SINCLAIR KNIGHT MERZ
SKM

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Port Hedland Outer Harbour Development

MARINE BENTHIC HABITAT SURVEY

- WV03716-MV-RP-0028
- Revision 0
- 07 December 2009

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Limitation Statement

The sole purpose of this report and the associated services performed by Sinclair Knight Merz ("SKM") is to detail the field surveys undertaken to collect data and describe the marine benthic habitats and benthos; and describe the desktop analysis and modelling undertaken to estimate the areal coverage of different benthic categories in accordance with the scope of services set out in the contract between SKM and the Client (FAST JV). That scope of services, as described in this report, was developed with the Client.

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Executive Summary

BHP Billiton Iron Ore is proposing to expand its existing iron ore export capabilities at Port Hedland through the development of a new outer harbour. The proposed Outer Harbour Development would see the construction of a jetty from the coastline, on Finucane Island, to a wharf located approximately 4 km offshore. Substantial dredging will be required for shipping access and dredge material will be disposed into offshore spoil grounds.

For proposed developments such as this, the Western Australian Environmental Protection Authority (EPA) requires proponents to estimate the potential impact of activities on marine benthic habitats, with particular attention to benthic primary producer habitat (BPPH) and the benthic primary producers (BPP) that are or could be supported by the habitat. Such impacts may occur directly (through infrastructure insertion, dredging, spoil disposal) or indirectly (through dredging and spoil disposal plumes).

To determine the potential impacts on benthic habitats an identified risk area was delineated. This was determined to be approximately 50 km to the east and west of the development, and 40 km offshore from the coastline, for a total study area of 3,650 km^2. Sinclair Knight Merz undertook a field survey programme to determine benthic habitat composition, followed by modelling to produce a habitat map of the study area.

The first stage of the process was acquisition and analysis of bathymetric information to identify areas of interest. Existing bathymetric charts were inadequate, so Light Detection and Ranging (LiDAR) techniques were used to capture detailed bathymetric data of the study area.

Habitat investigations, including towed video and diver video transects, were undertaken at sites selected based on bathymetric features and existing knowledge of the area. Additional benthic habitat information was gathered opportunistically during other marine investigations. The study area was observed to be dominated by sand plains interspersed with a series of hard substrate ridgelines running parallel to the coastline. The ridgelines were located on surrounding seabed that was generally deeper than - 10 m Chart Datum (CD).

LiDAR datasets and habitat data collected in the field were then input into a model to generate maps predicting the presence of biota, substrate and combined habitat classes across the entire study area. Prediction of the presence of a biota or substrate class in a given location was reliant on a benthic percentage cover of ≥5%. Consequently, the presence of one class did not preclude the presence of another; intermingling of classes was common. For biota classes, BPP and non-BPP, this was particularly so across the hard bottom ridgelines. Approximately one quarter of the available data were withheld during the modelling process for validation purposes. Validation established that there was a high degree of confidence in the model outputs.

Modelling predicted the study area to be comprised of the following substrate classes:

- 88% sediment;
- 7% hard substrate;
- 3% sediment covered hard substrate (when two categories above predicted in same location); and
- 2% not modelled with confidence.

Biota classes, either BPP or non-BPP, were predicted to occur in isolation or mixed assemblages over 13% of the study area. Presence of biota in the study area was predicted as follows:

BPP

- hard coral: 5.0% (of which 2.8% was predicted to occur in isolation);
- macroalgae: 4.4% (2.2% in isolation); and
- seagrass: could not be modelled as it was not recorded at enough sites in the study area.

Non-BPP

- invertebrates including sponges, soft corals, ascidians: 5.6% (2.8% in isolation).

Of areas where biota were predicted, 5.2% occurred in mixed assemblages (13% - 2.8% (hard coral) – 2.2% (macroalgae) – 2.8% (non-BPP))

In relation to BPPH, habitat modelling of the study area predicted the following percentage covers:

- 86.7% was non BPPH (sand or sediment not capable of supporting BPP);
- 11.5% was BPPH; and
- 1.8% could not be accurately modelled.

Benthic habitat, biota or community structures considered to be endemic, especially unique or of regional significance have not been identified within the study area. BPPH was not observed to support dense or complex BPP communities. Likewise, no unique organisms or communities were observed on non BPPH areas.

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1. Introduction

1.1. Project Overview

BHP Billiton Iron Ore exports iron ore from port facilities in Port Hedland, Western Australia. The port operations consist of processing, stockpiling and shiploading facilities at Nelson Point and Finucane Island (referred to as the Inner Harbour), located on opposite sides of the Port Hedland Harbour. The operations currently have an approved capacity of 155 million tonnes per annum (Mtpa).

BHP Billiton Iron Ore is now embarking on a development program at their Western Australian iron ore operations and is investigating a number of port development options, one of which is to develop an Outer Harbour at Port Hedland.

The proposed Outer Harbour Development will be a new port facility near Port Hedland with an export capacity of approximately 240 Mtpa of iron ore. Construction will be in stages (referred to as Stages 1–4). Stage 1 of the Outer Harbour Development will take approximately three years to construct. Construction of Stage 1 is proposed to commence late 2010/early 2011, with the first ore shipments scheduled in 2014. Dependent on the market conditions, the proposed total construction period of all stages would be approximately eight years.

1.2. Project Description

The proposed Outer Harbour Development expansion stages will occur through four separate stages, each with a nominal capacity of up to 60 Mtpa.

The marine infrastructure for the new offshore loading facility will be constructed on Finucane Island. The new jetty and wharf will extend nominally 4 km offshore in a northerly direction, adjacent to the existing inner harbour shipping channel (**Figure 1.1**). The new iron ore loading facility will be capable of berthing and loading vessels up to 320,000 deadweight tonnes (DWT).

The key components of the offshore maritime infrastructure comprise the following:

- an abutment (on Finucane Island), jetty and wharf accommodating 8 berths;
- mooring and associated mooring dolphins;
- associated transfer stations, ore conveyors and shiploaders;
- dredging for berth pockets, basins and channels; and
- aids to navigation.

The construction of the Outer Harbour Development will require dredging to enable vessel access to the proposed wharf infrastructure. Dredging operations will include the creation of new:

- berth pockets;
- swing basins;
- arrival and departure basins;
- link channel to the existing inner harbour shipping channel;
- departure channel; and
- tug access channel linking the existing channel to the wharf head area.

The new departure channel will be approximately 34 km in length. The basins, berth pockets and up to 3 km of the new departure channel will be located in State waters, with the remainder of the departure channel being in Commonwealth waters (**Figure 1.1**). The total volume of dredged material is estimated to be approximately 54 Mm^3, including an allowance for over-dredging. There is a range of material types in the proposed dredging footprint, thus requiring the use of a trailing suction hopper dredger (TSHD) for softer material, while harder materials will first require cutting/crushing using a cutter suction dredger (CSD). Geotechnical studies completed to date have identified no areas in the dredging footprint that would require marine blasting operations for material extraction.

It is envisaged that dredging will occur in a staged manner as follows:

- **Stage 1** – dredging of berth pockets, eastern swing and departure basins, a tug access channel and a link channel to the existing channel to provide two loading berths;
- **Stage 2** – dredging of the western swing and departure basins to provide two additional loading berths. This stage also includes the dredging works for the new 34 km departure channel and the cross link channel;
- **Stage 3** – dredging for the extension of the wharf with additional berth pockets and the swing and departure basins to accommodate another four loading berths; and
- **Stage 4** – there is no dredging activity proposed for this stage; it involves construction of two loading berths and a shiploader

Figures in this report show the final proposed spoil ground options. Further details of the selection process are provided in the Outer Harbour Development Spoil Ground Selection Study prepared by SKM (SKM 2009b). Landside development will include an infrastructure corridor (including conveyors, access roadway and utilities) from the stockyards on the mainland to a transfer station on Finucane Island that connects to a marine jetty.

Figure 1.1 Proposed Outer Harbour Development Showing Construction, Dredging and Proposed Spoil Grounds

1.3. Regulatory Guidelines

The Environmental Protection Authority of Western Australia (EPA) has issued a Guidance Statement which assists in the protection and management of benthic primary producer habitat (BPPH) in Western Australia. Guidance Statement No. 29 (EPA 2004) provides guidance on marine BPPH and the benthic primary producers (BPPs) supported by these habitats including corals, seagrasses and macroalgae.

The EPA's definition of BPP as covered by Guidance Statement No. 29 (EPA 2004) is:

"predominantly marine plants (e.g. seagrasses, mangroves, seaweeds and turf algae) but include invertebrates such as scleractinian corals, which acquire a significant proportion of their energy from symbiotic microalgae that live in coral polyps. These organisms grow attached to the seabed (i.e. subtidal and intertidal), sequester carbon from surrounding seawater or air and convert it to organic compounds through photosynthesis."

Guidance Statement No. 29 (EPA 2004) defines BPPH as:

"…both the BPP communities described above as well as the substrata that can/do support these communities."

The EPA contends that both vegetated (supporting BPP) and non-vegetated (not supporting BPP) substrates can be classed as BPPH if it is reasonable to assume they could, at some future point, support BPP (EPA 2004). Thus, examples of BPPHs include coral reefs, dense and patchy seagrass meadows, and seabed where macroalgae, coral or seagrass communities have grown or could grow.

While the primary focus of the habitat surveys and mapping is to provide data to inform an impact assessment of potential impacts to BPPH and supported BPP communities in the vicinity of the proposed Outer Harbour Development, non BPPH habitats were also examined and modelled to detect any unique assemblages that may require consideration.

The Western Australian Department of Environment and Conservation (DEC) has produced a report titled Pilbara Coastal Water Quality Consultation Outcomes: Environmental Values and Environmental Quality Objectives. This report details a set of environmental quality objectives (EQO's) within an Environmental Quality Management Framework (EQMF) for water quality in the Pilbara after extensive consultation with bodies including residents, industry and other government agencies (DoE 2006). The EQMF proscribes a 'high' level of protection to the waters offshore of Port Hedland, indicating that contamination levels must be kept 'very low' and biological indicators must not display changes detectable from natural variability.

The mapping of benthic habitats and communities informed the installation of monitoring sites to determine baseline water quality and health of BPPs. The collation of background water quality and BPP data, and the establishment of impact assessment criteria, are two of the items identified during the consultation process as being essential to meet proscribed the proscribed EQO's (DoE 2006).

1.4. Scope of Work

Sinclair Knight Merz was commissioned to undertake field investigations and development of habitat maps to describe the distribution and composition of benthic habitats (including BPPH and BPPs) in the vicinity of the proposed Outer Harbour Development. The specific objectives were to:

- define suitable boundaries for a study area in which to investigate and map benthic habitats;
- survey and provide a quantitative description of the existing sub-tidal marine habitat in the vicinity of the proposed Outer Harbour Development;
- determine the spatial extent of benthic organisms, in particular BPPs including hard corals, seagrasses and macroalgae, and development of a habitat map; and
- inform the Outer Harbour Development Public Environmental Review/Environmental Impact Statement (PER/ EIS) of existing benthic habitats to support proposed BPPH cumulative loss and impact assessment studies.

This report summarises the work undertaken to achieve the stated objectives.

The report is not intended to serve as a baseline environmental investigation for comparison against repeatable surveys after the commencement of dredging. Monitoring sites have been established since June 2008 for the purposes of comparing water quality and coral health before, during and after dredging and spoil disposal activities (SKM 2009c; SKM 2009d).

2. Methods

2.1. Overview

A marine study area was designated based on the proposed Outer Harbour Development infrastructure footprint and a preliminary dredge plume model estimate. The study area was defined prior to numerical dredge plume modelling and relied upon experience with similar projects in the region (e.g. Cape Lambert Port A and B Developments) (SKM 2007a; SKM 2009g). The study area covers approximately 3,650 km^2, extending 50 km to both the east and west of Port Hedland Harbour, and 40 km seaward.

Prior to design and implementation of field investigations, a literature review was conducted to gather existing knowledge of the benthic habitat in the study area (DEWHA 2009; Le Provost *et al*. 1984). Hydrographical charts were then examined to identify bathymetry likely to be capable of supporting BPPs, such as rocky outcrops or ridgelines (**Figure 2.1**). The information and level of resolution provided on these charts was considered insufficient for the purposes of selecting survey sites representative of the study area. The detail was also inadequate for habitat modelling.

More detailed bathymetric data was acquired during aerial surveys using Light Detection and Ranging (LiDAR) technology. The LiDAR data were verified by ground truthing as accurate to 0.5 m in the z plane (vertical, or depth) and 3.5 m in the x, y (horizontal) plane. These high resolution bathymetric charts covered the entire study area and illustrated benthic structures previously unidentified on hydrographical charts (**Figure 2.2**). Sites for habitat investigation were chosen based on LiDAR bathymetry which highlighted a range of geographic features and depths. Replicate sites were then chosen in each system to ensure sufficient representation of the various habitat types.

Benthic habitat data were collected in the field from a combination of diver video transects and vessel based video tows at targeted sites; and also from opportunistic observations made by scientific divers when completing other environmental investigations, such as sediment sampling.

Data obtained during field surveys were then used in conjunction with LiDAR data to inform habitat modelling and mapping, and to allow characterisation of the broader project area. A portion of the habitat data were withheld and used to verify the accuracy of predicted habitat distributions. During development of the habitat model, additional data were collected in less heavily surveyed areas with targeted video tows.

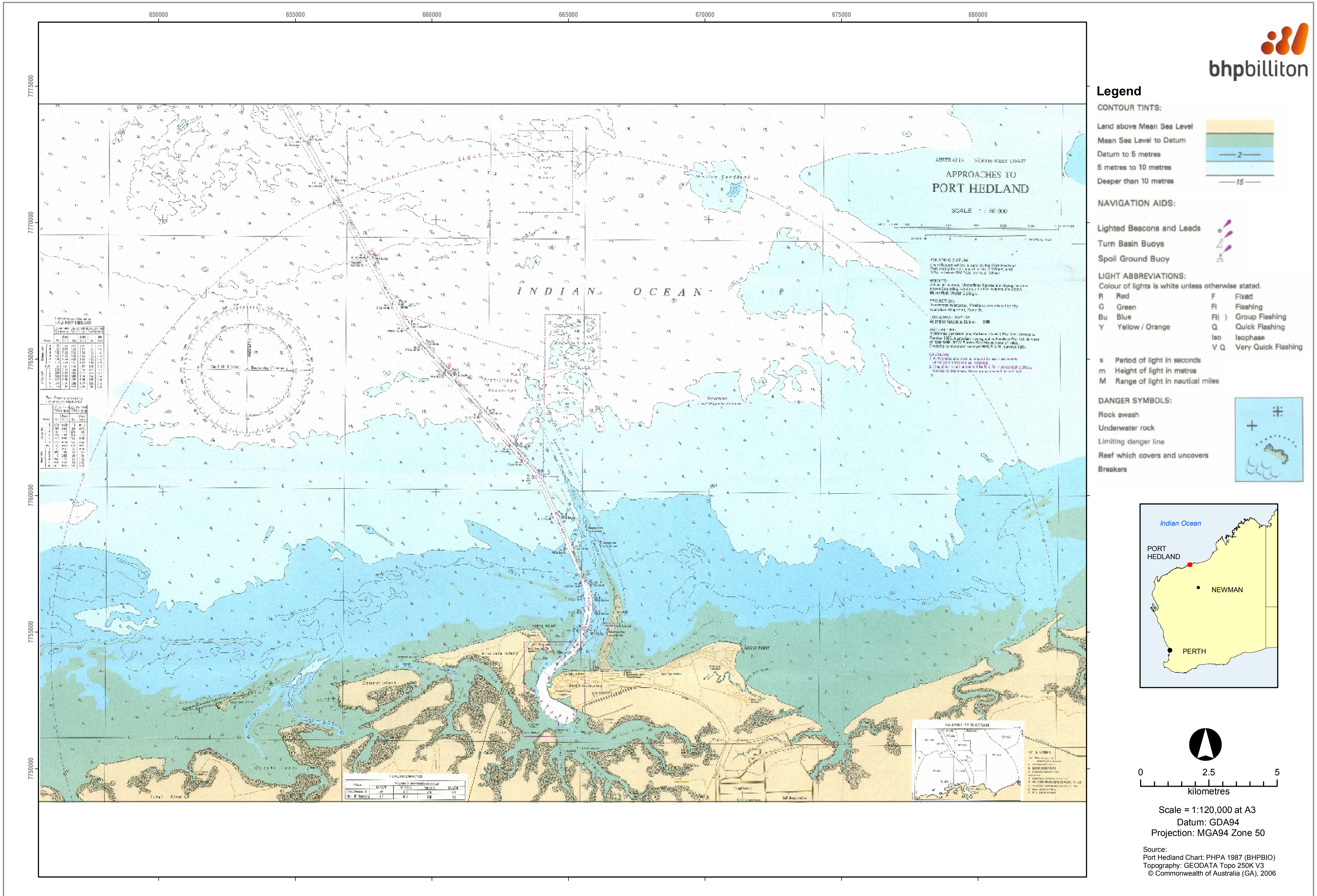

Figure 2.1 Example of Existing Hydrographic Chart of the Port Hedland Area

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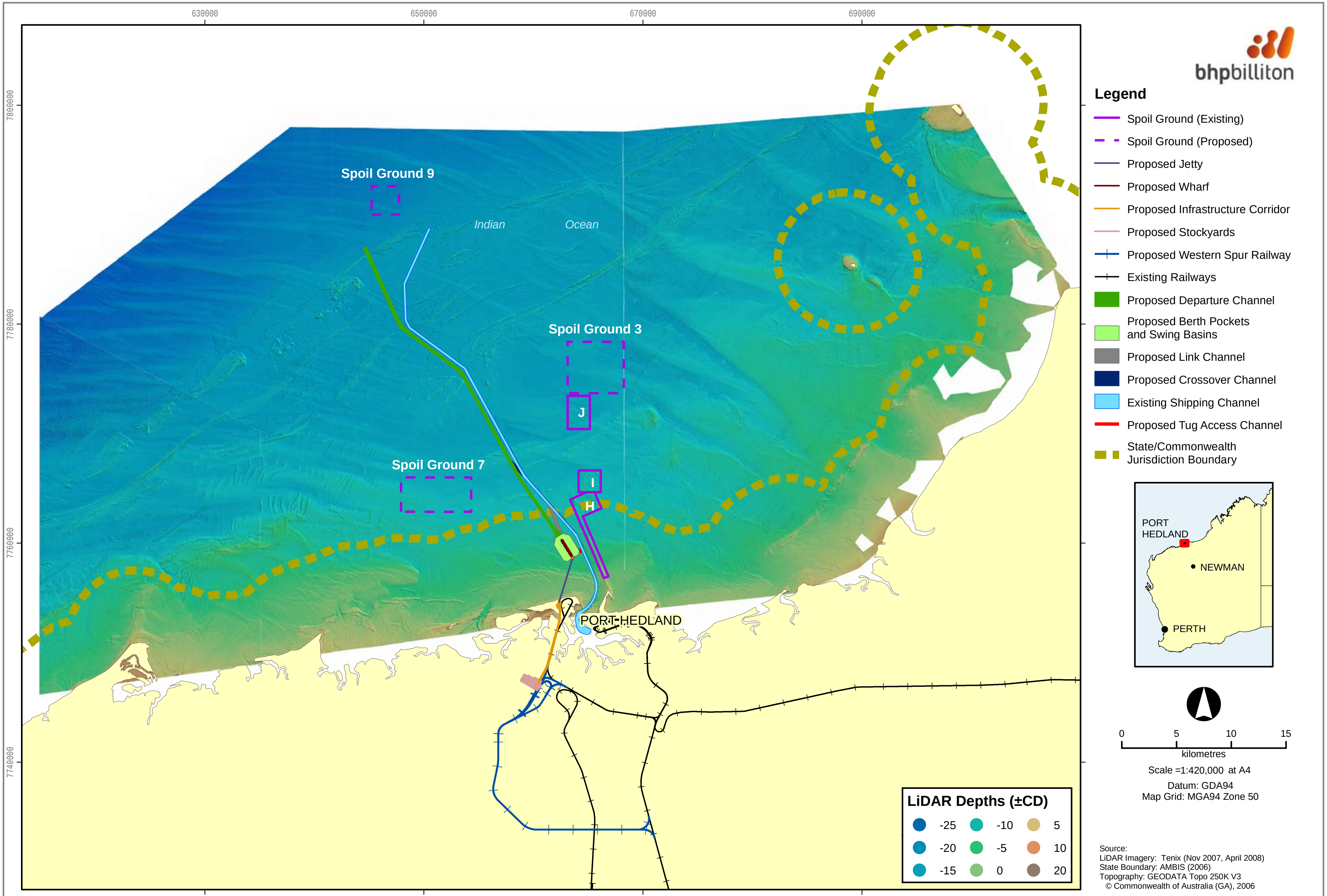

Figure 2.2 Sea Bed Bathymetry of the Study Area from LiDAR Surveys

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2.2. Benthic Habitat Field Investigations

A summary of quantitative and qualitative surveys of the study area seabed undertaken between December 2007 and October 2008 are summarised in **Table 2.1** and illustrated on **Figure 2.3**. For clarity, only diver video transect sites are labelled on this figure.

- **Table 2.1 Marine Investigations within the Study Area Providing Benthic Habitat Data**

Task Description	Number of Sites/Transects	Date/Period
Towed video transects	42	December 2007
Sediment sampling	213	December 2007 – September 2008
Diver video transects	52	January – May 2008
Spot dives (Aborted diver video transects)	13	January – May 2008
Towed video sites	21	October 2008
Total	**341**	

In addition to these subtidal investigations, the following supporting surveys were conducted:

- A walkover of the Finucane Island intertidal platform in February 2009 to describe BPPH and BPPs. Previous investigations of the platform in July 2007 had observed it to be sand covered with no evidence of BPPs (SKM 2007b).
- Intertidal and supratidal habitats were described and photographed at two sites each on North Turtle, Little Turtle and Weerdee Islands. These visits were undertaken opportunistically during diver video transect field investigations and observations are not described in this report.
- Analysis of benthic drop video footage captured in inlets behind Weerdee and Downes Island.

2.2.1. Broad Scale Initial Investigations

Forty-two (42) towed video transects were collected from the *Sea Sprint* in December 2007 to gather a broad scale understanding of benthic habitat in the study area. Transects were predominantly undertaken within a preliminary alignment of the proposed dredge footprint, and in nearby potential spoil ground locations (**Figure 2.3**). Additional transects were recorded on nearby areas of vertical relief identified from LiDAR bathymetry.

The video camera was towed at a speed of approximately 1–2 knots at a distance above the seabed that allowed adequate control to avoid obstacles but still allowed visual observation of the seabed features. In most cases this distance was 1–2 m but in turbid conditions the potential for snagging the video on hard substrate was too great, thus these transects were aborted. The recordings did not lend themselves to quantitative assessment due to the quality of footage thus the assessment was based on qualitative observation of the habitat, which provided some input into the habitat modelling process.

The transect length was highly variable (0.5–6 km) as the trajectory was selected to optimise the classification of benthic habitats in different regions; however, the primary focus was to characterise the seabed along the footprint of the proposed dredge footprint at the time.

2.2.2. Opportunistic Diver Observations

A total of 213 dives were completed to investigate the suitability of several potential spoil grounds to the east and west of the existing channel and for the collection of sediment for sampling and analysis associated with the preparation of a sea dumping application (see **Figure 2.3**; 'sampling and analysis sites' and 'spoil ground sample sites'). The dives were primarily undertaken to collect sediment samples with visual observations being made of the benthic topography, sediment grain size and biotic cover.

Observations from a further 13 spot dives were recorded from locations that had been considered potential sites for diver video transects. These sites were observed to be bare sand or mud devoid of BPPs or BPPH and are labelled as 'spot dives' on **Figure 2.3**.

The GPS coordinates of the sites investigated by SCUBA are provided in **Appendix A**.

2.2.3. Sites Targeted for Habitat Surveys

2.2.3.1. Diver Video Transects

The positioning of diver video transect sites was based on the relief shown on LiDAR bathymetric charts. Video recording of belt transects was undertaken by SCUBA divers at each of 52 sites in triplicate. These sites are labelled on **Figure 2.3**, with representative photographs from each site provided in **Appendix D**. Three transects were recorded at each site running parallel to each other. The centre transect was marked by laying a 50 m measuring tape along the substrate of relatively uniform depth. The other two transects ran parallel to the centre transect approximately 2 m apart. The GPS (Global Positioning System) location was recorded at the start of transects, however transects were not permanently marked underwater. At sites where the coral cover was not uniform, transects were orientated to pass over areas of highest coral cover to incorporate a measure of conservatism when estimating the percentage cover of hard coral at a given site.

Video recordings were acquired by movement of a Sony 3CCD Digital Video camera in a Stingray housing along the 50 m transects according to the protocol developed by the Australian Institute of Marine Science (Carleton and Done 1995). A SCUBA diver maintained a constant speed and the video was kept approximately 0.4 m above the surface of the benthic habitat. This captured an image size of approximately 0.4 m wide by 0.3 m high and a total area of 20 m^2 per site. The methods used to analyse and summarise this footage are provided in **Section 2.3**.

During the period when diver video transect surveys were undertaken, two intertidal platform sites on each of North Turtle, Little Turtle and Weerdee Islands were visited and described, but not quantitatively surveyed. In addition, the intertidal platform off Finucane Island was visited at a later date when BPPH was observed in late 2008 to early 2009. Prior to this time, the platform was not considered capable of supporting BPPs based on video surveys conducted in 2007 for another BHP Billiton Iron Ore project (SKM 2007b). Further detail is provided in **Section 3.2.2**.

2.2.3.2. Towed Video Sites

After the development of preliminary habitat models, a further 21 benthic sites were surveyed in October 2008 to provide additional ground truthing information to support the modelling process. The sites are labelled on **Figure 2.3** as ‘towed video site’. These additional tows were undertaken within sections of the study area with a relatively low density of benthic habitat data points. The earlier towed video transects (**Section 2.2.1**) were conducted to gather a broad understanding of the seabed prior to detailed information being available.

In addition, a separate habitat mapping study conducted for BHP Billiton Iron Ore in May 2009 delineated 4 patches of seagrass (*Halophila ovalis*) in the inlet between Weerdee and Downes Island. Whilst outside the defined study area, the identification of four sparse to medium density seagrass patches was noted and is described in **Section 3.2.4**.

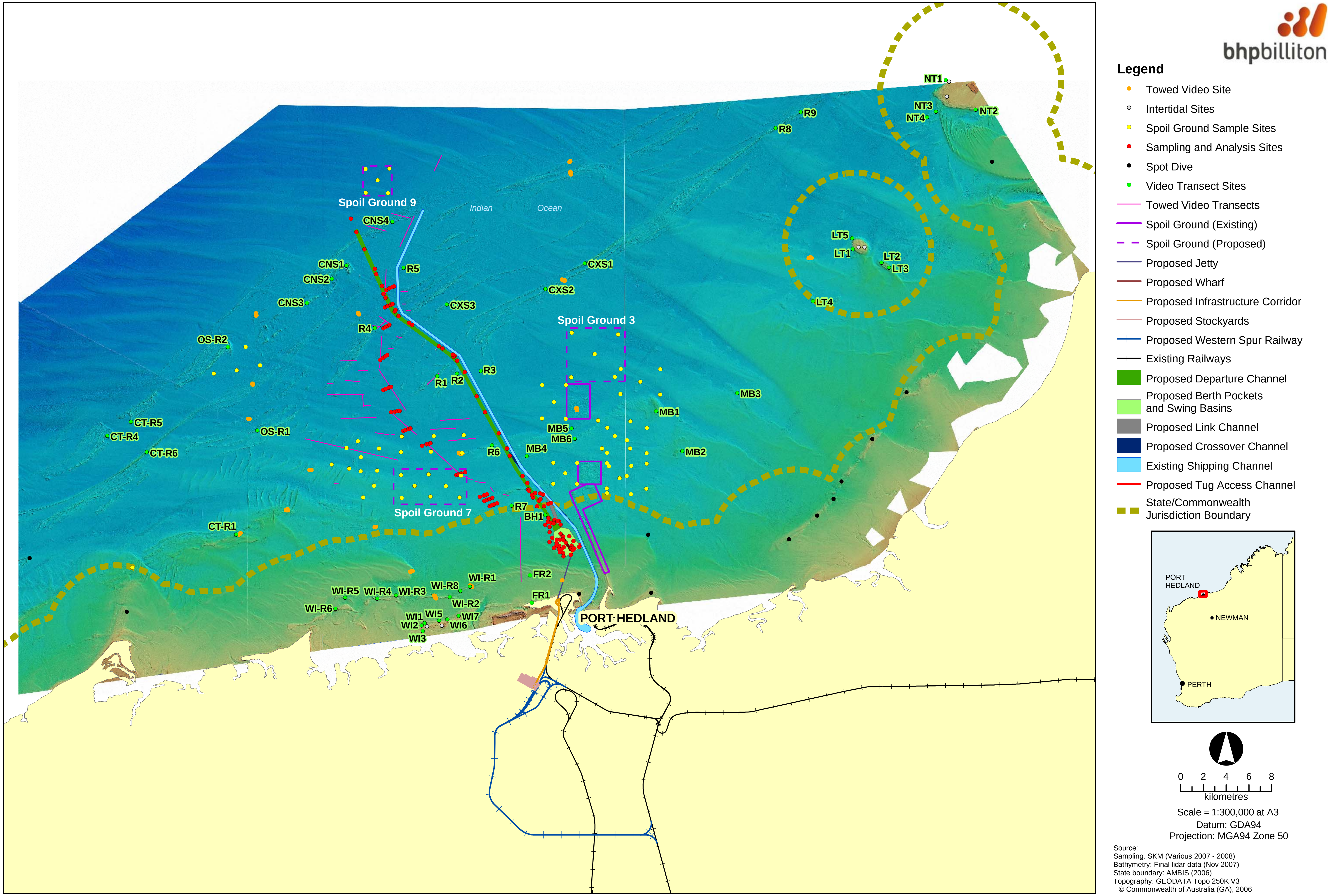

Figure 2.3 Study Area Showing Survey Sites

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2.3. Data Management and Analysis

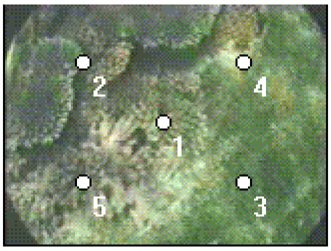
2.3.1. Qualitative Benthic Descriptions

Seabed characteristics and biota at every dive site visited during the marine environmental investigations were described by divers upon surfacing and noted by support crew. At the majority of these sites, still or video footage was also captured by the diver. The field records and footage provided data to support habitat modelling.

Video footage stamped with Global Positioning System (GPS) co-ordinates was captured at the ‘towed video sites’ and was analysed every two seconds along transects for presence or absence of organisms and substrate types. As the footage was from transects (as opposed to a discrete spot dive site), multiple data points were recorded at each site for habitat modelling purposes.

2.3.2. Substrate Classification from Diver Video Transects

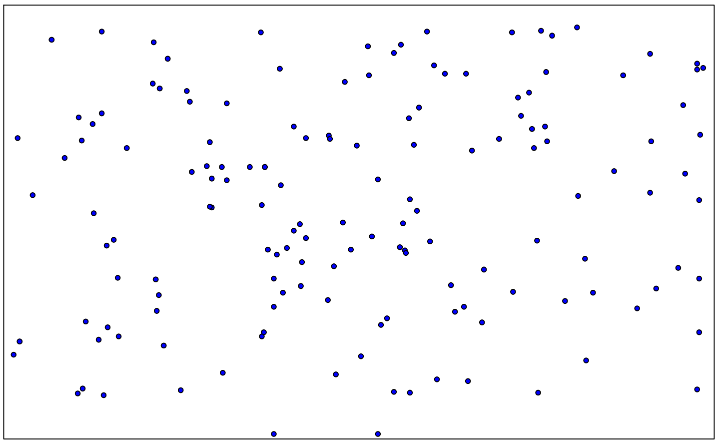
Video recordings of the 52 sites were captured electronically, saved to file and then stored on a DVD. The Sinclair Knight Merz Video Transect Analysis System (SKMVTAS) then retrieved the electronically recorded transect for analysis. The SKMVTAS program is set up to randomly select 150 frames of the video transect footage from each transect and allocate 1 random spot to each frame (see **Figure 2.4**). Alternatively, it can be set up to analyse 5 fixed spots from 30 frames. This number of frames along a 50 m transect provides a representation of percentage cover and also avoids overlap of frames. This is the equivalent to a movement of a 2.4 second duration or 0.33 m in distance. The effective randomisation of the 150 spots over the length of a transect as they would appear when accumulated on one screen, is shown in **Figure 2.5**.



