareous shell grit with abundant inclusions of coral debris and varying minor proportions of silts and fine-to-medium grained sands. In general, the proportion of silts, clays and fine sands increased rapidly with increasing distance from the shoal (RPS 2007a).

Sediments in the permit area were dominated by olive green/grey silty sands with varying proportions of clay and shell fragments (Figure 5-9). Sediments in the vicinity of WS13 mainly comprised heavily consolidated clay and silt fractions, with retrieval of a representative sample requiring many grab sample attempts at different locations (within 1 km) due to the high density of the clay in the sediment (RPS 2007a).

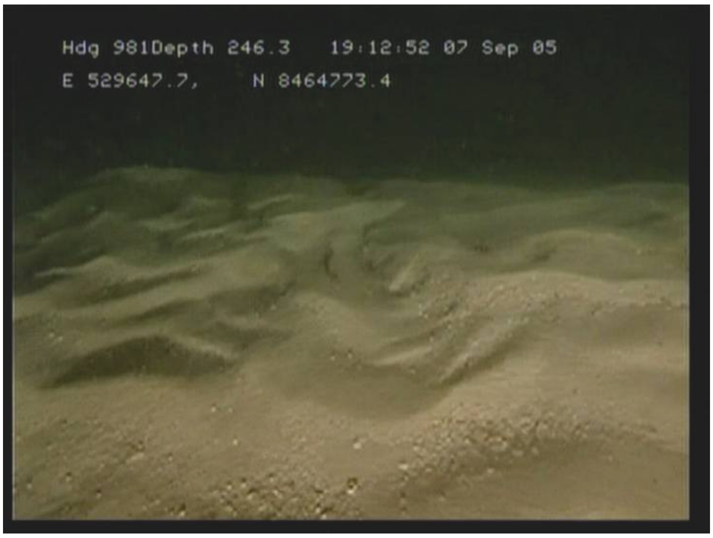


Figure 5-9 Heavily rippled sand wave in 246 m water depth. Source: RPS (2007a)

Nutrients

The concentration of nutrients in sediment samples taken at offshore sites is presented in Table 5-8. The concentration of measured forms of nitrogen (TKN) and phosphorus (TP) were highest at site WS11, WS13, and WS17 (TP only) (RPS 2007a).

Table 5-8 Concentrations of nutrients and total organic carbon in sediment samples collected from offshore locations in May 2007. Source: RPS (2007a)

Survey Date	Site	Analyte		
		TKN	Total P	TOC
		mg.N/g	mg.P/g	%C
May 2007	WS11	0.9	0.74	0.4
	WS12	0.5	0.71	0.4
	WS13	0.7	0.93	0.4
	WS14	0.6	0.71	0.4
	WS15	0.6	0.72	0.4
	WS16	0.2	0.92	0.4
	WS17	0.3	2.1	0.4
	WS18	0.4	0.81	0.4
Laboratory Limit of Reporting		0.1	0.05	0.4
denotes below Laboratory Limit of Reporting				

6.1 Background

All of the cetaceans that may be present in or near the proposed offshore development areas are protected by state and federal legislation or international agreements, as follows:

Western Australian legislation

All native Australian fauna are protected in Western Australia under the *Wildlife Conservation Act 1950*. Cetaceans that are specially protected under the *Wildlife Conservation Act 1950* and/or Fish Resources Management Regulations 1995, and that may be present in or near the proposed development areas, are identified in Table 6-1 (RPS 2007b).

Federal legislation

All cetaceans are protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The EPBC Act also established the Australian Whale Sanctuary, which encompasses the area of the Exclusive Economic Zone (EEZ) outside state waters and which generally extends 200 nautical miles from the coast, but further in some areas to cover the continental shelf and continental slope. It is an offence to kill, injure, take, trade, keep, move or interfere with a cetacean in the Australian Whale Sanctuary (RPS 2007b).

Marine species protected under the EPBC Act that may be present in or near the proposed development areas, and their level of protection, are described in Table 6-1. The presence of the species listed was established from the *Protected Matters Database* maintained by the Commonwealth Department of Environment, Water, Heritage and Arts (DEWHA), as well as from DEWHA's *Species Profile and Threats Database* and field observations (RPS 2007b).

International protection and conservation status

Cetaceans that are considered to be under a global threat of extinction may be listed on the IUCN Red List of Threatened Species. They may otherwise be protected by the Convention on International Trade in Endangered Species (CITES), or the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention). Species that are listed/protected by these conventions are listed in Table 6-1.

Table 6-1 Protected cetaceans that may be present in the offshore development area, and their conservation status. Adapted from: RPS 2007b

Common Name	Scientific Name	Conservation Status				
		Federal [a]	State [b, c]	IUCN [d]	Bonn Convention [e]	CITES [f]
Baleen whales						
Minke whale	*Balaenoptera acutorostrata*	*L(C) **		*LR(NT)*		
Dwarf minke whale	*Balaenoptera acutorostrata subsp.*	*L(C)*		*LR(NT)*		
Antarctic minke whale, dark-shoulder minke whale	*Balaenoptera bonaerensis*	*L(C)(MM)*		*LR(CD)*	*II*	*I*
Sei whale	*Balaenoptera borealis*	*V & L(C)(MM)*	*S1[b]*	*E*	*I & II*	*I*
Bryde's whale	*Balaenoptera edeni*	*L(C)(MM)*			*II*	*I*
Blue whale	*Balaenoptera musculus intermedia*	*E & L(C)(MM)*	*S1[b]*	*E*	*I*	*I*
Pygmy blue whale	*Balaenoptera musculus brevicauda*	*E & L(C)(MM)*		*E*		
Fin whale	*Balaenoptera physalus*	*V & L(C) (MM)*	*S1[b]*	*E*	*I & II*	*I*
Humpback whale	*Megaptera novaeangliae*	*V & L(C)(MM)*	*S1[b]*	*V*	*I*	*I*
Beaked and toothed whales						
Pygmy killer whale	*Feresa attenuata*	*L(C)*		*DD*		
Pygmy sperm whale	*Kogia breviceps*	*L(C)*		*LR(LC)*		
Dwarf sperm whale	*Kogia simus*	*L(C)*		*LR(LC)*		
Beaked whale species	*Mesoplodon sp.*	*L(C)*		*DD*		
Melon-headed whale	*Peponocephala electra*	*L(C)*		*LR(LC)*		
Sperm whale	*Physeter macrocephalus*	*L(C)(MM)*		*V*	*I & II*	
False killer whale	*Pseudorca crassidens*	*L(C)*		*LR(LC)*		
Cuvier's beaked whale, goose-beaked whale	*Ziphius cavirostris*	*L(C)*				
Dolphins						
Long-beaked common dolphin	*Delphinus capensis*	*L(C)*		*LR(LC)*		
Short-beaked common dolphin	*Delphinus delphis*	*L(C)*		*LR(LC)*	*II*	

Common Name	Scientific Name	Conservation Status				
		Federal [a]	State [b, c]	IUCN [d]	Bonn Convention [e]	CITES [f]
Short-finned pilot whale	*Globicephala macrorhynchus*	*L(C)*		*LR(LC)*		
Risso's dolphin	*Grampus griseus*	*L(C)*		*DD*	*II*	
Fraser's dolphin	*Lagenodelphis hosei*	*L(C)*			*II*	
Irrawaddy dolphin/snubfin dolphin	*Orcaella brevirostris/heinsohni*	*L(C)(MM)*		*DD*	*II*	
Killer whale	*Orcinus orca*	*L(C)(MM)*		*LR(CD)*	*II*	
Indo-Pacific humpback dolphin	*Sousa chinensis*	*L(C)(MM)*		*DD*	*II*	
Spotted dolphin, pantropical spotted dolphin	*Stenella attenuata*	*L(C)*		*LR(CD)*	*II*	
Striped dolphin	*Stenella coeruleoalba*	*L(C)*		*LR(CD)*	*II*	
Spinner dolphin	*Stenella longirostris*	*L(C)*		*LR(CD)*	*II*	
Dwarf spinner dolphin	*Stenella longirostris roseiventris*	*L(C)*		*LR(CD)*		
Rough-toothed dolphin	*Steno bredanensis*	*L(C)*		*DD*		
Spotted bottlenose dolphin, Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	*L(C)(MM)*			*II*	
Offshore bottlenose dolphin	*Tursiops truncatus s. str.*	*L(C)*		*DD*	*II*	

[a] Federal – Environment Protection and Biodiversity Conservation Act 1999:
CE = Critically Endangered (NES), E = Endangered (NES), V = Vulnerable (NES), L = Listed Cetacean (C), Marine (M), Migratory Marine (MM)
(NES = Matters of National Environmental Significance)
[b] State – Wildlife Conservation Act 1950:
S1 = Schedule 1, fauna that is rare or likely to become extinct
S2 = Schedule 2, fauna presumed to be extinct,
S4 = Schedule 4, other specially protected fauna
[c] State – Fish Resources Management Act, 1994
Listed in Fish Resources Management Regulations, 1995, Schedule 2:
P1 = Part 1, commercially protected fish
P2 = Part 2, totally protected fish

[d] International – IUCN Red List of Threatened Species:
CE = Critically Endangered, E = Endangered, V = Vulnerable, LR = Lower Risk, DD = Data Deficient
Conservation Dependent (CD), Near Threatened (NT), Least Concern (LC).
[e] International – Bonn Convention:
I = Appendix I, Endangered Migratory Species,
II = Appendix II, Migratory Species.
[f] International – CITES:
I = Appendix I, species threatened with extinction
II = Appendix II, includes species not necessarily threatened with extinction, but in which trade must be controlled to avoid utilisation incompatible with their survival
III = Appendix III, includes all species which any Party identifies as being subject to regulation within its jurisdiction for the purpose of preventing or restricting exploitation, and as needing the cooperation of other Parties in the control of trade.

Humpback whales

Humpback whales (*Megaptera novaeangliae*) are baleen whales that grow to between 16 and 17 m. They are found throughout the Australian Antarctic and in most Commonwealth and state waters of Australia. In the Southern Hemisphere, the International Whaling Commission (IWC) currently recognises six Feeding Areas (I to VI) around Antarctica which are thought to be associated with seven high-latitude Breeding Stocks (A–G). It has been generally hypothesised that most populations maintain regular movement between the feeding and breeding areas and remain segregated year-round. The humpback whale stock that winters off the Western Australian coast is known as the Breeding Stock D, or Group IV population (RPS 2007b).

Breeding Stock D humpback whales migrate annually from the Antarctic waters south of Western Australia to the Kimberley, a distance of approximately 3600 nautical miles, visiting northern waters between June and November each year (Figure 6-1). The peak of the north-bound migration is between late July and early August, and the peak of the south-bound migration is from late August to early September. However, the timing of the migration can vary by as much as three weeks between years, probably due to annual variations in the availability of food in the Antarctic. There is a marked segregation of animals during the northern migration. Sexually immature animals and females at the end of lactation migrate northwards first, most adult males travel in the middle of the migration period, and pregnant females migrate last. On the southern migration, the first to arrive in the Kimberley are the first to depart, with the pregnant females being the last to leave (RPS 2007b).

The majority of Stock D humpback whales appear to end their northern migration at Camden Sound some 100 km to the south-east of the Ichthys Field. Between 1994 and 1997, Coastwatch personnel observed only scattered pods of humpback whales north of Camden Sound. Similarly, in a survey during July and August 1989 that covered the area within 50 km of the Kimberley coast, singing humpback whales were found as far north as 15 °S (near the Prince Regent River), with more frequent observations south of Camden Sound (15.4 °S). Coastwatch pilots in the early 1990s reported observations of humpback whales as far offshore as Ashmore Reef (12 °S) and as far north as Admiralty Gulf (14 °S) (RPS 2007b).

Three areas of high humpback whale concentrations were identified by Jenner et al. (2001): Pender Bay, Tasmanian Shoals (in the Buccaneer Archipelago), and Camden Sound (Figure 6-2 and Figure 6-3). The area around Tasmanian Shoals is thought to be a staging area used by the whales to rest or to wait for favourable tidal conditions on their way to Camden Sound. The area around Camden Sound, covering approximately 23 000 km^2 from the Lacepede Islands in the south, to Adele Island in the north, and to Camden Sound in the east, has been identified as a calving area for Stock D humpback whales, while Pender Bay is thought to be a resting place for cow/calf pods on their south-bound migration (RPS 2007b).

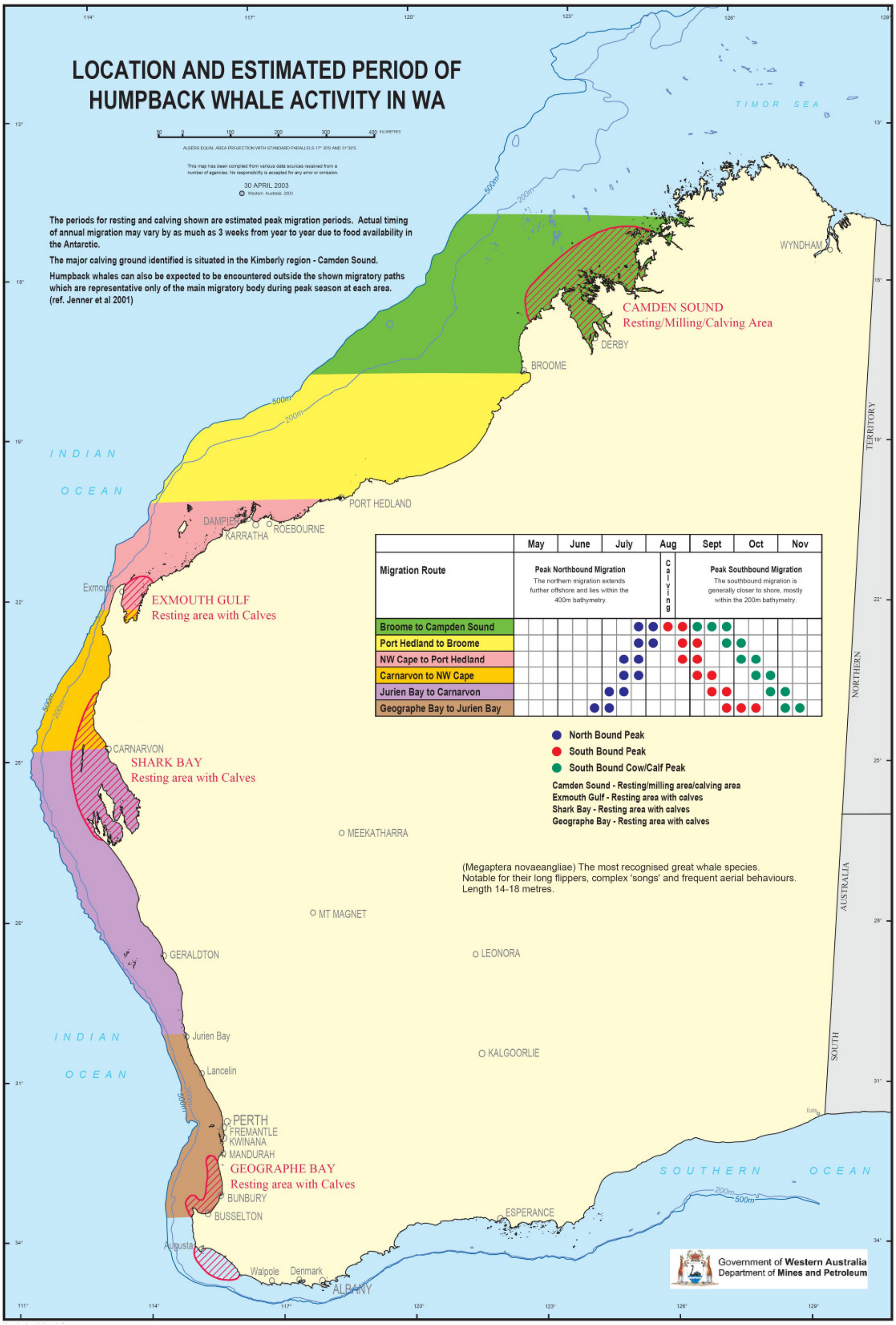


Figure 6-1 Distribution and activity of humpback whales in Western Australia. Source: Department of Mines and Petroleum (2003)

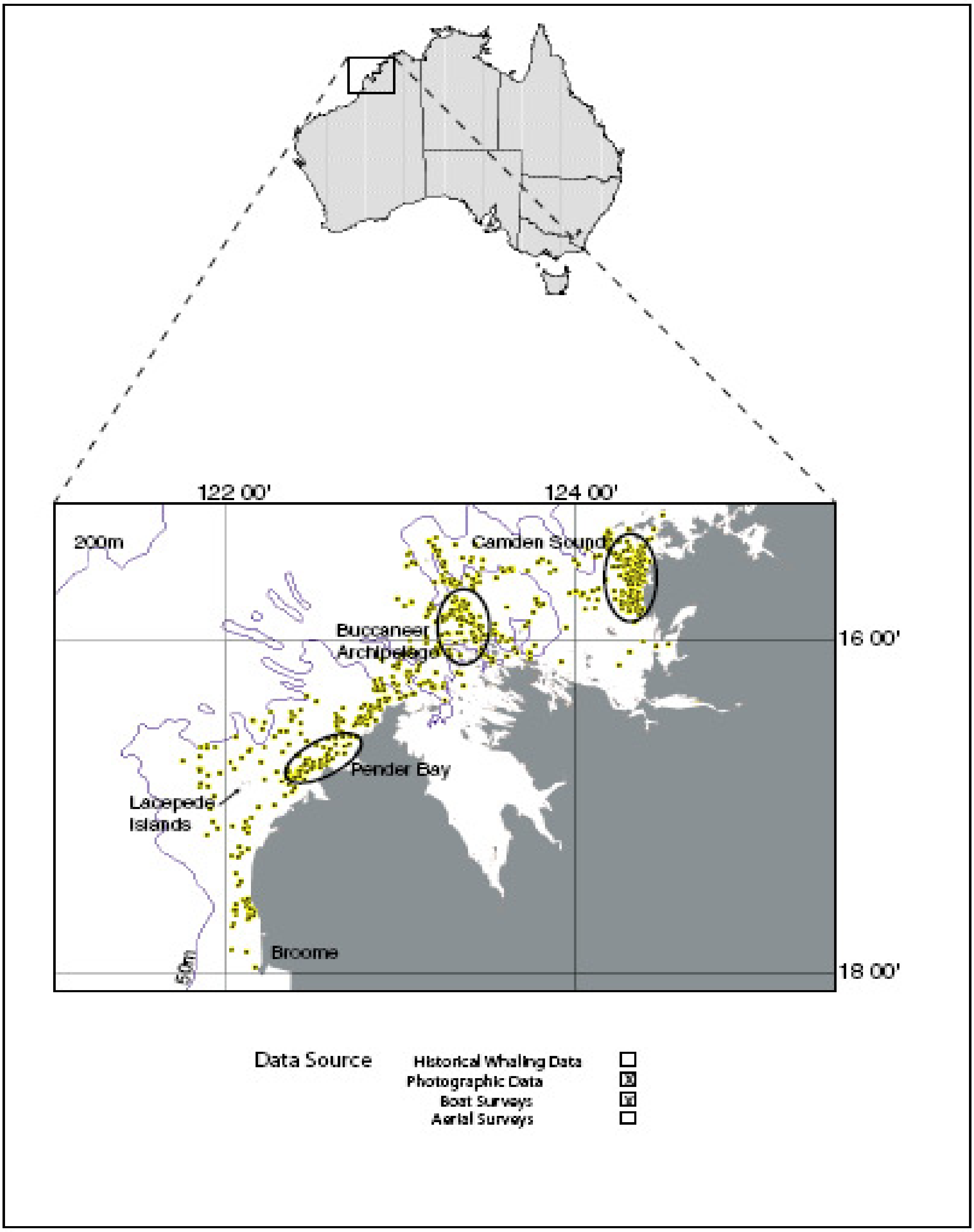


Figure 6-2 Humpback whale pods recorded during 1995–1996 surveys of the Kimberley coast. Source: Jenner et al (2001), in RPS (2007b)

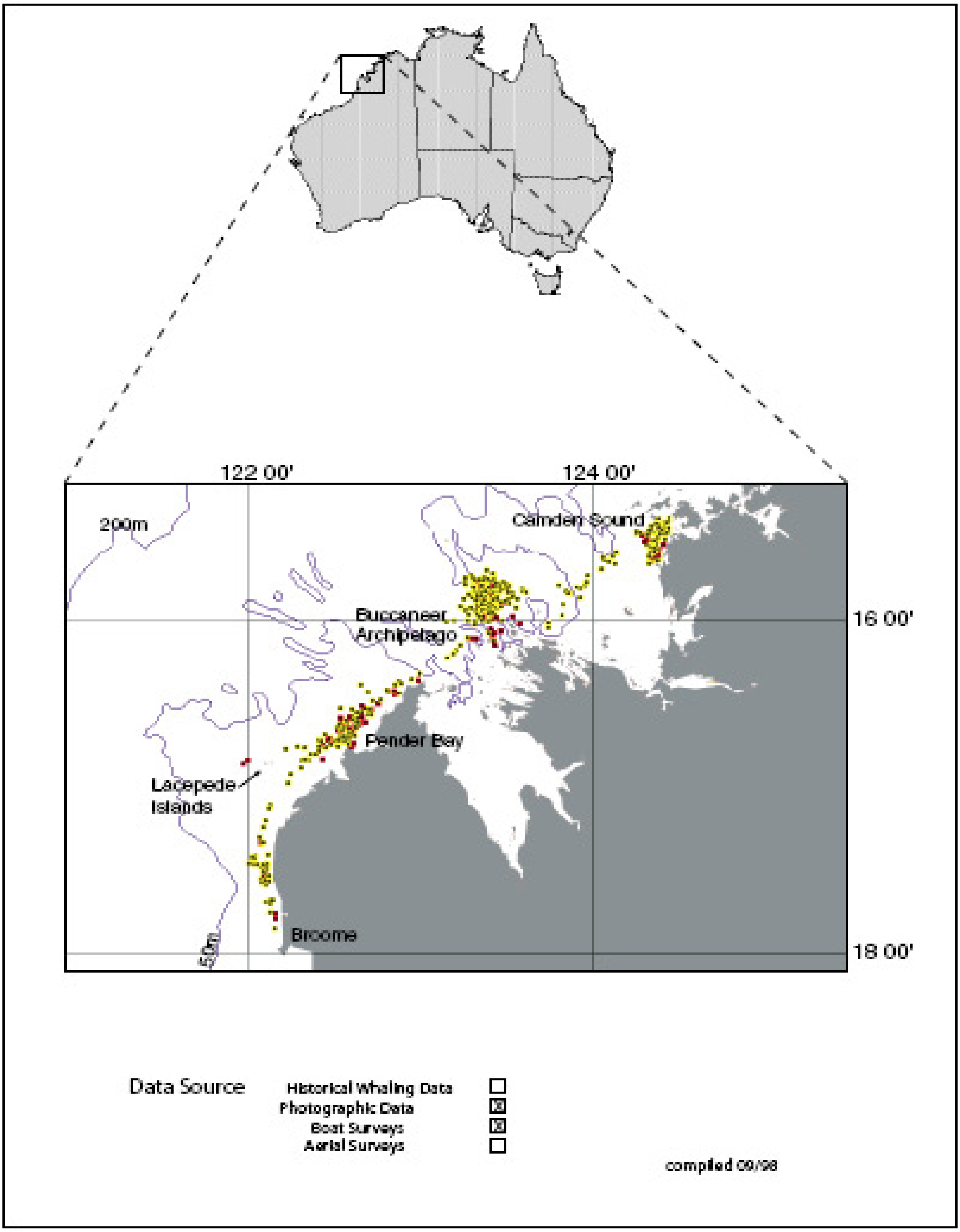


Figure 6-3 Humpback whale pods recorded during 1997 surveys of the Kimberley coast. Source: Jenner et al (2001), in RPS (2007b)

Whaling pressure in the 19th and 20th centuries reduced numbers of Group IV humpback whales from possibly 17 000 to fewer than 300 individuals in 1968. The Western Australian humpback whale population has been increasing steadily since the abolition of whaling for this species in Australian waters in 1963 (RPS 2007b).

In recent years, the abundance estimates reported for Feeding Area IV have been noted to be much higher than estimates made for the corresponding Stock D. Japan's Antarctic Research Program (JARPA) estimated the size of the Group IV population, using the DISTANCE analysis program and JARPA observation data from longitudinal range 70–130 ºE, to be 33 010 in 2001/02, and 31 750 in 2003/04. In contrast, aerial surveys conducted in the low-latitude breeding grounds estimated that there were 13 145 humpback whales (95% CL 4984–38 726) in Breeding Stock D in 2005 (RPS 2007b).

The difference between estimates of abundance of humpback whales in the Antarctic and in the low-latitude breeding grounds might be due to a substantial proportion of the Stock D humpback whales not migrating to the breeding grounds each year. This theory is supported by a male-biased sex ratio observed in Western Australia in 2002/03, when 194 males and 64 females were sampled migrating past North West Cape (RPS 2007b).

The size of the humpback whale population in the Southern Ocean has been estimated by the IWC's International Decade of Cetacean Research (IDCR) and Southern Ocean Whale Ecosystem Research (SOWER) circumpolar surveys. The IDCR/SOWER surveys circled the Antarctic south of 60 ºS three times: 1978/79–1983/84 (CPI), 1985/86–1990/91 (CPII), and 1991/92–2003/04 (CPIII). Abundance estimates of Breeding Stock D from each survey are presented in Table 6-2. The rate of population increase for Breeding Stock D has been estimated at 10.15% per year. At this rate of increase, the population estimates from the CPIII surveys in 1998/99 would have increased to approximately 38 000. Feeding ground estimates from IDCR/SOWER and JARPA provide a more accurate estimate of abundance for Stock D humpback whales than the breeding ground surveys, and estimates that Stock D has more than 30 000 individuals (RPS 2007b).

Table 6-2 Estimates of the size of Breeding Stock D. Source: RPS (2007b)

Circumpolar Survey No.	Year	Breeding Stock D
CPI	1978/79	1219
CPII	1988/89	4202
CPIII	1998/99	17 959

Despite a significant recovery, humpback whales are still listed as nationally threatened under the EPBC Act and a federal recovery plan has been developed for the species. The objectives of the Humpback Whale Recovery Plan 2005–2010 (DEH 2005a) are:

- the recovery of populations of humpback whales utilising Australian waters so that the species can be considered secure in the wild
- a distribution of humpback whales utilising Australian waters that is similar to the pre-exploitation distribution of the species
- to maintain the protection of humpback whales from human threats.

