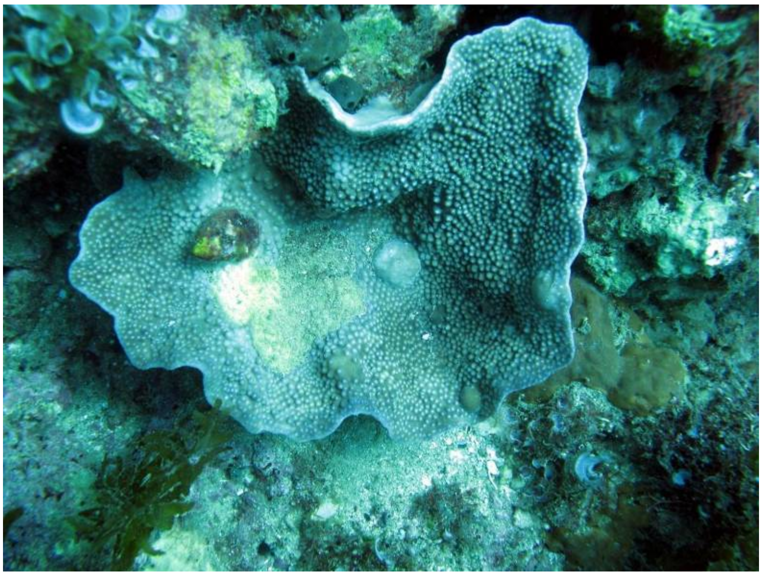
Port Hedland Outer Harbour Development



SUBTIDAL MARINE BENTHIC HABITATS IMPACT ASSESSMENT

- WV05024.402
- Revision 3
- 7 October 2011

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The sole purpose of this report and the associated services performed by Sinclair Knight Merz (“SKM”) is to assess the impacts of the proposed Outer Harbour Development on the subtidal marine benthic habitats at Port Hedland, in accordance with the scope of services set out in the contract between SKM and the Client. That scope of services, as described in this report, was developed with the Client.

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Executive Summary

Background

BHP Billiton Iron Ore operates a port in the Port Hedland region of Western Australia. In recent times, BHP Billiton Iron Ore has experienced unprecedented demand for iron ore from overseas markets and is now embarking on a development program to cater for this increased demand. BHP Billiton Iron Ore is currently investigating a number of port development options, one of which is to develop an Outer Harbour at Port Hedland. The marine component of the proposed Outer Harbour Development includes dredging and the development of a new jetty/wharf structure, berths and ship loading infrastructure (see Figure 1).

The proposed Outer Harbour Development has the potential to impact upon marine benthic primary producers (BPPs) such as hard corals, seagrasses and macroalgae both directly (infrastructure insertion, dredging) and indirectly (dredging and spoil disposal plumes).

The Environmental Protection Authority (EPA) recognises the importance of BPPs and benthic primary producer habitat (BPPH) in contributing to marine ecological functions and provision of environmental services (EPA 2004). Consequently, the EPA has produced Environmental Assessment Guideline No. 3, *Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment* (EPA 2009), and Environmental Assessment Guideline No. 7, *Marine Dredging Proposals* (EPA 2011), to provide advice on the considerations that must be addressed by any proponent of a development that may negatively impact upon the suite of environmental services and ecological functions supported by the BPPH.

Objectives

The objectives of this marine subtidal BPPH Impact Assessment are to:

- define the direct and indirect impacts related to the proposed Outer Harbour Development;
- predict the spatial extent of impacts to BPPH within State and Commonwealth waters;
- calculate potential cumulative losses of BPPH within defined Local Assessment Units (LAUs);
- evaluate direct and indirect losses and impacts in State waters against the EPA's EAG No. 3 and No. 7; and
- consider the BPPH in a regional context to determine its ecological significance.

Methods

This report covers subtidal marine BPPH and associated BPP communities in State and Commonwealth waters offshore from Port Hedland. All intertidal habitats along the coastline within the project footprint, including inshore from Finucane Island, are covered by a separate Intertidal BPPH Assessment report (Appendix B3 of the Public Environmental Review/Environmental Impact Statement; PER/EIS).

Predictive sediment plume modelling was undertaken by Asia-Pacific Applied Science Associates (APASA) to evaluate the extent of water quality perturbations resulting from dredging activities. Perturbations included reduced irradiance of light at the seabed (resulting from increased total suspended solid concentrations) and elevated sedimentation rates. In addition, threshold criteria based on tolerances of hard corals were applied to the modelling outputs such that impacts to benthic habitats and benthic communities could be determined (Appendix B10 of the PER/EIS).

A number of LAUs were proposed within State waters of the proposed Outer Harbour Development area. The LAUs and their boundaries were proposed to the EPA Marine Branch Service Unit in January 2011 and were accepted. The LAUs relevant to this assessment are LAUs 6 and 8.

The proposed and predicted losses and impacts to BPPH have been assessed in the State waters each LAU and the Commonwealth waters component of the proposed Outer Harbour Development area. The assessment has considered direct and indirect losses of BPPH arising from the proposed Outer Harbour Development, and indirect impacts to BPP communities.

Outcomes

Direct loss of BPPH would occur as a result of dredging and construction of the marine infrastructure, accounting to 3.8 (±0.38) ha (1% ±0.1%) in LAU 8 in State waters and 67 (±6.7) ha (0.2% ±0.02%) in Commonwealth waters. Loss of BPPH due to smothering of the benthos from elevated sedimentation rates is predicted to also occur close to the dredging activities; 27 (±2.7) ha of LAU 8 and 7 (±0.7) ha of LAU 6 in State waters, and 240 (±24) ha in Commonwealth waters.

Historical losses were estimated for the Port Hedland Inner Harbour LAU (4.17 (±) ha; ~2%) and LAU 8 (14.5 (±) ha; ~4%) and when combined with estimated losses from the proposed development, amounts to a cumulative loss of 53 (±5.3) ha (~0.06%) of BPPH within State waters for the proposed Outer Harbour Development, primarily due to indirect losses arising from sedimentation in the Zone of High Impact. The predicted indirect losses due to decreases in the surface irradiance of light at the benthos from increases in suspended solids in the water column in the Zone of High Impact would not result in the loss of the underlying hard substratum on which BPP’s grow.

The ecological significance of the losses of BPPH arising from the proposed Outer Harbour Development is considered to be minimal. Hard corals are the most dominant BPP growing along the ridgelines that may be affected by dredging activities, and the dominant corals present are from the genus *Turbinaria* and from the families Faviidae and Poritidae. Based on the low percent cover (0 to ~27% on hard substratum), species richness and abundance of corals and dominance of *Turbinaria*, coral communities that inhabit subtidal habitats in the Port Hedland region are considered to be high turbidity, high sedimentation adapted communities. Furthermore, the evidence of high turnover and recruitment of coral indicates that temporary losses would be recoverable within a five-year timeframe.

The benthic communities within the Zone of Moderate Influence may experience decreased light at the benthos (due to increased suspended solids concentrations) and increased sedimentation rates. However, due to the frequent (twice-daily) resuspension and redistribution of sedimentary material due to tidal movements this would provide temporary relief from deposited and suspended materials. Due to this tidal flushing, it is considered that BPPs and non-BPPs would not suffer indirect losses in this zone, and at most, sub-lethal impacts such as reduced photosynthetic activity.

The low level of cover of BPPH throughout the area and the acclimatisation of the communities and individuals to elevated turbidity and high levels of disturbance give confidence to the predictions of low levels of loss and high likelihood of recoverability. The species present are considered turbid water specialists that are physiologically suited to colonising disturbed habitats. The high level of variability throughout the study area both in terms of spatial and temporal distribution indicate that the recovery is likely to occur in a short time. The natural turnover of corals within the study area appears to be on a timescale of approximately five years, hence it is expected that the communities present would recover to pre-dredge levels within this period.

Contents

List of Figures

List of Tables

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
A	08/05/09	R Burgess	J Lazorov	08/05/09	Draft for client Review – Chapters 1–5 only.
B	16/07/09	H Astill	R Burgess	16/07/09	Complete Draft for client review
C	10/08/09	R Burgess	R Burgess	10/08/09	Revised Draft for client review
D	22/09/09	JR Hanley	R Burgess	22/09/09	Revised Draft for client review
E	05/10/09	R Burgess	R Burgess	05/10/09	Final Draft for Client Review
F	14/10/09	S Neale	R Burgess	14/10/09	Revised Final Draft
0	20/11/09	B Brown	R. Burgess	02/12/09	Final for use
1	4/2/2011	J Phillips	R. Burgess	7/2/2011	Revised based on Agency Comments
2	2/10/2011	J Hanley	A. De Vos	03/10/11	Revised Final Draft
3	7/10/2011	C Adnitt	A. De Vos	07/10/2011	Final for use

Distribution of copies

Revision	Copy no	Quantity	Issued to
A	1	1	B Lampacher, B Jenkins (FASTJV); S Mavrick (BHP Billiton Iron Ore)
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3	1	1	S Mavrick (BHP Billiton Iron Ore)

Printed:	7 October 2011
Last saved:	7 October 2011 03:02 PM
File name:	I:\WVES\Projects\WV05024\Technical\200 Live PER Rev B\B Appendices\Appendix B2 BPPH Impact Assessment Subtidal M3\Rev 3\M3 Marine BPPH Impact Assessment_Rev3A.doc
Author:	Helen Astill, Steve Neale, Chris Adnitt and Sofie Harrison
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Name of organisation:	Sinclair Knight Merz
Name of project:	Port Hedland Outer Harbour Development
Name of document:	Marine Benthic Primary Producer Habitat Impact Assessment
Document version:	Revision 3
Project number:	WV05024.402

1. Introduction

1.1. Project Overview

BHP Billiton Iron Ore operates a port in the Port Hedland region of Western Australia. The current 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 (**Figure 1-1**).

BHP Billiton Iron Ore is investigating a number of port development options to further extend capacity of its port operations, one of which is to develop an Outer Harbour at Port Hedland.

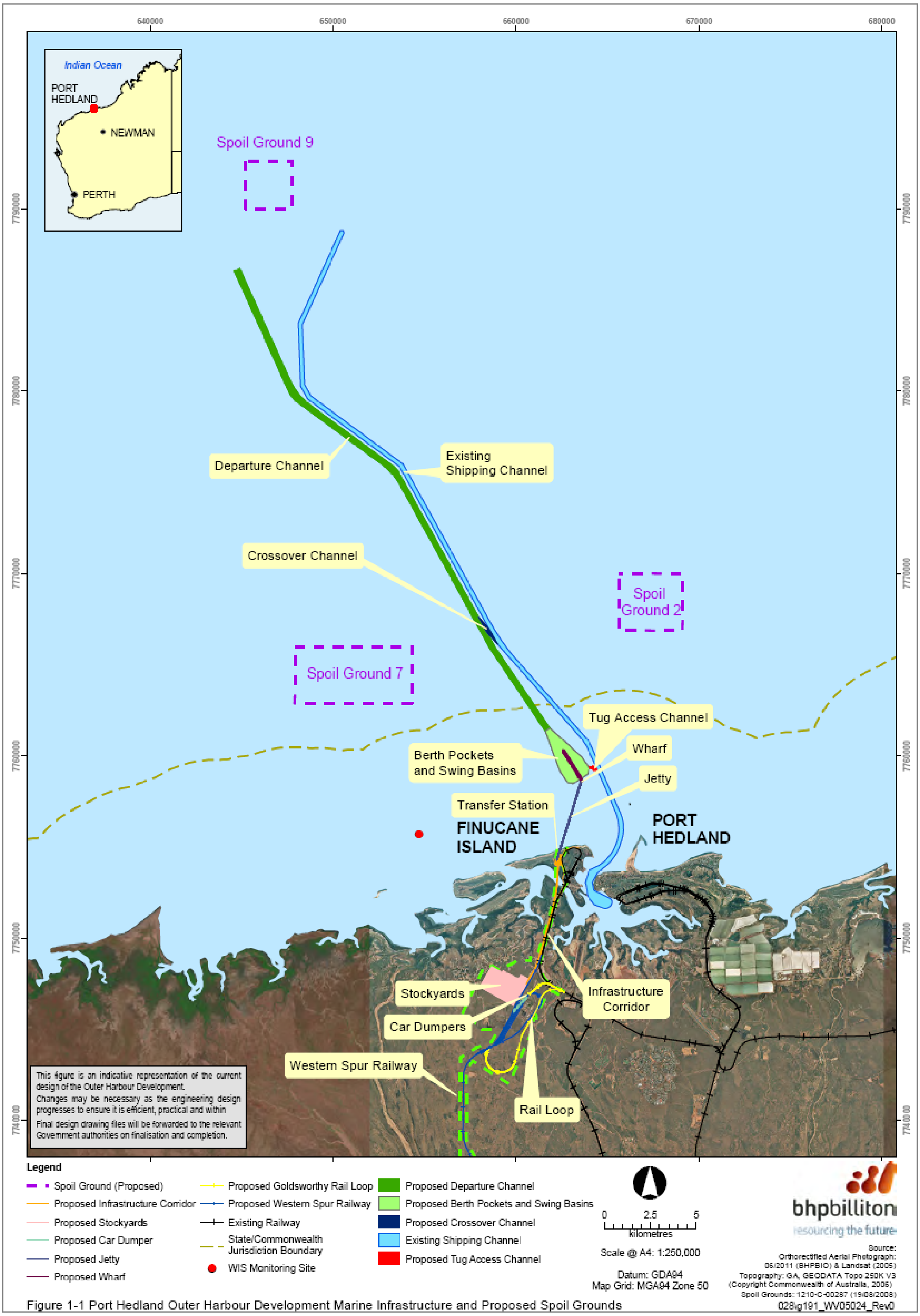
The proposed Outer Harbour Development is expected to provide an additional nominal export capacity of approximately 240 Mtpa of iron ore from to BHP Billiton Iron Ore’s Port Hedland. The proposed expansion is planned to occur in four stages, with incremental expansions brought on line to reach the maximum capacity. Expansion stages would occur through four separate modules, each with a nominal capacity of up to 60 Mtpa.

The Outer Harbour Development involves the construction and operation of landside and marine infrastructure for the handling and export of iron ore. Landside development includes:

- rail connections from the existing BHP Billiton Iron Ore mainline to proposed stockyards at Boodarie;
- rail loops at Boodarie;
- stockyards at Boodarie; and
- an infrastructure corridor (including conveyors, access roadway and utilities) from the stockyards to a transfer station on Finucane Island that connects to a marine jetty.

Key proposed marine structures and activities are shown on **Figure 1-2** and include:

- an abutment, jetty and wharf;
- mooring and associated mooring dolphins;
- transfer station and deck;
- associated transfer stations, ore conveyors and ship loaders;
- dredging for berth pockets, basins and channels; and
- aids to navigation.



This figure is an indicative representation of the current design of the Outer Harbour Development.
Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within
Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Scale @ A4: 1:250,000

Datum: GDA94
Map Grid: MGA94 Zone 50

Source:
Orthorectified Aerial Photograph: 06/2011 (BHPBIO) & Landsat (2005)
Topography: GA, GEODATA Topo 250K V3 (Copyright Commonwealth of Australia, 2006)
Spoil Grounds: 1210-C-00287 (19/08/2008)

Figure 1-1 Port Hedland Outer Harbour Development Marine Infrastructure and Proposed Spoil Grounds

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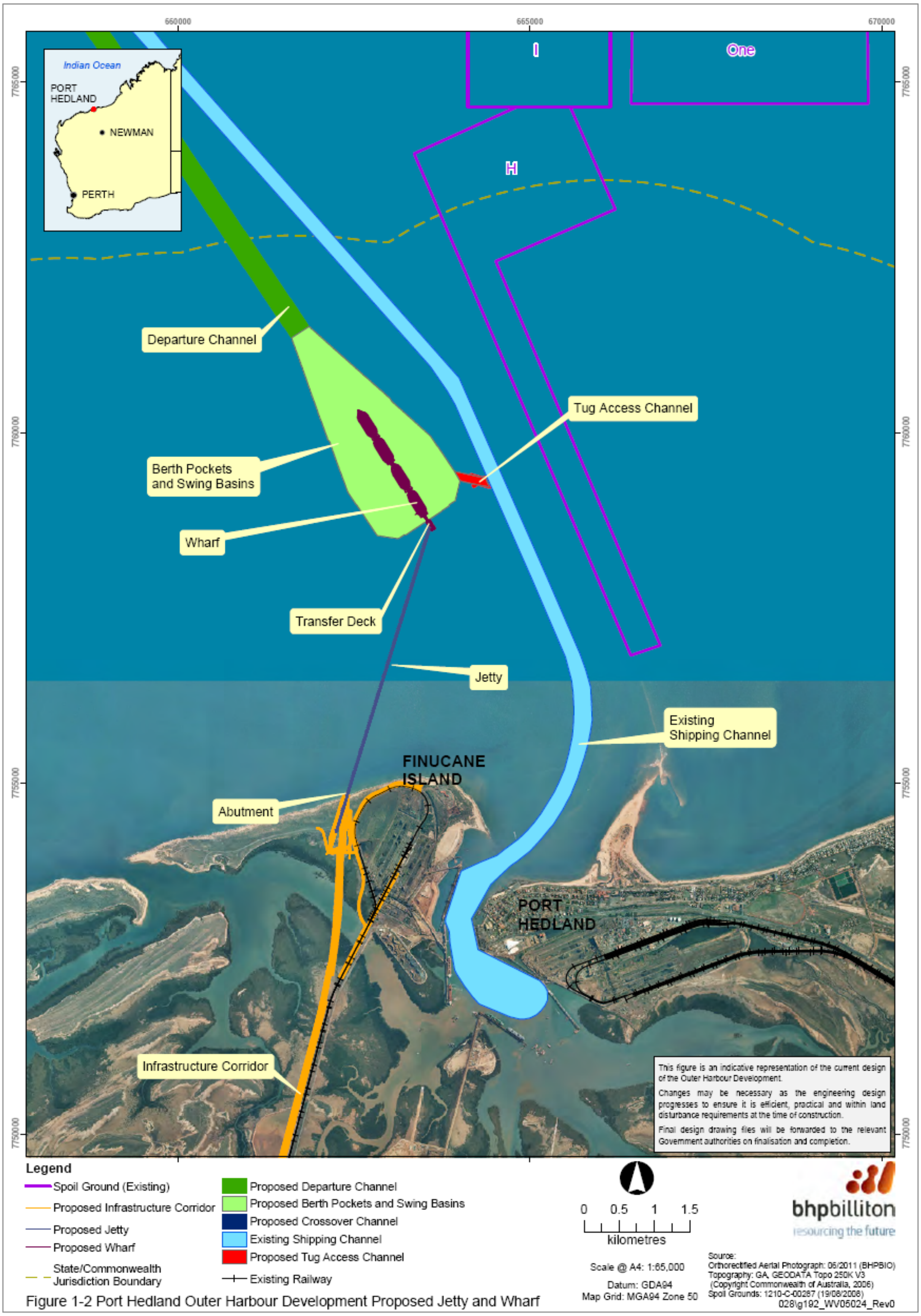
- **Figure 1-1: Port Hedland Outer Harbour Development Marine Infrastructure and Proposed Spoil Grounds**



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Source:
Orthorectified Aerial Photograph: 06/2011 (BHPBIO)
Topography: GA, GEODATA Topo 250K V3
(Copyright Commonwealth of Australia, 2006)
Spoil Grounds: 1210-C-00287 (19/08/2008)
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- **Figure 1-2: Port Hedland Outer Harbour Development Proposed Jetty and Wharf**

1.2. Study Objectives

The proposed Outer Harbour Development may have direct and indirect impacts on subtidal marine benthic habitats in the Port Hedland offshore environment. As required by the *Environmental Protection Act, 1986,* an assessment of the environmental impacts arising from the proposed project is to be made by BHP Billiton Iron Ore.

This document presents an assessment of the subtidal habitats and associated benthic communities that may be impacted by the proposed Outer Harbour Development, and an outline of the activities causing the impacts. All intertidal habitats along the coastline within the project footprint, including inshore from Finucane Island and in the tidal creeks of the Port Hedland region, are covered by a separate Intertidal BPPH Assessment report (Appendix B3 of the PER/EIS).

1.3. Structure of this Report

This report comprises the following:

- **Section 2**: an overview of the legislative and policy framework for assessment of environmental impacts to subtidal marine habitats in State and Commonwealth waters;
- **Section 3**: a description of the proposed construction, operation and dredging activities;
- **Section 4**: a summary of the hydrodynamics, sediment and water quality of the marine environment within the project footprint;
- **Section 5:** a summary of the subtidal benthic habitats and ecological communities within the project footprint;
- **Section 6**: predictions of the likely behaviour and spatial distribution of dredge and dredge spoil disposal plumes from sediment plume modelling outputs;
- **Section 7**: water quality threshold setting and rationale;
- **Section 8**: approach to assessment of impacts to benthic communities and benthic habitats;
- **Section 9**: predicted impacts to benthic communities and benthic habitats arising from construction dredging and disposal activities;
- **Section 10**: management of impacts to BPPH during construction dredging activities; and
- **Section 11**: a summary of the environmental impact assessment provided in this document.

2. Relevant Guidelines

2.1. State Guidelines

The Environmental Protection Authority (EPA) issues Environmental Assessment Guidelines (EAGs) that assist in the protection and management of sensitive environments in Western Australia. There are two EAGs relevant to the environmental impact assessment undertaken in this report:

- EAG No. 3, *Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment*, provides guidance on assessing potential impacts, including cumulative irreversible loss and serious damage to, benthic primary producer habitats in Western Australia's marine environment; and
- EAG No. 7, *Marine Dredging Proposals*, has been designed to impart clarity and consistency to the information presented to the EPA for the environmental impact assessment of marine dredging proposals through the provision of a single assessment framework.

A brief summary of each EAG is provided in the sub-sections below.

2.1.1. Environmental Assessment Guideline No. 3

The geographic scope of EAG No. 3 covers all coastal waters of Western Australia, from the highest water mark of the intertidal zone associated with the mainland, islands and emergent reefs to the depth maxima for benthic primary producer habitats in the subtidal zone of these waters.

In applying the intent of EAG No. 3 and ensuring that impact assessment is undertaken as intended by the EPA, a clear understanding of a number of terms is required:

- Benthic primary producer habitats are functional ecological communities that inhabit the seabed within which algae (e.g. macroalgae, turf and benthic microalgae), seagrass, mangroves, corals or mixtures of these groups are prominent components. Benthic primary producer habitats also include areas of seabed that can support these communities.
- Loss of benthic primary producer habitat would commonly be associated with activities such as excavation or burial. In almost all cases, these activities directly modify benthic primary producer habitat so significantly that impacted habitat would not be expected to recover to the pre-impact state and therefore the impact is irreversible.
- Serious damage refers to damage to benthic primary producer habitat that is effectively irreversible or, where recovery is predicted, it is not predicted to occur within a 5-year timeframe.

2.1.2. Environmental Assessment Guideline No. 7

The direct and indirect impacts of dredging on benthic communities and habitats are the primary concerns of EAG No. 7. Specifically, the main focus of EAG No. 7 is:

- direct loss of benthic habitats and communities by removal or burial; and
- indirect impacts on benthic habitats and communities from the effects of sediments introduced to the water column by the dredging.

At a minimum, direct losses would occur within the footprints of dredged areas and some spoil grounds, and may extend to areas immediately surrounding infrastructure where acute or ongoing sediment-related impacts are expected to occur (e.g. sedimentation). Direct losses are considered irreversible unless a scientifically-sound case can be made for recovery within a timeframe of five years or less.

Indirect impacts generally occur as a consequence of the intensity, duration and frequency of sediment-related pressure imposed on benthic biota such as:

- Suspended sediment in the water column (turbidity): reduces quality and quantity of light available at the seabed for photosynthesis, can clog feeding apparatus of filter feeders and deposit feeders and inhibit key ecological processes that occur in the water column (e.g. fertilisation of pelagic gametes, survivorship and competency of propagules).
- Sediment deposited on the benthos (sedimentation): smothers biota, can cause abrasion of exposed tissues, can alter sea bed load or produce other effects similar to those caused by turbidity.

2.2. Commonwealth Guidelines

The Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) is responsible for the management of the marine environment in Commonwealth waters and for the management of threatened marine species listed under the *EPBC Act 1999.* There are presently no specific guidelines relevant to water quality thresholds in Commonwealth waters and the EAGs described above do not apply since they are concerned only with State waters. However, for the sake of consistency, the guidance outlined for State waters has been applied to thresholds for Commonwealth waters. Whilst there are no guidelines for acceptable loss, or otherwise, of benthic habitat in Commonwealth waters, impacts to these habitats may affect listed marine species (since they may be used as refuge or as foraging habitat) and therefore habitat loss would be reported and assessed in these terms.

In addition, impacts to benthic habitats predicted or proposed to occur in Commonwealth marine areas are considered in context of the *Environment Protection (Sea Dumping) Act 1981*.

3. Project Description

The proposed Outer Harbour Development includes the following key marine infrastructure and activities:

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

The marine infrastructure for the offshore loading facility would be constructed from Finucane Island in an approximately northerly direction with a new wharf constructed adjacent to the existing shipping channel. The marine infrastructure and activities are described in the following subsections and illustrated in **Figure 1-2**.

3.1. Marine Jetty

A steel piled jetty of approximately 4 km in length is proposed to be constructed from Finucane Island to the wharf. The jetty would support conveyors, maintenance services and a two lane roadway for vehicle access to the wharf. The jetty conveyors would be constructed to transfer ore material from the transfer station on Finucane Island to the transfer deck, then onto the wharf conveyors and into the shiploaders.

The passage of recreational water craft under the elevated jetty trestle would be permitted at controlled locations, for the purposes of safety.

3.2. Wharf Structure/Transfer Deck

The proposed wharf structure and associated berthing and mooring dolphins would be located approximately 4 km north of Finucane Island. The wharf would be approximately 2 km in length and designed to accommodate:

- shiploaders and shiploader rail system;
- access roadway and access walkways;
- maintenance bays;
- the conveyor systems;
- cyclone tie down facilities, and
- support services (including amenities, offices etc).

It is anticipated that the wharf would be constructed in stages, each nominally taking two years to construct. Each stage of wharf development would include two berths and a shiploader to complete the facility with a total of eight berths operating with four conveyors and four shiploaders. The proposed transfer deck would be located at the end of the jetty and would connect to the wharf structure. The transfer deck would provide services and support facilities for construction, operational and maintenance personnel.

3.3. Dredging and Spoil Disposal

The construction of the proposed Outer Harbour Development requires dredging to enable vessel access to the wharf and for loaded vessels to depart to deep water.

Dredging operations would create new berth pockets, swing/departure basins, a departure link channel to the existing shipping channel, a proposed 34 km long departure channel and a tug access channel from the existing channel into the berth pockets.

The required depths would be approximately -22 m CD for the berth pockets, -23 m CD for the wharf footprint area, -11 m CD for the swing basins and -16 m CD for the departure basins, based upon a 250,000 Dry Weight Tonnes (DWT) vessel. The swing basins, departure basins, berth pockets and up to 3 km of the new departure channel would be located in State waters, with the remainder of the departure channel being in Commonwealth waters (**Figure 1-1**). The depths along the departure channel would range from approximately -15 m to -17 m CD.

The total volume of dredge spoil is estimated to be approximately 50.4 million cubic metres (Mm^3) of material, including over-dredging (**Table 3-1**). The majority of material can be removed by trailing suction hopper dredgers (TSHD). A smaller percentage of the material is harder substratum and would require a cutter suction dredger (CSD). Based on the geotechnical studies completed to date, which involved the analysis of 100 vibrocores taken from the dredge footprint (Worley Parsons 2011), there have been no areas identified in the dredging footprint that would necessitate blasting operations for material extraction. Dredging operations involve a workforce of up to 160 persons and be conducted 24 hours per day, 7 days per week. The estimated duration of dredging is approximately 46 months. It is proposed that dredging would occur in a staged manner, as follows:

- **Stage 1** – dredging of wharf and berth pockets, departure and swing basins, tug access channel and the new 34 km departure channel to provide two loading berths with a single shiploader (34.6 Mm^3);
- **Stage 2** – dredging of the swing and departure basins to provide two additional loading berths and a shiploader (7.8 Mm^3);
- **Stage 3** – dredging for the remaining wharf with additional berth pockets and the swing and departure basins, and departure channel to accommodate another four loading berths and an additional two shiploaders (8.0 Mm^3); and
- **Stage 4 –** no dredging activity proposed.

The disposal of dredged material would be carried out in accordance with the Dredge and Spoil Disposal Management Plan (DSDMP; Appendix A3 of the PER/EIS). The suitability of a number of potential spoil disposal locations has been investigated and there are three preferred offshore locations that have been identified as part of the application for a Commonwealth Sea Dumping Permit (Appendix B11 of the PER/EIS). A separate spoil ground selection phase study report to describe the history of the process has been undertaken (Appendix B20 of the PER/EIS). All of these offshore spoil grounds would be located in Commonwealth waters in depths greater than -10 m CD (**Figure 1-1**).

3.4. Construction of the Marine Infrastructure

The construction of the proposed Outer Harbour Development is intended to be phased to match BHP Billiton Iron Ore's future operational and capacity requirements.

Construction of marine civil infrastructure would maximise the use of precast or prefabricated components. These components would be prepared offsite, shipped to Port Hedland and offloaded via a temporary offloading facility. Lay down areas on Finucane Island and at Boodarie would be utilised to temporarily store marine structures and equipment.

At the jetty abutment, a temporary platform consisting of a structural truss or frame and supported by the piles and crossheads would be utilised to drive successive piles and to install and erect the structures for the first 3 km of the jetty structure. Construction of the jetty trestle would involve jack up barges for piling. Jack up barges and cranes would be used for erecting and installing structures. Overall, a total of approximately 1,840 piles would be driven over a period of approximately 24 months for the jetty. The pile installation method may require some drilling.

Construction work is proposed 24 hours per day, 7 days per week, with favourable conditions. Piling activities would take place 24 hours a day, 7 days per week. It is proposed that physical piling is proposed to be 12 hours per day (7 am to 7 pm), 13 days per fortnight. Occasionally for safety reasons, there would be an allowance to continue piling activities up to 10 pm to accommodate the completion of a pile.

Approximately 40 to 50 marine vessels would be used including supply boats, tugs, barges and other marine craft that transport supplies, materials, equipment, consumables and personnel.

3.5. Project Schedule

The dredging involved in this project would be undertaken in three stages. Volumes of material to be dredged include over-dredge allowance of 1 m. The three stages and volumes from each area are as shown in **Table 3-1**.

- **Table 3-1: Outer Harbour Development Dredging Summary Schedule**

Stage	Dredge Area	Approximate Volume (Mm^3)	Disposal Location Approximate Distribution
Stage 1	Wharf and berth pockets, departure and swing basin, tug access channel and departure channel	34.6	Up to 90% Spoil Ground 7 (45.4 Mm^3) Up to 20% Spoil Ground 2 (10.1 Mm^3) Up to 10% Spoil Ground 9 (5.05 Mm^3)
Stage 2	Swing and departure basins	7.8	
Stage 3	Wharf and berth pockets, swing and departure basins and departure channel	8.0	
Total		**50.4**	

3.6. Operation of the Marine Infrastructure

Once completed, the proposed infrastructure would provide a nominal export capacity of approximately 240 Mtpa of iron ore. The marine loading facility would be capable of berthing and loading 250,000 DWT vessels with a design provision for 320,000 DWT vessels to berth and load in the future. Operational activities pertinent to benthic habitats include:

- maintenance dredging of the access channel and navigational facilities;
- vessel movement with associated propeller wash and sediment disturbance;
- loading of iron ore; and
- wastes, discharges and spills associated with vessels and infrastructure.