5 fixed spots per frame

1 random spot per frame

- **Figure 2.4 – Location of Spots on the Video Frame**



- **Figure 2.5 – Randomisation of Spots for a Transect as Shown on the Video Frame**
Transect 1 for Cornelisse Shoal 1 (not to scale)

The substrate type beneath the respective spots was assigned one of the following 14 benthic categories (also refer to **Figure 2.6**):

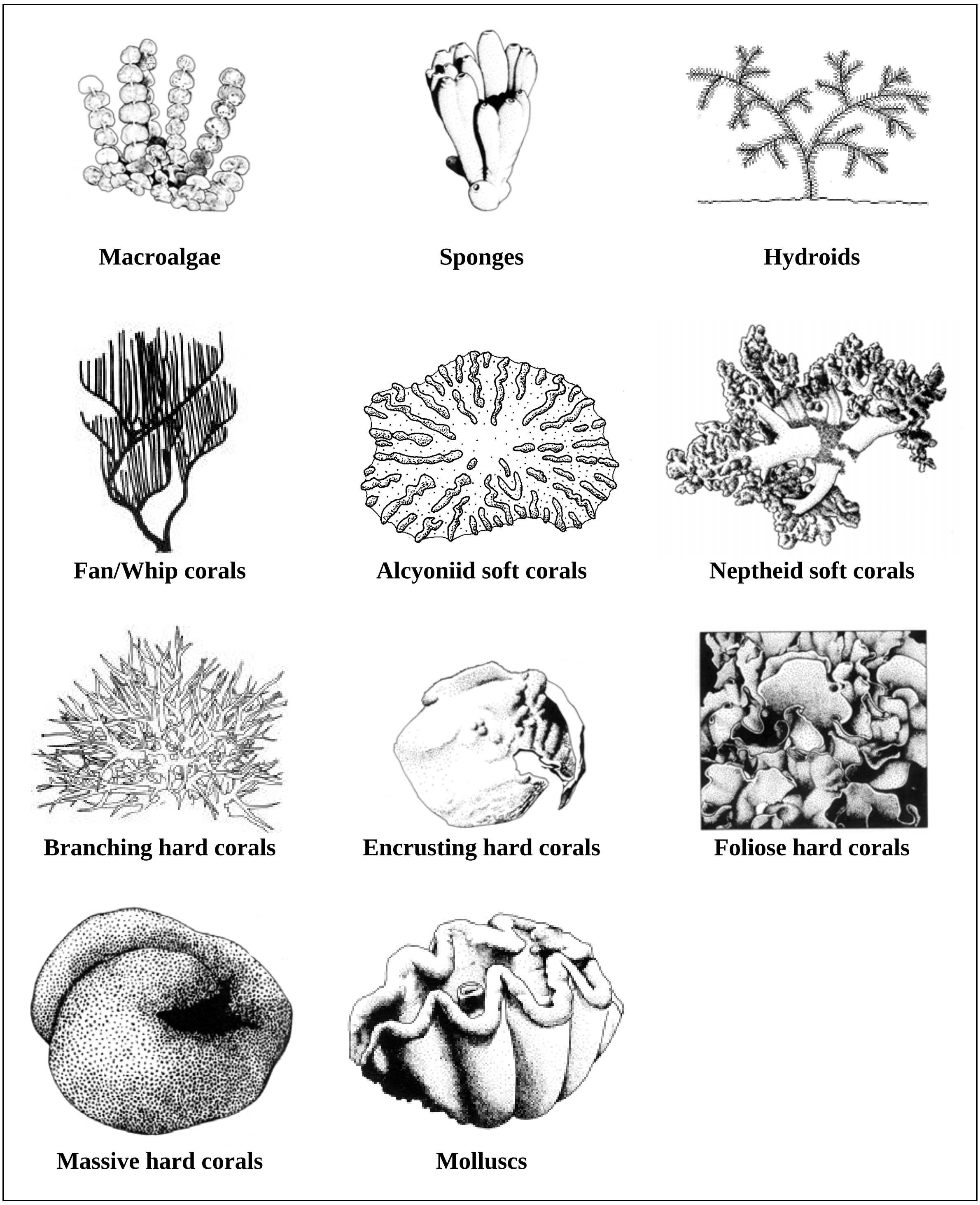
- sand;
- rubble;
- rock;
- macroalgae;
- sponges;
- hydroids;
- fan/ whip corals (soft coral group);
- nephtheid soft corals;
- alcyoniid soft corals;
- branching corals;
- encrusting corals;
- foliose corals;
- massive corals; and
- molluscs.

No seagrass was observed along any transects at the sites surveyed by diver video. Seagrass has been identified at other locations, the most substantial habitat being four areas of *Halophila ovalis* in close proximity to each other in the embayments to the west of Finucane Island, totalling approximately 85 hectares (see **Section 3.2.4**).

Since the purpose of the transect analyses was to provide a general description of the benthic habitat, and the potential presence of BPPs, the benthos was identified to functional group level rather than genus or species. Once a benthic descriptor was assigned and the respective frame completed, the program advanced the recording to the next randomly selected frame and this process was repeated until the designated number of frames was completed. Upon completion, the computer program tallied counts and percentage cover (Osborne and Oxley 1997). The data for each station were exported into an Excel spreadsheet for graphical presentation.

Data have been presented as percentage cover of each benthic category at each site. In addition, the data were grouped into six categories and graphically presented. These groupings were as follows:

- three abiotic categories (sand, rubble and rock);
- BPP hard corals (branching, encrusting, foliose and massive);
- BPP macroalgae;
- sponges;
- soft corals (fan/ whip corals, neptheid and alcyoniid soft corals); and
- other sessile invertebrates (hydroids, molluscs and ascidians).



- **Figure 2.6 – Benthic Life-Form Categories (from English et al 1997)**

2.4. Subtidal Habitat Modelling

2.4.1. Predictive Modelling, Validation and Mapping

The distribution and spatial extent of benthic habitats found in the study area of the proposed Outer Harbour Development were modelled and predicted using a combination of high resolution LiDAR bathymetry data and in-field survey, or ground truthing, data. While such an approach is relatively new, it has previously been used for the broad scale mapping of marine benthic habitats for management (e.g. Holmes *et al*. 2007), research (e.g. Holmes *et al*. 2008), and commercial activities (SKM, unpublished data). The full methods used to develop the models and maps of the subtidal habitat are provided in **Appendix B**, and consist of the following components:

1) From the bathymetry data, a series of secondary data sets that provide textural information about the seafloor are developed (e.g. slope, aspect, and rugosity (roughness factor)). With the bathymetry data, these data provide a quantitative description of the physical characteristics of the seabed.
2) The presence/absence of each of the classes (or types of biota) of interest are determined from the collected in-field ground truthing data (the observed distribution of each class in the diver video transects). A presence is recorded when the habitat class or biota type has a coverage greater than 5%, otherwise, an absence is recorded.
3) Models (Classification and Regression Tree – CART) are developed by relating the observed distribution data of each class (75% of it) to the physical characteristics of the seabed. The accuracy of each model must be validated using the remaining 25% of the ground truth data that was not used to develop the models. That is, the predicted distribution is compared to the observed distribution for this 25% of data to provide a measure of accuracy.
4) These models are then used to predict the distribution of each type of biota present at any location across the extent of the bathymetry data, creating full coverage maps of the predicted distribution of each biota and substrate class (either individually or combined).
5) The predicted distributions of each class can then be used to develop combined habitat maps (i.e. combine substrate and biota types) for the area of interest. The resulting maps can have various combinations of biota distribution displayed to represent the distribution of habitat likely to support that type or combination of biota types.

As the primary intent of the mapping was to determine the distribution of benthic habitat types and in particular BPPH, the final combined map has placed greater importance on displaying the distribution of where BPPs (namely hard coral and macroalgae) do or could grow, thus representing BPPH (see **Section 3.1**).

2.4.2. Spatial Accuracy of Predictive Modelling

The bathymetry data points were obtained to an accuracy of 3.5 m in the horizontal (*x*, *y*) plane and 0.5 m in the vertical (*z*) plane by aerial surveys using LiDAR equipment and converted into a bathymetry grid dataset with a 5 m x 5 m resolution. The data used in the model (bathymetry and secondary data) were based on this grid. Field sites investigated by divers and video tows were located by GPS to an accuracy of, at worst, 10 m in the horizontal plane. As such, the maximum offset between the location on the seabed where a ground truth point was 'recorded' to be and where it 'actually' was would be up to 10 m in the horizontal plane, which equates to an offset of 2 grid cells in the bathymetry and secondary data grids. As the study area is approximately 3,650 km^2, a potential discrepancy of 10 m is considered to be acceptable. Tests of the accuracy of the predicted distributions versus observed data support this view (see **Section 3.1**).

2.4.3. Habitat Modelling Limitations

The model is used as a predictive tool to support assessment and decision making. It is important to consider that no model can ever replicate the complexities of the natural system. The extent and range of the collected ground truthing data will not only influence the models developed (the relationships that the models define), but will also influence the assessment of model accuracy.

It is very difficult to sample all of the environmental conditions (including substrate type, biota and habitat combinations) found in such a large study area. Consequently, some conditions will not have been sampled as often as others and this may result in the models not defining these aspects of the habitat-environment relationships as well as it could for others. For example, the regions near the proposed development footprint were sampled more heavily than locations nearer to the boundary of the study area. The consequence of this is that the model is likely to over predict the distribution and spatial extent that benthic biota actually occurs, given that it predicted biota to occur where there was topographically complex seabed. It could therefore be considered that the modelling exercise produces results that are conservative and likely to indicate greater distribution and spatial extent of BPPH than may occur.

3. Results

3.1. Subtidal Habitat Mapping Outputs

This section presents the results of the classification modelling process used to map different substrate and biota classes across an area of approximately 3,650 km^2 (365,000 ha). The classified map outputs are presented for all substrate and biota types, along with corresponding map accuracy. Analyses of field data recorded at diver video transect sites used to inform the modelling process is provided in **Section 3.2**.

3.1.1. Predicting the Distribution of Substrate Types

Final substrate types of 'hard substrate' (either rock or rubble as described in **Section 3.2**) and 'sediment' were predicted with high accuracy (97% and 87% correct classification rate respectively, **Table 3.1**). The predicted distribution of each of these substrate types throughout the study area are shown in **Figure 3.1** and **Figure 3.2**, respectively. When combined, the predicted distribution of these two substrate classes created a third class, 'sediment covered hard substrate'. The predicted distribution of the three different substrate types is provided in **Figure 3.3** and the area that each covered (in hectares and as a proportion of the total area) is given in **Table 3.2**.

Sediment was by far the most prominent substrate class mapped and was predicted to occur over 88% of the study area. Hard substrate was predicted to occur over 7% of the area and sediment covered hard substrate was predicted to cover less than 3% of the area. The models were unable to predict the distribution of substrate with any confidence across the remaining 1.7% of the area.

3.1.2. Predicting the Distribution of BPP and Other Biota Types

The distribution of the different biota classes were found to be accurately predicted with correct classification rates above 82% for all classes (**Table 3.1**). The predicted distributions of each of the modelled biota classes are shown in **Figure 3.4** – **Figure 3.8**. These figures demonstrate that the majority of the BPP and non BPP biota classes were predicted to occur on the areas of topographic complexity also associated with hard substrate; essentially the limestone ridgelines and shoals visible on LiDAR imagery (**Figure 3.12**).

Seagrass was mapped separately in the sheltered embayments between Weerdee Island and Downes Island, but was not observed at sufficient ground truthing sites within the LiDAR mapping area to enable it to be modelled. Hard corals were predicted to occur over approximately 5.0% of the total area (18,089 ha) making this the largest individual area of BPP. Macroalgae distribution overlapped with hard corals in many areas, occurring as mixed habitat, but had a slightly smaller predicted area of distribution within the study area (15,866.3 ha; 4.4%) (**Table 3.3**). As the hard substrate areas were identified as the primary substrate that do support hard coral BPP or could support hard coral BPP, all hard substrate including presently bare hard substrate is therefore included as BPPH.

Non BPP biota categories included sponges, which were predicted to occur over 7,997.2 ha, or 2.2% of the total area and soft corals which were predicted over only 3402.5 ha or 0.9%.

Invertebrates are a non BPP mapping category and include all sessile (attached to the seabed) invertebrates (other than hard corals). Invertebrates were predicted to occur over the largest area of any of the biota classes (20,288.4 ha, 5.6% of total area) however, the distribution is largely overlapping with that of hard corals and other biota classes as they are predicted to mainly occur on areas of hard substrate, which is also classed as BPPH as its supports some BPP (hard corals). Invertebrates in this class such as sponges, soft corals, gorgonian corals and ascidians are also predicted to extend from the ridgelines out onto sediment covered hard substrate and further down the slope into deeper water than hard corals, hence the wider distribution.

Of the area predicted to contain BPP and non BPP biota, hard coral was predicted to occur in isolation across 10,169 ha (21% of biota covered area) and this was mainly along the ridgelines of the hard substrate (**Figure 3.4**). BPP consisting of macroalgae were predicted to occur in isolation across 7,911 ha (17% of biota covered area) particularly in the nearshore areas, but offshore were predicted to occur mainly as part of mixed communities (**Figure 3.8**).

Non BPP classes including invertebrates were predicted to occur in isolation over 9,933 ha (21% of biota area), but across the less topographically complex areas bordering the ridgelines (**Figure 3.7**). The remaining 41% of the area mapped as biota contained mixed assemblages of BPP and non BPP biota.

3.1.3. Final Combined Habitat Maps

The final combined habitat map showing the four broad classes defined in **Appendix B** is displayed in **Figure 3.9** and the areas are given in **Table 3.4**. This map further demonstrates that the area is composed primarily of bare sediment or bare sediment covered hard substrate. Areas of BPPs and other biota are typically found in areas of topographic complexity where the hard substrate rises from the seabed as can be seen from the LiDAR imagery in **Figure 3.12**.

As previously stated, non-BPPH areas of bare substrate make up the majority of the study area covering 315,816 ha or 86.7% of the total mapped area (**Table 3.4**). The combined habitat class of hard substrate, both with and without BPPs, has been classed as BPPH because any hard substrate was considered to potentially support BPP and this class occurred over 25,582 ha or 7% of the area mapped. The next largest BPPH class was sediment supporting BPP, predominantly macroalgae, this class occurred over an area of approximately 11,681 ha or 3.2% of the area mapped. The remaining BPPH class, sediment covered hard substrate with BPPs including mixed macroalgae and sparse hard coral, this class occurred over 4,596 ha or 1.3% of the area mapped (**Table 3.4**).

On the figures illustrating habitat classes over the entire study area, it is possible for smaller classes to not display on the figures due to resolution. For clarity, two areas of the mixed biota have been shown at a much higher resolution in **Figure 3.10** and **Figure 3.11** to demonstrate the mixed nature of the benthic communities in the areas where BPP types and other biota are all present in varying percent covers.

Table 3.1 – Accuracy of the Habitat Modelling Predictions

Habitat class	Prevalence in training data (n = 316)	Prevalence in testing data (n = 109)	Area Under Curve (AUC)[1]	Discriminatory ability	Correct classification rate
Hard substrate	119[2]	36	0.91	high	97%
Sediment	288	97	0.79	acceptable	87%
Hard coral	63	21	0.84	high	87%
Soft coral	40	16	0.98	high	94%
Sponges	81	28	0.88	high	84%
Invertebrates	118	38	0.85	high	82%
Macroalgae	90	30	0.96	high	94%

Note: accuracy of model predictions was evaluated by calculating AUC values and the correct classification rate (%) using testing data withheld from the modelling process (i.e. 25% of the collected ground truth data was withheld and compared to the predicted values for the same locations).

Also note that n = 425 (316 + 109) due to the acquisition of multiple data points from towed video sites (see **Section 2.3.1**).

Table 3.2 – Areal Coverage Predicted for the Different Substrate Classes

Substrate class	Area (ha)	Proportion of total area (%)
Sediment	322,020	88.4
Hard substrate	25,632	7.0
Sediment covered hard substrate[3]	10,426	2.9
Undefined substrate[4]	6,022	1.7

[1] See **Appendix B** for further description

[2] Hard substrate recorded at 119 of 316 data points

[3] Areas where both sediment and hard substrate were predicted to occur

[4] Undefined substrate: where the modelling could not predict the substrate type with confidence

Table 3.3 – Areal Coverage Predicted for the Different Individual Biota Classes

	Biota class	Area (ha)	Proportion of total area (%)
BPP Biota Classes	Hard coral	18,089	5.0
	Macroalgae	15,866	4.4
Non BPP Biota Classes	Sponges	7,997	2.2
	Soft coral	3,402	0.9
	Sessile invertebrates[1]	20,288	5.6

Table 3.4 – Areal Coverage Predicted for the Four Aggregated Habitat Classes

	Habitat Class	Area (ha)	Proportion of total area (%)
BPPH Classes[2]	Hard substrate (with & without BPP)[3]	25,582	7.0
	Sediment covered hard substrate with BPP[4]	4,596	1.3
	Sediment with BPP[5]	11,681	3.2
	Sub Total	41,859	11.5
Non BPPH	Bare sediment not BPPH[6]	315,816	86.7
	Unclassified habitat[7]	6,429	1.8
	Sub Total	322,245	88.5
	Total	**364,103**	**100**

[1] Sessile invertebrates (attached to seabed) other than hard coral.

[2] These classes are considered capable of supporting BPPs and as such, the combination of the areas in these classes can be considered to be the benthic primary producer habitat (BPPH) within the study area.

[3] BPP supported by this class is mainly hard corals, macroalgae, turf algae and coralline algae. Also includes hard substrate that may be bare but could potentially support BPP.

[4] BPP supported by this class is mainly macroalgae and turf algae.

[5] This class of sediment with BPP is considered to mainly support macroalgae.

[6] May or may not contain invertebrates, but does not include BPPs

[7] Unclassified: the area where the modelling could not predict the habitat type with confidence

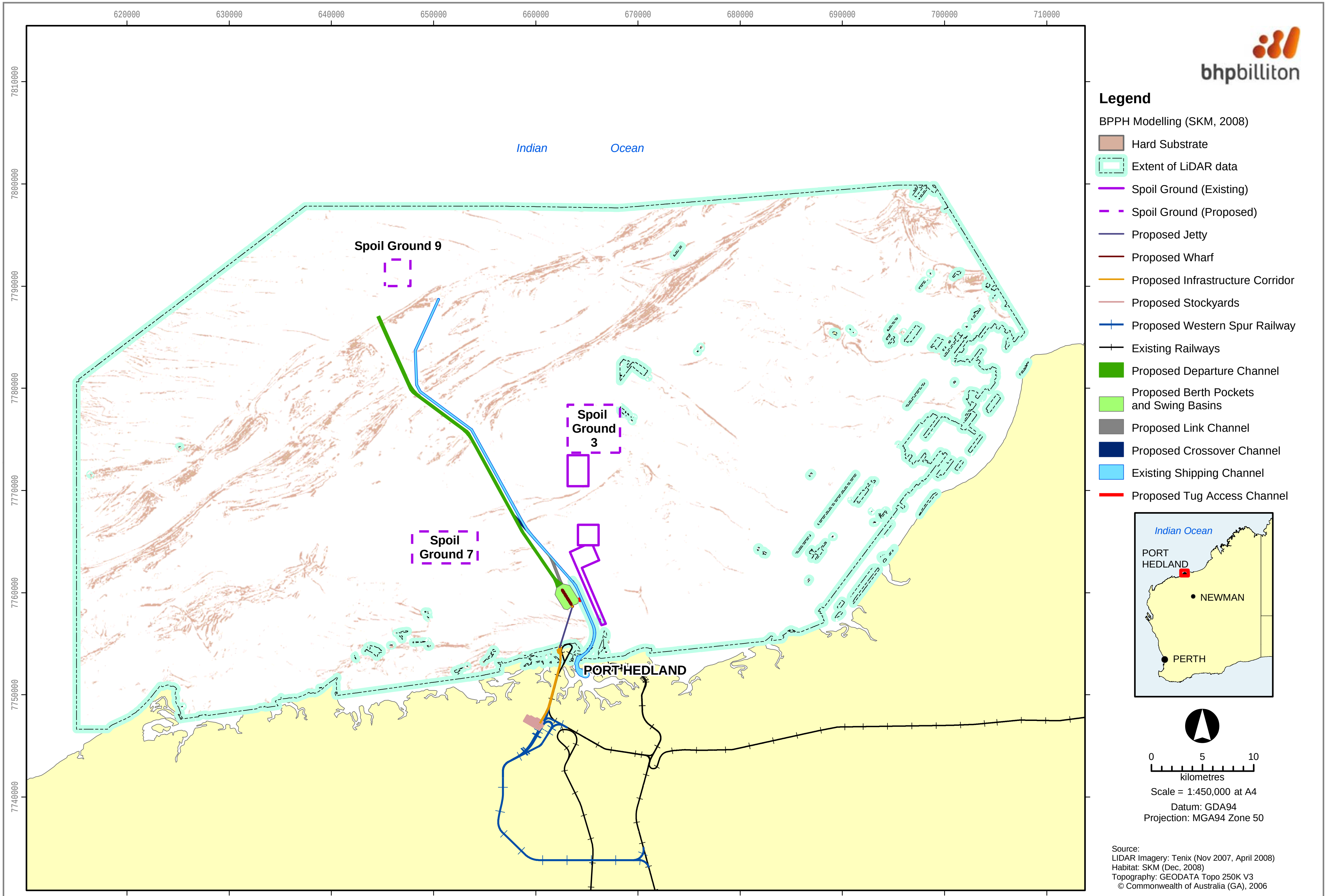


Figure 3.1 Predicted Distribution of Hard Substrate in Relation to the Proposed Infrastructure

130\g164_WV03716_Rev0

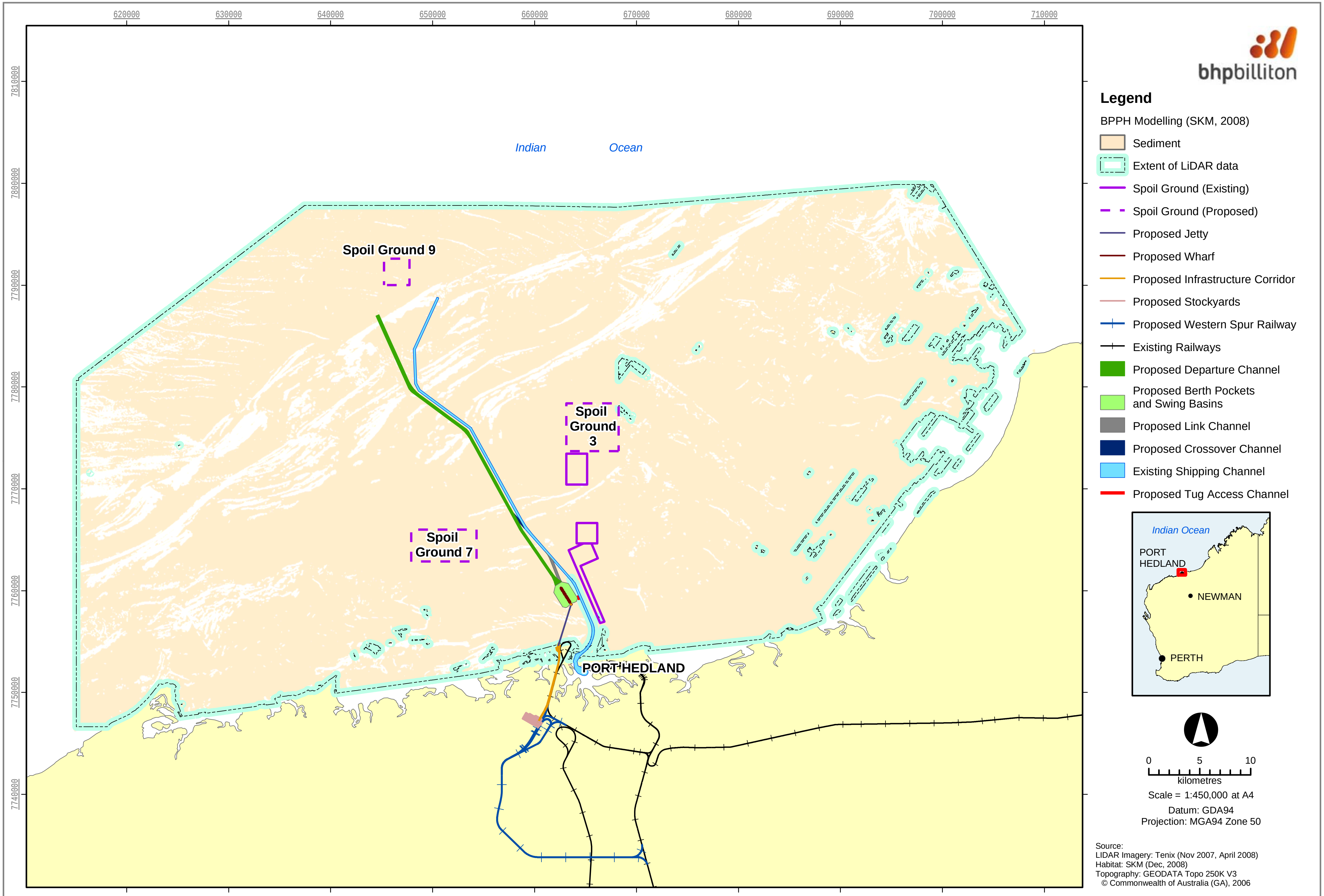


Figure 3.2 Predicted Distribution of Sediment in Relation to the Proposed Infrastructure

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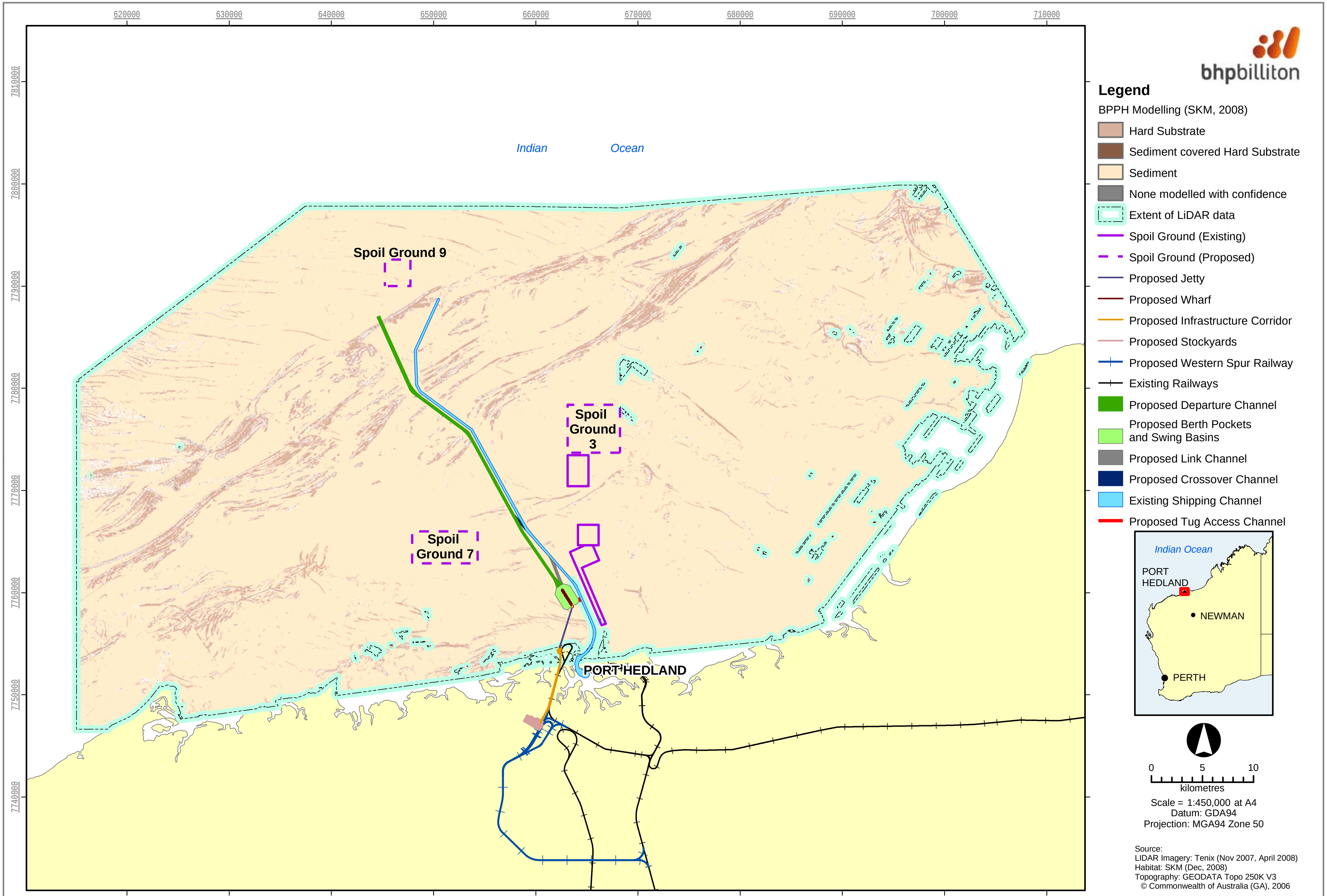


Figure 3.3 Predicted Distribution of the Three Substrate Classes in Relation to the Proposed Infrastructure

130\g171_WV03716_Rev0

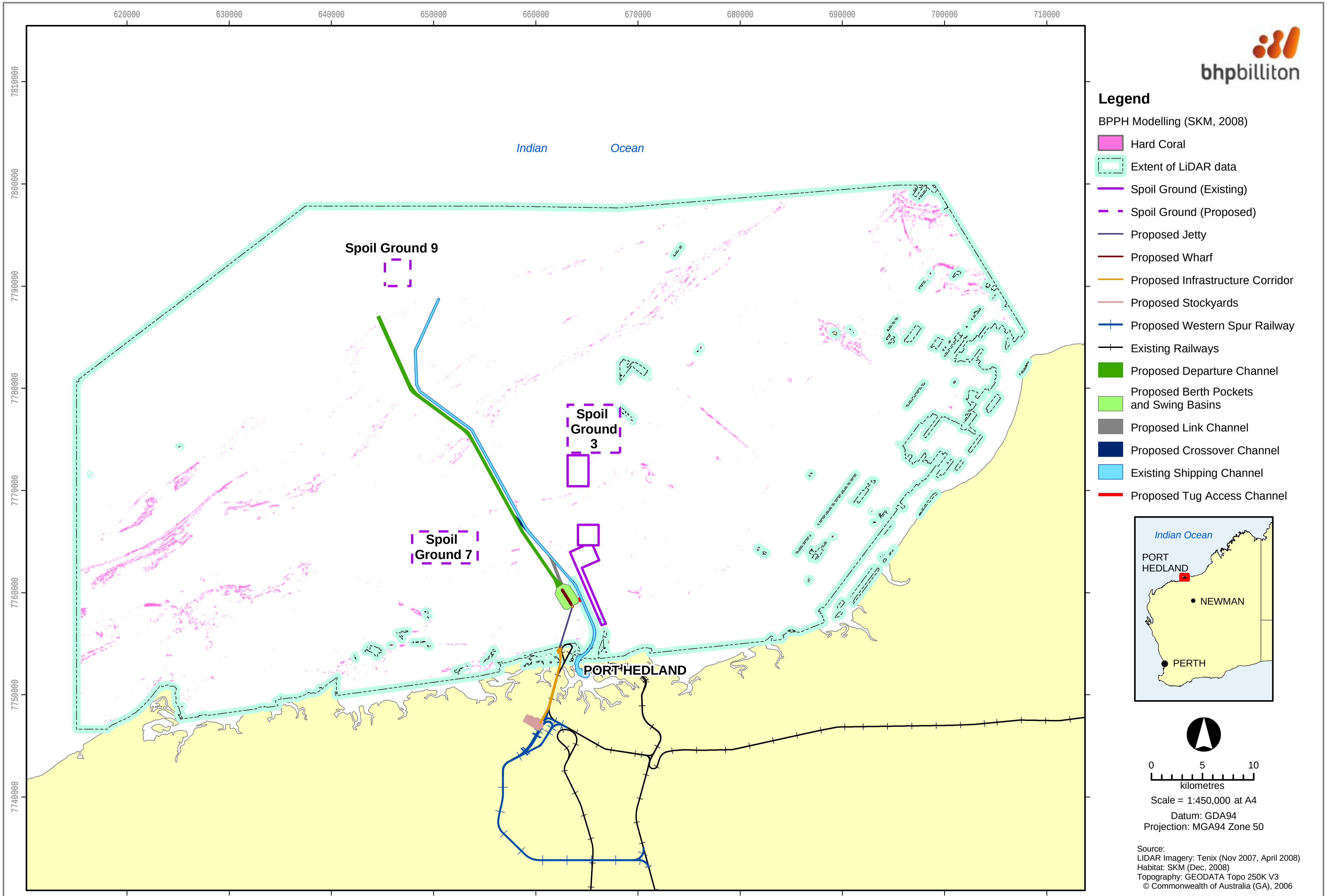


Figure 3.4 Predicted Distribution of Hard Corals in Relation to the Proposed Infrastructure

130\g166_WV03716_Rev0

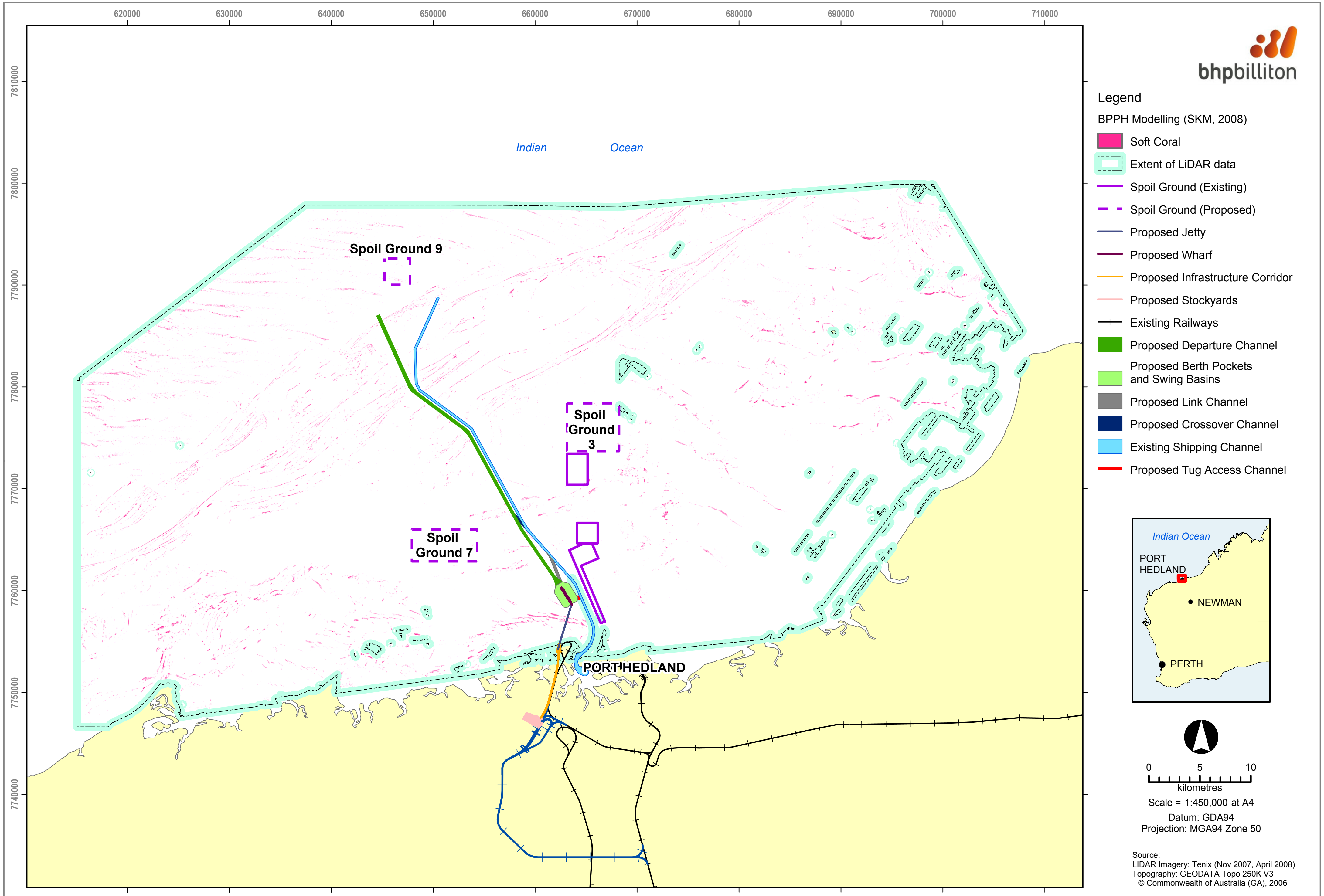


Figure 3.5 Predicted Distribution of Soft Corals in Relation to the Proposed Infrastructure