The recovery plan describes the habitats that are important to, and potentially critical to the survival of, humpback whales. These include areas that support significant seasonal aggregations of whales and ecosystem processes on which humpback whales rely, in particular, known calving, resting and feeding areas and certain sections of the migratory pathways. The area around Camden Sound has been identified as critical calving habitat for humpback whales (RPS 2007b).

Blue whales

Blue whales (*Balaenoptera musculus*) are the largest of the whale species, growing to a length of 33 m. They can be distinguished from other whale species by their large size, flat u-shaped head and mottled blue-grey colouration. Blue whales are the most specialised feeders among the rorquals, or groove-throated baleen whales (Family Balaenopteridae), feeding almost exclusively on euphausiids, or krill. Blue whales consume up to two tonnes of prey per day, more than any other predatory species (RPS 2007b).

Two subspecies of blue whale are found in the southern hemisphere: the ‘true’ blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*Balaenoptera musculus brevicauda*). The true blue whale is the larger of the two subspecies and is found mainly south of the Antarctic convergence zone, whereas the smaller pygmy blue whale is found further north. Both true and pygmy blue whales have been seen along the Western Australian coast, having been detected in the Perth Canyon between November and July, with peak abundance between March and May. On average, a maximum of 30 animals may be present at any given time (RPS 2007b).

There are two well-known blue whale feeding aggregation areas in Australian waters. In south-east Australia, pygmy blue whales aggregate in an area known as the Bonney Upwelling, a shelf-break upwelling region that extends from the eastern Great Australian Bight to western Bass Strait. In Western Australia, it is thought that the whales feeding in the Perth Canyon, a steep-sided bathymetric feature that dissects the continental shelf west of Fremantle, are pygmy blue whales. Passive acoustic logger data have shown that calling pygmy blue whales may also be spread out along the coast to the north of Perth, indicating that feeding may occur along the continental shelf north of the Perth Canyon. True blue whales are thought to feed almost exclusively in the Antarctic (RPS 2007b).

Migratory links have been demonstrated for blue whales between the Perth Canyon and the Bonney Upwelling (one photo-ID record), and between both the Bonney Upwelling and Perth Canyon, and the Sub-tropical Front to the south of Australia (one ARGOS tagged whale from each Australian feeding area) (RPS 2007b).

The migratory habits of true and pygmy blue whales are poorly understood, although they are both known to move between warm water breeding areas and cold water feeding areas. The ‘Australian’ pygmy blue whales are thought to migrate to Indonesia during May to November, returning to Australia between November and May. Acoustic logger records from the Western Australian coast at latitude 21 °S have indicated blue whales migrating northwards between June and July, and southwards between November and December. However, links between Australian feeding grounds and tropical wintering grounds are yet to be confirmed by photo-ID or satellite data (RPS 2007b).

Current evidence for the theory of tropical migration of blue whales in Western Australia includes:

- Blue whales have been recorded on many occasions during winter months in locations such as the Savu Sea west of Timor.

- Blue whales have been detected acoustically off Exmouth in November.
- Russian whaling data from the 1960s and 1970s shows a distribution along the Western Australian coast up to Indonesia that is consistent with a migration to a warm water calving ground.
- Blue whales have been recorded feeding at Cape Londonderry, near the Western Australian/ Northern Territory border.

Both true and pygmy blue whales were hunted heavily during the 1950s and 1960s, and were driven almost to extinction. For example, a Soviet factory whaling ship processed 269 whales along the coast from Albany to Exmouth in 1965, most of which were believed to be pygmy blue whales. Historical blue whale numbers in the southern hemisphere have been estimated at between 160 000 and 240 000 animals, including 10 000 pygmy blue whales. The current estimated population of southern hemisphere true blue whales is between 1000 and 2000 animals. There is no current consensus on the size of the pygmy blue whale population, but in 1996 there were estimated to be 6000 animals (RPS 2007b).

A federal recovery plan has been developed for blue whales in Australia (DEH 2005b). The objectives of this plan are:

- the recovery of populations of blue, fin and sei whales utilising Australian waters so that the species can be considered secure in the wild, and
- to maintain the protection of blue, fin and sei whales from human threats.

The recovery plan identifies the Perth Canyon as a critical feeding area for blue whales.

The limited knowledge about the distribution and abundance of blue whales makes the definition of the habitats that are critical to their survival impossible. The best information to-date relates to aggregation areas, in particular feeding areas. These can be considered important to the survival of blue whales because they support significant seasonal aggregations of whales and those ecosystem processes on which blue whales rely (RPS 2007b).

Fin and sei whales

Fin (*Balaenoptera physalus*) and sei (*Balaenoptera borealis*) whales may be present in the proposed development areas. Sei whales grow to 19.5 m and fin whales grow to 27.1 m (RPS 2007b).

There is limited biological and life history information for fin and sei whales. Sei whales are thought to migrate from high latitudes to low latitudes in winter; they also appear unexpectedly in certain areas, and then do not return for up to a decade or more. Fin whales do not appear to migrate. Both species inhabit coastal, shelf and oceanic waters (RPS 2007b).

The critical habitats of fin and sei whales are not known. Both are known to feed in the Antarctic, and some individuals have been observed in blue whale feeding areas (i.e. Bonney Upwelling and Perth Canyon).

The populations of both fin and sei whales were severely depleted by whaling in the early 1900s. The fin whale population in the southern hemisphere was reduced from an estimated 500 000 to about 25 000. Historical numbers of sei whale in the southern hemisphere were estimated to be approximately 100 000. The current size of fin and sei whale populations in the southern hemisphere is not known (RPS 2007b).

Both fin and sei whales are listed as vulnerable under the EPBC Act and a recovery plan has been developed for the species (DEH 2005b). The objectives of this plan are:

- the recovery of populations of blue, fin and sei whales utilising Australian waters so that the species can be considered secure in the wild, and
- to maintain the protection of blue, fin and sei whales from human threats.

Other cetaceans

Many other cetacean species, not listed as threatened under the EPBC Act, may be present in the proposed development areas. Cetacean species recorded by Jenner et al. (2001) in the Kimberley included false killer whales (*Pseudorca crassidens*), dwarf spinner dolphins (*Stenella longirostris roseiventris*), spinner dolphins (*Stenella longirostris*), bottlenose dolphins (*Tursiops aduncus* and *Tursiops truncatus*), snubfin dolphins (*Orcaella brevirostris*) and Indo-Pacific humpback dolphins (*Sousa chinensis*) (RPS 2007b).

Townsend (1935) reported the distribution of sperm whales (*Physeter macrocephalus*) and humpback whales killed by American pelagic whalers between 1785 and 1913. The sperm whale catches off north Western Australia indicate a distribution well off the continental shelf, which is consistent with their preference for deep water in the Atlantic (RPS 2007b).

Offshore species of dolphins likely to be present in the Browse Basin area include:

- long-beaked common dolphins (*Delphinus capensis*)
- short-beaked common dolphins (*Delphinus delphis*)
- short-finned pilot whales (*Globicephala macrorhynchus*)
- Risso's dolphins (*Grampus griseus*)
- Fraser's dolphins (*Lagenodelphis hosei*)
- pantropical spotted dolphins (*Stenella attenuata*)
- striped dolphins (*Stenella coeruleoalba*)
- spinner dolphins (*Stenella longirostris*)
- dwarf spinner dolphins (*Stenella longirostris roseiventris*)
- rough-toothed dolphins (*Steno bredanensis*)
- offshore bottlenose dolphins (Tursiops truncatus) (RPS 2007b).

6.2 Recent surveys

6.2.1 Objectives

Surveying of cetaceans in the offshore development area was conducted by vessel surveys in 2006 and 2007 (RPS 2007b), acoustic logging from 2006 to 2008 (McCauley 2009) and vessel surveys in 2008 (CWR 2009).

The objectives of this research were to determine the importance of the proposed development area to cetaceans, and to establish a baseline dataset on which future monitoring surveys could be planned.

6.2.2 Survey approaches

2006/2007 vessel survey

The known presence of humpback whales in the Kimberley from July to November each year, and the possible passage of pygmy blue whales through the region, were the focus of this study of whales in the development area, by RPS Environmental (RPS) (Figure 6-4) (RPS 2007b).

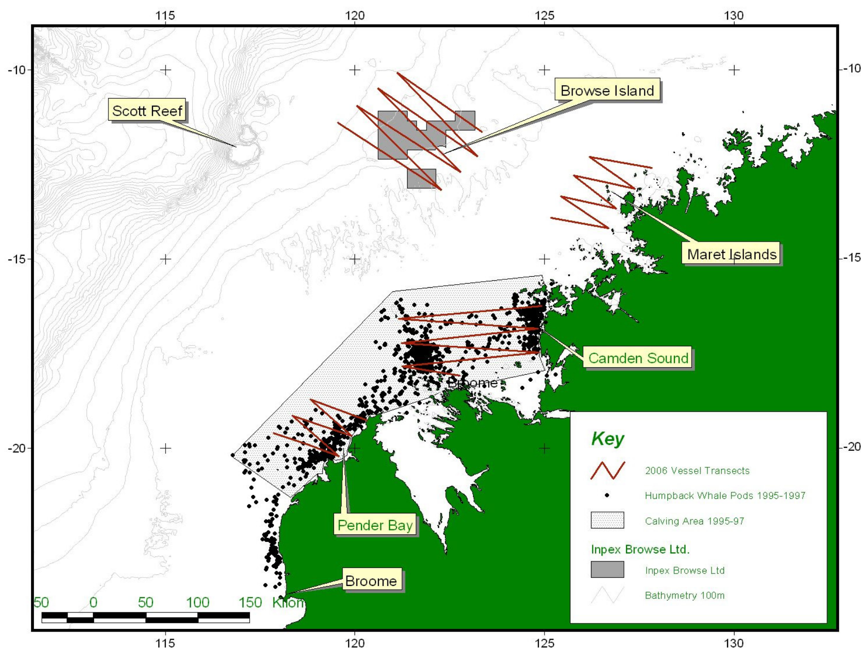


Figure 6-4 Vessel survey areas in offshore and nearshore Kimberley waters, in relation to humpback whale distribution (from Jenner et al 2001). Source: RPS (2007b)

A line transect sampling strategy was used to describe the temporal and spatial patterns of cetacean use of the area employing both vessel-based and aerial survey methods. Whale behaviour was recorded during opportunistic closing mode vessel surveys so that feeding, resting and calving grounds and other critical areas could be identified (RPS 2007b).

Studies targeting the possible blue whale migration period were conducted in May 2007. Satellite tags were fixed to pygmy blue whales in the Perth Canyon, and an unsuccessful attempt was made to follow them northwards to learn more about a potential northward migration (RPS 2007b).

Acoustic sea noise loggers

An acoustic logger was deployed to monitor great whales and fish in the Browse Basin, by R.D. McCauley, in association with the Centre for Whale Research (CWR) and the Centre for Marine Science and Technology (CMST).

2008 vessel survey

Vessel-based line transects were positioned east-west between oceanographic sampling stations at 25 km intervals across the entire Browse Basin region, encompassing depths ranging from 2300 m in the far west, to 100 m in the far east (Figure 6-5). These surveys were conducted by CWR (CWR 2009).

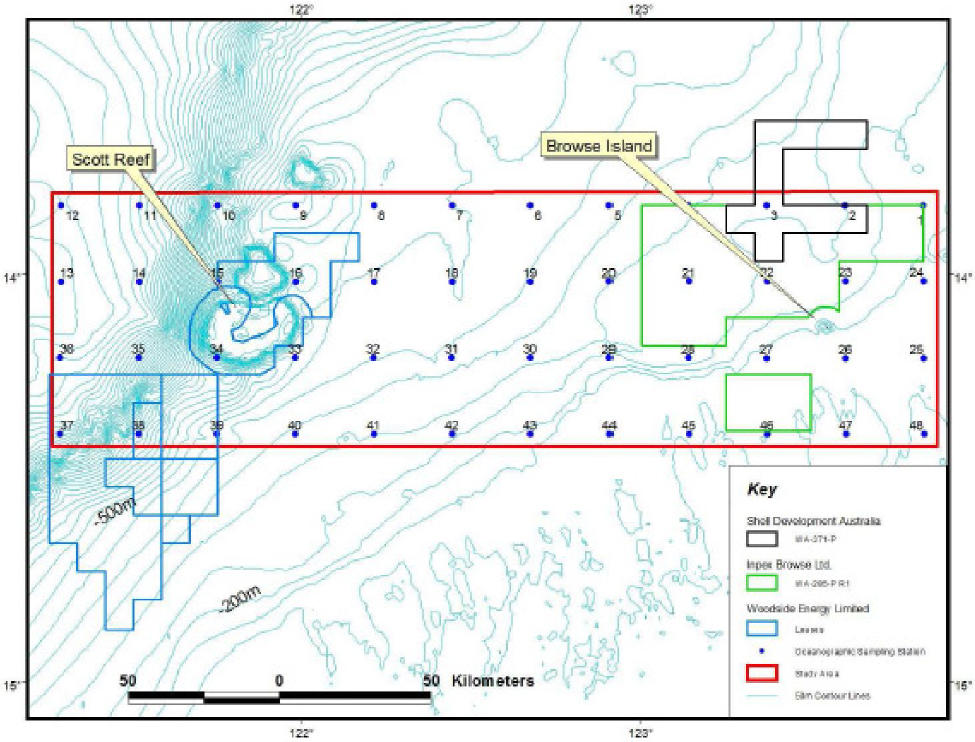


Figure 6-5 Vessel survey area in the Browse Basin. Source: CWR (2009)

6.2.3 Survey schedules

2006/2007 vessel survey

Vessel-based cetacean surveys were conducted between August and November 2006, and between July and August 2007 (Table 6-3).

Table 6-3 Schedule for 2006–07 vessel-based cetacean surveys. Source: RPS (2007b)

Time block	Dates	Vessel survey days	Year Total
1-06	15 Aug–03 Sep 2006	20	
2-06	09 Sep–28 Sep 2006	20	
3-06	04 Oct–23 Oct 2006	20	
4-06	29 Oct–07 Nov 2006	10	**70**
1-07	05 Jul–23 Jul 2007	18	
2-07	29 Jul–17 Aug 2007	20	**38**

Acoustic sea noise loggers

Acoustic loggers were deployed in the Browse Basin to record vocalising cetaceans and other relevant noises including fish and invertebrate activities (McCauley 2009). A summary of deployment times and valid samples is provided in Table 6-4.

Table 6-4 Deployment times and valid samples collected by acoustic loggers. Source: McCauley (2009)

Mooring	Start	End	No. of valid samples*	Length (days)
Browse Basin	13 Sep 2006	03 Feb 2007	13 741	143.12
Tristan	01 Apr 2006	12 Nov 2007	21 291	225.10
Reef	30 Nov 2007	11 Aug 2008	21 492	255.10

* A sampling regime of 200 seconds every 15 minutes.

2008 vessel survey

Transect surveys were conducted in four 20-day time blocks, two surveys during the anticipated northern migratory period for pygmy blue whales at this latitude (June/July 2008) and two surveys during the southern migratory period (October/November 2008) (CWR 2009).

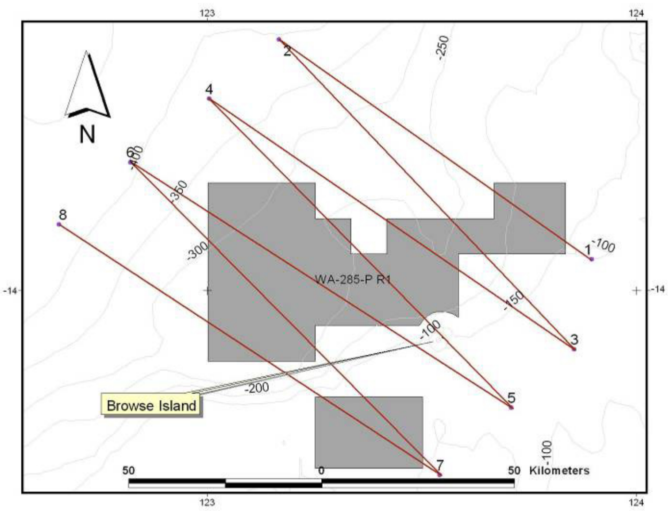
Table 6-5 Survey dates with corresponding pygmy blue whale migratory phase. Source: CWR (2009)

Survey Number	Range Date	Survey Hours	Migration Phase
1	June 09 to 28, 2008	171.8	Northern
2	July 04 to 23, 2008	159.8	Northern
3	October 17 to November 05, 2008	204.2	Southern
4	November 11 to 30, 2008	204.2	Southern
Year Total	**80 days**	**726.9**	**-**

6.2.4 Sampling methods and equipment

2006/2007 vessel survey

A 'saw-tooth' survey was conducted in 'passing-mode' (animals are observed while the vessel is passing) across Browse Basin (Figure 6-6). The transects were designed to achieve 75% coverage of each area, with an effective survey width of 6 nautical miles from the upper deck of the vessel (height of eye was 5.5 m). The details of the vessel transects are provided in Table 6-6. All transects were conducted between sunrise and sunset, and any transects unfinished at sunset were resumed at sunrise the following day or when weather allowed (RPS 2007b).



Site	Coordinates	
1	123.89584	-13.92770
2	123.16676	-13.41449
3	123.85511	-14.13746
4	123.00384	-13.55297
5	123.70848	-14.27391
6	122.82055	-13.70164
7	123.54148	-14.43072
8	122.65355	-13.84623

Figure 6-6 Browse Basin cetacean survey vessel transects. Source: RPS (2007b)

Table 6-6 Details of vessel transects. Source: RPS (2007b) adapted

Location	No. of transects	Survey (km)	Survey days (185 km/day)	Distance to next area (km)	Transect area (km²)
Browse Basin	7	891	5	187	9901

A 24-m motorised vessel, the FV Exodus, was used for the survey. Three observers scanned the horizon during daylight hours while the vessel steamed at between 8 and 9 knots along a series of transects that was repeated on each survey. Binoculars were used to identify fauna that were not readily identifiable by eye. An electronic hand-bearing compass was used to determine the bearing to observed cetaceans, and their distance from the vessel was estimated. A GPS waypoint was entered for each observation. The vessel's track was recorded every two seconds by GPS and logged on a laptop computer (RPS 2007b).

An "observer calibration" process was conducted at the beginning of each survey, where the observers estimated, and then refined, their range estimates to a distant radar reflector buoy. Those observer(s) with consistently the best assessment of range were consulted on the distance for each observation throughout the voyage (RPS 2007b).

In periods of good weather, an inflatable dinghy was launched to collect photo-identification images of humpback whales. The Exodus remained on transect during these operations.

Observations of cetaceans were recorded in the modified IFAW programme 'Logger'. Positions of cetaceans were then projected on the appropriate bearing and distance from the observation waypoint using OziExplorer software. Pod size, observation cue, direction and speed of travel, and behavioural data were also recorded when possible. The presence or absence of calves was also recorded, as a cow/calf pod if calves were present, and as a non-cow/calf pod if no calves were present (RPS 2007b).

Physical data were recorded at the beginning of each hour during the surveys, including time, position, water depth, surface and mid-water current direction and speed (using a JLN-620 ADCP current meter), sea surface temperature, predicted tide height and source of information, wind speed and direction, percentage cloud cover, and visibility range (RPS 2007b).

Paired observers searched a 180° sector on each side of the vessel using a zigzag searching technique from the side of the vessel out to the horizon, by unassisted visual search and using binoculars. All cetacean observations were recorded to species level where possible. If identification was uncertain, the most suitable category was chosen (e.g. "unidentified minke whale" rather than "dwarf minke", when pectoral fins were not visible). For each sighting, bearing and distance, pod-size and vessel position were recorded in Logger, with the relevant waypoint number and any comments or other observations recorded at the time. Photos were taken of all cetaceans near the vessel (or when animals were approached) (RPS 2007b).

Acoustic sea noise loggers

Three acoustic logger deployments in the offshore development area north-west of Browse Island (see Figure 6-7) occurred at the coordinates shown in Table 6-7, in water depths of 235–240 m. As shown in Figure 6-7, another logger was deployed near the Maret Islands, in Kimberley nearshore waters, but is not discussed in this report as the site is distant from the offshore development area.

Table 6-7 Locations of acoustic loggers off Browse Island. Source: McCauley (2009)

Mooring	Date start	Date end	Location
Browse Basin	13-Sep-2006	03-Feb-2007	13º50.436'S, 123 º17.625'E
Tristan	01-Apr-2007	12-Nov-2007	13º50.531'S, 123º 17.707'E
Reef	30-Nov-2007	11-Aug-2008	13º50.299'S, 123º 17.833'E

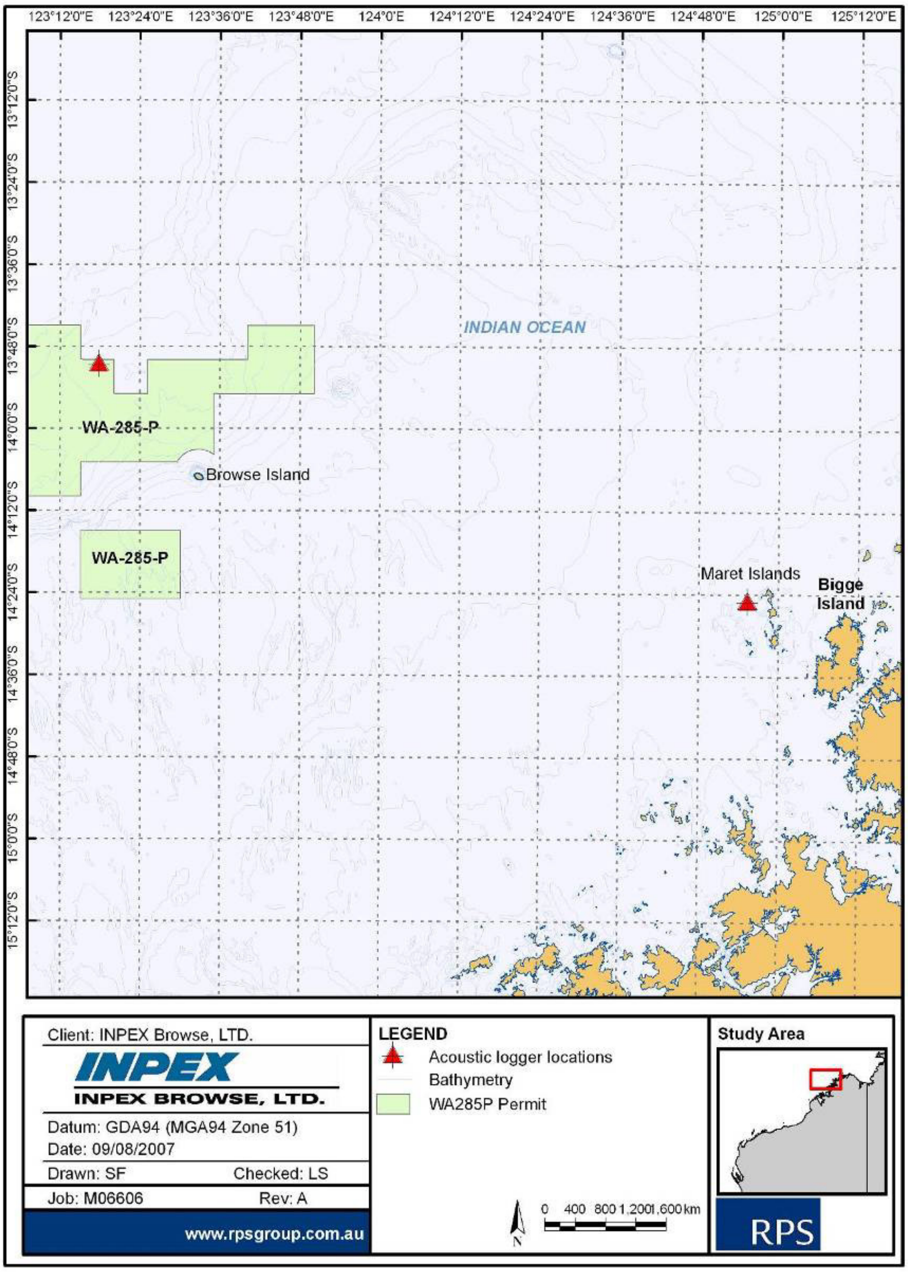


Figure 6-7 Location of the offshore acoustic logger. Source: RPS (2007b)

The sea noise logger comprised an external hydrophone (HiTek HTI 90-U) connected through a bulkhead connector to logging electronics designed and maintained at Curtin University, Western Australia (CMST DSTO noise loggers). The loggers provide:

- impedance matching for the hydrophone
- low-noise amplification for the hydrophone signal
- signal conditioning with anti-aliasing filters and a low frequency roll off to flatten the high levels of low frequency background sea noise and thus reduce the input signals' dynamic range while retaining the calibration
- 16 bit A-D conversion; two input channels, each with potentially multiple sampling schedules
- storage capacity of up to 125 GB on a single hard disk
- a fully programmable sampling schedule, set up using a serial link and PC communications package.

The loggers recorded a 200 second sample every 15 minutes. This sampling regime has been found to provide a sample of sufficient length for censussing marine mammals and fish at a comfortable deployment length of approximately 10 months duration. The sampling bandwidth, up to 2.8 kHz, is suitable for all great whales and most fish calls, but only detects the low frequency vocalisations of toothed whales which typically vocalise at much higher frequencies than baleen whales (McCauley 2009).

The logger was calibrated with white noise of a known level at the appropriate logger settings prior to deployment.

2008 vessel survey

A cetacean survey was conducted by CWR, along the transects shown in Figure 6-5 during daylight hours only. A 24-m motorised vessel, the RV WhaleSong II, was used for the survey. Three observers located 7.2 m above sea level (height of eye) scanned from the vessel to the horizon (estimated range 12.8 km) while steaming at a constant speed of 7–8 knots (CWR 2009).

Binoculars (hand-held 7 x 50 and ship-mounted 25 x 150) were used to identify fauna that was not readily identifiable by eye. A hand-bearing compass was used to determine the bearing of sighted species and their range to the vessel was determined by estimation (see below). The ships track was recorded every 10 seconds by GPS and logged to the ships computer and a dedicated data logging computer (CWR 2009).

At the beginning of each survey a calibration period where the observers estimated, and then refined their distance estimates, to radar targets was carried out. The observer(s) with consistently the best assessment of range were consulted on the distance for each sighting throughout the voyage (CWR 2009).

Sightings of all cetaceans were recorded in the modified IFAW programme "Logger". Positions of cetaceans were then projected at the appropriate bearing and distance from the sighting waypoint using an Excel macro. Group size, sighting cue migratory/swimming direction were also recorded (when possible) (CWR 2009).