Maintenance dredging and disposal of dredged material would be raised on an as-needed basis, as the need for maintenance dredging arises. Therefore, the impacts of maintenance dredging are not considered in this impact assessment.

Impacts of vessel movements, loading of iron ore and wastes/discharges/spills may result in disturbances to the benthic communities. However, it is not predicted that irreversible or indirect impacts to benthic habitats, as described by EAG No. 3 and EAG No. 7, would result from vessel movements. As such, consideration of the disturbances from these activities are addressed in Chapter 10 of the PER/EIS and are not considered in the environmental impact assessment undertaken in this report.

4. Baseline Hydrodynamics, Sediment and Water Quality

4.1. Hydrodynamics

The nearshore area is dominated by the large semi-diurnal tidal regime. The large tides drive oscillating currents of around 2 knots with increasing speed in the entrances to the numerous tidal creeks. Wind provides a secondary force for local currents and typically drives persistent, residual flows along the coastline. A slight dominance in strength and persistence of west to north-westerly winds creates longshore drift towards the east and north-east.

The area is subject to sporadic, intense storms during the wet season (December – May) and experiences an average of three to four cyclones each season (CSIRO 2008). Cyclones have affected the Port Headland area on average about once every two years, with seven severe (Category 3 or greater) cyclones recorded since 1910 (BoM 2008). During cyclonic periods strong currents and possibly extreme waves may significantly alter the tidal-driven circulation patterns and act to resuspend previously settled material, dispersing it over a large area. In addition, riverine flows increase during these times and can produce large plumes of suspended sediment in the nearshore waters.

4.2. Sediment Characteristics

The seabed in the study area consists of a thin layer of sediment substratum, mostly coarse unconsolidated sand (indicative of a high energy environment) over a calcarenite pavement, clays, weakly cemented gravels and soft sandstones. The sediment is less than 3 m thick throughout and less than 1 m thick for a large proportion of the marine development footprint (Fugro 2006). There is a limestone ridge covered mostly by shallow sediments running parallel to the shore which provides habitat for attachment of sessile benthic communities. Photographic evidence shows that the sediment within the area is highly mobile with species that are reliant on a hard surface for attachment appearing to be growing out of the sand (**Figure 5-1**).

4.3. Sediment Quality

Based on sediment analysis results, material within the proposed dredging footprint is considered to be clean of contaminants and suitable for unconfined ocean disposal at designated spoil grounds (Appendix B6 of the PER/EIS). Although concentrations of arsenic, chromium and nickel measured in the sediments were above the National Ocean Disposal Guidelines for Dredged Material (NODGDM; EA 2002) guidelines, these are believed to be naturally-occurring (DEC 2006b) and were also found in the background material (pilot study) of the study area and in boreholes of undisturbed base material. Hence, these metals are not considered to be contaminants of anthropogenic origin.

4.4. Water Quality

Background levels of turbidity were monitored using water quality loggers downloaded fortnightly at six locations over a period of 22 months between June 2008 and March 2010 (Appendix B18 of the PER/EIS). The results of monitoring show that the median turbidity (NTU) was low at all sites over the 22-month baseline monitoring period (less than 2 NTU). There was a large range in turbidity between seasons and between sites, indicating a highly variable environment within the study area. Turbidity fluctuations were greatest at the inshore site Weerdee Island (WIS; ranging from 0.1 to 124 NTU), followed by the mid-shore sites and the offshore sites showed the least variability in turbidity. There was a distinct seasonal transition in turbidity from the dry (June to November) to the wet (December to May) season. The turbidity at all six sites increased at the onset of the wet season, which was to be expected since background levels of turbidity within the Pilbara are generally higher during the summer months (wet season) due to storms and cyclones (Gilmour et al. 2006).

5. Benthic Habitats and Communities

Provided below is a summary of the benthic habitats and communities observed and mapped utilising a habitat modelling approach within the proposed Outer Harbour Development study area and the studies undertaken to model and define distribution of benthic habitats. Further detail on the existing marine environment, an overview of the benthic ecology of the region, and description of the surveys undertaken are provided in Chapter 6 and Appendix B21 of the PER/EIS.

Marine benthic substrata within the study area include sedimentary habitats (mainly coarse sand) and hard substratum present as limestone ridgelines running roughly parallel to the shoreline (**Table 5-1**). Benthic habitats extend from the high water mark of the intertidal zone, through to all areas of the subtidal zone (Appendix B21 of the PER/EIS). This report covers benthic habitats in the subtidal zone only, classed as marine habitats occurring offshore of the lowest astronomical tidal boundary and including the habitat types of hard and soft substratum.

- **Table 5-1 Summary of BPPH, BPP and Non-BPP Coverage in the Study Area**

Habitat Type	Total Area (ha)*	State (ha)*	Commonwealth (ha)*
Benthic class			
Hard substratum (with and without BPP)	17,441	2,598	14,843
Sediment covered hard substratum with BPP	16,920	2,735	14,185
Sediment with BPP	11,697	3,377	8,320
BPP			
Hard coral	18,085	4,936	13,148
Macroalgae	15,864	3,083	12,781
Non-BPP			
Soft coral	3,400	733	2,667
Sponges	7,989	1,680	6,309
Sessile invertebrates	20,275	3,294	16,981

*****An error estimate of 10% has been applied to the estimates of cover.

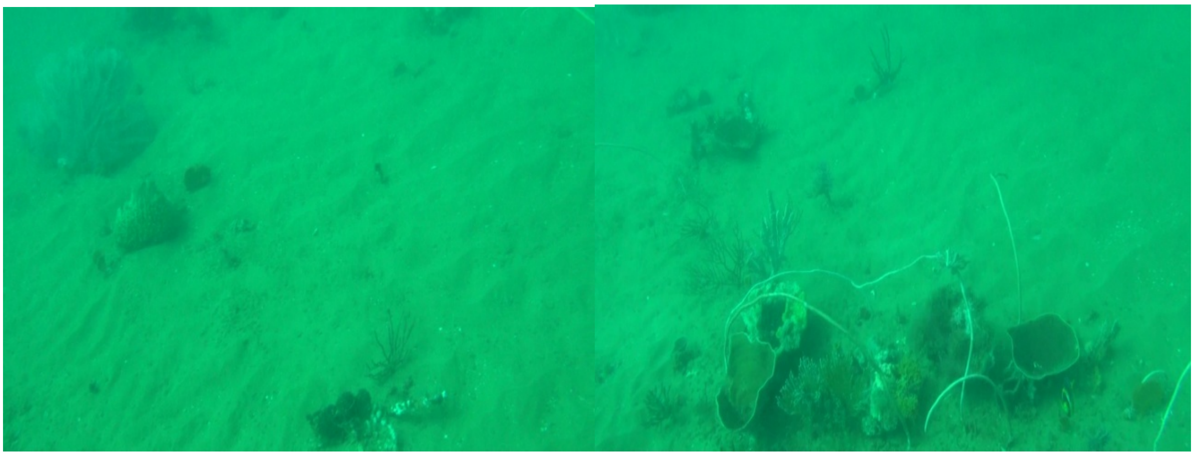
Baseline surveys of subtidal BPPH in the Port Hedland region were undertaken between December 2007 and May 2008 (Appendix B18 and Appendix B21 of the PER/EIS). The area surveyed was extensive, covering approximately 3,650 km^2 (50 km to the east and west of Port Hedland Harbour and 40 km seaward) and included 343 survey locations.

Data derived from Light Detection and Ranging surveys (LiDAR), in combination with observations made by underwater video and diver investigations, were used to model, predict and validate the distribution of BPPH, other dominant habitats and BPP in areas that may potentially be impacted by the proposed development (

Figure 5-2). Representative areas identified as BPPH were then surveyed in more detail to provide data on the composition and cover of various benthic communities.

The results of these subtidal surveys show that benthic substrata offshore of Port Hedland predominantly consists of extensive plains of coarse sediments with smaller areas of hard substratum comprising ridgelines of limestone pavement (Appendix B21 of the PER/EIS; **Table 5-1**). The extensive plains surveyed are predominantly bare of any large marine flora or fauna (either BPP or non-BPP). Many of the offshore limestone ridgelines run parallel to the coastline (**Figure 5-2**), and those areas of ridges surveyed support typically low coverage mosaic communities comprising both BPP (predominantly hard corals and macroalgae) and non-BPP, (predominantly soft corals and sponges). This type of mosaic community is also associated with hard substratum with a veneer of overlying coarse sand suggesting a dynamic environment whereby coarse mobile sediments temporally cover and uncover limestone hard substratum.

The physical conditions within the study area are variable with highly mobile substratum over much of the zone, as indicated by the sand ripples over much of the sediment and the mobility of the sediment as evident from the natural smothering of species, which require hard substratum for attachment (**Figure 5-1**). The particle size distribution (PSD) of this material ranges from 90-100% of particles classed as >150µm, with 40-95% of the material being >500µm in diameter across the water quality monitoring baseline sites (Appendix B19 of the PER/EIS). The prominence of coarse material implies that the study area is a high energy environment, sufficient to prevent the accumulation of fines.



- Figure 5-1: Evidence of Mobility of Sediments in the Nearshore Environment of the Outer Harbour Development Study Area

5.1. Marine Benthic Primary Producers

Hard Corals

The distribution and percent cover of hard corals within the proposed Outer Harbour Development study area was determined from benthic marine habitat survey at 52 sites (Appendix B21 of the PER/EIS). The field survey results show that percentage cover of hard corals on the hard substratum sites ranged from 0 to ~27% with the majority of the substrata at all sites being bare substratum (sand, rubble and rock) (**Table 5-2**). Habitat modelling highlighted that the distribution of corals matched that of hard substratum along ridgelines (**Figure 5-3**). The non-reef areas, including the potential spoil grounds, were primarily sandy sediment with no observed coral (**Figure 5-2**). The outer ridgeline systems generally have higher coral cover than the islands or the inner ridgelines.

A total of 51 species of coral from 19 genera were identified from areas offshore from Port Hedland, which is considerably lower than the 120 coral species from 43 genera recorded in the Dampier Port and inner Mermaid Sound, Dampier (Blakeway & Radford 2005). The species richness of coral taxa at all sites surveyed in the region was very low in comparison to other studies carried out in the Pilbara region and no corals considered endangered or unique to the region have been identified. The results of coral monitoring from six sites within State and Commonwealth waters indicated that the coral communities within the Outer Harbour Development Study Area comprise mainly *Turbinaria* spp., with *Pocillopora* spp., *Montipora* spp., *Acropora* spp., faviids and poritid corals also present (Appendix B18 of the PER/EIS).

Based on the generally low species richness and abundance of corals and the dominance of corals of the genus *Turbinaria*, coral communities that inhabit subtidal habitats in the Port Hedland region can be described as predominantly high turbidity (low light), high sedimentation adapted communities (Appendix B18 of the PER/EIS).

Interpretation of images derived from video transects at sites in State waters surveyed during baseline coral and subtidal BPPH monitoring has revealed information on the age structure of *Turbinaria* spp. communities at these sites (**Appendix A**). This indicates that the age of *Turbinaria* spp. communities in State waters is typically skewed towards younger age classes typical of communities that experience a high level of natural disturbance (Done 1999). This study revealed that sites tended to be dominated by corals of less than two years of age with the majority of all coral colonies younger than 5 years.

- **Table 5-2 Hard Coral Cover as Recorded by Field Observations in the Subtidal Marine Environment around Port Hedland**

Area		Proximity to Port Hedland entrance	Hard Coral Cover (%)	Bare Component (%)
Outer Ridgeline Systems	Outermost Ridgeline	37 km NW	4.9–27.1	>60
	Middle Ridgeline	31 km NW	5.8–21.8	>69
	Innermost Ridgeline	24 km NW	3.3–22.9	>67
Inner Ridge/Shoal Systems	Minilya Bank	19 km NE	3.6–19.6	>67
	Proposed Port Areas	4–6 km N	0.0–12.9	>79
	Weerdee Ridge	11 km W	0.2–21.6	11–75
	Cape Thouin Area	40 km W	7.6	>78
Islands	Weerdee Island	12 km W	<5	12–66
	North Turtle Island	58 km NE	0.2–18.9	>81
	Little Turtle Island	40 km NE	8.4–17.8	>69
Sand Plains	Eastern Shoreline	Inshore, from Port Hedland to Spit Point	0	100
	Proposed Spoil Ground Locations	Refer to Figure 5-2	0	100*
	Proposed Channel Footprint[1]	Refer to Figure 5-2	0	100**

Source: Summarised from Appendix B18 of the PER/EIS (surveyed December 2007 to May 2008)

[1] sites sampled at a proposed footprint which was subsequently realigned. Further investigations conducted within the current dredge footprint concluded the same results

* with the exception of sparse coverage of epifauna

**with the exception of the final section of the channel which intersects the outermost ridgeline (refer to table above for composition of hard coral and bare environment to overall benthic environment of the outermost ridgeline).

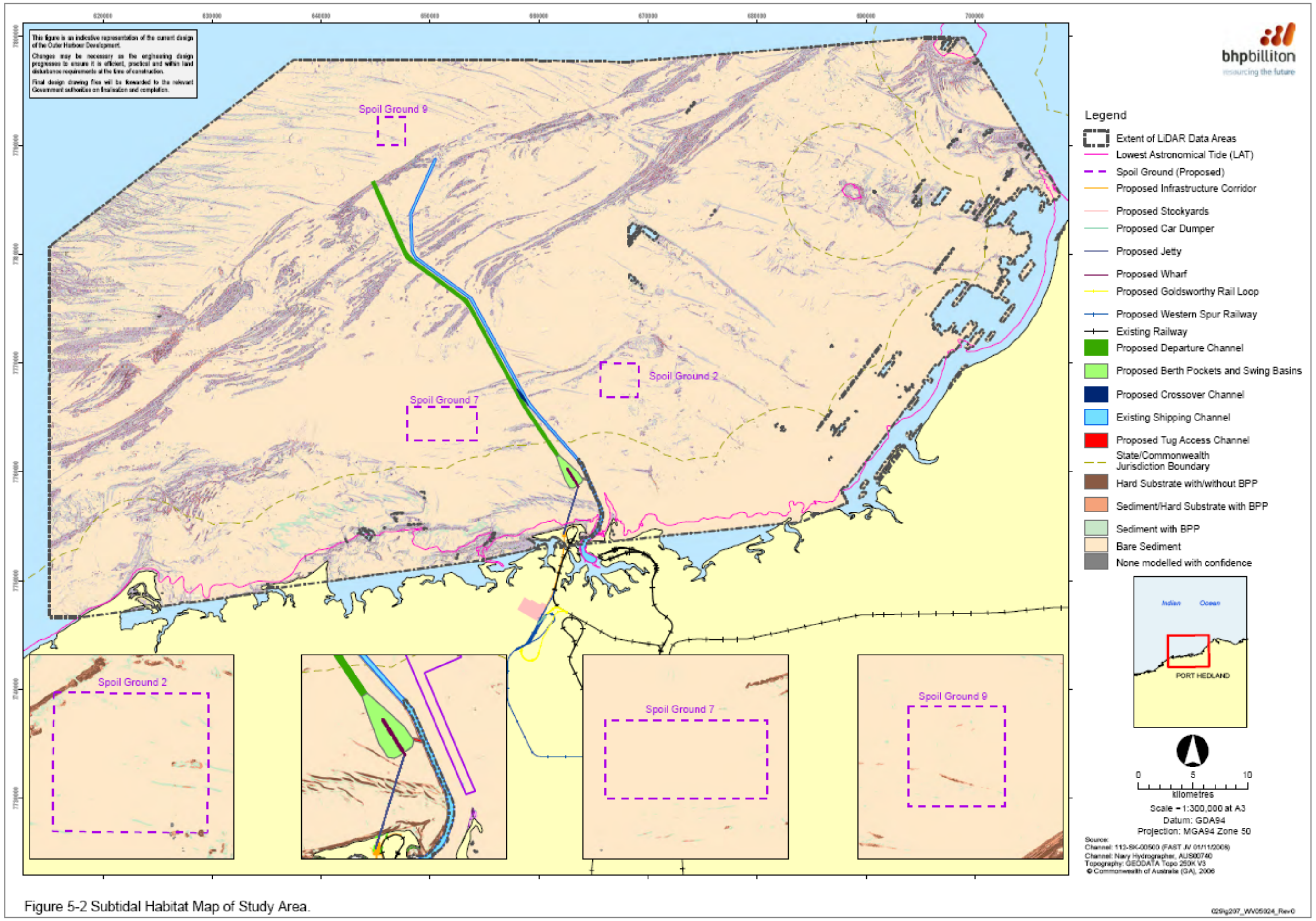
Macroalgae

Surveys of the three outermost limestone ridgelines undertaken for the proposed Outer Harbour Development recorded varying cover of macroalgae between 0 and 15% (mostly less than 5%) (**Figure 5-4**; Appendix B21 of the PER/EIS). At Weerdee Ridge, a more inshore ridgeline, 11 km west of the Port Hedland Harbour entrance, macroalgal cover varied considerably between sites and over time. Baseline sampling between December 2007 and May 2008 revealed that the proportion of macroalgae observed at seven Werdee Ridge sites varied between 0 and ~70% with green algae, including *Caulerpa* and *Halimeda* spp. dominant (Appendix B21 of the PER/EIS). More recent sampling between June and July 2011 at another site along this ridgeline has shown macroalgae to be extremely variable over time with the proportion increasing from 0 to ~24% between June and July (SKM 2011a). One of the more common genera observed at this site was *Sargassum* spp., which is common in Pilbara waters and known to increase in biomass from early winter to late summer before dying off (senescence) after reproduction. At Little Turtle Island, macroalgal cover on subtidal pavement ranged from 0 to 15% (generally less than 5%), while subtidal pavement around North Turtle Island did not support any macroalgae (Appendix B21 of the PER/EIS). Surveys of the intertidal pavement along the offshore shoreline of Finucane Island have revealed green algae (*Caulerpa* spp., *Halimeda* spp. and *Neomeris* spp.) and brown algae (*Sargassum* spp.).

Seagrasses

Previous surveys in the Outer Harbour Development Study Area have shown that seagrasses are not common and those that have been observed are mainly ephemeral species such as *Halophila ovalis* and *Halodule uninervis*, which are present at low densities and typically exhibit high levels of temporal variability. The only seagrasses observed during past surveys was in the intertidal zone (between the lowest and highest astronomical tides), inshore of Weerdee Island where an approximate area of 86 ha contained sparse (5-25% coverage) patches of seagrass which was present as a mixed assemblage with small green algae and sponges. A follow up drop camera survey undertaken in April 2011 found that sparse patches of *H. ovalis* in this area consisted of <5% cover (GHD 2011).

Smaller patches of extremely sparse (<5%) seagrass (*H. uninervis*) have been observed within 3 km offshore from Finucane Island (**Figure 5-5**) whilst sparse *H. uninervis* and *Thalassia hemprichii* have been observed from a shallow lagoon on the eastern side of Finucane Island (Appendix B21 of the PER/EIS). Further offshore, a small stand of *H. ovalis* was observed in the lee of North Turtle Island and a small stand (25 m^2) of *H. decipiens* has been observed offshore of Weerdee Island (Appendix B18 of the PER/EIS). Recent surveys in these two offshore areas, however, have not identified any seagrass, indicating that these small areas of BPP are ephemeral (GHD 2011).



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Scale = 1:300,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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Figure 5-2 Subtidal Habitat Map of Study Area.

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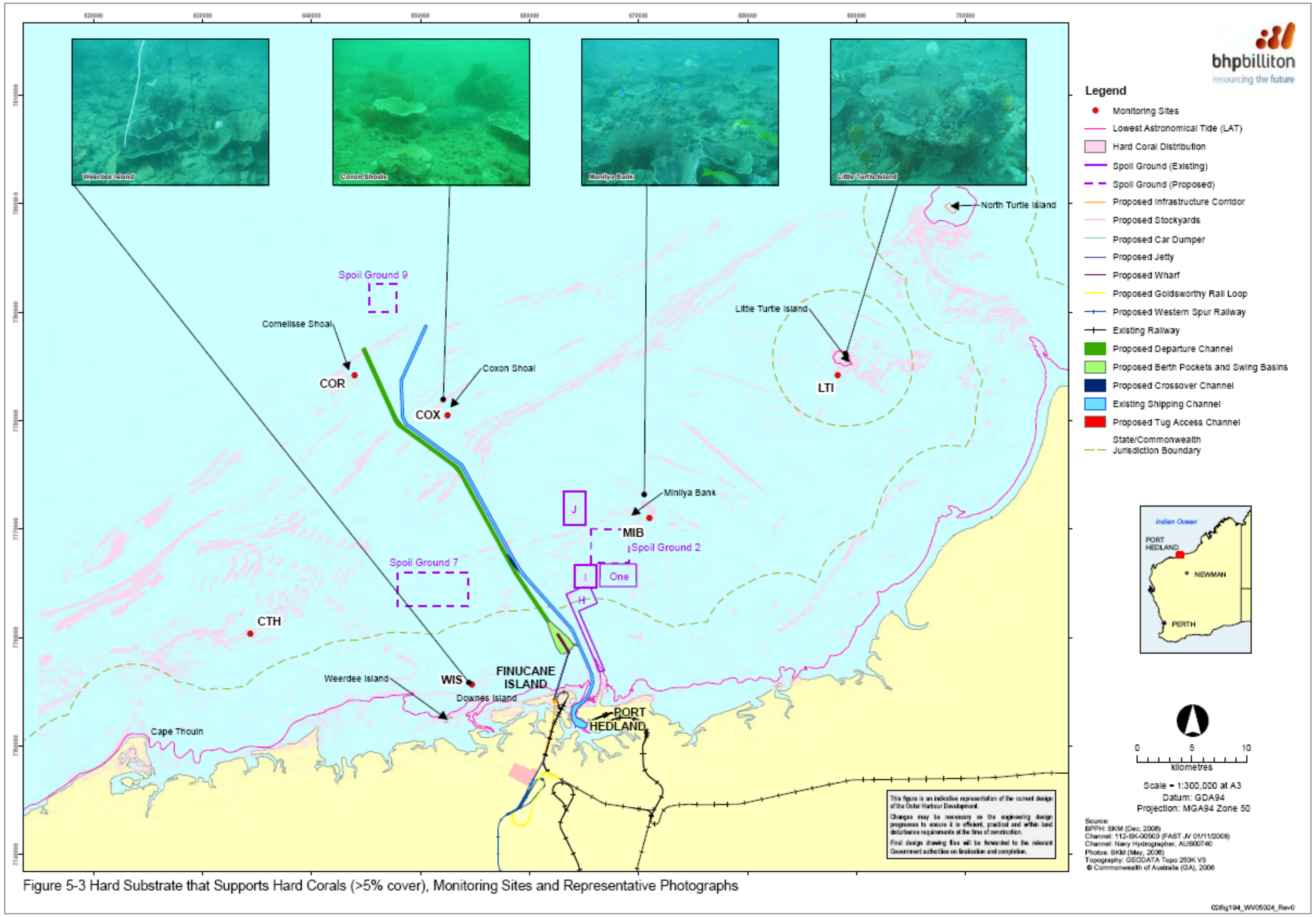
- **Figure 5-2 Subtidal Habitat Map of Study Area**



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Scale = 1:300,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
BPPH: SKM (Dec, 2008)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Photos: SKM (May, 2008)
Topography: GEODATA Topo 250K V3
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Figure 5-3 Hard Substrate that Supports Hard Corals (>5% cover), Monitoring Sites and Representative Photographs

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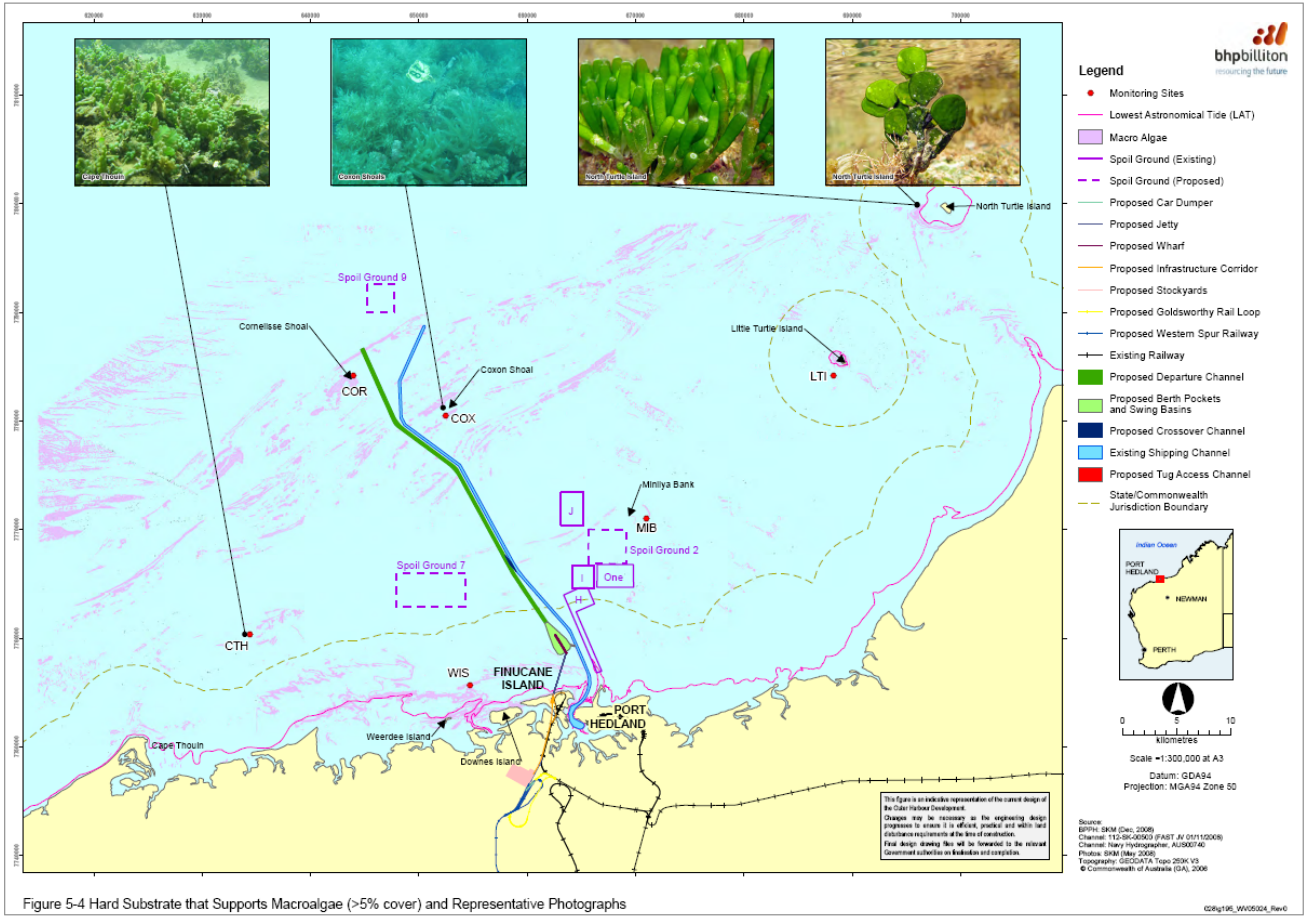
- **Figure 5-3: Hard Substratum that Supports Hard Corals (>5% cover), Monitoring Sites and Representative Photographs**



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Source:
BPPH: SKM (Dec, 2008)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Photos: SKM (May 2008)
Topography: GEODATA Topo 250K V3
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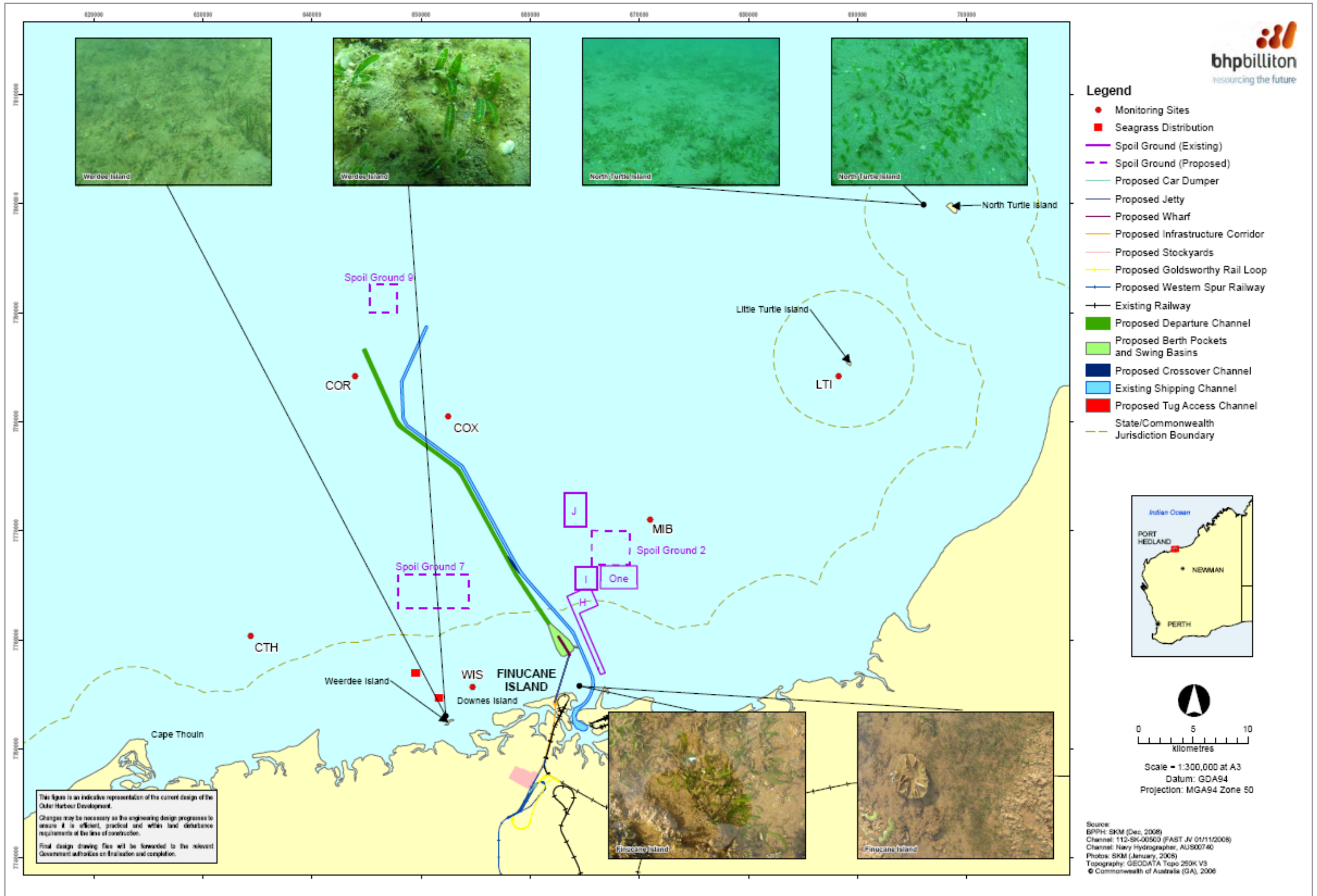
- **Figure 5-4: Hard Substratum that Supports Macroalgae (>5% cover) and Representative Photographs**



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Source:
BPPH: SKM (Dec, 2008)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Photos: SKM (January, 2008)
Topography: GEODATA Topo 250K V3
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Figure 5-5 Seagrass Distribution and Representative Photographs

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- **Figure 5-5: Seagrass Distribution and Representative Photographs**

5.2. Marine Non-BPP

Sponges and Soft Corals

Sponges and soft corals are typically classified as non-BPP although some types of sponges and soft corals (e.g. alcyoniid soft corals) have the ability to photosynthesize. Throughout the Outer Harbour Development Study Area, sponges and soft corals typically occur in conjunction with hard corals and macroalgae as mixed mosaic communities associated with ridgelines of hard substratum (Appendix B21 of the PER/EIS). Sponges and soft corals are also observed associated with areas of hard substratum with a thin veneer of surface sediment extending onto a narrow margin of the inter-ridge flats. The proposed spoil ground locations are predominantly bare with the exception of some sparsely distributed individuals of soft corals and sponges (**Table 5-3**; Appendix B20 of the PER/EIS).