130\g167_WV03716_Rev0

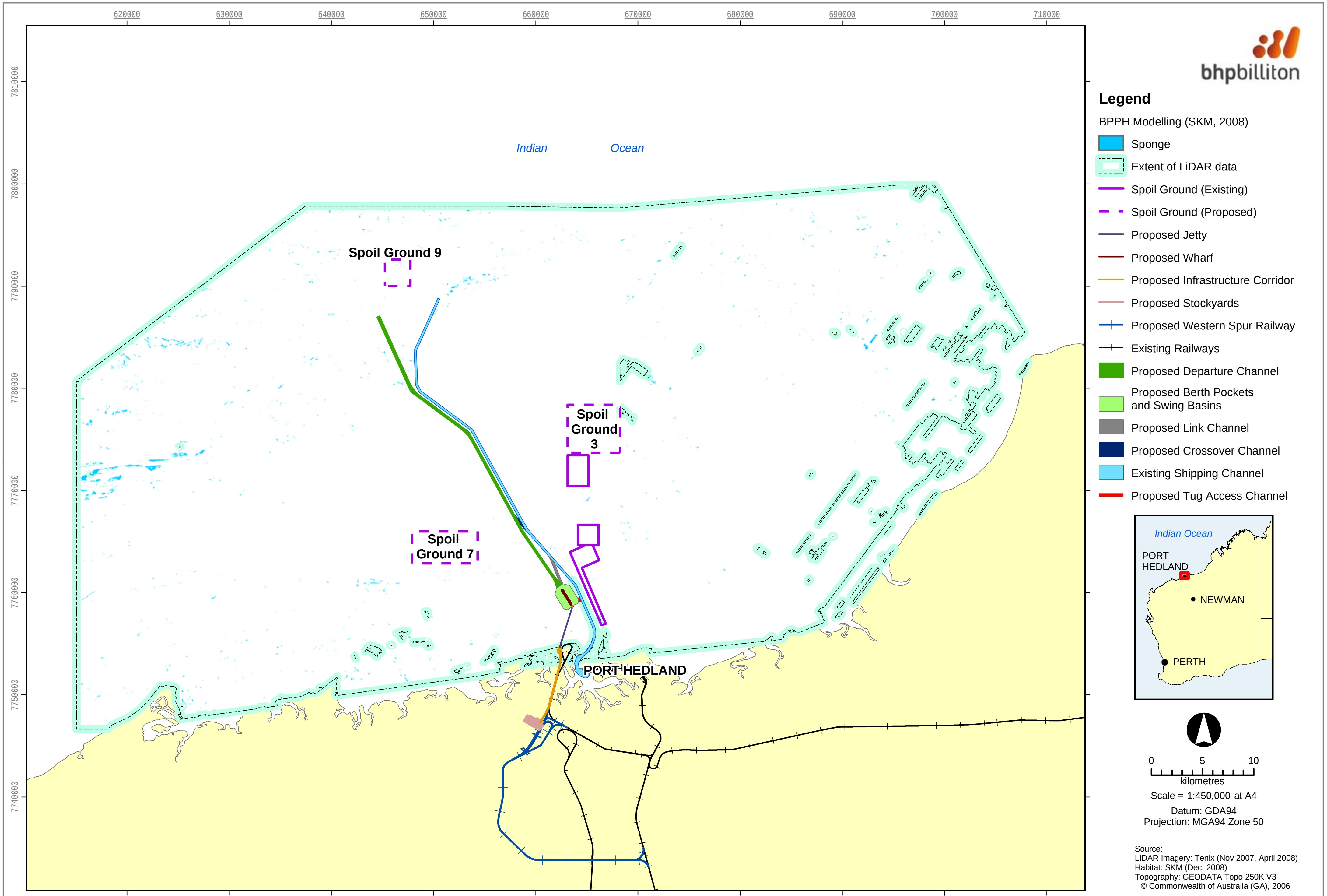


Figure 3.6 Predicted Distribution of Sponges in Relation to the Proposed Infrastructure

130\g168_WV03716_Rev0

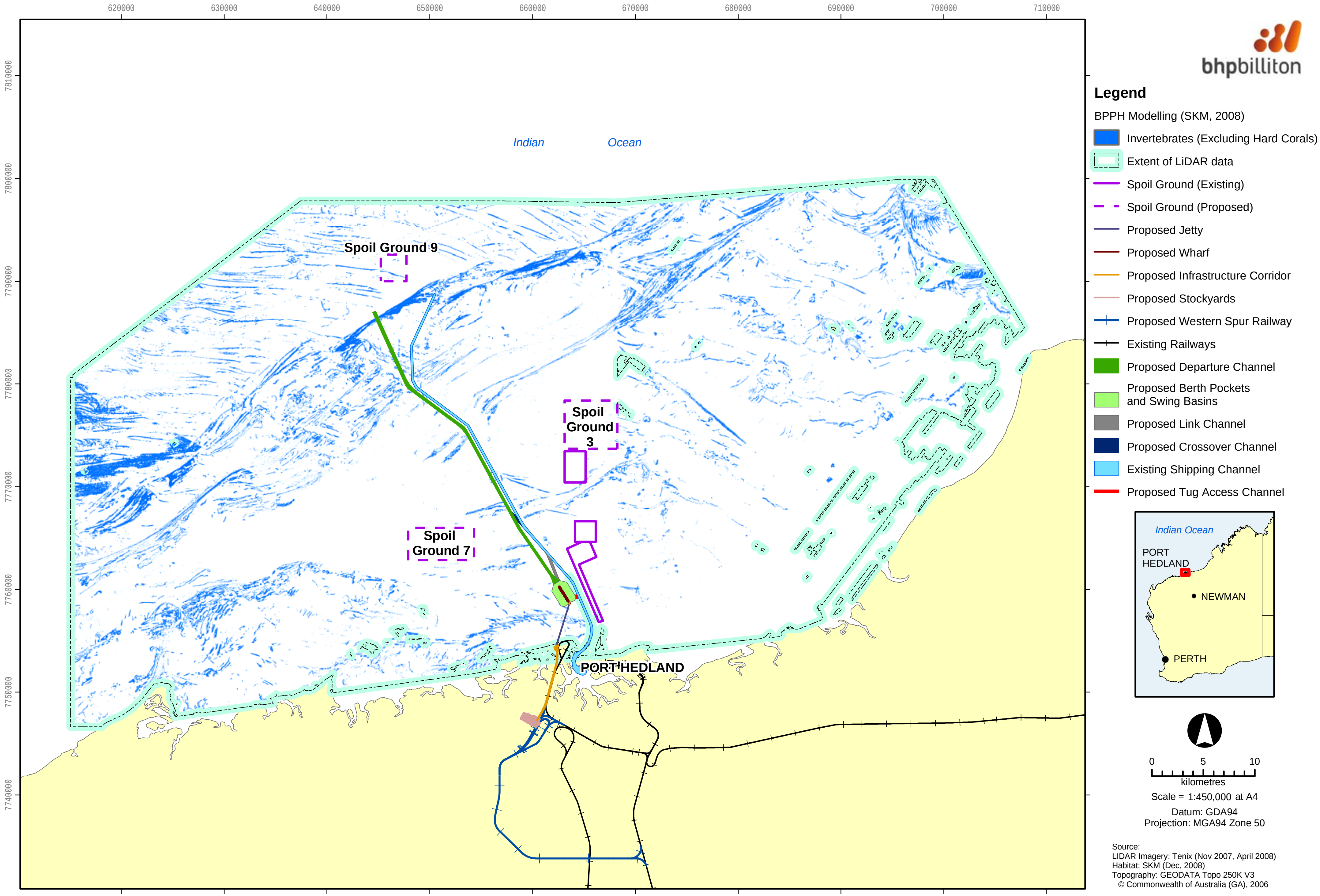


Figure 3.7 Predicted Distribution of Invertebrates (Excluding Hard Corals) in Relation to the Proposed Infrastructure

130\g169_WV03716_Rev0

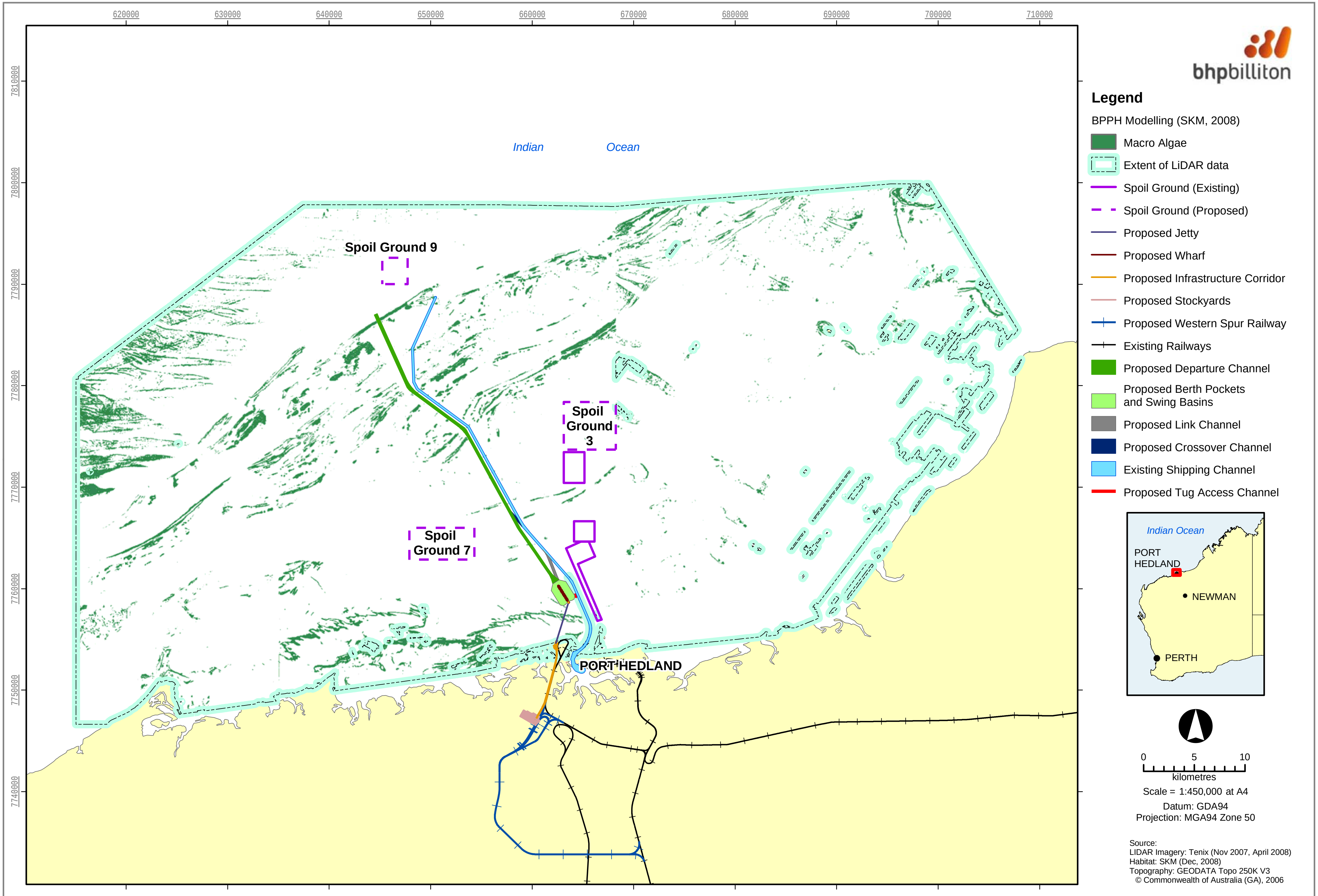


Figure 3.8 Predicted Distribution of Macroalgae in Relation to the Proposed Infrastructure

130\g170_WV03716_Rev0

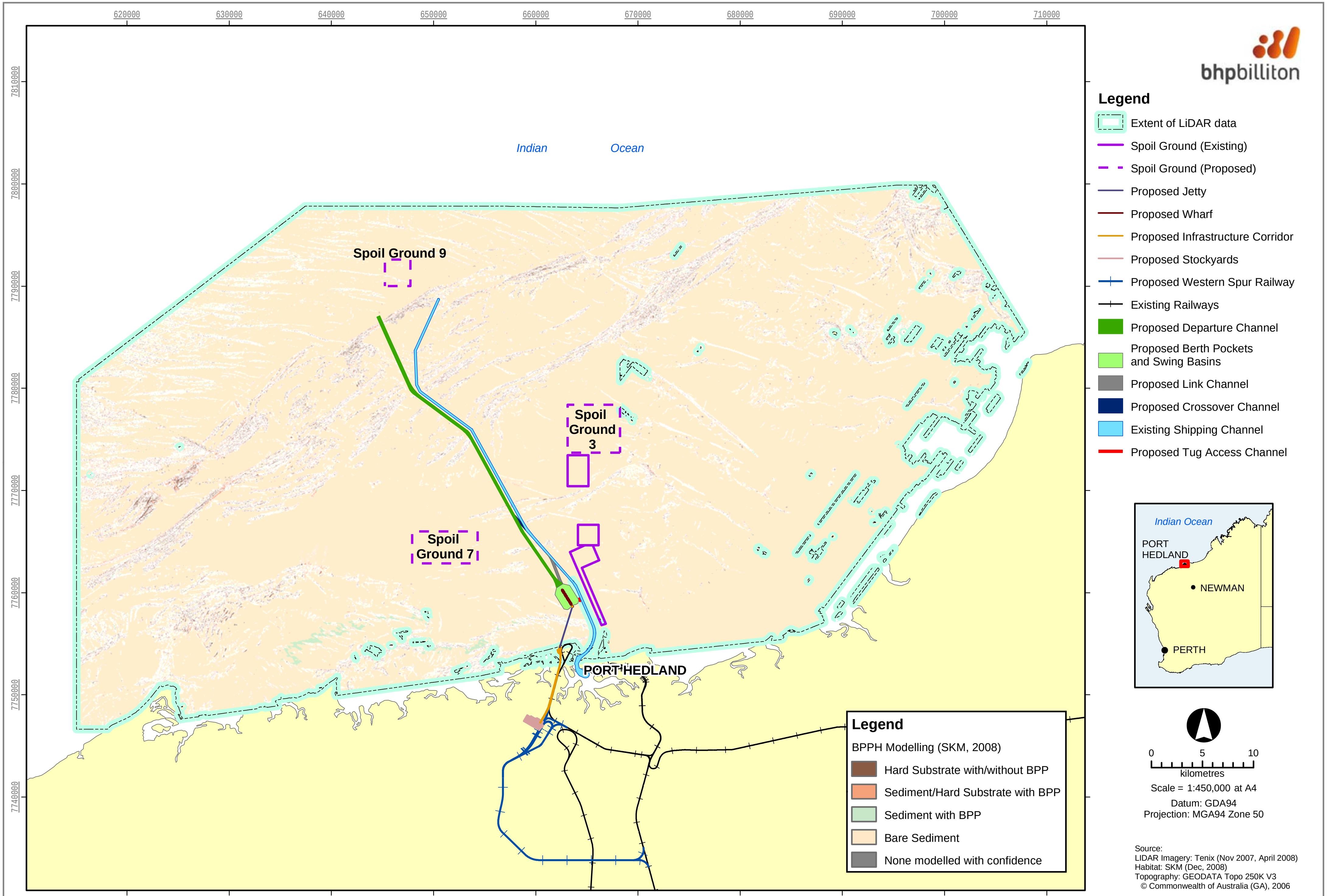


Figure 3.9 Final Combined Habitat Map Showing the Predicted Distribution of Four Major Groups in Relation to the Proposed Infrastructure

130\g172_WV03716_Rev0

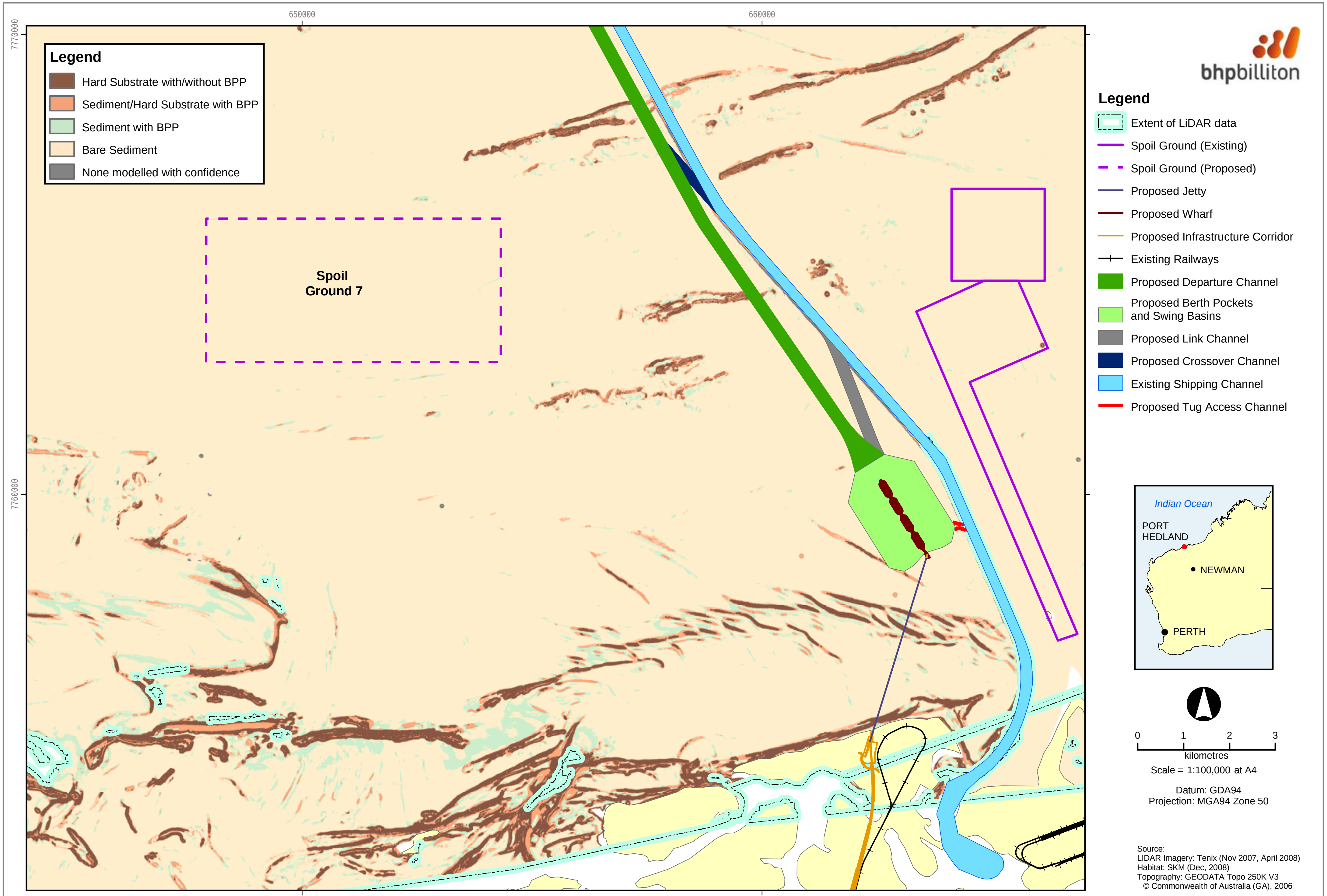
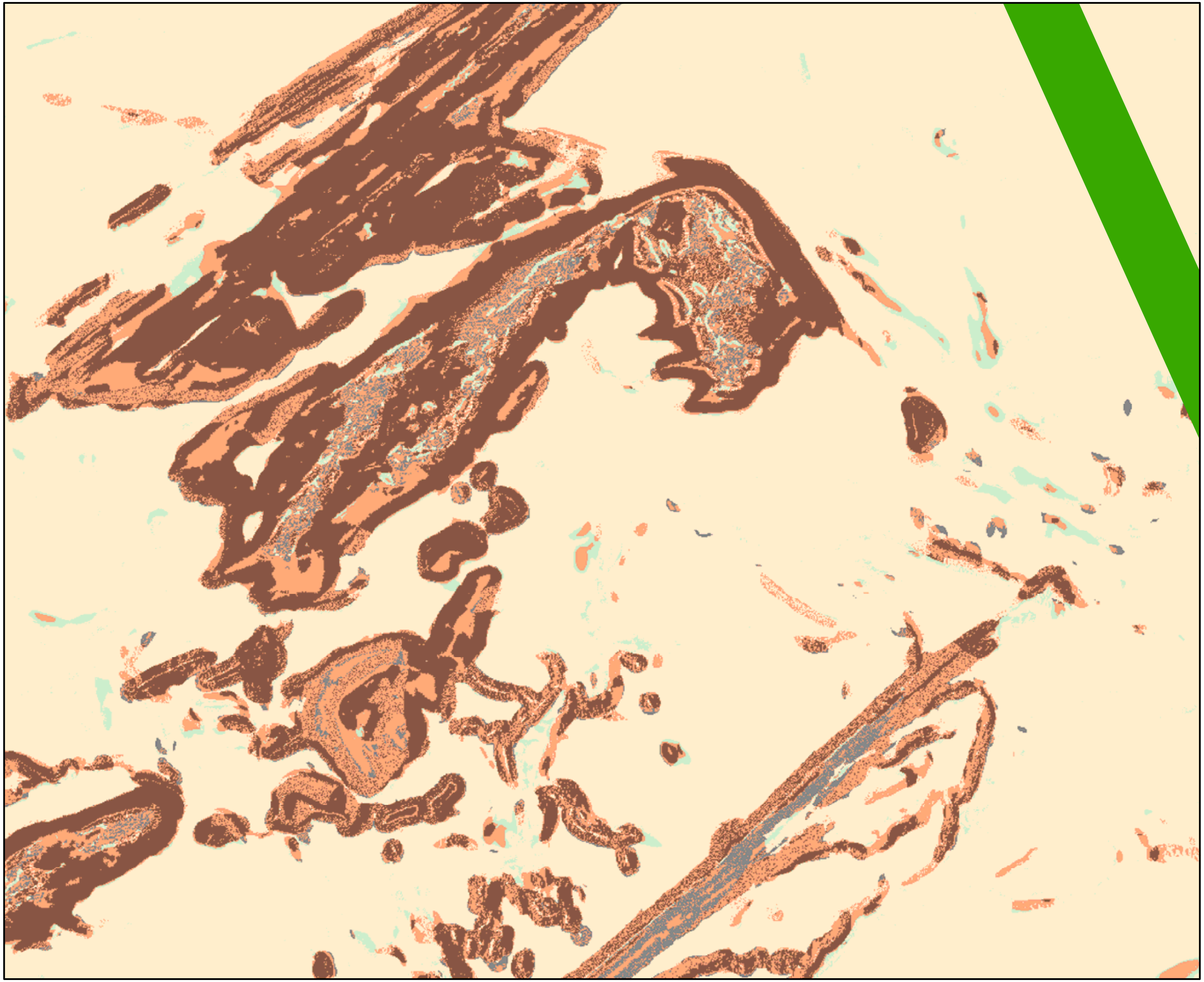


Figure 3.10 Detail of an Inshore Area of the Final Combined Habitat Map Shown in Figure 3.9

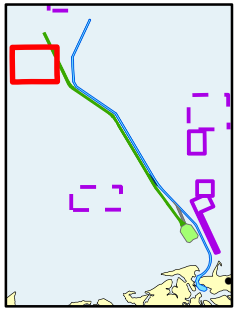
130\g173_WV03716_Rev0



Legend

BPPH Modelling (SKM, 2008)

- Hard Substrate with/without biota
- Sediment/Hard Substrate with BPP
- Sediment with BPP
- Bare Sediment
- None modelled with confidence
- Proposed Departure Channel



0 300 600 900
metres

Scale = 1:25,000 at A4

Datum: GDA94
Projection: MGA94 Zone 50

Source:
LIDAR Imagery: Tenix (Nov 2007, April 2008)
Habitat: SKM (Dec, 2008)
Topography: Geoscience Australia,
GEODATA Topo 250K V3

Figure 3.11 Detail of an Offshore Area of the Final Combined Habitat Map Shown in Figure 3.9

130\g174_WV03716_Rev0

3.2. Field Survey Results

The prevalent features of the study area are a series of hard bottom ridgelines running in a south-west to north-east direction. They are surrounded by seabed which is generally – 10 m Chart Datum (CD) or deeper. In shallower waters nearer to the coastline, benthic habitat is dominated by sand and mud. However, BPPH and sparse BPPs (hard corals and macroalgae) were observed on intertidal platforms of near shore islands.

For practicality, in this section summaries of benthic habitats within the study area have been divided into systems based on the seabed structural features identified from LiDAR bathymetry. Note that the systems listed below are not indicative of management units and were simply created to assist descriptions in this report. The management units for BPPH are defined and described in the Subtidal BPPH Impact Assessment Report (SKM 2009a).

The systems are described in the groupings outlined below.

Offshore Ridgeline Systems:

- Outermost Ridgeline;
- Middle Ridgeline; and
- Innermost Ridgeline.

Inshore Ridgeline Systems:

- Minilya Bank area;
- Weerdee Ridgeline;
- Proposed Port area; and
- Cape Thouin area.

Island Ridge Systems:

- North Turtle Island;
- Little Turtle Island;
- Weerdee Island; and
- Finucane Island (surveyed on foot, no analysis of video transects).

These systems are shown in **Figure 3.12 - Figure 3.14**. Each of the video transect sites are described based on the following information:

- general location description;
- description of the habitat;
- tabulation of habitat classification by percentage cover; and
- figures showing the habitat percentage cover by:
  - benthic categories; and
  - grouped benthic categories.

The locations of all video transect sites described in **Section 3.2.1** – **Section 3.2.4** are shown on **Figure 2.3**. A representative photograph of each site is provided in **Appendix D**.

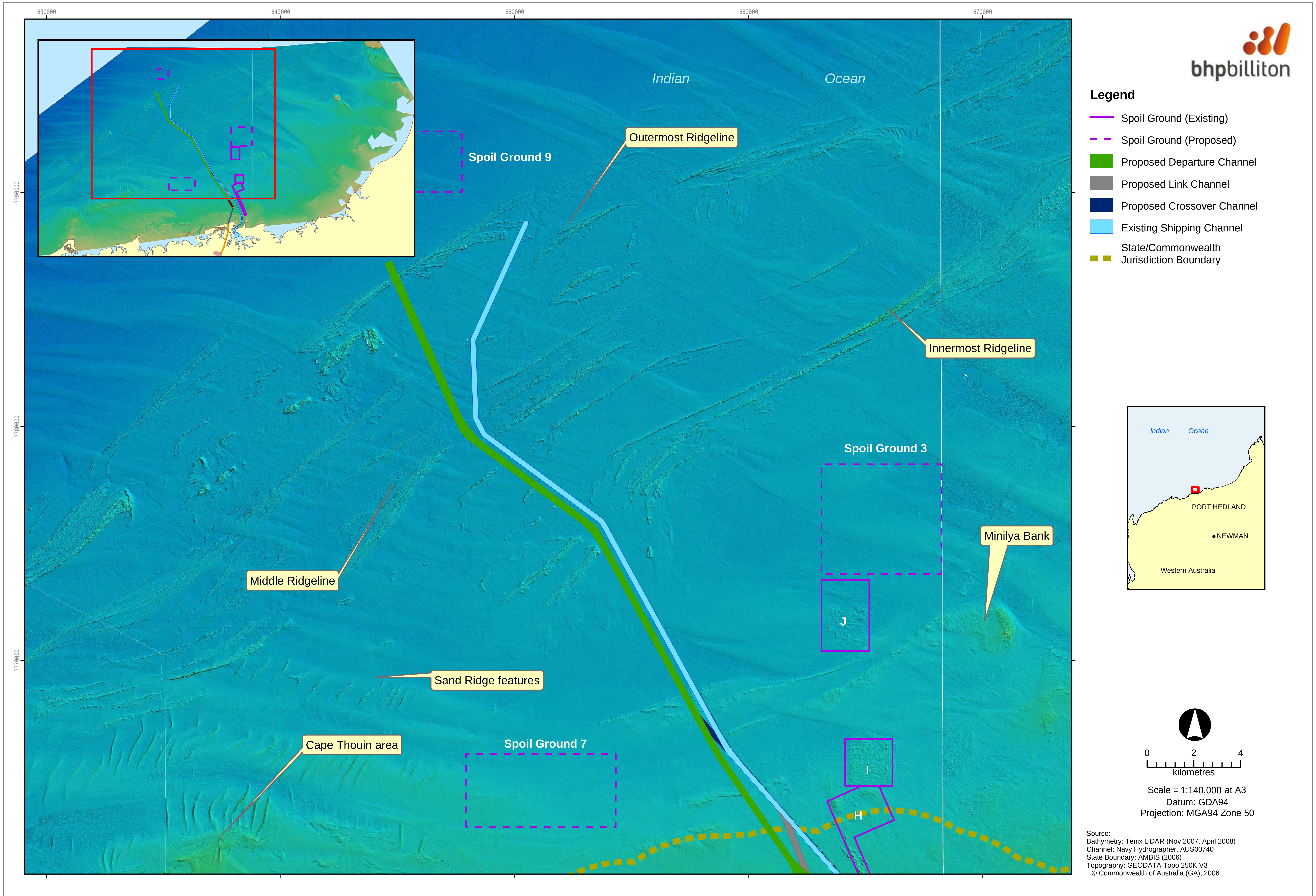


Figure 3.12 Sea Bed Topographic Features of the Offshore Part of the Survey Area

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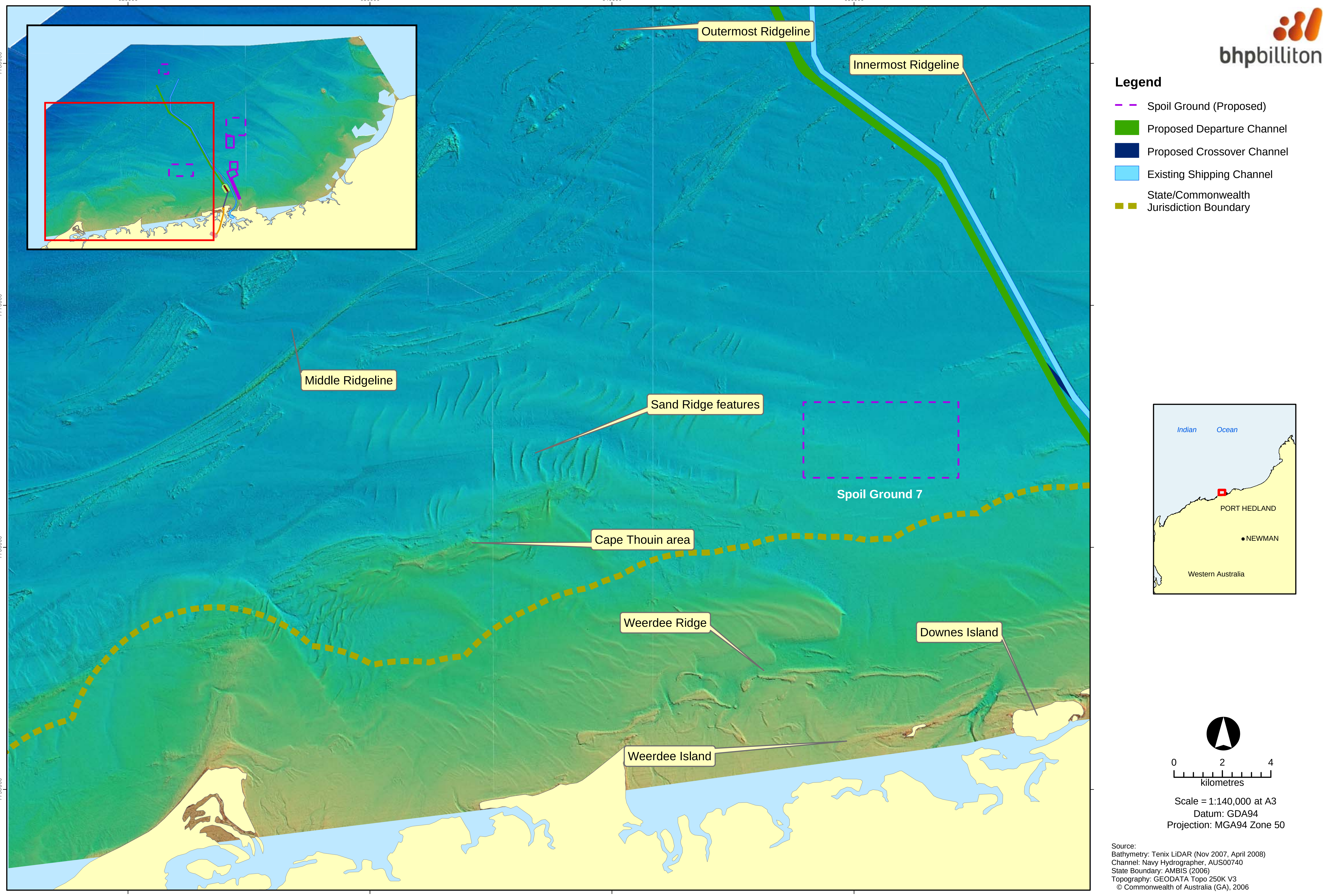