6.2.5 Data analysis

2006/2007 vessel survey

The types of data collected can be broadly classified as “temporal”, “spatial”, “behavioural” and “physical”. The information generated includes the time of the year (temporal) that a species uses a particular area (spatial), and how it uses the area (behavioural), and environmental conditions (physical) that may affect its distribution or behaviour (RPS 2007b).

The GIS programme Arcview v3.2, with extensions Spatial Analyst and Animal Movement, was used to describe the distribution of cetaceans encountered during the surveys. Vessel transects were evenly spaced so that a 75% coverage was achieved in each of the four sample areas. A Kernel home-range estimator was used to assess the tendency for clumping (preferred habitat) of each species within the sample area, based on an assumption of an equal sample effort across the area. Probability contour maps that show 50% (preferred home range), 75% and 95% (extent of area usage) zones were generated (RPS 2007b).

A smoothing factor (‘h’ statistic) controls the size of the home range reported, and has been demonstrated to be not consistently applicable across all sample sizes. For this reason, a second technique, the minimum convex polygon (MCP) method, was used to estimate home-range size. The MCP was used as the area of the home range and the smoothing factor was adjusted until the area of the 95% kernel equalled the area of the MCP. This provides an objective method for selecting the smoothing factor (RPS 2007b).

The logistical constraints associated with covering a large survey area also resulted in limitations for the vessel surveys. Ten-day blocks are a standard sample period used for comparing separate areas within and between seasons. However, due to the large distances covered by this study, each site was sampled only once every 20 days, resulting in fewer sampling opportunities per season, preventing analysis for trends and patterns on a fine-scale. Further, some portions of the vessel surveys in time blocks 1-07 and 2-07 could not be completed due to windy conditions (RPS 2007b).

Acoustic sea noise loggers data

Sea noise data were plotted to show sound intensity within the four frequency bands from each logger. These “stacked” plots were produced by taking the time-averaged power spectra of each 200-second sample at four frequency resolutions, averaging each of these across selected samples, and stacking a combination of the averaged four frequency resolutions through time on a colour plot. The figures are displayed with a logarithmic frequency scale from 10 Hz to 2800 Hz (the upper calibrated limit of the recording system), and a fixed colour scale with bounds from 55 to 110 dB re 1 µ Pa^2/Hz (McCauley 2009).

2008 vessel survey

Physical data was recorded at the beginning of each hour during surveys and included time, position, sea surface temperature, tide height and source, wind speed and direction, cloud cover percentage, visibility range. Other bio-physical oceanographic features such as current shear lines, algal slicks, and changes in water colour were recorded as encountered in the Logger software (CWR 2009).

The number and identity of observers on watch was recorded in Logger. Bearing and distance, group size and other categories of information were recorded immediately on sighting and a GPS position was taken (if Logger was not connected to the GPS). All cetacean sightings were entered in Logger with the relevant Waypoint number and any comments, and all other categories of information known at the time of sighting. If species identification was made at a later time, through resights of the animal/s (or reference to photos), this information was either entered directly into Logger or onto notes sheets that were consulted during the data validation process (CWR 2009).

6.3 Results

6.3.1 2006/2007 vessel survey

Humpback whales

From vessel surveys between mid-August and late October 2006, and between July and mid-August in 2007, 21 humpback whales were seen in the Browse Basin, in 13 pods (Table 6-8). They were seen as far north as 13°40' S, 55 km NNW of Browse Island and 275 km offshore. Humpback whale densities were significantly higher in Camden Sound and Pender Bay (Figure 6-8). Humpback whales in the Browse Basin were recorded at the lowest density of all areas surveyed, across all time blocks, followed by the Maret Islands where 59 whales in 38 pods were recorded (RPS 2007b).

Kernel density distribution maps were generated using a consistent smoothing (h) factor of 0.1 for four time blocks in which humpback whales were observed (Figure 6-9 to Figure 6-12). "High" density areas are defined within the 50% probability contours, while "medium" density areas are within the 75% probability contours, and "low" density areas are defined by the 95% probability contours. Density estimates were not attempted for time block 1-07 (3–23 July 2007) because the full survey was not completed for this period; the locations of humpback whales sighted during this period are shown in Figure 6-13 (RPS 2007b).

Table 6-8 Number of humpback whales recorded in the Browse Basin. Source: RPS (2007b) adapted

Time block	Date interval	Browse Basin
1-06	15/08–03/09	9 (4,0)*
2-06	09/09–28/09	0
3-06	04/10–20/10	0
4-06	22/10–29/10	0
1-07	05/07–23/07	–
2-07	29/07–17/08	12 (9, 1)*
	Total	**21 (13,1)***

*(number of pods, number of pods with calves)

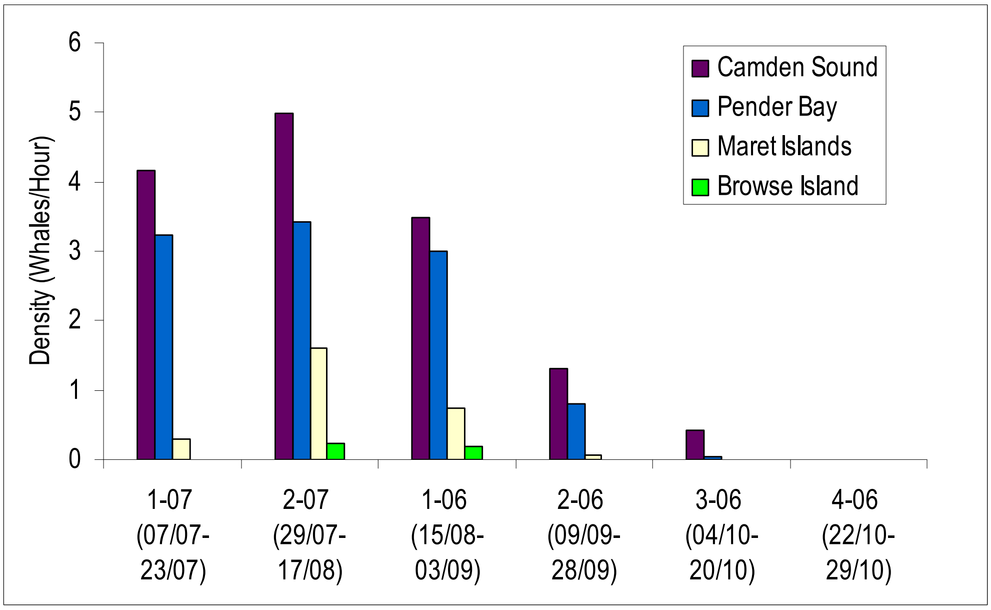


Figure 6-8 Humpback whales recorded per search hour in all survey areas. Source: RPS (2007b)

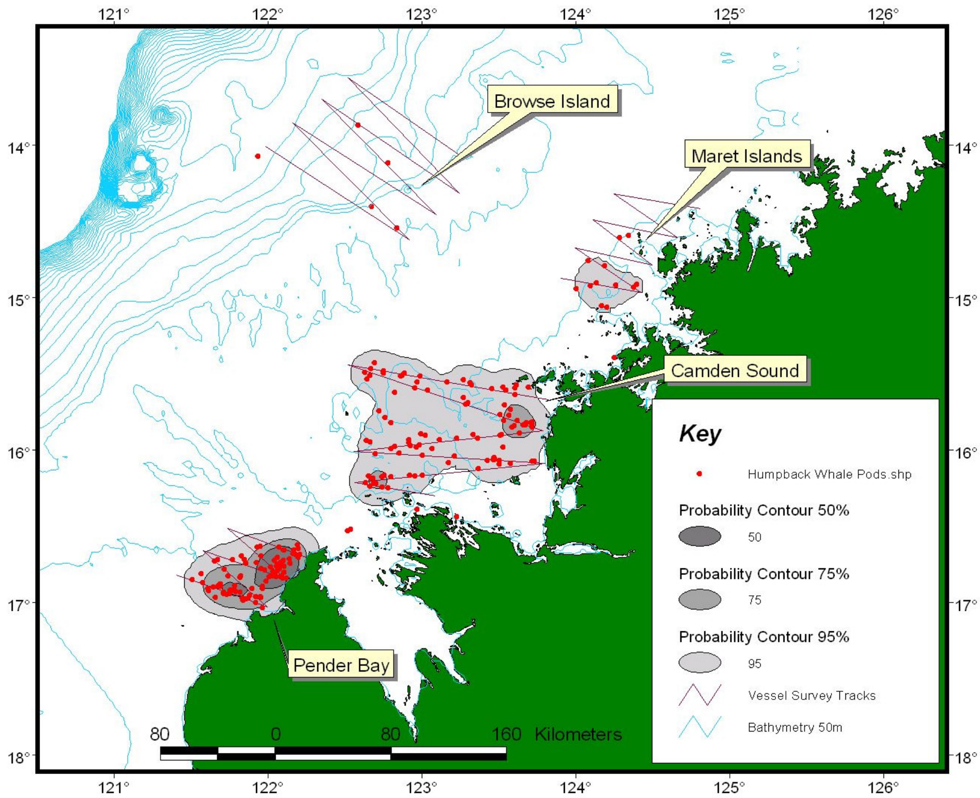


Figure 6-9 Distribution of humpback whales during survey period 15 August–3 September 2006. Source: RPS (2007b)

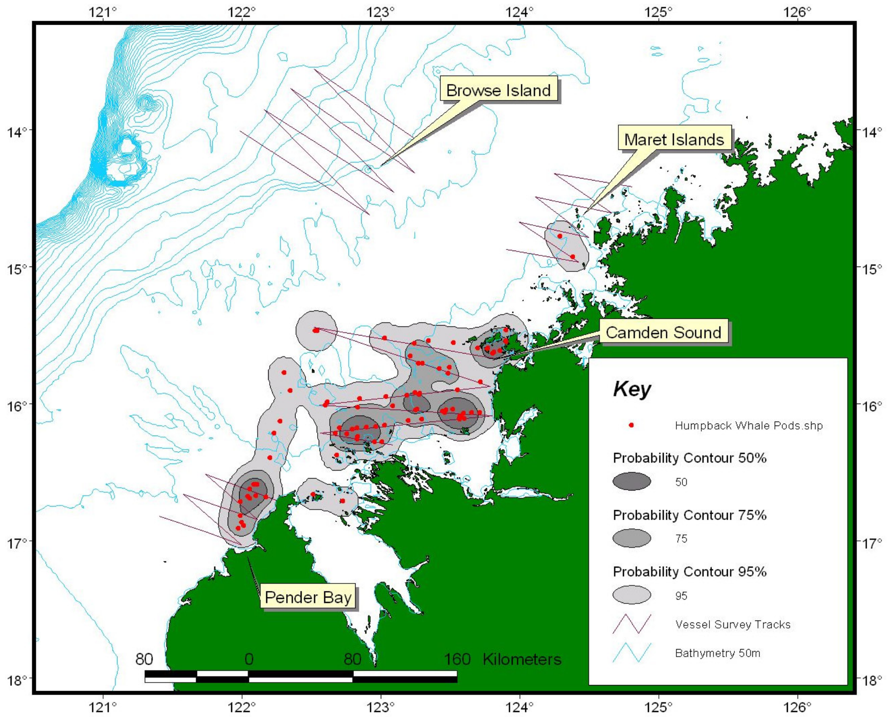


Figure 6-10 Distribution of humpback whales during survey period 9–28 September 2006. Source: RPS (2007b)

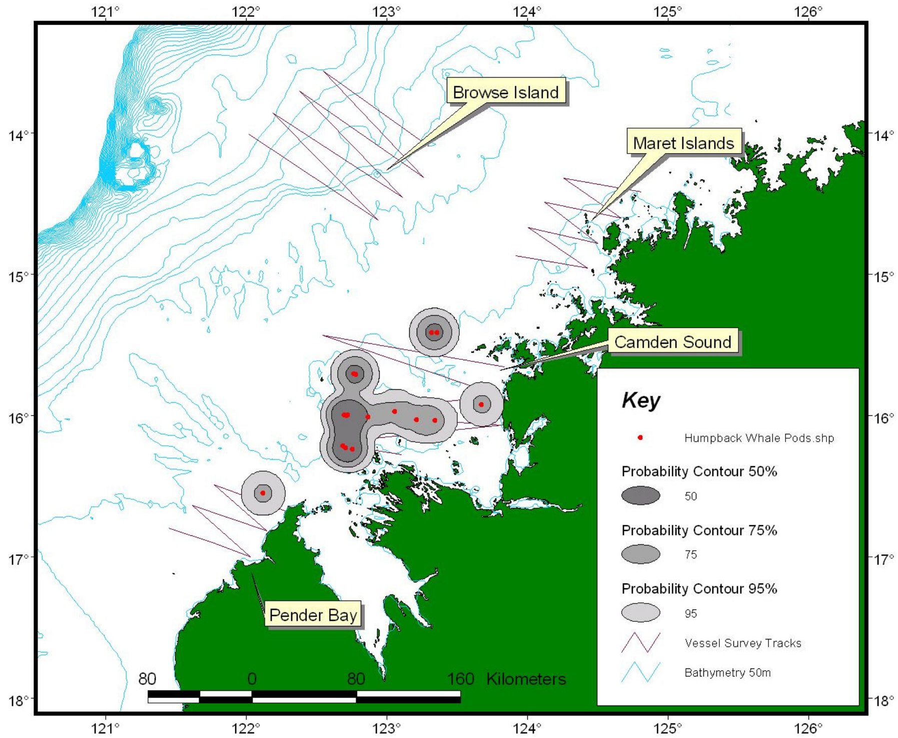


Figure 6-11 Distribution of humpback whales during survey period 4– 23 October 2006. Source: RPS (2007b)

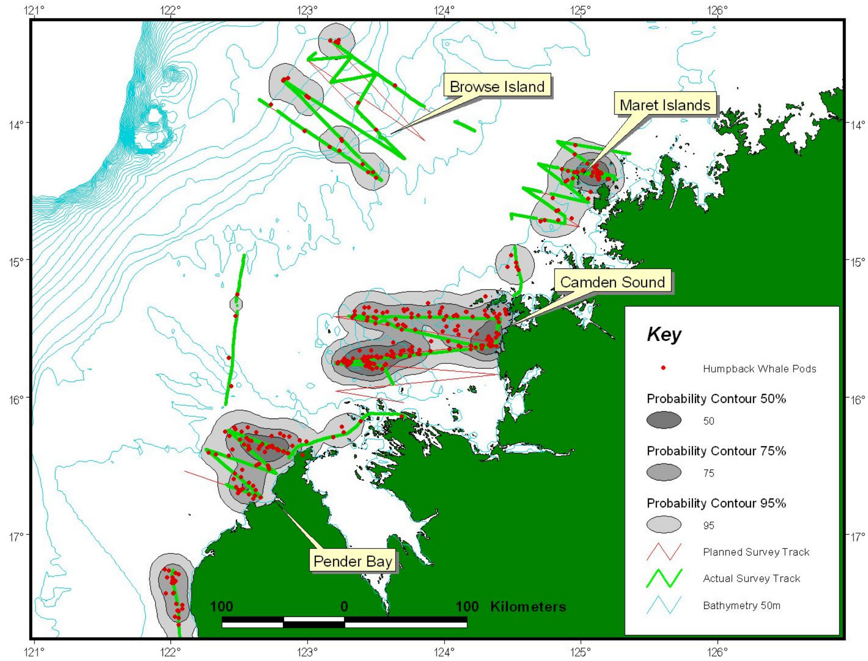


Figure 6-12 Distribution of humpback whales during survey period 29 July–17 August 2007. Some portions of the survey were incomplete due to windy conditions. Source: RPS (2007b)

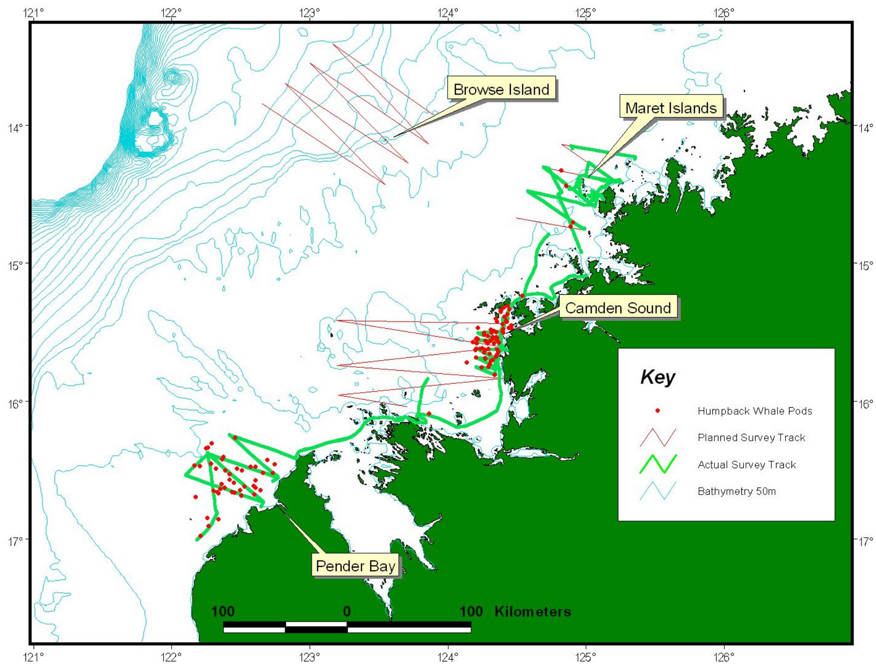


Figure 6-13 Locations of humpback whale pods observed during the 3-23 July 2007 survey. Density estimates not presented due to the survey being incomplete. Source: RPS (2007b)

Only one cow–calf pod was observed in the Browse Basin area across both seasons. Camden Sound had the highest numbers of cow–calf pods (25) and generally higher densities, although the density of cow–calf pods in Pender Bay was higher than in Camden Sound during the early August survey (Figure 6-14) (RPS 2007b).

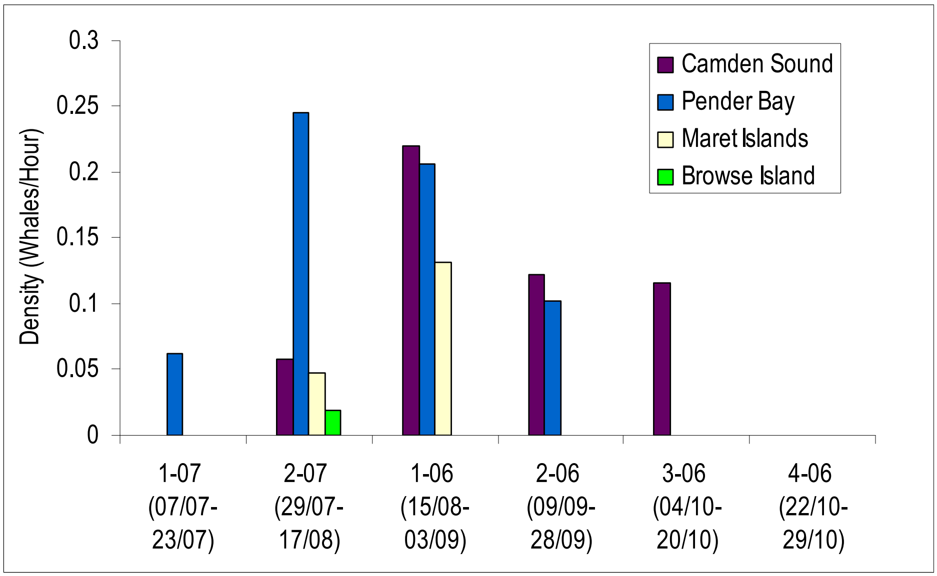


Figure 6-14 Humpback whale calves recorded per search hour. Source: RPS (2007b)

The majority of whales recorded in all four areas displayed "surface passive" behaviour types, e.g. travelling, lolling and milling, which is indicative of resting areas, as opposed to "surface active" behaviour types, e.g. breaching, pectoral fin slapping and lob tailing, (Figure 6-15 to Figure 6-18). The small number (33 across all four areas) of whales recorded during time blocks 3-06 and 4-06 were also mostly displaying surface passive behaviour (data not presented due to low relative numbers) (RPS 2007b).

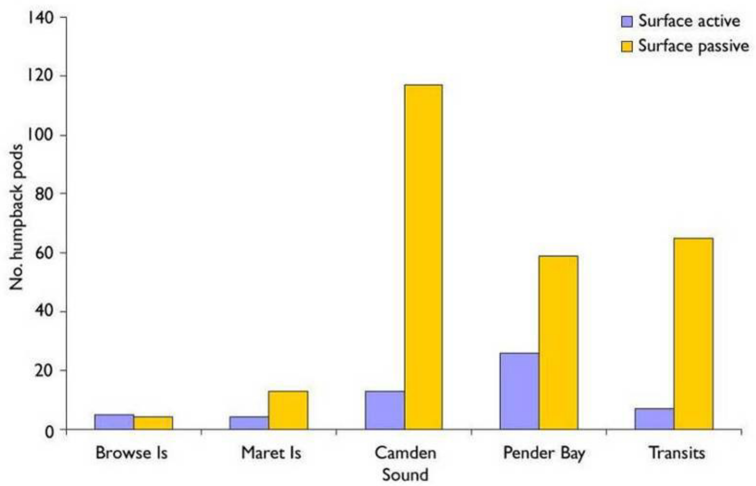


Figure 6-15 Whale behaviour recorded; 15 August–3 September 2006. Source: RPS (2007b)

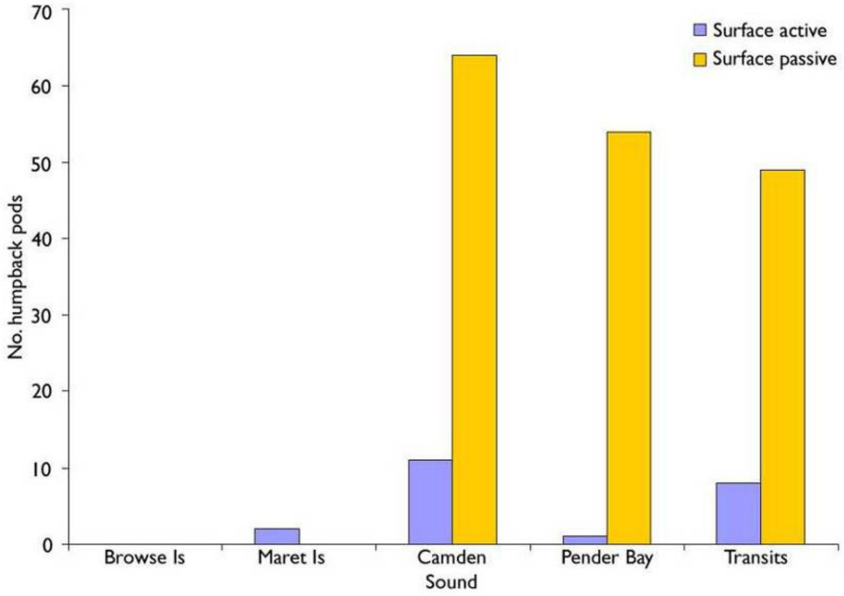


Figure 6-16 Whale behaviour recorded; 9–28 September 2006. Source: RPS (2007b)

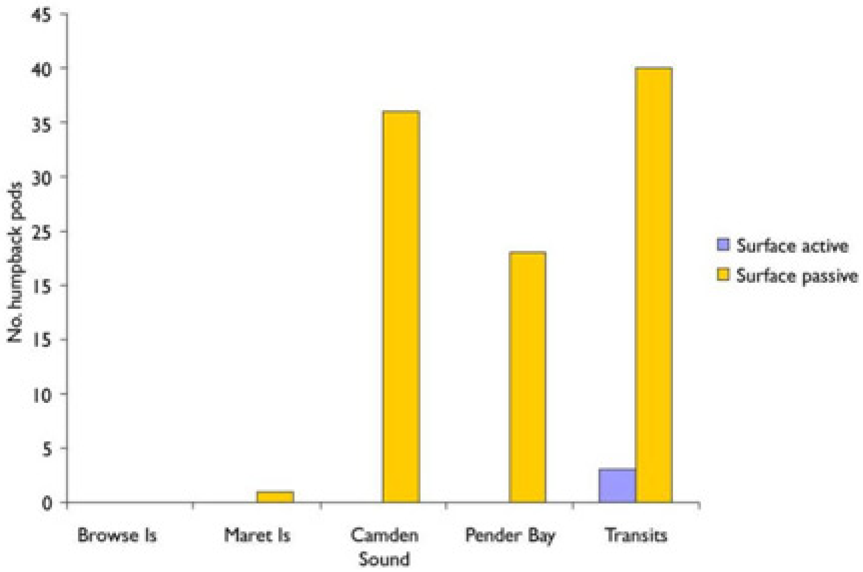


Figure 6-17 Whale behaviour recorded; 5–23 July 2007. Source: RPS (2007b)

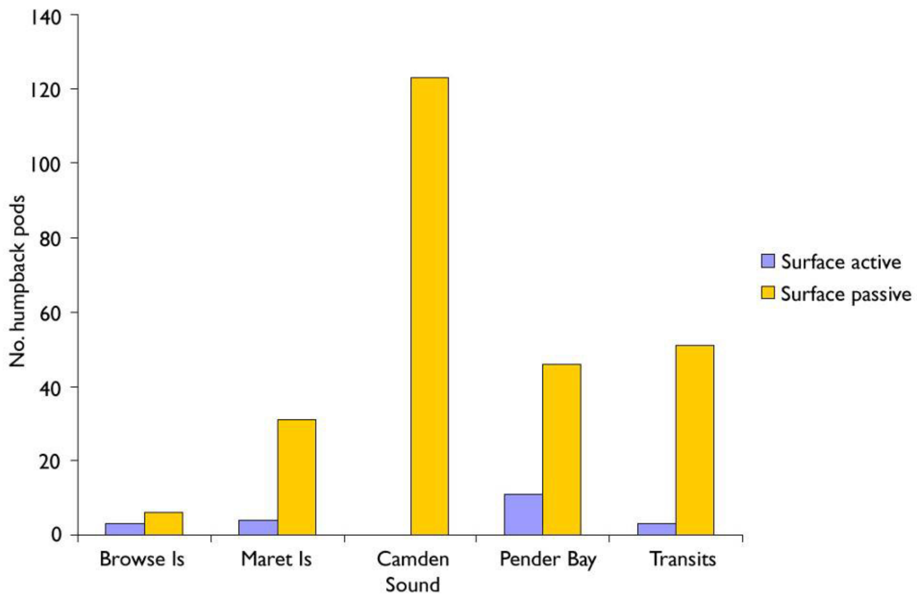


Figure 6-18 Whale behaviour recorded; 29 July–17 August 2007. Source: RPS (2007b)

During time block 1-06 (15 August to 3 September 2006) in the south-eastern-most sector of the Browse Basin area, two humpback whales were observed exhibiting swimming and diving behaviour that was consistent with feeding. This occurred where a +0.5 °C temperature front and very high levels of bird, fish and other wildlife activity were also recorded. Humpback whales were again recorded feeding in the Browse Basin area in 2007, approximately 70 km further offshore than the 2006 observation. Side-lunge feeding by sub-adult sized humpback whales (<10 m) was also reported. Pilot whales also appeared to be feeding in the same area (RPS 2007b).