- **Table 5-3 Sponge and Soft Coral Cover in the Port Hedland Area**

Area		Proximity to Port Hedland entrance	Sponges Cover (%)	Soft Coral Cover (%)	Bare Component (%)
Outer Ridgeline Systems	Outermost Ridgeline	37 km NW	2.9–11.6	0.0–3.1	>60
	Middle Ridgeline	31 km NW	3.6–9.6	0.2–1.8	>69
	Innermost Ridgeline	24 km NW	2.7–8.4	0.0–3.6	>67
Inner Ridge/Shoal Systems	Minilya Bank	19 km NE	6.4–9.8	0.0–6.0	>67
	Proposed Port Areas	4–6 km N	3.1–6.4	1.1–1.6	>79
	Weerdee Ridge	11 km W	1.8–12.2	0.0–7.1	11–75
	Cape Thouin Area	40 km W	7.8	1.1	>78
Islands	Weerdee Island	12 km W	minimal	minimal	12–66
	North Turtle Island	58 km NE	0.0–8.2	0.0–2.9	>81
	Little Turtle Island	40 km NE	2.9–9.6	<5	>69
Sand Plains	Eastern Shoreline	Inshore, from Port Hedland to Spit Point	0	0	100
	Potential Spoil Ground Locations	Refer to Figure 5-2	minimal	minimal	100[2]
	Proposed Channel Footprint[1]	Refer to Figure 5-2	0	0	100[3]

Source: summarised from Appendix B21 of the PER/EIS (surveyed December 2007 to February 2008)

[1] sites sampled at a proposed footprint which was subsequently realigned. Further investigations conducted within the current dredge footprint concluded the same results

[2] with the exception of sparse coverage of epifauna

[3] with the exception of the final section of the channel which intersects the outermost ridgeline (refer to table above for composition of hard coral and bare environment to overall benthic environment of the outermost ridgeline)

Sessile Invertebrates

Sessile invertebrates (other than hard corals, sponges and soft corals) include hydrozoans, bryozoans, ascidians and molluscs, which are all classified as non-BPP. Sessile invertebrates generally require hard substratum such as limestone pavement to provide permanent attachment points and hence within the Outer Harbour Development Study Area sessile invertebrates are typically part of mixed mosaic communities associated with areas of hard substratum. Sessile invertebrates were therefore generally not associated with areas of sediment within the study area.

Mobile Invertebrates

The most conspicuous mobile invertebrates observed on hard substratum were hydroids, feather stars (crinoids), sea cucumbers and ascidians. Many of the mobile epifaunal species are cryptic, such as rock lobster, crabs and gastropod molluscs, and were less commonly observed by divers during baseline surveys. The most conspicuous mobile invertebrates associated with areas of sediment were echinoderms, such as sea stars, sea urchins and sea cucumbers.

Infauna

A benthic infauna survey conducted at Spoil Ground One (**Figure 1-1**) for BHP Billiton Iron Ore’s Rapid Growth Project 6 (BHP Billiton Iron Ore 2009) found that fauna groups were typical of lower latitude soft bottom benthic environments (SKM 2010). The most species rich phyla were Annelida, Crustacea and Mollusca, while the most abundant phyla were Crustacea and Annelida.

6. Sediment Plume Modelling

Provided below is a summary of the approach to sediment plume modelling, and the modelling outputs used to predict impacts to benthic communities and habitats due to sediment plumes generated by construction dredging activities of the proposed Outer Harbour Development. For a more detailed account of this information, refer to Appendix B4 of the PER/EIS.

Construction dredging for the proposed Outer Harbour Development includes the dredging of 50.4 Mm^3 of material to accommodate the construction of the channel and navigational facilities. Dredging is proposed to occur in a staged approach, resulting in 46 months of dredging. A summary of the construction dredging activities, their timing and the associated volumes of material is provided in **Section 3** and **Table 3-1**.

Due to the range of sediment material types present, a combination of dredging methods is required. It is proposed that a trailing suction hopper dredger (TSHD) would be used for unconsolidated materials, while harder materials would first require cutting and/or crushing using a cutter suction dredger (CSD). Once consolidated material has been crushed by the CSD, the material would be left on the seabed and subsequently removed by the TSHD.

In shallower areas to be dredged, it is proposed that the CSD is likely to be required to dredge materials initially so that the water depths are deep enough for the TSHD to operate in these areas. Where this is the case, the material dredged by the CSD would be stockpiled in deeper water within the dredge footprint, from where the TSHD would subsequently remove the material once water depths are sufficient for access.

The dredging program would release sediment particles into the water column resulting in a sediment plume. The extent of the sediment plume would be influenced by a range of factors including the dredging method, sediment characteristics of the dredged material, ambient current movement, depth of water column and wind direction. The net effect of sediment particles being mobilised into the water column from the dredging would be an increase in total suspended solid (TSS) concentrations in the water column, and the potential for increased sedimentation rates because the higher load of sediment particles in the water column means that a higher amount of sediment may fall out of the water column when conditions favour settlement. Where the particles fall out is governed by the hydrodynamics and the particle size, in areas with strong currents, particles would likely remain suspended while in calmer waters particles are more likely to fall out of suspension; larger sediment particles would fall out of suspension before smaller particles because they are heavier and more energy is required to keep them in suspension.

Modelling of the impacts from the sediment plume generated by the proposed dredging and spoil disposal activities, as indicated by the measures of TSS and sedimentation, was undertaken by Asia

Pacific ASA (APASA). Provided here is a summary of the modelling approach, objectives and findings. For a full account of sediment plume modelling refer to Appendix B4 of the PER/EIS.

6.1. Modelling Approach

Modelling of the sediment plume likely to be generated by construction dredging and disposal activities of the proposed Outer Harbour Development was based on detailed hydrodynamic and wave models in combination with a sediment transport model (SSFATE).

The sediment transport model accounts for the sinking rates of particles depending on their size (i.e. how long particles remain in suspension), sedimentation of particles (i.e. when and where particles drop out of the water column) and resuspension (i.e. the re-mobilisation of deposited dredged particles). The model computes the TSS concentration above background that directly results from dredging operations given the prevailing current (hydrodynamic) and wave conditions.

The model HYDROMAP was used to describe the flow-field conditions that are locally induced in the Port Hedland coastal region where tides and winds are the most important sources of hydrodynamic forcing. Validation of the hydrodynamic model demonstrated that HYDROMAP faithfully reproduced both shorter-term tidal magnitudes and directions, and longer-term transport along the coast.

The wave model used was the Simulating Waves Nearshore (SWAN) model, a regional model developed to simulate spatially-varying wave conditions over a wide domain. The large-sized model domain enabled sediments to be tracked over the long time span of the dredging and disposal construction activities of the proposed Outer Harbour Development. Validation of the SWAN model showed faithful reproduction of observed wave parameters across the full wave spectra.

The DREDGEMAP model computes suspended sediment distributions that result from dredging and disposal operations using a Lagrangian particle approach, given assumptions for the particle size distribution and rate of discharge for sources of sediment input and the influence of the prevailing current, wave conditions and turbulence. All sediment discharges were represented as a mixture of particles fitting 5 size classes (<7 µm, >7<35 µm, >35<75 µm,>75<130 µm, >130 µm), the proportion of which were varied relevant to each discharge.

The model applied minimum, size-dependent sinking rates to the particles, derived from empirical measurements (ranging from 0.0008 m/s to 0.1 m/s for the size class range) but modified these rates (higher) for the two smaller size classes (representing silt and clay-size particles) based on the concentration of sediments. Empirical sinking rate measurements were not available for the local sediments.

The model calculates only for the far-field fate of the sediment (not the finer scale dynamics of an initial jet discharge) so that the initial vertical distribution of the sediments (hence the fall distance to the bed) set up by a particular discharge was a required input. These were specified as an assumed vertical distribution, kept constant for a particular combination of sediment source and operation, either by near-field modelling (for the high velocity CSD discharge, TSHD overflow and propeller wash) or from accounts from previous operations.

By fitting the particle addresses to a three-dimensional grid at regular output steps, suspended sediment concentrations are predicted at each 1 m of water depth within the water column within each 250 m x 250 m horizontal grid cell. The model computes settlement of the sediments suspended by the dredging and disposal sources (exclusive of any background sedimentation) onto the seabed, if they sink to the bed layer, based on the particle size of the sediment and estimates for the bed-shear stress calculated from estimates of the current and wave magnitudes. Subsequent resuspension of previously settled sediment is calculated, if the estimates of the current and wave magnitudes indicate sufficient bed-shear stress to lift the sediment from the bed (size dependent).

Following the estimates of Van Rijn (1989), resuspension was suppressed (greater, size-dependent, shear-stress is required) if a particle remained settled for greater than 12 hours. This process is included to represent settlement and incorporation of the dredged sediment into the natural bed but will not prevent resuspension if the tidal energy or wave energy is sufficient for resuspension.

The modelling domain[1] was sufficiently large to encompass the total area that may be affected by sediment plumes generated by the dredging and disposal activities, including cumulative impacts due to resuspension of particles distant from the project activities. As such, the model domain spanned 131 km from east to west and 83 km from north to south.

Collectively, the current and wave models were demonstrated to be fit for the purpose of representing ambient current and wave fields as input to sediment fate modelling.

Data used to run the models included:

- detailed bathymetric data derived from the LiDAR survey to provide high resolution in areas proposed for dredging and disposal, and in surrounding areas a larger bathymetric grid resolution was used;
- The wave and current data represented natural variations in the wind-and tide-induced current and wave climate over the period of 2000 to 2004 inclusive (offset 12 years to represent a schedule spanning 2012 to 2016 inclusive), hence included all storm events over that period.

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[1] The modelling domain is the spatial extent represented by the predictive models.

The years 2000 to 2004 encompass Southern Oscillation Indices (i.e. La Niña and El Niño events);

- geotechnical information providing detail on the particle sizes of the sediments to be dredged in the proposed areas throughout the entire dredging depth profile; and
- details of the dredging method likely to be used including the types of dredges, predicted dredge logs (i.e. when, where and for how long a dredge would operate) and disposal of the dredge spoil.

6.2. Assumptions and Limitations

Assumptions and limitations of the modelling outputs included:

- The model accounts for variances in the water depth with the tidal cycle specified by the current model;
- the grid cells used to calculate the depth-averaged light attenuation at the seabed are fixed as the mean sea level (MSL);
- the model computes the TSS concentration inclusive of background[2] that results from dredging operations given the prevailing tidal, current and wave conditions;
- TSS results that are predicted are depth averaged through the water column (**Section 7.3.1**);
- the model computes the total sediment deposition above background levels; and
- resuspension of fine sediment is continuous throughout the dredging and may result in an over estimate of TSS through material being repeatedly resuspended.

To balance suitable temporal and spatial resolution while maintaining acceptable computational times, the minimum time step in the model was set at 10 minutes. This required the durations provided in the dredge logs to be adjusted to multiples of 10 minutes, while maintaining the mass-balance of the discharge to those specified. The output step for all results was set at 2 hourly, resulting in 12 estimates of concentration per day for each 1 m layer in the water column, and at the seabed, within each 250 m x 250 m grid cell.

The model predicts that during the dredging program, the amount of fine sediment available as a source for resuspension will continually increase such that a sediment plume is generated well away from the immediate dredging and disposal areas.

---

[2] Background is a reference to natural conditions of the existing environment.

6.2.1. Background TSS Contribution

Model output parameters were chosen so that depth averaged TSS concentrations were generated. It is these concentrations that are most applicable to the impacts of the sediment plume on benthic primary producers and their habitats. The background contribution of TSS concentrations was calculated from the baseline 50%ile monthly TSS values. These were derived by calculating the mean 50%ile NTU values from the baseline water quality monitoring dataset, spanning 22 months of data collection from June 2008 to March 2010 (Appendix B19 of the PER/EIS). These values were then converted to TSS using the TSS/NTU relationship reported by GHD (2011; y = 0.87 x). This relationship was derived using baseline TSS and NTU data collected from February to August 2011 (~7 months) at a range of sites (both inshore and offshore) throughout the Port Hedland Outer Harbour project study area (n = 124) and is considered the best to describe the ‘background’ TSS.

The 50%ile monthly background TSS values were representative of ‘near bottom’ due to the location of the turbidity loggers that the data were collected from. No attempt was made to define depth-dependent background TSS levels for any of the zones as this would have added an additional layer of complexity into the modelling. Although background TSS levels vary throughout the water column (GHD 2011), a number of substantial errors inherent in the application of zone-wide bottom monthly averages exist, given that these are based upon a small number of sites. Hence, no improvement in the accuracy of predictions would result from the introduction of depth-dependent background TSS.

6.2.2. Conversion of TSS to Light Attenuation

Sediment plume modelling outputs (TSS concentrations) were reconciled to light attenuation using a relationship between turbidity, TSS and light attenuation of samples collected from the proposed Outer Harbour Development dredge footprint (as described in Appendix B10 of the PER/EIS). This reconciliation was required for the application of impact thresholds relevant to BPPs, described in **Section 7**.

6.3. Scenarios

Initial modelling investigations were undertaken to test and compare the influence of disposal location on the outcome of this component of the operation. The study used two procedures to identify the optimum disposal location, in terms of the stability of deposited sediments and the potential for sediments to impinge upon adjacent sensitive habitats from either the initial release or from remobilisation of deposited sediments.

Firstly, predictions of shear-stress were calculated at seabed level throughout the domain shared by the hydrodynamic and wave models. This analysis provided an indication of the likely stability of spoil that is initially deposited within each area.

Secondly, disposal was simulated into areas that had been identified as potentially suitable for disposal of dredge spoil on the basis of logistic and environmental considerations. The results were primarily judged by examining overlap of the expected distributions of TSS and sedimentation with buffer areas that are designated around limestone ridges adjacent to the disposal areas.

6.4. Modelling Results – Changes to Surface Irradiance of Light from TSS Concentrations

Dredging and disposal operations are likely to release a proportion of relatively fine sediments (clay, silt and fine sand) that would be subject to the current and wave climate. Heavier sediments and a proportion of the finer sediments are predicted to deposit around the dredging and disposal operations; finer sediments are predicted to deposit as thin layers for short durations over a wider area.

Sediment plumes are expected to disperse as a benthic plume (close to the seabed), undergoing cycles of settlement and resuspension due to tide and waves. In particular, the diurnal tide would induce cycles of sedimentation and resuspension for a portion of the finer sediments. While resuspended, these fine sediments would migrate with a tendency to distribute near the seabed. Sedimentation rates would also be subject to the prevailing waves, with a more irregular frequency.

The modelling demonstrated that the proposed Outer Harbour Development dredging and spoil disposal activities will create a sediment plume characterised by increased suspended solid concentrations (resulting in a reduction of light at the benthos) and sedimentation rates relative to ambient conditions. Migration of sediment particles is predicted to vary over seasonal and shorter time scales. Flooding and ebbing tides will move sediment back and forwards over short durations and are predicted to spread sediment plumes in a generally onshore-offshore direction (south-east to north-west, respectively).

In the longer term, the tropical dry (June to November) and wet (December to May) seasons create a directional change in the plume. A net migration of sediment to the west is indicated by the middle of the dry season, while during the wet season the plume is advected in an east and north-east direction. The influence of both typical (50th percentile; median) and adverse (80th percentile) metocean conditions on the predicted distribution, measured as Light Attenuation Coefficient (LAC) during the wet, dry and transition periods are illustrated in **Figure 6-1** to **Figure 6-3**.

The height of the wet season will bring a strong north-easterly movement to the plumes, resulting in reduced surface irradiance of light at the seabed **Figure 6-1**. The wet season distribution of LAC during adverse conditions will be influenced by strong winds and large waves in combination with tidal currents, causing resuspension and dispersion of finer sediments. Late in the wet season the intensity of the plume to the north-east is expected to reduce, followed by a transitional period (**Figure 6-2**) and reestablishment of the dry season **Figure 6-3**.

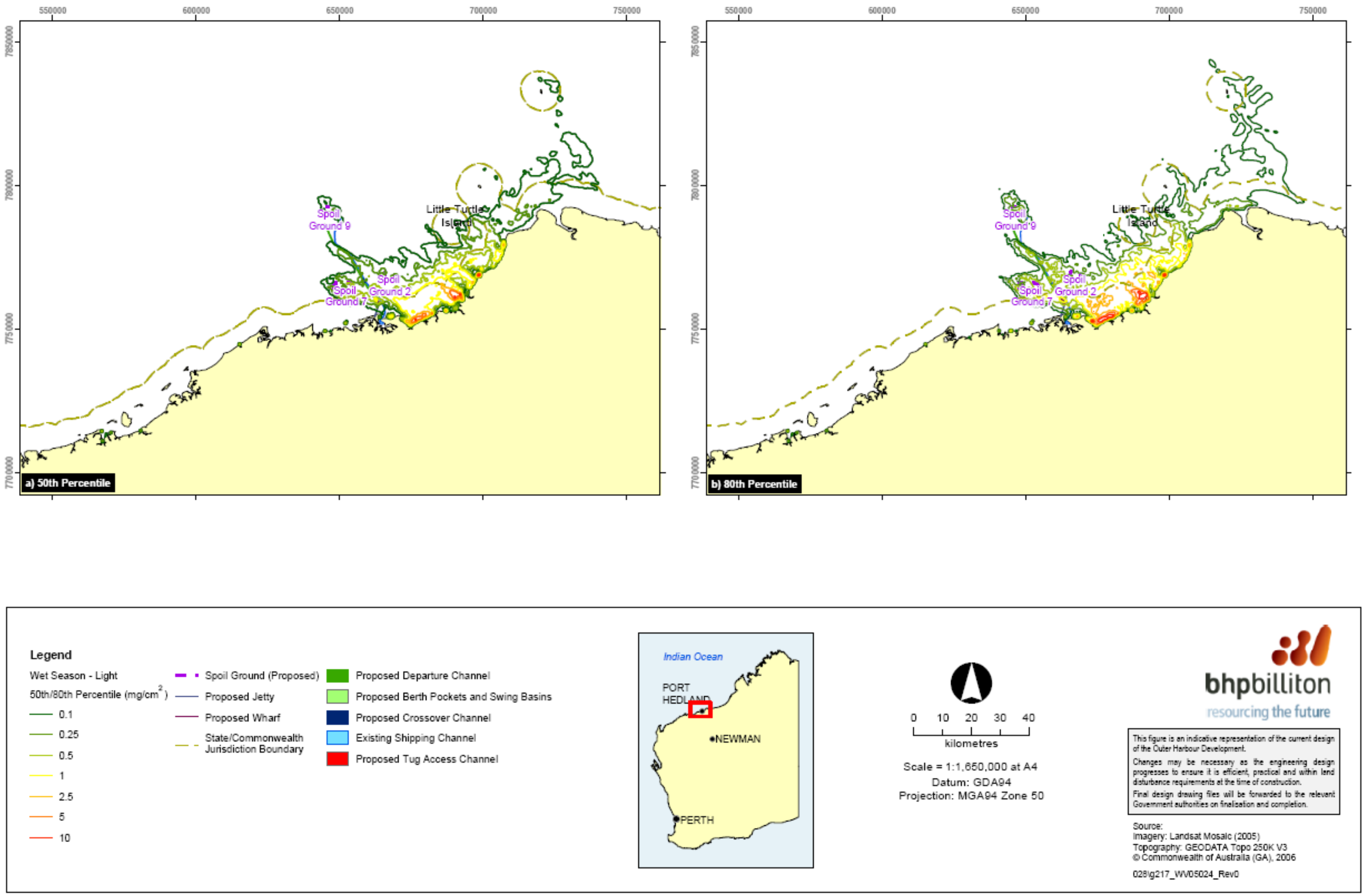


Figure 6-1 Dredge Plume Model Predictions of Light Attenuation at the Seabed During the Wet Season (December to March)

- **Figure 6-1: Sediment Plume Model Predictions of Light Attenuation at the Seabed During the Wet Season (December to March)**

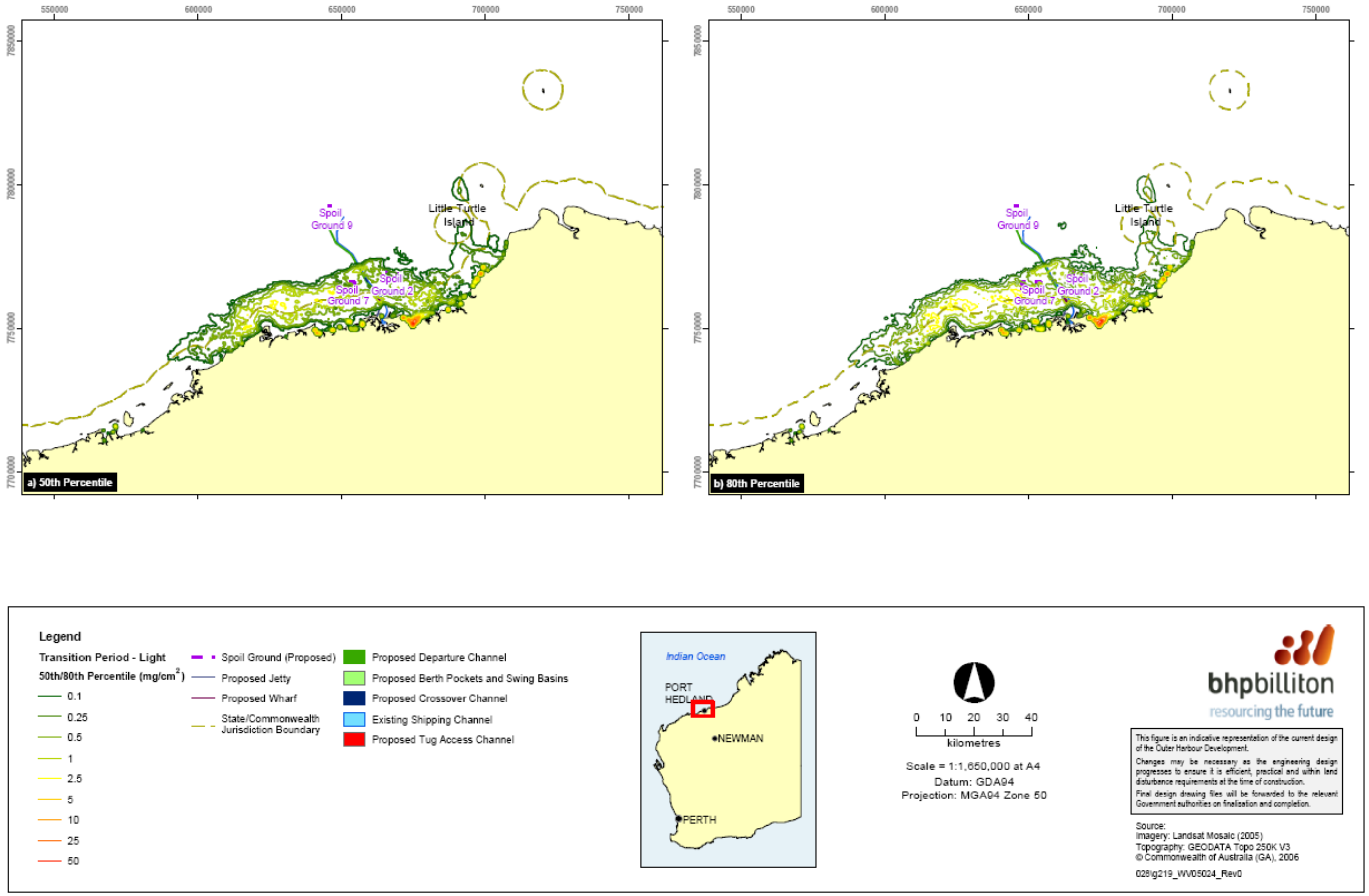


Figure 6-2 Sediment Plume Model Predictions of Light Attenuation at the Seabed During the Transition Period (April to May; October to November)

- **Figure 6-2: Sediment Plume Model Predictions of Light Attenuation at the Seabed During the Transition Period (April to May; October to November)**

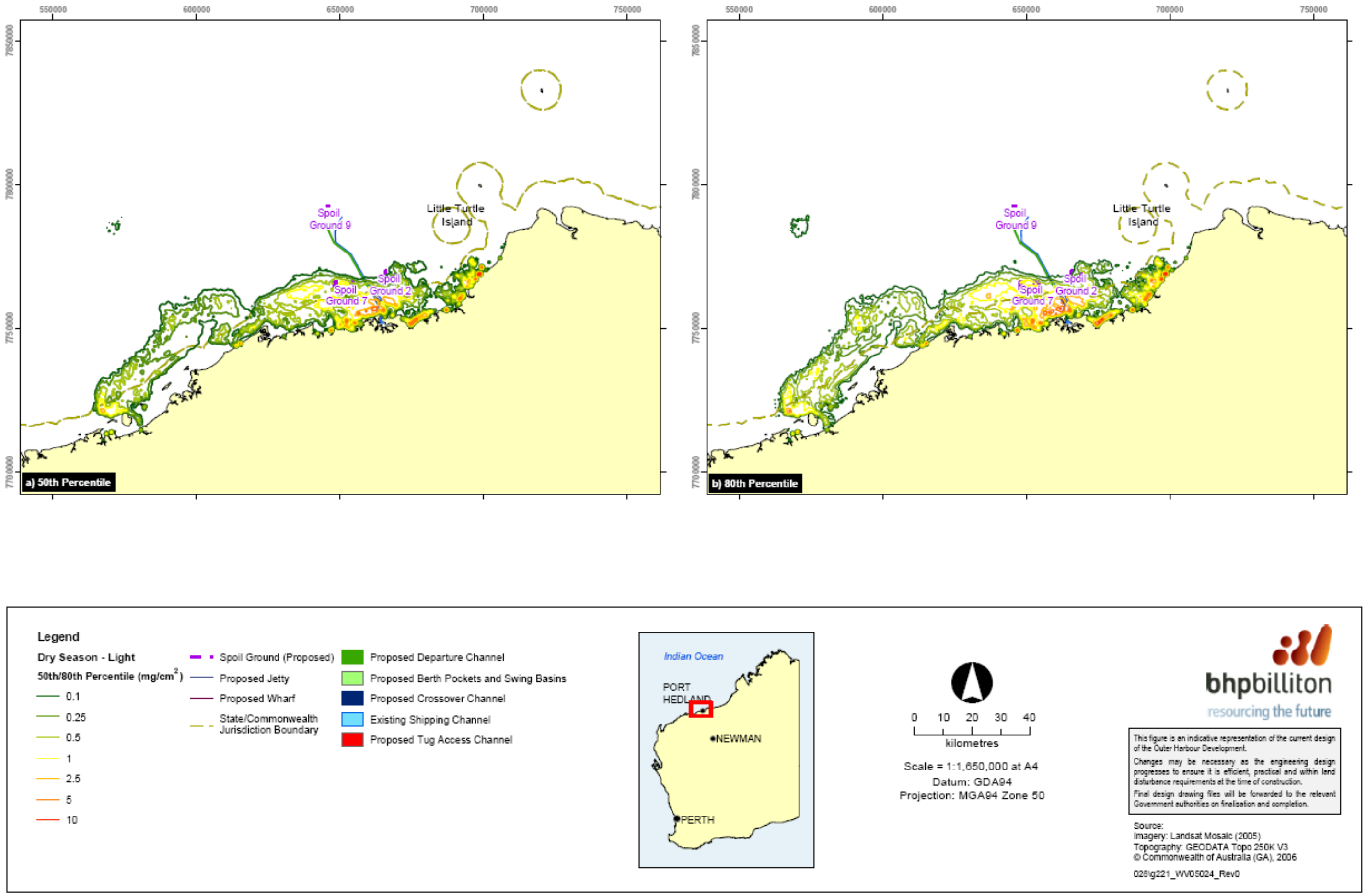


Figure 6-3 Dredge Plume Model Predictions of Light Attenuation at the Seabed During the Dry Season (June to September)

- **Figure 6-3: Sediment Plume Model Predictions of Light Attenuation at the Seabed During the Dry Season (June to September)**

6.5. Modelling Results – Changes to Sedimentation Rates

The area of the proposed Outer Harbour Development is considered to be dispersive meaning that sediment particles naturally susceptible to resuspension will be moved away from the area over time. Modelling of sediment deposition indicates that the majority of the sediment would sink from the surface within a short distance from the construction dredging and disposal activities. However, with increasing inputs and spreading of the sediment particles, predicted deposits would extend progressively further away from these areas.