Figure 3.13 Sea Bed Topographic Features of the Western Part of the Survey Area

130\g443_WV03716_Rev0

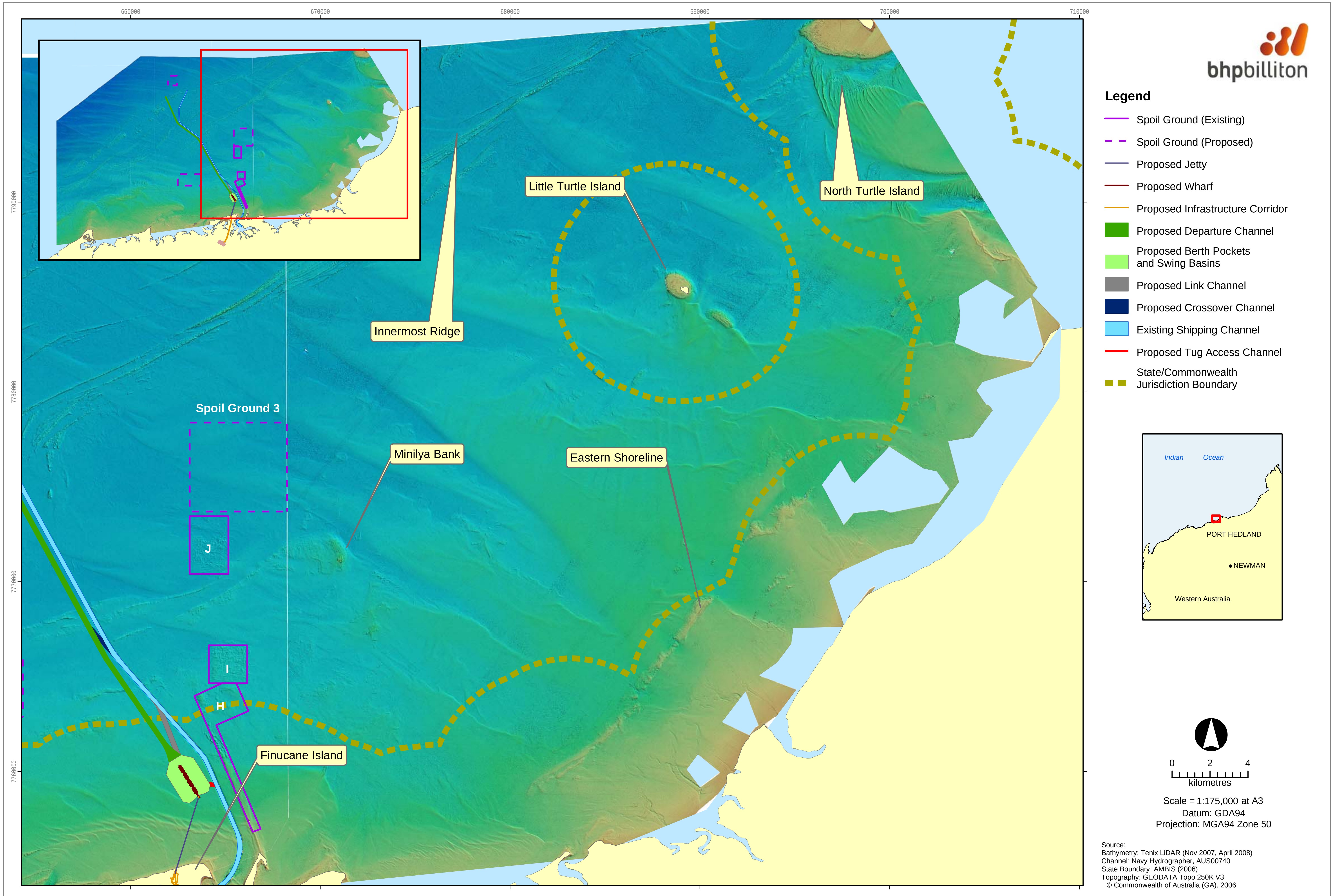

Figure 3.14 Sea Bed Topographic Features of the Eastern Part of the Survey Area

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3.2.1. Offshore Ridgeline Systems

The offshore ridgeline feature shown in **Figure 3.12** consists of three main ridges running roughly parallel to the coastline with numerous small ridges and shoals. For the purposes of the survey results these are discussed below as the Outermost, Middle and Innermost Ridgeline.

Outermost Ridgeline

This ridgeline is approximately 37 km north-west of the entrance to Port Hedland Harbour. The system is approximately 68 km in length and runs in a south-west to north-east direction. Cornelisse Shoal forms part of this ridgeline complex but is not continuous along its length; ridge peaks range from - 3.2 to - 9.0 m CD. Seven sites were surveyed along the length of this ridgeline (**Figure 2.3**). The composition of the benthic community at these sites is provided as percentages in **Table 3.5** and graphically in **Figure 3.15**.

The abiotic component varied between sand-rubble dominated seabed and rock. On the hard substrate BPPH, the BPP was predominantly macroalgae (1.3–14.7%, average 4.9%) and hard corals (4.9–27.1%; 13.7%). The hard corals were dominated by foliose, massive and encrusting varieties; however, there was a small component of branching corals (*Acropora* spp) at CNS3 and CNS4. The highest percentage cover of hard corals was located at the western most margin of the study area at CTR4. The coral categories observed were indicative of slightly turbid waters subject to strong hydrodynamic forces. The presence of a small proportion of branching corals (*Acropora* spp) on Cornelisse Shoal would indicate slightly less turbid conditions than at ridges closer to shore (Blakeway and Radford 2005).

The non BPP biota comprised mainly sponges (2.9–11.6%; average 6.9%). The shoal also had varying quantities (<5%) of soft corals and hydroids and molluscs.

Table 3.5 - Percentage Benthic Cover on the Outermost Ridgeline

Outermost Ridgeline	CTR4	CTR5	OSR2	CNS1	CNS2	CNS3	CNS4	Average % Cover
Water Depth (m CD)	6.2	12.3	9.3	10.3	10.7	8.6	10.3	
Categories:								
Sand	0.0	0.0	0.0	20.0	37.3	1.6	0.0	8.4
Rubble	0.0	0.0	0.0	14.0	29.6	31.3	1.8	11.0
Rock	58.2	74.7	71.6	26.9	7.6	49.6	79.3	52.6
Macroalgae	0.0	6.4	4.9	4.9	14.7	2.4	1.3	4.9
Sponges	11.6	9.1	5.1	8.7	3.3	7.6	2.9	6.9
Hydroids	0.0	0.0	0.2	3.6	2.4	0.0	0.0	0.9
Alcyoniid soft corals	1.1	0.2	0.9	0.7	0.0	0.0	0.9	0.5
Neptheid soft corals	2.0	0.2	0.2	0.7	0.0	0.0	0.2	0.5
Fan/whip corals	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Branching corals	0.2	0.0	0.0	0.0	0.0	0.4	0.9	0.2
Encrusting corals	12.2	5.8	11.3	11.1	0.9	4.7	7.3	7.6
Foliose corals	9.6	1.8	5.1	8.7	2.9	0.9	0.0	4.1
Massive corals	5.1	1.8	0.7	0.9	1.1	1.6	1.1	1.8
Molluscs	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.6
Grouped:								
Abiotic	58.2	74.7	71.6	60.9	74.4	82.4	81.1	71.9
Macroalgae BPP	0.0	6.4	4.9	4.9	14.7	2.4	1.3	4.9
Sponges	11.6	9.1	5.1	8.7	3.3	7.6	2.9	6.9
Soft corals	3.1	0.4	1.1	1.3	0.2	0.0	1.1	1.0
Hard corals BPP	27.1	9.3	17.1	20.7	4.9	7.6	9.3	13.7
Others	0.0	0.0	0.2	3.6	2.4	0.0	4.2	1.5

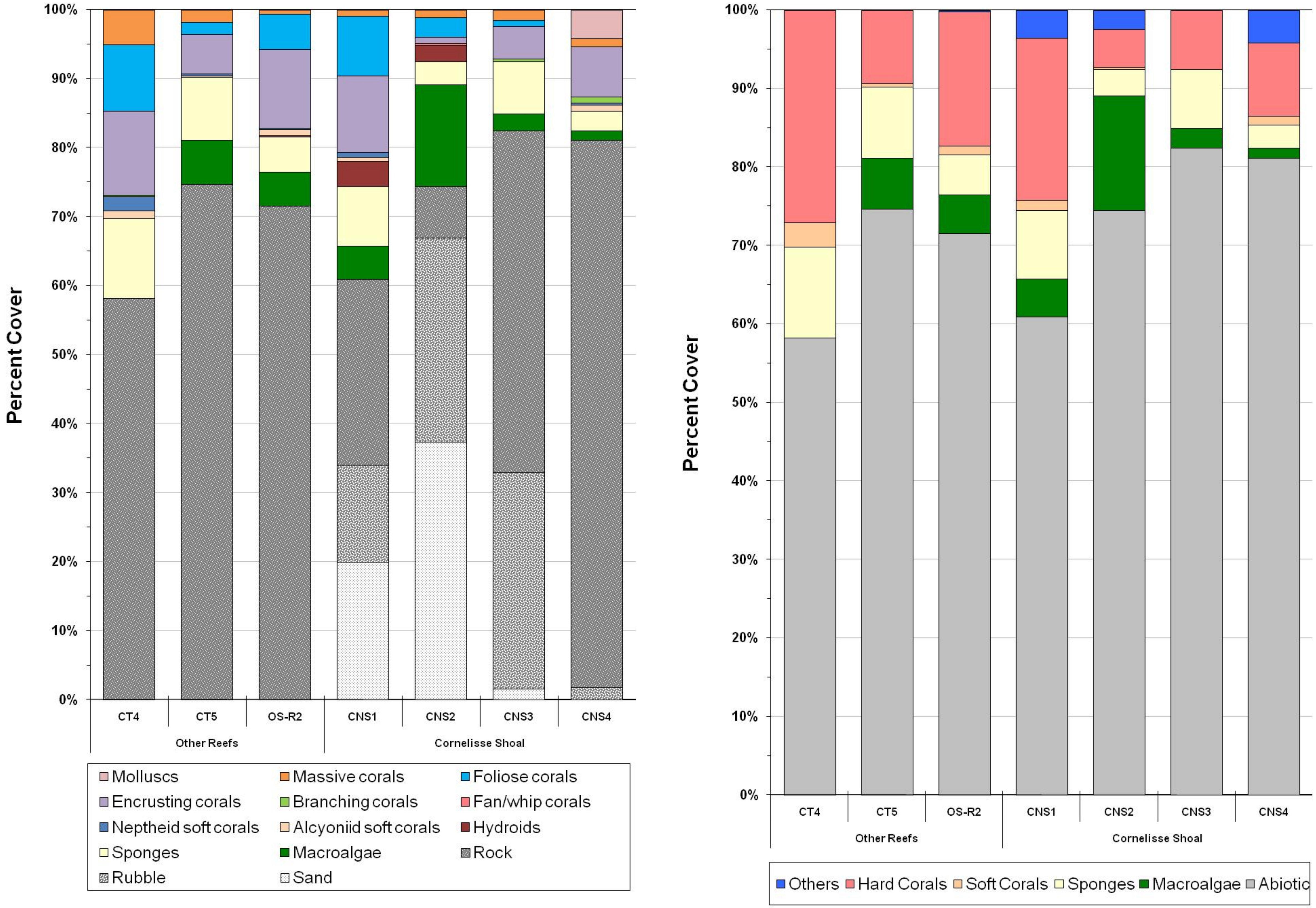


Figure 3.15 – Outermost Ridgeline Benthic Categories and Grouped Categories

Middle Ridgeline

Between the outermost and innermost ridgelines is another parallel system (**Figure 3.12**). This ridgeline is approximately 31 km north-west of the entrance to Port Hedland Harbour. The system is approximately 69 km in length and runs in a south-west to north-east direction. The ridges within this system vary in length from 0.5 to 8 km; and the ridge peaks range from - 6.6 to - 10.0 m CD. The composition of the benthic community at the sites is provided as percentages in **Table 3.6** and graphically in **Figure 3.16**.

The abiotic component of the ridges varied between a sand and rubble dominated seabed to rock. On the areas of BPPH, the dominant BPP were macroalgae (0.0–14.7%; average 4.8%) and hard corals (5.8–21.8%; average 10.7%). The hard corals comprised foliose, massive and encrusting varieties. The non BPP biota consisted mainly of sponges (3.6–9.6%; average 7.0%) and a small amount of hydroids and soft corals (<3%).

The coral categories and the hydroids and soft corals observed were indicative of slightly turbid waters subject to strong hydrodynamic forces (Gilmour et al 2007).

- **Table 3.6 – Percentage Benthic Cover on the Middle Ridgeline**

Middle Ridgeline	CTR6	OSR1	R4	CXS3	R5	Average % Cover
Water Depth (m CD)	8.5	9.3	12.6	9.8	13.6	
Categories:						
Sand	31.3	11.6	12.7	1.1	5.3	12.4
Rubble	21.8	7.1	17.8	3.6	4.7	11.0
Rock	16.2	55.8	49.6	68.4	72.0	52.4
Macroalgae	14.7	6.9	0.0	0.2	2.0	4.8
Sponges	9.6	7.6	7.1	3.6	7.1	7.0
Hydroids	0.4	2.9	0.7	0.4	0.0	0.9
Alcyoniid soft corals	0.0	0.0	0.9	0.2	0.4	0.3
Neptheid soft corals	0.2	0.0	0.0	0.7	0.2	0.2
Fan/whip corals	0.0	0.4	0.9	0.0	0.4	0.3
Encrusting corals	1.6	3.1	2.0	15.3	2.9	5.0
Foliose corals	2.9	2.4	4.9	4.4	2.9	3.5
Massive corals	1.3	2.2	3.6	2.0	2.0	2.2
Grouped:						
Abiotic	69.3	74.4	80.0	73.1	82.0	75.8
Macroalgae BPP	14.7	6.9	0.0	0.2	2.0	4.8
Sponges	9.6	7.6	7.1	3.6	7.1	7.0
Soft corals	0.2	0.4	1.8	0.9	1.1	0.9
Hard corals BPP	5.8	7.8	10.4	21.8	7.8	10.7
Others	0.4	2.9	0.7	0.4	0.0	0.9

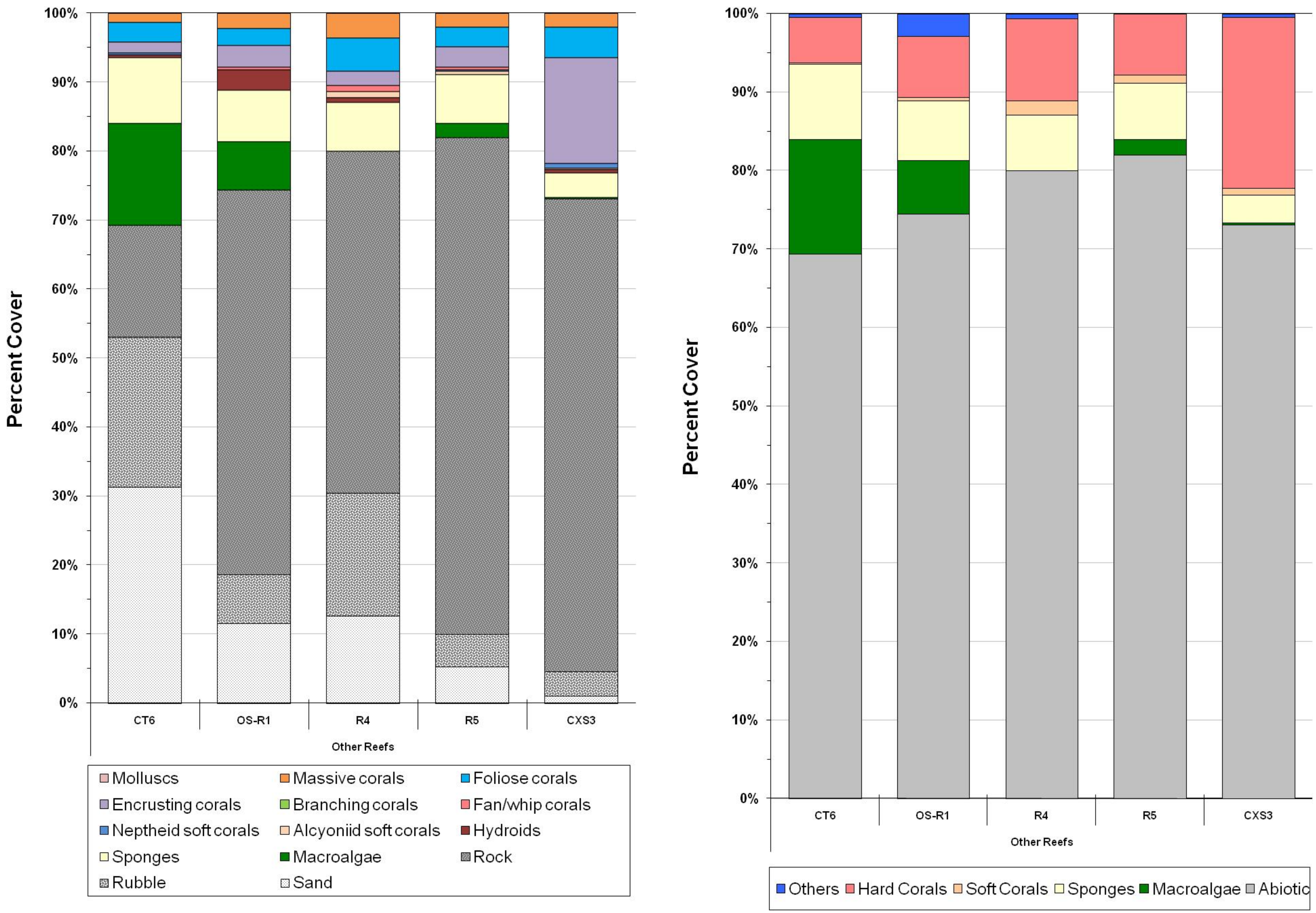


Figure 3.16 – Middle Ridgeline Benthic Categories and Grouped Categories

Innermost Ridgeline

This ridgeline is approximately 24 km north-west of the entrance to Port Hedland Harbour (**Figure 3.12**). Coxon Shoal is located within this system. The system is approximately 45 km in length and runs in a south-west to north-east direction, varying in depth from - 3.5 to - 9.0 m CD. Seven sites were surveyed along the length of this system (**Figure 2.3**). The composition of the benthic community at these sites is provided as percentages in **Table 3.7** and graphically in **Figure 3.17**.

The abiotic component was dominated by rock (38.9–67.3%; average 48.1%); however, the combination of sand and rubble (12.5–44.7%; average 30.5%) also contributed significantly. On areas of BPPH, the BPP was predominantly hard corals (3.3–22.9%; average 12.7%) with <5% cover of macroalgae. The hard corals were comprised of foliose, massive and encrusting varieties. The highest percentage covers of hard corals were located at sites R2 and R3 on either side of the navigation channel which passed through a gap in the shoal. The coral categories observed are indicative of slightly turbid waters subject to strong hydrodynamic forces (Gilmour et al 2007). Branching corals, which are more easily damaged by cyclonic conditions and are less tolerant of turbidity than encrusting and massive corals, were not observed on this ridgeline. These factors may play a role in the absence of branching corals at the sites surveyed.

The non-BPP present were mainly sponges (2.7–8.4%; average 6.0%). The shoal also had small quantities of soft corals (<5%), and hydroids and molluscs (<1%).

- **Table 3.7 – Percentage Benthic Cover on the Innermost Ridgeline**

Innermost Ridge Line	R1	R2	R3	CXS2	CXS1	R8	R9	Average % Cover
Water Depth (m CD)	10.8	11.8	10.8	11.2	10.4	12.5	12.4	
Categories:								
Sand	20.4	9.1	7.6	10.9	26.4	32.7	27.6	19.2
Rubble	8.2	15.6	24.7	1.6	5.8	12.0	10.9	11.3
Rock	38.9	42.4	42.9	67.3	51.6	48.7	45.1	48.1
Macroalgae	3.4	0.7	0.4	0.2	2.0	0.0	0.0	1.0
Sponges	6.0	7.3	3.3	7.1	8.4	2.7	6.9	6.0
Hydroids	0.2	0.7	0.0	0.0	0.0	0.7	0.0	0.2
Alcyoniid soft corals	0.2	0.2	0.4	0.4	1.3	0.0	0.0	0.4
Neptheid soft corals	3.1	0.7	0.0	0.0	0.0	0.0	0.0	0.5
Fan/whip corals	0.2	0.2	0.4	2.7	0.2	0.0	0.7	0.6
Encrusting corals	4.0	8.2	4.7	4.0	1.8	0.7	5.1	4.1
Foliose corals	14.4	12.2	10.7	4.9	1.6	2.7	2.9	7.1
Massive corals	0.9	2.4	4.9	0.9	0.9	0.0	0.9	1.6
Molluscs	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Grouped:								
Abiotic	67.6	67.1	75.1	79.8	83.8	93.3	83.6	78.6
Macroalgae BPP	3.4	0.7	0.4	0.2	2.0	0.0	0.0	1.0
Sponges	6.0	7.3	3.3	7.1	8.4	2.7	6.9	6.0
Soft corals	3.6	1.1	0.9	3.1	1.6	0.0	0.7	1.6
Hard corals BPP	19.3	22.9	20.2	9.8	4.2	3.3	8.9	12.7
Others	0.2	0.9	0.0	0.0	0.0	0.7	0.0	0.3

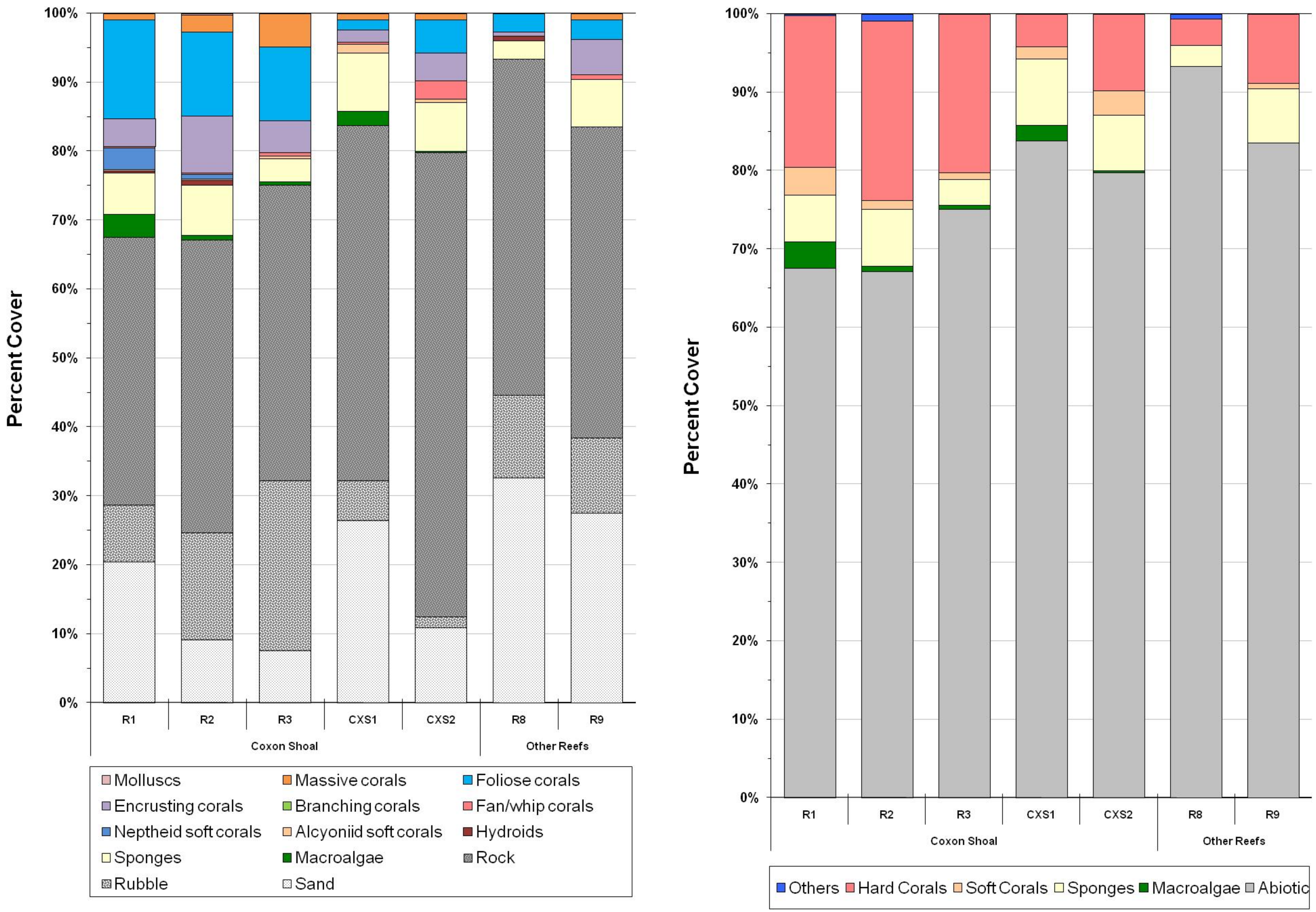


Figure 3.17 – Innermost Ridgeline Benthic Categories and Grouped Categories

3.2.2. Inshore Ridgeline Systems

Minilya Bank

Minilya Bank is approximately 19 km north-north-east of the entrance to Port Hedland Harbour (**Figure 3.14**). Site MB1 is directly on the bank and rises to within - 3.0 m CD of the surface and is surrounded by an elevated area of sand. This shallow portion of the bank was comprised of hard substrate BPPH dominated by rock with a covering of predominantly macroalgae and encrusting or massive hard corals. There were a number of dead *Turbinaria* hard corals (foliose) present that were intact but overgrown by sponges or turf macroalgae.

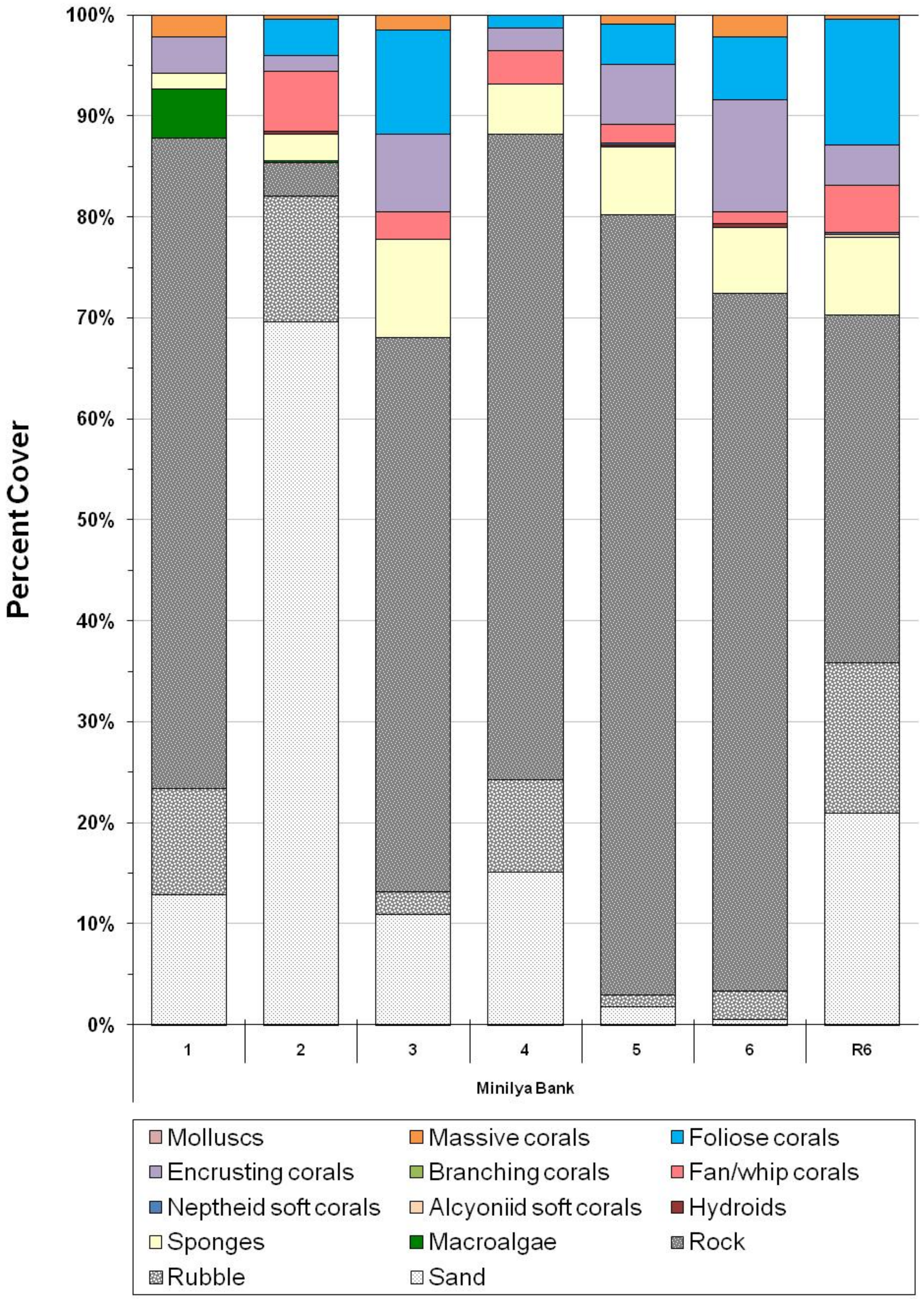
Minilya Bank extends as a low relief ridgeline to the west of site MB1 with ridge peaks ranging from - 9.5 to - 11.7 m CD. Southeast of Minilya Bank (site MB2) is an area rising to within -5.0 m CD of the surface (**Figure 2.3**). The seabed at this location (- 7.1 m CD) was comprised of sand covering a hard pavement with rubble and some rock proud of the seabed and this is classified as BPPH due to the presence of BPP comprising hard corals on the sediment covered hard substrate. This site was surveyed and found to have a benthic community dominated by BPP comprising hard corals (predominantly foliose with some encrusting and massive corals), sponges and soft corals (fan and whip corals).

The predominant cover of non-BPP across all Minilya Bank sites was sponge (6.4–9.8%; average 5.7%) and BPP included mainly hard coral (3.6–19.6%; average 11.7%), predominantly *Turbinaria* and encrusting corals, than the other areas surveyed on Minilya Bank.

The composition of the benthic community at the seven Minilya Bank sites is provided as percentages in **Table 3.8** and graphically in **Figure 3.18**.