Blue whales

Neither true blue whales nor pygmy blue whales were observed during the vessel surveys.

Other cetaceans

Eighteen species of dolphins and whales other than humpback whales, comprising 3659 individuals, were recorded during the 2006 and 2007 vessel surveys (Table 6-9). The most species-rich area was the Browse Basin (15 species), and the highest number of individuals (1123 identified and 524 unidentified animals) was recorded in time block 1-06 (15 August to 3 September 2006). Two hundred and ninety-five whales and 1127 dolphins could not be identified to species level due to distance from the vessel or short surface intervals, and were grouped separately, based on whether they appeared 'whale-sized' (>6 m) or 'dolphin-sized' (RPS 2007b).

For comparative purposes, the species recorded (Table 6-9) were classified generally into four groups:

- inshore dolphins
- offshore dolphins
- small, toothed whales

- baleen whales (non-humpbacks).

Large pods of offshore dolphins were common in the Browse Basin area (Figure 6-19). Inshore dolphins, such as *Tursiops aduncus*, were more commonly observed in the Maret Islands area, although some large pods (50–100 individuals) of *T. aduncus* were also found in the Browse Basin area (Figure 6-20). Small toothed whales were uncommon, and were mostly observed in time blocks 2-06, 3-06 and 4-06, in the Browse Basin area and near Camden Sound (Figure 6-21). A single beaked whale (Family Ziphiidae) of undetermined species was seen on 23 August 2006 in the Browse Basin. Seven minke whales were seen during the surveys, four of which were identified as the dwarf sub-species (Figure 6-22).

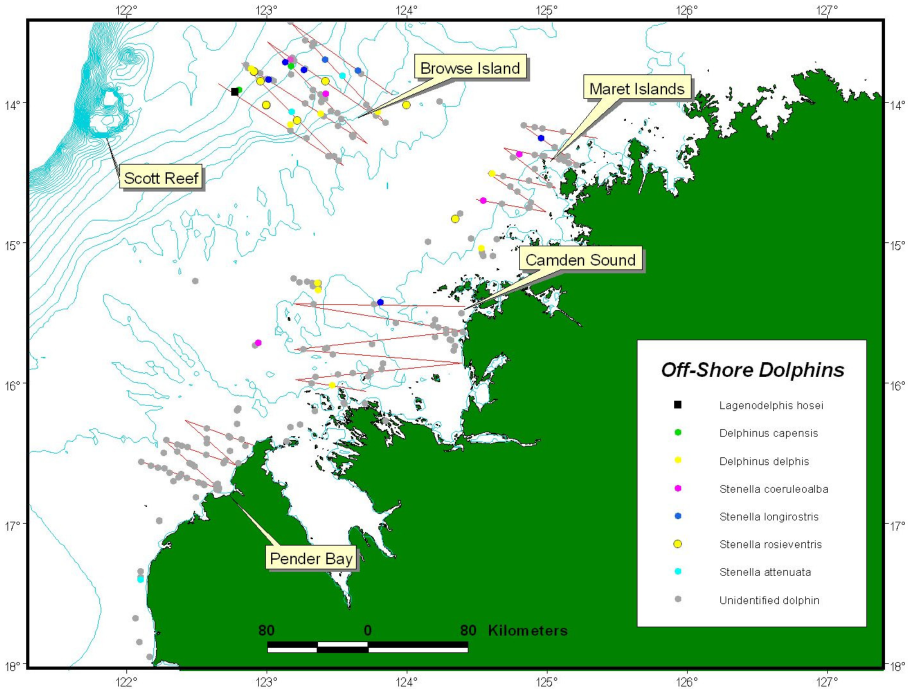


Figure 6-19 Distribution of offshore and unidentified dolphins for all vessel surveys. Source: RPS (2007b)

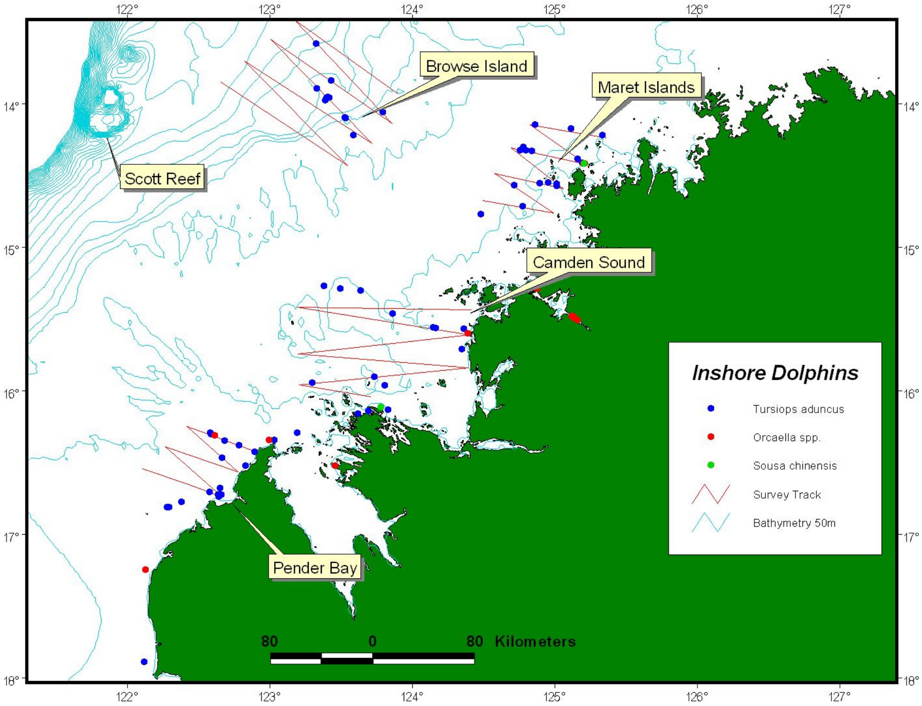


Figure 6-20 Distribution of inshore dolphins for all vessel surveys. Source: RPS (2007b)

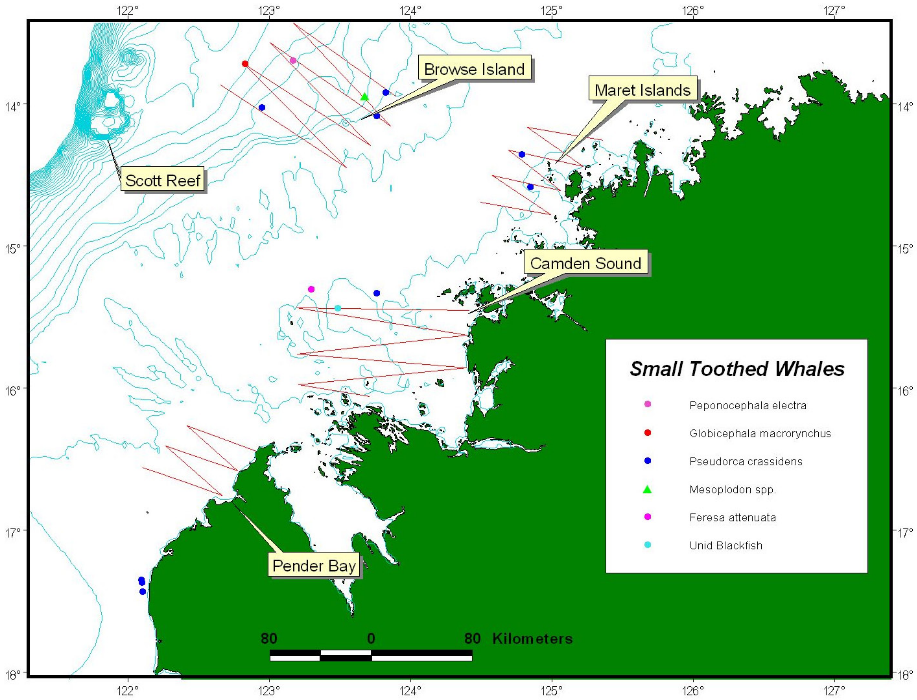


Figure 6-21 Distribution of small toothed whales for all vessel surveys. Source: RPS (2007b)

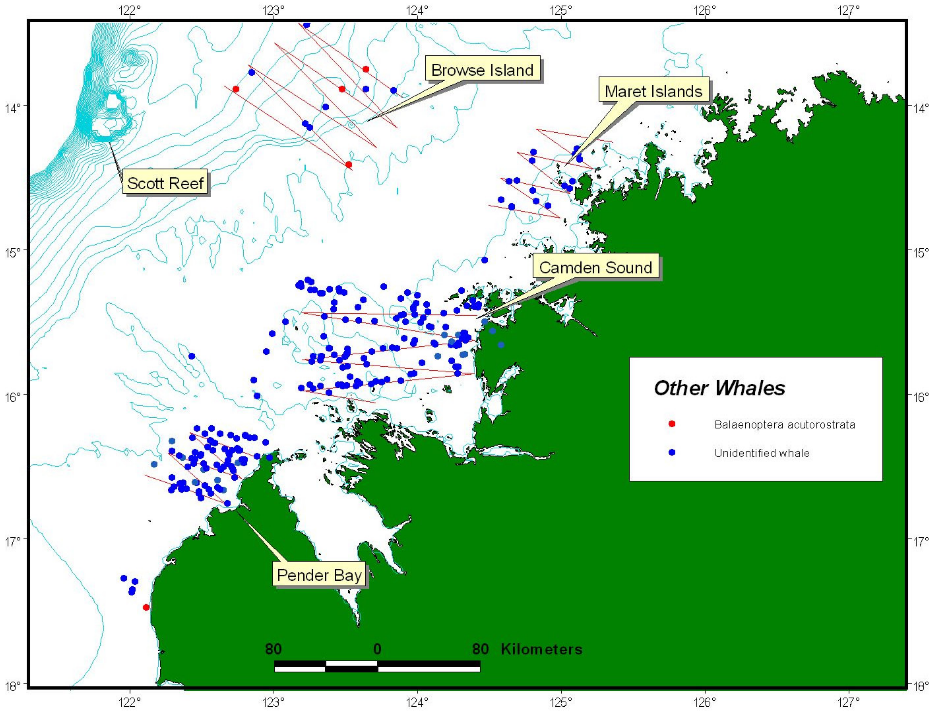


Figure 6-22 Distribution of minke whales and unidentified whales for all vessel surveys. Source: RPS (2007b)

Cetaceans

Table 6-9 Cetacean species recorded in each survey area. Source: RPS (2007b)

Group	Common name	Scientific name	Browse Basin*	Maret Islands*	Camden Sound*	Pender Bay*	Transit*	Total*
Inshore Dolphins	Snubfin dolphin	*Orcaella heinsohni*	-	4 (2)	-	-	18 (4)	**22 (6)**
	Indo-Pacific humpback dolphin	*Sousa chinensis*	-	-	-	2 (1)	2 (1)	**4 (2)**
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	192 (5)	154 (4)	52 (2)	51 (5)	38 (9)	**487 (25)**
Offshore Dolphins	Long-beaked common dolphin	*Delphinus capensis*	200 (1)	-	-	-	106 (2)	**306 (3)**
	Short-beaked common dolphin	*Delphinus delphis*	58 (1)	-	2 (1)	-	-	**60 (2)**
	Fraser's dolphin	*Lagenodelphis hosei*	12 (1)	-	-	-	-	**12 (1)**
	Pantropical spotted dolphin	*Stenella attenuata*	140 (1)	-	-	-	10 (1)	**150 (2)**
	Striped dolphin	*Stenella coeruleoalba*	50 (1)	61 (1)	-	-	25 (1)	**136 (3)**
	Spinner dolphin	*Stenella longirostris*	434 (5)	12 (1)	40 (1)	-	2 (1)	**488 (8)**
	Dwarf spinner dolphin	*Stenella longirostris roseiventris*	337 (2)	-	-	-	-	**337 (2)**
	Offshore bottlenose dolphin	*Tursiops truncatus*	100 (1)	-	7 (1)	-	-	**107 (2)**
Small Toothed Whales	Pygmy killer whale	*Feresa attenuata*	-	-	5 (1)	-	-	**5 (1)**
	Short-finned pilot whale	*Globicephala macrorhynchus*	12 (1)	-	-	-	-	**12 (1)**
	Beaked whale species	*Mesoplodon sp.*	1	-	-	-	-	**1**
	False killer whale	*Pseudorca crassidens*	38 (2)	22 (1)	23 (1)	-	-	**83 (4)**
	Melon headed whale	*Peponocephala electra*	20 (1)	-	-	-	-	**20 (1)**
Baleen Whales (non-humpback)	Dwarf minke whale	*Balaenoptera acutorostrata subsp.*	4 (3)	-	-	-	-	**4 (3)**
	Minke whale species	*Balaenoptera acutorostrata*	3 (2)	-	-	-	-	**3 (2)**

*Number of individuals (number of groups).

6.3.2 Acoustic sea noise loggers

There were at least four great whale signal types catalogued over the two year period including; pygmy blue whale, humpback and possible Antarctic minke whale signals together with one unknown type. However anthropogenic noise (predominantly vessel noise) dominated the noise spectra at the Browse site over most of the two years of deployment. The timing of humpback whale presence could still not be determined (McCauley 2009).

Acoustic signals attributed to pygmy blue whales were recorded on 27 October 2006 on the acoustic logger at the Browse Basin site (Figure 6-23 and Figure 6-24); the gross signal structure is identical to signals recorded from the Perth Canyon. At least two calling animals were present, indicating that several whales were probably in the area of the noise logger (not all whales vocalise). Otherwise, the species was not recorded in the estimated 75-km radius pygmy blue whale listening area of this logger over the two year period of the survey. This single visit of pygmy blue whales coincided with a period of intense activity produced by nocturnally active planktivorous fishes associated with the deep scattering layer, suggesting that at this time secondary productivity at the offshore site was high (McCauley 2009).

It is expected that the preferred pygmy blue whale migratory corridor for animals at the Browse latitude would be west of the Ichthys Field. The 500-m depth contour is around 90 km NW of the Browse Basin logger location at its closest point. Given that this is just beyond the detection range of pygmy blue whales from the Browse location, then it is probable that the animals travelling north and south between Indonesia and the north-west shelf keep offshore in mostly >500 m water depths to strike the shelf near Seringapatam Reef, west of the Browse site (McCauley 2009).

Cetaceans

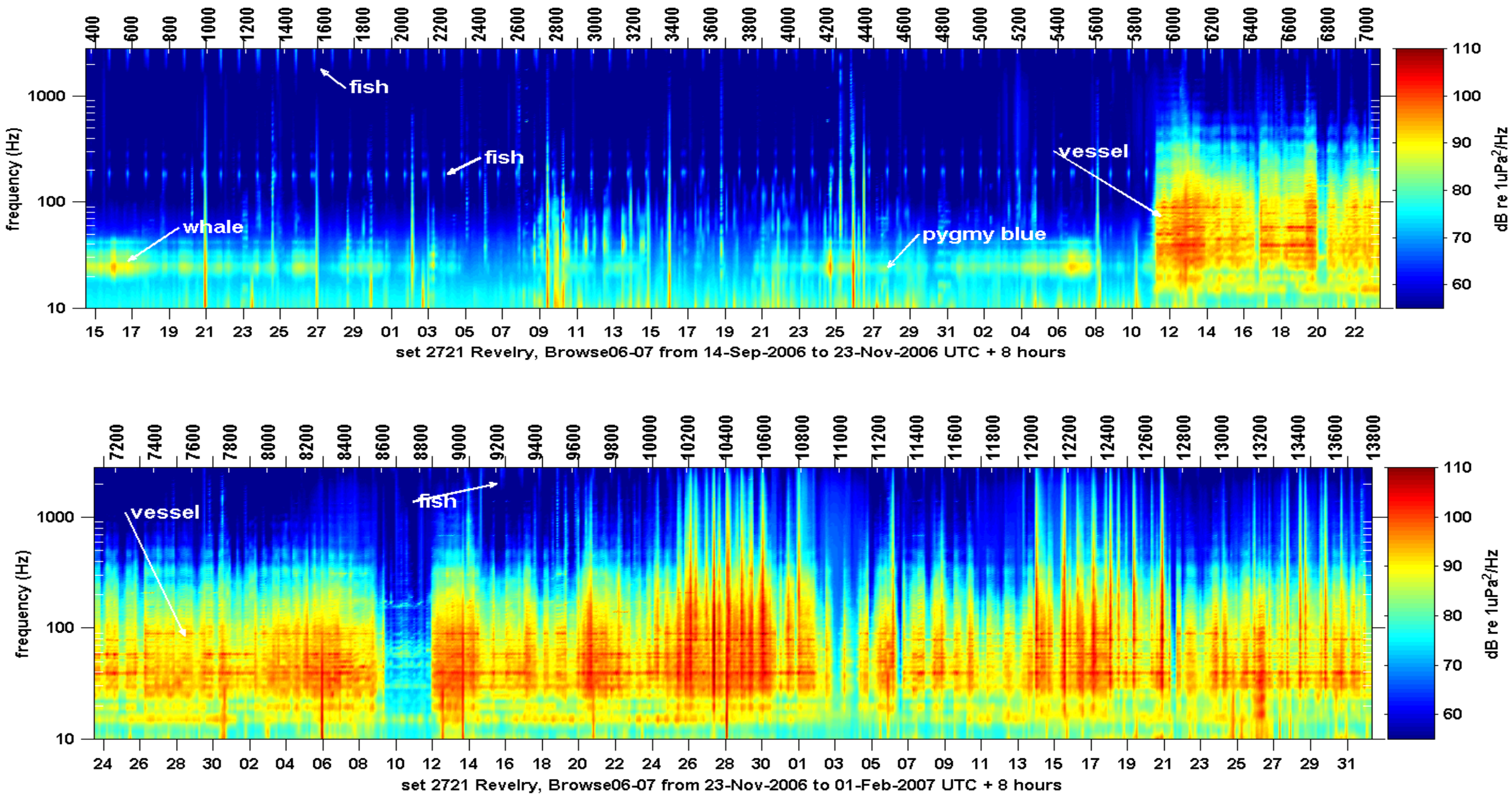


Figure 6-23 Seventy-day stacked sea noise spectra for the offshore logger from 14 September 2006 to 1 February 2007. A log frequency scale is used and the colour bounds have been fixed from 55 to 110 dB re 1µPa^2/H. Source: McCauley (2009)

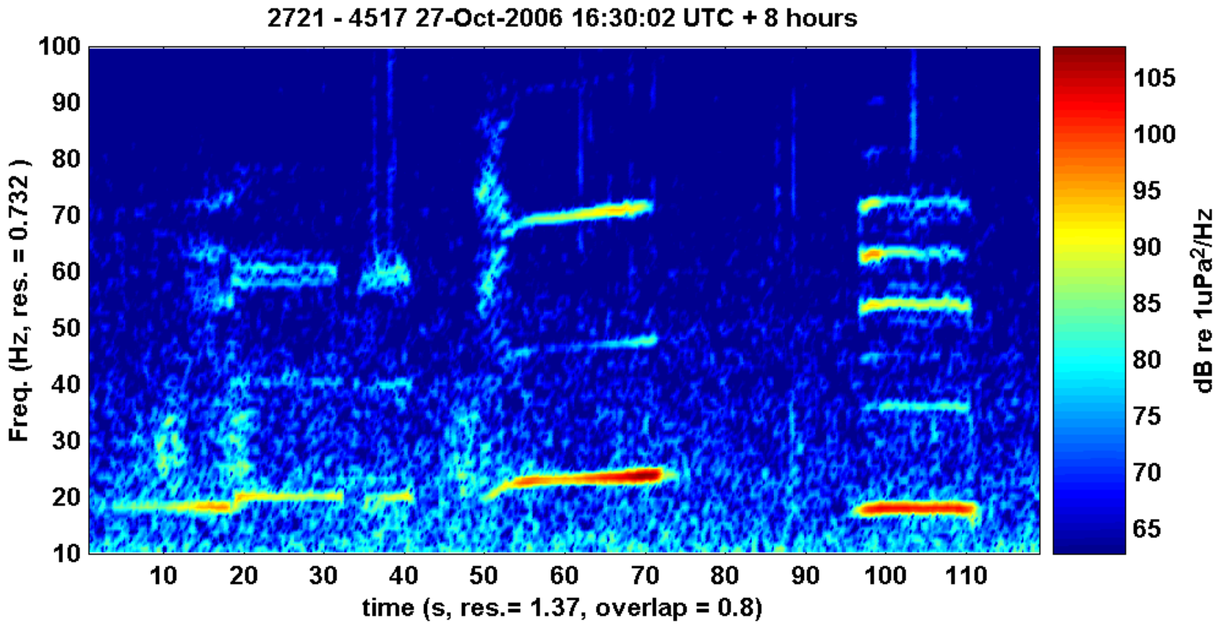


Figure 6-24 Spectrogram of a pygmy blue whale call recorded in the Browse Basin in late October 2006. Source: McCauley (2009)

Several unknown signals consistent with great whale calls (powerful, low-frequency, complex frequency structure, and not repeated in a clear daily pattern) were recorded on the offshore logger. Similar signals have been recorded in other regions, but their sources have not been identified (McCauley 2009).

The most persistent unknown signal was evident as a 'splodge' on the spectrograms (Figure 6-25). This signal-type has two parts, lasts about 10 seconds (although this varies with signal-to-noise ratio), and spans a frequency range of 20–50 Hz. This signal-type has been recorded offshore from Exmouth, 120 nautical miles north-west of Broome in mid-year, and also on the shelf-break north of Darwin in mid-year. Based on signal-to-noise ratio and typical inter-call spacing from individual animals, it is believed that all of the signal-pairs in Figure 6-25 were from different individuals, indicating that the source must be relatively common in the area. The 'splodge' was common in September in recordings from the Browse Basin logger, then the calling rates tapered off, although some periods of calling were evident into early November (McCauley 2009).

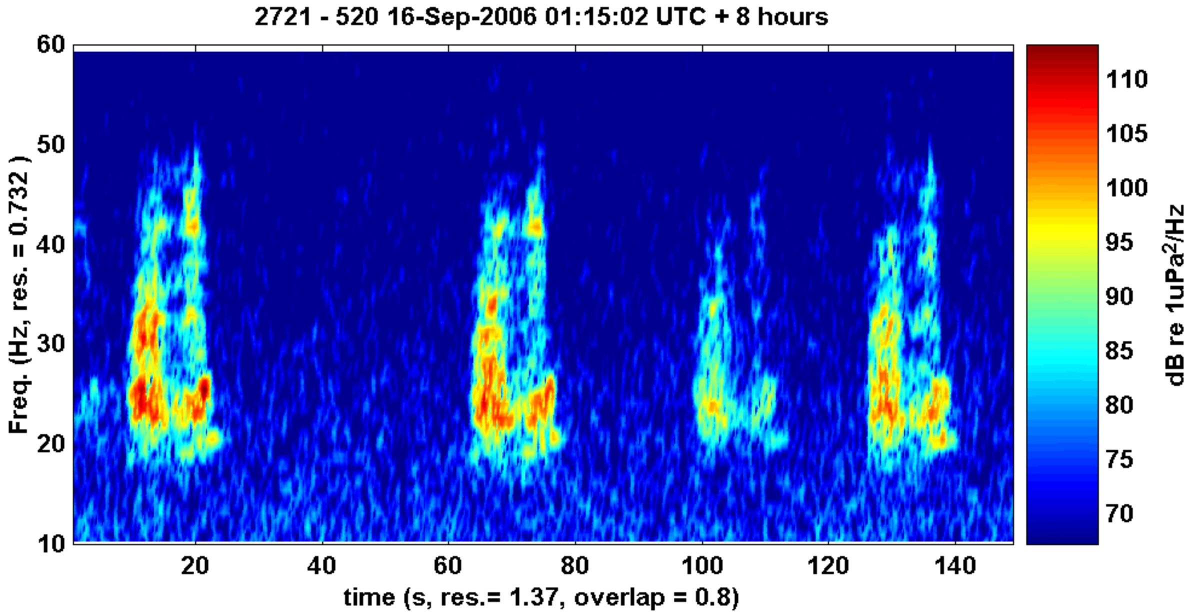


Figure 6-25 Spectrogram of the unknown great whale call referred to as the 'splodge' at the offshore logger on 16 September 2006. Source: RPS (2007b)

A second unknown great whale call was recorded by the offshore logger (Figure 6-26). This signal has not been described or noted previously, so little is known about it. The signals were evident only in one recording between 10 and 14 October, with four sessions of calling over this period, the last three occurring around midday.

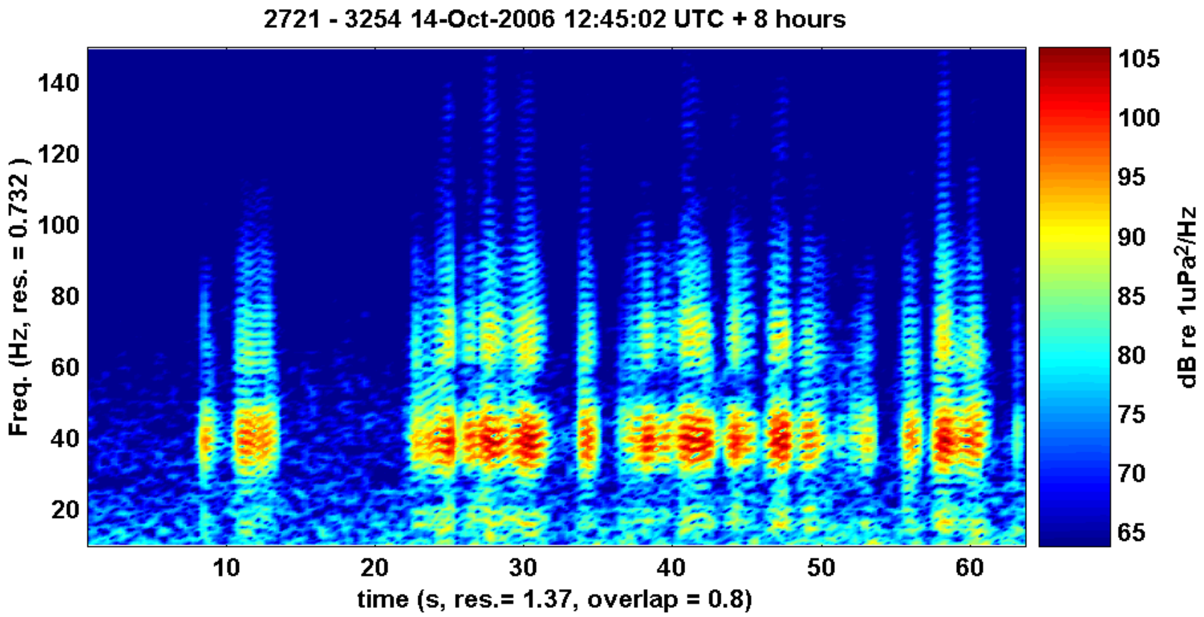


Figure 6-26 Spectrogram of an unknown great whale call at the offshore logger on 14 October 2006. Source: RPS (2007b)

A pulsed signal-type was identified by the offshore logger, which has also been detected along the Australian south coast and as far north as Exmouth, and in southern ocean waters. Several variants were recorded (Figure 6-27) along with some weaker humpback song and an unknown source. The call is consistent with that of the Antarctic sub-species of the minke whale, *Balaenoptera bonaerensis* (McCauley 2009).

