Port Hedland Outer Harbour Development

BENTHIC PRIMARY PRODUCER ASSESSMENT: INTERTIDAL

- PREP-1210-G-12108
- Revision 2
- 14 February 2011

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Limitation

The sole purpose of this report and the associated services performed by Sinclair Knight Merz (SKM) is to provide an assessment of potential environmental impacts upon intertidal Benthic Primary Producer Habitats and associated Benthic Primary Producers from the proposed Port Hedland Outer Harbour Development in accordance with the scope of services set out in the contract between SKM and BHP Billiton Iron Ore (‘the Client’). That scope of services was defined by the request of the Client.

SKM derived the data in this report from a number of primary sources including the relevant scientific literature, previous work undertaken for earlier project approvals and field survey work undertaken by an expert survey team. The passage of time, manifestation of latent conditions or impacts of future events may require further exploration of the study area and subsequent data analysis and re-evaluation of the findings, observations and conclusions expressed in this report.

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Executive Summary

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 Outer Harbour Development will increase export capacity and will include dredging and the development of a new jetty/wharf structure, berths and shiploading infrastructure. The terrestrial works include the development of a rail spur and loop from the existing BHP Billiton Iron Ore rail line, the construction of iron ore stockyards at Boodarie, a conveyor corridor to transfer ore to shiploading facilities and a causeway where conveyors will cross West Creek to Finucane Island.

This report provides the findings of an assessment of the intertidal Benthic Primary Producer Habitat (BPPH) areas that may be impacted by the proposed Port Hedland Outer Harbour development; including

- a classification of vegetation associations within the area of potential impact, based on the intertidal BPPH assessment;
- a description of the current knowledge of the ecological functions of the Benthic Primary Producers (BPP) that may be impacted by the proposed development;
- identification of expected and potential impacts on BPPH and associated BPP; and
- calculation of the historical and cumulative losses of mangrove BPPH within the relevant management unit.

The assessment concludes that the area of interest within and adjacent to the proposed corridor to Finucane Island supports a range of mangrove vegetation associations, salt marsh dominated by samphires and areas of bare tidal flat that may support cyanobacterial mats when and if suitable environmental conditions occur.

The mangrove vegetation associations, salt marsh and cyanobacterial mats present are not unusual and are representative of the broad vegetation associations recorded throughout the harbour and the wider Pilbara region.

A comparative assessment of the relative value of each BPP concludes that the mangrove areas are the key component providing major inputs into the support of ecosystem function within the Port Hedland Industrial Land Assessment Unit (LAU)[1].

The historical losses of mangrove within the Management Unit have recently been estimated by comparisons between 1963 and 2008 image sets, and because of substantial new growth of mangroves during that period, the actual historical loss of mangroves is now estimated to be just 2.2% of the 1963 total up to 2008.

Cumulative loss estimates of mangroves are then presented to include the recently approved 18.6 hectares (ha) for the Port Hedland Port Authority (PHPA) Utah Point development; 6.5 ha for the BHP Billiton Iron Ore Rapid Growth Project 5 (RGP5) and 4 ha for the BHP Billiton Iron Ore Rapid Growth Project 6 (RGP6); and 40 ha for the proposed PHPA South West Creek Dredging and Reclamation.

The footprint of the proposed corridor for the Outer Harbour Development is examined and a further 27 ha of mangroves will be lost in the worst case scenario, which would produce a cumulative loss of about 5.7% in total.

Evidence is also provided to demonstrate that the relative value of mangroves varies considerably inside the LAU, primarily as a consequence of natural environmental stresses associated with height in the intertidal zone. The value of different mangrove stands can be quantified in terms of above ground biomass (AGB) and this varies considerably between the high value stands of closed canopy forest lining the creek channels when compared with the low value scattered mangroves that occupy the uppermost limits of the areas where mangroves can survive in the intertidal zone.

The report provides a breakdown of the historical losses that have occurred by mangrove vegetation type and demonstrates that most of the historical losses have been within the scattered mangrove vegetation association that provides the least contribution to ecosystem functions.

The forecast losses associated with the proposed Outer Harbour Development include stands of high value mangrove vegetation, but are not considered to be a significant impact on the ecological functions of these mangrove vegetation associations as they are widespread in the harbour and elsewhere in the Pilbara region.

[1] Also known as the Port Hedland Industrial Area Management Unit, as identified in EPA (2001) Guidance Statement 1.

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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.

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 Outer Harbour Development will provide an ultimate export capacity of 240 million tonnes per annum (Mtpa) when completed. This will be established in four separate stages, with incremental expansions brought on line to reach the maximum capacity. Each expansion stage will increase the nominal capacity of up to 60 Mtpa. Regulatory approvals are being sought for the infrastructure required to deliver the total capacity of 240 Mtpa.