▪ Table 3.8 – Percentage Benthic Cover at Minilya Bank

Minilya Bank	MB1	MB2	MB3	MB4	MB5	MB6	R6	Average % Cover
Water Depth (m CD)	3.0	7.1	9.5	11.7	11.1	9.8	9.5	
Categories:								
Sand	12.9	69.6	10.9	15.1	1.8	0.4	20.9	18.8
Rubble	10.4	12.4	2.2	9.1	1.1	2.9	14.9	7.6
Rock	64.4	3.3	54.9	64.0	77.3	69.1	34.4	52.5
Macroalgae	4.9	0.2	0.0	0.0	0.0	0.0	0.0	0.7
Sponges	1.6	2.7	9.8	4.9	6.7	6.4	7.8	5.7
Hydroids	0.0	0.2	0.0	0.0	0.2	0.4	0.0	0.1
Alcyoniid soft corals	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Neptheid soft corals	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.1
Fan/whip corals	0.0	6.0	2.7	3.3	1.8	1.1	4.7	2.8
Encrusting corals	3.6	1.6	7.8	2.2	6.0	11.1	4.0	5.2
Foliose corals	0.0	3.6	10.2	1.3	4.0	6.2	12.4	5.4
Massive corals	2.2	0.4	1.6	0.0	0.9	2.2	0.4	1.1
Grouped:								
Abiotic	87.8	85.3	68.0	88.2	80.2	72.4	70.2	78.9
Macroalgae BPP	4.9	0.2	0.0	0.0	0.0	0.0	0.0	0.7
Sponges	1.6	2.7	9.8	4.9	6.7	6.4	7.8	5.7
Soft corals	0.0	6.0	2.7	3.3	2.0	1.1	5.1	2.9
Hard corals BPP	5.8	5.6	19.6	3.6	10.9	19.6	16.9	11.7
Others	0.0	0.2	0.0	0.0	0.2	0.4	0.0	0.1



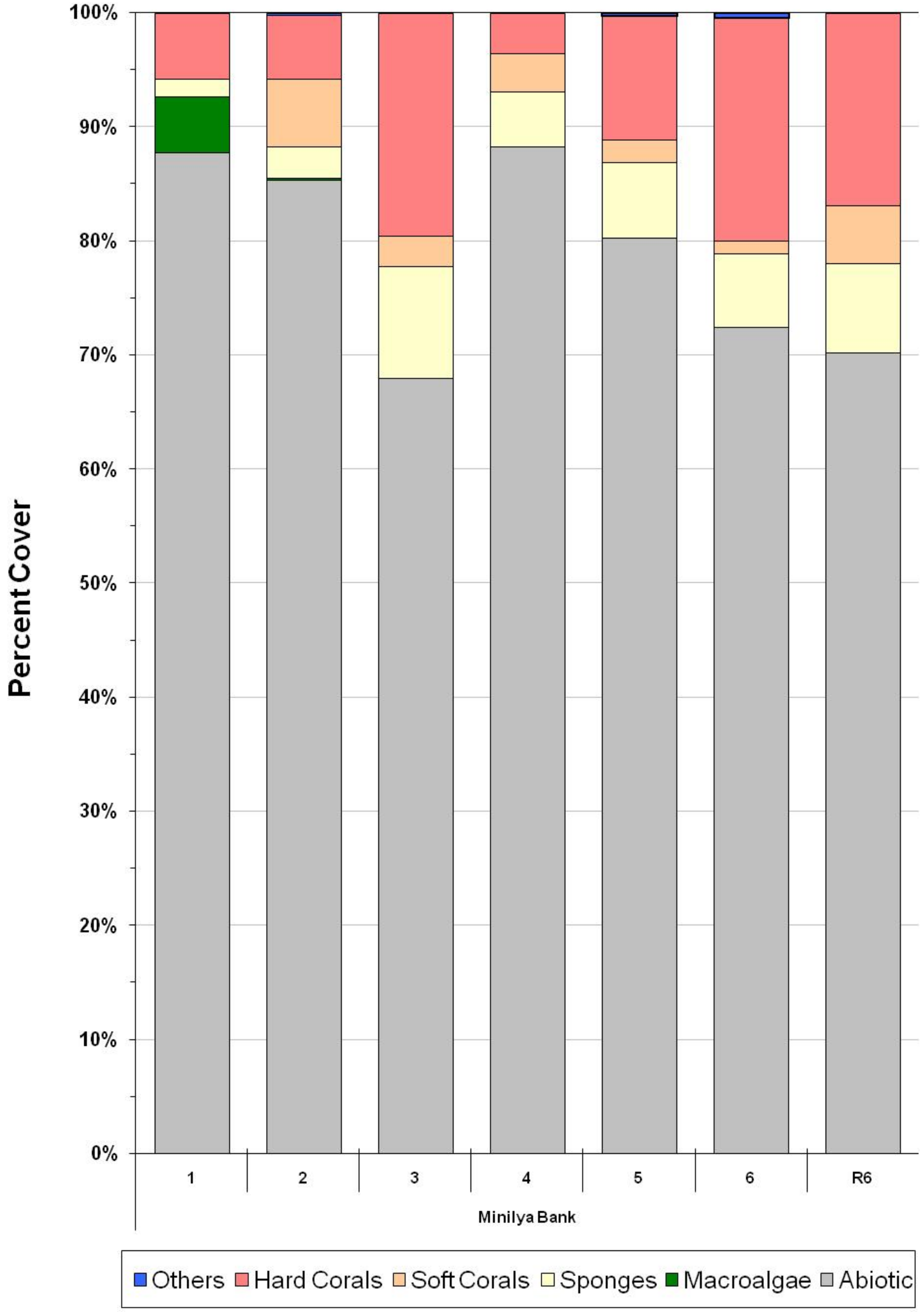


Figure 3.18 – Minilya Bank Benthic Categories and Grouped Categories

Proposed Port Footprint

Three sites were surveyed in the region of the proposed jetty/wharf structure (see **Figure 2.3**). BH1 is in the region of the proposed berth pockets and swing basin and is the site where two bore holes were drilled for geotechnical purposes. This site was characterised by hard pavement covered by a thin layer of sand and is classified as BPPH due to the presence of BPP comprising hard corals. The dominant benthic cover was sponge and BPP hard corals (encrusting and foliose hard corals).

A low-relief site to the north-west (R7) was surveyed and found to be predominantly sand substrate with a low percentage of sponge and soft coral (<4%) and no BPP hard coral.

To the south-west was another low-relief site (FR1), which was also dominated by sand substrate. As with site R7 this site had a low percentage of sponge and soft coral (<4%) but unlike R7 it had a low percentage cover of BPP hard coral (1.3%) and hydroids (1.1%).

Another site due south of the proposed port footprint and closer to shore was site FR2, which appeared to be low-relief based on the bathymetry and was found to be silty sand mounds devoid of any epibenthic cover. It was not surveyed by video transect.

The composition of the benthic community at the three sites in the vicinity of the proposed port area is provided as percentages in **Table 3.9** and graphically in **Figure 3.19**.

- **Table 3.9 – Percentage Benthic Cover in the Vicinity of the Proposed Port Footprint**

Proposed Port Footprint	BH1	R7	FR1	Average % Cover
Water Depth (m CD)	9.5	8.1	5.4	
Categories:				
Sand	27.6	95.1	87.3	70.0
Rubble	12.2	0.0	3.1	5.1
Rock	39.8	0.0	2.7	14.2
Macroalgae	0.0	0.0	0.0	0.0
Sponges	6.4	3.3	3.1	4.3
Hydroids	0.0	0.0	1.1	0.4
Neptheid soft corals	0.0	0.0	0.4	0.1
Fan/whip corals	1.1	1.6	0.9	1.2
Branching corals	1.3	0.0	0.0	0.4
Encrusting corals	5.6	0.0	0.0	1.9
Foliose corals	4.9	0.0	1.3	2.1
Massive corals	1.1	0.0	0.0	0.4
Grouped:				
Abiotic	79.6	95.1	93.1	89.3
Macroalgae BPP	0.0	0.0	0.0	0.0
Sponges	6.4	3.3	3.1	4.3
Soft corals	1.1	1.6	1.3	1.3
Hard corals BPP	12.9	0.0	1.3	4.7
Others	0.0	0.0	1.1	0.4

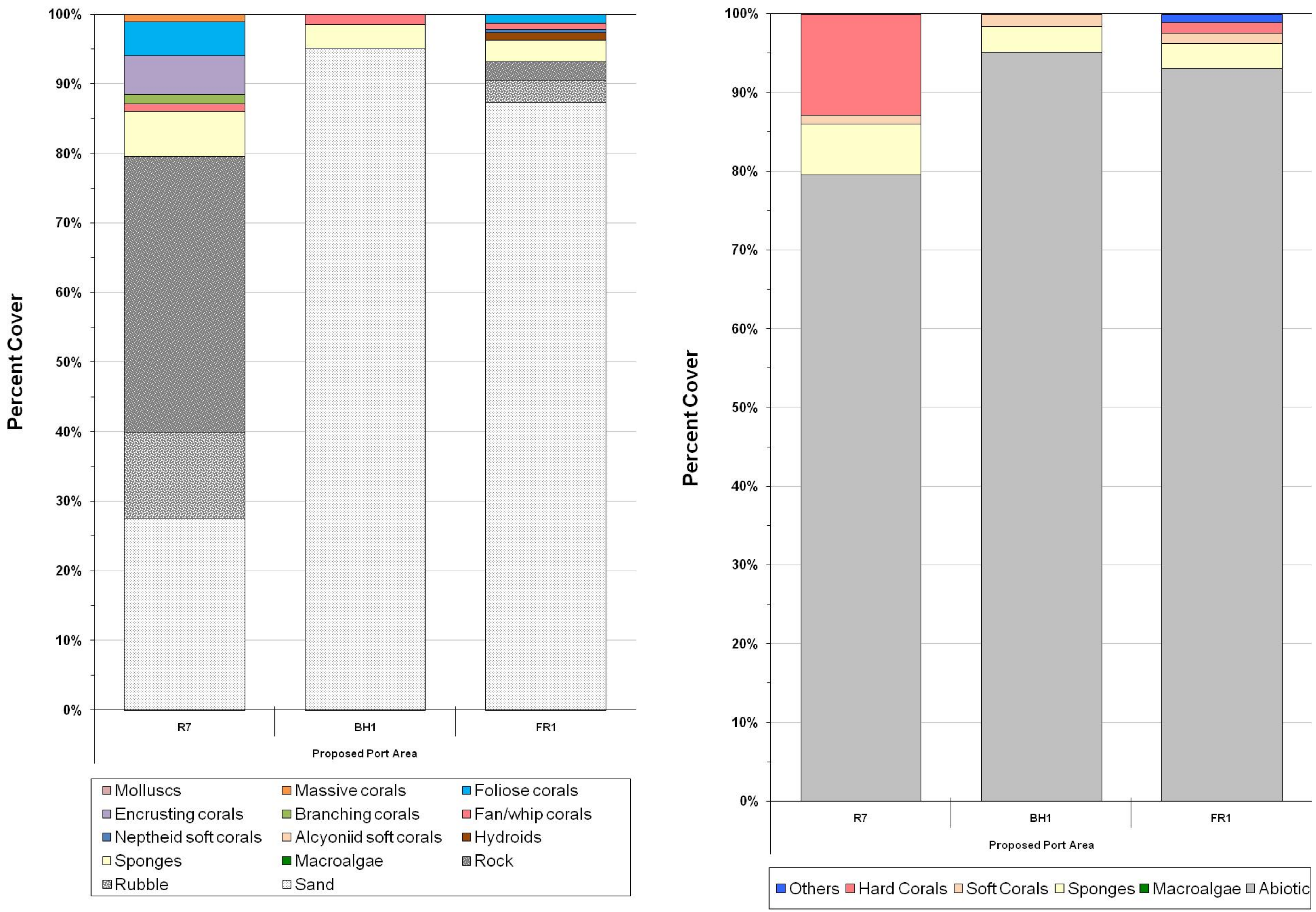


Figure 3.19 – Proposed Port Area Benthic Categories and Grouped Categories

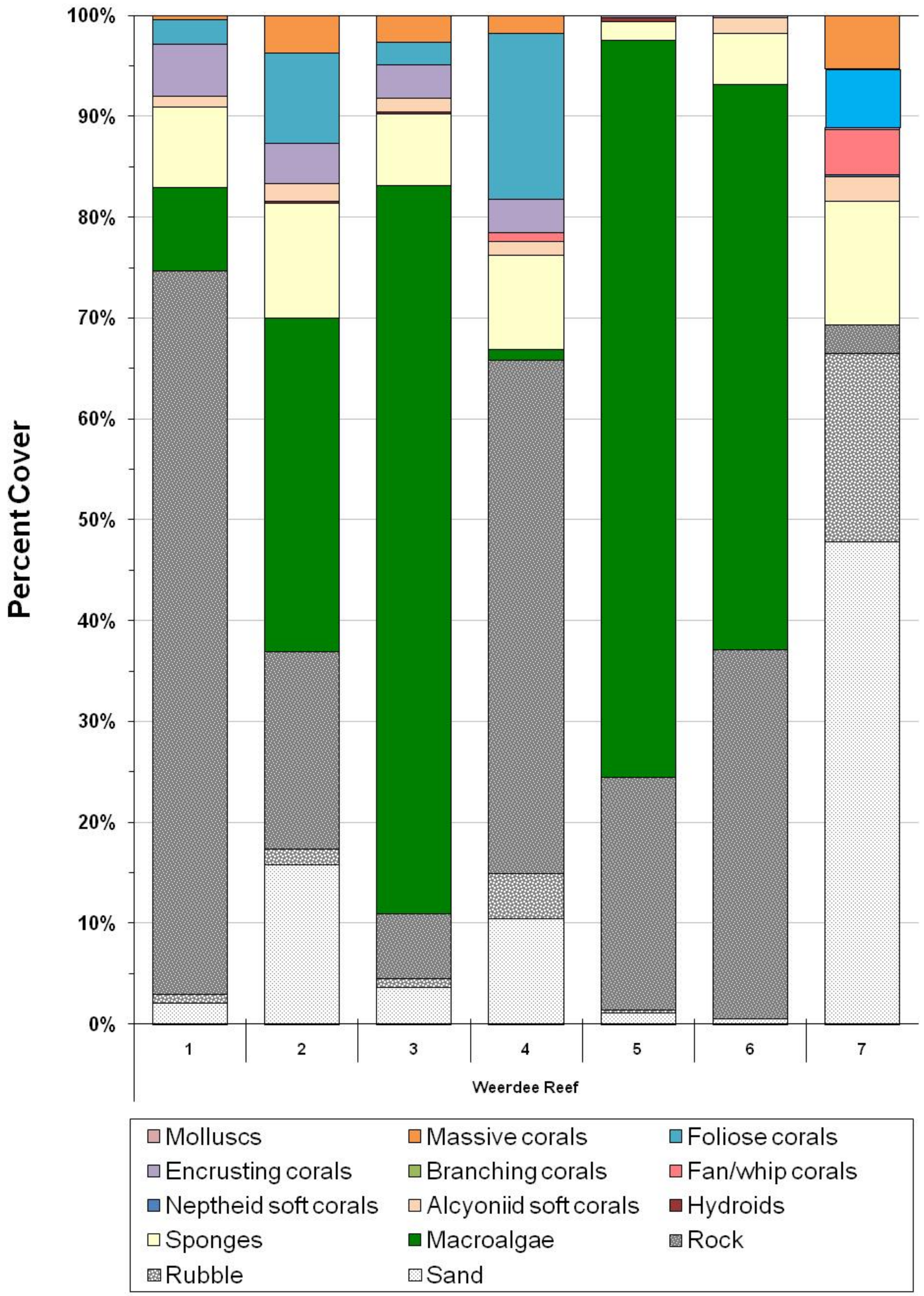
Weerdee Ridgeline

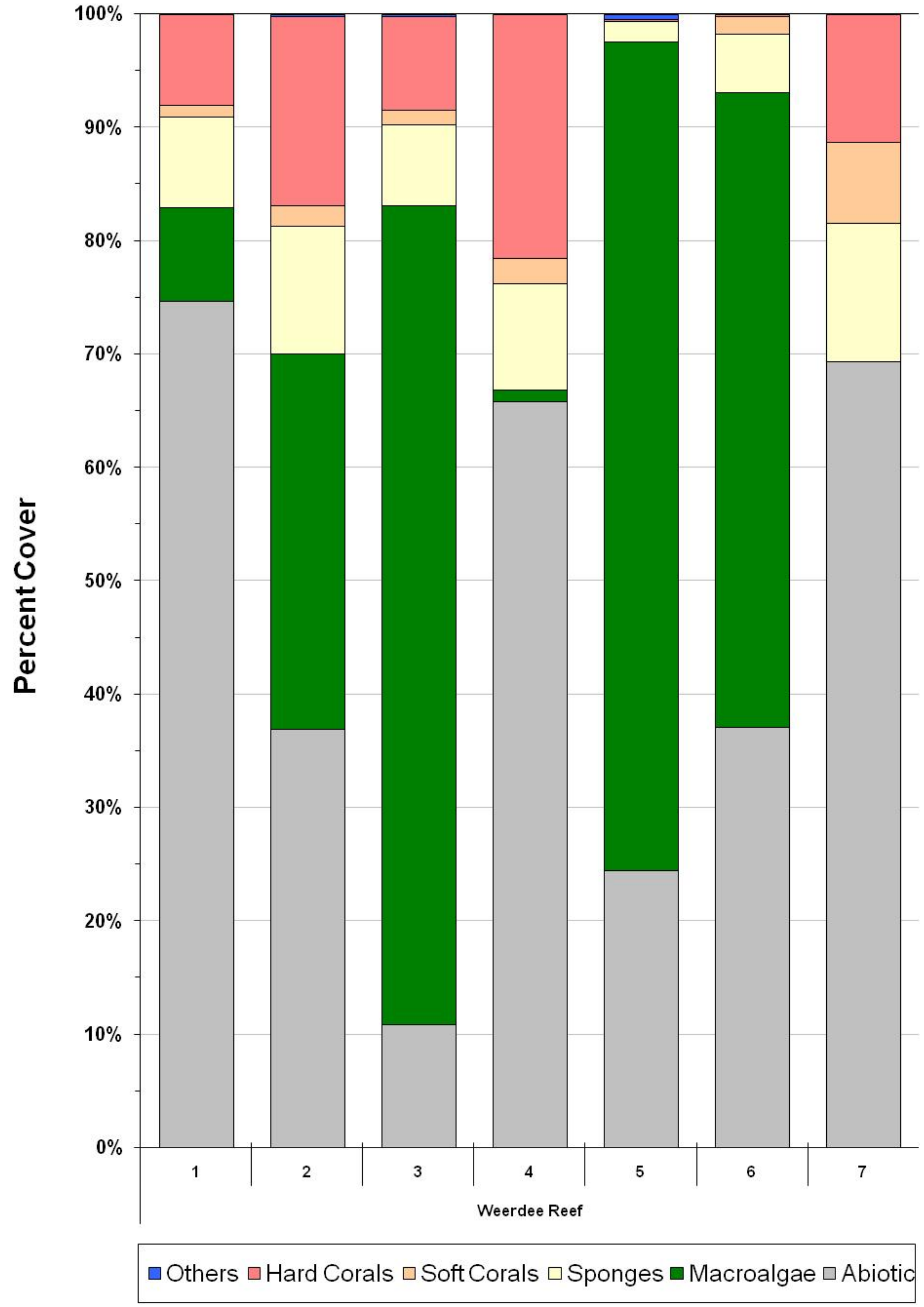
Weerdee ridgeline is approximately 11 km west of the entrance to Port Hedland Harbour and 3 km north-east of Weerdee Island (**Figure 3.13**). The ridgeline is a broken string of ridges approximately 12 km in length and runs in a south-west to north-east direction. This shallow system has a low profile with ridge peaks ranging from - 3.0 to - 6.0 m CD.

The seabed at this location was predominantly sand and rubble covering a hard rocky pavement. The percentage cover of biota was highly variable but predominantly BPP including macroalgae (0.0–71.3%; average 34.8%) and hard corals (0.2–21.6%; average 9.5%) with non BPP including sponges (1.8–12.2%; average 7.8%) and soft corals (0.0–7.1%; average 2.2%). The macroalgae present were predominantly species from the phylum Chlorophyta and included the genera *Caulerpa* and *Halimeda*. The hard corals were dominated by foliose (*Turbinaria*) and massive (*Porites*) varieties. The composition of the benthic community at Weerdee ridgeline is provided as percentages in **Table 3.10** and graphically in **Figure 3.20**.

- **Table 3.10 – Percentage Benthic Cover at Weerdee Ridgeline**

Weerdee Ridgeline	WR6	WR5	WR4	WR3	WR2	WR7	WR1	Average % Cover
Water Depth (m CD)	3.7	3.7	5.8	3.4	5.5	3.5	4.5	
Categories:								
Sand	0.4	1.1	10.4	3.6	15.8	47.8	2.0	11.6
Rubble	0.0	0.2	4.4	0.9	1.6	18.7	0.9	3.8
Rock	36.7	23.1	50.9	6.4	19.6	2.9	71.8	30.2
Macroalgae	56.0	73.1	1.1	72.2	33.1	0.0	8.2	34.8
Sponges	5.1	1.8	9.3	7.1	11.3	12.2	8.0	7.8
Hydroids	0.0	0.4	0.0	0.2	0.2	0.0	0.0	0.1
Alcyoniid soft corals	1.6	0.0	1.3	1.3	1.8	2.4	1.1	1.4
Neptheid soft corals	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Fan/whip corals	0.0	0.0	0.9	0.0	0.0	4.4	0.0	0.8
Encrusting corals	0.2	0.2	3.3	3.3	4.0	0.2	5.1	2.3
Foliose corals	0.0	0.0	16.4	2.2	8.9	5.8	2.4	5.1
Massive corals	0.0	0.0	1.8	2.7	3.8	5.3	0.4	2.0
Grouped:								
Abiotic	37.1	24.4	65.8	10.9	36.9	69.3	74.7	45.6
Macroalgae BPP	56.0	73.1	1.1	72.2	33.1	0.0	8.2	34.8
Sponges	5.1	1.8	9.3	7.1	11.3	12.2	8.0	7.8
Soft corals	1.6	0.0	2.2	1.3	1.8	7.1	1.1	2.2
Hard corals BPP	0.2	0.2	21.6	8.2	16.7	11.3	8.0	9.5
Others	0.0	0.4	0.0	0.2	0.2	0.0	0.0	0.1





▪ **Figure 3.20 – Weerdee Ridgeline Benthic Categories and Grouped Categories**

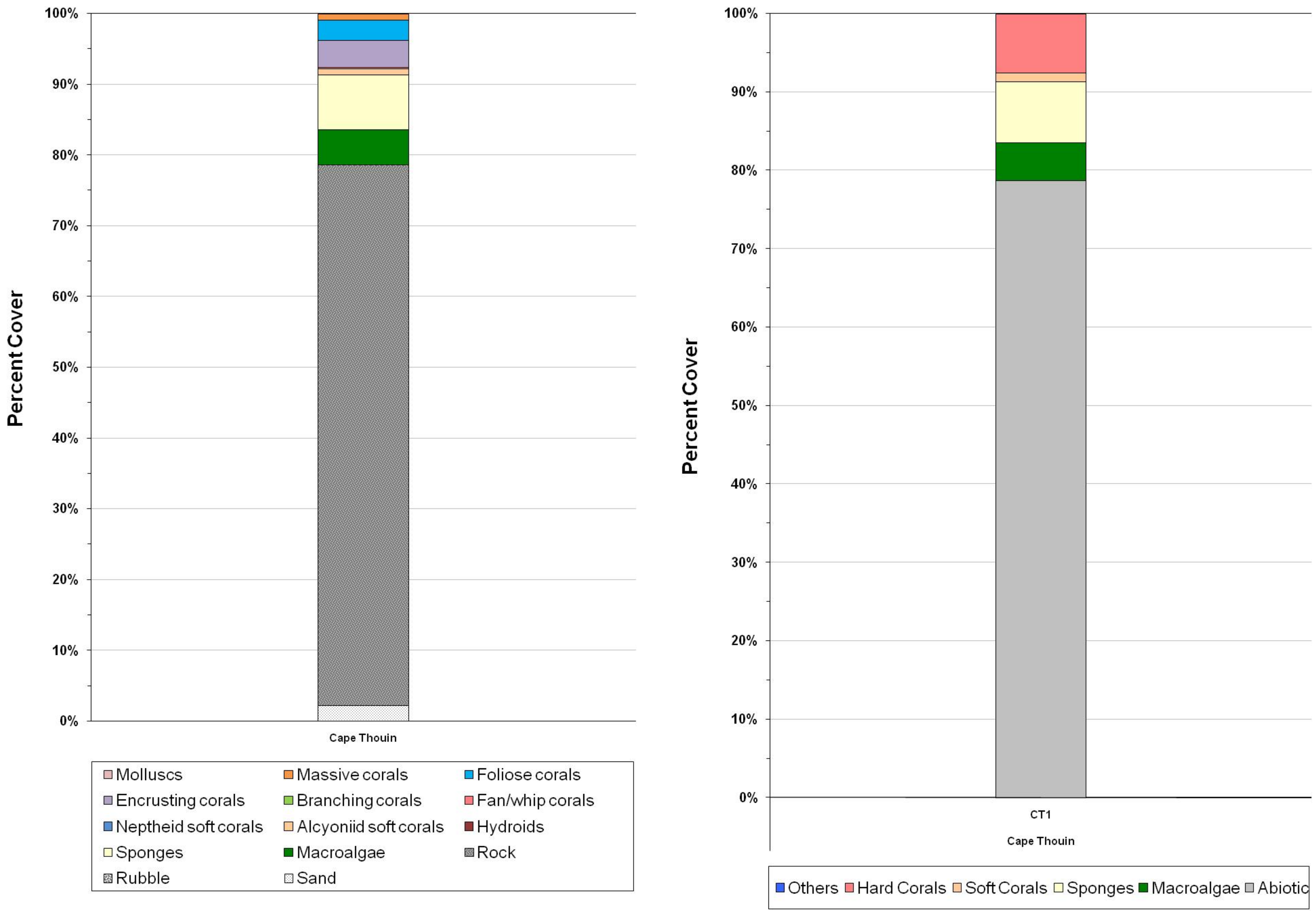
Cape Thouin Area

Cape Thouin is approximately 40 km west of the entrance to Port Hedland Harbour (**Figure 3.13**). Offshore of Cape Thouin is a shallow sandy intertidal area with a few rocky bommies but is devoid of epibenthic cover. Further offshore, there are numerous seabed features aligned approximately north-south resembling parallel ridgelines on the LiDAR bathymetry. The mapping initially interpreted these as areas of topographic relief that may support biota, however further investigations found them to be sand ridges with minimal vertical relief and devoid of epibenthic cover. They were subsequently re-classified in habitat cover calculations and on the habitat map. Fourteen kilometres to the north-east of Cape Thouin is a low relief patch which is predominantly rocky with small patches of sand.

The percentage cover of BPP was predominantly macroalgae (4.9%), and hard corals (7.6%) and non BPP sponges (7.8%). The macroalgae present were predominantly species from the phylum Chlorophyta and included the genera *Caulerpa* and *Halimeda*. The hard corals were dominated by foliose (*Turbinaria*) and encrusting varieties (*Montipora*). The composition of the benthic community in the Cape Thouin area is provided as percentages in **Table 3.11** and graphically in **Figure 3.21**.

- **Table 3.11 – Percentage Benthic Cover in the Vicinity of Cape Thouin**

Cape Thouin area	CTR1
Water Depth (m CD)	7.1
Categories:	
Sand	2.2%
Rubble	0.0%
Rock	76.4%
Macroalgae	4.9%
Sponges	7.8%
Alcyoniid soft corals	0.9%
Fan/whip corals	0.2%
Encrusting corals	3.8%
Foliose corals	2.9%
Massive corals	0.9%
Grouped:	
Abiotic	78.7%
Macroalgae BPP	4.9%
Sponges	7.8%
Soft corals	1.1%
Hard corals BPP	7.6%
Others	0.0%



▪ **Figure 3.21 – Cape Thouin Benthic Categories and Grouped Categories**

3.2.3. Island Ridge Systems

The nearshore subtidal waters of three islands (Weerdee, North Turtle and Little Turtle Islands) were surveyed by video transect (**Figure 3.13** and **Figure 3.14**). The description of the benthic habitat at these sites is provided below.

The macroalgae of the intertidal areas of North and Little Turtle Island were more comprehensively surveyed and are the subject of a separate field summary report and species list (Huisman 2008; **Appendix C**). The survey identified one species of macroalgae, *Ganonema samaense* (Tseng) Huisman, not previously reported in Western Australia, although the lack of observations of this species in the Port Hedland region is likely a result of the limited collections undertaken in the area. The report concludes that any macroalgal species growing in the subtidal waters around the Turtle Islands have established under naturally turbid conditions.

Finucane Island intertidal platform was surveyed with still photography and field notes taken by marine scientists in early 2009.

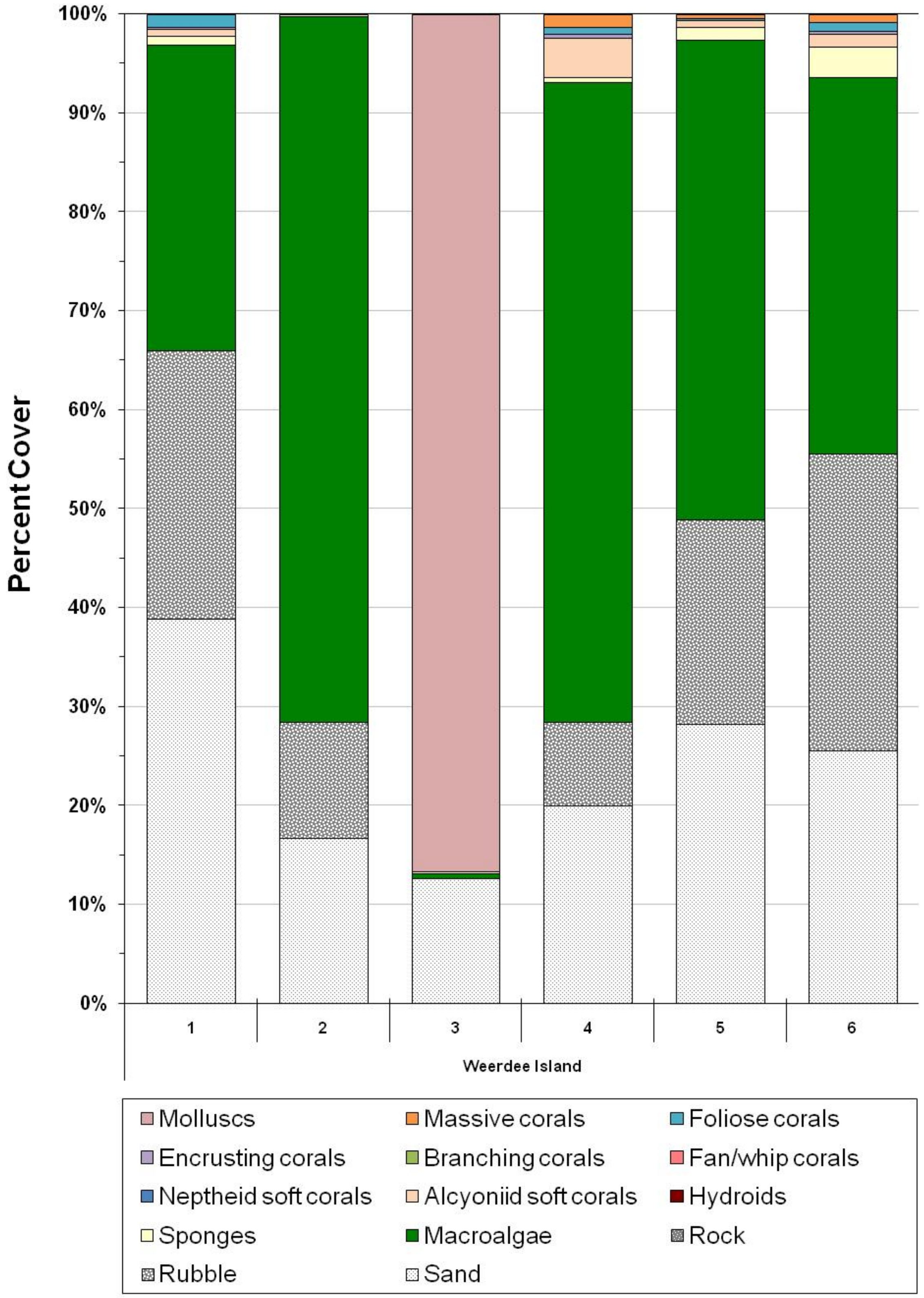
Weerdee Island

Weerdee Island is approximately 12 km west of the entrance to Port Hedland Harbour and 1.8 km offshore of the mainland. The island is approximately 1.5 km long, with a rocky intertidal area that extends east and west to increase the length of the island to just under 6 km at low tide. The island is predominantly sandy with areas of mangrove and a rocky beach area. The intertidal area is completely exposed at any tide below 2.4 m CD. The intertidal platform is rocky and covered with rock oysters, barnacles and grapsid crabs.

The sub tidal area was very shallow (< - 2 m CD) and was comprised of patchy areas of BPP, either macroalgae, a combination of macroalgae and sparse hard corals (<5%) or patches of non BPP entirely comprised of small bivalves (*Brachidontes ustulatus*). The small colonies of hard corals found in the area belonged to the encrusting, foliose and massive coral categories. The composition of the benthic community at the six Weerdee Island sites is provided as percentages in **Table 3.12** and graphically in **Figure 3.22**. A small patch (approximately 5 x 5 m) of *Halophila decipiens* was observed adjacent to the area covered by video transects.