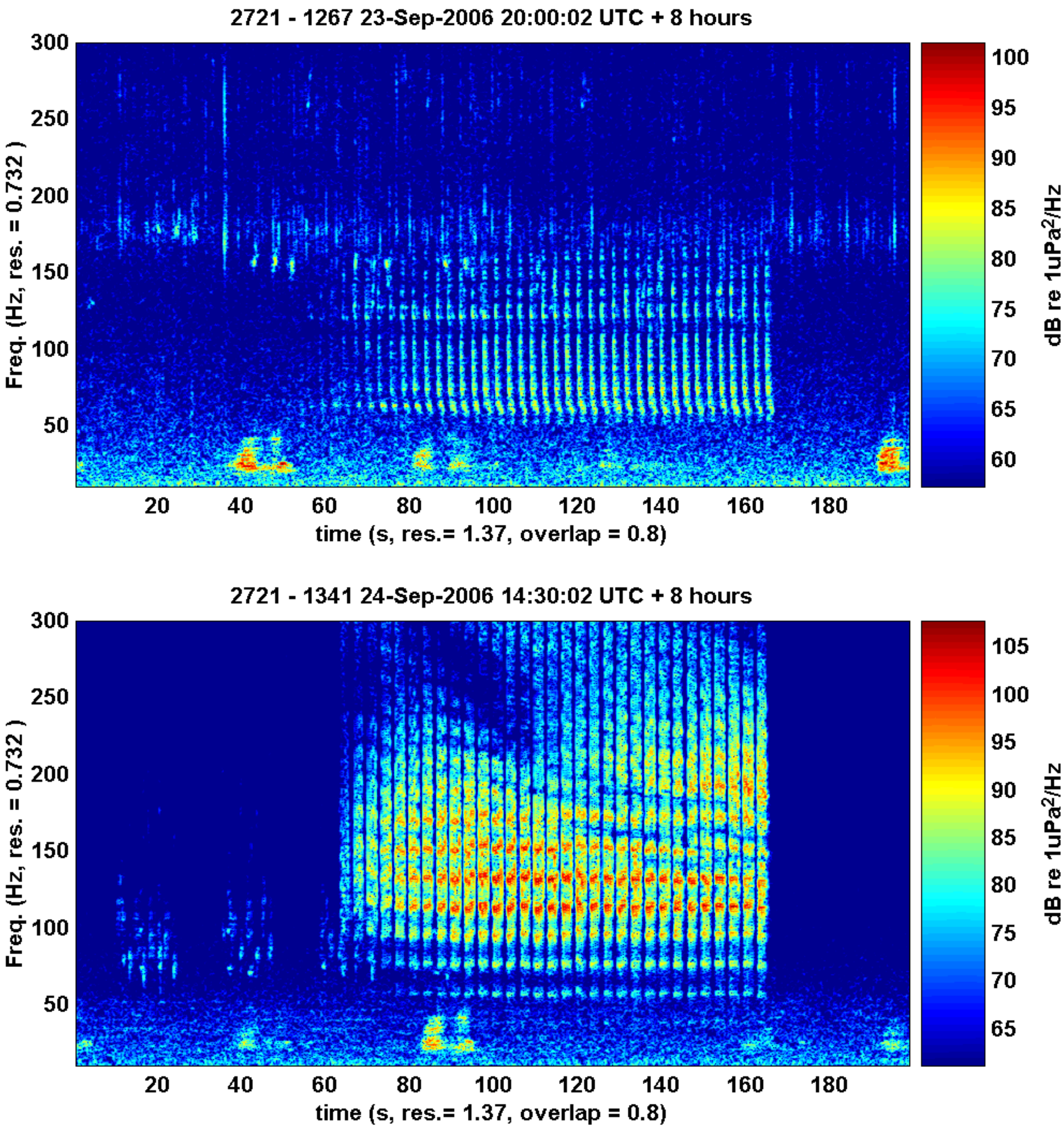


Figure 6-27 Spectrograms of variants of possible Antarctic minke whale signals (60–170 secs each plot) recorded at the offshore logger on 23–24 September 2006. Weaker humpback signals are evident in the background (energy over 50–200Hz) and an unidentified great whale signal is evident over 25–50Hz. Source: McCauley (2009)

6.3.3 2008 vessel survey

Weather conditions during the June–July northern migratory period were generally less favourable for sighting cetaceans or other species than the calmer October–November period. Survey 2 (July 2008) experienced the least favourable weather conditions with strong easterly winds and rain squalls limiting effort. Whales or dolphins sighted too far away for accurate species description or in poor light were classed as unidentified whales and dolphins (CWR 2009).

A total of 27 cetacean sightings of, at minimum, eight species were sighted (total 263 animals) during Survey 1 (Table 6-10). Species sighted included a pygmy blue whale, humpback whales, a diversity of dolphin species (*Stenella* sp., *Tursiops* sp., *Grampus griseus* and *Delphinus* sp.) and some blackfish species (i.e. Pilot whales, false killer whales, pygmy killer whales, etc.).

A total of 32 cetacean sightings of, at minimum, six species were sighted (total 218 animals) during Survey 2 (Table 6-11). Species sighted included humpback whales, a dwarf minke whale and several dolphin species (*Grampus griseus*, *Pseudorca crassidens* and *Delphinus* sp.).

A total of 56 cetacean sightings of, at minimum, eight species were sighted (total 1764 animals) during Survey 3 from 17 October to 5 November 2008 (Table 6-12). Species sighted included pygmy blue whales, humpback whales, a dwarf sperm whale (carcass) and several Delphinid species (*Pseudorca, Lagenodelphis*, *Stenella*, *Tursiops* and *Delphinus* sp.).

A total of 48 cetacean sightings of, at minimum, seven species were sighted (total 1455 animals) during Survey 4 from 11 to 30 November 2008 (Table 6-13). Species sighted included a pygmy blue whale, Brydes whales, and a diversity of delphinid species (*Stenella* sp., *Tursiops* sp., *Grampus* and *Pseudorca*).

Table 6-10 Cetacean sightings during Survey 1 (June 2008)

Common Name	Scientific Name	Number of Sightings	Number of Individuals
Pygmy Blue whale	*Balaenoptera musculus brevicauda*	1	1
Humpback whale	*Megaptera novaeangliae*	2	2
Common bottlenose dolphin	*Delphinus delphis*	1	25
Indo-pacific bottlenose dolphin	*Tursiops aduncus*	1	4
Long-snouted spinner dolphin	*Stenella longirostris*	4	87
Pantropical spotted dolphin	*Stenella attenuata*	1	10
Risso's dolphin	*Grampus griseus*	1	24
Short-finned pilot whale	*Globicephala macrorhynchus*	1	25
Unidentified cetaceans		15	85

Table 6-11 Cetacean sightings during Survey 2 (July 2008)

Common Name	Scientific Name	Number of Sightings	Number of Individuals
Dwarf minke whale	*Balenoptera acutorostrata*	5	218
Humpback whale	*Megaptera novaeangliae*	1	1
Undetermined minke whale	Like *Balenoptera acutorostrata*	1	1
Common bottlenose dolphin	*Delphinus delphis*	2	23
False killer whale	*Pseudorca crassidens*	1	7
Long-beaked common dolphin	*Delphinus capensis*	1	46
Risso's dolphin	*Grampus griseus*	2	16
Unidentified cetaceans		21	120

Table 6-12 Cetacean sightings during Survey 3 (October 2008)

Common Name	Scientific Name	Number of Sightings	Number of Individuals
Blue whale	*Balaenoptera musculus*	2	5
Humpback whale	*Megaptera novaeangliae*	3	5
Dwarf sperm whale	*Kogia sima*	1	1
False killer whale	*Pseudorca crassidens*	2	135
Frasers dolphin	*Lagenodelphis hosei*	1	80
Long-snouted spinner dolphin	*Stenella longirostris*	21	651
Short-beaked common dolphin	*Delphinus delphis*	2	450
Tursiops spp.	*Tursiops spp.*	5	125
Unidentified cetaceans		21	317

Table 6-13 Cetacean sightings during Survey 4 (November 2008)

Common Name	Scientific Name	Number of Sightings	Number of Individuals
Blue whale	*Balaenoptera musculus*	1	1
Bryde's whale	*Balenoptera edeni*	4	4
False killer whale	*Pseudorca crassidens*	3	35
Long-snouted spinner dolphin	*Stenella longirostris*	15	598
Pilot whale spp.	*Globicephala spp.*	4	150
Risso's dolphin	*Globicephala spp.*	1	30
Tursiops spp.	*Tursiops spp.*	7	388
Unidentified cetaceans		18	254

6.4 Discussion

6.4.1 Vessel surveys

Humpback whales

Humpback whales were more abundant in nearshore areas than in offshore areas, although they were recorded occasionally out to the Browse Basin. The peak in the densities of humpback whales in the study area (from Pender Bay to Browse Island) during August is consistent with the peak season reported during the 1995–1997 CWR surveys (RPS 2007b).

Cow/calf pods were dispersed widely and in equal densities throughout the Kimberley during mid-August to early September but, by mid-to-late September, the majority of cow/calf pairs had begun to move south, out of the Kimberley. The highest densities at this time were observed near Pender Bay, where the majority of whales exhibited surface passive behaviour which is indicative of resting areas. Similar patterns were observed in the 1995–1997 studies, and the timing correlates with Chittleborough’s (1965) observations that south-bound cow/calf pods trail the main migratory herd by three to four weeks. Cow/calf pods appear to congregate in the area between Pender Bay and the Lacepede Islands during mid-September, using the area as a staging point and resting place before beginning their southern migration. The congregation of the main migratory herd (separate from the cow/calf pods) appears to peak in number in mid-August, and begins leaving the Kimberley for southern waters shortly after (RPS 2007b).

There is no evidence from this study that the waters of the Browse Basin are critical calving grounds for humpback whales. The current study indicates that the main calving areas for humpback whales in the Kimberley are around Camden Sound and Pender Bay. These results are consistent with previous studies of humpback distribution and calving areas in the Kimberley, and suggest that humpback whale aggregation areas and migratory routes have not altered significantly in the past 10 years. However, the timing of the start of the study in mid-August 2006 could mean that the surveys did not cover the northern-most extent of the humpback whale distribution during the calving period (RPS 2007b).

Two humpback whales were observed feeding in the Browse Basin area in August 2006 and also in 2007. These are the first records of humpback whales feeding in the Kimberley. The observation was made where a +0.5 °C temperature front and very high levels of bird, fish and other wildlife activity were also recorded. This is consistent with observations that oceanographic features such as oceanic frontal and convergence zones typically support significant aggregations of macro zooplankton including krill. Further, the results from the acoustic logger at the Browse Basin site recorded an evening fish chorus similar to one that occurs off the shelf-break of Western Australia, and is also prominent in the Perth Canyon where small fishes of the family Myctophidae have been implicated as its source. The presence of the myctophids has been found to correlate with high levels of productivity and may therefore be an indicator of high local levels of secondary productivity, potentially euphausiids (krill) on which they feed, at the offshore site (RPS 2007b). However, during the 80 days of vessel surveys in the Browse Basin during 2008 there were no signs of either humpback whales or minke whales feeding, as had been observed in previous surveys (CWR 2009).

Blue whales

No true or pygmy blue whales were observed near the Ichthys Field during vessel surveys, however pygmy blue whales were observed near Scott Reef in the Browse Basin in 2008. Prior to these records, pygmy blue whale acoustic signals had been recorded along the west coast from north of the Montebello Islands, south then east across to Bass Strait, and as far south as the Antarctic convergence zone (45 °S to 55 °S).

The known distribution of pygmy blue whales and true blue whales in the Southern Hemisphere indicates that the Western Australian continental slope, from the Perth Canyon (32 °S) towards the Indonesian Archipelago, is a likely migratory path between a feeding area and an undetermined northern calving area. Based on recent noise logger information across the North-West Shelf including the Ichthys Field and Scott Reef in the Browse Basin, pygmy blue whales are believed to utilise an offshore migration path in water depths of around 500 m (McCauley 2009). These water depths occur around 90 km north-west of the Ichthys Field.

It currently appears that pygmy blue whales migrate southwards past Exmouth between October and December each year, with a peak in late November. These whales, and possibly others from the Indian Ocean, appear to then spread out across southern Australian waters to feed on krill patches from summer to early autumn. Between April and May, a proportion of the population appears to migrate northwards along the Western Australian coast, passing Exmouth in June and July. There is evidence that some of these north-bound animals head into northern Indonesia waters (Banda Sea) to over-winter (RPS 2007b).

Blue whales are the most specialised feeders among the rorquals, concentrating almost exclusively on euphausiids (krill). Blue whales are present in the Perth Canyon, on the west coast of Western Australia, between November and July each year. The warm, oligotrophic Leeuwin Current flows southwards over the Perth Canyon, while a cooler, deeper counter-current flows northwards. The interaction of these currents and the canyon’s bathymetry induces an upwelling of colder, nutrient-rich water that reaches no closer to the surface than 200 m. The whales must dive under the Leeuwin Current to depths of 200 to 500 m to feed on the krill, *Euphausia recurva* (RPS 2007b).

Other cetaceans

Minke whales (possibly an Antarctic minke) and dwarf minke whales are known to occur in the region. Minke whales are widely distributed and are generally oceanic. They undertake extensive seasonal migrations between cold-water feeding grounds and warmer-water breeding areas. The Browse Basin may support feeding while the minkes are in the region (RPS 2007b).

Of particular interest from this study was the large numbers of other megafauna species observed, particularly cetaceans. The number of species observed in the Kimberley study area during a 70 day sample period surpasses that recorded in any other region in Western Australia. The most species-rich area was the Browse Basin from mid-August to early September. Very large pods of oceanic dolphins were consistently seen, suggesting that there is a substantial underlying food web in the area (RPS 2007b).

6.4.2 Acoustic loggers

A large diversity of great whale and fish calls were recorded in the Browse Basin over the two years of sampling. At least four great whale signal types have been catalogued, these included signals from pygmy blue whales, humpbacks, possible Antarctic minke and one unknown sources. Fish chorus were common and based on the authors previous experience they suggest that the offshore site is reasonably productive. Fish chorus show clear daily, lunar and possibly seasonal patterns in the recordings. Vessel noise was also dominant at the Browse Basin site over most of the two years of deployment. (McCauley 2009).

Pygmy blue whales

The recording sets from the Ichthys Field noise logger site detected the passage of up to six pygmy blue whales through the area in late October 2006. This was followed by an intense and sustained period of vessel and seismic survey activity in the region and no more pygmy blue whale detections. One could argue that the vessel and seismic survey activity deterred whales from passing through the Browse area or made them vocalize less often. However, recordings available to the author from other north-west Australian acoustic logger sites which were set inshore from the shelf break detected few to no pygmy blue whales. Therefore, it is probable that the Ichthys Field area would normally be only rarely visited by pygmy blue whales. It is expected that the preferred pygmy blue whale migratory corridor would be west of the Ichthys Field along the 500-m depth contour. The 500-m depth contour is around 90 km north-west of logger location at the Ichthys Field, at its closest point. Given that this is just beyond the detection range of blue whales from the Ichthys Field noise logger location, then it is probable that the animals travelling between Indonesia and the north-west shelf keep offshore in mostly > 500 m water depths to strike the shelf near Seringapatam Reef (McCauley 2009).

It has been established that the continental slope (200–500 m depth) in other regions such as the north west shelf are often associated with increased productivity as a result of upwellings, wind shear and other seasonal forcing factors which create favourable feeding grounds for cetaceans. The bathymetry of the Browse Basin may promote localised upwellings of cold water and nutrients, similar to productivity cycles studied in other parts of the world, potentially creating a feeding area for pygmy blue whales. Water quality samples for the area show elevated total nitrogen concentrations that increase with depth (RPS 2007b).

Blue whales appear to feed opportunistically in any area, taking advantage of seasonal or ephemeral krill blooms along their migratory path. However, to forage successfully, blue whales need to find regions with dense aggregations of krill, consuming up to two tonnes of food per day. Prey density appears to be a critical determining factor in baleen whale feeding, with sufficient threshold densities required before the expense of energy on feeding can be compensated for by the nutritional value of the prey (RPS 2007b).

While the results from studies suggest that the Browse Basin area could be a feeding area for blue whales during their migration, it is unknown whether there is reliable seasonal secondary productivity in this area that the whales seek each year, or whether productivity is stochastic, with the cetaceans feeding opportunistically. As a result, the importance of the Browse Basin area as a feeding ground for cetaceans is unknown (RPS 2007b).

The evening fish chorus recorded on the acoustic logger near the Ichthys Field is consistent with the chorus of small fishes of the family Myctophidae recorded at the Perth Canyon. Some species of myctophid fish in the Perth Canyon feed on euphausiids, as do the pygmy blue whales. The seasonal average intensity of the evening fish chorus in the Perth Canyon and the numbers of pygmy blue whales using the Canyon appear to correlate, suggesting that the fish and the blue whales could relate to the same factor, the krill density. The myctophid chorus may act as an acoustic 'beacon' for rich regions of krill aggregation.

It is not known whether the myctophid fishes detected by the offshore loggers in the Browse Basin are indicative of krill biomass in that area, because these fish are not limited to a diet of euphausiids, some species being known to feed on a variety of macro zooplankton. The presence of the myctophid fishes does indicate, however, that the area is potentially high in secondary productivity (zooplankton) and therefore could be an opportunistic feeding area for cetaceans (RPS 2007b). The trend in activity patters of the fish chorus at the Ichthys Field noise logger indicated that secondary productivity was high in late 2006 (when the pygmy blue whale vocalisation recording occurred), however dropped away in early 2007, stayed low until late 2007, then picked up to low levels into 2008 (McCauley 2009) indicating potentially high variability in productivity in the region.

Humpback whales

While analysis of humpbacks at the Ichthys Field logger site was not completed entirely, this data when taken in conjunction with data sets collected along the northern Western Australian coast allows a number of conclusions on the distribution of humpbacks in the Ichthys Field area to be made. Humpbacks arrive around mid July and leave around mid to late September. Previous analysis of humpback seasonality based on passive acoustic data sets, indicates they are very predictable in arrival and departure dates at various latitudes along the Western Australian coast (McCauley 2009).

The 24-hour averaged counts of calling humpbacks at the Ichthys Field logger site reached approximately 1.3 instantaneous callers in mid-August 2007, over the days that were fully counted. This suggests the peak of season at the Ichthys Field site would have been around 5–25 August, with maximum numbers of calling whales at 2–3 when averaged over a 24-hour period. Estimates of the number of whales in the listening area of the logger can be derived, assuming a whale residency time and known proportions of animals calling (8–12 % for humpbacks, from Noad and Cato 2007). While this has not been done here, the estimate for the location most similar, that to the south-east of Scott Reef in 330 m of water, gave an initial approximation of 33 individual humpbacks utilising the area over a season and at the height of a season a median of 16 whales in the logger listening area (McCauley and Salgado Kent, 2008). The similar estimate for the number of animals utilising the area near Seringapatam Reef was five whales. These estimates were considered conservative. Thus at the Ichthys Field site, based on the similarity of the small section analysed to date, it can be expected that perhaps 30 or so humpbacks were present in the general area over a season, which runs from approximately the second week of July to 26 September each year, peaking in mid August (McCauley 2009).

Section 7 Turtles

7.1 Background

Six species of marine turtle occur in northern Western Australia; green turtles, flatback turtles, hawksbill turtles, loggerhead turtles, leatherback turtles and olive ridley turtles. The conservation status of these species is summarised in Table 7-1. All six species are listed in Schedule I (fauna that are rare or likely to become extinct) under the *Wildlife Conservation Act* and are protected under the EPBC Act, as either 'vulnerable migratory marine species' or 'endangered migratory marine species'. Marine turtles are also listed under the Bonn Convention and CITES. The IUCN has assigned 'critically endangered' status to the hawksbill and leatherback turtles and 'endangered' status to green and loggerhead turtles, while flatback turtles are listed as 'data deficient' (RPS 2009a).

Table 7-1 Marine turtles that may be present in the offshore development area, and their conservation status

Common Name	Scientific Name	Conservation Status				
		Federal [a]	State [b]	IUCN [c]	Bonn Convention [d]	CITES [e]
Green turtle	*Chelonia mydas*	L (V)(MM)	S1 [b]	E	I & II	I
Flatback turtle	*Natator depressus*	L (V)(MM)	S1 [b]	DD	II	I
Hawksbill turtle	*Eretmochelys imbricata*	L (V)(MM)	S1 [b]	CE	I & II	I
Loggerhead turtle	*Caretta caretta*	L (E)(MM)	S1 [b]	E	I & II	I
Leatherback turtle	*Dermochelys coriacea*	L (V)(MM)	S1 [b]	CE	I & II	I
Olive ridley turtle	*Lepidochelys olivacea*	L (E)(MM)	S1 [b]	V	II	I

[a] Federal – *Environment Protection and Biodiversity Conservation Act 1999*: E = Endangered, V = Vulnerable, Migratory Marine (MM)
[b] State – *Wildlife Conservation Act 1950:*
S1 = Schedule 1, fauna that is rare or likely to become extinct
[c] International – IUCN Red List of Threatened Species:
CE = Critically Endangered, E = Endangered, V = Vulnerable, DD = Data Deficient
[d] International – Bonn Convention:
I = Appendix I Endangered Migratory Species; II = Appendix II Migratory Species.
[e] International – CITES:
I = Appendix I Species threatened with extinction

Green and flatback turtles are the predominant species that nest on islands of the Kimberley coast. Some evidence of hawksbill turtle nesting has also been documented. Green turtles nesting in the region are part of the North West Shelf Management Unit (NWS MU), which includes the rookeries between North West Cape and the Lacepede Islands. The population of female green turtles in the NWS MU, including the Kimberley region, has been estimated at between 34 500 and 162 500 individuals. The peak nesting season for green turtles on the Maret Islands occurs from December to March, with peak hatchling emergence in March (RPS 2009a).

The peak nesting season for flatback turtles occurs slightly earlier, between November and February, with most hatchling emergences from January to April. This suggests that flatback turtles in the Kimberley region are part of the NWS MU breeding stock, rather than the West Arnhemland Management Unit, which nests during the winter months (June to August). Flatback turtles demonstrate relatively long post-nesting migrations to potential feeding areas in northern waters of Western Australia (RPS 2009a).

Olive ridley turtles are not known to nest in Western Australia and are only known from a few individuals caught by fishermen off the Kimberley-Pilbara coast. Based on their wider distribution and absence from surveyed areas, it is likely that olive ridley nesting in the north-west of Australia is restricted to areas of the northern Kimberley coast such as the Joseph Bonaparte Gulf. They are not considered likely to occur in the Bonaparte Archipelago (RPS 2009a).

Hawksbill, loggerhead and leatherback turtles have been observed in the waters of the Bonaparte Archipelago, but are considered vagrant species (RPS 2009a).

7.2 Recent surveys

7.2.1 Objectives

In order to characterise marine turtle distributions in the offshore development area, RPS collected information through aerial, vessel and beach surveys, coinciding with aggregation and peak nesting periods for green and flatback turtles in the Kimberley region.

Objectives of the research included the following:

- to identify key turtle rookeries in the northwest Kimberley region
- to identify critical habitats (e.g. nearshore aggregations, inter-nesting areas and foraging grounds) in the vicinity of the proposed development
- to determine the hatchling production from nesting beaches in the region, with comparisons between the 2006–07 and 2007–08 nesting seasons
- to determine the migration paths of flatback turtles after nesting at nearshore Kimberley islands (e.g. Maret Islands) (RPS 2009a).

7.2.2 Approach and schedule

In the absence of guidelines for marine reptile surveys, marine turtle surveys were conducted in accordance with a Level 2 Assessment for Terrestrial Fauna under EPA Guidance 56 (Environmental Protection Authority 2004). Desktop surveys involved collating information on previous turtle research in northern Australia and biological information on the turtle species expected to occur in the Kimberley region.

A vessel-based reconnaissance survey during June–July 2006 covered Browse Island, the Maret Islands and other islands of the Bonaparte Archipelago to determine the distribution of potential turtle nesting beaches, based on observations of tracks and body pits. A sampling program was then designed to survey potential nesting beaches in the Kimberley.

Aerial surveys were scheduled around the expected timing of turtle reproductive events as follows:

- mating aggregations of green and flatback turtles from October to January
- peak nesting periods for green and flatback turtles from November to March
- hatchling emergence from December to May (RPS 2009a; RPS 2009b).

7.2.3 Regional nesting activity (aerial surveys)

Given that green turtles are the predominant species in the Kimberley region, an aerial survey of island and mainland beaches was flown at the peak of the green turtle nesting period to gain a ‘snapshot’ of relative nesting densities throughout the region. Potential nesting beaches were identified as sandy beaches longer than 200 m that were visible on satellite imagery. Aerial surveys covered approximately 80% of the sandy beaches between Broome and the Eclipse Islands near Truscott (Figure 7-1) (RPS 2009a).