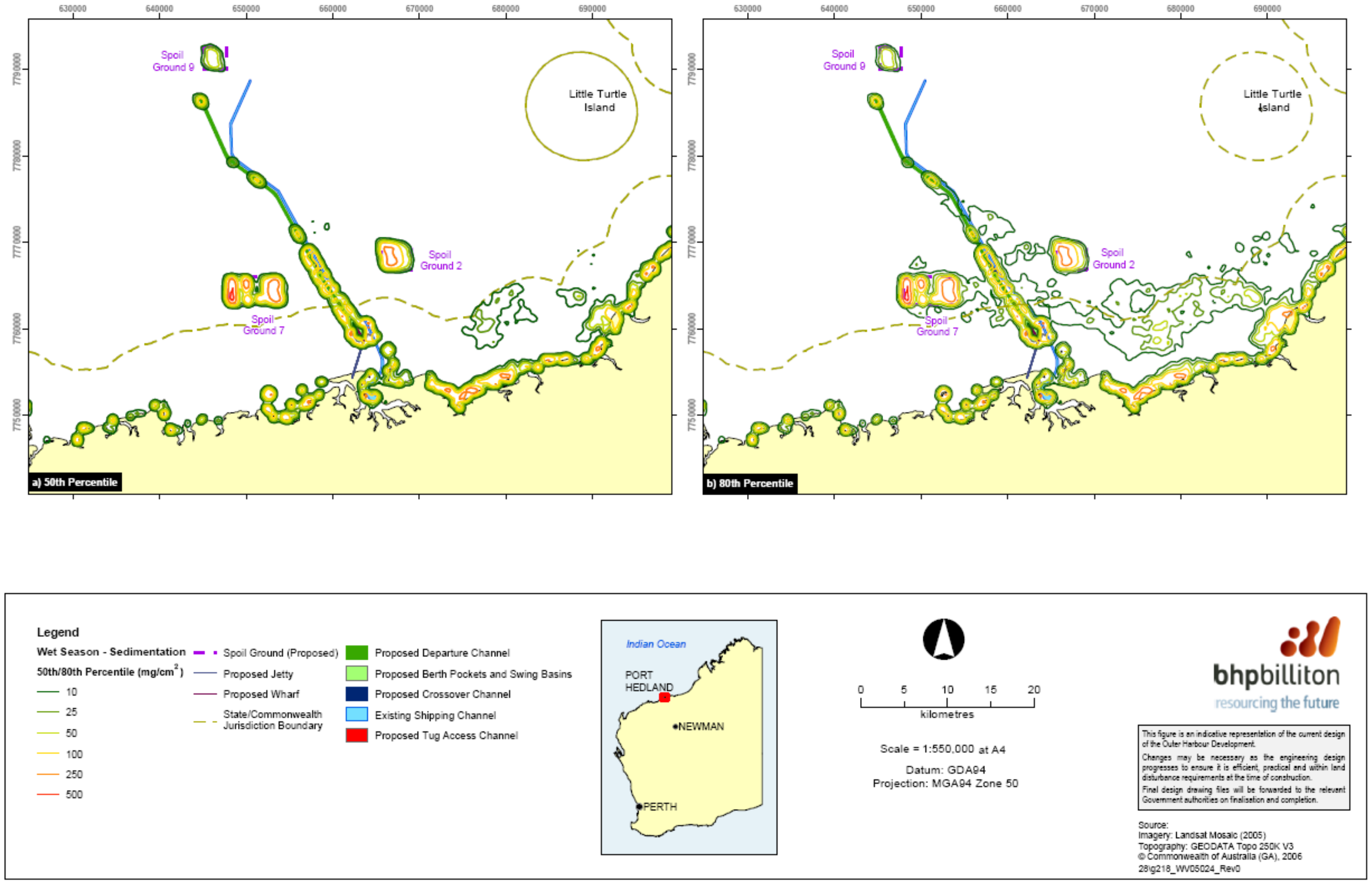
The seasonal patterns in the sediment plume indicated by sedimentation rates show a migration of particles to the east during the wet (**Figure 6-4**) and dry season (**Figure 6-6**), with a smaller distribution during the transition period (**Figure 6-5**).

Although the predictions for sediment deposition over time indicate a progressive build-up of sediment particles in the intertidal zone, this trend is not expected to be consistent in the longer term. Periods of highly energetic hydrodynamic conditions that are predicted to create the most extensive sediment plumes as indicated by the pattern in LAC show a far smaller plume distribution when modelled as sedimentation. This is because much of the fine sediments will either remain suspended during this period or will be resuspended. This will result in a time lag between the worst LAC conditions occurring, caused by particles resuspended into the water column, and the worst sedimentation conditions caused by less energetic conditions that allow sediment particles to settle out of the water column.

The regular onshore-offshore pulsing of the tide is predicted to result in an onshore-offshore migration of suspended sediments released by the operations as well as resuspension of settled sediments. Because shear stresses decrease during slack tides at the end of the ebb and flood, there will be a resulting increase in the rate of settlement over the turning of the tides followed by an increased rate of resuspension as the tidal current speeds increase thereafter.

The relatively strong tidal currents in shallow areas are predicted to establish sufficient shear stress at the seabed to inhibit settlement of finer sediment particles (clays and silts) onto the seafloor and to resuspend a proportion of fine particles that had previously deposited. Resuspension of finer sediment particles is also predicted to generate secondary surface plumes and to contribute to sedimentation rates along the shallow coastal margin.

Over the longer term, the modelling predicted that material deposited in the disposal areas, which are located in water depths sufficiently shallow enough for storm swells to penetrate the seabed, will disturb the heavier sediment particles resulting in trapped fines being resuspended. Given that this circumstance is related to storms, resuspension of fines from disposal areas is likely to occur for several years after completion of construction disposal.



Scale = 1:550,000 at A4

Datum: GDA94
Projection: MGA94 Zone 50

This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevent Government authorities on finalisation and completion.

Source:
Imagery: Landsat Mosaic (2005)
Topography: GEODATA Topo 250K V3
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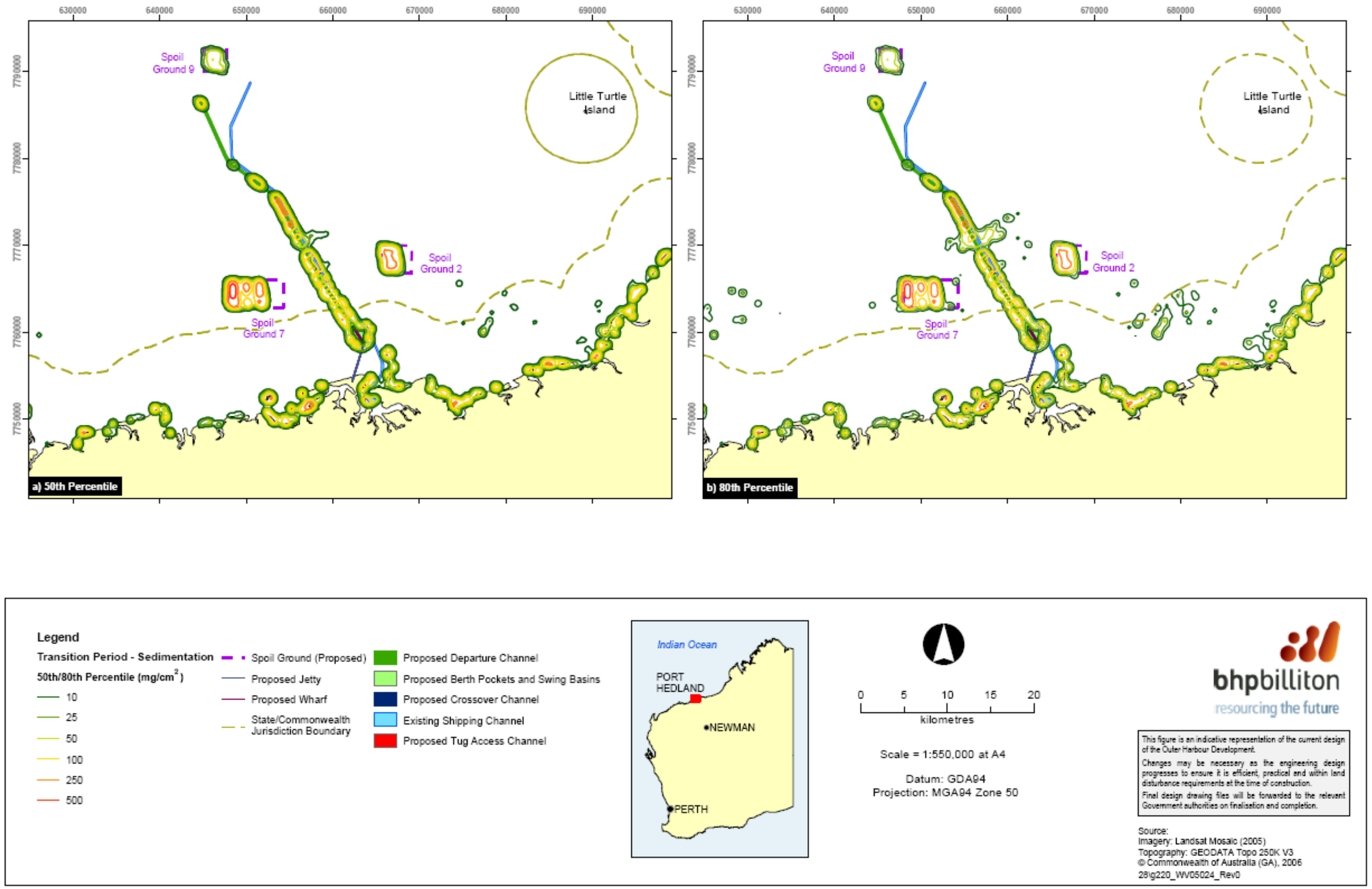
Figure 6-4 Dredge Plume Model Predictions of Sedimentation During the Wet Season (December to March)

- **Figure 6-4: Sediment Plume Model Predictions of Sedimentation During the Wet Season (December to March)**



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

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Imagery: Landsat Mosaic (2005)
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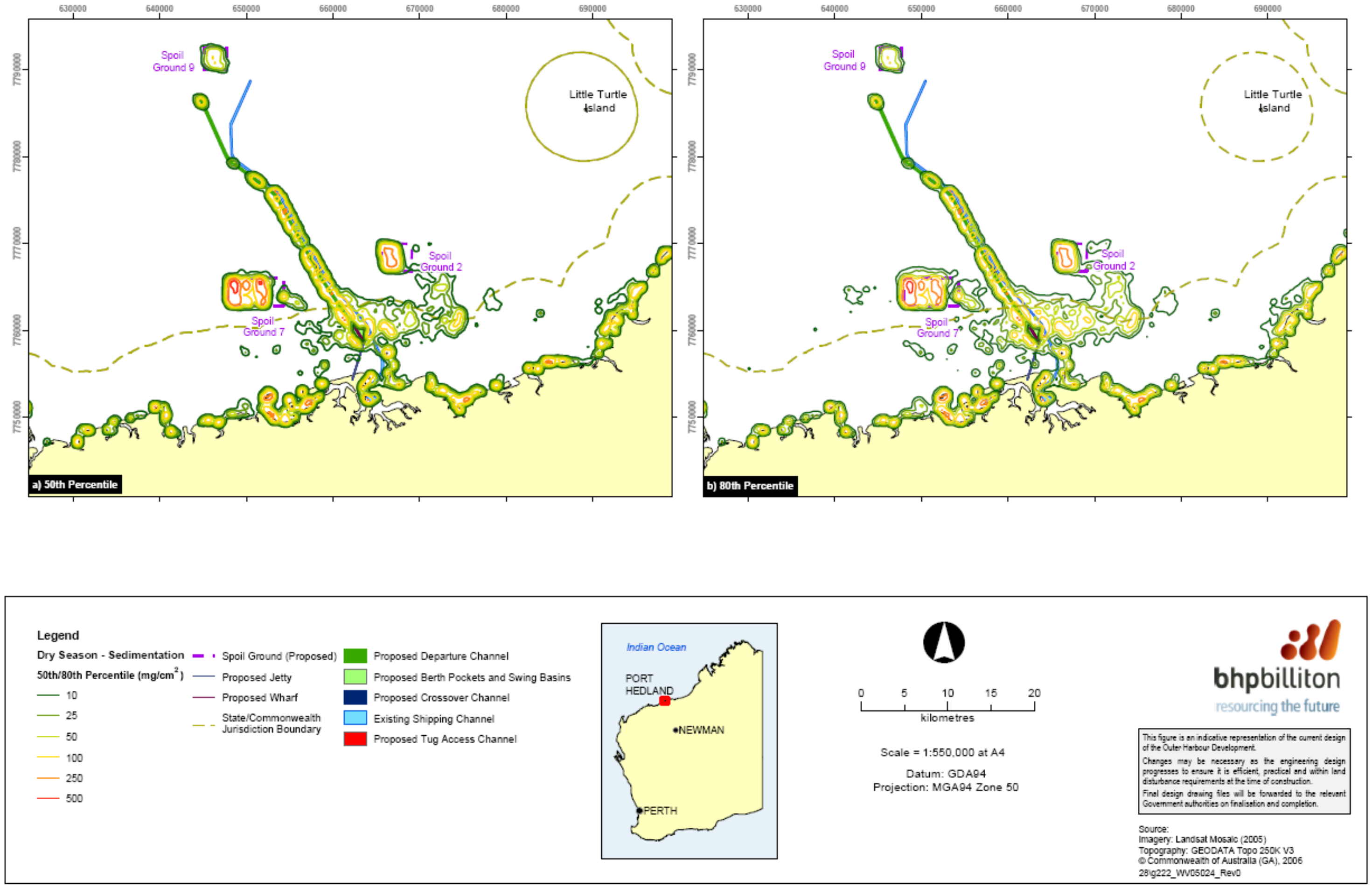
Figure 6-5 Dredge Plume Model Predictions of Sedimentation During the Transition Period (April to May; October to November)

- **Figure 6-5: Sediment Plume Model Predictions of Sedimentation During the Transition Period (April to May; October to November)**



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

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Figure 6-6 Dredge Plume Model Predictions of Sedimentation During the Dry Season (June to September)

- **Figure 6-6: Sediment Plume Model Predictions of Sedimentation During the Dry Season (June to September)**

6.6. Summary of Predicted Impacts

Sediment plume modelling of the construction dredging and disposal activities of the proposed Outer Harbour Development predicts that heavier sediment particles and a proportion of finer sediments would deposit around the dredging and disposal operations while finer sediments would deposit as thin layers, for short durations, over a wider area.

The model predicted smaller sediment particles (silts and clays) as being susceptible to the prevailing levels of shear stress arising from tidal currents, causing sediment plumes to migrate and disperse close to the seabed (Appendix B4 of the PER/EIS). In addition, daily cycles of settlement and resuspension of sediment are likely to occur due to the strong tides and influence of waves, with flooding and ebbing tides spreading the particles and plume in an onshore-offshore direction. Over seasons, a net migration of finer particles to the east and north-east in summer months and west in winter months is predicted.

Evaluation of sediment plume behaviour associated with dredge spoil disposal predicted a net drift of spoil material into areas up to 10 to 15 km towards the shore from disposal area boundaries, a response to the onshore steering of tidal currents with proximity to land. In addition, heavier sediment particles would be distributed during storm events in disposal areas located in shallower waters, resulting in trapped fines being resuspended. This would likely occur for several years after completion of construction disposal, and would be a function of the frequency of local storm events.

7. Interpreting Sediment Plume Modelling Outputs

For a full account on the development of the approach used to interpret the sediment plume modelling outputs refer to Appendix B10 of the PER/EIS.

7.1. Impact Thresholds for State and Commonwealth Waters

Using information from the baseline water quality (Appendix B19 of the PER/EIS) and coral health monitoring (Appendix B18 of the PER/EIS) and relevant literature, impact thresholds for BPPs and non-BPPs were developed to enable an impact assessment of benthic habitats in the Outer Harbour Development area to be undertaken. As recommended by EAG No. 7, thresholds incorporating intensity, duration and frequency in units applicable to the sediment plume modelling outputs were developed.

Also as recommended by EAG No. 7, thresholds applicable to the biotic component, BPP or non-BPP, were developed upon the organisms considered to be most sensitive/least tolerant of altered water quality conditions within this biotic component. In the case of the Outer Harbour Development area, the most sensitive organisms are hard corals, and these organisms were herein used as proxys to represent both the sensitivity and spatial representation for BPPs and non-BPPs.

The thresholds for BPPs and non-BPPs of the Outer Harbour Development area in State and Commonwealth waters are summarised in **Table 7-1** and **Table 7-2**, respectively. A review of the relevant literature and detailed explanation of the impact thresholds are provided in Appendix B10 of the PER/EIS.

- **Table 7-1 Thresholds for the Outer Harbour Development Benthic Impact Assessment in State Waters**

Zone	Effect	Driver	Intensity	Duration	Frequency
Zone of High Impact	Lethal	Light	≤1% Surface Irradiance (SI at benthos)	All daylight*	>40 days in a rolling 60 day period
		Sedimentation	110 mg/cm^2/day	Daily	>34 days in a rolling 50 day period
Zone of Moderate Impact	Sub-lethal	Light	Less than 15% SI at benthos[3]	All daylight*	>40 days in a rolling 60 day period
		Sedimentation	110 mg/cm^2/day	Daily	>15 days in a rolling 50 day period
Zone of Influence	No measurable change	TSS	Not more than 5 mg/L above background	All daylight*	>8 consecutive days
		Sedimentation	50 mg/cm^2/day	Daily	>15 days in a rolling 50 day period

*Refers to 10 daylight hours (0800 – 1800)

- **Table 7-2 Thresholds for the Outer Harbour Development Benthic Impact Assessment in Commonwealth Waters**

Zone	Effect	Driver	Intensity	Duration	Frequency
Zone of High Impact	Lethal	Light	≤1% SI at benthos	All daylight*	>7 days in a rolling 20 day period
		Sedimentation	50 mg/cm^2/day	Daily	>15 days in a rolling 30 day period
Zone of Moderate Impact	Sub-lethal	Light	Less than 15% SI at benthos	All daylight*	>7 days in a rolling 20 day period
		Sedimentation	50 mg/cm^2/day	Daily	>7 days in a rolling 30 day period
Zone of Influence	No measurable change	TSS	Not more than 5 mg/L above background	All daylight*	>8 consecutive days
		Sedimentation	25 mg/cm^2/day	Daily	>7 days in a rolling 30 day period

*Refers to 10 daylight hours (0800 – 1800)

7.2. Application of Thresholds to the Sediment Plume Modelling Outputs

The light component of the threshold units developed for BPPs are in % SI, which were reconciled with the sediment plume modelling outputs (TSS concentrations) using a relationship between turbidity, TSS and light attenuation of samples collected from the proposed Outer Harbour Development dredge footprint (as described in Appendix B10 of the PER/EIS).

TSS thresholds are based on Allowable Total TSS = background TSS + dredging-derived TSS, where the background contribution of TSS was calculated from the baseline data set (Appendix B19 of the PER/EIS).

The dredge-sourced net daily sedimentation rate has been used to define thresholds based on sedimentation.

7.3. Total Suspended Solids/Surface Irradiance Thresholds

As shown in **Table 7-1** and **Table 7-2**, the threshold values set to delineate the Zone of High Impact in State and Commonwealth waters are based on TSS concentrations that occlude at least 99% of light from reaching the benthic community, referred to as 1%SI. The review of the literature indicated that an extinction of light over the relative durations and frequencies are considered necessary to induce at least partial mortality of hard corals; however, these periods are considered to be conservative.

The Zone of Moderate Impact thresholds are based on the same approach as the Zone of High Impact, including the durations and frequencies for each zone, and background TSS loadings. The only difference is in the level of SI reduction that would produce sub-lethal stress (e.g. reduced photosynthetic activity, increased mucous production) but not mortality. The level of percentage SI considered likely to produce stress but no mortality in the most sensitive species of corals is set at <15% SI (**Table 7-1** and **Table 7-2**).

The use of TSS of 5 mg/L in addition to the background level (**Section 7.1**) has been used to define the Zone of Influence at the specified durations and frequencies, as a zone where water quality changes substantively from background (i.e. a discernable signal from the dredged material in the water quality data) (**Table 7-1** and **Table 7-2**).

7.3.1. Accounting for Variance in Depth in the Sediment Plume Model

As per the sediment plume modelling approach detailed in **Section 6.1**, the model accounts for variances in the water depth with the tidal level specified by the current model. However, the grid cells used to calculate the depth-averaged light attenuation at the seabed use a fixed bathymetry based on MSL (**Section 6.2**). This approach results in either an over- or underestimate of the actual reduction of light at the seabed for a specific concentration of TSS as the actual water depth oscillates around MSL in response to the tidal regime. This effect is theoretically balanced out by the equal time steps that the water depth is above and below the MSL.

However, the water depth influences the amount of light reaching the seabed, whereby a particular level of depth-averaged TSS may exceed the relative SI threshold at a specific location at the MSL but not at lower water depths experienced during low tide and vice versa. This is of importance in relation to applying the thresholds, as the % SI estimate is required to be less than the relative threshold level (i.e. 1% SI or 15% SI; **Table 7-1** and **Table 7-2**) for *all* daylight hours between 0800 and 1800. Any single hour of daylight in which the %SI estimate rises above the relative threshold level because the water level falls below MSL due to a combination of TSS level and tidal height would render the daily duration criterion for the exceedance invalid.

Hence, the model is unable to account for events when, for a particular TSS concentration, the level of light at the seabed rises above the relative threshold level because of low tide and this results in overestimation of the number of exceedances of the daily duration criterion. This has resulted in an overestimation of the occurrences and distribution of exceedances of the thresholds and should be considered when interpreting the predicted zones of impact for light.

7.4. Sedimentation Thresholds

The sedimentation thresholds used to define the Zone of High Impact in State and Commonwealth waters (**Table 7-1** and **Table 7-2**, respectively) were based levels of sedimentation that are likely to cause mortality to hard corals (see the literature review discussed in Appendix B10 of the PER/EIS). The setting of thresholds in the Zone of Moderate Impact and Zone of Influence were arbitrary as there is little evidence to base it upon from the literature.

7.5. Applicability of Thresholds to Other BPP and Non-BPP

As discussed above, thresholds applicable to BPP and non-BPP, were developed upon hard corals, considered to be most sensitive/least tolerant of altered water quality conditions within this biotic component. Thresholds relevant to the other components of BPP (macroalgae and seagrass) and non-BPP (sponges, soft corals and sessile invertebrates) are detailed in Appendix B10 of the PER/EIS.

The distribution of macroalgae and seagrasses in the project area is patchy, with seasonal trends (**Section 5.1**). Impacts to these components of BPP resulting from reductions in water quality are likely to be temporary (i.e. less than five-year recovery), unless the benthos on which they occur is smothered by sediments.

8. Approach to Impact Assessment

Provided in this section is an outline to the approach used in assessing the potential impacts to BPPH and BPP in the proposed Outer Harbour Development study area.

8.1. State Waters

This BPPH impact assessment has been undertaken in accordance with EAG No. 3 (2009) and EAG No. 7 (EPA 2011); refer to **Section 2**). Boundaries for LAUs have been determined and impacts considered within each LAU where perturbations to water quality or removal/disposal of material is proposed. In addition, specific descriptions of the benthic ecology in the LAUs of interest with respect to the proposed project infrastructure, impacts arising from the proposed construction and operational activities and identified as ecologically significant to the region offshore of Port Hedland, are provided. Finally, a summary of historical losses of benthic habitat is also provided.

8.1.1. LAU Boundaries

The approach to assessing impacts to benthic communities and benthic habitats is spatially based, as defined in EAG No. 3 (EPA 2009; p. 7):

‘*The EPA has termed the areas within which to calculate cumulative losses*[3] *Local Assessment Units (LAUs). The EPA is of a view that LAUs should normally be approximately 50 km^2.*’

In accordance with this approach, LAU boundaries have been proposed to enable the assessment of cumulative impacts to subtidal marine BPPH due to the proposed Outer Harbour Development construction activities. The LAUs and their boundaries have incorporated the following considerations:

- LAUs will be approximately 50 km^2 in area;
- the lowest astronomical tide mark forms the shoreward boundary (as the LAUs are intended to assess impacts to subtidal benthic habitats); and
- the State waters boundary forms the seaward boundary.

The Office of the EPA Marine Ecology Branch was consulted on the 13th of January 2011 and is in agreement to the boundary setting approach described.

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[3] Cumulative impact is defined as the sum of all irreversible loss of, and serious damage to, benthic primary producer habitat caused by human activities since European habitation of Western Australia. In this context, cumulative impacts do not include changes to benthic primary producer habitat caused by natural disturbances.

The proposed LAUs and their boundaries are presented in **Figure 8-1**. The total areas covered by each LAU where impacts to BPPH are predicted are provided in **Table 8-1**.

- **Table 8-1: Proposed LAUs for the Impact Assessment of Subtidal BPPH**

LAU	**Area**	
	ha	**km^2**
6	4,767	47.67
8	5,680	56.80
Port Hedland Inner Harbour LAU	4210	42.10

8.1.2. Benthic Ecology in LAUs of Interest

Provided in the sub-sections below is a brief description of the BPPH, BPP and non-BPP that have been observed or predicted to occur in each of the LAUs of interest (LAU 6 and 8). An LAU is of interest if it is one of the following:

- predicted to be impacted by permanent loss due to the proposed activities at some time over the construction timeframe;
- nearby to the LAU predicted to contain substantial impacts; or
- an area that supports benthic habitats considered to be ecologically significant.

8.1.3. Predictive Habitat Modelling

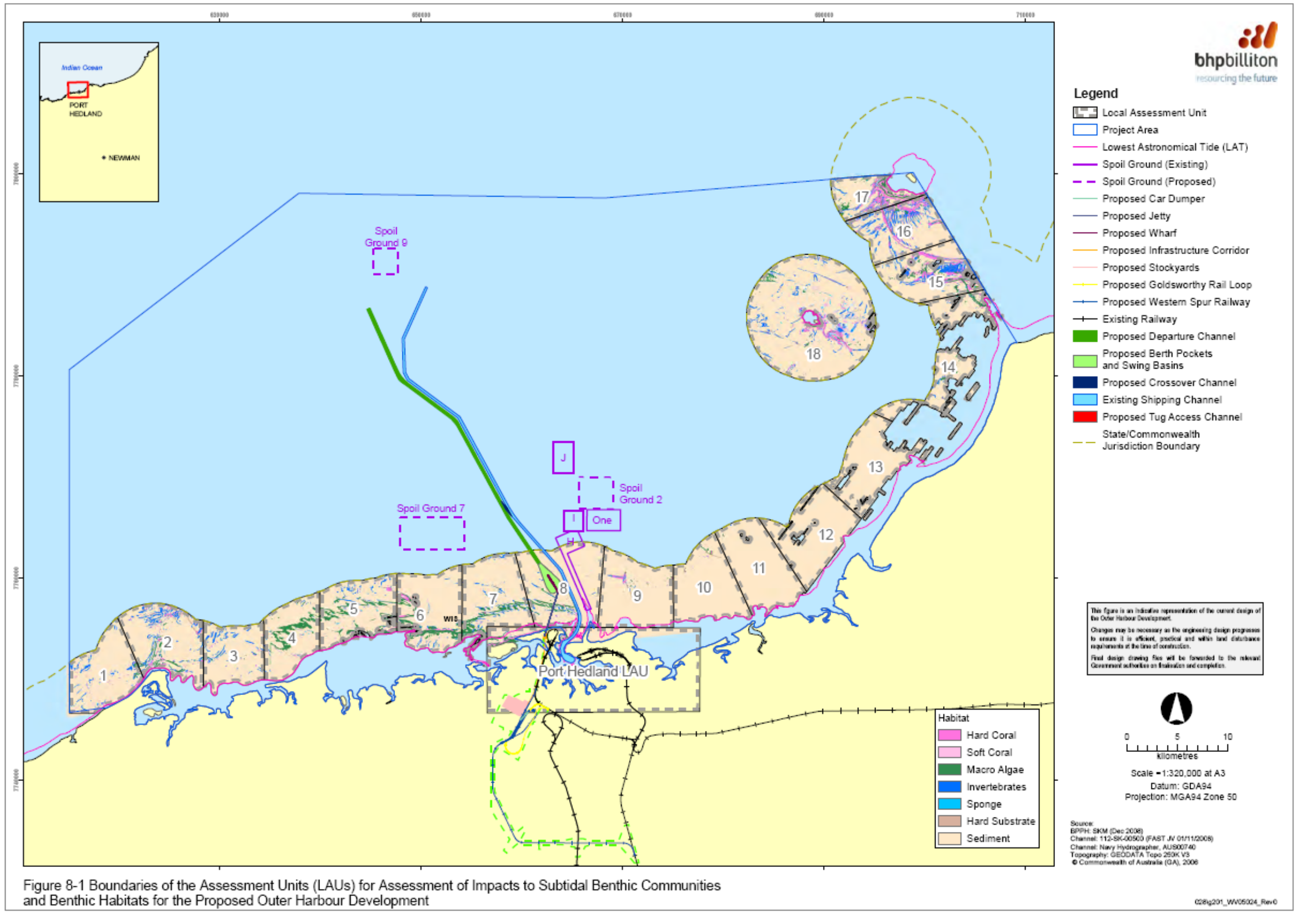
Habitat investigations, including towed video and diver video transects, were undertaken at sites selected based on bathymetric features and existing knowledge of the area (Appendix B21 of the PER/EIS). Additional benthic habitat information was gathered during subsequent marine investigations (**Section 5**).

LiDAR datasets and habitat data collected in the field were then input to a model to generate maps predicting the presence of biota, substratum and combined habitat classes across the entire Port Hedland Outer Harbour Development study area. Prediction of the presence of a biota or substrata class in a given location was reliant on a benthic percentage cover of more than or equal to 5% (Appendix B21 of the PER/EIS).

The dimensions of the given locations or ‘cells’ used in the habitat modelling interrogation represented a 25 m^2 area. Where each cell was deemed to have more than or equal to 5% cover of a particular BPP then the percentage cover within this cell is assumed at 100% cover. As a result, the habitat model over-predicts the amount (in hectares) of each individual mosaic BPP likely to be present on the suitable substratum in a given area. For example, in LAU 6 less than 5% of the benthic community at Weerdee Island was recorded as being hard corals, while on the Weerdee Ridge system the proportion of benthic community represented by hard corals was between 0.2 and 21.6% (**Section 8.1.4**).

As set out in EAG No. 3 (EPA 2009), when comparing the cumulative loss to the cumulative loss guidelines the EIA documentation should provide the most ‘realistic’ BPPH loss scenario. In this case, the use of data from *in situ* surveys of the habitats in each LAU provides the most realistic loss estimates.

There is always a level of uncertainty in any predictions of habitat boundaries, particularly in the marine environment (Appendix B21 of the PER/EIS; Hanley 2011). The predictions made were supported by ground truthing, which gave a high degree of confidence in the predictions (ranging from 82% for sessile invertebrates to 97% for hard substratum), but there was still a predicted error estimate of approximately 10%. Values for loss are therefore provided as a range in order to take account of this uncertainty.