- **Table 3.12 – Percentage Benthic Cover at Weerdee Island**

Weerdee Island	WI1	WI2	WI3	WI4	WI5	WIS6	Average % Cover
Water Depth (m CD)	1.0	1.0	0.5	1.0	0.5	0.5	
Categories:							
Sand	38.9	16.7	12.7	20.0	28.2	25.6	23.7
Rubble	27.1	11.8	0.0	8.4	20.7	30.0	16.3
Macroalgae	30.9	71.3	0.4	64.7	48.4	38.0	42.3
Sponges	0.9	0.2	0.2	0.4	1.3	3.1	1.0
Alcyoniid soft corals	0.7	0.0	0.0	4.0	0.7	1.3	1.1
Encrusting corals	0.2	0.0	0.0	0.4	0.0	0.2	0.1
Foliose corals	1.3	0.0	0.0	0.7	0.2	0.9	0.5
Massive corals	0.0	0.0	0.0	1.3	0.4	0.9	0.4
Mollusc	0.0	0.0	86.7	0.0	0.0	0.0	14.5
Grouped:							
Abiotic	66.0	28.4	12.7	28.4	48.9	55.6	40.0
Macroalgae BPP	30.9	71.3	0.4	64.7	48.4	38.0	42.3
Sponges	0.9	0.2	0.2	0.4	1.3	3.1	1.0
Soft corals	0.7	0.0	0.0	4.0	0.7	1.3	1.1
Hard corals BPP	1.6	0.0	0.0	2.4	0.7	2.0	1.1
Others	0.0	0.0	86.7	0.0	0.0	0.0	14.5



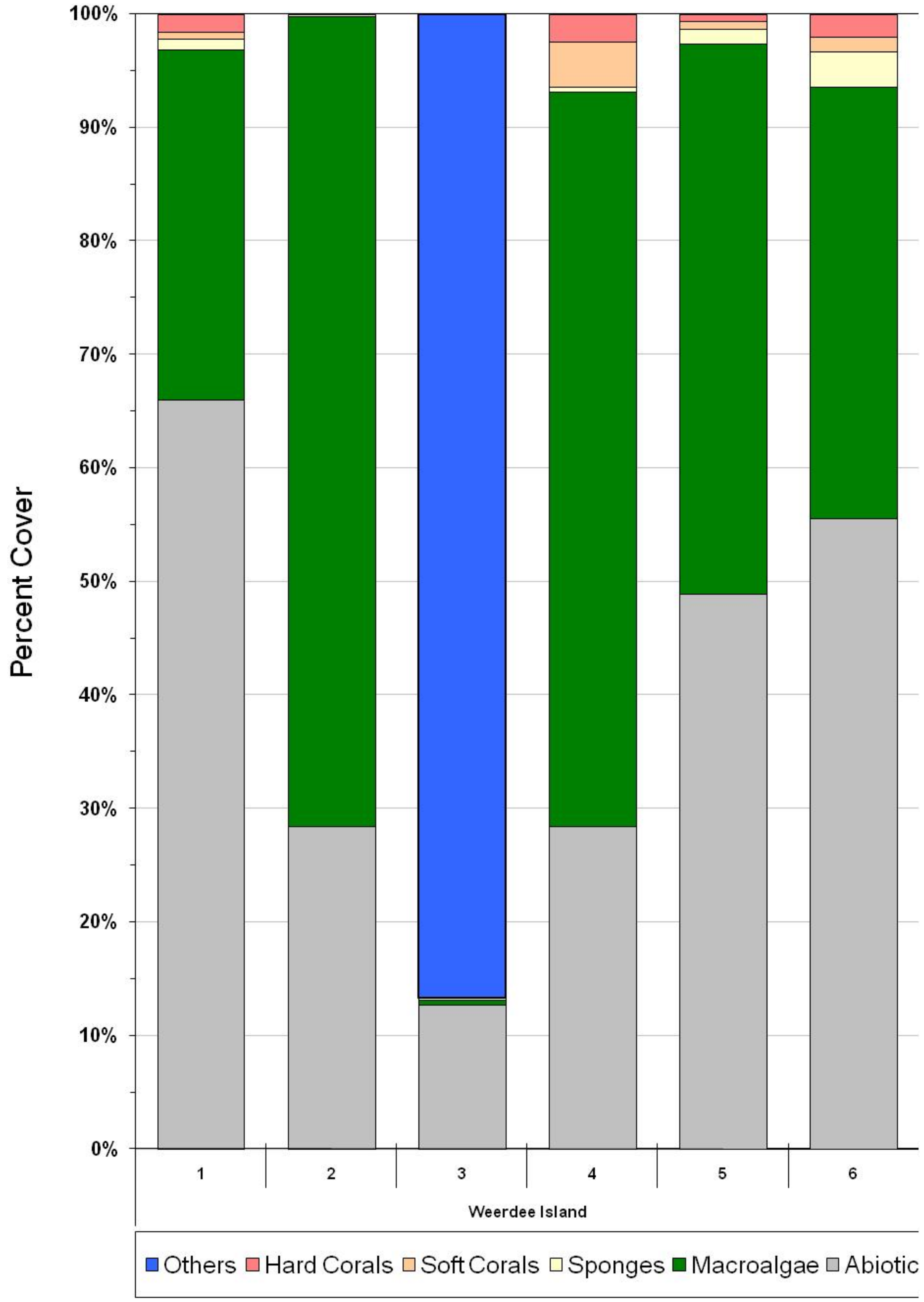


Figure 3.22 – Weerdee Island Benthic Categories

North Turtle Island

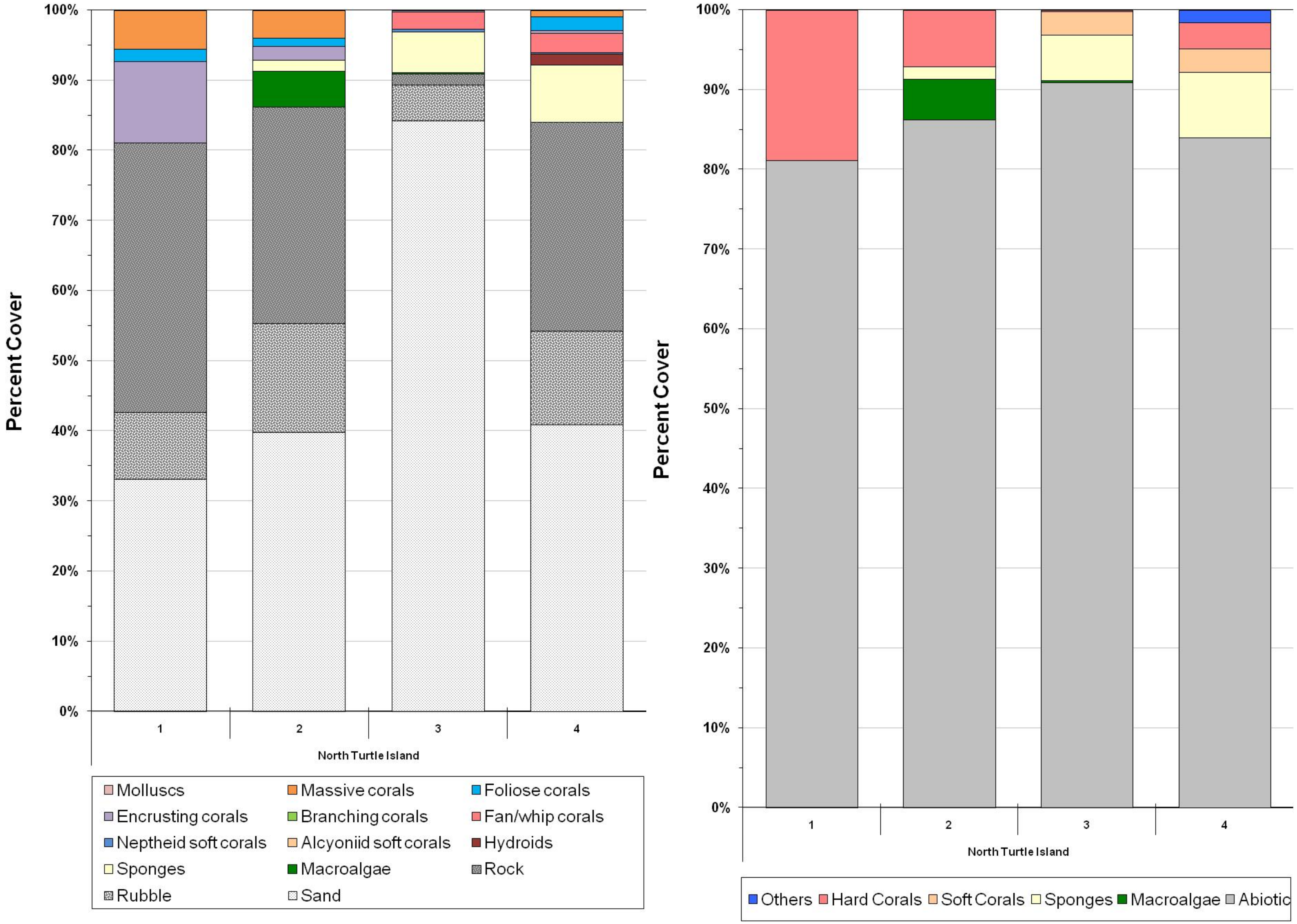
North Turtle Island is approximately 58 km north-east of the entrance to Port Hedland Harbour (**Figure 3.14**). The island was surveyed once during January 2008. The island is comprised of vegetated sand and is 1.1 km long by 0.5 km wide. The island is in the centre of a large fringing subtidal platform area that extends in all directions to a distance of up to 3.0 km. The intertidal platform is completely exposed at any low tide below 4.9 m CD and is rocky with numerous shallow (<1 m) pools of varying sizes. The surface of the intertidal platform is dominated by a diversity of macroalgae BPP; however, there were small colonies of encrusting and massive corals. The non BPP epifauna was dominated by sponges, gastropod and bivalve molluscs, sea cucumbers and octopi.

A number of boulders were observed to be colonised by rock oysters, barnacles and grapsid crabs. Across most of the intertidal area, where there was sufficient water depth, numerous green turtles were observed feeding on macroalgae. The larger turtles were observed along the outer margin of the platform whilst smaller animals were found across the platform area. More details of turtle abundance and distribution in the Outer Harbour Development study area are provided in a separate report (Pendoley Environmental 2009). Closer to the island itself was an area of shallow sand over pavement increasing in depth towards a sandy beach area. The supratidal area had turtle tracks and signs of turtle nesting as well as large numbers of cormorants and pelicans. At the time of the survey there was a large congregation of young pelicans.

The subtidal sites surveyed indicated a seabed that was comprised of sand and rubble covering a hard rocky pavement. The percentage cover of BPP was predominantly hard corals (0.2–18.9%) with lesser percentages of macroalgae and non BPP including sponges, soft corals and hydroids. The hard corals were dominated by encrusting and massive varieties. The composition of the benthic community at the four sites is provided as percentages in **Table 3.13** and graphically in **Figure 3.23**.

Table 3.13 – Percentage Benthic Cover at North Turtle Island

North Turtle Island	NT1	NT2	NT3	NT4	Average % Cover
Water Depth (m CD)	8.0	3.5	9.3	9.7	
Categories:					
Sand	33.1	39.8	84.2	40.9	49.5
Rubble	9.6	15.6	5.1	13.3	10.9
Rock	38.4	30.9	1.6	29.8	25.2
Macroalgae	0.0	5.1	0.2	0.0	1.3
Sponges	0.0	1.6	5.8	8.2	3.9
Hydroids	0.0	0.0	0.0	1.6	0.4
Neptheid soft corals	0.0	0.0	0.4	0.2	0.2
Fan/whip corals	0.0	0.0	2.4	2.7	1.3
Encrusting corals	11.6	2.0	0.2	0.4	3.6
Foliose corals	1.8	1.1	0.0	2.0	1.2
Massive corals	5.6	4.0	0.0	0.9	2.6
Grouped:					
Abiotic	81.1	86.2	90.9	84.0	85.6
Macroalgae BPP	0.0	5.1	0.2	0.0	1.3
Sponges	0.0	1.6	5.8	8.2	3.9
Soft corals	0.0	0.0	2.9	2.9	1.5
Hard corals BPP	18.9	7.1	0.2	3.3	7.4
Others	0.0	0.0	0.0	1.6	0.4



▪ **Figure 3.23 – North Turtle Island Benthic Categories and Grouped Categories**

Little Turtle Island

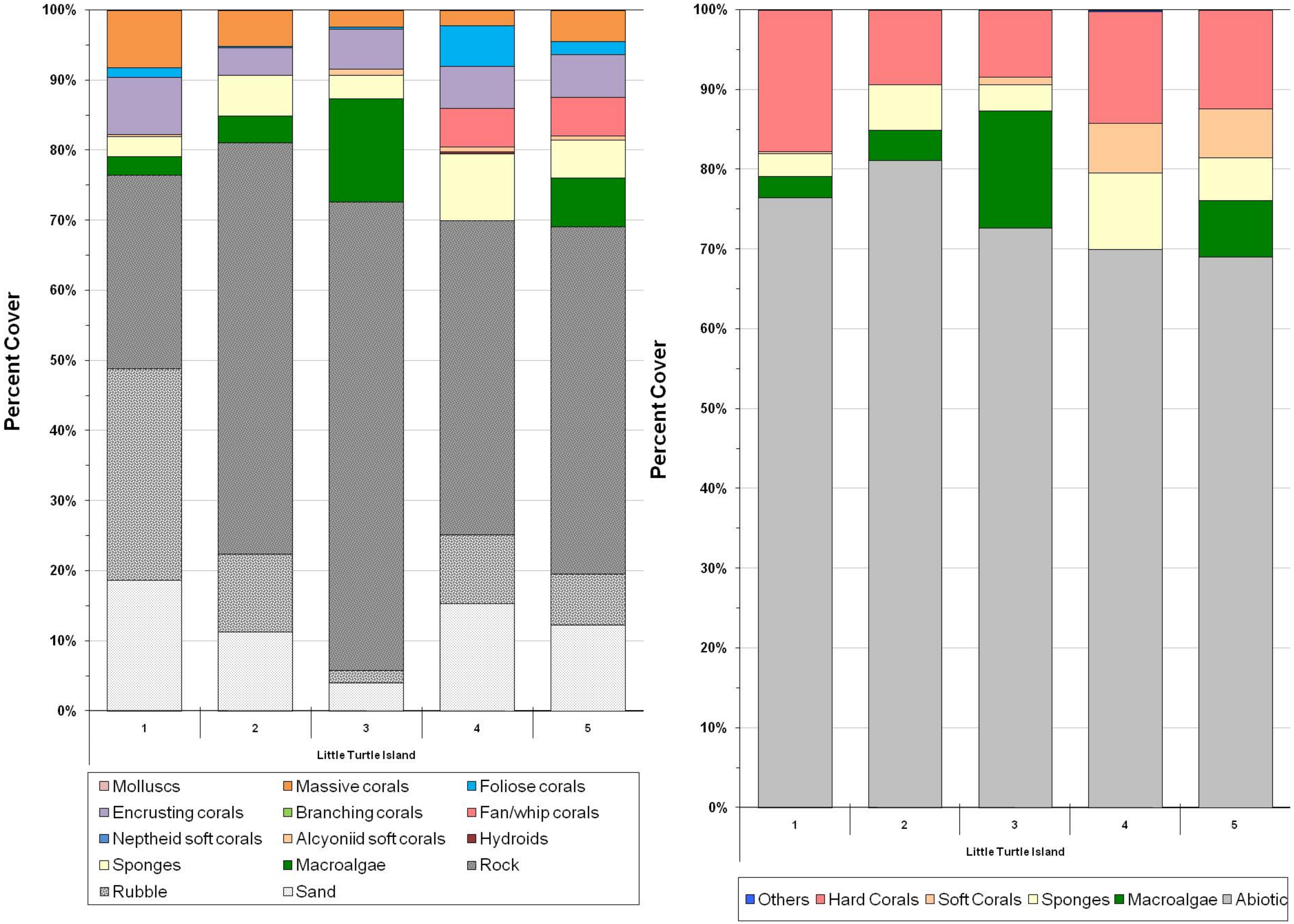
Little Turtle Island is approximately 40 km north-east of the entrance to Port Hedland Harbour (**Figure 3.14**). The island is approximately 0.5 km long and is almost awash at high tide. It has a fringing subtidal area that extends over 1.1 km to the north-west and marginally around the rest of the island. Two sites were surveyed just outside the margin of the intertidal area (LT1 and LT5). To the south-east of the island is a large submerged area approximately the same length as the intertidal area at Little Turtle Island but much narrower. Two sites were surveyed on this submerged area (LT2 and LT3). Six kilometres to the south-west of the island is a low relief area that was found to have epibenthic cover and was surveyed (LT4).

The intertidal area of the island was found to be predominantly rocky with shallow pools. The macroalgal BPP cover was sparse but diverse. The non BPP epifauna was dominated by gastropod and bivalve molluscs, sea cucumbers and an abundance of mantis shrimp and octopuses. Along the north-western margin was a rocky ridge colonised by rock oysters, barnacles and grapsid crabs. A single small green turtle was observed resting in a pool on the intertidal platform.

The subtidal area in the vicinity of Little Turtle Island was comprised of a combination of sand, rubble and rock. The percentage cover of BPP was predominantly macroalgae (0.0–14.7%; average 5.6%), and hard corals (8.4–17.8%; average 12.4%) dominated by encrusting and massive varieties. The site also had non BPP sponges (2.9–9.6%; average 5.4%) and a small amount (<5%) of soft corals and hydroids. The composition of the benthic community at Little Turtle Island is provided as percentages in **Table 3.14** and graphically in **Figure 3.24**.

- **Table 3.14 – Percentage Benthic Cover at Little Turtle Island**

Little Turtle Island	LT1	LT2	LT3	LT4	LT5	Average % Cover
Water Depth (m CD)	6.8	6.0	6.0	7.9	9.6	
Categories:						
Sand	18.7	11.3	4.0	15.3	12.3	12.3
Rubble	30.2	11.1	1.8	9.8	7.2	12.0
Rock	27.6	58.7	66.9	44.9	49.5	49.5
Macroalgae	2.7	3.8	14.7	0.0	7.0	5.6
Sponges	2.9	5.8	3.3	9.6	5.4	5.4
Hydroids	0.0	0.0	0.0	0.2	0.0	0.0
Alcyoniid soft coral	0.2	0.0	0.9	0.7	0.6	0.5
Fan/whip corals	0.0	0.0	0.0	5.6	5.6	2.2
Encrusting corals	8.2	4.0	5.8	6.0	6.0	6.0
Foliose corals	1.3	0.2	0.2	5.8	1.9	1.9
Massive corals	8.2	5.1	2.4	2.2	4.5	4.5
Grouped:						
Abiotic	76.4	81.1	72.7	70.0	69.1	73.9
Macroalgae BPP	2.7	3.8	14.7	0.0	7.0	5.6
Sponges	2.9	5.8	3.3	9.6	5.4	5.4
Soft corals	0.2	0.0	0.9	6.2	6.1	2.7
Hard corals BPP	17.8	9.3	8.4	14.0	12.4	12.4
Others	0.0	0.0	0.0	0.2	0.0	0.0



▪ **Figure 3.24 – Little Turtle Island Benthic Categories and Grouped Categories**

Finucane Island

An assessment of the intertidal platform was undertaken during a spring low tide in February 2009, during which marine scientists were able to walk over a large extent of the platform. Three main zones were distinguished based on physical characteristics (**Figure 3.25**), supporting different biotic assemblages:

- Lower Intertidal Zone: This zone was characterised by prominently exposed serpulid worm casing mounds (see plate on **Figure 3.25**). It supported mixed BPP (mainly macroalgae and hard corals) and non BPP including motile and non motile invertebrates (sponges, echinoderms and molluscs); and serpulid worms (evidenced by sand casing mounds). A drop off of approximately 30 cm was identified on the seaward edge, but the seaward extent of any additional BPPs could not be accurately determined due to water coverage.

- Central Zone: This zone was predominantly flat with numerous rock pool depressions. The dominant BPPs in this zone were green and brown macroalgae, including the green macroalgae genera *Caulerpa, Halimeda, Neomeris*; and the brown macroalgae genus *Sargassum* (see plate on **Figure 3.25**). Living or dead hard corals were conspicuously absent from the permanently submerged rock pools. Numerous motile invertebrates were observed in the rock pools, including octopi, crabs and starfish.

- Upper Intertidal Zone: This zone was gently sloped and marked by numerous rivulets running perpendicular to the shoreline. It was typically the most landward zone, but was also observed close to the seaward ledge along part of the platform. It was more elevated than the other zones and as such is likely to be exposed to air for longer durations than the other zones. At the time of the survey, BPP coverage in this zone was restricted to turf algae on the flats and macroalgae in the rivulets (see plate on **Figure 3.25**).

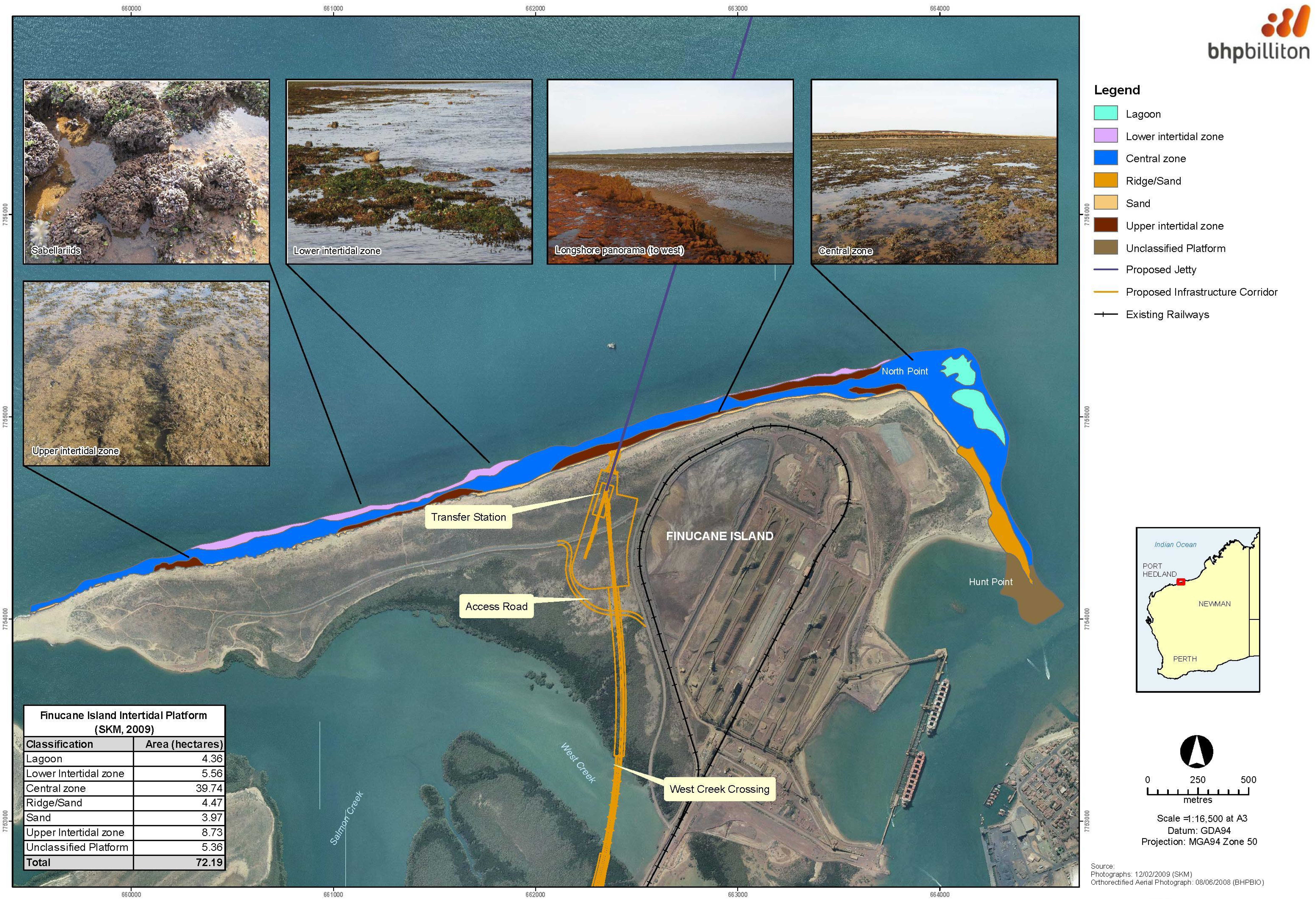
The main factors influencing the distribution of biota on the platform can be summarised as:

1) Height on intertidal zone: Diversity and density of BPPs, including hard corals and macroalgae, was observed to be inversely related to platform height. Hard corals were restricted to the lowest elevation sections of the platform, while only turf algae and macroalgae was present on the upper intertidal sections.
2) Geology: The presence of rivulets is likely caused by water movement, either from rain or retreating sea water. It was within the depressions of the rivulets that macroalgae were observed, presumably due to a longer wetted duration, than the surrounding flats that supported turf algae.
3) Sand Accumulation and Movement: Based on field observations and archival aerial imagery, a large section of the platform appeared to be inundated with sand for at least part of the year. This assertion was supported by field observations, including:

- The lack of living or dead hard corals in the permanently wetted rock pools which are seen in similar Pilbara intertidal zones, such as Cape Lambert. The lack of dead (or recently bleached) hard corals within the Finucane Island pools suggests that they have been prevented from settling due to smothering or scouring by sand.
- The presence of numerous and large serpulid worm tube casings in the lower intertidal zone; these worms require sand to construct their cases.
- In the lower intertidal zone, presumably the wave energy is still great enough to prevent the build up of sand allowing survival of hard corals.

In addition to the zones described above, there were two large lagoons on the eastern (Hunt Point) end of Finucane Island, up to 1 m deep and supporting numerous *Porites* colonies (hard coral BPP) (**Figure 3.25**). The colonies reached up to 1 m in diameter, but were height limited due to the lack of water coverage. These colonies have previously been monitored as part of PHPA environmental monitoring (URS 2005). In addition, small patches of *Thalassia hemprichii* and *Halodule uninervis* (each less than 5 m^2) were observed within the lagoon.

Figure 3.25 illustrates estimates of the areal extent of sand coverage, but it must be noted that the satellite imagery in this figure was captured in 2002 (as it was the lowest tide available), so the estimate of sand coverage is indicative of that time only and appears to be variable over time, as demonstrated by the amount of available BPPH observed in July 2007 compared to February 2009.



Finucane Island Intertidal Platform (SKM, 2009)	
Classification	**Area (hectares)**
Lagoon	4.36
Lower Intertidal zone	5.56
Central zone	39.74
Ridge/Sand	4.47
Sand	3.97
Upper Intertidal zone	8.73
Unclassified Platform	5.36
Total	**72.19**

Figure 3.25 Deliniation and areal coverage of BPPs on Finucane Island Seaward Platform, February 2009

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3.2.4. Other Areas

Eastern Shoreline

The nearshore area to the east of Port Hedland has a series of bathymetric features that appear to be ridgelines (**Figure 3.14**). Subtidal investigations of these structures, including a feature offshore of Cook Point and one between North Turtle Island and the mainland, found the seabed to be comprised of silty sand with no BPP or other epibenthic biota. The location of these sites is shown on **Figure 2.3** as 6 black dots along the coastline to the east of Port Hedland.

Potential Spoil Ground Locations

A number of potential spoil ground locations were investigated, resulting in a series of spot dives as follows:

- two potential spoil ground locations to the north-west of the proposed port area;
- five potential spoil ground locations to the east of the shipping channel in the vicinity of the existing spoil grounds H, I and J; and
- six potential spoil ground locations surrounding the proposed port area.

In total, 13 potential spoil ground locations have been investigated resulting in 76 spot dives to characterise the seabed in the area. These locations represent the deeper (approximately – 15 to –30 m CD) regions of the study area that have no bathymetric features. The sites were found to have varying degrees of sand cover (20 – 50+ cm) overlying harder substrate. None of the locations had any BPP or appreciable non BPP biota cover. Epifauna observed at some locations was very sparsely distributed and limited to small sponges and sea whips attached to rubble, feather stars clinging to sea whips and hydroids attached to small rocks.

Proposed Channel Footprint

Three series of sampling sites were investigated as part of the sampling and analysis plan (SAP) to characterise the sediment chemistry for sea dumping. The first series of 60 sites was along a channel option that was subsequently realigned, resulting in a further 50 sampling sites. Minor adjustments to this footprint necessitated another 27 sampling sites, for a total of 137 sites relating to the proposed dredge footprint. At each of these sites the benthic habitat was assessed and photographs taken. None of the locations had any appreciable BPP cover apart from the final section of the currently proposed channel alignment that intersects the outermost ridgeline. Visual observations indicated that this site supported BPP classes in similar proportions to other sites on the outermost ridgeline described in **Section 3.2.1**.

Low Relief Areas

Towed video was undertaken in non-ridgeline areas to characterise the broad scale benthic habitat in the nearshore and offshore areas. The seabed in non-ridgeline areas was found to have coarse sandy sediment of varying thickness. Those areas where the sediment is a thin (< 20 cm) veneer over pavement or other rocky substrate are associated with sponge and soft coral benthic communities however these areas between the ridgelines were generally devoid of any BPPs.

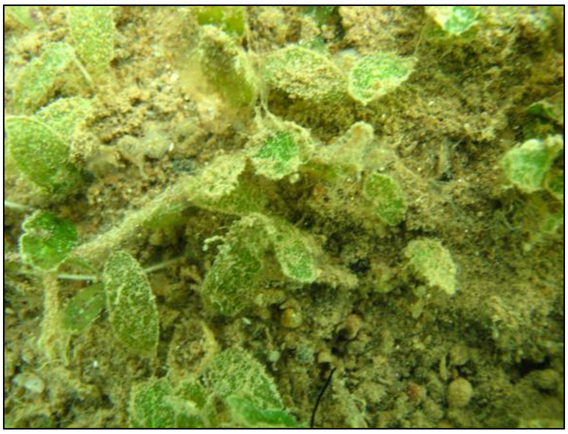
Areas where the sediment was thicker supported predominantly mobile epifaunal communities such as echinoderms. The stability of these soft sediment layers is unclear but what is clear is that the thickness of the sediment dictates what sessile fauna can become established.

These data appear to correlate well with the habitat modelling undertaken using the ground truthing observations and LiDAR bathymetry.

Protected Embayments

Recent drop video investigations in the embayments between Weerdee and Downes Islands, to the west of Finucane Island (**Figure 3.13**; and SKM 2009f) identified patches of seagrass, predominantly *Halophila ovalis*. The seagrass exists in mixed assemblages at four locations totalling approximately 85 ha, most commonly mixed with macroalgae and occasionally with sponges. The plates below give an indication of the density and epiphytic cover of the seagrass. Further consideration of these seagrass patches are discussed in the Subtidal BPPH Impact Assessment (SKM 2009a).

Halophila ovalis in embayment to south of Downes Island



Halophila ovalis with epiphytic growth, Oyster Inlet

4. Summary and Conclusion

Summary

The benthic habitat of the proposed Port Hedland Outer Harbour Development marine study area is dominated by sand plains interspersed with a series of hard substrate ridgelines running parallel to the coastline, generally in surrounding water depths ≥ - 10 m CD.

Field surveys and LiDAR bathymetry data informed the habitat modelling and mapping process. This process assumed a benthic class to be present when it was recorded at ≥5% cover within diver video transects. The presence of a class was then extrapolated across the entire study area where the same factors were found (such as rugosity and water depth). Habitat mapping was conducted by modelling classification of the entire study area to predict substrate type and cover of both BPP and non BPP biota. Habitat classes were developed from the combination of substrate type and biota distribution to predict the distribution of BPPH and non BPPH classifications.

Benthic habitat modelling of the study area predicted the following percentage covers:

- 87% is non BPPH (sand or sediment not capable of supporting BPP);
- 11.5% is BPPH[1]; and
- 1.5% could not be accurately modelled.

The distributions of the BPP and non-BPP biota classes were predicted to be strongly associated with the areas of topographic complexity associated with hard substrate, particularly the ridgelines. As the hard substrate areas were identified as the primary substrate that does or could support BPP (primarily hard coral and macroalgae), all hard substrate including presently bare hard substrate, was included as BPPH.

The 11.5% benthic habitat considered to be BPPH was comprised of:

- 7.0% hard substrate (with and without BPP);
- 1.3% sediment covered hard substrate with BPP; and
- 3.2% sediment with BPP.

[1] Habitat currently supporting BPP or considered capable of supporting BPP, as defined by EPA Guidance Statement 29

The presence of BPPs (at ≥5% cover) was predicted to occur across the study area as such:

- 5.0% hard coral;
- 4.4% macroalgae; and
- seagrass could not be modelled due to a lack of field survey observations.

This does not imply that hard coral completely covers 5.0% of the study area. It indicates that hard coral is predicted to occur across 5% of the study area, at a minimum of 5% benthic cover in these locations, as explained earlier in the summary.

Analyses of field measurements that were used to inform habitat modelling and mapping, and other general descriptions, are summarised below:

Offshore Ridgeline Systems:

- Outermost Ridgeline: predominantly abiotic (> 60%); BPPs: hard coral cover (4.9-27.1%) and macroalgal cover (1.3–14.7%); non-BPPs: sponges (2.9–11.6%) and soft corals (0.0–3.1%).
- Middle Ridgeline: predominantly abiotic (> 69%); BPPs: hard coral cover (5.8–21.8%) and varying quantities of macroalgae (0.0–14.7%); BPPs: sponges (3.6–9.6%) and soft corals (0.2–1.8%).
- Innermost Ridgeline: predominantly abiotic (> 67%); BPP: hard coral cover (3.3–22.9%) and macroalgal cover (0.0–3.4%); BPPs: sponges (2.7–8.4%) and soft corals (0.0–3.6%).

Inshore Ridgeline Systems:

- Minilya Bank: predominantly abiotic (> 67%); BPPs: hard coral cover (3.6–19.6%) and macroalgal cover (0.0–4.9%); BPPs: sponges (6.4–9.8%) and soft corals (0.0–6.0%).
- Proposed Port Area: predominantly abiotic (> 79%); BPPs: hard coral cover (0.0–12.9%); and non-BPPs: varying quantities of sponges (3.1–6.4%) and soft corals (1.1–1.6%).
- Weerdee Ridgeline: BPPs: predominantly macroalgae (0.0–71.3%) and hard coral cover (0.2–21.6%); and non-BPPs: sponges (1.8–12.2%) and soft corals (0.0–7.1%).
- Cape Thouin Area: predominantly abiotic (> 78%); BPPs: hard coral cover (7.6%) and macroalgal cover (4.9%); and non-BPPs: sponges (7.8%) and soft corals (1.1%).

Island Ridge Systems:

- Weerdee Island: The sub tidal area was very shallow (< 2 m CD) and was comprised of BPPs including patchy areas of either macroalgae (71.3%), a combination of macroalgae (30.9–64.7%) and sparse small hard corals (< 5%). The hard coral colonies belonged to the encrusting, foliose and massive coral categories. There was also non-BPP patches entirely comprised of small bivalves (*Brachidontes ustulatus*).

- North Turtle Island: The subtidal sites surveyed indicated a seabed that was comprised of sand and rubble covering a hard rocky pavement. The cover of BPPs was dominated by hard corals (0.2–18.9%) and macroalgae (0.0–5.1%). The hard corals were dominated by encrusting and massive varieties. Non-BPP comprised sponges (0.0–8.2%) and soft corals (0.0–2.9%).
- Little Turtle Island: The subtidal area in the vicinity of Little Turtle Island was comprised of a combination of sand, rubble and rock. The cover of BPPs was dominated by macroalgae (0.0–14.7%) and mainly encrusting and massive hard corals (8.4–17.8%). Non-BPPs included sponges (2.9–9.6%), and small amounts of soft corals and hydroids.
- Finucane Island: the intertidal platform of Finucane Island is capable of supporting primary producers but, based on field observations and archival aerial images, the availability of suitable substrate appears to be temporally variable due to sediment build up. The rock pool zone was the most widespread during the February 2009 survey, and was estimated using aerial photography and GIS analysis as representing approximately 55% of the platform area.