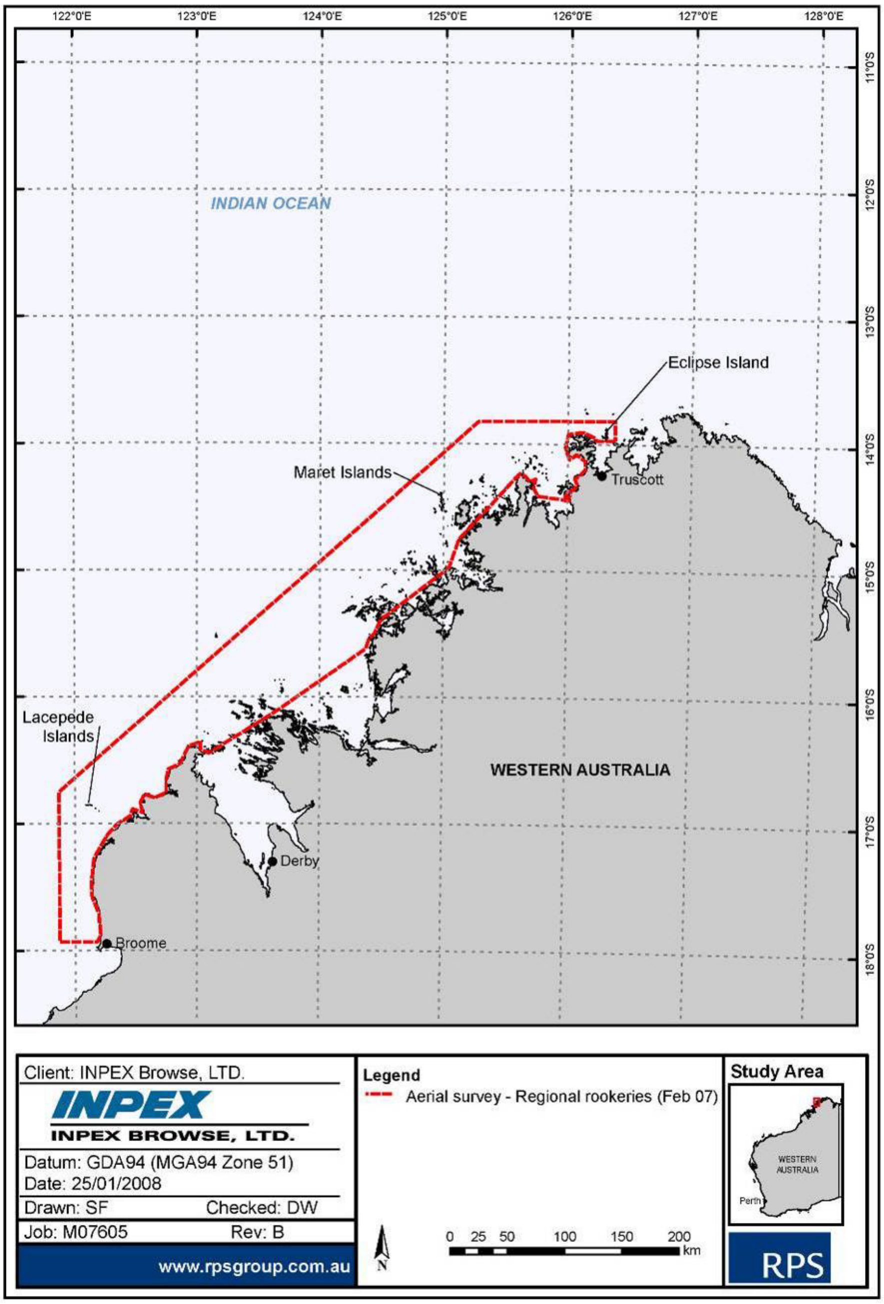


Figure 7-1 Survey area for identifying key rookeries in the Kimberley region

Aerial surveys were flown over three consecutive days (31 January, 1 and 2 February 2007) following an optimal tide (highest tide at sunset). The high tide at sunset cleared all turtle tracks from the previous night. Fresh tracks created after the tide receded were visible between the previous high tide mark and the water line at the time of the survey (Figure 7-2). The morning high tides were lower than the evening high tides which meant that the landward ends of the fresh tracks were not washed away until the following evening (RPS 2009a).

Figure 7-2 Aerial image (video frame grab) of green turtle tracks at South Maret Island, February 2007. Source: RPS (2009)

The methods for recording the tracks were modified from other aerial surveys undertaken in Australia and America. Each flight lasted approximately four hours, commencing at approximately 06:00, to take advantage of the low angle of the sun. At low angles, the sun cast shadows across the tracks and made them more visible from the air. Light winds during the surveys meant there was minimal erosion of the tracks before each survey (RPS 2009a).

A Kawasaki BK117 helicopter was flown at 45° degrees from the high tide mark on the seaward side of the beaches, at an altitude of 80–100 m. The most effective aircraft survey speed was between 60 and 80 knots, depending on the density of turtle tracks and the speed and direction of the wind (RPS 2009a).

Tracks were first identified with the naked-eye and then recorded on a high definition digital video camera for quantitative analysis. GPS coordinates and corresponding times were recorded at the start of each beach transect. Track identification methods were applied to the analysis of still images taken from the video footage (Figure 7-2). Beach lengths were calculated from satellite imagery using GIS software (RPS 2009a).

Data analysis

The number of fresh tracks, length of beach, habitat description and species present were recorded. Densities of fresh tracks were calculated by dividing the total number of fresh tracks/day by the length (km) of the beach (RPS 2009a).

Data collected during the study and population trends in published data were used to estimate the total adult female green turtle population in the Kimberley region during the survey year. The total regional population estimate was extrapolated from the survey data, allowing for a large proportion of the population that does not nest in any given year (RPS 2009a).

7.2.4 Post-nesting migration (satellite telemetry)

The post-nesting migration paths of green and flatback turtles were identified from the satellite tracking data attained from Platform Terminal Transmitters (PTTs). Two different types of transmitters were used; Fastloc PTTs and KiwiSat 101 PTTs. Fastloc PTTs transmit with greater positional accuracy (approximately 16–50 m) than KiwiSat 101 PTTs and are useful for exploring the short-range movements that are expected during inter-nesting. The lower accuracy of KiwiSat 101 PTTs (approximately 150–1000 m) is suitable for large-scale movements that are expected during post-nesting migration (RPS 2009b).

Deployment of the PTTs occurred in four events, as follows:

1) December 2006—6 Fastloc PTTs deployed on green turtles, from South Beach, South Maret Island
2) January 2007—3 Fastloc PTTs deployed on flatback turtles, from South Beach, South Maret Island
3) November–December 2007—4 Fastloc PTTs deployed on flatback turtles, from South Beach and Cormorant Beach, South Maret Island
4) April 2008—15 KiwiSat 101 PTTs deployed on green turtles, from Brunei Beach, North Maret Island, and from Sparrowhawk, Kingfisher and Sandpiper beaches, South Maret Island.

The Maret Islands are located around 35 km west of the Kimberley coast.

Fastloc PTTs

The Fastloc PTTs were configured to operate continuously for the first 90 consecutive days and then switch to a “12-hour on/72-hour off” cycle to lengthen the battery life. The transmitters were capable of relaying a GPS coordinate to satellites within the area every 45 seconds once in range. The location of the turtles could only be determined when the turtle was on land or at the sea surface for long enough for the satellite to lock onto the signal transmitted by the PTT. A saltwater switch was fitted to the PTTs to extend battery life by turning the transmitter off when the turtle was underwater.

Transmitters were attached to the turtles using custom built harnesses (Figure 7-3) based on a design refined by Pendoley (2005). The transmitters were attached to the turtles on the beach while returning to the water. The harnesses become detached from the turtle after approximately one year as the metal crimps around the harness corrode from the exposure to seawater. The size of the turtle, tag number, PTT number, time, date and location of deployment were recorded when each PTT was deployed.

Figure 7-3 PTT unit attached to a flatback turtle, South Maret Island. Source: RPS (2009a)

KiwiSat 101 PTTs

Fifteen KiwiSat 101 PTTs were glued to green turtles nesting on beaches at the North and South Maret Islands. The duty cycle of these transmitters was to operate continuously for the first 60 days and then switch to "12-hours on/48-hours off" for the remainder of the battery life (RPS 2009b).

The transmitters were attached to the second vertebral (central) scute of the turtle's carapace. This area was scraped clean with a paint-scraper, scrubbed with steel wool, sanded, scored and then cleaned with acetone before the PTT was attached. The fixative used was a two-part epoxy resin. The resin was carefully fared into a hydrodynamic shape in fitting with general contours of the carapace to help reduce drag. Longlife Antifouling Blue (International Paint, Queensland) was used to ensure the area was not fouled. Turtles were contained in a wooden pen for no longer than 3.5 hours to allow for the glue set. The size of the turtle, tag number, PTT number, time, date and location of deployment were recorded when each PTT was deployed (RPS 2009b).

Data analysis

The location fixes for the tracked turtles were downloaded from the transmitters via the ARGOS satellite system. Fastloc PTTs were analysed using Fastloc processing software provided by Sirtrack Wildlife Tracking Solutions, while Kiwisat 101 PTTs were analysed using the STAT program of www.seaturtle.org.

The error in Fastloc PTT location estimates is typically less than 50 m. Fixes on turtle locations are most effective when five or more satellites can be detected, with eight satellites providing the most accurate position (RPS 2009b).

KiwiSat 101 PTTs are generally less accurate than Fastloc PTTs, but provide fixes that are adequate for determining the distribution of migrating turtles. The three most accurate location classes (1–3) were used to represent the data. The satellite fixes falling within these classes are less than 1 km. Datum points were disregarded if they implied biologically unrealistic speeds or distance travelled (e.g. >5 km/h). Maps were drawn using the mapping tool available in the STAT program of www.seaturtle.org (RPS 2009b).

Post-nesting migration was taken to commence on the day the turtle departed the nesting area after her final nesting event, and continued until the transmitter no longer provided data, or until she reached foraging grounds. Arrival at foraging grounds was identified when the turtle remained in the same general area for an extended period (approximately >30 days) (RPS 2009b).

7.3 Results

7.3.1 Regional nesting activity

Observations of body pits and fresh tracks during the reconnaissance survey in July 2006 indicated that Browse Island, the Maret Islands, the Montalivet Islands and Lamarck Island supported viable nesting habitat. Beach surveys in July 2006 indicated that green turtles were the predominant nesting species on Browse Island with evidence of low density mid-year nesting and hatching around the entire island (RPS 2009a).

Aerial surveys over the entire west Kimberley region revealed widespread nesting, with a few key rookeries. Approximately 1157 fresh tracks were counted on beaches surveyed by aircraft over three consecutive days in January–February 2007. The main rookeries identified in the region were on the Lacepede Islands, the Maret Islands and Cassini Island (Table 7-2) (RPS 2009a).

Table 7-2 Number of tracks recorded in aerial surveys conducted in January–February 2007. Source: RPS (2009a)

Site	No. of tracks	Percentage of tracks (%)
Lacepede Islands	723	62
Maret Islands	198	17
Berthier-Albert Islands	45	4
Montalivet Islands	38	3
Cassini Island	70	6
Other beaches	83	7
Total	**1157**	**100**

Patterns of nesting density were observed in relation to distance from the mainland coast. The outer islands of the Kimberley coast, including the Lacepede and Maret Islands, had the greatest track densities (>100 tracks), followed by offshore islands surrounding the Maret Islands including Albert, Montalivet and Cassini islands (10–100 tracks), and lower track densities (<10 tracks) were recorded at nearshore islands and mainland beaches (Figure 7-4). Most mainland beaches were identified as unsuitable nesting habitats (e.g. rocky outcrops, unstable dune systems, muddy substrates and narrow beaches that are inundated during spring tides). Some tracks could be identified from the aerial imagery and the majority of these were green turtle tracks (RPS 2009a).

Estimates of the total available nesting habitat in the Kimberley region, based on satellite imagery and the average track densities of turtles in the region were used to estimate the nesting effort for the whole region from Eclipse Island to Broome. A regional estimate 1446 tracks was calculated for the expected peak of nesting. This count was used to estimate nesting effort for the whole region (RPS 2009a).

Given that only 5–15 % of turtles in the area are likely to nest on a given day, the total number of individuals nesting during the peak of the season was approximately 3810 to 11,420. If 70–80 % of the population nest during the seasonal peak, then the regional population of female turtles that nested during the entire 2006–07 season was approximately 4760–16,310 individuals. If we assume that 87% of the tracks counted are green turtles and the remainder are flatback turtles, the regional female populations are 4140–14,190 for green turtles and 620–2120 for flatback turtles (RPS 2009a).

The total regional populations, including all turtles in post-nesting phase, can be estimated using average re-migration intervals of five years for green turtles and three years for flatback turtles. Assuming that the 2006–07 season was an ‘average’ year in terms of nesting activity, the total regional population would be 20 700–70 950 female green turtles and 1860–6360 female flatback turtles (RPS 2009a).

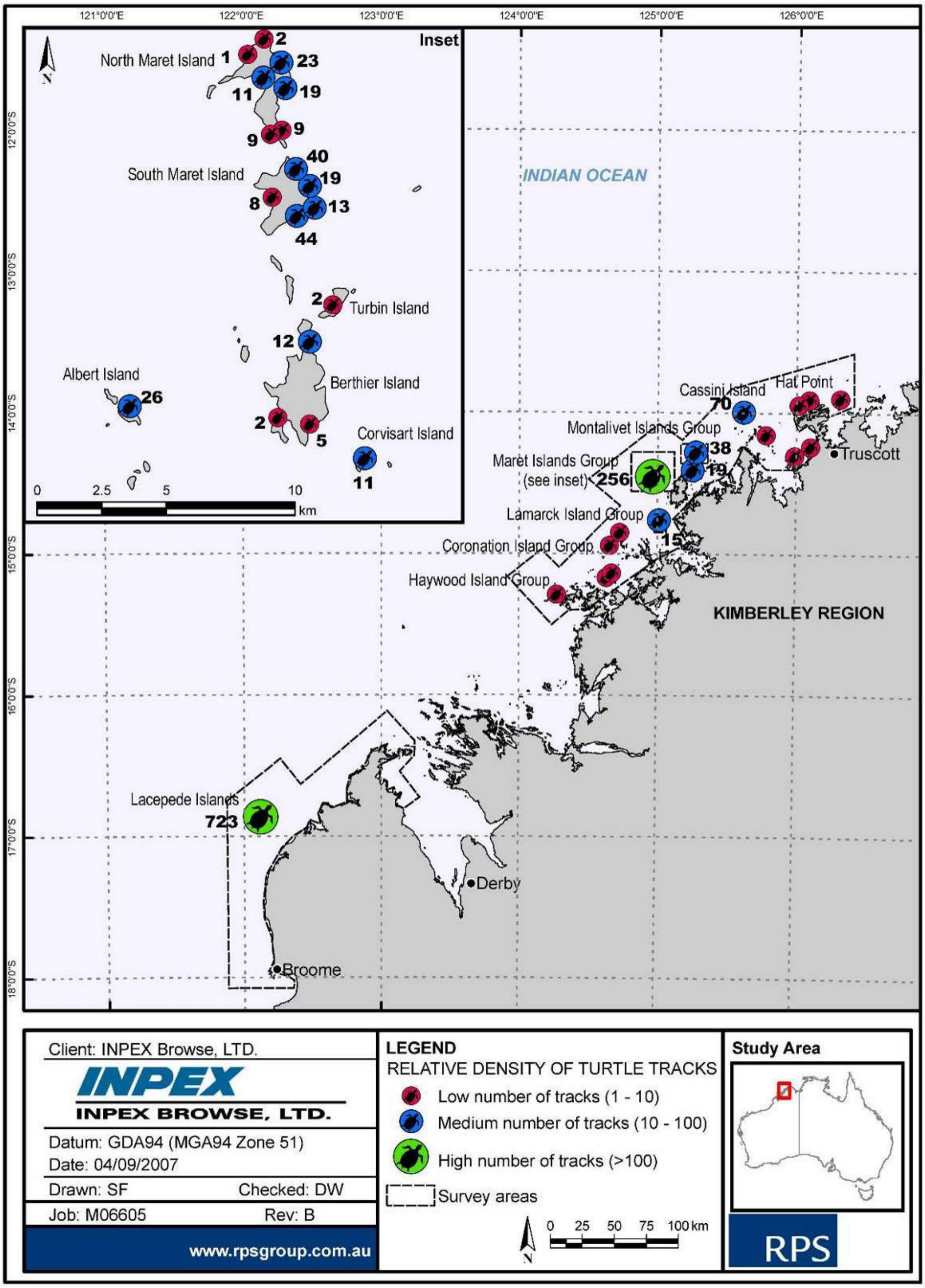


Figure 7-4 Distribution and abundance of turtle tracks from aerial surveys of the Kimberley region. Source: RPS (2009)

7.3.2 Post nesting migration

The results provided in this section are a combination of those presented by RPS (2009b) and additional tracking data obtained subsequently from a Satellite Tracking and Analysis Tool (from www.seaturtle.org).

Turtles tagged during the satellite tracking program are described in Table 7-3. All turtles were female, and are identified by numbers on their tags. While some of the PTTs returned data only for short periods (indicated by a small number of "days at large" in Table 7-3), others remained attached to the turtles and functioning for many months (e.g. for turtles 72674, 79716 and 79722, with 427, 331 and 418 days respectively).

Green turtles

The six turtles tracked from December (deployment 1) remained close to the Maret Islands—probably indicative of the inter-nesting period, rather than post-nesting migration. Of the 15 PTTs attached to green turtles in April (deployment 4), ten travelled in a north-eastern direction and five travelled in a south-western direction. The majority of green turtles that headed north were still migrating at the time of last transmission, while those that travelled south after leaving the Maret Islands appear to have reached foraging destinations (RPS 2009b). Migration movements generally commenced in July, while some individuals started migrating as late as August or September (Table 7-3).

Of the north-migrating green turtles, five were last recorded in Western Australia, four were recorded in the Northern Territory and one was in north-west Queensland. Four of the turtles still in Western Australia (72707, 79714 and 72717) were in the vicinity of Long Reef/East Holothuria Reef. Turtles 79709 and 79719 travelled along the mainland coast approximately 150 km north-east of the Maret Islands (RPS 2009).

The green turtles recorded in the Northern Territory were tracked until reaching the Tiwi Islands (Melville and Bathurst islands) (Figure 7-5, Figure 7-6). Turtle 79713 travelled across the Joseph Bonaparte Gulf to the Tiwi Islands, then followed the Northern Territory coastline from Cobourg Peninsula to Truant Island. She then travelled across the Gulf of Carpentaria and was last recorded heading for Cape York Peninsula (Figure 7-6). At final transmission she had covered a total distance of 2188 km in 73 days, an average of 30 km per day (RPS 2009b).

Of the turtles that migrated south, 79718 was last recorded in waters adjacent to Eighty Mile Beach, and 79710 and 79711 were last recorded at Roebuck Bay near Broome, which is used extensively by commercial and recreational vessels. 72708 followed the outer coastal islands for about 10 days until she reached the Cockell Reefs, south of Camden Sound. 72706 also followed the outer coastal islands until she reached the Champagny Islands. She then headed west until she reached Adele Island after about 10 days (RPS 2009b).

Table 7-3 Turtles tagged in satellite tracking program

Deployment	Tag No.	Turtle species	Deployment location	Deployment date	Date of last logging	Days at large	Description of movements
1	72673	Green	South Beach, South Maret Is	15/12/2006	16/03/2007	91	Remained around the Maret Islands, probably in inter-nesting period
1	72674	Green	South Beach, South Maret Is	14/12/2006	14/02/2008	427	Remained around Maret Islands for full tracking period.
1	72677	Green	South Beach, South Maret Is	16/12/2006	4/03/2007	78	Remained around the Maret Islands, probably in inter-nesting period
1	72678	Green	South Beach, South Maret Is	17/12/2006	23/02/2007	68	Remained around the Maret Islands, probably in inter-nesting period
1	72679	Green	South Beach, South Maret Is	17/12/2006	24/04/2007	128	Remained around the Maret Islands, probably in inter-nesting period
1	72680	Green	South Beach, South Maret Is	17/12/2006	18/02/2007	63	Remained around the Maret Islands, probably in inter-nesting period
2	72676	Flatback	South Beach, South Maret Is	11/01/2007	23/06/2007	163	Travelled north away from coastal waters, spending most time in waters of 50-100 m depth. Travelled up to 270 km from origin, from Day 10 onwards (late Jan-early June).
2	72681	Flatback	South Beach, South Maret Is	13/01/2007	30/08/2007	229	Travelled north away from coastal waters, moving around in waters 50-100m depth. Also moved towards Long Reef. Total distance and timing data not available.
2	72682	Flatback	South Beach, South Maret Is	13/01/2007	12/08/2007	211	Travelled north in coastal and deeper nearshore waters (50-100m depth), reaching up to 220 km from origin. Travel mainly between Day 15 and Day 100 (January-April).
3	72675	Flatback	South Beach, South Maret Is	15/11/2007	21/11/2007	6	Travelled towards Kimberley coastal waters. Tracked for 6 days only.
3	79720	Flatback	Cormorant Beach, South Maret Is	12/12/2007	15/12/2007	3	Travelled west from Maret Islands towards offshore waters. Tracked for 3 days only.

Deployment	Tag No.	Turtle species	Deployment location	Deployment date	Date of last logging	Days at large	Description of movements
3	79721	Flatback	South Beach, South Maret Is	9/12/2007	30/04/2008	143	Travelled south-west along coastal waters for around 600 km. Travel carried out mainly within the first 30 days (December-early January), with little movement afterwards.
3	79722	Flatback	South Beach, South Maret Is	9/12/2007	30/01/2009	418	Travelled north away from coastal waters, spending time in 50-100 m water depth. Began moving straight after deployment, reaching up to 350 km from origin.
4	79705	Green	Brunei Beach, North Maret Is	31/03/2008	19/11/2008	233	Travelled north-east across Bonaparte Gulf to reach western coast of Tiwi Islands (approx 850 km). Travelled between Day 40 and Day 70 (mid May-early June).
4	79706	Green	Brunei Beach, North Maret Is	1/04/2008	15/06/2008	75	Travelled through coastal Kimberley waters and out to nearshore islands, heading south-west for approx 300 km. Travelled mainly between Day 90 and Day 100 (early July).
4	79707	Green	Brunei Beach, North Maret Is	3/04/2008	28/10/2008	208	Travelled through coastal Kimberley waters, heading north-east towards Long Reef. Travelled mainly between Day 90 and Day 135 (July-early August).
4	79708	Green	Brunei Beach, North Maret Is	4/04/2008	11/09/2008	160	Travelled through coastal Kimberley waters heading south-west for around 180 km. Travelled between Day 95 and Day 105 (July).
4	79709	Green	Brunei Beach, North Maret Is	5/04/2008	13/09/2008	161	Travelled north-east in coastal Kimberley waters for approx 200 km. Travel mainly between Day 95 and Day 110 (July).
4	79710	Green	Brunei Beach, North Maret Is	6/04/2008	13/07/2008	98	Travelled south-west through coastal waters for approx 600 km, between Day 100 and Day 150 (late July-August).
4	79711	Green	Brunei Beach, North Maret Is	6/04/2008	3/12/2008	241	Travelled south-west through coastal waters for approx 650 km, between Day 95 and Day 110 (July).
4	79712	Green	Brunei Beach, North Maret Is	6/04/2008	2/12/2008	240	Travelled north-east through coastal waters, then across the Bonaparte Gulf to the east coast of the Tiwi Islands, approx 800 km. Moving from Day 95 (early July) but main migration across the gulf occurred between Day 150 and Day 180

Deployment	Tag No.	Turtle species	Deployment location	Deployment date	Date of last logging	Days at large	Description of movements
							(September).
4	79713	Green	Sparrowhawk Beach, South Maret Is	5/04/2008	24/07/2008	110	Travelled north-east to Cape York, via coastal Kimberley waters, across Bonaparte Gulf, via Tiwi Is and coastal Northern Territory waters, and across the Gulf of Carpentaria. Migrated from Day 95 to Day 160 (early July-mid Sept), over approx 1900 km.
4	79714	Green	Kingfisher Beach, South Maret Is	6/04/2008	12/08/2008	128	Travelled north-east in coastal waters towards Long Reef/East Holothuria Reef. Travelled approx 250 km, from Day 110 to Day 120 (July).
4	79715	Green	Brunei Beach, North Maret Is	7/04/2008	24/09/2008	170	Travelled north-east to east coast of the Tiwi Islands, approx 800 km. Travelled from Day 140 to Day 160 (late August-early Sept).
4	79716	Green	Sandpiper Beach, South Maret Is	8/04/2008	5/03/2009	331	Travelled north-east to the southern coast of Tiwi Islands. Travelled approx 750 km, between Day 150 and Day 170 (September).
4	79717	Green	Sparrowhawk Beach, South Maret Is	7/04/2008	12/09/2008	158	Travelled north-east towards Long Reef, approx 150 km, between Day 150 and Day 160 (September)
4	79718	Green	Sparrowhawk Beach, South Maret Is	9/04/2008	5/10/2008	179	Travelled south-west through coastal waters for approx 700 km, between Day 100 and Day 130 (July).
4	79719	Green	Sandpiper Beach, South Maret Is	10/04/2008	30/01/2009	295	Travelled north-east through coastal waters for around 150 km, between Day 120 and Day 130 (August).