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Source:
BPPH: SKM (Dec 2008)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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Figure 8-1 Boundaries of the Assessment Units (LAUs) for Assessment of Impacts to Subtidal Benthic Communities and Benthic Habitats for the Proposed Outer Harbour Development

- **Figure 8-1: Boundaries of the Local Assessment Units (LAUs) for Assessment of Impacts to Subtidal Benthic Communities and Benthic Habitats for the Proposed Outer Harbour Development**

8.1.4. LAU 6 – Weerdee Island

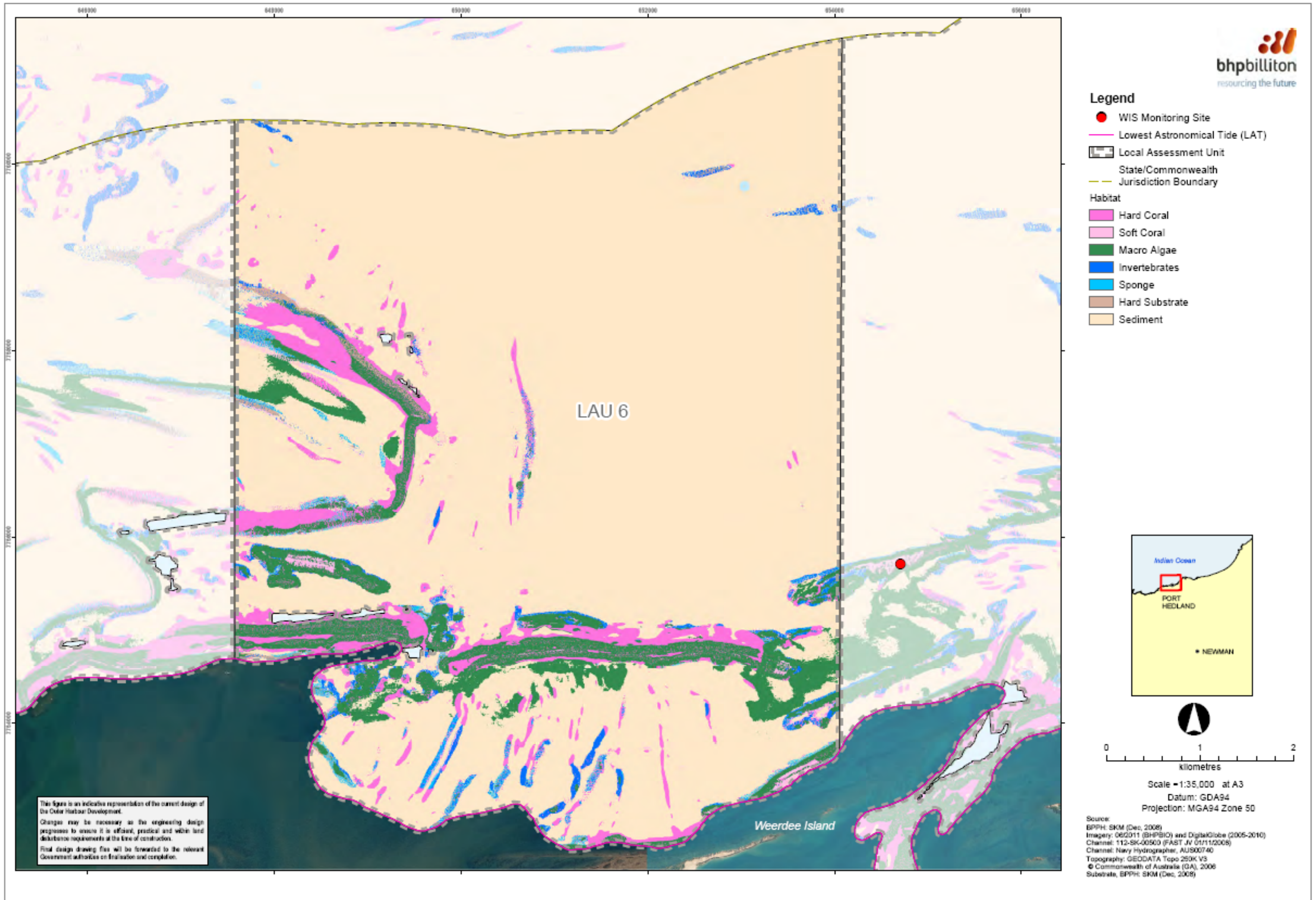
LAU 6 is 4,767 ha in area, with the composition of BPPH, BPP and non-BPP presented in (**Table 8-2**). Areas of hard substratum were predicted to support a mosaic benthic community. Within LAU 6 hard coral cover is estimated to be about 6% of the total area of substratum, and it exhibits a patchy distribution. Whilst the predictive habitat mapping assumes 100% cover of the area of BPP (see **Section 8.1.3**), less than 5% of the benthic community at Weerdee Island was recorded as being hard corals, while on the Weerdee Ridge system the proportion of benthic community represented by hard corals was between 0.2 and 21.6% (**Figure 8-2**).

A sparsely inhabited area (approximately 25 m^2) of the seagrass species *Halophila decipiens* was observed offshore of Weerdee Island (**Figure 5-5**).

- **Table 8-2: Breakdown of BPPH, BPP and Non-BPP within LAU 6**

Component	Area (in ha)*	Proportion of Area (%)*
BPPH		
Hard substratum (with and without BPP)[1]	275	5.8
Sediment covered hard substratum[1]	148	3.1
Sediment with BPP	328	6.9
Total	**750**	**15.7**
BPPs		
Hard coral	284	6.0
Macroalgae	487	10.2
Total	**771**	**16.2**
Non-BPPs		
Sponges	264	5.5
Soft coral	27	0.6
Sessile invertebrates	178	3.7
Total	**468**	**9.8**

*****An error estimate of 10% has been applied to the estimates of cover.
[1] It is assumed that all hard substratum is potential BPPH.



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Source:
BPPH: SKM (Dec, 2008)
Imagery: 06/2011 (BHPBIO) and DigitalGlobe (2005-2010)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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Substrate, BPPH: SKM (Dec, 2008)

Figure 8-2 BPPH and BPP Areas Present within LAU 6

- **Figure 8-2: BPPH and BPP Areas Present within LAU 6**

8.1.5. LAU 8 – Project Footprint

LAU 8 is 5,680 ha in area, with the composition of BPPH, BPP and non-BPP presented in (**Table 8-3**). Within LAU 8 hard coral is estimated to be less than 2% of the total area of substratum, and it exhibits a patchy distribution. During a recent survey of the subtidal marine environment directly north of Finucane Island, biota coverage ranged from very sparse (<5%) to dense (>75%), but more commonly covered 5-50% of the substratum (SKM 2011b). No one biota class was recorded to occupy more than 5% of the study area.

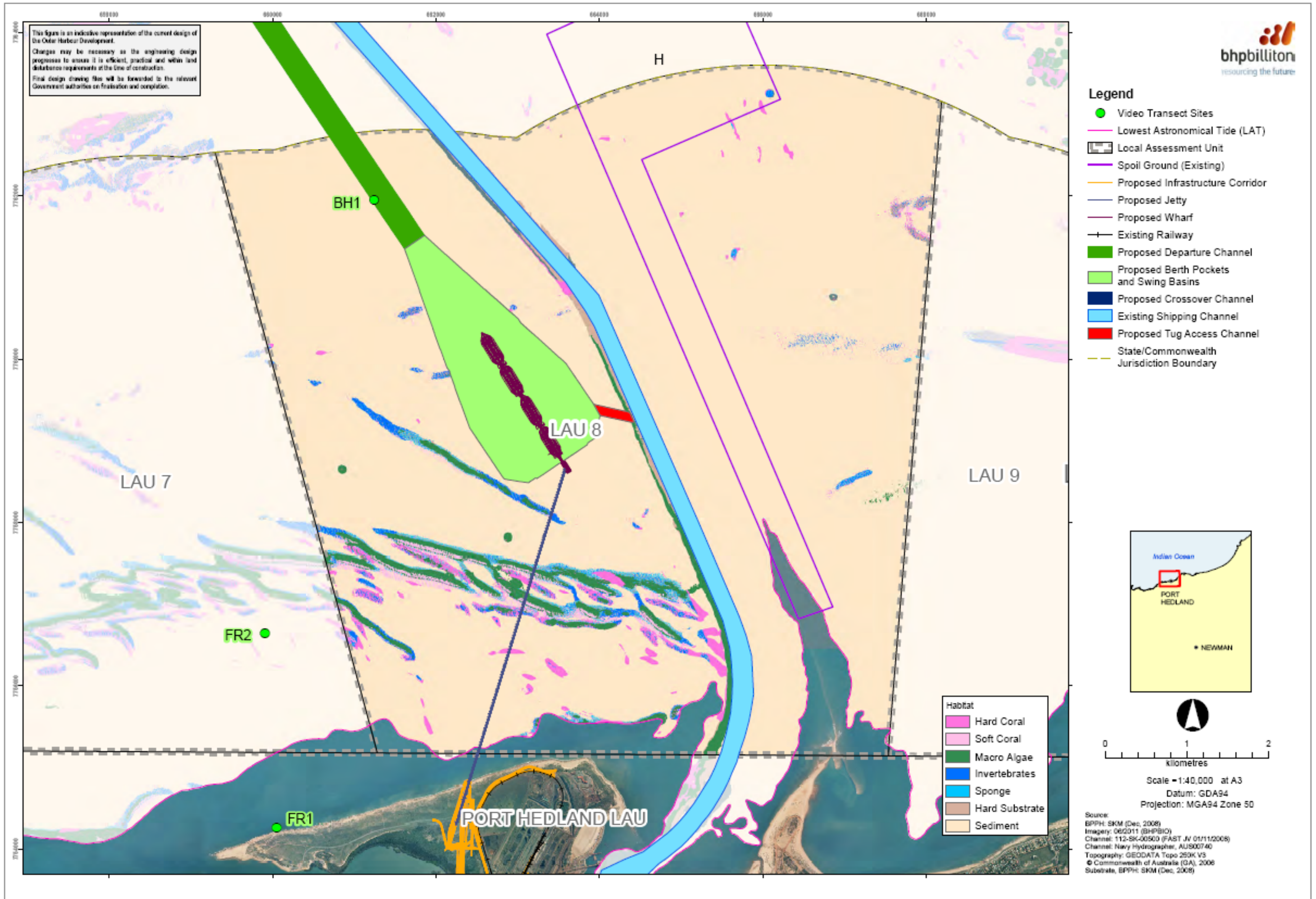
In addition, three sites were surveyed within LAU 8 (**Figure 8-3**). Site BH1 is in the region of the proposed berth pockets and swing basin, and was characterised by low-relief hard pavement substratum covered by a thin layer of sand. It was classified as BPPH due to the presence of BPP comprising hard corals. The dominant benthic cover was sponge and BPP hard corals (encrusting and foliose forms). Site FR1 was another low-relief site, which was dominated by sandy substratum. This site had a low percentage of sponge and soft corals (less than 4%) and a low percentage cover of BPP hard coral (1.3%) and hydroids (1.1%). Site FR2 was found to have a substratum of silty sand mounds devoid of any epibenthic cover.

■ **Table 8-3: Breakdown of BPPH, BPP and Non-BPP within LAU 8**

Component	Area (in ha)*	Proportion of Area (%)*
BPPH		
Hard substratum (with and without BPP)[1]	115 ()	2.0
Sediment covered hard substratum[1]	137	2.4
Sediment with BPP	131	2.3
Total	**383**	**6.7**
BPPs		
Hard coral	93	1.6
Macroalgae	165	2.9
Total	**258**	**4.5**
Non-BPPs		
Sponges	148	2.6
Soft coral	56	1.0
Sessile invertebrates	107	1.9
Total	**312**	**4.5**

*****An error estimate of 10% has been applied to the estimates of cover.

[1] It is assumed that all hard substratum is potential BPPH.



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Scale =1:40,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
BPPH: SKM (Dec, 2008)
Imagery: 06/2011 (BHPBIO)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
© Commonwealth of Australia (GA), 2006
Substrate, BPPH: SKM (Dec, 2008)

Figure 8-3 BPPH and BPP Areas Present within LAU 8

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- **Figure 8-3: BPPH and BPP Areas Present within LAU 8**

8.2. Commonwealth Waters

The Commonwealth waters component of the Port Hedland Outer Harbour Development study area covers 264,225 ha, with the composition of BPPH, BPP and non-BPP presented in (**Table 8-2**). Hard coral is estimated to be approximately 5% of the total area of substratum, and it exhibits a patchy distribution (**Figure 5-3**).

- **Table 8-4: Breakdown of BPPH, BPP and Non-BPP within Commonwealth Waters**

Component	Area (in ha)*	Proportion of Area (%)*
BPPH		
Hard substratum (with and without BPP)[1]	14,843	5.1
Sediment covered hard substratum[1]	14,185	5.0
Sediment with BPP	8,320	3.6
Total	**37,348**	**13.6**
BPPs		
Hard coral	11,926	4.9
Macroalgae	11,350	4.3
Total	**23,276**	**6.3**
Non-BPPs		
Sponges	5,790	2.2
Soft coral	2,522	1.0
Sessile invertebrates	16,466	6.2
Total	**24,778**	**7.4**

*****An error estimate of 10% has been applied to the estimates of cover.
[1] It is assumed that all hard substratum is potential BPPH.

8.3. Definition of Impacts

The terms used in defining the nature of impacts to benthic communities and habitats are summarised in **Table 8-5**. In addition, the list of definitions provided by EAG No. 7 (EPA 2011; refer **Table 8-6**) have been adopted in this report.

- **Table 8-5: List of terms used to define impacts to benthic communities and benthic habitats**

Term	Definition
Loss	Direct removal or destruction of BPPH. Considered to be irreversible
Damage	Alteration to the structure or function of a community
Serious Damage	Timeframe for full recovery is expected to be longer than five years
Minor Damage	Timeframe for full recovery is expected to be less than five years

- **Table 8-6: List of definitions as described in EAG No. 7**

Word or Phrase	Definition
Benthos	Benthos are the organisms which live on, in, or near the seabed
Dredge spoil	Seabed substrata after it has been excavated from the seabed
Dredging	Activities that involve excavation of the seabed from the upper intertidal zone to the subtidal zone. Dredging in the sense of the EAG No. 7 means both dredging and dredge spoil disposal activities
Extent	The area over which an impact extends
Infrastructure	Is taken to mean the areas developed by dredging. Shipping channels, turning basins, berth pockets, pipeline trenches, spoil disposal sites, sub-sea mine areas and land reclamations are some examples of infrastructure
Irreversible	Lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less
Near real-time	Refers to a system for monitoring and interpreting data where the time lag between collecting monitoring data and responding is sufficiently short to be considered as immediate as practicable
Persistence	The period of time that an impact continues
Prediction	A forecast of future outcomes
Pressure threshold	Pressure thresholds signify a level of pressure (intensity, frequency and duration) that equates to a pre-defined level of impact in the biota of interest
Recoverable	See reversible
Reversible	A capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less
Severity	The degree of harm caused. For example, the degree of harm or severity of impact to biota could range from sub-lethal effects to mortality or loss
State coastal water	The State coastal waters extend three nautical miles seaward from the territorial baseline. EAG No. 7 applies to dredging or dredging-related impacts in these waters
Uncertainty	In relation to prediction is doubt or concern about the reliability of achieving predicted outcomes

Source: EPA (2011)

8.4. Dredging Induced Impacts on BPPH

EAG No. 7 (EPA 2011) focuses on the direct loss of benthic habitats and communities by removal or burial, and the indirect impacts on benthic habitats and communities from the effects of sediments introduced to the water column by the dredging. Specifically, EAG No. 7 defines direct and indirect impacts as follows (EPA 2011; p. 13):

- *direct impacts are, for the most part, coincident with the footprint of infrastructure and the areas immediately around the infrastructure; and*
- *indirect impacts arise when the pressure imposed by dredging exceeds the biota's natural tolerance to that type of pressure. The severity of indirect impacts will range from irreversible to readily-recoverable effects.*

Section 9 presents BPPH loss assessments relating to direct loss of BPPH and BPP through removal due to construction of the marine infrastructure as proposed for the Outer Harbour Development, and indirect losses due to smothering of BPPH from elevated sedimentation.

Indirect effects on benthic habitats and communities due to the effects of sediments introduced to the water column by dredging are discussed in **Section 10.2**.

8.5. Definition of Impact Zones

EAG No. 7 requests that impact zones due to marine construction activities be provided as follows (EPA 2011; p. 19):

- **Zone of High Impact (ZoHI)**: the area directly impacted (e.g. the channel and spoil disposal site) and a zone immediately surrounding the proposed dredging and dumping areas where indirect impacts are predicted to be severe and irreversible. This zone defines the area where mortality of, and long term (i.e. months to years) serious damage to, biota and their habitats would be predicted. The impacts on the BPPHs and their habitats would be predicted. The impacts on the BPPHs within the ZoHI should be considered in the context of EAG No. 3;
- **Zone of Moderate Influence (ZoMI)**: abuts, and lies immediately outside of, the ZoHI. Within this zone sub-lethal effects on key benthic biota would be predicted, but there should be no long term damage to, or modification of, the benthic organism, the communities they form or the substrata on which they grow. Proponents should provide information about impacts in this zone both in the context of what would be impacted and what would be protected. The outer boundary of this zone is coincident with the inner boundary of the next zone, the Zone of Influence;
- **Zone of Influence (ZoI)**: the area where at some time during the proposed dredging and spoil disposal activities small changes in sediment-related environmental quality, which are outside natural ranges might be expected, however the intensity and duration is such that no detectable effects on benthic biota or their habitats should be experienced; and
- **Outer Boundary of the ZoI**: the point beyond which there should be no dredging (or spoil disposal) related changes from natural conditions. This is the area where it would be appropriate to establish suitable reference sites for the purpose of monitoring potential effects of dredging in the ZoHI, ZoMI and ZoI.

This approach has been applied in the assessment of impacts to BPPH as undertaken in this report. Specifically, the decision rules that have been used to determine the zones and/or their boundaries as outlined above are summarised in **Table 8-6**.

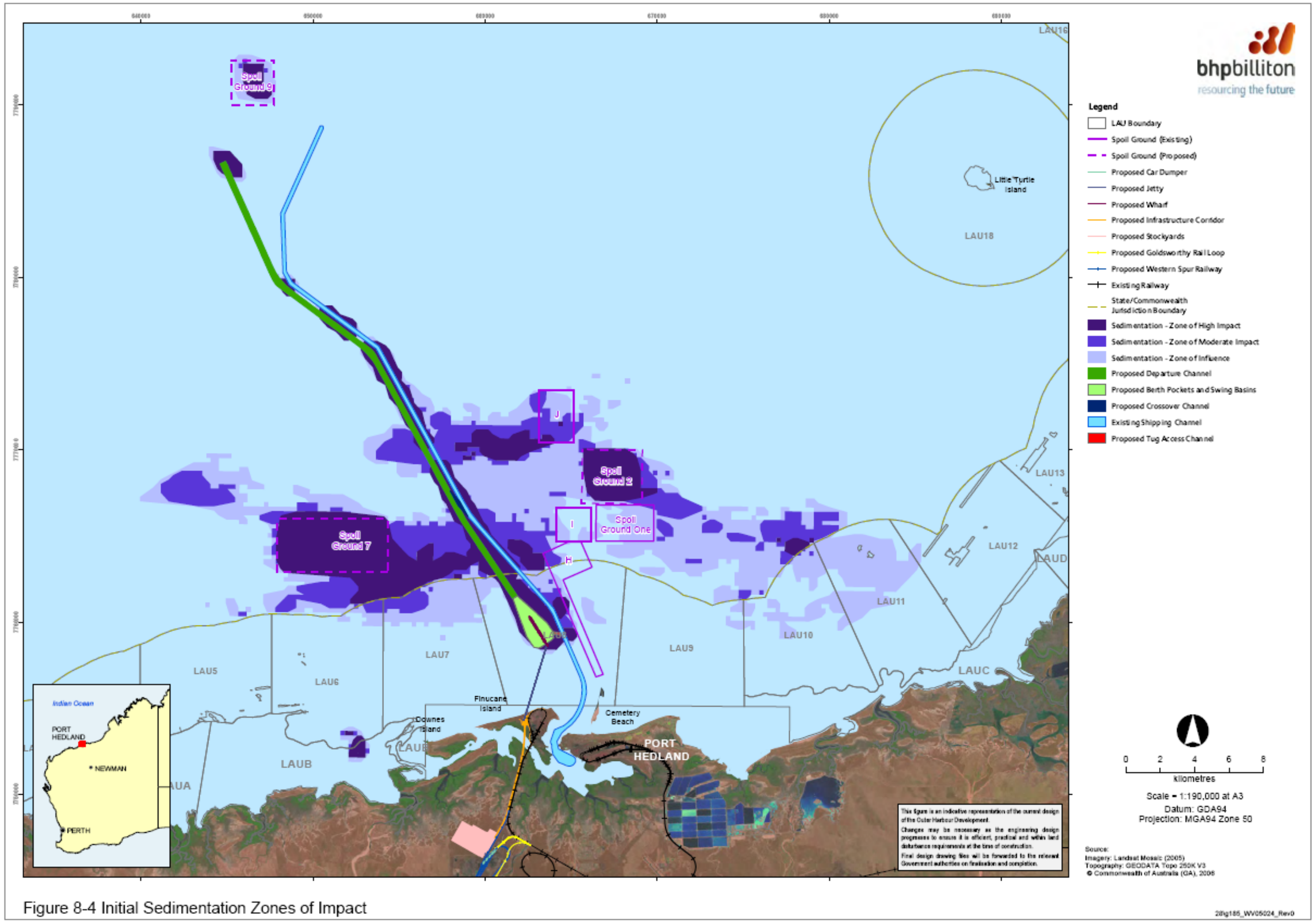
- **Table 8-6: Decision Rules Used to Determine the Zones of Impact and their Boundaries**

Zone	**Description of Decision Rule**	
	State Waters	**Commonwealth Waters**
Zone of High Impact (lethal)	■ Anywhere that direct removal of BPPH is proposed to occur; ■ where the benthic environment is predicted to experience <1% SI of light for >40 days in a rolling 60-day period; and ■ where the mean daily net sedimentation rate of 110 mg/cm^2/day for >34 days in a rolling 50-day period is predicted to occur	■ Anywhere that direct removal of BPPH is proposed to occur; ■ where the benthic environment is predicted to experience <1% SI of light for >7 days in a rolling 20-day period; and ■ where net mean daily net sedimentation rates of 50 mg/cm^2/day for >15 days in a rolling 30-day period is predicted to occur
Zone of Moderate Impact (sub-lethal)	■ Areas predicted to experience <15% SI of light for >40 days in a rolling 60-day period; and ■ where the mean daily net sedimentation rate of 110 mg/cm^2/day for >15 days in a rolling 30-day period is predicted to occur.	■ Areas predicted to experience <15% SI of light for >7 days in a rolling 20-day period; and ■ where 50 mg/cm^2/day of net sedimentation rates for >7 days in a rolling 30-day period is predicted to occur.
Zone of Influence (no measureable change)	■ Areas where water column TSS concentrations are >5 mg/L above background concentrations for >8 consecutive days; and ■ Where the mean daily net sedimentation rate of 50 mg/cm^2/day for >15 days in a rolling 50-day period is predicted to occur.	■ Areas where water column TSS concentrations are >5 mg/L above background concentrations for at least 8 consecutive days; and ■ Where the mean daily net sedimentation rate of 25 mg/cm^2/day for >7 days in a rolling 30-day period is predicted to occur.
Outer Boundary of the ZoI	■ Water column TSS concentrations are 5 mg/L or less above background at any point in time	■ Water column TSS concentrations are 5 mg/L or less above background at any point in time.

8.6. Predicted Impact Zones

By applying the thresholds discussed in **Section 7**, the initial zones of impact have been estimated as shown in **Figure 8-4** and **Figure 8-5**.

However, due to a number of factors it is considered that the zones of impact shown above are unnecessarily conservative and overestimate the extent of potential impact. These factors include the uncertainty in the predictions of habitat type and modelling, which are inherent in all marine benthic predictions due to the nature of the environment, and the variability in baseline conditions (see Appendix B21 of the PER/EIS; Hanley 2011). The zones of impact also require further consideration due to the type, distribution and abundance of communities and environmental conditions present within the study area.



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Source:
Imagery: Landsat Mosaic (2005)
Topography: GEODATA Topo 250K V3
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Figure 8-4 Initial Sedimentation Zones of Impact

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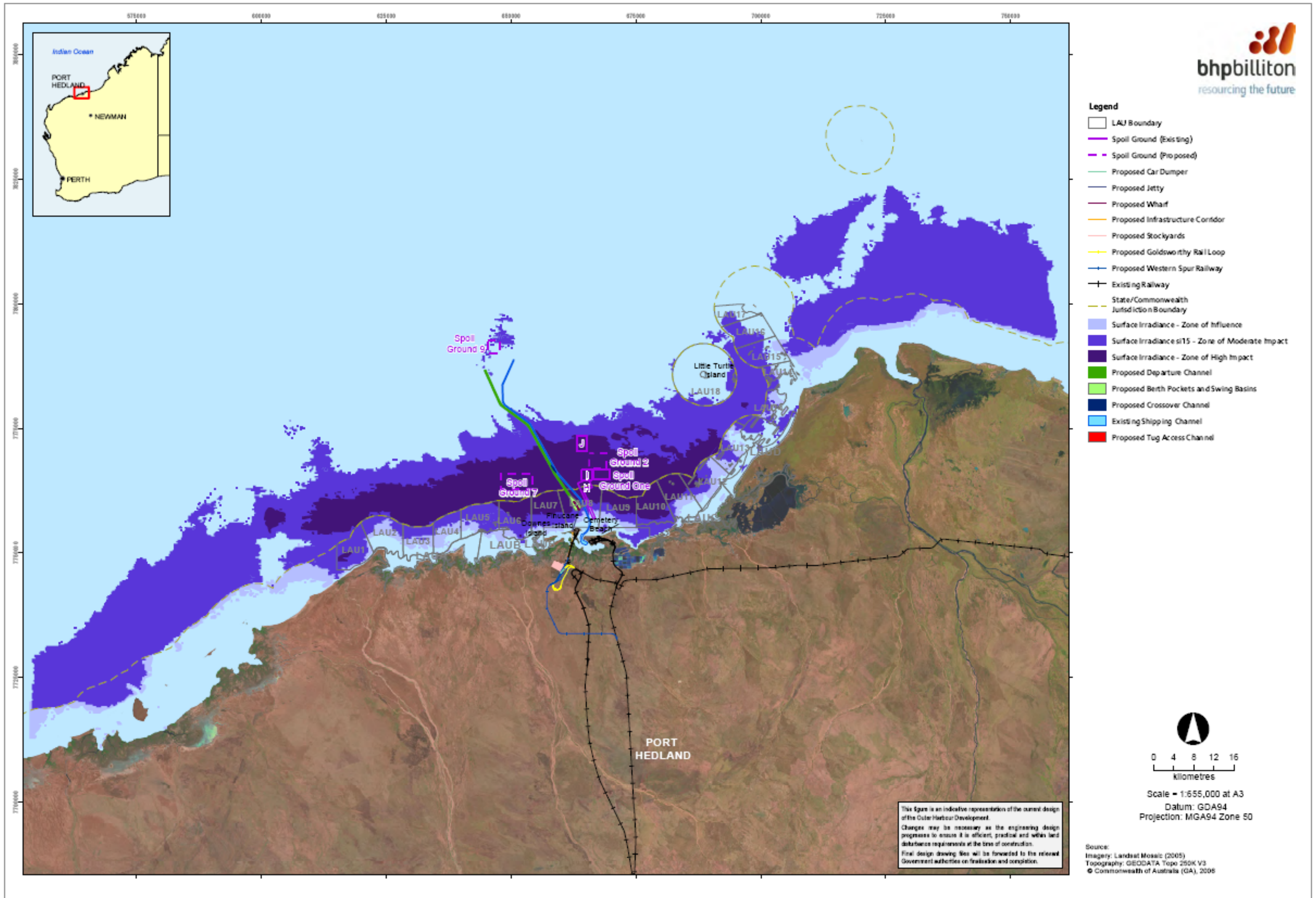
- **Figure 8-4: Initial Sedimentation Zones of Impact**



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Scale = 1:655,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
Imagery: Landsat Mosaic (2005)
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Figure 8-5 Initial Surface Irradiance Zones of Impact

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- **Figure 8-5: Initial Surface Irradiance Zones of Impact**

8.6.1. Sediment Plume Modelling

As with any modelling predictions, there are a number of assumptions that must be made based on the hydrodynamic conditions, weather conditions and dredge method (**Section 6.2**). These assumptions are based on available data to provide a realistic baseline but there is a risk of natural phenomena occurring which can change predicted conditions outside the boundaries expected. The modelling therefore takes a precautionary approach to ensure some built in conservatism to the results.

8.6.2. Type, Distribution and Abundance of Biota Types

The surveys undertaken for the baseline assessment and subsequent surveys have all shown a very patchy distribution of biota throughout the State waters. The total cover of substratum by biota within all of the sites surveyed is very low with between 7 and 36% cover within a site (**Section 5.1**). Where cover was higher in one site this was due to the presence of seasonal algal species. Cover in general throughout the site is between 7 and 14%. The species present are those that are considered to be tolerant to a high level of disturbance and elevated levels of turbidity.

Hard corals are likely to be the most sensitive BPP within State waters affected by dredging activities. The dominant corals present are from the genus *Turbinaria* and from the families Faviidae and Poritidae (Appendix B18 of the PER/EIS). The dominance of *Turbinaria* spp. and overall low species richness and abundance (0-21.6% cover) of corals within subtidal waters in the Port Hedland area suggest that these coral communities experience, and are adapted to, high turbidity and sedimentation rates. This type of coral community is considered typical of the broader marine environment of the Pilbara region, and is also similar to other *Turbinaria* dominated coral communities in macrotidal, turbid waters elsewhere in northern Australia. No new species or records of occurrence for WA waters have been recorded from surveys in the area (Appendix B18 of the PER/EIS).

Whilst the diversity and abundance of the coral community within subtidal waters around Port Hedland has been characterised (Appendix B18 of the PER/EIS), there has been little focus on the size-frequency distributions of coral colonies. This type of information can provide insight into the age structure of coral colony populations which can help predict the recovery time of a coral population in the event of an impact, and provide insight into the frequencies and scales of natural disturbances causing mortality among corals in the region. This has particular relevance to the EAG No. 3 (2009) with respect to impacts to BPPH.

Analysis of the size-class frequency of corals within the subtidal waters of the study area indicates a high turnover of individuals at site WIS within State waters (**Figure 8-6**). Surveys of percent cover have been undertaken at monitoring sites over time and analysis of the data to estimate age classes of corals was undertaken. The analysis indicates that, although there are some individuals that have grown to large sizes indicative of 5 years or more of growth, the majority of individuals (between approximately 70-90% of individuals) are younger than 5 years (**Appendix A**). This indicates that there are regular periodic disturbances in the nearshore environment (e.g. tropical cyclones approximately once every two years; **Section 4.1**), which prevent many of the individuals from surviving much beyond 5 years of age. The data also indicate there has been regular recruitment in recent years to the sites surveyed with all age classes represented. The corals are dominated by the genus *Turbinaria*, which is known to be more tolerant than many other corals to elevated levels of turbidity, sedimentation, and fluctuations in salinity.