Other Areas:

- Eastern Shoreline: The nearshore area between Port Hedland and Spit Point along the eastern shoreline has a series of bathymetric features that appear to be ridgelines; however, they were found to be comprised of silty sand with no epibenthic biota.
- Potential Spoil Ground Locations: None of the locations surveyed had any appreciable benthic cover. Epifauna observed at some locations were very sparsely distributed and limited to small sponges and sea whips attached to rubble, feather stars clinging to sea whips and hydroids attached to small rocks. Despite this the LiDAR data and subsequent habitat mapping has identified some areas of potential BPPH within the spoil grounds. Although this does not represent a large area, the eastern boundaries of Spoil Ground 3 have been modified to avoid an area of BPPH.
- Proposed Channel Footprint: The footprint for the proposed channel had no appreciable benthic cover apart from the final section of the channel that transects the outermost ridgeline.
- Protected Embayments: Patches of *Halophila ovalis* have been observed at four locations between Weerdee and Downes Islands. This seagrass is of sparse to medium density and is usually intermingled with other benthic biota, primarily macroalgae.

Conclusion

At sites where hard coral was quantitatively surveyed within the proposed Outer Harbour Development study area with diver video transects, the percentage cover ranged from 0.2%–27.1%. This range was slightly less than the percentage cover of hard coral reported from 22 offshore survey sites at Cape Lambert, approximately 150 km south-west of Port Hedland, where cover ranged from less than 2% to over 40% (SKM 2008a). The sites at Cape Lambert were located in water depths ranging from approximately - 7 m to - 15 m CD, with the most seaward site approximately 20 km from the coastline.

The hard corals identified within the Port Hedland study area were found to be growing on limestone structures rather than on bases of calcium carbonate accretion (e.g. not true coral reefs). This growth form was also observed offshore of Cape Lambert (SKM 2008a).

In terms of species diversity, a total of 51 species from 19 genera were recorded from the study area, dominated by massive, encrusting and foliose varieties. By comparison, Blakeway and Radford (2005) recorded 120 species from 43 genera within Dampier Port and Inner Mermaid Sound, a further 50 km south west of Cape Lambert. The species list recorded from the Blakeway and Radford (2005) study was also dominated by massive, encrusting and foliose varieties.

Gilmour et al. (2006) examined the water quality environment in the Pilbara region and identified a range of potential water quality stressors to corals such as turbidity, sedimentation and reduction in light. The susceptibility of a range of coral taxa to these stressors was characterised into three categories: High, Medium and Low. The dominant coral taxa occurring in the Port Hedland area is *Turbinaria* which is described by Gilmour et al. (2006) as having low susceptibility to increases in sedimentation and the reduction in light regime due to increases in turbidity. Other sub dominant genera in the Port Hedland region such as corals from the Faviidae and Poritidae families and branching *Acropora*, were described by Gilmour et al. (2006) as having medium susceptibility to major changes in the sedimentation and light regime.

Based on the low species richness and abundance of corals and dominance of *Turbinaria* and the results of the investigations by Gilmour et al. (2006); coral communities that inhabit sub tidal habitats in the study area can be described as predominantly high turbidity (low light) and sedimentation adapted communities.

Fifty-eight macroalgal species were recorded during a survey conducted in May 2008 (Huisman 2008). The marine plant flora was typical of the Pilbara region and included many species collected by the author during unpublished surveys of other Pilbara localities (e.g. Barrow Island). One species, *Ganonema samaense*, is newly recorded for Western Australia.

Huisman (2008) stated that as the waters in the region are typically turbid, the subtidal marine flora will have become established under those conditions. During the field survey, very few marine plants were collected or observed from the subtidal sites, which were dominated by invertebrate filter feeders. This indicates that these sites (at least) are already unsuitable in some way for marine plants. However, underwater photographs from other locations spread throughout the study region have shown extensive stands of 1–2 species of the green algae genera *Caulerpa* and *Halimeda*, which are presumably adapted to growth under low light conditions. These were also the genera most commonly observed in the wider subtidal study area during habitat surveys. Transient stands of *Sargassum* have also been observed by divers at monitoring sites, during winter and spring (see SKM 2009d).

Sparse to medium density patches of the four seagrass species previously identified by Walker and Prince (1987) were observed in embayments and intertidal lagoons, adjacent to the modeled study area. The largest area of seagrass observed was *Halophila ovalis* in the embayments between Downes and Weerdee Islands, totaling approximately 85 ha. This species is recognised as being ephemeral and a coloniser species, as it is one of the first seagrass species to recruit following disturbance (Lanyon and Marsh 1995). Seagrass was not recorded within any of the diver video transects, so was not predicted to occur within the study area by habit modeling. Other studies in the Pilbara have also described sparse and ephemeral seagrass coverage (SKM 2008a, SKM 2008b).

It is important to note that the marine environment offshore of Port Hedland is not in pristine condition. The nearshore environs have been modified as a result of development in Port Hedland, and the offshore area has been impacted on by the existing dredged shipping channel and disposal of dredged material in spoil grounds (Le Provost et al 1984).

At the conclusion of literature reviews, field investigations and habitat mapping, it is considered that the identified benthic habitats, communities and organisms are not endemic, unique or of regional significance. Furthermore, the detail collected from these investigations has informed baseline monitoring of habitats and water quality that will satisfy recommendations outlined in Guidance Statement 29 (EPA 2004) and the Pilbara Coastal Water Quality Consultation Outcomes (DoE 2006).

5. References

Brayford, B., Chatfield, B. & Baxter, K. (2008) Marine habitat classification scheme suitable for mapping subtidal habitats. Unpublished report. Sinclair Knight Merz, Perth, Western Australia.

Blakeway, D. and Radford, B.T.M. (2005). Scleractinian corals of the Dampier Port and inner Mermaid Sound: species list, community composition and distribution data. From: Corals of the Dampier Harbour: Their survival and reproduction during the dredging programs of 2004. Eds: Stoddart, J.A. and Stoddart, S.E. MScience Pty Ltd, Perth WA, 78pp.

Breiman, L., Freedman, J., Olshen, R., & Stone, C. (1984) Classification and Regression Trees. Wadsworth, California.

Carleton, J.H. and Done, T.J. (1995) Quantitative video sampling of coral reef benthos: large scale application. Coral Reefs 14:35–46.

Department of Environment (2006). Pilbara Coastal Water Quality Consultation Outcomes: Environmental Values and Environmental Quality Objectives. 62pp.

Department of the Environment, Water, Heritage and the Arts (2009) Marine Bioregional Planning in the North-west. Available online:http://www.environment.gov.au/coasts/mbp/publications/north-west/bioregional-profile.html. Accessed October 20 2009.

EPA (2004). Benthic Primary Producer Habitat Protection for Western Australia's Marine Environment – Guidance Statement No. 29. Environmental Protection Authority, Perth, WA.

ESRI (2006) ArcGIS software version 9.2

Fielding, A.H. and Bell J.F. (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 241:38–49.

Garrard, C. (2005) StatMod Zone software extension. Accessed on 15 August 2008 from: http://www.gis.usu.edu/~chrisg/avext/

Gilmour, J.P., Cooper, T.F., Fabricus, K.E. and Smith, D.L. (2007). Early warning indicators of change in the condition of corals and coral communities in response to key anthropogenic stressors in the Pilbara, Western Australia. Australian Institute of Marine Science, 101pp.

Hanley, J.A. and McNeil, B.J. (1982) The meaning and use of the area under a receiver operating characteristic (ROC). Radiology 143: 29–36.

Holmes, K.W., Radford, B., Van Niel, K.P., Kendrick, G.A., Grove, S.L. and Chatfield, B. (2007) Mapping the Benthos in Victoria's Marine National Parks, Volume 1: Cape Howe. Parks Victoria. Technical Series No. 40. Parks Victoria, Melbourne.

Holmes, K.W., Van Niel, K.P., Radford, B. & Kendrick, G.A. (2007) Mapping sessile benthic communities and substrate types: an ecological modelling approach Point Addis Marine National Park. Accessed from: http://www.coastal.crc.org.au/Assets/03CaseStudies/03_10References/BenthicHab/Ireland_mini_talk_v3.pdf

Holmes, K.W., Van Niel, K.P., Radford, B., Kendrick, G.A. and Grove, S.L. (2008) Modelling the distribution of marine benthos from hydroacoustics and underwater video. Continental Shelf Research 28: 1800–1810.

Hosmer, D. & Lemeshow, S. (1989) Applied Logistic Regression. Wiley & Sons, New York.

Huisman, J. (2008). Marine Plants of North Turtle and Little Turtle Islands, Port Hedland, May 2008. Report prepared for Sinclair Knight Merz.

Insightful Corporation (2007) SPLUS Software version 8.0 for Windows.

Lanyon, J.M. and Marsh, H. (1995). Temporal changes in the abundance of some tropical intertidal seagrasses in North Queensland. Aquatic Botany 59: 217 – 237.

Le Provost, I., Semeniuk, V. and Chalmer, D. (1984). Environmental description of proposed dredge spoil grounds, Port Hedland, Western Australia. Prepared for Mount Newman Mining Company, 46pp.

Mount, R., Bircher, P. and Newton, J. (2007) National Intertidal/Subtidal Benthic Habitat Classification Scheme. School of Geography and Environmental Studies, University of Tasmania.

Osborne, K. and Oxley, W.G. (1997) Sampling benthic communities using video transects. In: Survey manual for tropical marine resources. Edited by S. English, C. Wilkinson and V. Baker. Australian Institute of Marine Science.

Pendoley Environmental (2009) Port Hedland Outer Harbour Development: Marine Turtle within the Port Hedland Region and Impact Assessment of the Outer Harbour Development. Report prepared for Sinclair Knight Merz/BHP Billiton Iron Ore.

Schroeder, B. (2004) ROC & AUC-Calculation–evaluating the predictive performance of habitat models. Software version 1.3 available from http://brandenburg.geoecology.uni-potsdam.de/users/schroeder/download.html

Sinclair Knight Merz (2007a). Dredging Program for the Cape Lambert Port Upgrade Environmental Referral Document. Prepared for Robe River Iron Associates.

Sinclair Knight Merz (2007b). Preliminary Assessment of Benthic Primary Producer Habitat Finucane Island Near-shore Environment. Report prepared for BHP Billiton Iron Ore, September 2007.

Sinclair Knight Merz (2008a). Cape Lambert Port B Development: Abundance and distribution of inter and subtidal benthic habitats in the Cape Lambert area: 2008 Survey. Prepared for Rio Tinto Pty Ltd. 68pp.

Sinclair Knight Merz (2008b). Cape Lambert Port B Development: Dredging and dredge spoil assessment: including benthic primary producer assessment. Prepared for Rio Tinto Pty Ltd. 87pp.

Sinclair Knight Merz (2009a). Port Hedland Outer Harbour Development: Subtidal Benthic Primary Producer Habitat Impact Assessment. Report prepared for BHP Billiton Iron Ore, July 2009.

Sinclair Knight Merz (2009b). Port Hedland Outer Harbour Development: Spoil Ground Selection Study. Report prepared for BHP Billiton Iron Ore, July 2009.

Sinclair Knight Merz (2009c). Port Hedland Outer Harbour Development: Baseline Water Quality Monitoring Report Periods 1 – 13. Report prepared for BHP Billiton Iron Ore, July 2009.

Sinclair Knight Merz (2009d). Port Hedland Outer Harbour Development: Baseline Coral Health Monitoring Report Periods 1 – 13. Report prepared for BHP Billiton Iron Ore, July 2009.

Sinclair Knight Merz (2009e). Port Hedland Outer Harbour Development: Water Quality Thresholds. Report prepared for BHP Billiton Iron Ore, July 2009.

Sinclair Knight Merz (2009f). RGP6 Port Facilities Definition Phase: Benthic Primary Producer Reference Area Subtidal Habitat Mapping. Report prepared for BHP Billiton Iron Ore, July 2009. Unpublished, 42pp.

Sinclair Knight Merz (2009g). Cape Lambert Port B Development: Public Environmental Review and Draft Public Environmental Report. Prepared for Pilbara Iron Pty Ltd.

Tenix (2008). Tenix LADS Report of survey: Bathymetric LiDAR survey at Port Hedland. Prepared for BHP Billiton Iron Ore, February 2008.

URS (2005). Maintenance Dredging Campaign: Environmental Monitoring 2004. Prepared for Port Hedland Port Authority. 60pp.

6. Glossary

Abiotic	Non living. For example, abiotic substrate includes the sand, rubble and rock component rather than the benthos living on and within it.
Assemblage	Recognisable grouping or collection or individuals or organisms.
Bathymetry	Measurement of the changing ocean depth to determine the sea floor topography.
Benthic	Bottom dwelling.
Benthic Primary Producer (BPP)	Predominantly marine plants (e.g. seagrasses, mangroves, seaweeds and turf algae) but include invertebrates such as scleractinian corals, which acquire a significant proportion of their energy from symbiotic microalgae that live in coral polyps.
Benthic Primary Producer communities (BPP communities)	Biological communities, including the plants and animals within which the benthic primary producers defined above predominate.
Benthic Primary Producer Habitat (BPPH)	Both the BPP communities and the substrata that can/does support these communities.
Benthos	All biota living upon or in the sediment of an aquatic habitat.
Biota	The plants, animals and micro-organisms of a region.
Bommie	A protrusion on the seabed, e.g. rock or coral.
CD	Chart datum. The level of water that charted depths are measured from. In Australia the CD is based on the Lowest Astronomical Tide.
Community	Ecologically, any naturally occurring group of different organisms sharing a particular habitat.
DEM	Digital Elevation Model. A digital representation of ground surface topography.
Density	The number of organisms per unit area.
Echinodermata	The group of animals containing sea stars, brittle stars, urchins, crinoids and sea cucumbers.

Encrust	To cover over a hard surface with sessile invertebrates.
Endemic	Native species confined to a given region.
Environment	The surroundings of an organism including the other biota with which it interacts.
Epifauna	Benthic animals that move about on the sea bed or are firmly attached to it.
Epiphyte	Plant which grows attached to the surface of another plant or animal.
Fauna	Collectively, the animal life of any particular region.
Flora	Collectively, the plant life of any particular region.
Habitat	The place where the physical and biological elements of ecosystems provide a suitable environment including the food, cover, and space resources needed for plant and animal livelihood.
Impact	The change in the chemical, physical (including habitat) or biological quality or condition of a water body caused by external sources.
Infauna	Animals that live within the sediments of aquatic environments.
Intertidal	Lying between the high and low tide marks.
Invertebrate	Collective term for all animals which do not have a backbone or spinal column.
LAT	Lowest Astronomical Tide. The height of water at the lowest theoretical tide.
Light attenuation	Light reduction (usually refers to a decrease in available light which occurs with increasing depth of water).
Macroalgae	A diverse group of aquatic plant-like organisms. The larger members of this group that occur in the marine environment, are called seaweeds and the microscopic members that float in the water are called phytoplankton.
Molluscs	Soft-bodied invertebrates of the phylum Mollusca usually partly or wholly enclosed within a calcium carbonate shell.

Neap tides	Sets of moderate tides which recur every two weeks and alternate with spring tides.
Nearshore	Offshore to 10 m bathymetric contour
Offshore	Offshore beyond 10 m bathymetric contour
Population	Aggregate of individuals of a biological species that are geographically isolated from other members of the species and are actually or potentially interbreeding.
Reference site	Specific locality on a water body which is unimpaired or minimally impaired and is representative of the expected biological integrity of other localities on the same water body or nearby water bodies.
Sea level (mean)	Mean Sea Level is often abbreviated as MSL. It is necessary to convert the pressure readings to equivalent mean sea level pressures, otherwise the important horizontal changes in pressure would be overwhelmed by vertical variations simply due to differences in height between observing stations. In this way, a Mean Sea Level Pressure map will then show pressures affected by changing weather conditions, not because of changing altitude.
Sessile	Attached to a substrate and thus non-mobile.
Species	A group of organisms that, under normal circumstances, can interbreed.
Spring tides	Extremely high and low tides which alternate with neap tides and recur every two weeks.
Subtidal	Below the low tide mark.
Supratidal	Above the high tide mark.
Suspended Solids	Any solid substance present in water in an undissolved state.
Turbidity	Measure of the clarity of a water body.

Appendix A Sampling Site Coordinates

All co-ordinates are in datum WGS 84 Zone 50K

A.1 Subtidal Video Transect Sites

Site	Description	Easting	Northing	Latitude	Longitude
BH1	Bore hole 1	0661240	7761951	S 20°13.997'	E118°32.614'
CNS1	Cornelisse Shoal 1	0643769	7783870	S 20°02.200'	E 118°22.477'
CNS2	Cornelisse Shoal 2	0642495	7782709	S 20°02.835'	E 118°21.752'
CNS3	Cornelisse Shoal 3	0640299	7780574	S 20°04.002'	E 118°20.502'
CNS4	Cornelisse Shoal 4	0647802	7787726	S 20°00.092'	E 118°24.771'
CT-R1	Cape Thouin area	0634091	7760237	S 20°15.052'	E118°17.030'
CT-R4	Cape Thouin area	0622758	7768920	S 20°10.391'	E118°10.486'
CT-R5	Cape Thouin area	0624850	7770141	S 20°09.721'	E118°11.682'
CT-R6	Cape Thouin area	0626228	7767473	S 20°11.162'	E118°12.484'
CXS1	Coxon Shoal 1	0664711	7784073	S 20°01.990'	E 118°34.487'
CXS2	Coxon Shoal 2	0661254	7781815	S 20°03.231'	E 118°32.516'
CXS3	Other offshore Ridge	0652591	7780462	S 20°04.007'	E 118°27.553'
FR1	Finucane Ridge 1	657755	7758768	S 20°15.740'	E118°30.629'
LT1	Little Turtle island 1	0688256	7785329	S 20°01.181'	E 118°47.981'
LT2	Little Turtle island 2	0690780	7784127	S 20°01.817'	E 118°49.435'
LT3	Little Turtle island 3	0691452	7783696	S 20°02.047'	E 118°49.823'
LT4	Little Turtle island 4	0684766	7780745	S 20°03.685'	E 118°46.007'
LT5	Little Turtle island 5	0688208	7786278	S 20°00.666'	E 118°47.947'
MB1	Minilya Bank 1	0670983	7771075	S 20°09.002'	E 118°38.157'
MB2	Minilya Bank 2	0673284	7767565	S 20°10.892'	E 118°39.497'
MB3	Minilya Bank 3	0678111	7772679	S 20°08.094'	E 118°42.238'
MB4	Minilya Bank 4	0659615	7767122	S 20°11.203'	E 118°31.653'
MB5	Minilya Bank 5	0663555	7769572	S 20°09.855'	E 118°33.902'
MB6	Minilya Bank 6	0663839	7768651	S 20°10.353'	E 118°34.070'
NT1	North Turtle Island 1	0696436	7800196	S 19°53.075'	E 118°52.575'
NT2	North Turtle Island 2	0699048	7797589	S 19°54.472'	E 118°54.089'
NT3	North Turtle Island 3	0695564	7797407	S 19°54.592'	E 118°52.094'
NT4	North Turtle Island 4	0694773	7796904	S 19°54.869'	E 118°51.644'
OS-R1	Offshore Ridges	0635942	7769384	S 20°10.086'	E118°18.052'
OS-R2	Offshore Ridges	0633367	7776716	S 20°06.123'	E118°16.542'
R1	Other offshore ridge 1	0651754	7774147	S 20°07.433'	E 118°27.105'
R2	Other offshore ridge 2	0653487	7774369	S 20°07.305'	E 118°28.098'
R3	Other offshore ridge 3	0655574	7774600	S 20°07.170'	E 118°29.295'
R4	Other offshore ridge 4	0646272	7778385	S 20°05.162'	E 118°23.939'
R5	Other offshore ridge 5	0648798	7783680	S 20°02.280'	E 118°25.362'
R6	Other offshore ridge 6	0656553	7768089	S 20°10.694'	E 118°29.890'
R7	Other offshore ridge 7	0658284	7762785	S 20°13.560'	E 118°30.912'
R8	Other offshore ridge 8	0681479	7795957	S 19°55.459'	E 118°44.032'
R9	Other offshore ridge 9	0683682	7797377	S 19°54.677'	E 118°45.286'
WI-1	Weerdee Island 1	0650638	7752455	S 20°19.196'	E 118°26.573'
WI-2	Weerdee Island 2	0650388	7752253	S 20°19.307'	E 118°26.430'
WI-3	Weerdee Island 3	0650484	7751752	S 20°19.578'	E 118°26.488'
WI-5	Weerdee Island 5	0651903	7752655	S 20°19.082'	E 118°27.299'
WI-6	Weerdee Island 6	0652635	7752784	S 20°19.008'	E 118°27.719'

Site	Description	Easting	Northing	Latitude	Longitude
WI-7	Weerdee Island 7	0653629	7753095	S 20°18.835'	E 118°28.288'
WI-R1	Weerdee Ridge1	0654625	7755670	S 20°17.435'	E 118°28.847'
WI-R2	Weerdee Ridge2	0652866	7754753	S 20°17.940'	E 118°27.841'
WI-R3	Weerdee Ridge3	0648134	7754898	S 20°17.884'	E 118°25.122'
WI-R4	Weerdee Ridge4	0646469	7754609	S 20°18.048'	E 118°24.167'
WI-R5	Weerdee Ridge5	0643648	7754694	S 20°18.015'	E 118°22.546'
WI-R6	Weerdee Ridge6	0642815	7753708	S 20°18.553'	E 118°22.072'
WI-R7	Weerdee Ridge7	0653771	7755269	S 20°17.656'	E 118°28.358'

A.2 Subtidal Spot Sites

Site	Description	Easting	Northing	Latitude	Longitude
NT5	North Turtle Island 5	0700485	7793002	S 19°56.949'	E 118°54.942'
CP1	Offshore of Cook Point	0670285	7760215	S 20°14.891'	E118°37.817'
CT-R2	Cape Thouin area	0624955	7757344	S 20°16.658'	E118°11.795'
CT-R3	Cape Thouin area	0615941	7758163	S 20°16.247'	E118°06.613'
CT-R7	Cape Thouin area	0624471	7753463	S 20°18.763'	E118°11.533'
EC1	East Coast 1	0682658	7759828	S 20°15.033'	E118°44.924'
EC2	East Coast 2	0685136	7761911	S 20°13.890'	E118°46.335'
EC3	East Coast 3	0686565	7763373	S 20°13.089'	E118°47.146'
EC4	East Coast 4	0687270	7764905	S 20°12.255'	E118°47.541'
EC5	East Coast 5	0689972	7768639	S 20°10.215'	E118°49.069'
EC6	East Coast 6	0692983	7772735	S 20°07.978'	E118°50.771'
FR2	Finucane Ridge 2	0659907	7756639	S 20°16.883'	E118°31.876'
PHR	Port Hedland Ridge	0670550	7755115	S 20°17.654'	E118°37.998'
4-01	SAP	0662589	7761117	S 20°14.443'	E118°33.393'
4-02	SAP	0662420	7761412	S 20°14.283'	E118°33.294'
4-03	SAP	0662325	7761429	S 20°14.275'	E118°33.239'
4-04	SAP	0661974	7761204	S 20°14.399'	E118°33.039'
4-05	SAP	0661625	7760931	S 20°14.548'	E118°32.840'
4-06	SAP	0662041	7761523	S 20°14.225'	E118°33.076'
4-07	SAP	0661734	7761262	S 20°14.368'	E118°32.901'
4-08	SAP	0661244	7761106	S 20°14.455'	E118°32.620'
4-09	SAP	0661470	7761355	S 20°14.319'	E118°32.749'
4-10	SAP	0661519	7761657	S 20°14.155'	E118°32.775'
4-11	SAP	0661735	7763022	S 20°13.415'	E118°32.892'
4-12	SAP	0661498	7762937	S 20°13.462'	E118°32.756'
4-13	SAP	0661131	7762726	S 20°13.578'	E118°32.547'
4-14	SAP	0660521	7762731	S 20°13.578'	E118°32.196'
4-15	SAP	0660694	7763227	S 20°13.309'	E118°32.293'
4-16	SAP	0660809	7763350	S 20°13.241'	E118°32.359'
4-17	SAP	0661036	7763739	S 20°13.029'	E118°32.487'
4-18	SAP	0660797	7763858	S 20°12.966'	E118°32.349'
4-19	SAP	0660170	7763488	S 20°13.170'	E118°31.991'
4-20	SAP	0660079	7763719	S 20°13.045'	E118°31.937'
4-21	SAP	0660349	7763885	S 20°12.954'	E118°32.091'
4-22	SAP	0659815	7764062	S 20°12.860'	E118°31.784'
4-23	SAP	0659750	7764193	S 20°12.790'	E118°31.746'
4-24	SAP	0659672	7764772	S 20°12.476'	E118°31.698'
4-25	SAP	0659251	7765385	S 20°12.146'	E118°31.453'
4-26	SAP	0658122	7767158	S 20°11.191'	E118°30.796'
4-27	SAP	0657880	7767810	S 20°10.839'	E118°30.653'

Site	Description	Easting	Northing	Latitude	Longitude
4-28	SAP	0657152	7769128	S 20°10.128'	E118°30.229'
4-29	SAP	0655951	7770991	S 20°09.124'	E118°29.530'
4-30	SAP	0655207	7772385	S 20°08.372'	E118°29.096'
4-31	SAP	0654165	7774507	S 20°07.227'	E118°28.487'
4-32	SAP	0653504	7775536	S 20°06.672'	E118°28.102'
4-33	SAP	0653285	7775965	S 20°06.441'	E118°27.974'
4-34	SAP	0653173	7775887	S 20°06.484'	E118°27.910'
4-35	SAP	0653124	7776052	S 20°06.395'	E118°27.882'
4-36	SAP	0652220	7776580	S 20°06.113'	E118°27.360'
4-37	SAP	0651893	7776788	S 20°06.001'	E118°27.172'
4-38	SAP	0649563	7778665	S 20°04.995'	E118°25.825'
4-39	SAP	0649275	7778841	S 20°04.901'	E118°25.659'
4-40	SAP	0648352	7779431	S 20°04.585'	E118°25.127'
4-41	SAP	0648010	7779854	S 20°04.358'	E118°24.929'
4-42	SAP	0648084	7779964	S 20°04.298'	E118°24.971'
4-43	SAP	0647212	7781058	S 20°03.709'	E118°24.465'
4-44	SAP	0647023	7781401	S 20°03.524'	E118°24.355'
4-45	SAP	0646905	7782094	S 20°03.148'	E118°24.284'
4-46	SAP	0646398	7783131	S 20°02.589'	E118°23.988'
4-47	SAP	0646274	7783591	S 20°02.340'	E118°23.915'
4-48	SAP	0645357	7785309	S 20°01.413'	E118°23.381'
4-49	SAP	0644640	7786808	S 20°00.604'	E118°22.962'
4-50	SAP	0644158	7788007	S 19°59.956'	E118°22.680'
T01-1	SAP	0656352	7762735	S 20°13.597'	E118°29.803'
T01-2	SAP	0656529	7762802	S 20°13.560'	E118°29.904'
T01-3	SAP	0656734	7762880	S 20°13.516'	E118°30.021'
T01-4	SAP	0656997	7762980	S 20°13.461'	E118°30.172'
T02-1	SAP	0655886	7763199	S 20°13.348'	E118°29.533'
T02-2	SAP	0656136	7763296	S 20°13.294'	E118°29.676'
T02-3	SAP	0656342	7763375	S 20°13.250'	E118°29.794'
T02-4	SAP	0656593	7763472	S 20°13.196'	E118°29.937'
T03-1	SAP	0655495	7763551	S 20°13.159'	E118°29.306'
T03-2	SAP	0655849	7763676	S 20°13.089'	E118°29.509'
T03-3	SAP	0655976	7763721	S 20°13.064'	E118°29.582'
T03-4	SAP	0656115	7763770	S 20°13.037'	E118°29.661'
T04-1	SAP	0653427	7765463	S 20°12.132'	E118°28.109'
T04-2	SAP	0653597	7765517	S 20°12.102'	E118°28.206'
T04-3	SAP	0653867	7765602	S 20°12.055'	E118°28.361'
T04-4	SAP	0654204	7765709	S 20°11.995'	E118°28.554'
T05-1	SAP	0650420	7768044	S 20°10.748'	E118°26.370'
T05-2	SAP	0650798	7768157	S 20°10.685'	E118°26.586'
T05-3	SAP	0651008	7768219	S 20°10.650'	E118°26.706'
T05-4	SAP	0651159	7768264	S 20°10.625'	E118°26.793'
T06-1	SAP	0648763	7769354	S 20°10.045'	E118°25.412'
T06-2	SAP	0648937	7769413	S 20°10.013'	E118°25.512'
T06-3	SAP	0649213	7769506	S 20°09.961'	E118°25.670'
T06-4	SAP	0649395	7769567	S 20°09.927'	E118°25.774'
T07-1	SAP	0647710	7770994	S 20°09.162'	E118°24.800'
T07-2	SAP	0648033	7771045	S 20°09.132'	E118°24.985'
T07-3	SAP	0648241	7771078	S 20°09.113'	E118°25.104'
T07-4	SAP	0648439	7771109	S 20°09.096'	E118°25.218'

Site	Description	Easting	Northing	Latitude	Longitude
T08-1	SAP	0647002	7772955	S 20°08.102'	E118°24.384'
T08-2	SAP	0647225	7773042	S 20°08.054'	E118°24.511'
T08-3	SAP	0647512	7773154	S 20°07.992'	E118°24.676'
T08-4	SAP	0647698	7773226	S 20°07.952'	E118°24.782'
T09-1	SAP	0646743	7775583	S 20°06.678'	E118°24.222'
T09-2	SAP	0646966	7775740	S 20°06.592'	E118°24.350'
T09-3	SAP	0647192	7775899	S 20°06.505'	E118°24.479'
T09-4	SAP	0647361	7776018	S 20°06.440'	E118°24.575'
T10-1	SAP	0647024	7778360	S 20°05.172'	E118°24.370'
T10-2	SAP	0647199	7778463	S 20°05.115'	E118°24.470'
T10-3	SAP	0647402	7778583	S 20°05.049'	E118°24.586'
T10-4	SAP	0647547	7778669	S 20°05.002'	E118°24.669'
T11-1	SAP	0647151	7780206	S 20°04.171'	E118°24.434'
T11-2	SAP	0647369	7780307	S 20°04.115'	E118°24.559'
T11-3	SAP	0647650	7780438	S 20°04.043'	E118°24.719'
T11-4	SAP	0647814	7780514	S 20°04.001'	E118°24.813'
T12-1	SAP	0647274	7781748	S 20°03.334'	E118°24.497'
T12-2	SAP	0647534	7781869	S 20°03.268'	E118°24.646'
T12-3	SAP	0647793	7781990	S 20°03.201'	E118°24.794'
T12-4	SAP	0647950	7782063	S 20°03.161'	E118°24.883'

A.3 Intertidal Sites

Site	Description	Easting	Northing	Latitude	Longitude
LT-I1	Little Turtle Island Intertidal 1	0689286	7785492	S 20°01.086'	E118°48.570'
LT-I2	Little Turtle Island Intertidal 2	0688761	7785483	S 20°01.094'	E118°48.269'
NT-I1	North Turtle Island Intertidal 1	0696719	7800053	S 19°53.151'	E118°52.738'
NT-I2	North Turtle Island Intertidal 2	0696524	7798738	S 19°53.865'	E118°52.635'
WI-I1	Weerdee Island Intertidal 1	0650858	7752180	S 20°19.344'	E118°26.701'
WI-I2	Weerdee Island Intertidal 2	0652164	7752210	S 20°19.321'	E118°27.451'

A.4 Potential Spoil Ground Sites

Site	Description	Easting	Northing	Latitude	Longitude
1-1	Spoil ground	0644782	7768432	S 20°10.563'	E118°23.131'
1-2	Spoil ground	0642468	7766403	S 20°11.674'	E118°21.813'
1-3	Spoil ground	0645242	7763487	S 20°13.242'	E118°23.419'
1-5	Spoil ground	0645020	7765785	S 20°11.997'	E118°23.281'
3-1	Spoil ground	0634917	7776729	S 20°06.109'	E118°17.431'
3-2	Spoil ground	0632127	7774390	S 20°07.389'	E118°15.840'
3-4	Spoil ground	0636185	7775094	S 20°06.990'	E118°18.166'
3-5	Spoil ground	0634128	7774672	S 20°07.227'	E118°16.988'
SGA-1	Spoil ground A	0671357	7774765	S 20°07.000'	E 118°38.350'
SGA-2	Spoil ground A	0667871	7774799	S 20°07.000'	E 118°36.350'
SGA-3	Spoil ground A	0669603	7773675	S 20°07.600'	E 118°37.350'
SGA-4	Spoil ground A	0667850	7772585	S 20°08.200'	E 118°36.350'
SGA-5	Spoil ground A	0671335	7772551	S 20°08.200'	E 118°38.350'
SGB-1	Spoil ground B	0670173	7769610	S 20°09.800'	E 118°37.700'
SGB-2	Spoil ground B	0666689	7769644	S 20°09.800'	E 118°35.700'
SGB-3	Spoil ground B	0668421	7768520	S 20°10.400'	E 118°36.700'
SGB-4	Spoil ground B	0666668	7767430	S 20°11.000'	E 118°35.700'
SGB-5	Spoil ground B	0670152	7767396	S 20°11.000'	E 118°37.700'
SGC-1	Spoil ground C	0670143	7766474	S 20°11.500'	E 118°37.700'

Site	Description	Easting	Northing	Latitude	Longitude
SGC-2	Spoil ground C	0666659	7766508	S 20°11.500'	E 118°35.700'
SGC-3	Spoil ground C	0668390	7765384	S 20°12.100'	E 118°36.700'
SGC-4	Spoil ground C	0666638	7764294	S 20°12.700'	E 118°35.700'
SGC-5	Spoil ground C	0670121	7764260	S 20°12.700'	E 118°37.700'
SGD-1	Spoil ground D	0663065	7773369	S 20°07.800'	E 118°33.600'
SGD-2	Spoil ground D	0660974	7773388	S 20°07.800'	E 118°32.400'
SGD-3	Spoil ground D	0662006	7771903	S 20°08.600'	E 118°33.000'
SGD-4	Spoil ground D	0660947	7770436	S 20°09.400'	E 118°32.400'
SGD-5	Spoil ground D	0663038	7770417	S 20°09.400'	E 118°33.600'
SGE-1	Spoil ground E	0664046	7766533	S 20°11.500'	E 118°34.200'
SGE-2	Spoil ground E	0661956	7766552	S 20°11.500'	E 118°33.000'
SGE-3	Spoil ground E	0662993	7765620	S 20°12.000'	E 118°33.600'
SGE-4	Spoil ground E	0661939	7764707	S 20°12.500'	E 118°33.000'
SGE-5	Spoil ground E	0664029	7764688	S 20°12.500'	E 118°34.200'
A1-1	Area 1	0666845	7766231	S 20°11.649'	E 118°35.808'
A1-2	Area 1	0668801	7766271	S 20°11.617'	E 118°36.931'
A1-3	Area 1	0667773	7765182	S 20°12.213'	E 118°36.347'
A1-4	Area 1	0666684	7763872	S 20°12.928'	E 118°35.729'
A1-5	Area 1	0668781	7763771	S 20°12.972'	E 118°36.934'
A2-1	Area 2	0665897	7770264	S 20°09.468'	E 118°35.242'
A2-2	Area 2	0668721	7770183	S 20°09.497'	E 118°36.863'
A2-3	Area 2	0667349	7768893	S 20°10.204'	E 118°36.083'
A2-4	Area 2	0666220	7767804	S 20°10.800'	E 118°35.441'
A2-5	Area 2	0668700	7767804	S 20°10.787'	E 118°36.864'
A3-1	Area 3	0663573	7777983	S 20°05.296'	E 118°33.866'
A3-2	Area 3	0667645	7777835	S 20°05.356'	E 118°36.203'
A3-3	Area 3	0670764	7777949	S 20°05.278'	E 118°37.992'
A3-4	Area 3	0665592	7776100	S 20°06.307'	E 118°35.035'
A3-5	Area 3	0669006	7776123	S 20°06.277'	E 118°36.994'
A3-6	Area 3	0663527	7774058	S 20°07.424'	E 118°33.861'
A3-7	Area 3	0667350	7774081	S 20°07.392'	E 118°36.055'
A3-8	Area 3	0670685	7774036	S 20°07.399'	E 118°37.969'
A7-1	Area 7	0650996	7765505	S 20°12.121'	E 118°26.713'
A7-2	Area 7	0653839	7765424	S 20°12.152'	E 118°28.346'
A7-3	Area 7	0652508	7764497	S 20°12.660'	E 118°27.586'
A7-4	Area 7	0651157	7763569	S 20°13.170'	E 118°26.815'
A7-5	Area 7	0653718	7763489	S 20°13.201'	E 118°28.286'
A8-1	Area 8	0643777	7767844	S 20°10.887'	E 118°22.557'
A8-2	Area 8	0646640	7767804	S 20°10.895'	E 118°24.201'
A8-3	Area 8	0645047	7767038	S 20°11.318'	E 118°23.290'
A8-4	Area 8	0644019	7766029	S 20°11.869'	E 118°22.705'
A8-5	Area 8	0646479	7765868	S 20°11.945'	E 118°24.118'
A9-1	Area 9	0645453	7792378	S 19°57.581'	E 118°23.402'
A9-2	Area 9	0647551	7792394	S 19°57.563'	E 118°24.605'
A9-3	Area 9	0646514	7791364	S 19°58.126'	E 118°24.015'
A9-4	Area 9	0645469	7790288	S 19°58.714'	E 118°23.421'
A9-5	Area 9	0647425	7790256	S 19°58.722'	E 118°24.543'

Appendix B Habitat Modelling Methods

Overview

The distribution and spatial extent of the benthic habitats found in the study area for the proposed BHP Billiton Iron Ore Outer Harbour Development were modelled and predicted using a combination of high resolution bathymetry data and in-field ground truth data. While such an approach is relatively new, it has previously been used for the broad scale mapping of marine benthic habitats for management (e.g. Holmes et al. 2007), research (e.g. Holmes et al. 2008), and commercial activities (Sinclair Knight Merz, unpublished data).