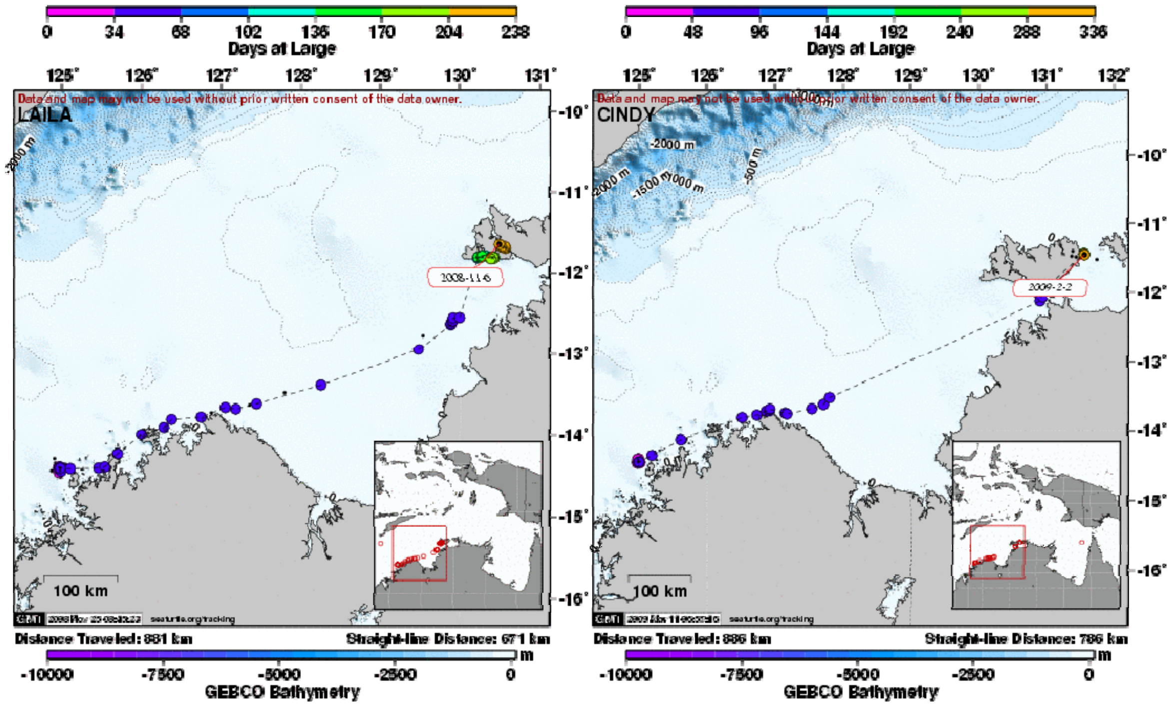


Figure 7-5 Post-nesting migration of green turtles 79705 (left) and 79716 (right). Source: RPS (2009b)

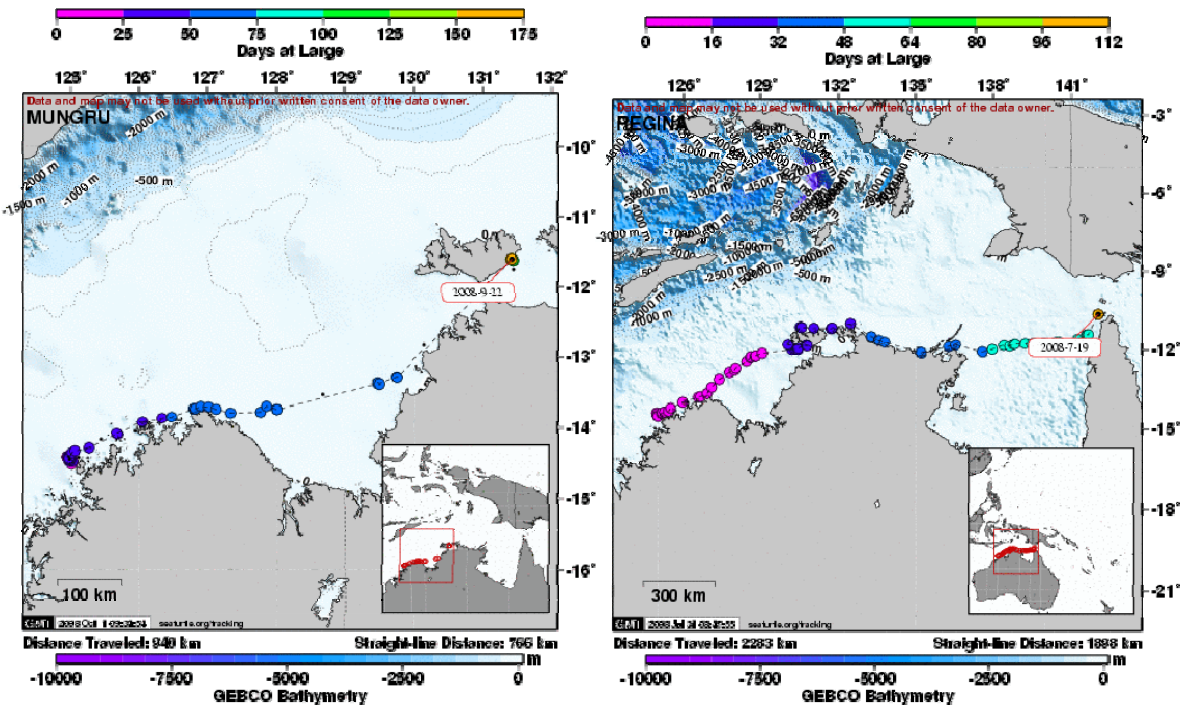


Figure 7-6 Post-nesting migration of green turtles 79715 (left) and 79713 (right). Source: RPS (2009b)

Flatback turtles

Of the seven PTTs attached to flatback turtles, two failed to provide data for longer than a few days (Table 7-3). Four of the turtles left the Maret Islands soon after tagging (December–January) and travelled north to an open ocean area, in water depths of 50–100 m (see Figure 7-7).

Turtle 72721 followed the coastline 697 km south-west from the Maret Islands until she reached Casuarina Reef off Cape Rossut, near Bidyadanga, after about 65 days. She remained at Casuarina Reef until her last transmission in late April (RPS 2009b).

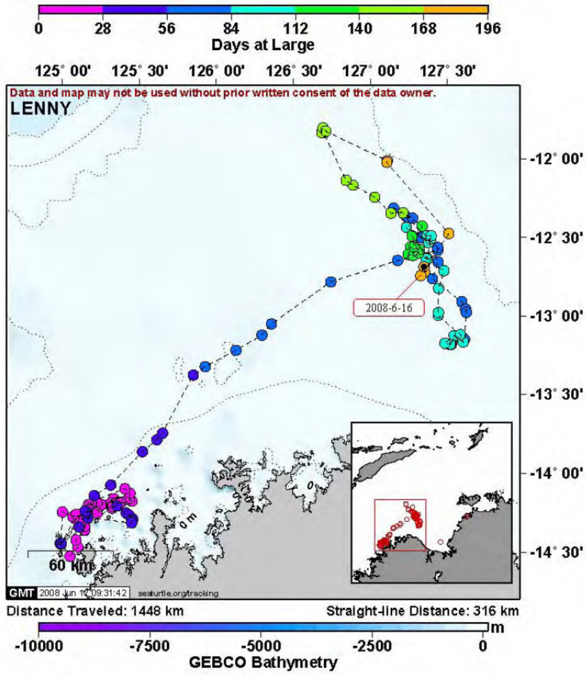


Figure 7-7 Post-nesting migration of flatback turtle 79722. Source: RPS (2009b)

7.4 Discussion

7.4.1 Regional nesting activity

The reconnaissance survey of Browse Island, North and South Maret Islands, Lamarck Island, Albert Island, Berthier Island, East and West Montalivet Islands, Prudhoe Islands and Bigge Island indicated widespread turtle nesting. The subsequent regional aerial surveys indicated that nesting densities of marine turtles were highest on offshore islands such as the Maret Islands, Cassini Island and the Lacepede Islands, and were low or absent from nearshore island and mainland beaches (RPS 2009a).

The beaches of the Lacepede Islands, in the southern Kimberley region, supported the highest level of turtle nesting activity (~1000 beach emergences per night) in the region. Other studies have identified the Lacepede Islands as one of the major green turtle rookeries in Western Australia, along with the Muiron Islands, Serrurier (Long) Island, the Montebello Islands, Barrow Island, the Dampier Archipelago and sandy mainland beaches of the Ningaloo Marine Park. The highest track densities recorded during the current study in the west Kimberley region, were on the beaches of the Maret Islands and surrounding islands (~200 emergences per night). Lesser Kimberley rookeries include Browse Island, Cassini Island, Scott Reef (Sandy Island), Cartier Islet and the islands at Ashmore Reef (Prince 1994) (RPS 2009).

7.4.2 Post-nesting migration

All of the turtles that were tracked from the Maret Islands remained close the northern Australian coastline during their post-nesting migration. It is possible that the turtles were feeding while migrating and using underwater features along the coastline to aid navigation (RPS 2009b).

Green turtles

The tracking data for green turtles show north and south migrations from the Maret Islands. Tagging studies conducted in Western Australia indicate that green turtles migrate to the Gulf of Carpentaria, which is recognised as an important foraging area. Genetic studies conducted by RPS at the Maret Islands in 2006–07 confirmed this by showing genetic linkages with the Gulf of Carpentaria Management Unit. The tracking data in this study also confirms the importance of the Gulf of Carpentaria as a foraging area for turtles in northern Western Australia, as one turtle travelled from the Maret Islands to Cape York with three other turtles following a similar path (RPS 2009b).

According to Limpus (2004), up to 80% of green turtles from eastern Australia migrate to feeding grounds in Indonesia. Green turtles are harvested by Indonesian fishers in the Cartier-Ashmore Island Group and broader South-East Asia. Indonesian harvest of green turtles nesting in Australia could explain why green turtles from the Maret Islands and Ashmore Reef are smaller than those found in other parts of Australia. However, the migration paths of female green turtles nesting at the Maret Islands show no migrations to Indonesia, suggesting that these turtles are not influenced by harvesting (RPS 2009b).

Although green turtles are known to undertake long-distance migrations from nesting areas to feeding areas, some turtles are likely to colonise feeding areas near their rookery and only make short nesting migrations. From the satellite tracking data, Long Reef was identified as being a nearby foraging area for green and flatback turtles nesting in the Kimberley region (RPS 2009b).

Flatback turtles

Flatback turtles nesting at the Maret Islands undertook long-distance post-nesting migrations in 2006–07 and 2007–08, and some appeared to reach their feeding grounds. 72721 travelled to Casuarina Reef off Cape Rossut, near Bidyadanga, which has also been identified as a post-nesting destination for green turtles nesting at Barrow Island. In contrast, others travelled to an open ocean area at depths ranging between 50–100 m near a shoal in northern Joseph Bonaparte Gulf (RPS 2009b).

The extensive migration of flatback turtles along the northern Australian coast supports the hypothesis that there may be some genetic exchange between the Bonaparte Management Unit and the NWS MU. Further genetic analysis is needed to understand the strength of the genetic relationship between these management units (RPS 2009b).

7.4.3 Limitations of the study

The local life-history parameters and population estimates presented here are based on two breeding seasons. While these are useful preliminary metrics that gauge the importance of the Bonaparte Archipelago turtle rookeries, they must be treated with caution. Turtle nesting populations are known in many instances to exhibit large scale inter-annual variations (Limpus and Nicholls 1988; Broderick, Godley & Hays 2001; Limpus et al. 2003). There are many factors that are believed to influence this, such as the Southern Oscillation Index (Limpus and Nicholls 1988; Limpus et al. 2003). However the nature of the influence and how these different factors may interact is unclear and consequently our understanding of inter-annual variations is limited (RPS 2009b).

8.1 Background

8.1.1 Protected species

There are a number of marine species (apart from cetaceans and turtles) that may be present in or near the offshore development area and are protected by state and federal legislation or international agreements (Table 8-1), according to the EPBC Act Protected Matters Database and field observations (e.g. RPS 2007b, CWR 2009, McCauley 2009). These include dugongs and some species of marine snakes, sharks, rays and seabirds, and for the purposes of this discussion will be collectively referred to as “megafauna”. The distribution and ecology of these marine animals, particularly in relation to the offshore development area, are described below:

Dugongs

Dugongs (*Dugong dugon*) are the only living species in the Family Dugongidae, and are the only members of the Order Sirenia found in the Indian and Pacific Oceans, where they are distributed throughout coastal areas between the latitudes of approximately 27 ºN and 26 ºS. Dugongs generally inhabit shallow protected bays, mangrove channels and the lee sides of large inshore islands where seagrass grows. They may also be found further offshore in areas where the continental shelf is wide, shallow and protected. Dugongs appear to calve in shallow waters such as tidal sandbanks and estuaries, possibly to avoid predation by sharks (RPS 2007b).

Dugongs are herbivorous with a strong preference for seagrasses of the genera *Halophila* and *Halodule*, and have been known to forage selectively for *Halodule* rhizomes. However they will also eat algae having been observed foraging in areas where seagrass is limited and algae are abundant (RPS 2007b).

Important dugong aggregation areas in Western Australia include the Shark Bay and Exmouth Gulf regions. In 1994, it was estimated that there were 10 529 dugongs in the Shark Bay area and 1006 in Ningaloo Marine Park and Exmouth Gulf. In July 1999, the population at Shark Bay had increased to 13 929, and the population at Ningaloo/Exmouth had declined to 337. It has been suggested that the Exmouth dugongs migrated to Shark Bay following the destruction of seagrass beds in Exmouth Gulf by cyclone Vance in March 1999. The size of the Kimberley population of dugongs is unknown (RPS 2007b).

Dugongs are threatened by indigenous harvest, entanglement in fishing nets, and habitat degradation (RPS 2007b).

Other Marine Megafauna

Table 8-1 Protected marine megafauna (and their conservation status) that may be present in the offshore development area. Source: RPS (2007b) adapted

Common name	Scientific name	Conservation Status				
		Federal [a]	State [b, c]	IUCN [d]	Bonn Convention [e]	CITES [f]
Sirenians						
Dugong	*Dugong dugon*	MM	S4[b]	V	II	I
Reptiles						
Estuarine crocodile, saltwater crocodile	*Crocodylus porosus*	M	S4[b]	LR(LC)	II	II
Horned sea snake	*Acalyptophis peronii*	M				
Short-nosed sea snake	*Aipysurus apraefrontalis*	M				
Dubois' sea snake	*Aipysurus duboisii*	M				
Eydoux's sea snake, spine-tailed sea snake	*Aipysurus eydouxii*	M				
Leaf-scaled sea snake	*Aipysurus foliosquama*	M				
Dusky sea snake	*Aipysurus fuscus*	M				
Golden sea snake, olive sea snake	*Aipysurus laevis*	M				
Mjoberg's sea snake, brown-lined sea snake	*Aipysurus tenuis*	M				
Stokes' sea snake	*Astrotia stokesii/ Disteira stokesii*	M				
Spectacled sea snake	*Disteira kingii*	M				
Olive-headed sea snake	*Disteira major*	M				
Turtle-headed sea snake	*Emydocephalus annulatus*	M				
Beaked sea snake	*Emydocephalus schistosa*	M				
North-western mangrove sea snake, southern mud snake	*Ephalophis greyi or greyae*	M				
Black-ringed mud/sea snake	*Hydrelaps darwiniensis*	M				
Black-headed sea snake	*Hydrophis atriceps*	M				
Slender-necked sea snake	*Hydrophis coggeri*	M				
Fine-spined sea snake, geometrical sea snake	*Hydrophis czeblukovi or geometricus*	M				

Common name	Scientific name	Conservation Status				
		Federal [a]	State [b, c]	IUCN [d]	Bonn Convention [e]	CITES [f]
Elegant sea snake, bar-bellied sea snake	*Hydrophis elegans*	M				
Plain sea snake	*Hydrophis inornatus*	M				
Small-headed sea snake, McDowell's sea snake	*Hydrophis macdowelli/ mcdowelli*	M				
Spotted sea snake	*Hydrophis ornatus or ocellatus*	M				
Large-headed sea snake	*Hydrophis pacificus*	M				
Spine-bellied sea snake	*Lapemis curtus/ Lapemis hardwickii*	M				
Northern Mangrove sea snake	*Parahydrophis mertoni*	M				
Yellow-bellied sea snake	*Pelamis platurus or platura*	M				
Sharks and Rays						
Narrow sawfish	*Anoxypristis cuspidata*		P2[c]	CE		
Grey nurse shark (west coast population)	*Carcharias taurus*	V	S1 [b]	V		
Pondicherry shark	*Carcharhinus hemiodon*		P1[c]	CE		
Oceanic whitetip shark	*Carcharhinus longimanus*		P1[c]	VU		
Great white shark	*Carcharodon carcharias*	V	S1[b], P2[c]	V	I & II	II
Gulper shark	*Centrophorus granulosus*		P1[c]	V		
Fossil shark	*Hemipristis elongatus*		P1[c]	V		
Longfin mako	*Isurus paucus*		P1[c]	V		
Tawny nurse shark	*Nebrius ferrugineus*		P1[c]	V		
Lemon shark	*Negaprion acutidens*		P1[c]	V		
Dwarf sawfish	*Pristis clavata*		P2[c]	CE		
Freshwater sawfish	*Pristis microdon*	V	P2[c]	CE		
Green sawfish	*Pristis zijsron*		S1[b], P2[c]			
Bowmouth guitarfish	*Rhina ancylostoma*		P1[c]	V		

Common name	Scientific name	Conservation Status				
		Federal [a]	State [b, c]	IUCN [d]	Bonn Convention [e]	CITES [f]
Whale shark	*Rhincodon typus*	V	P2[c]	V	II	II
Common shovelnose ray	*Rhinobatos typus*		P1[c]	V		
White-spotted guitarfish	*Rhynchobatus australiae*		P1[c]	V		
Zebra shark, leopard shark	*Stegostoma fasciatum*		P1[c]	V		
Seabirds						
Streaked shearwater	*Calonectris leucomelas/ Puffinus leucomelas*	MM				
Fork-tailed swift	*Apus pacificus*	MM				
Great egret, white egret	*Ardea alba*	MM			II	
Cattle egret	*Ardea ibis*	MM				
Little tern	*Sterna albifrons*	MM			II	

[a] Federal – *Environment Protection and Biodiversity Conservation Act* 1999:
V = Vulnerable, M = Marine (M), MM = Marine Migratory (MM)
[b] State – *Wildlife Conservation Act* 1950:
S1 = Schedule 1, fauna that is rare or likely to become extinct
S2 = Schedule 2, fauna presumed to be extinct,
S4 = Schedule 4, other specially protected fauna
[c] State – *Fish Resources Management Act* 1994
Listed in Fish Resources Management Regulations, 1995, Schedule 2:
P1 = Part 1, commercially protected fish
P2 = Part 2, totally protected fish

[d] International – IUCN Red List of Threatened Species:
CE = Critically Endangered, E = Endangered, V = Vulnerable, LR = Lower Risk, DD = Data Deficient
Conservation Dependent (CD), Near Threatened (NT), Least Concern (LC).
[e] International – Bonn Convention:
I = Appendix I, Endangered Migratory Species,
II = Appendix II, Migratory Species.
[f] International – CITES:
I = Appendix I, species threatened with extinction
II = Appendix II, includes species not necessarily threatened with extinction, but in which trade must be controlled to avoid utilisation incompatible with their survival
III = Appendix III, includes all species which any Party identifies as being subject to regulation within its jurisdiction for the purpose of preventing or restricting exploitation, and as needing the cooperation of other Parties in the control of trade.

Marine snakes

Australia has the world's highest sea snake species richness and endemism. Sea snakes (Family Hydrophiidae) and sea kraits (Family Laticaudidae) are protected in Australia. All but five of Australia's sea snake species may be found in the Kimberley, and several species are likely to be present in the offshore development area (Table 8-1) (RPS 2007b).

Sea snake ecology is poorly understood for most species. Sea snakes occur only in the tropical and subtropical waters of the Indian and Pacific Oceans, usually on the continental shelves, and have been recorded at depths to approximately 55 m. Most species feed on fish (including eels) or fish eggs, and they may be found over sandy bottoms and/or coral reefs, in gulfs, harbours or further offshore (RPS 2007b).

Sharks and rays

Numerous shark and ray species have distributions that overlap with the offshore development area, although it is unlikely that large numbers of any of Australia's threatened shark species will be present there. Great white sharks are uncommon north of North West Cape and, although the grey nurse shark inhabits tropical waters, it has not been recorded north of Shark Bay in Western Australia (RPS 2007b).

Whale sharks are highly migratory, travelling an average of 24 km per day and up to 1800 km in a month, and may migrate through the offshore development area. The Kimberley region has not been identified as critical habitat for whale sharks (RPS 2007b).

Seabirds

The Roebuck Bay–Eighty Mile Beach area on the Kimberley coast (approximately 250 km south of the Ichthys Field) is identified as an internationally important site for migratory birds that utilise the East Asian-Australasian Flyway. Hundreds of thousands of shorebirds have been recorded here, arriving during the southern migration period between August and November, with many birds staying through the non-breeding period of December to February (Bamford et al. 2008). Flight paths between key foraging and resting areas in the region are not well known and may vary between migratory bird species.

Ashmore Reef (around 160 km north of the Ichthys Field) is also recognised as regionally important for seabirds, with 16 breeding species identified there including large nesting colonies of sooty terns, common noddies, bridled terns and crested terns (Milton 2005).

8.2 Recent surveys

Studies conducted to characterise cetacean distributions in the offshore development area also provided observations and data on other marine megafauna in the survey areas. These studies included vessel-based surveys in 2006 and 2007 (RPS 2007b), underwater acoustic logging from 2006 to 2008 (McCauley 2009) and more vessel-based surveys in 2008 (CWR 2009). The collection of data on megafauna during these surveys is described briefly below. However, for full details on survey methods, including schedules, sampling, equipment and data analysis, refer to Section 6.2.

2006/2007 vessel survey

Marine wildlife (sea snakes, sharks, rays, fish at the surface, jellyfish, crabs) were all recorded as individual observations by RPS during cetacean surveys, to provide a biodiversity index of relative abundance for the area. This was possible when there was relatively low abundance. If species such as seabirds, flying fish and jellyfish were being seen too often to record individually, observations were moved to "high density mode". This involved making a note in the logger that a species was being seen frequently, and this mode of observations stopped when that frequency diminished significantly (RPS 2007b).

Acoustic logging

The acoustic logger deployed in the Browse Basin to monitor great whales also provided data on fish choruses in the area (McCauley 2009).

2008 vessel survey

Wildlife other than cetaceans (e.g. seabirds, turtles, sea snakes, sharks, rays, fish at the surface, jellyfish, crabs) were recorded as individual sightings when their abundance was relatively low. If seen regularly and too often to record individually, observations were changed to 'density mode' which involved recording densities of animals sighted per five minute time bins (100/min., 200/min., etc.). This provided a biodiversity index of relative abundance for the area without compromising the search effort for cetaceans. Species abundance and diversity are indicators of trophic complexity and structure and may be directly or indirectly indicative of food resources for cetaceans. Surface activity of wildlife assisted to identify potential areas of high biological activity.

The visual detection methods designed for cetaceans were also considered reasonably effective for seabirds. Individual birds and flocks (mixed and single species) of birds were identified to species level when possible, usually when sighted within 500 m of the trackline.

Visual detection methods were considered much less effective for fish, marine reptiles and marine invertebrates because most are inconspicuous and usually occur below the surface. In addition to wildlife sightings, marine debris and the presence and position of other vessels were recorded.

Photos were taken of all sightings (particularly seabirds and cetaceans) that were near or approached the vessel. The photos were used for species identification and confirmation post sighting and, in the case of cetaceans, to identify individual animals (CWR 2009).

8.3 Results

8.3.1 2006/2007 vessel survey

Dugongs were uncommon throughout the survey period; only one dugong was recorded in the Browse Basin during October (RPS 2007b).

Sea snakes were recorded during the 2006 vessel surveys over the four time blocks. Identification to species level was not possible unless the animals were within 25–50 m of the survey track, hence the reporting of numerous 'unidentified' species. Two species that were readily identified were the olive-headed sea snake (*Disteira major*) and Stoke's sea snake (*Disteira stokesii*). One hundred and ninety-three sea snakes were recorded, with the highest density in Pender Bay during time block 1-06 (Figure 8-1) (RPS 2007b).

Individual fish and schools of fish that were visible from the surface were recorded throughout the vessel surveys (Figure 8-2). 'Unidentified fish' refers to surface "feed balls" that were likely to contain several species, where smaller fish, such as hardy heads, are concentrated near the surface by the circling below of predators such as tuna, mackerel or dolphins. Fish were least abundant across all areas in time block 1-06 (326 observations) and most abundant in time block 3-06 (2117 observations) (RPS 2007b).

Sharks were most abundant in the Browse Basin area (Figure 8-3). Rays were only occasionally seen on the sea surface (Figure 8-4) and included manta rays (*Manta birostris*) and several unidentified species (RPS 2007b).