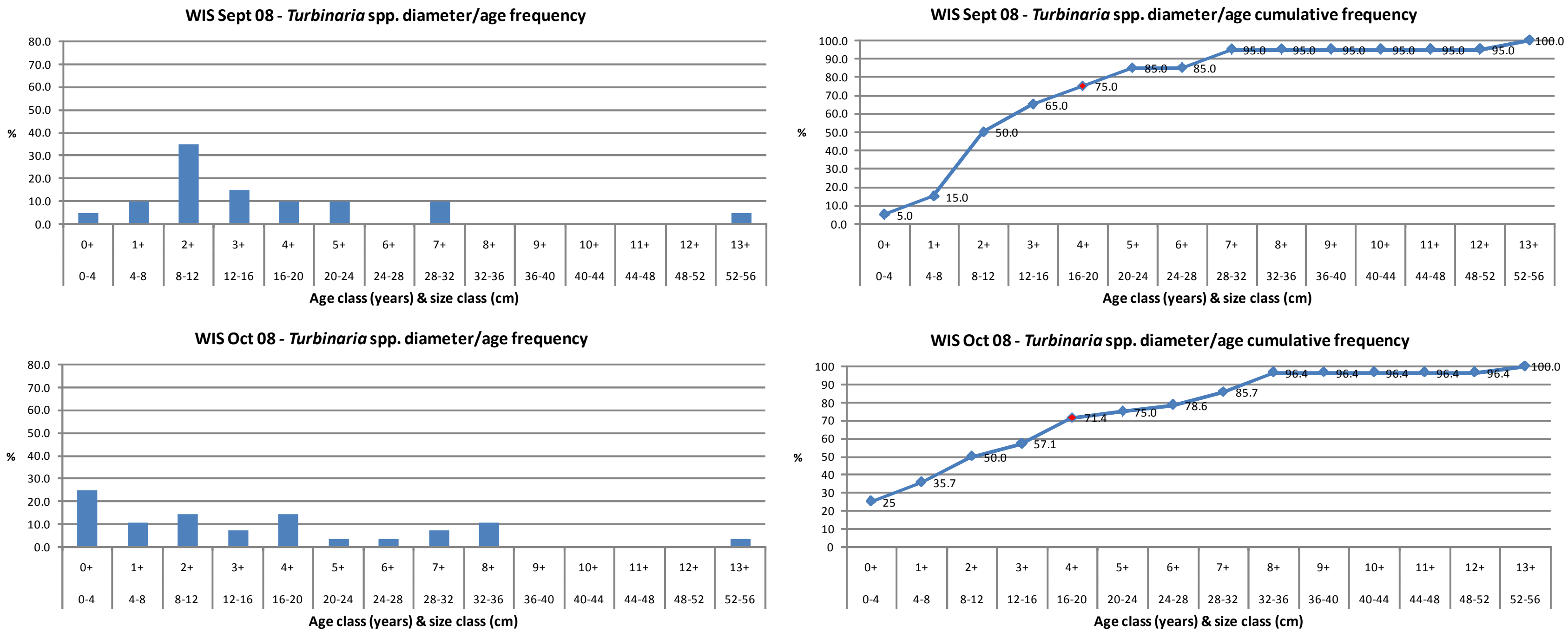
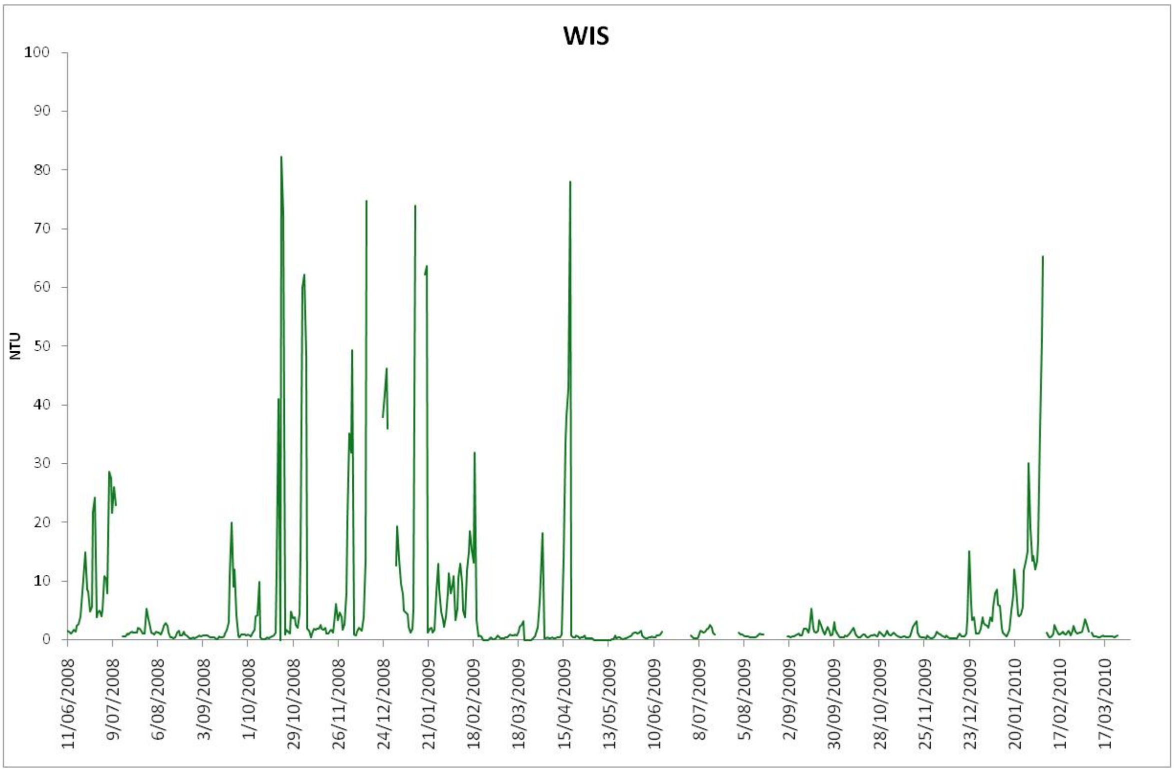


Figure 8-5: Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp colonies at Weerdee Island (WIS) during September and October 2008

8.6.3. Physical Characteristics

The Pilbara region is subject to regular disturbance of shallow water nearshore marine habitats from cyclones (**Section 4.1**), which would cause direct physical damage to corals and other benthos through wave action, scouring, sedimentation and would also result in high periods of increased turbidity leading to a reduction of light availability for BPP. The results of the baseline water quality monitoring from 2008 to 2010 at a nearshore station indicates several periods of extreme levels of daily median turbidity (**Figure 8-6**; Appendix B19 of the PER/EIS). Consequently, the BPP community comprises a high proportion of opportunistic species able to colonise disturbed areas including *Turbinaria* spp., algal species such as *Sargassum* spp. and *Halimeda* spp. and the seagrasses that occur in the more sheltered areas (*Halophila* spp.).



▪ **Figure 8-6: Daily Median Turbidity (NTU) at WIS Monitoring Site in State Waters**

8.7. Summary

The data collected from field surveys, the literature, and the physical characteristics of the region demonstrate that the community types found within the State and Commonwealth waters are highly likely to be tolerant to the changes that could occur due to the dredging and spoil disposal activities. Where losses are predicted it is highly likely that the majority of species would recover within a timeframe of 5 years. The area shown for high levels of sedimentation would incur losses, which may not recover due to the change in habitat likely to occur if the deposited sediment remains *in situ*. Other species may then colonise these areas but they may be different species to those present prior to dredging activity and this is considered to be a permanent loss for the purpose of this assessment. The Zone of High Impact is therefore considered to be the area shown on **Figure 9-3,** which is subject to high levels of sedimentation (**Table 9-3**). Outside of this zone there may be periodic elevations of TSS concentrations, which although they may cause the loss of some species, it is expected that recovery would occur within 5 years.

The Zone of High Impact is therefore reduced in scale, to take account of the above findings, to cover only the direct footprint of dredging and the area covered by high levels of sedimentation which cause the smothering of benthos and have lasting effects on the habitat type such that the same, or similar species are unlikely to recolonise the area.

9. Predicted Loss of BPPH

The impacts to BPPH described in this section are predicted to occur within the Zone of High Impact.

The impacts detailed include historical impacts to BPPH (either estimated or recorded), the proposed losses of BPPH due to removal during construction of the proposed marine infrastructure, and indirect impacts due to smothering of BPPH from elevated sedimentation and changes in water quality caused by the dredging activities.

As discussed in **Section 8.1.3**, there is always a level of uncertainty in any predictions of habitat boundaries, particularly in the marine environment (Appendix B21 of the PER/EIS; Hanley 2011). The predictions made were supported by ground truthing, which gave a high degree of confidence in the predictions, but there was still a predicted error estimate of approximately 10%. Values for loss are therefore provided as a range in order to take account of this uncertainty.

9.1. Historical Loss of BPPH

In estimating historical loss of BPPH, it has been assumed that permanent loss has occurred only where substratum has been physically removed during the dredging of channels, hard substratum has been smothered by sediment either through placement at the spoil disposal grounds or settlement of material suspended from the dredging or placement activities. In these areas, irreversible loss is predicted if the changes have occurred to sediments that change the characteristics of the habitat such that it is unlikely to be recolonised by similar species or construction has occurred directly onto the substratum.

Port Hedland has been an operating port since the late 1800’s, when a jetty was created to service the pastoral industry of the eastern Pilbara. Prior to 1965, the harbour was crescent-shaped and had a maximum depth of 9 m at its widest point near the southern end (Hope Downs Management Services 2002). In 1965, with the development of the iron ore industry in the region, dredging began to alter the natural bathymetry of the harbour. Since that time, modifications have included:

- dredging of an approach channel to the harbour;
- reclamation of East Creek to accommodate developments at Nelson Point;
- construction of iron ore, salt and general cargo wharves; and
- dredging of a turning basin and berthing pockets.

Much of the development to date at Port Hedland has taken place inside the harbour, within the area of the tidal creek system, and impacts outside the mouth of the creek system have been confined to the shipping channel, spoil grounds and anchorages. Outside the harbour, dredge spoil has either been used for land reclamation or disposed of at the large spoil bank immediately to the east, north of the township. More recently, dredge spoil has been disposed of at offshore spoil grounds One, H, I and J (**Figure 1-1**). The build up of sediment in the harbour channel requires maintenance dredging to be conducted every three to four years. Capital dredging for new projects has also occurred.

The exact extent of historical BPPH loss due to previous dredging and spoil disposal activities is difficult to determine because there is no baseline habitat data or mapping available prior to the first dredging and disposal activities. The detailed habitat mapping carried out for the proposed Outer Harbour Development is the first time the subtidal marine habitat offshore from Port Hedland has been quantified. This detailed habitat map aids in assessing the estimates for historical loss of BPPH.

By interpreting where the existing channel has cut through hard substratum or ridgelines, approximately 14.5 (±1.45) ha of BPPH from the LAU 8 were removed (**Figure 9-1**). Spoil dredged from the entrance to the Inner Harbour was disposed to the east of the existing channel forming a large bank and an artificial sand spit to the north of the township, now known as ‘spoil bank’. The spoil bank extends from the shore covering areas that would have been intertidal rocky platform and near shore bare sandy habitat. Again it is difficult to determine the exact extent of historical BPPH loss resulting from this spoil disposal. Assuming that the rocky intertidal area may have supported similar habitat to the area east of spoil bank, and the base of the spoil bank is approximately 1 km wide where it adjoins the beach to the north of the town, an area of approximately 5 to 10 ha may have been lost depending on the width of the platform.

Historical spoil ground H was located on areas of bare sediment and generally avoided areas of limestone reef or substratum that would have supported BPPH.

Due to the naturally harsh environment and a long history of anthropogenic impacts, the Inner Harbour was not considered to have substantial benthic communities. Consequently, direct and indirect impacts to BPPH for projects undertaken in the Inner Harbour had not been evaluated prior to Rapid Growth Project 6 (BHP Billiton Iron Ore 2009).

The predicted impacts to subtidal BPPH in the Inner Harbour due to Rapid Growth Project 6 were due to the dredge footprint, where sparse macroalgal and filter feeding invertebrate communities had been identified. A total area of 4.17 (±0.4) ha or 2.19% (±0.2%) of the total area of BPPH mapped (190.07 (±19) ha) was predicted and approved to be lost due to this project.

Subsequent to the approval of Rapid Growth Project 6, the South West Creek Dredging and Reclamation Proposal has been released. The proposal notes that indirect impacts to a small coral community in the western arm of South West Creek are predicted, due to the proximity to the dredging footprint and increases in water column turbidity and sedimentation rates. A loss for this BPPH however was not predicted.

A summary of the discussion on likely or known historical losses that have occurred within the Port Hedland Inner Harbour LAU[4] (PHIH LAU) are provided in **Table 9-1**.

- **Table 9-1: Historical losses of BPPH (in ha and proportion (%) of the total area)**

LAU	Estimated Original Area (ha)*	Historical Loss (ha)*	Historical Loss (%)*	EPA Category and Loss Threshold
LAU 8	383 (±38)	Access channel: 14.5 (±1.45)	4 (±0.4)	E – 10%
PHIH LAU	190 (±19)	RGP6: 4 (±0.4) South West Creek: 0	2 (±0.2)	E – 10%
Totals	**498 (±49)**	**19 (±1.9)**	–	–

*****An error estimate of 10% has been applied to the estimates of cover.

9.2. Direct Loss of BPPH due to Marine Infrastructure Footprint

Direct irreversible loss of BPPH would occur in the proposed Outer Harbour Development footprint from construction of the jetty and wharf, from removal of seabed during dredging of the berth area, turning basin and departure channel (**Figure 9-1**). The estimated areas of BPPH directly impacted by these activities are summarised in **Table 9-2**.

- **Table 9-2: Proposed Direct losses of BPPH (in ha and proportion (%) of the total area) due to the Marine Infrastructure Footprint**

LAU	Total Area of BPPH (ha)*	Proposed Loss due to Infrastructure (ha)*	Loss due to infrastructure (%)*	EPA Category and Loss Threshold
LAU 8	383 (±38)	3.8 (±0.38)	1 (±0.1)	E – 10%

*****An error estimate of 10% has been applied to the estimates of cover.

The majority of the proposed channel appears to have been aligned to follow the deepest areas between the limestone ridgelines and thereby it has largely avoided hard substratum, and hence potential BPPH. The channel alignment can be clearly seen in the habitat mapping as being located over areas mainly comprising bare sandy habitat (**Figure 9-2**). The channel does, however, intersect limestone substratum near the harbour entrance.

There are no proposed spoil grounds within State waters for the proposed Outer Harbour Development (**Figure 1-1**).

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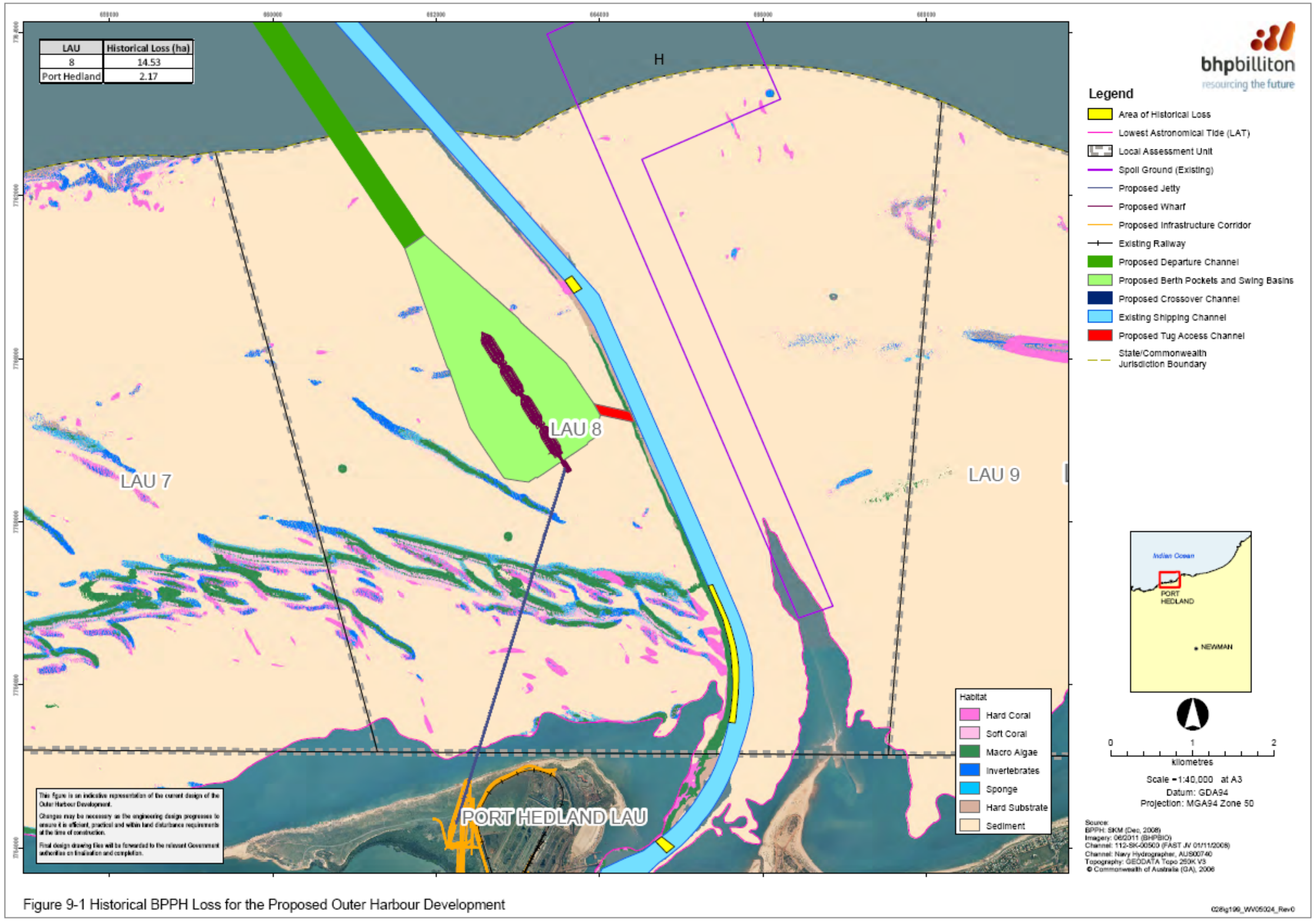
[4] Previously the Port Hedland Industrial Management Unit



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Scale = 1:40,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
BPPH: SKM (Dec, 2008)
Imagery: 06/2011 (BHPBIO)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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Figure 9-1 Historical BPPH Loss for the Proposed Outer Harbour Development

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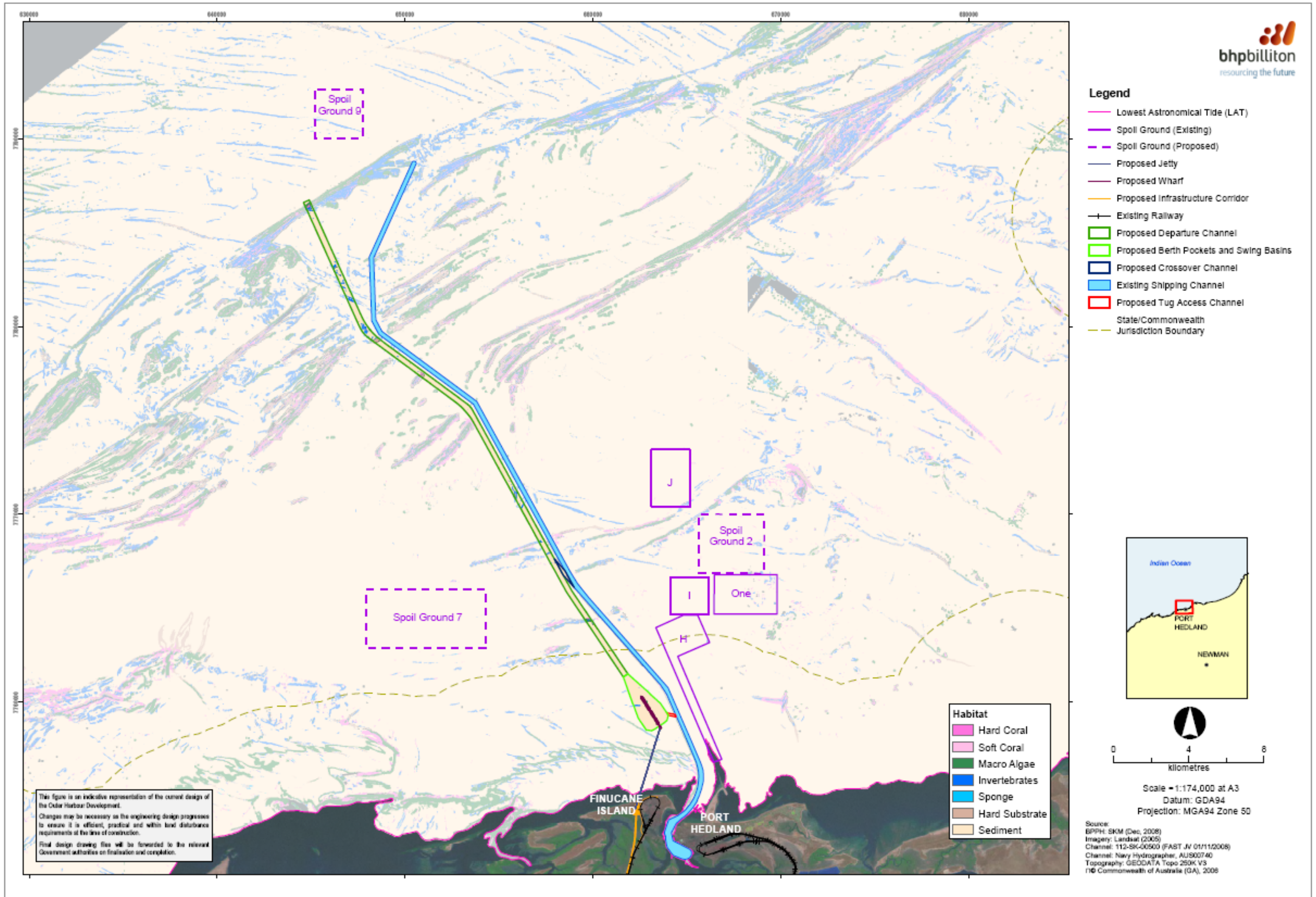
- **Figure 9-1: Historical BPPH Loss for the Proposed Outer Harbour Development**



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BPPH: SKM (Dec, 2008)
Imagery: Landsat (2005)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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Figure 9-2 Direct Losses to BPPH due to the Proposed Marine Infrastructure Footprint

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- **Figure 9-2: Direct Losses to BPPH due to the Proposed Marine Infrastructure Footprint**

9.3. Indirect Loss to BPPH due to Sedimentation

9.3.1. Water Quality Conditions in the Zone of High Impact

During the dredging and spoil placement activities, water quality conditions in the ZoHI may result in extremely elevated sedimentation rates of very coarse sediment particles in certain locations (**Section 6.5**). The fact that a large proportion of the material to be dredged (approximately 70%) is very coarse-grained, heavy particles that cannot be transported far is the main reason behind the high predicted sedimentation rates and the small areas over which this impact would occur.

The nature of the predicted water quality perturbations would be such that very coarse sediment particles would fall rapidly out of suspension in these areas close to the dredging and spoil disposal activities, and it is likely that they may remain where they fall until very strong metocean conditions are experienced (e.g. cyclone). As a result, indirect losses of BPPH are predicted to occur in the ZoHI due to elevated sedimentation rates (refer **Section 1.1**). The losses are only considered to be permanent where the sediment remains and changes the nature of the habitat, which is expected to be within approximately 1 km of the dredge footprint and spoil disposal grounds. Wherever the sediment is resuspended and continues to be moved with the prevailing currents, or where the sediment stays once settled but is similar to the pre-settlement habitat, then some of the losses within the ZoHI would be reversible whereby species from adjacent areas may recolonise the habitat. Recovery is expected to occur within a period of 5 years once suitable habitat is available and these losses would therefore not be considered permanent.

9.3.2. Indirect Losses of BPPH due to Sedimentation

Indirect Losses of BPPH due to Sedimentation in LAUs in State Waters

Indirect and irreversible loss of BPPH is predicted to occur in LAUs 6 and 8 due to elevated sedimentation rates associated with the proposed Outer Harbour Development construction dredging activities. The areas of BPPH predicted to be lost due to these indirect impacts of sedimentation are summarised in **Table 9-3.**

- **Table 9-3: Estimated Indirect Losses of BPPH (in ha and proportion (%) of the total area) in State Waters due to the Dredge-Related Sedimentation**

LAU	Total Area of BPPH (ha)*	Proposed Loss due to Smothering (ha)*	Indirect Permanent Loss (%)*	EPA Category and Loss Threshold
LAU 8	383 (±38)	27 (±2.7)	7 (±0.7)	10%
LAU 6	750 (±75)	7 (±0.7)	0.9 (±0.1)	5%
Total	-	34 (±3.4)	-	-

*****An error estimate of 10% has been applied to the estimates of cover.

Figure 9-3 illustrates the predicted irreversible losses of BPPH in LAUs 6 and 8 due to elevated sedimentation rates.

Indirect Losses of BPPH due to Sedimentation in Commonwealth Waters

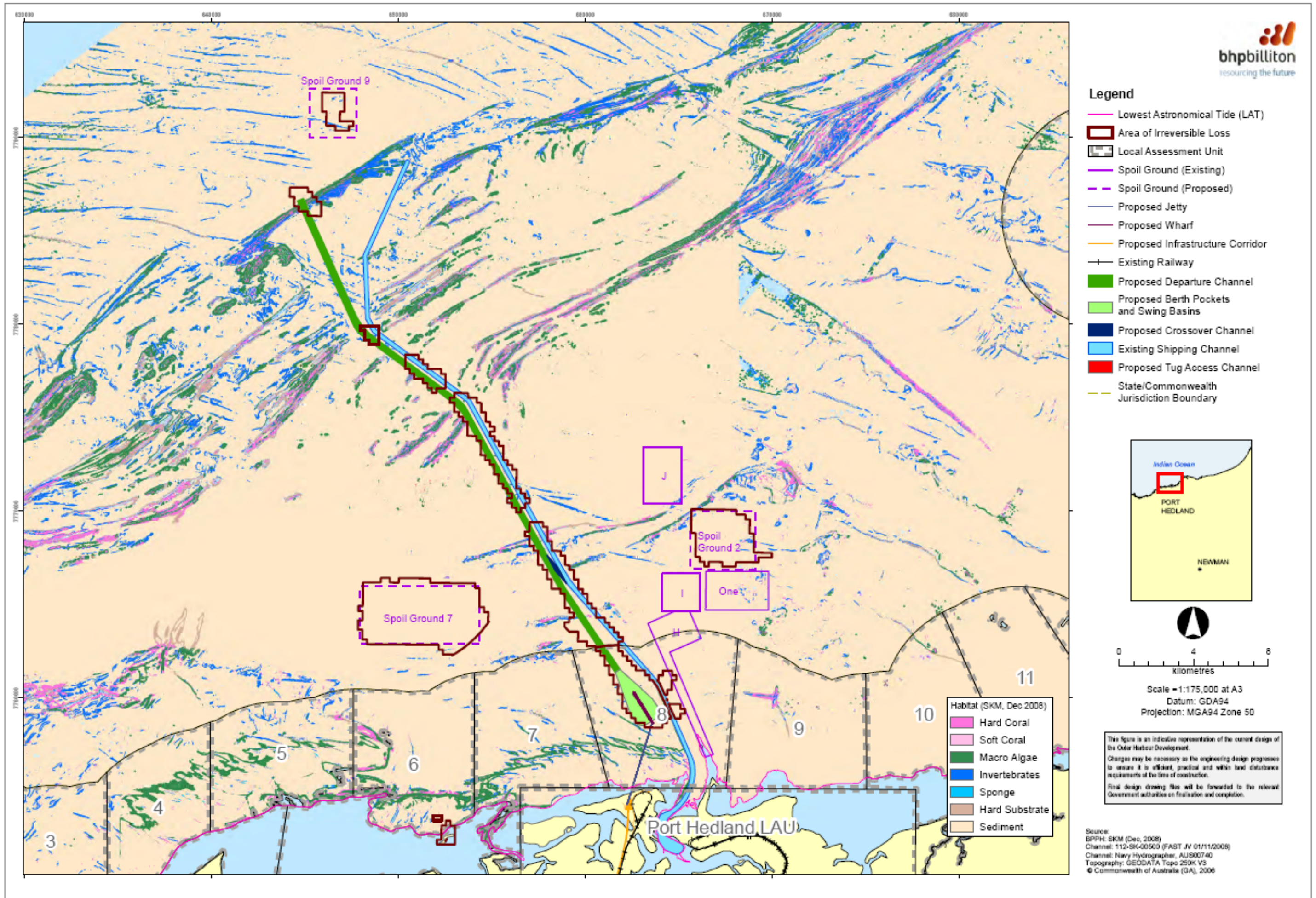
As above, indirect and irreversible loss of BPPH is predicted to occur in Commonwealth waters due to elevated sedimentation rates associated with disposal of spoil into the proposed spoil grounds and dredging of the departure channel. The areas of BPPH predicted to be lost due to these indirect impacts of sedimentation are summarised in **Table 9-3.**

Figure 9-3 illustrates the predicted irreversible losses of BPPH in Commonwealth waters due to elevated sedimentation rates.

- **Table 9-4: Estimated Indirect Losses of BPPH (in ha and proportion (%) of the total area) in Commonwealth Waters due to the Dredge-Related Sedimentation**

Total Area of BPPH (ha)*	Proposed Loss due to Smothering (ha)*	Indirect Permanent Loss (%)*	EPA Category and Loss Threshold
37,348	240 (±24)	0.7 (±0.07)	N/A in Commonwealth waters

*****An error estimate of 10% has been applied to the estimates of cover.



Scale = 1:175,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Source:
BPPH: SKM (Dec, 2008)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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Figure 9-3 Predicted Area of Irreversible Loss of BPPH due to smothering of BPPH from Elevated Sedimentation

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- **Figure 9-3: Predicted Irreversible Losses of BPPH due to Smothering of BPPH from Elevated Sedimentation Rates**

9.4. Indirect Loss to BPPH due to Decreased SI

Within the Zone of High Impact there are expected to be some losses of the most sensitive species (such as *Acropora* spp.) due to a reduction in the surface irradiance of light resulting from elevated levels of TSS during dredging and spoil disposal; however, it is expected that these losses would be of a temporary nature. Given that the habitat is likely to return to its pre-dredge state in these areas (outside of the area predicted for irreversible loss within the ZoHI for sedimentation) it is expected that recovery may occur within 5 years. This prediction is based on the biological and physical characteristics of the existing environment within this area (**Section 8.6**).

9.5. Summary of BPPH Losses

A summary of the historical losses estimated for the region, direct losses proposed for removal during construction of the marine infrastructure, and irreversible indirect losses predicted to occur due to elevated sedimentation rates, is provided in **Table 9-4**.

The total cumulative permanent loss of State subtidal habitat is therefore 48.5 (±4.8) ha, with resultant percentage losses of 17% (±1.7%) in LAU 8; 1% (±0.1%) in LAU 6 and 2% (±0.2%) in the PHIH LAU.

The total cumulative permanent loss of subtidal BPPH in Commonwealth waters is 240 (±24) ha, with resultant percentage losses of 0.7% (±0.07%).

- **Table 9-4: Estimated Cumulative Permanent Losses of BPPH (in ha and Proportion (%) of the Total Area) due to the Proposed Project**

Area*	Total Area of BPPH (ha)	Historic Loss (ha)	Estimated loss due to direct impacts of Outer harbour Development (ha)	Proposed Loss due to Smothering from Outer Harbour Development (ha)	Total permanent Loss (Historic Loss plus Losses due to Outer Harbour Development)[1] (ha)	Total permanent Loss (%)	EPA Category & Loss Threshold
State Waters							
LAU 8	383 (±38)	14.5 (±1.45)	3.8 (±0.4)	27 (±2.7)	41.5 (±4.2)	11 (±1.1)	10%
LAU 6	750 (±75)	0	0	7 (±0.7)	7 (±0.7)	0.9 (±0.1)	5%
PHIU	190	4 (±0.4)	0	0	4 (±)	2.1 (±0.2)	10%
State Waters Sub-total	89,765 (±9,000)	18.5 (±1.9)	3.8 (±0.4)	34 (±3.4)	52.5 (±5.3)	0.06 (±0.006)	-
Commonwealth Waters	37,348	0	70 (±7)	240 (±24)	240 (±24)	0.7 (±0.07)	N/A in Commonwealth waters

*****An error estimate of 10% has been applied to the estimates of cover.

[1] Total permanent loss equals the historic loss plus the loss due to the Outer Harbour Development. The area lost due to smothering from the Outer Harbour Development also includes the area lost due to direct impacts (both impacts overlap), therefore total losses due to the Outer Harbour Development are considered to be equal to the loss due to smothering.

10. Management of Impacts during Construction Dredging Activities

The management measures to be used for the minimisation of impacts to marine BPPH during the proposed Outer Harbour Development have been drawn from management plans for the project.

The management measures recommended fall into the following categories:

- Best practicable measures during design of dredging program;
- controls around dredging and disposal equipment and methods to minimise impacts to water quality; and
- location of spoil grounds to minimise impacts to BPPH supporting BPP communities.