This approach defines the relationships between a series of environmental data ('predictor' variables: bathymetry and derived data) and observed habitat distribution data (from ground truth sampling). From these relationships, the distribution of different substrate types (hard substrate, sediment and sediment covered hard substrate) and benthic biota (hard coral, soft coral, sponges, invertebrates and macroalgae) can be predicted and mapped across the entire area for which the environmental data exists.

Bathymetric Data Collection

High resolution bathymetry data were collected by Tenix LADS Corporation (TLC) under sub-contract to Sinclair Knight Merz (SKM). The hydrographic survey was undertaken using the LADS Mk II Bathymetric LiDAR (Light Detection and Ranging) system which was operated from a dedicated Dash-8 200 series aircraft.

The data were collected at a 5 m spot spacing over an area of 3,641 km^2 between October 2007 and February 2008 in three separate surveys. The main sounding lines were flown at 220 m spacing to provide 100% coverage of the seabed, while the inshore areas were flown at 110 m spacing to provide 200% coverage over this often turbid area. Validation and checking of the data was conducted by TLC to ensure it met the requirements of the International Hydrographic Organisation (IHO) Order 1 Survey Standards for horizontal and vertical accuracy. The final data provided by TLC were in digital format (xyz files) and referenced to the World Geodetic System 1984 (WGS84). The data were imported into the ArcGIS 9.2 software package (ESRI 2006), projected to the Geocentric Datum of Australia (GDA 1994), Map Grid of Australia Zone 50 (MGA Zone 50) reference system before being used to create a digital elevation model (DEM) (5 m x 5 m resolution).

It should be noted that the central area in **Figure 3.1** underwent more rigorous processing than surrounding areas to determine the relative reflectance value for each sounding to support maritime engineering design requirements. Consequently the precision of the data in the central area is greater than that for the eastern and western areas. This needs to be considered when interpreting model output.

Ground Truth Data Collection

Ground truth data were collected using a combination of diver transects, spot dives, drop camera observations and towed video surveys. A total of 52 diver-operated video transects and 226 spot dives were undertaken between December 2007 and September 2008. The area covered by these ground truth surveys (**Figure 2.3**) was based on an early prediction of a possible turbidity plume that may result from dredging and/or disposal works. These surveys were undertaken before numerical modelling to predict the distribution and extent of the potential turbidity plume had been undertaken with final dredge logs. Consequently, the survey design relied upon experience with similar projects in the region with ground truth sites selected based on features visible from the LiDAR bathymetry, navigational charts and aerial photography. A follow up survey using a drop video was completed in October 2008 to provide additional coverage over the area, particularly in deeper areas offshore. The design of this survey was based around sampling both the spatial extent and range of environmental conditions present by focussing on gradients identified in the LiDAR data.

Preparation of Data for Modelling

Environmental data

From the bathymetry data (the DEM[1]), a series of secondary datasets were derived using ArcGIS (ESRI 2006) that described the topographic complexity of the seabed in the local neighbourhood. These datasets included slope, aspect, planar curvature, profile curvature, absolute residual depth and rugosity (surface area and surface area ratio). In addition, a number of variables were calculated that describe the variation in the observed bathymetry over different neighbourhood areas. These included standard deviation, range (maximum minus minimum bathymetry), morans I (a measure of spatial autocorrelation) and hypsometric index (a measure of topographic complexity), which were all calculated using circular kernels (neighbourhoods) with radii of 5, 10, 25 and 50 m (the larger neighbourhoods incorporated seabed features from further away to derive the new value).

Such variables have been shown to be correlated with the distribution of the different substrate and biota categories (e.g. Holmes et al. 2008) and can be used as indirect predictors of substrate and biota presence. The secondary datasets derived from the bathymetry data are listed in **Table 3.4**.

Habitat classification scheme

Following the collection of ground truth data, the habitat at each site was classified using a hierarchical classification scheme that is based largely on defining habitat type as a combination of substrate and biota characteristics (**Figure B 1**). The scheme has been developed by SKM

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[1] Digital Elevation Model. A digital representation of ground surface topography.

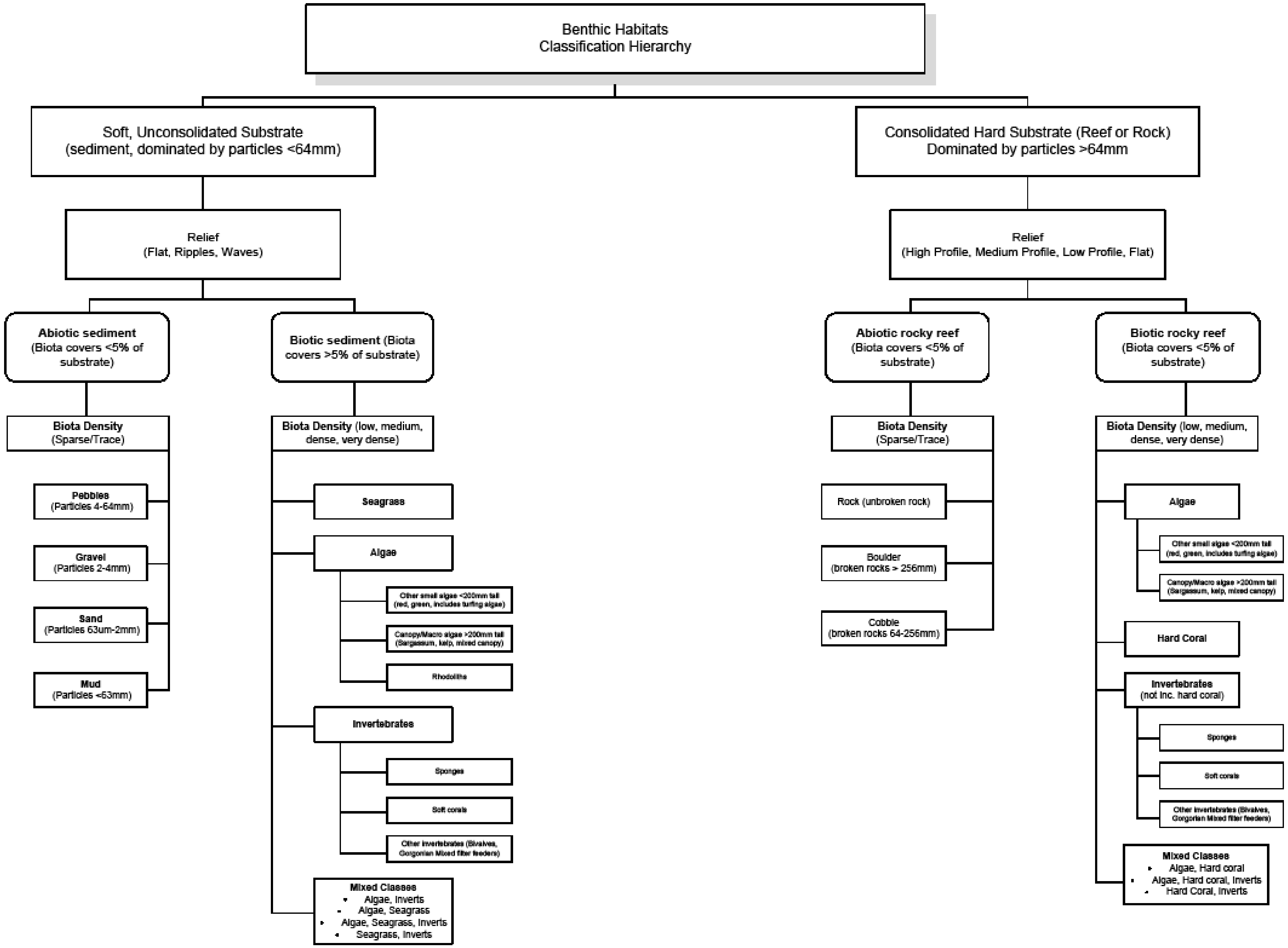
(Brayford et al. 2008) but is also consistent with the National Intertidal / Subtidal Benthic (NISB) Habitat Classification Scheme (Mount et al. 2007) and that used during similar habitat modelling studies (e.g. Holmes et al. 2007). The biota of interest in this study were hard corals, soft corals, sponges, invertebrates, macroalgae and seagrass, and the substrate types were hard substrate (e.g. consolidated limestone ridge), sediment and sediment covered hard substrate.

As the classification scheme is hierarchical, it can be used to combine data collected from a number of sources, and at different scales of resolution. While only details of the primary biota groups and substrate type were of interest in this study, the scheme does allow for detailed taxonomic data of biota to be collected in the same format and nested within the higher groups. The advantage of this approach for modelling applications is that as all data are recorded, they can be easily aggregated to the level for which there are sufficient numbers of observations required to undertake modelling.

For the diver transects and spot dives, classified habitat information was recorded against the GPS (Global Positioning System) coordinates of each site. For the tow video survey data, a GPS signal was recorded simultaneously with the video footage, and using a custom designed spreadsheet in Microsoft Excel, a habitat classification was assigned to each GPS coordinate (approximately every two seconds of video footage). From these data, a table detailing the presence (1) and absence (0) of each biota and substrate type at each ground truth site was developed for use in the modelling.

Table B 1 - Secondary datasets (predictor variables) included in the modelling process to predict the distribution of benthic substrate and biota

Secondary variables	Acronym
Aspect	aspect
Curvature	curv
Depth	depth
Depth residual (depth - linear trend of depth)	depthresid
Hypsometric index (5 m radius)	hyp5
Hypsometric index (10 m radius)	hyp10
Hypsometric index (25 m radius)	hyp25
Hypsometric index (50 m radius)	hyp50
Morans I (5 m radius)	moran5
Morans I (10 m radius)	moran10
Morans I (25 m radius)	moran25
Morans I (50 m radius)	moran50
Plan curvature	plcurv
Profile curvature	prcurv
Range (5 m radius)	rng5
Range (10 m radius)	rng10
Range (25 m radius)	rng25
Range (50 m radius)	rng50
Rugosity (surface area)	sarea
Rugosity (surface area ratio)	saratio
Slope	slope
Standard deviation (5 m radius)	stdev5
Standard deviation (10 m radius)	stdev10
Standard deviation (25 m radius)	stdev25
Standard deviation (50 m radius)	stdev50



- **Figure B 1 - Habitat classification scheme used (from Brayford et al. 2008)**

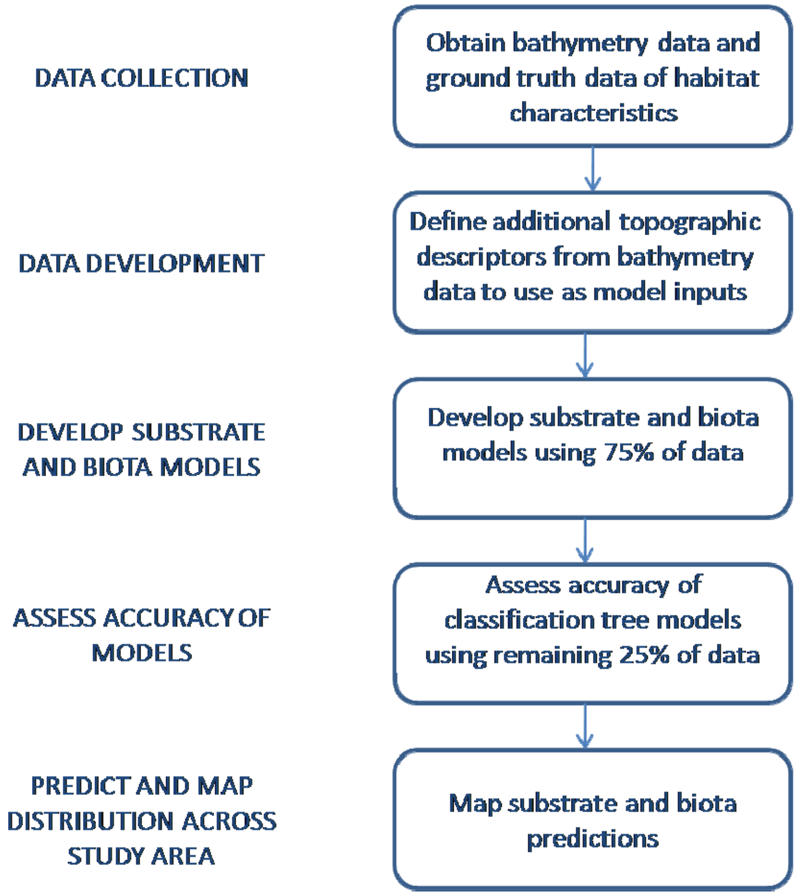
Modelling and Predicting the Distribution of Benthic Habitats

Modelling Approach

To define the relationship between the environmental data (bathymetry and derived data) and the observed habitat distribution (classified habitat data), Classification and Regression Tree models (CART, Breiman et al. 1984) were used. CARTs use binary partitioning of the predictor variables to differentiate between the presence and absence of the habitat class being modelled (e.g. if depth >10 m and <25 m, with slope >5, then class A = present, else class A = absent). They are particularly well suited to modelling categorical data and their non-parametric approach is well suited to modelling the complex relationships that often exist in ecological datasets. CARTs also allow interacting predictor variables to be modelled in the same process, and each variable can be used more than once in each model.

Using the defined relationships, the model output predicts the probability of occurrence (ranging between 0 and 1) for each modelled class for given a set of environmental conditions. By applying the models the extent of the environmental data (e.g. the LiDAR extent), the likely occurrence of the different habitat classes can be predicted and mapped across the entire area. The final step is to evaluate the accuracy of the model predictions by comparing the predicted values with observed ground truth data that were withheld from the model development.

This multi-stage process to model and map substrate and biota types is outlined in **Figure B 2**.



- **Figure B 2 - Summary of the process used to model and classify substrate and benthic habitat types**

Development of Substrate and Biota Models

Before undertaking any modelling, the corresponding bathymetry and derived data values for each ground truth site are extracted for modelling. As only a single GPS location was recorded for the 50 m diver transects, the average value of each environmental variable within a 50 m radius of this point was used in the model. The towed video data provides classified habitat information for every two seconds of footage, which means that multiple habitat classification data are collected within a single 5 m x 5 m grid cell (resolution of the environmental data). Using all of these data is not appropriate as they are repeated data (not independent) and could bias the model, so only one record per 5 m grid cell was used in the modelling.

The final data set for modelling was then split into a training dataset (75% of the data was used to train the model) and a testing set (25% of the data used to evaluate the model accuracy) using the SPLUS statistical program, version 8.0 (Insightful Corp. 2007). This was done to allow independent validation of the accuracy of the models after predicting the distribution of the different substrate and biota classes.

The presence and absence of the different substrate and biotic classes in the training data were modelled using TREE, a classification tree library of SPLUS (Insightful Corp. 2007). This involved a number of steps to develop appropriate models that minimise misclassification errors, but that are still able to accurately predict in locations where no video data are available.

During the model development, the data are repeatedly split into classes of common factors for a substrate or biota. A graphical 'tree' is produced with corresponding end nodes, representing the environmental conditions that define the presence or absence of the biota or substrate class. All classification models will group the data and produce detailed trees, however a highly detailed tree can be produced that is very specific to the data, but is not very good at classifying beyond the training data. Similarly, a less complex tree may be so general as to render the prediction meaningless. Trees are typically 'grown' to a certain size and then 'pruned' to avoid over-fitting the data and producing redundant branches or splits that provide no further information.

In this study, 10-fold cross validation was used to choose the most appropriate tree size. Cross validation allows the model to train on 9/10 of the data, then it tests the classification on the remaining 1/10. This process was repeated four times to produce misclassification plots of tree size (no. of branches) versus classification error (Breiman et al. 1984). The tree size that minimised the misclassification rate was then chosen to help prune the trees (using S-plus command 'prune.misclass') and determine the final classification tree model. The final model was then applied to the full extent of the environmental variables to predict the distribution of each class across the area. The accuracy of the prediction was then assessed by comparing the predicted values to the known substrate and biota data withheld from the modelling (i.e. the testing data).

Assessing Accuracy

The predictive performance of each model was assessed by comparing the observed presence and absence values in the testing data (the 25% of the ground truth data not used in the model development) to the presence absence values predicted by the model. This was done in two ways and provides a measure of reliability or a degree of confidence for the mapped results. First, the ability of the model to discriminate between presence and absence states was determined from the measured area under the curve (AUC) value of receiver-operating characteristic plots (ROC plots, Hanley & McNeil 1982, Fielding and Bell 1997).

An AUC value of 1 indicates that the model can discriminate perfectly between presences and absences. That is, when a class was observed to be present, the corresponding predicted probability of occurrence for that observation will be higher than the probability of occurrence for an absence observation 100% of the time. A score of 0.5 indicates a discriminatory ability no better than by chance alone, i.e. that a presence observation will only have a probability of occurrence greater than an absence observation 50% of the time. AUC values >0.8 are considered high, 0.7–0.8 acceptable and <0.5 are no good at discriminating (Hosmer & Lemeshow, 2000). The ROC AUC software program (Schroeder, 2004) was used to calculate ROC curves and corresponding AUC values to assess the accuracy of all substrate and biota classifications.

The second measure of predictive performance was to calculate the correct classification rate (CCR) to evaluate how accurately the models correctly predicted the observed presences and absences (percentage of correct predictions). For example, a classification rate of 80% indicates that the model correctly predicted the observed value (presence or absence) 80% of the time. In order to calculate CCR a threshold or cut-off value must be determined to convert the predicted probability of occurrence determined by the model (ranging between 0 and 1) to either a presence or an absence value. The commonly used 0.5 cut-off, above which presence is assigned and below absence, does not take into account any misclassifications that may occur. ROC analysis takes into account how accuracy or predictive ability varies according to the cut-off and the point along the ROC curve that avoided extreme over or underestimation of presence/absence predictions (p-kappa) was chosen as the cut-off to map the results for each substrate and biota type.

Mapping the Predicted Results Across the LiDAR Extent

Based on the final tree model, continuous predictive maps were developed across the extent of the LiDAR data using the StatMod Zone extension (StatModz.avx) in ArcView GIS (Garrard 2005). This extension applies the final classification tree model results to the bathymetry and derived datasets for the entire area, assembling a final prediction surface, with each cell having a probability of occurrence value between 0 and 1. This process was repeated for all substrate and biota types modelled with individual maps produced of each type in ArcGIS (ESRI 2006).

Creating Final Substrate, Biota and Combined Habitat Maps

Final maps showing the predicted distribution (presence and absence) of each of the different substrate and biota classes individually and the combined substrate classes were created. A final map showing the distribution of the combined benthic habitats (i.e. the combination of the three different substrate types and five different biota types) was also developed. However, as there were far too many substrate and biota combinations (over 100) to be able to represent on a map, it was simplified to display four classes:

1. hard substrate or hard substrate with biota;
2. sediment covered hard substrate with biota;
3. sediment with biota; and
4. bare sediment or bare sediment covered hard substrate.

The first three classes are considered to be representative of benthic primary producer habitat (BPPH), while the fourth class is non-BPPH.

Limitations

A model is used as a predictive tool to support assessment and decision making. It is important to consider that no model can ever replicate the complexities of the natural system. The extent and range of the collected ground truth data will not only influence the models developed (the relationships that the models define), but they will also influence the assessment of model accuracy. As there was considerably more ground truth data collected throughout the central area due to the greater certainty of potential impacts, the accuracy of the predictions made in this area can be more reliably assessed (through the use of the testing data) than for the areas on either side. See **Figure 3.1** for an illustration of the three LiDAR survey areas; AB (eastern), C (central) and D (western).

It should also be considered that it is very difficult to sample all of the environmental conditions found in a study area that is over 3,641 km^2. Consequently, some conditions will not have been sampled as often as others and this may result in the models not defining these aspects of the habitat-environment relationships as well as it could for others. For example, the large sand banks found at the boundary between Area D and C, and at the south-eastern corner of Area AB which are visible on the LiDAR imagery (**Figure 2.3**). While these areas are topographically complex but contain no biota (from the ground truth data collected), the majority of other ground truth data collected over topographically complex areas did have large amounts of biota (i.e. ridgeline areas). As a result, the models predicted biota to occur on any area that was topographically complex. For those areas of topographic complexity that were known to contain no biota (from ground truth data), the predicted habitat was edited to reflect the actual existing habitat. The consequence of this is that the model is likely to over predict the distribution and spatial extent that benthic biota actually occurs. It could therefore be considered that the modelling exercise produces results that are conservative and likely to indicate greater distribution and spatial extent of BPPH than may potentially occur.

Appendix C Macroalgal Field Report

Marine Plants of North Turtle and Little Turtle Islands, Port Hedland, May 2008

Report prepared for SKM by John Huisman, School of Biological Sciences and Biotechnology, Murdoch University.

Introduction

This report documents the marine plants observed and/or collected during a field survey in May 2008 to the North Turtle and Little Turtle Islands. In addition, a small number of marine plants were identified based on photographs taken during other survey trips by SKM staff. No vouchers were collected of the latter.

Specimens were observed and/or collected by walking on the intertidal reef platform, or by shallow snorkeling. The specimens collected were pressed on-site onto herbarium sheets and will be incorporated into the WA State Herbarium (Perth).

Fifty-eight species were recorded during the survey. The marine plant flora was typical of the region and included many species collected by the author during unpublished surveys of other Pilbara localities (e.g. Barrow Island). One species, *Ganonema samaense*, is newly recorded for Western Australia.

North Turtle Island, intertidal reef walk (19°53.865'; 118°52.635'. 13 May 2008)

This site included an extensive reef platform that was mostly flat pavement with shallow to deep pools. The medium-sized brown alga *Sargassum* was common, but it was mostly senescing or reproductive, indicating the end of the growth season. Other common species were *Cystoseira trinodis*, *Cystoseira* sp., and occasional extensive turfs of the green alga *Cladophora patentiramea*. Additional species observed or collected are listed in Table 1.

Little Turtle Island, snorkel survey (20°01.086'; 118°48.570'. 13 May 2008)

Little Turtle Island was visited twice, initially a short snorkel on the leeward side, then followed up by a more extensive survey on the windward side. The species assemblage was similar to that of North Turtle but several additional species were encountered, including *Liagora ceranoides* and *Ganonema samaense*. There were occasional large stands of the green alga *Bornetella oligospora*. Additional species observed or collected are listed in Table 1.

Sensitivity of Marine Plants to Increased Sediment Load/Turbidity

As primary producers relying on sunlight, any extended and severe turbid episode will eventually cause the death of marine plants, either through reduction of light or smothering. This is unlikely to happen at the Turtle Island sites for several reasons.

1. The waters in the region are typically turbid, so historically the marine flora will have become established under those conditions. During the recent field survey, very few marine plants were collected or observed from the subtidal sites, which were dominated by invertebrate filter feeders. This indicates that these sites (at least) are already unsuitable in some way for marine plants. However, underwater photographs from other locations within the study region have shown extensive stands of 1-2 species of the green algae *Caulerpa* and *Halimeda*, which are presumably adapted to growth under low light conditions.

2. The intertidal sites at North Turtle and Little Turtle supported extensive stands of macroalgae. As these are intertidal, turbidity becomes less of an issue due to their periodic exposure. Similarly, the intertidal is typically more energetic and sediments are unlikely to accumulate to any significant degree.

3. The sensitivity of individual species of marine plants in the region is not well known, but most of the species encountered during the survey are widespread and common components of tropical areas, suggesting that they are essentially 'robust'. One species, *Ganonema samaense* (Tseng) Huisman, represents a new record for Western Australia, its rarity possibly indicating it is locally endangered. Species of *Ganonema* are seasonal, however, and the apparent rarity of *G. samaense* is more likely a result of the limited collections undertaken in the region. The species is likewise known only from limited collections from Queensland (Huisman, 2006), but it is widespread elsewhere in the tropical Indo-Pacific.

4. There is also evidence that some particulate matter on the plant surface acts as a source of nutrients and actually enhances growth in several species of *Sargassum* (Schaffelke, 1999). Growth rates up to 180% higher were recorded and it was suggested that the use of particle-derived nutrients as a source alternative to nutrients in the water column may outweigh any potential adverse effects of the thallus particle layer.

References

Huisman, J.M. 2006. *Algae of Australia: Nemaliales*. ABRS, Canberra.

Schaffelke B. 1999. Particulate organic matter as an alternative nutrient source for tropical *Sargassum* species (Fucales, Phaeophyceae). *J. Phycol*. 35: 1158-1161.

Table 1: Macroalgae Species Identified at Little Turtle and North Turtle Islands During Field Survey, May 2008

Species	North Turtle Island	Little Turtle Island	From Photos
CHLOROPHYTA			
Anadyomene plicata	X	X	
Boergesenia forbesii	X	X	
Bryopsis indica		X	
Bornetella oligospora		X	
Caulerpa corynephora			X
Caulerpa lentillifera	X		
Caulerpa racemosa	X	X	
Caulerpa sertularioides	X	X	
Cladophora catenata	X	X	
Cladophora patentiramea	X		
Cladophora vagabunda	X		
Dictyosphaeria cavernosa	X	X	
Halimeda cf. *discoidea*	X	X	X
Halimeda minima	X	X	
Ulva flexuosa		X	
Ulva sp.		X	
Valoniopsis pachynema		X	
PHAEOPHYCEAE			
Cystoseira trinodis		X	
Cystoseira sp.	X	X	
Hormophysa cuneiformis	X	X	
Padina australis	X	X	
Padina boryana		X	
Sargassum sp. 1 'smooth stem'	X		
Sargassum myriocystum	X		
Sargassum sp. A (drift)	X		
Sargassum sp. B (drift)	X		
Sphacelaria rigidula	X		
RHODOPHYTA			
Amphiroa cf. *foliacea*		X	
Amphiroa fragilissima	X	X	
Botryocladia leptopoda		X	
Ceramium isogonum	X		
Ceratodictyon spongiosum	X	X	
Coelothrix irregularis	X		
Corallophila apiculata	X		
Crustose coralline 'spiky'	X	X	
Digenea simplex		X	
Ganonema samaense		X	
Gelidiella acerosa	X		
Gelidiopsis scoparia	X		
Gracilaria salicornia	X	X	
Hydrolithon reinboldii	X	X	
Hydropuntia urvillea	X		
Hypnea pannosa	X	X	
Hypnea sp.	X		
Jania adhaerans	X	X	
Jania sp.		X	
Laurencia obtusa		X	
Laurencia sp. 1 'pale pink'		X	
Laurencia sp. 2 'green'		X	
Leveillea jungermannioides	X		
Peyssonnelia sp. 1	X		
Peyssonnelia sp. 2		X	
Pterocladiella caerulescens	X		
Portieria hornemannii	X	X	
Rhodymenia?	X		
Tricleocarpa cylindrica		X	
CYANOBACTERIA			
Leptolyngbya crosbyana		X	
Symploca hydnoides		X	

Appendix D Representative Photographs From Video Transect Sites

Offshore Ridgeline Systems - Outermost Ridge


CTR4


CTR5


OSR2


CNS1


CNS2


CNS3

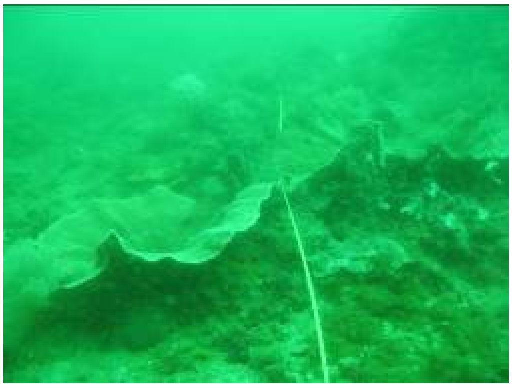

CNS4

Offshore Ridgeline Systems – Middle Ridgeline


CTR6


OSR1

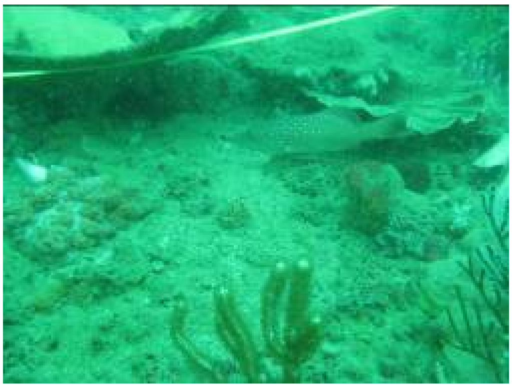

R4


CXS3


R5

Offshore Ridgeline Systems – Innermost Ridgeline


R1


R2


R3


CXS2


CXS1


R8


R9

Inshore Ridgeline – Minilya Bank


MB1


MB2


MB3


MB4


MB5


MB6


R6

Inshore Ridgeline – Proposed Port Footprint


BH1


R7


FR1

Inshore Ridgeline – Cape Thouin ridge

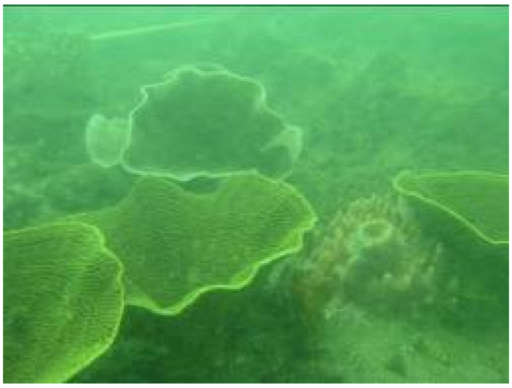

CTR1

Islands – Weerdee Island


WI1


WI2


WI3


WI4


WI5


WI6

Islands – North Turtle Island


NI1


NT2


NT3


NT4

Islands – Little Turtle Island


LT1


LT2


LT3


LT4


LT5

Islands – Finucane Island Intertidal Platform


Upper Intertidal Zone


Upper Intertidal Zone (macroalgae)


Mid Intertidal Zone


Seaward Zone


Seaward Zone (Goniopora sp.)


Seaward Zone (Sinularia sp)