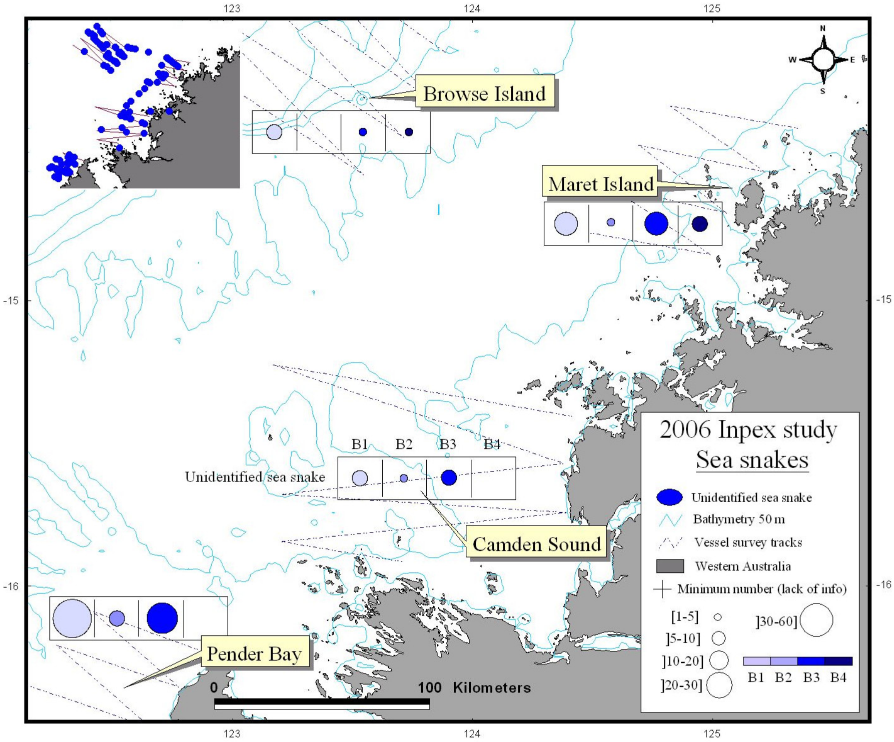


Figure 8-1 Distribution and abundance of sea snakes recorded during vessel surveys in 2006. Source: RPS (2007b)

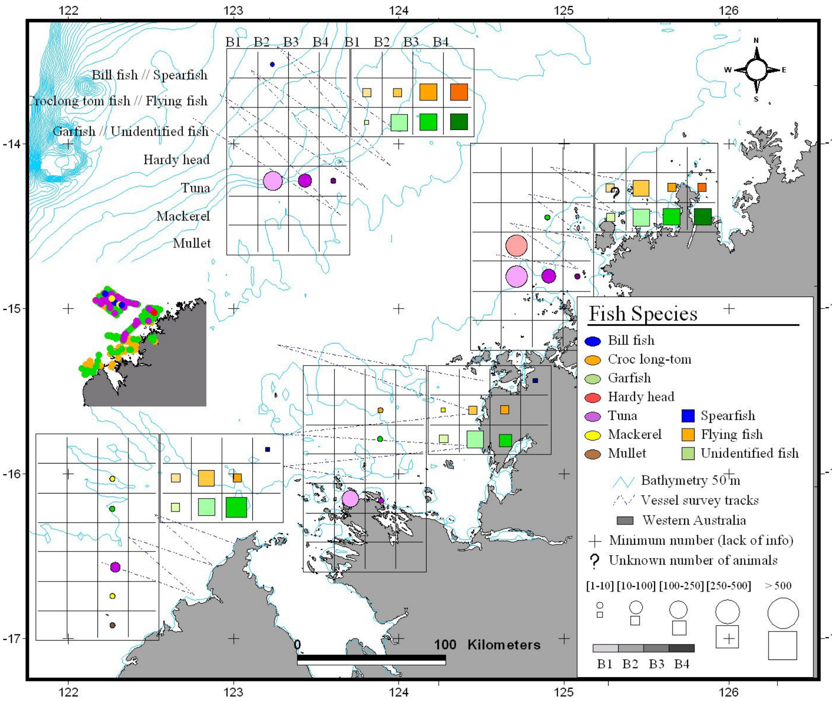


Figure 8-2 Distribution and abundance of bony fish recorded during vessel surveys in 2006. Source: RPS (2007b)

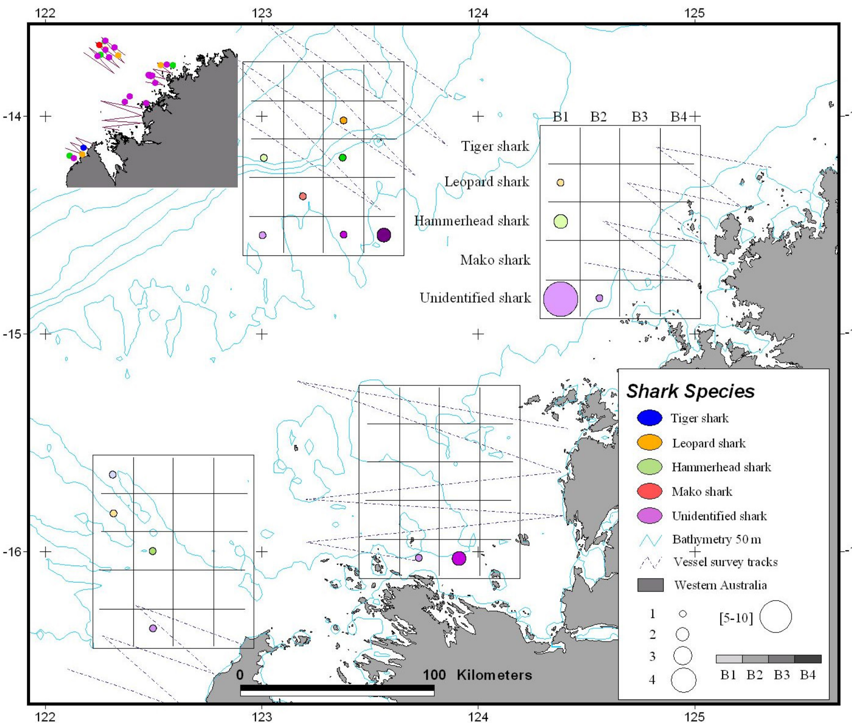


Figure 8-3 Distribution and abundance of sharks recorded during vessel surveys in 2006. Source: RPS (2007b)

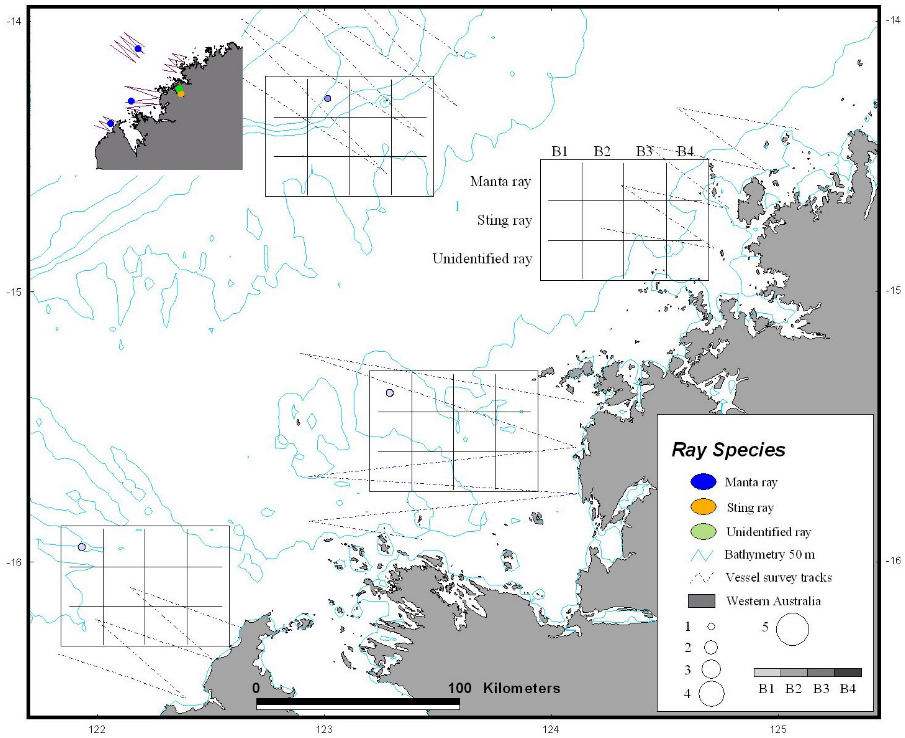


Figure 8-4 Distribution and abundance of rays recorded during vessel surveys in 2006. Source: RPS (2007b)

8.3.2 Acoustic logging

A fish chorus was heard each evening after dusk at the offshore logger site, starting at a frequency of approximately 1500 Hz and extending to beyond the logger's effective sample frequency at 2800 Hz (Figure 8-5). This type of chorus is common along the shelf-break off Western Australia and is particularly prominent in the Perth Canyon, where small fishes of the family Myctophidae have been implicated as the source. Data from the Perth Canyon suggest that the level of chorus reflects secondary productivity or krill biomass. The overall level of the Browse Basin chorus may therefore be an indicator of local secondary productivity (RPS 2007b).

The fish chorus in the Browse Basin is nondescript; it is rare for individual sources to stand out either audibly or in spectrograms. The chorus is predictable in timing, dictated by the time of local sunset. By aligning the "zero" of each day's recording to the time of local sunset, then averaging each evening's chorus level in the 2 kHz ⅓ octave across the entire recording period, the daily pattern stands out clearly with a peak occurring 1 to 1.5 hours after local sunset (Figure 8-6) (RPS 2007b).

The 2 kHz ⅓ octave level averaged each evening over 0.5 to 2 hours after sunset has been used as an indicator of seasonal variability in the chorus level. This can be seen in Figure 8-7, where the chorus level oscillates between 55–75 dB re 1 µ Pa^2/Hz. Note that the heavy line is the three-day running average, and the spikes towards the end of the recording are due to vessel noise (RPS 2007b).

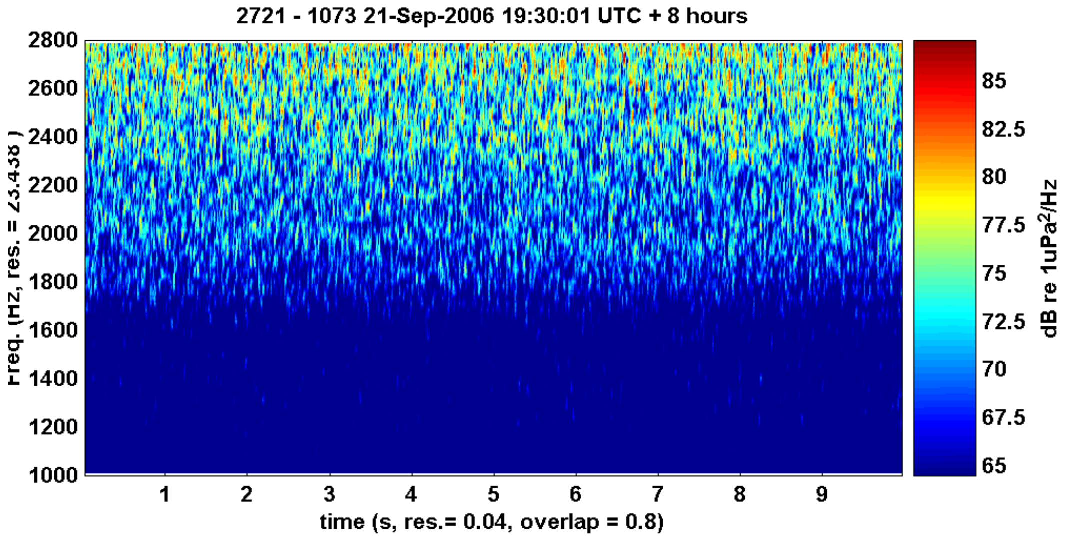


Figure 8-5 Spectrogram of offshore high-frequency fish chorus. Source: RPS (2007b)

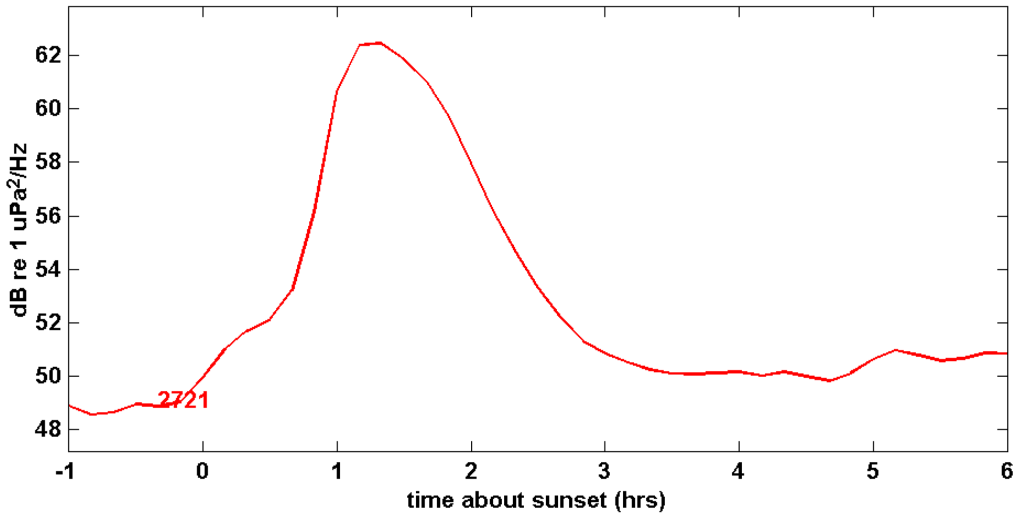


Figure 8-6 Evening fish chorus from the offshore site, with time zeroed to local sunset and the chorus level in the 2 kHz ⅓ octave averaged over the full recording period. Source: RPS (2007b)

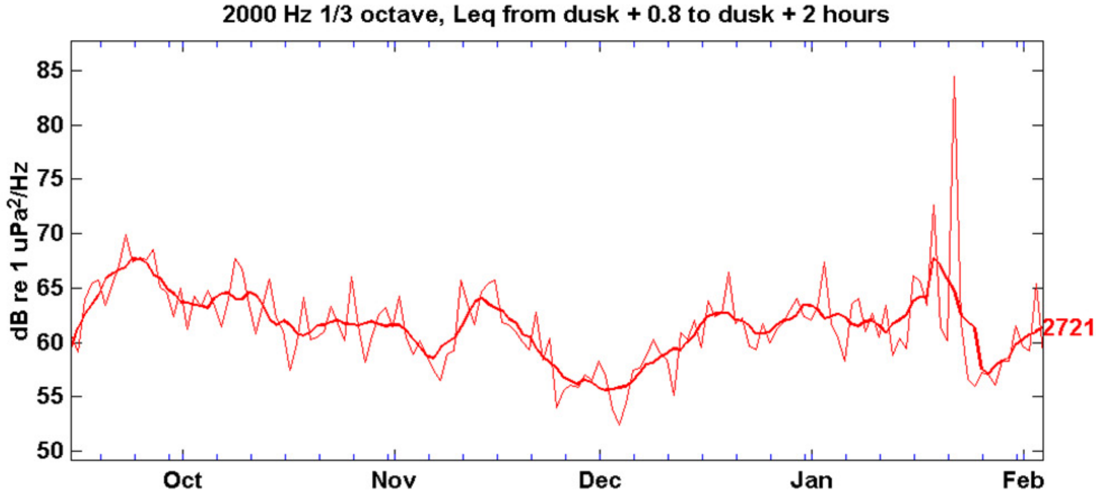


Figure 8-7 Seasonal pattern in 2 kHz, ⅓ octave averaged over 0.8 to 2 hrs post dusk each evening as an indicator of changes in fish chorus level. Source: RPS (2007b)

The 2 kHz fish chorus levels in the Browse Basin are below those measured in the Perth Canyon (typically 65–75 dB re 1 μPa^2/Hz), but are above those measured offshore from Exmouth (50–62 dB re 1 μPa^2/Hz) and at a site on the shelf-break due north of the Montebello Islands. It is not clear if these differences are due to differences in source density, or differences in sound transmission and the receiver 'averaging area' at each site (RPS 2007b).

A daily fish chorus near 200 Hz was evident at the offshore site until a large vessel arrived, after which time the chorus could not be distinguished. This chorus comprised many short 'pops' (Figure 8-8), running for approximately one hour and peaking 30 minutes after dusk.

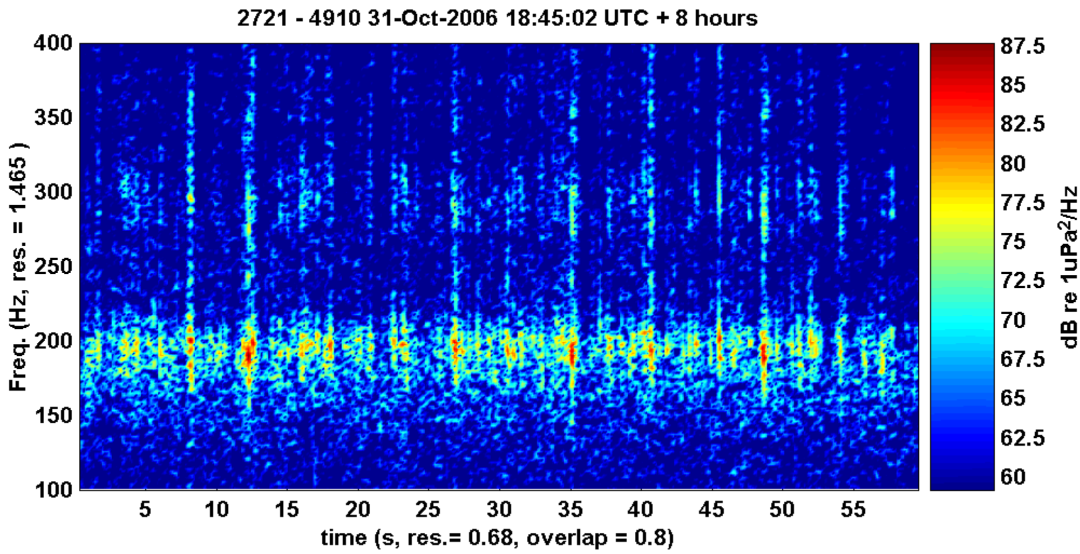


Figure 8-8 Spectrograms of the 200 Hz fish chorus signals recorded from the offshore logger. Source: RPS (2007b)

8.3.3 2008 vessel survey

General marine fauna

Wildlife recorded on the surveys consisted of sharks, invertebrates, sea-snakes and drifting cuttle bone and patches of seaweed. As most organisms could only be identified with low taxonomic resolution, it is not useful to talk about species diversity. However, a wide range of taxa was observed across these major groups. Unlike cetaceans and seabirds, most of these organisms were present across all four surveys.

A total of 24 701 organisms (of which 88% were flying fish) were counted, as well as 1225 cuttle bones and 1044 seaweed patches. Excluding flying fish, the most common organisms were cuttle bones, fish and jellyfish. Large fish and shark counts were typically less than 10 per survey, while bait balls and seaweed patches were common. Sea snakes were relatively abundant. As with cetaceans and seabirds, greater numbers of other wildlife organisms were observed during October–November than during June–July, primarily due to increases in observations of flying fish and jellyfish. Drifting seaweed and cuttle bone was also more common during October–November (CWR 2009).

Seabirds

At least 23 species of seabirds were observed, including frigatebirds, boobies, terns, noddies, tropicbirds, petrels, shearwaters and gulls (Table 8-2). As some individuals could not be identified to species, it is possible that more species were present. Of those seabirds that could be identified to species level, 26% occurred on three or four of the surveys. The number of seabird species observed by survey varied with 65% of the 23 species observed on Survey 1 (10–27 June 2008), 43% on Survey 2 (6–20 July 2008), and 70% and 48% on Surveys 3 (18 October–3 November 2008) and 4 (11–25 November 2008) respectively (CWR 2009).

2466 seabirds were recorded during the four surveys. The brown booby was the most common seabird, while a group of terns comprised 57% of sightings (Table 8-2). Seabird abundance was less highly skewed than cetacean abundance, although the three most common species still accounted for 71% of observations (CWR 2009).

As with cetaceans, more seabirds were observed during October–November (Surveys 3 and 4) (Table 8-2, Figure 8-9). The most abundant bird groups, boobies and terns, were found primarily in the eastern third of the study area during Survey 1 and 2. Shearwater sightings were notably higher during October–November than during June–July and brown booby numbers were substantially lower in Survey 4 than in previous surveys. In general, seabirds were found in higher numbers near the eastern near-shore area and around Scott Reef (CWR 2009).

Seabird species composition varied between the June–July and October–November periods (Table 8-2, Figure 8-10). A minimum of 15 species were encountered during June–July surveys and 16 during October–November surveys. Eight species (brown booby, masked booby, Christmas Island frigatebird, lesser frigatebird, Wilson's storm petrel, bridled tern, crested tern, common noddy) were common across both periods. Six species (red-tailed tropicbird, Herald petrel, white-faced storm petrel, short-tailed shearwater, gull-billed tern, lessercrested tern, Caspian tern) were recorded only in June–July and eight (Abbott's booby, white-tailed tropicbird, Bullwer's petrel, Matusdaira's petrel, streaked shearwater, common tern, little tern, sooty tern) only in October–November (CWR 2009).

Table 8-2 Seabirds recorded in study area. Source: CWR (2009)

Species	Survey 1	Survey 2	Survey 3	Survey 4	Total
Booby/frigatebird					
Brown booby	65 (44)	119 (85)	151 (109)	26 (23)	361 (261)
Masked booby	4 (3)	5 (3)	1 (1)	0	10 (7)
Abbott's booby	0	0	2 (2)	0	2 (2)
Christmas Island frigatebird	2 (2)	0	1 (1)	0	3 (3)
Lesser frigate	3 (3)	0	3 (3)	1 (1)	7 (7)
Frigatebird spp.	29 (19)	27 (25)	35 (9)	7 (3)	98 (56)
Tropicbird					
Red-tailed tropicbird	1 (1)	0	0	0	1 (1)
White-tailed tropicbird	0	0	3 (3)	0	3 (3)
Tropicbird spp.	1 (1)	0	1 (1)	0	2 (2)
Petrel/storm petrel					
Herald petrel (dark morph)	1 (1)	0	0	0	1 (1)
Bulwer's petrel	0	0	78 (28)	12 (12)	90 (40)
Petrel spp.	11 (10)	8 (8)	24 (15)	2 (2)	45 (35)
White-faced storm petrel	1 (1)	1 (1)	0	0	2 (2)
Wilson's storm petrel	7 (7)	6 (6)	5 (5)	39 (39)	57 (57)
Matsudaira's storm-petrel	0	0	3 (2)	1 (1)	4 (3)
Storm petrel spp.	20 (17)	14 (12)	0	4 (4)	38 (33)
Shearwater/gull					
Short-tailed shearwater	(1)	0	0	0	1 (1)
Streaked shearwater	0	0	1 (1)	24 (5)	25 (6)
Shearwater spp.	10 (7)	0	124 (11)	4 (4)	138 (22)
Gull spp.	9 (2)	0	0	0	9 (2)
Tern/noddy					
Bridled tern	6 (4)	5 (3)	5 (5)	136 (20)	152 (32)
Crested tern	26 (17)	62 (58)	4 (4)	3 (2)	95 (81)
Gull-billed tern	1 (1)	0	0	0	1 (1)
Lesser crested tern	14 (9)	55 (3)	0	0	1 (1)
Common tern	0	0	1 (1)	0	1 (1)
Little tern	0	0	6 (4)	9 (4)	15 (8)
Sooty tern	0	0	2 (1)	3 (1)	5 (2)
Caspian tern	2 (1)	0	0	0	2 (1)
Tern spp.	201 (100)	192 (142)	131 (60)	575 (103)	1099 (405)
Common noddy	4 (4)	0	1 (1)	0	5 (5)
Noddy spp.	5 (4)	2 (2)	16 (6)	6 (4)	29 (16)
Other seabirds					
Unidentified bird	41 (21)	2(2)	16 (6)	6 (4)	29 (16)
Total count	**464 (280)**	**484 (382)**	**655 (301)**	**863 (237)**	**2466 (1200)**
Min. species richness^	**15**	**10**	**16**	**11**	**23**

NOTE: Number of sighting events is given in parentheses.

^ Excludes taxa not identified to species level, except where identification to another taxonomic level provides definitive evidence of additional species richness (i.e. no identifications of the given taxonomic level to species level for that survey).

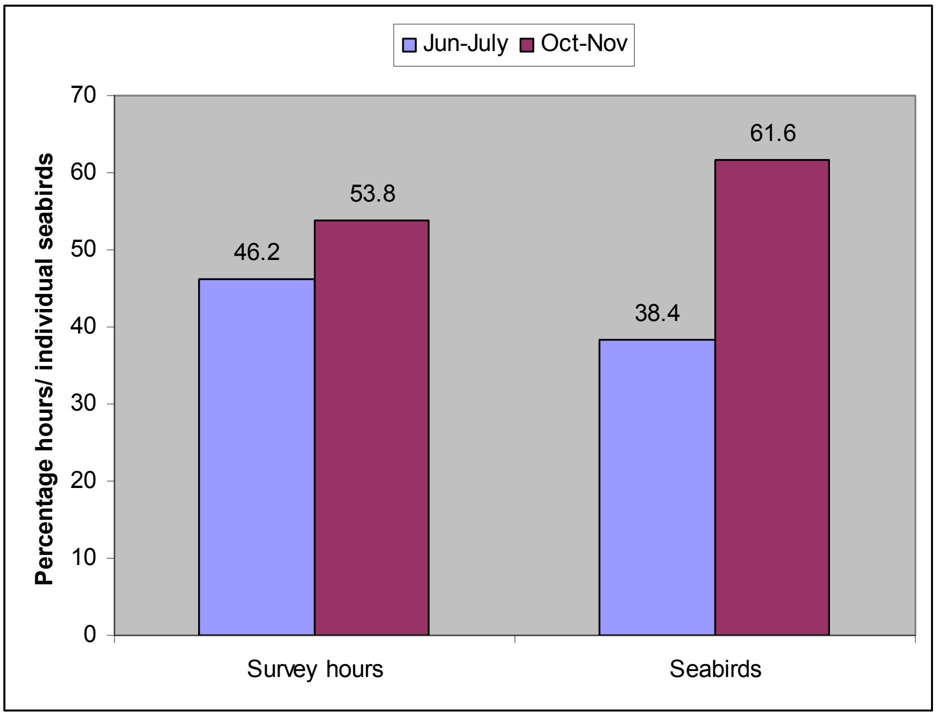


Figure 8-9 Sampling effort compared to percentage observation of seabirds. Source: CWR (2009)

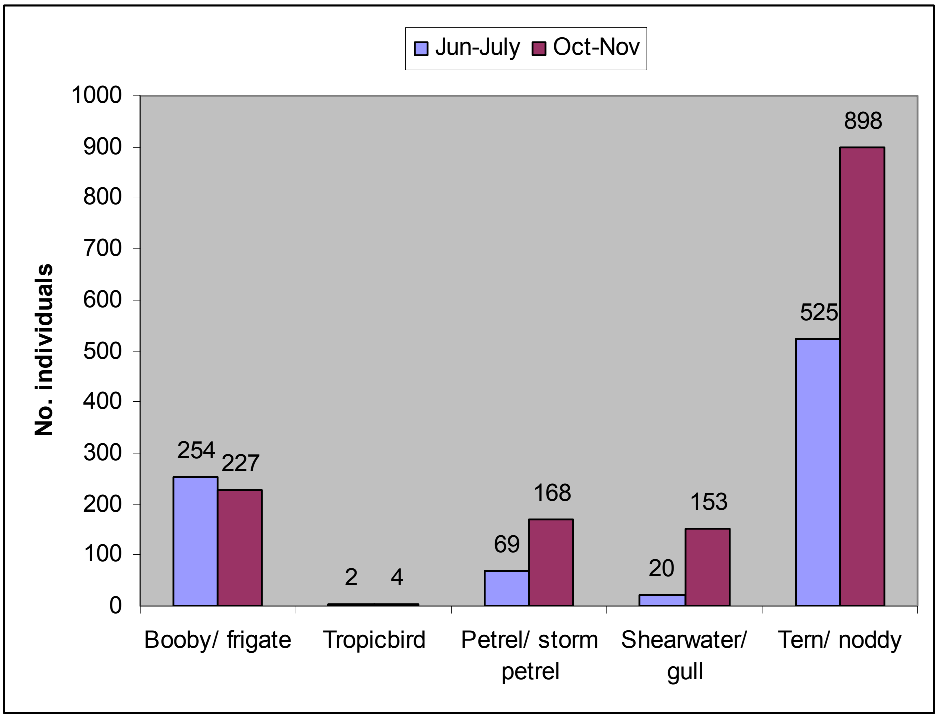


Figure 8-10 Comparison of occurrence of seabird taxonomic groups between survey periods. Source: CWR (2009)

8.4 Discussion

Dugongs were infrequent visitors to the offshore area. Only one dugong was observed during the vessel transects in the Browse Basin during October 2006. Pods of dolphin species that are known to bow-ride in other regions did not bow-ride during the vessel surveys, instead dispersing away from the survey ship. Dugongs are hunted by Australian Aborigines in motorised canoes, and are therefore likely to be boat-shy. It is not known if the boat-shy behaviour in dolphins in the study region reflects their being hunted (locally or otherwise) (RPS 2007b).

A large diversity of fish call-types were recorded on the acoustic logger. The fish noise displayed clear daily, lunar and possibly seasonal patterns, as also occurs on the Great Barrier Reef, where the levels of choruses exhibit distinct daily and lunar patterns, with higher levels around new moon periods, and seasonal patterns with peaks during the austral summer (RPS 2007b).

The higher seabird abundance in October–November across all taxonomic groups with the exception of boobies and frigatebirds could also be indicative of breeding cycle stage as feeding ecology and foraging ranges can vary between breeding and non-breeding periods depending on the dominant foraging population class (CWR 2009).

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Limitations Section 10

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

This report was in prepared between June and November 2009, and is based on the survey data obtained and other information reviewed up to the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

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