These are detailed in the DSDMP management strategies relevant to management of marine subtidal BPPH:

- Section 6.1 Benthic Habitat Management; and
- Section 6.2 Spoil Ground Management

10.1. Monitoring of Recovery of BPP

A monitoring program would be instigated to record the status of BPPH and associated BPP within the study area. The monitoring would take the form of transect surveys at selected locations to record percentage cover and biomass of particular biota types and particle size distribution of the substratum to confirm spatial and temporal variability and the potential for recovery within a 5 year timeframe in the event of any evidence of dredge related impacts on either BPPH or BPP. The monitoring sites would be established with increasing distance from the source of impact to allow determination of recovery rates with distance from the activity in the event of any apparent disturbance from the dredging operations. Reference sites would be selected if possible, but given the large area of the Zone of Influence, the sparse presence of BPPH in State waters and the absence of suitable sites to the north west of the development site it is unlikely that a standard BACI approach can be applied. The gradient approach proposed is therefore the best solution to the lack of suitable reference sites, but confidence in the impact monitoring is higher if reference sites can be found.

Given the natural variability of the area both spatially and temporally it would be very difficult to determine an adequate effect size to monitor with a suitable level of statistical power (>0.8). The effect size is likely to be large, and the issue is further complicated by the lack of sites with high enough coverage to provide a suitable monitoring site. The majority of sites only have coverage of flora and fauna of between 7 and 14%. These issues are discussed in more detail within the DSDMP, which describes the monitoring program in detail.

10.2. Indirect Impacts to BPPH within the Zone of Moderate Impact

Indirect impacts on benthic habitats and communities from the effects of sediments introduced to the water column by dredging are discussed in this section. These impacts are predicted to occur within the ZoMI and as such all impacts discussed here are considered to be either sub-lethal or recoverable within a five-year timeframe.

The results of the interrogation of the sediment plume model for impacts from reduced surface irradiance of light indicated that the vast majority of these impacts would occur in Commonwealth waters (**Figure 10-1** and **Table 10-1**).

- **Table 10-1: Estimated Area of Indirect/Temporary Loss of BPPH (in ha and Proportion (%) of the Total Area) in the Zone of Moderate Impact in State and Commonwealth Waters**

Area	Total Temporary Loss (ha)	Total Temporary Loss (%)	EPA Category and Loss Threshold
State Waters			
LAU 1	20.7 (±2.1)	2.5 (±0.3)	N/A[1]
LAU 5	10.1 (±1.0)	1.3 (±0.1)	
LAU 6	20.3 (±2.0)	2.7 (±0.3)	
LAU 7	85.7 (±8.6)	12.5 (±1.2)	
LAU 8	64 (±6.4)	16.7 (±1.7)	
LAU 9	90.1 (±9.0)	78.4 (±7.8)	
LAU10	36.9 (±3.7)	32.1 (±3.2)	
LAU 11	5.4 (±0.5)	1.8 (±0.2)	
Commonwealth Waters	5096.8 (±509.7)	13.7 (±1.4)	N/A[2]

[1] EPA Category and Loss Threshold applies to permanent loss only

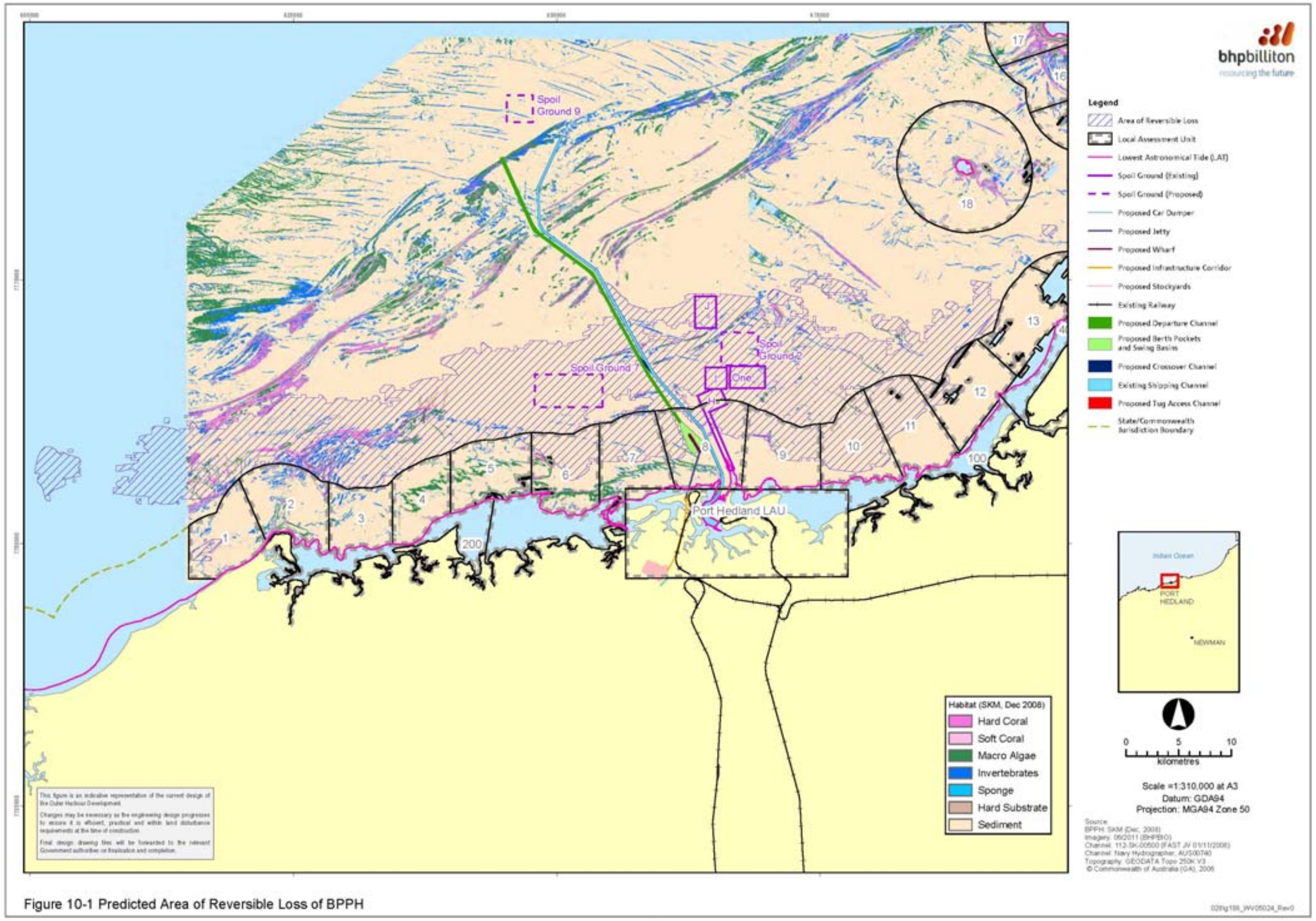
[2] EPA Category and Loss Threshold applies to permanent losses in State waters only

10.3. Water Quality Conditions in the Zone of Moderate Impact

Water quality conditions in the ZoMI would include elevated concentrations of sediment particles in suspension (i.e. increased TSS concentrations) and, where calmer water conditions are experienced, the coarser particles in suspension may fall out resulting in elevated sedimentation rates (**Figure 10-1**). These particles may then be resuspended relatively quickly and transported to other areas where the process repeats.

As detailed in **Section 6.4**, modelling of the sediment plume predicted that heavier sediment particles and a proportion of finer sediments would deposit around the dredging and disposal operations while finer sediments would deposit as thin layers, for short durations, over a wider area. In particular, daily cycles of settlement and resuspension of sediment in the broader area are likely to occur due to the strong tides and influence of waves. It is this thinner layer of sediments, deposited, resuspended and dispersed on a daily basis that is the driver of indirect impacts in the ZoMI.

Indirect impacts to the benthic ecology due to this thin layer of sediments redistributed on a daily basis would affect both benthic primary producers (BPPs) and non benthic primary producers (non-BPPs).



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Scale =1:310,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
BPPH: SKM (Dec. 2008)
Imagery: 06/2011 (BHPBIO)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
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- **Figure 10-1: Predicted Area of Reversible Loss of BPPH**

10.4. Indirect Impacts to BPPs

BPPs observed to be present at some time during the year within the ZoMI are hard corals and macroalgae. The majority of sedimentary material that may be suspended in the water column within the ZoMI would be fine (less than 64 µm) sediment particles that are easily resuspended through tide and wave action. As such, there may be times during the day when suspended materials would fall from the water column and deposit on the benthos (e.g. during slack tide) and there may be times of the day when the deposited material would be resuspended into the water column making the waters more turbid (e.g. during ebb tides). Given that tidal action is diurnal, this pattern would occur twice a day and possibly more if coincident wave conditions are energetic.

As a result of the predicted dynamic movement of fine sediment particles within the ZoMI, BPPs would experience windows of clearer water conditions, and removal of deposited sediment materials, on at least a daily basis. In addition the plume of sediment resulting from the dredging and placement activities, which would increase the concentration of TSS and increase sedimentation, is subject to strong seasonal patterns in current flows. During the wet season the predominant direction of the plume would be in a north-easterly direction and during the dry season the predominant direction is in a westerly direction.

Although the water column may be more turbid than background, and although a fine layer of silt may periodically deposit on BPPs within this zone, it is considered that the suspended and deposited material would be very mobile. This would create an environment that allows BPPs within the ZoMI to photosynthesise. Due to this regular opportunity to photosynthesise, together with the factors discussed in **Section 9** above, there are not predicted to be any irreversible losses due to turbidity and sedimentation predicted for BPPs in the areas demarcated by the ZoMI.

10.5. Indirect Impacts to Non-BPPs

As for BPPs, non-BPPs may experience increased sedimentation rates. The non-BPP assemblage in the State and Commonwealth waters of the proposed Outer Harbour Development comprises sessile invertebrates including sponges and soft corals. The non-BPP community are predominantly filter feeders.

Elevated suspended solids in the water column and increased sedimentation rates have the potential to impede filter feeding activity with an overload of suspended material. For example, mussels under such conditions may close up and avoid feeding until improved conditions return. When the water quality perturbation occurs over extended durations (e.g. days) this can reduce the feeding opportunities that mussels would otherwise undertake. For sponges that do not have the opportunity to shut down under such conditions, an overload of filtered material results.

As described in **Section 6**, the nature of the increase in suspended material and sedimentation rates is such that the material would be primarily fine particles and may be resuspended and redistributed on at least a twice daily basis. As such, sessile invertebrates comprising the majority of the non-BPP community may have a period of respite during the change of tide when material would be lifted and moved relieving any sedimentary cover they are experiencing, and during slack tides the concentration of suspended material would temporarily reduce. It is this daily dynamicity in suspended solid concentrations and sedimentation conditions that would allow non-BPPs to survive within the ZoMI.

10.6. Indirect Impacts to EPBC Listed Marine Fauna

The loss or reduction in quality of habitat may reduce the foraging and breeding areas available for marine fauna. The inability to find habitat easily or in familiar areas may reduce fitness in foraging animals, while lost quality or availability in breeding habitat may reduce reproductive success.

Turtles are considered to be the most sensitive marine fauna. Flatback Turtles use localised and distinct habitats in the Port Hedland area for nesting. Although juvenile and adult turtles utilise habitat within the project area for foraging and breeding, regionally significant areas occur beyond the project area (Pendoley Environmental 2009). The areas of BPP within the ZoHI are sparse and patchy, and hence are considered limited foraging habitat for turtles.

Although seagrass species suitable for foraging dugongs are known to occur in the Port Hedland region, the extent of these seagrasses is not considered adequate to support permanent populations.

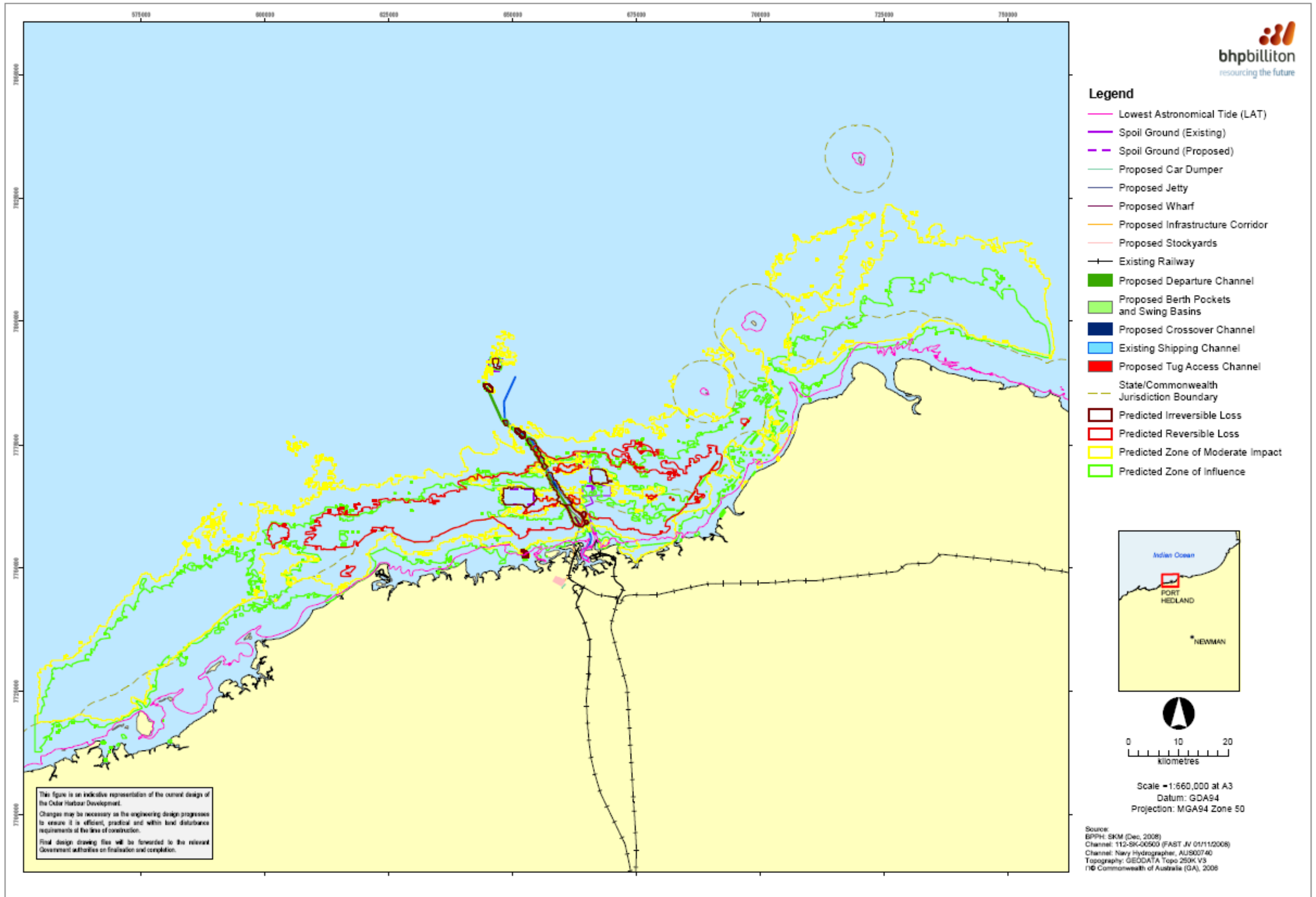
There is no recognised feeding or breeding areas for whales in the immediate vicinity of Port Hedland Harbour.

Impacts to EPBC listed species are further detailed in Chapter 10 of the PER/EIS.

10.7. Summary of BPPH Impacts

The benthic communities within the ZoMI may experience reduced surface irradiance of light and sedimentation rates (**Table 10-1**); however, it is due to the frequent (twice-daily) resuspension and redistribution of sedimentary material that would provide temporary relief from deposited and suspended materials.

It is due to this frequent relief of deposited fine sedimentary material within the ZoMI that results in the prediction that BPPs and non-BPPs would not suffer indirect losses in this zone, and at most, sub-lethal impacts such as reduced photosynthetic activity, increased mucus production and decreased filtration rates may occur.



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Scale =1:660,000 at A3
Datum: GDA94
Projection: MGA94 Zone 50

Source:
BPPH: SKM (Dec, 2008)
Channel: 112-SK-00500 (FAST JV 01/11/2008)
Channel: Navy Hydrographer, AUS00740
Topography: GEODATA Topo 250K V3
© Commonwealth of Australia (GA), 2006

Figure 10-2 Predicted Zones of Impact for the Outer Harbour Development

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■ **Figure 10-2: Predicted Zones of Impact for the Outer Harbour Development**

11. Benthic Habitat Loss Assessment Summary

Outcomes of the assessment of impacts to marine BPPH due to the proposed Outer Harbour Development, and a summary of the information underpinning the assessment, are provided below.

11.1. Irreversible BPPH Losses

The areas of estimated loss occur within and in close proximity to the dredging activities. Physical seabed disturbance from dredging would result in the removal and direct loss of 3.8 (±0.38) ha of BPPH within State waters (in LAU 8; **Table 9-4**) and 70 (±7) ha in Commonwealth Waters. In addition, smothering of BPPH due to elevated sedimentation rates is predicted to result in the loss of 34 (±3.4) ha of BPPH in State waters and 240 (±24) ha in Commonwealth waters.

The cumulative irreversible loss of BPPH from both historical and proposed losses is presented in **Table 9-4**. This level of cumulative irreversible loss is unavoidable if the Outer Harbour Development is to proceed as proposed, as the design and placement of the infrastructure footprint has minimised the potential BPPH losses.

11.2. Ecological Significance of Losses

LiDAR mapping offshore from Port Hedland indicates low relief ridgelines extending along the entire extent of the coastline from North Turtle Island in the north-east to beyond Cape Thouin in the south-west (**Figure 5-2**). The ridgelines extend well beyond the extent of the mapping, which implies a uniform ecosystem composed of parallel ridge lines extending for hundreds of kilometres.

11.2.1. Hard Corals

The ecological significance of estimated hard coral losses is minimal, based on the observations that:

- the direct losses of BPPH associated with the marine infrastructure represent a very small fraction of the total BPPH of this type in the Port Hedland region (**Table 9-2**);
- any areas in which indirect losses occur are expected to be rapidly recolonised because the supply of coral recruits through the extensive local and regional representation of this benthic community and habitat would be available;
- from a regional perspective, the species richness of coral taxa in the area affected is very low in comparison to elsewhere in the Pilbara region. In addition, these coral communities do not appear to contain endemic species and are not considered to be regionally significant coral communities with high preservation values; and
- there is little evidence of carbonate accretion onto the tops of the limestone ridges on which the coral communities are found, suggesting that the extreme metocean conditions the coral communities experience during the seasonal storms and frequent cyclones that occur in this

area may be responsible for the observed low diversity, relatively small colonies and low percent cover of coral. This is also confirmed by the low age class distribution of corals within the nearshore zone which indicates a frequent turnover of individuals.

11.2.2. Seagrasses

The impact assessment concluded that no permanent losses of seagrasses would result from the proposed Outer Harbour Development, and no impacts to the ecological significance and function of the seagrass beds would occur.

11.3. Recoverable Impacts to BPPH

The benthic communities within the ZoMI may experience increased suspended solids concentrations and sedimentation rates, however due to the frequent (twice-daily) resuspension and redistribution of sedimentary material this would provide temporary relief from deposited and suspended materials. There are also seasonal influences on the plume dispersion, which would also give temporary relief to areas.

It is due to this frequent relief of fine sedimentary material within the ZoMI that results in the prediction that BPPs and non-BPPs would not suffer indirect losses in this zone, and at most, sub-lethal impacts such as reduced photosynthetic activity.

11.4. Predicted Environmental Outcomes

Direct loss of BPPH (3.8 ha (±0.38); 1% of LAU 8) would be removed during construction of the marine infrastructure, and indirect loss of BPPH due to elevated sedimentation rates is predicted to also occur close to the dredging activities (27 (±2.7) ha of LAU 8; 7 (±0.7) ha of LAU 6). When accounting for historical losses in the PHIH LAU (4 ha) and in LAU 8 (14.5 ha) this amounts to a cumulative loss of BPPH within State waters for the proposed Outer Harbour Development of 42.5 ha of BPPH, primarily due to indirect losses arising from sedimentation in the ZoHI. The predicted indirect losses due to increases in sedimentation rates would not cause the loss of the underlying hard substratum on which BPPs grow.

The ecological significance of the losses of BPPH arising from the proposed Outer Harbour Development is considered to be minimal. Hard corals were the most dominant BPP growing along the ridgelines that would be affected by dredging activities, and the dominant corals present are from the genus *Turbinaria* and from the families Faviidae and Poritidae. Based on the low species richness and abundance of corals and dominance of *Turbinaria*, coral communities that inhabit subtidal habitats in the Port Hedland region are high turbidity, high sedimentation adapted communities. In addition, the species and habitats affected are considered typical of the broader marine environment of the Pilbara region, and no new species have been recorded.

No losses or impacts to seagrasses recorded within the proposed Outer Harbour Development area are predicted.

The low level of cover of BPPH throughout the area and the adaptations of the communities and individuals to elevated turbidity and episodic disturbance events give confidence to the predictions of low levels of loss and high likelihood of recoverability. The species present are often opportunistic and as such have high rates of growth and fecundity that are suited to colonising disturbed habitats. The high level of variability throughout the study area both in terms of spatial and temporal distribution indicate that the recovery may occur over short temporal scales. The natural turnover of corals within the study area appears to be on a timescale of approximately 5 years so it is expected that the communities present would recover to pre-dredge levels within this period.

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Appendix A Appendix A Hard Coral Cover and Size- Frequency Distribution Technical Note

Technical Note

Date	22 September 2011
Project No	WV05024
Subject	**Outer Harbour Development – Hard Coral Cover and Size-Frequency Distribution**

1. Introduction

The subtidal area of State waters potentially affected by the proposed Outer Harbour Development dredging and spoil disposal activities is dominated by coarse mobile sediments with areas of hard substratum (SKM 2009). These areas of hard substratum are either outcropping or covered by a thin veneer of sediment, and there is evidence they may be routinely buried, uncovered, and reburied in response to movements of sediments in response to drivers operating on different spatial and temporal scales including tides, seasonal prevailing winds and periodic storms and cyclones.

The Benthic Primary Producers (BPP, predominantly algae, hard coral and photosynthetic soft corals) and non-BPP (predominantly sponges, non-photosynthetic soft corals and other sessile invertebrates) present within State waters are mainly associated with areas of hard substratum where they comprise a mixed mosaic habitat of low percent cover. The composition of this mixed mosaic exhibits considerable variability through time with seasonally abundant BPP such as macroalgae sometimes evident, but with no one type of biota exhibiting persistently high percentage coverage. Sediment associated BPPs (e.g. seagrass) are spatially and temporally less common (SKM 2009).

Impacts from dredging activities are predicted to result from both increased sedimentation and elevation in suspended sediment levels over hard and soft substrates. The scale of the impacts has been predicted to range from irreversible loss of the benthic community under the infrastructure footprint and within the spoil grounds to reversible (temporary) loss of organisms through smothering and suspended sediment mediated light attenuation. Irreversible losses from the construction of infrastructure and the disposal of dredge spoil are relatively easy to predict based upon the area of these footprints. Reversible losses are less easy to predict and will likely be less reliable as such losses depend upon the intensity, duration and frequency of plume-driven sedimentation/turbidity events and the responses of organisms at the species and individual level.

Hard corals are likely to be the most sensitive BPP within State waters affected by dredging activities. The dominant corals present are from the genus *Turbinaria* and from the families Faviidae and Poritidae (SKM 2011). The dominance of *Turbinaria* spp. and overall low species richness and abundance (0-21.6% from SKM ground-truthing surveys) of corals within subtidal State waters in the Port Hedland area suggest that these coral communities experience, and are adapted to, high turbidity and sedimentation rates. This type of coral community is considered typical of the broader marine environment of the Pilbara region, and is also similar to other *Turbinaria* dominated coral communities in macrotidal, turbid waters elsewhere in northern Australia. No new species have been recorded from surveys in the area (SKM 2011).

Whilst the diversity and abundance of the coral community within subtidal State waters around Port Hedland has been characterised (SKM 2011), there has been little focus on the size-frequency distributions of coral colonies. This type of information can provide insight into the age structure of coral colony populations, which can help predict the recovery time of a coral population in the event of an impact, and provide insight into the frequencies and scales of natural disturbances causing mortality among corals in the region. This has particular relevance to the Environmental Protection Authority (EPA) Environmental Assessment Guideline (EAG) No. 3 (2009) with respect to impacts to BPP.

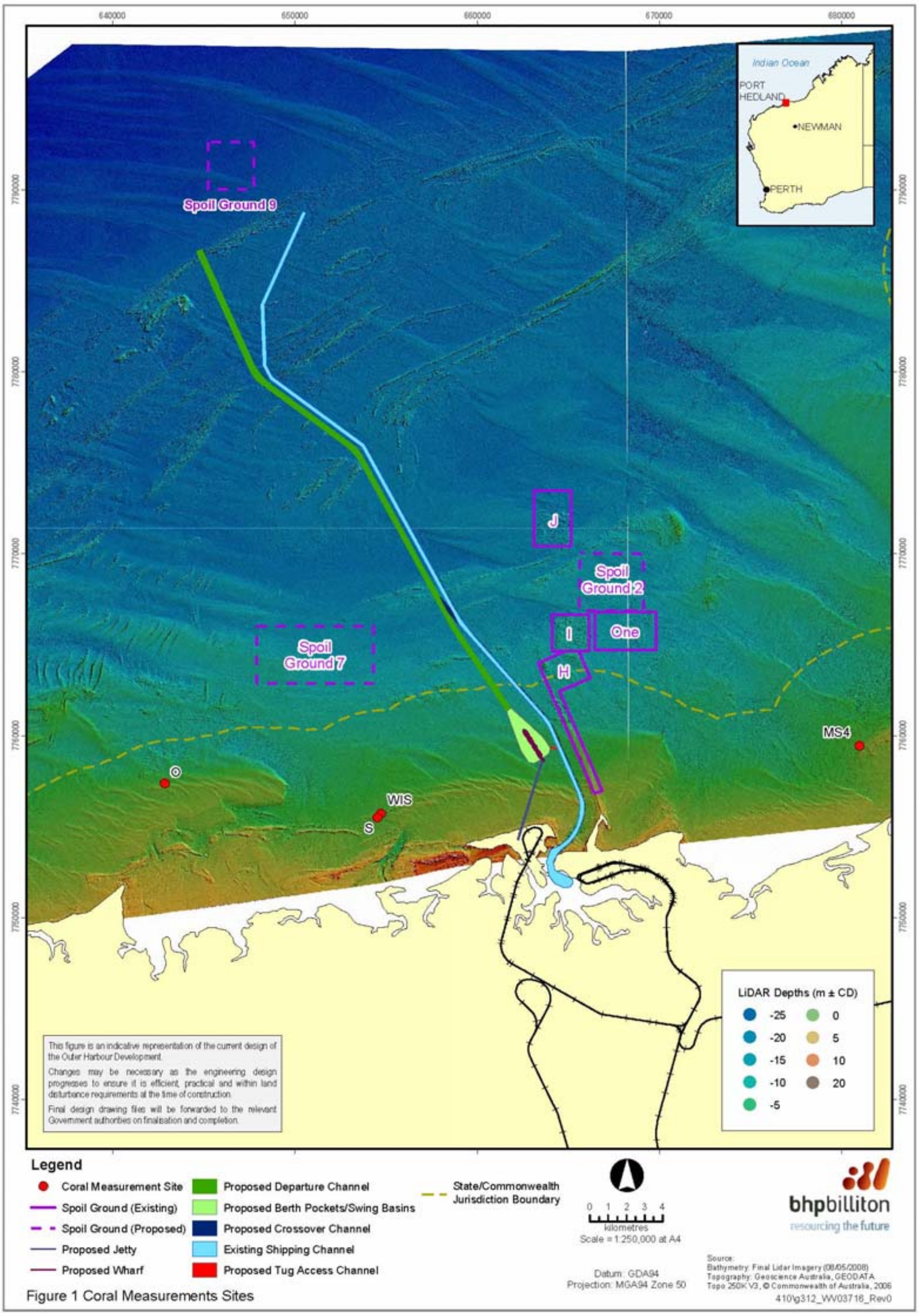
This technical note provides a summary of *Turbinaria* spp. size (diameter)-frequency distributions obtained by analysing images collected from past SKM surveys of subtidal habitats within Port Hedland State waters. This technical note aims to provide the following:

- Aid in the development of the BPP monitoring and management approach to be applied to the Outer Harbour Development;
- Relate size-frequency distribution to coral age and turnover rates;
- Estimate recovery times for *Turbinaria* spp.-dominated communities; and
- Describe relationships between colony size and health.

2. Method

Turbinaria spp. size-frequency distributions were determined using data collected from two separate sources of coral images:

- Diver surveys of permanent transects at the Weerdee Island (WIS) baseline coral monitoring site (SKM 2011); and
- Remotely operated towed video surveys at three sites monitored as part of a Subtidal BPPH Monitoring Pilot/Baseline Study (refer to Figure 1).



This figure is an indicative representation of the current design of the Outer Harbour Development.

Changes may be necessary as the engineering design progresses to ensure it is efficient, practical and within land disturbance requirements at the time of construction.

Final design drawing files will be forwarded to the relevant Government authorities on finalisation and completion.

Datum: GDA94
Projection: MGA94 Zone 50

Source:
Bathymetry: Final Lidar Imagery (08/05/2008)
Topography: Geoscience Australia, GEODATA
Topo 250K V3, © Commonwealth of Australia, 2006
410\g312_WV03716_Rev0

- **Figure 1 Coral Measurement Sites**

2.1 Weerdee Island (WIS) Permanent Transect Images

In May 2008, a coral health and water quality monitoring site Weerdee Island (WIS) was established in State waters to support environmental investigations for the Outer Harbour Development.

Three permanent transects of 10 m each were installed at WIS in an effort to determine changes in the overall composition of sessile biota and recruitment of new corals. A tape measure was spread between the endpoints of each transect. Photographs were taken of the area within a 0.25 m^2 quadrat, positioned at 1 m intervals by divers. Photographs have been utilised for the current study from six monitoring occasions:

- September 2008
- October 2008
- January 2009
- February 2009
- May 2009
- December 2009

The diameter of every *Turbinaria* spp. colony seen on these images was measured using the software program Coral Point Count with Excel extensions (CPCe). To enable measurements to be taken each image was calibrated using the increments of the tape measure visible in each of the images. Two measurements for each colony were taken, a short diameter and a long diameter which was then averaged to account for morphological differences in the shape of the colonies.

A conversion calculation was performed on the mean diameter of each colony to account for the angle of growth of *Turbinaria* spp. colonies. For this, an angle of growth of 36.4° was assumed based on data for *Turbinaria mesenterina* collected by Willis (1987). This was calculated by averaging the angle of growth for 5-10 cm *T. mesenterina* (37.4°) and 10-20 cm diameter *T. mesenterina* (35.6°).

Data were then organised by grouping the size data for coral colonies into 4 cm size classes. This was chosen as an increase in diameter of 4 cm equates approximately to 1 year of growth as shown by Willis (1987), who found average annual linear growth rates (increase in coral radius) for *Turbinaria mesenterina* of 1.73 cm for 5-10 cm corals and 1.94 cm for 10-20 cm corals. Given that these measurements were taken from a 4 m deep site from Magenetic Island, Queensland, which is at a similar depth and latitude, and has similar water temperature, to the

Port Hedland sites studied here, the use of these growth rates was deemed appropriate. Size/age frequency distributions and cumulative frequency distributions were created for each month from this data (**Section 3.1**).

In addition to recording diameter measurements, information on potential damage to *Turbinaria* spp. colonies through smothering of sediment, sponge or algae was recorded. When noted, the percent coverage of the colony was recorded as was the type of covering. This information was then plotted as the proportion of each size/age class affected and as a scatter-plot of size class versus percent of coverage for each type of covering (i.e. sediment, sponge, algae).

2.2 Towed Camera Survey Images

A pilot study using a remotely operated towed video camera was undertaken during Juneto August 2011 at three Port Hedland sites within State waters to the west of the proposed dredging footprint. This study was aimed at determining if this technique could be suitable for monitoring change in percent cover of biota classes over time as an alternative to diver-based monitoring methods. Video footage was collected over 30 transects of 50 m length at each site during each month and this footage then split into 60 discrete images per transect for habitat classification.

Images from two of these sites, Site S and Site O collected during June 2011 have been used for the purpose of taking *Turbinaria* spp. colony measurements. Site S is located close to, and on the same ridgeline, as the WIS monitoring site. June 2011 images were chosen as there was less canopy algae present during this month, which had the potential to obscure *Turbinaria* spp., particularly smaller colonies (i.e. <5 cm).

In addition, images from site MS4 were also used, which was briefly ground-truthed during August 2011 as a potential monitoring site for further baseline towed video monitoring. Footage was collected along transects of 100-200 m and split into discrete images.

As with the images from the permanent transects at site WIS, *Turbinaria* spp. diameter measurements were taken using CPCe. However for these images there was no reference scale (i.e. tape measure) present on the images to calibrate length measurements. To account for this, it was assumed from previous experience with the equipment, that the camera collected images at a position between 50 cm and 100 cm from the seabed at sites S and O and between 50 cm and 75 cm at site MS4. Based on these assumptions a calibration of the field of view was conducted with the camera above water at these distances from a known scale (ruler). From this calibration it could be determined that at 50 cm, images comprise 18.5 pixels cm^{-1}, at 75 cm they comprise 15.0 pixels cm^{-1}, whilst at 100 cm images comprise 11.5 pixels cm^{-1}. Using these calibration factors, measurements were taken in CPCe for the first 100 coral colonies encountered from images at sites S and O. This meant that images were taken from 6 transects at site S and 7 at site

O. For the site MS4, the first 200 coral colonies were measured to ensure that images were used from two transect in order to achieve a better representation of corals at the site.

Before a conversion of coral measurements was undertaken, to account for the angle of growth of corals, a conversion to account for the magnification of coral sizes due to water refraction was needed for these images. This was needed since the calibration of the images was performed above water but the calibration factor was used for images collected underwater. A magnification factor of 1.3x was assumed for this correction. This correction was applied by dividing the measured diameters by this amount, which reduced the diameter measurements since coral sizes appear larger on the images underwater than they would above water.

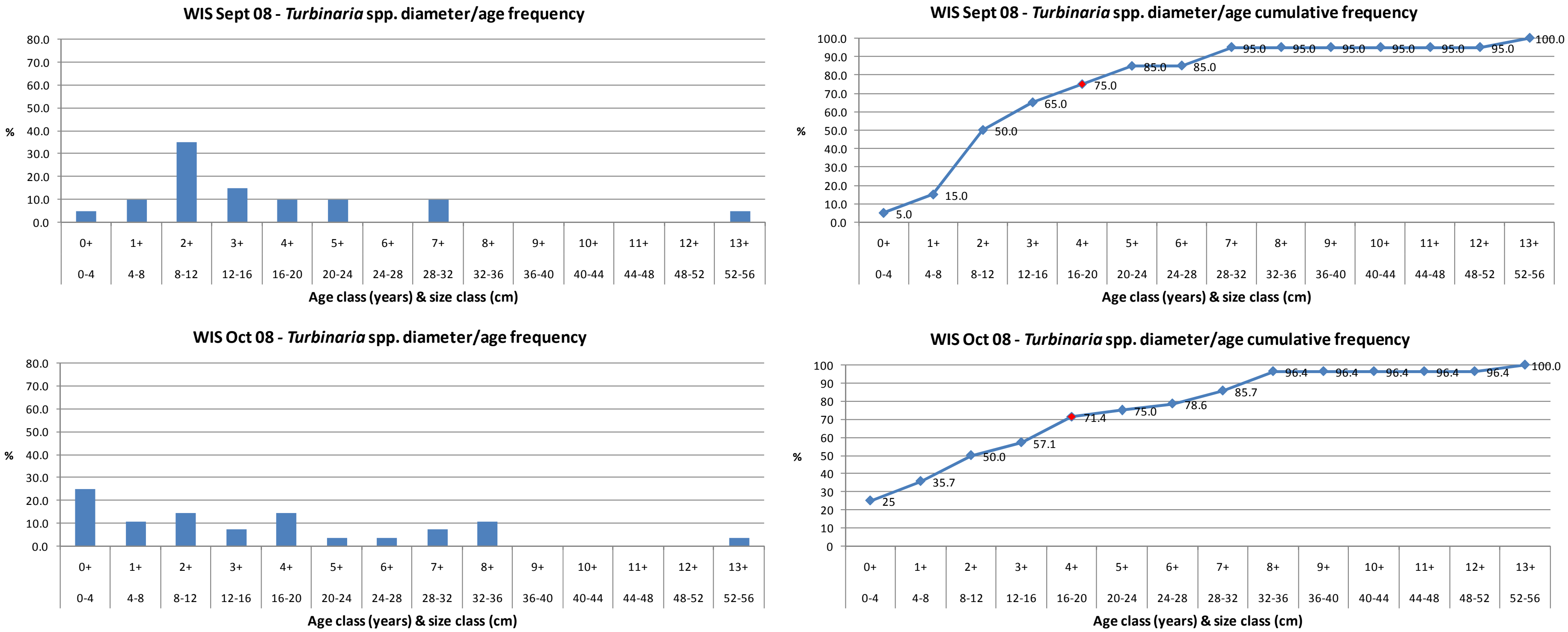
3. Results

3.1 Weerdee Island (WIS) Permanent Transects

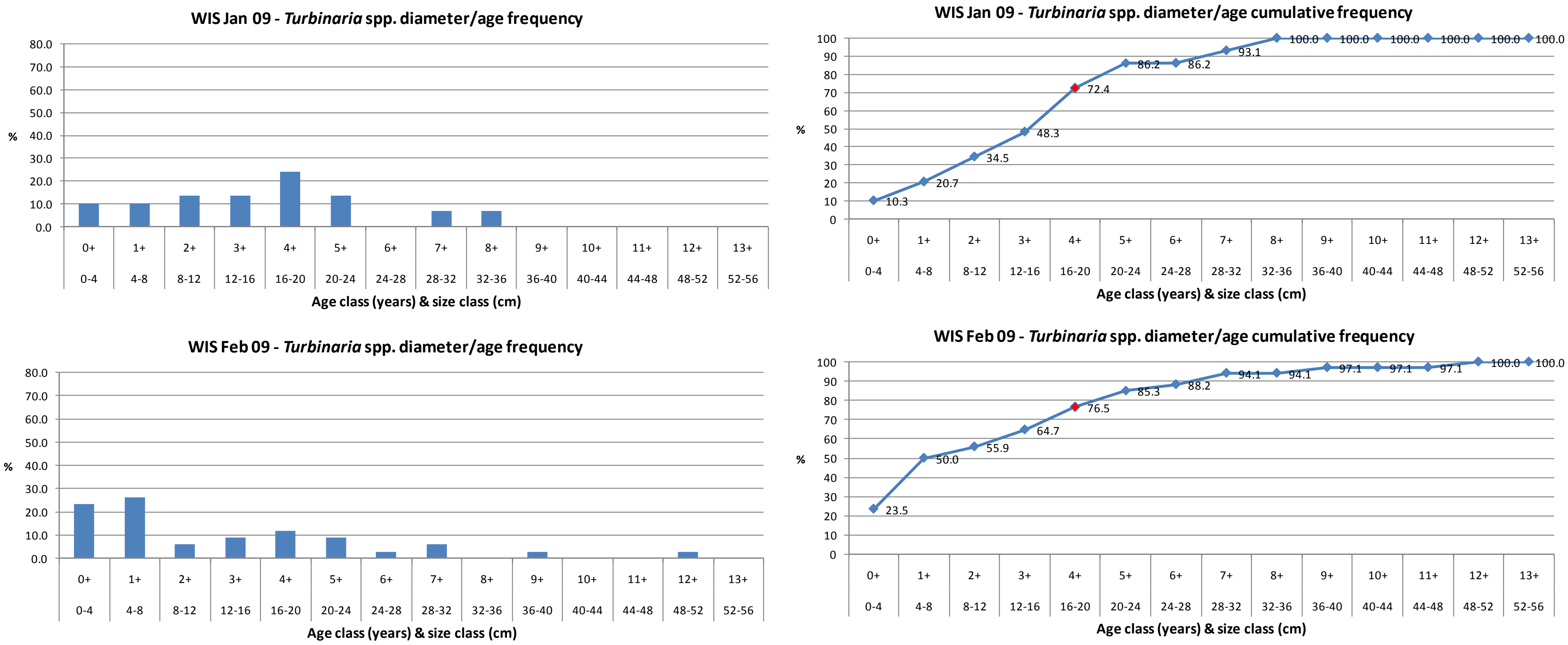
Turbinaria spp. diameters ranged between 0 and 56 cm, which represents colonies up to 14 years of age. With the exception of a few individuals within this 13+ age class all corals were <10 years of age (**Figure 3-1** to **Figure 3-3**). For all but one month, at least 50% of all colonies measured were <12 cm diameter or <3 years of age, whilst the proportion of corals aged <5 years ranged from 71.4 to 92.3%.

The dominant age class was typically 0+ or 1+ years, although 2+ age class corals were the most common age class observed in September 2008 and 4+ age class corals were the most common observed in January 2009 (**Figure 3-1** to **Figure 3-3**). The presence of macroalgae likely hampered the ability to locate the smaller age classes and potentially led to overestimation of larger size classes for these months. For all months, except May 2009 and December 2009, individual age classes contributed <40% each to the total colony abundance. In May and December 2009 the *Turbinaria* spp. community was dominated by the 0+ age class which comprised *ca* 70 and 60% of all colonies, respectively.

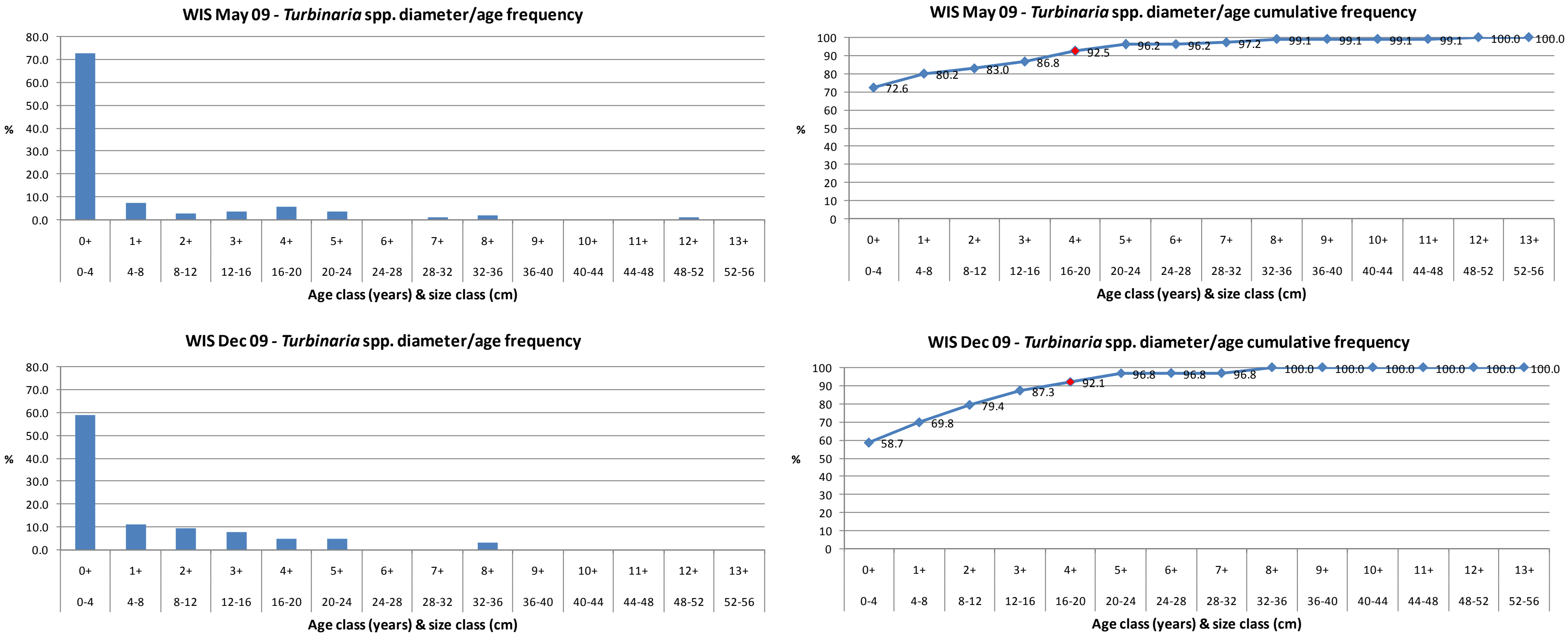
Smothering of *Turbinaria* spp. colonies by sediment or biota was recorded at this site. Smothering of colonies was observed within all age classes <6 years, with the proportion of colonies smothered generally increasing up to the 4+ age class of which *ca* 35% of colonies were affected (**Figure 3-4**). The type and percent coverage of smothering was dependent upon the size class of the colony. Smaller colonies <8 cm diameter, which roughly equates to colonies <2-years of age, were usually partially covered by sediment. Colonies >8 cm, which were ≥2 years of age were typically overgrown by algae or sponge. In the case of sponge growth, these larger colonies were usually completely overgrown (100% smothered, **Figure 3-5**).



- **Figure 3-1. Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp colonies at WIS during September and October 2008**



- **Figure 3-2 Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp colonies at WIS during January and February 2009**



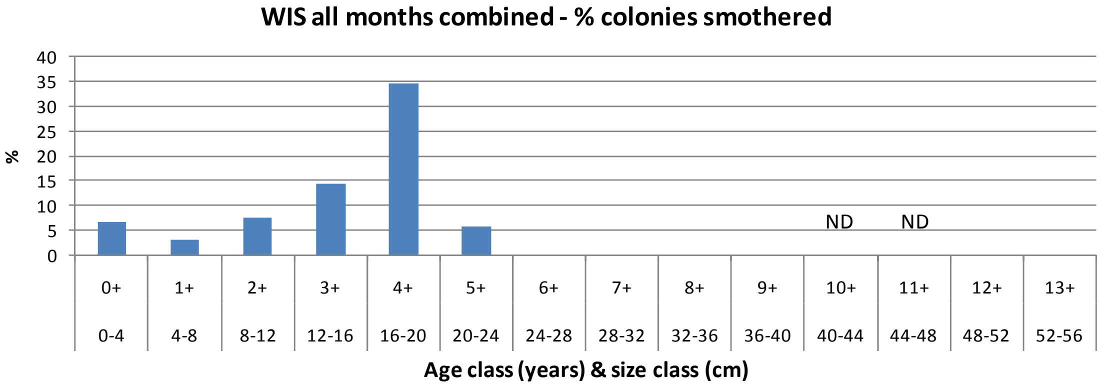
WIS May 09 - *Turbinaria* spp. diameter/age frequency

WIS May 09 - *Turbinaria* spp. diameter/age cumulative frequency

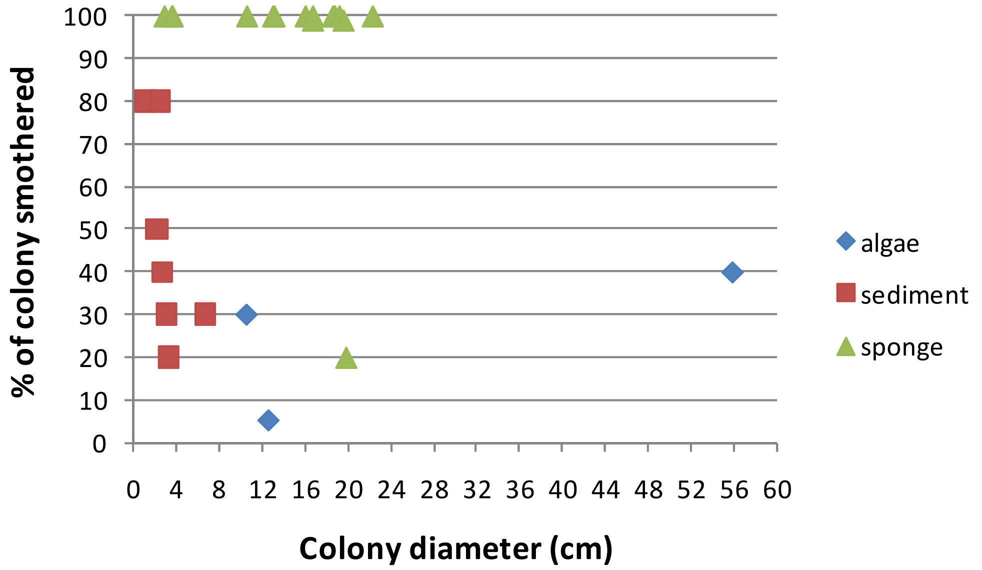
WIS Dec 09 - *Turbinaria* spp. diameter/age frequency

WIS Dec 09 - *Turbinaria* spp. diameter/age cumulative frequency

- **Figure 3-3 Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp colonies at WIS during May and December 2009**



- **Figure 3-4 Proportion of colonies in each size/age class smothered by sediment, sponge or algae. ND= no data**



- **Figure 3-5 Percent of *Turbinaria* sp. colony smothered vs colony size (diameter) for 25 affected colonies at site WIS**

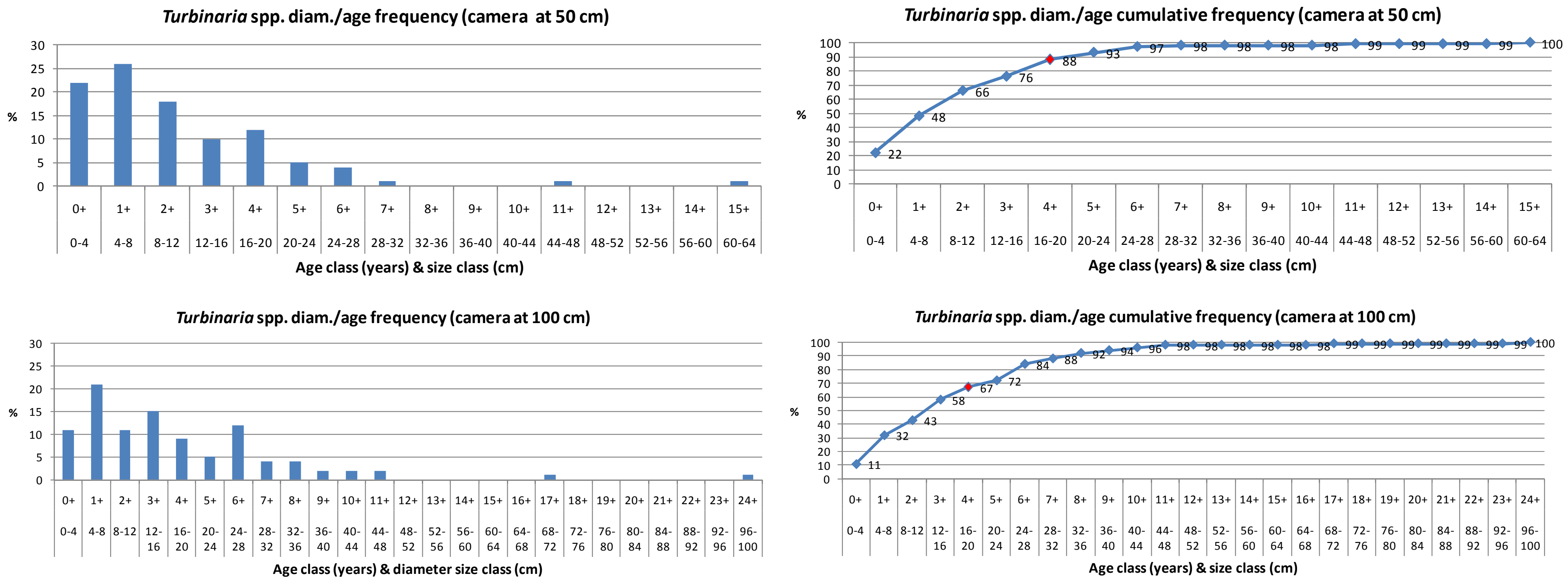
3.2 Towed Video Transects at sites S, O and MS4

The age structure of *Turbinaria* spp. colonies differed among sites but showed some broadly consistent patterns. At least *ca* 90% of all corals were <10 years of age at each site and the 0+ or 1+ age classes were always the most dominant within the community in terms of abundance (**Figure 3-6** to **Figure 3-8**). The percent contribution of age classes then decreased more or less progressively from the 1+ age class onwards.

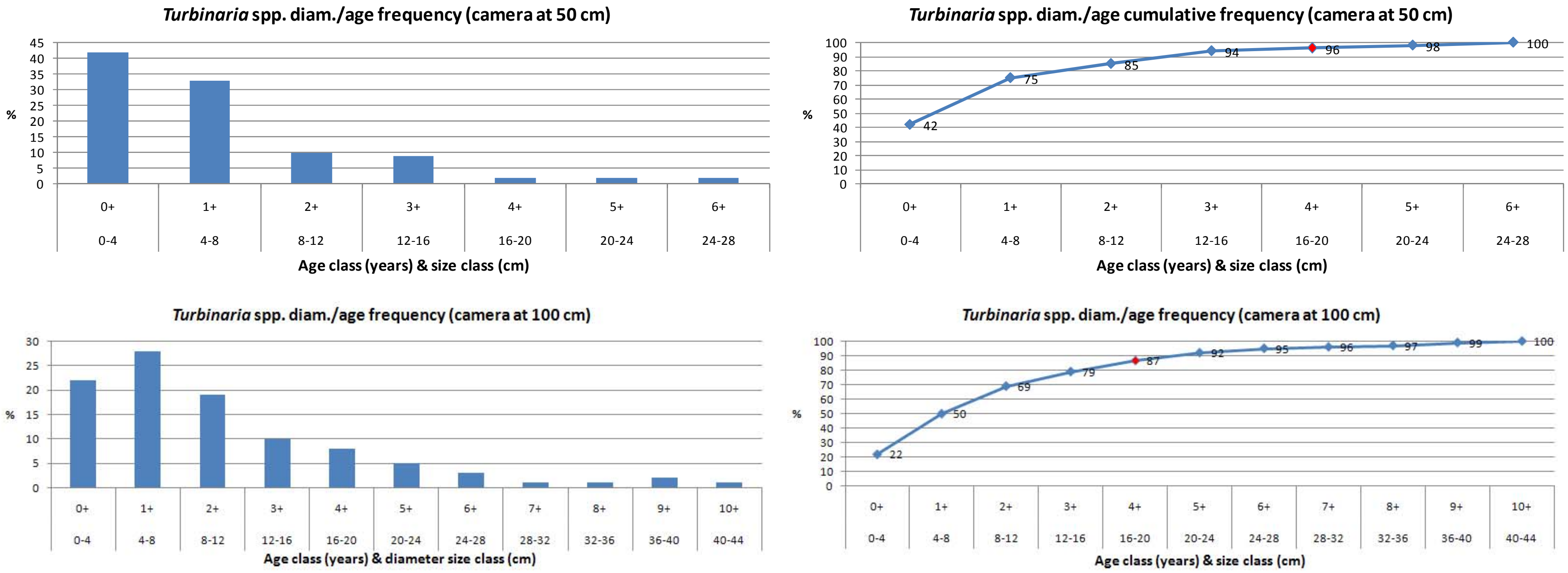
The *Turbinaria* spp. community at site O was the youngest of the three sites with 50-75% of the community <2 years of age and between 87 and 96% of the community <5 years of age (**Figure 3-6**). The oldest colony observed here was likely between 6 and 11 years of age.

The *Turbinaria* spp. community at site S was older than that at site O with 32-48% of the community <2 years of age and between 67 and 88% of the community <5 years of age (Figure 3-7). The oldest colony observed here was likely between 15 and 25 years of age.

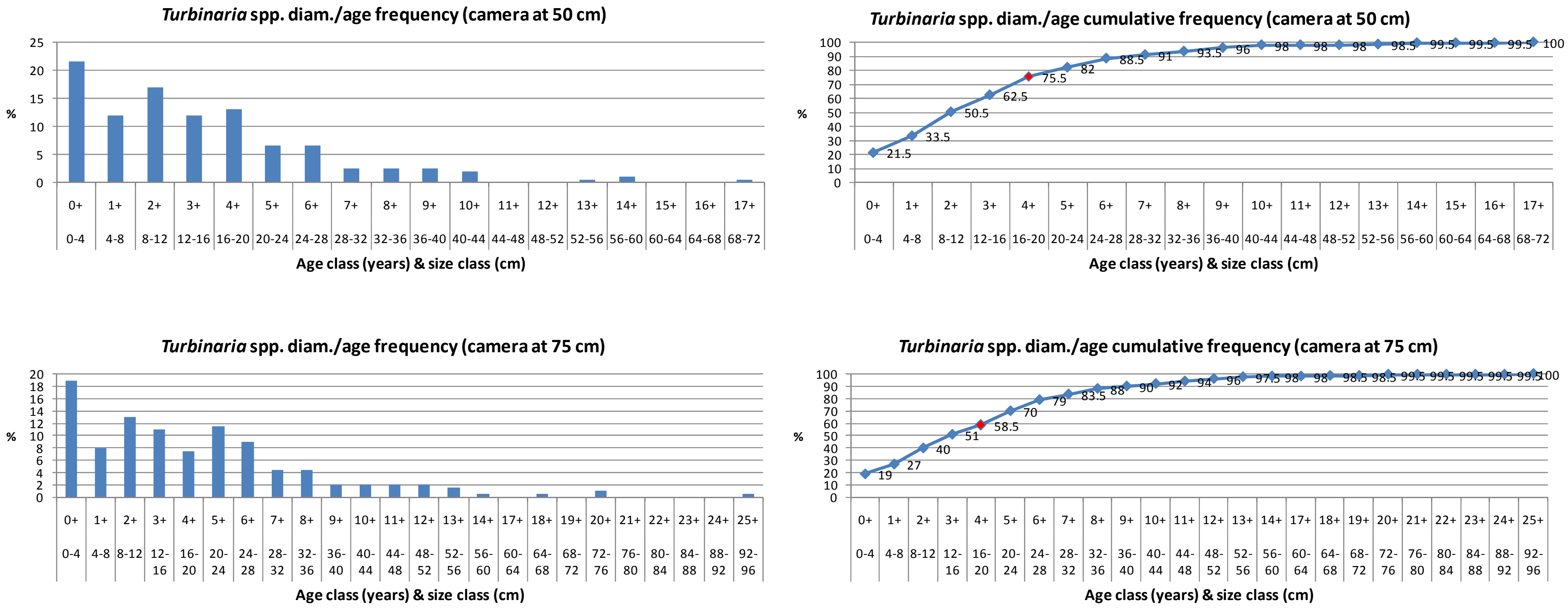
The *Turbinaria* spp. community at site MS4 was the oldest observed with 27-33.5% of the community <2 years of age and between 58.5 and 75.5% of the community <5 years of age (Figure 3-8). The oldest colony observed here was likely between 17 and 24 years of age.



- **Figure 3-6 Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp. colonies at site S during June 2011 assuming camera 50 cm (top) and 100 cm (bottom) above seabed**



- **Figure 3-7 Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp. colonies at site O during June 2011 assuming camera 50 cm (top) and 100 cm (bottom) above seabed**


Turbinaria spp. diam./age frequency (camera at 50 cm)

Turbinaria spp. diam./age cumulative frequency (camera at 50 cm)

Turbinaria spp. diam./age frequency (camera at 75 cm)

Turbinaria spp. diam./age cumulative frequency (camera at 75 cm)

- **Figure 3-8 Diameter/age frequency and cumulative frequency graphs for *Turbinaria* spp. colonies at site MS4 during August 2011 assuming camera 50 cm (top) and 75 cm (bottom) above seabed**

4. Discussion

Turbinaria spp. communities from the sites examined here exhibited age structures that were strongly skewed toward younger colonies, particular the 0+ and 1+ age classes. Coral communities that are susceptible to disturbance (i.e. cyclones, outbreaks of predators or disease) tend to have age and size-frequency distributions that are skewed towards earlier successional stages (Done 1999). The age structures observed here suggest regular successful annual recruitment of the 0+ age class at each site; this cohort dominates the community, in terms of abundance, for up to two years but then reduces in number over time due to mortality. The extremely high number of the 0+ age class observed at site WIS in May and December 2009 highlights this annual recruitment.

Observations of *Turbinaria* spp. colonies from the Port Hedland region suggest that mortality is likely driven in part by sedimentation in combination with overgrowth by other biota, e.g. sponges or algae, whilst physical damage from cyclonic events is also likely to occur. *Turbinaria* spp. colonies from the sites studied here were often observed protruding from apparently deep sediment, indicating the movement of a sand sheet over previously exposed hard substratum. Data presented from site WIS showed smothering of sediment to be more prevalent in younger age classes of ≤2 years of age, whilst smothering by other biota including algae, and in particular sponges, was observed in older age classes. It is difficult to infer whether smothering by biota occurs on live coral colonies or whether it occurs after mortality caused by other factors, such as disease, sedimentation or stress (i.e. thermal stress or reduced light availability). It is likely that younger age classes are more susceptible to smothering by mobile sand sheets due to their reduced height above the limestone pavement.

The differences in age structure observed at the three sites surveyed by towed video shows that there is likely a high level of spatial variability in the disturbances that lead to *Turbinaria* spp. mortality in the subtidal State waters of Port Hedland. Site O, which was the furthest from the shoreline, supported a comparatively young community of *Turbinaria* spp. This site is characterised by a relatively low relief with a veneer of coarse sediment overlying much of the limestone pavement. Such a site may be more susceptible to movement and smothering from sand sheets in response to tidal currents and storm events.

While the age structure of the coral communities studied here highlights their history of disturbance, it is more difficult to predict how long it would take communities at these sites to recover from a major disturbance and what this recovered community would look like. For the sites studied here there is evidence that the majority of age classes (58.5 to 96% depending upon the specific site) could return after 5 years in the event of complete mortality, provided that larval supply of new recruits and the availability of hard substratum for settlement remained at similar levels. It is considered likely that even in the event that all age classes could successfully return following such an event, the proportion of colonies within each age class, and the total number and percent cover of colonies may differ given the stochastic nature of major natural disturbances such as storms and cyclones. Such temporally-variable natural events may mean that the coral communities within State waters of Port Hedland never reach a constant stable state but instead exhibit flexible percent cover and age structure states over time.

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