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

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

Key marine structures and activities will include:

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

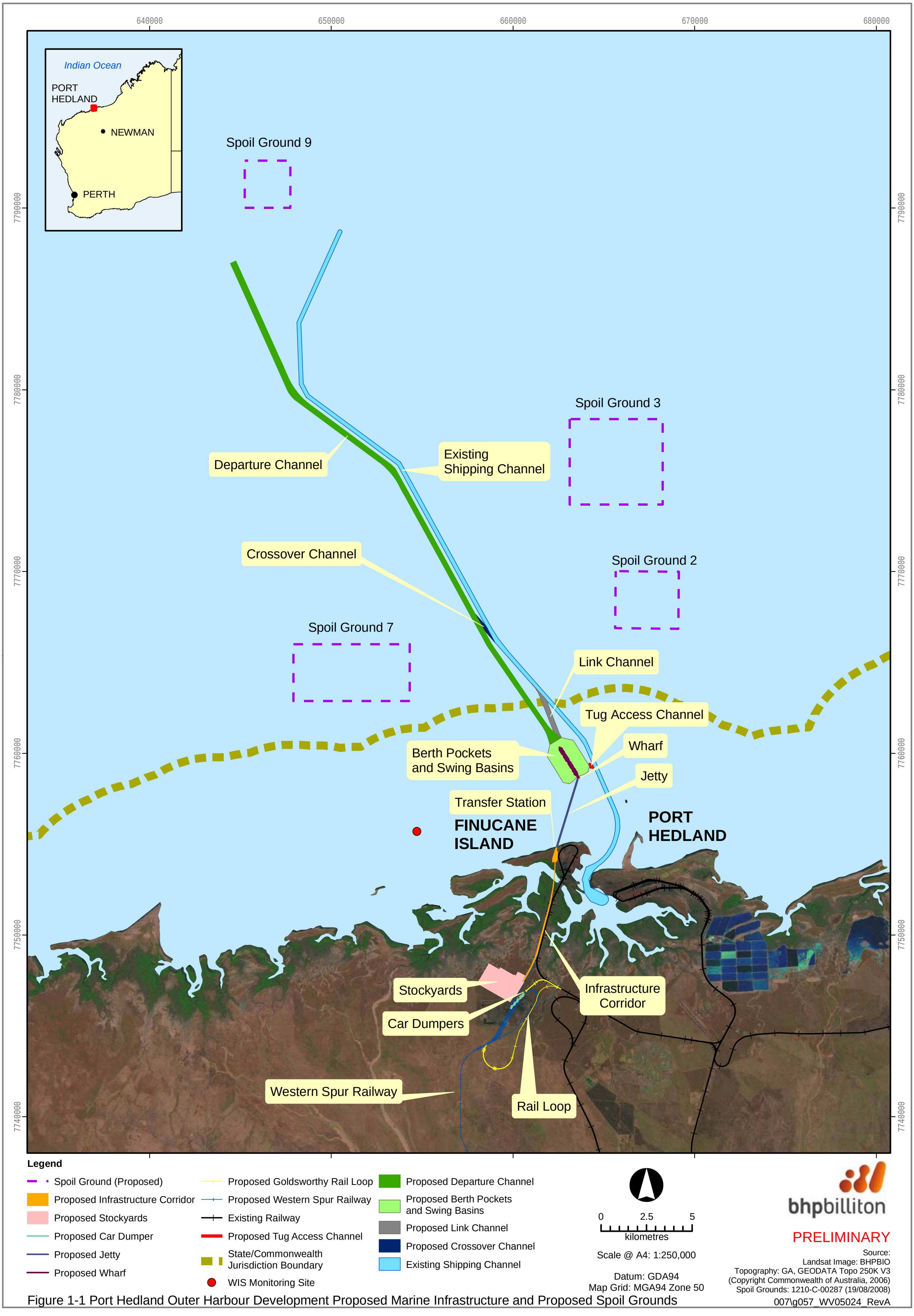

Figure 1-1 Port Hedland Outer Harbour Development Proposed Marine Infrastructure and Proposed Spoil Grounds

All dredged material will be disposed of in Commonwealth waters. An overview of the project's location, layout and footprint is shown in **Figure 1-1**.

This report deals specifically with the potential impacts to the intertidal habitat associated with the proposed conveyor corridor between the Boodarie stockyards and the shiploading facilities, including where the conveyor will cross West Creek to Finucane Island (**Figure 1-1**). The intertidal areas that will be impacted by these terrestrial works are typical of arid zone coastlines of the north-west of Australia and are characterised by stands of mangroves along seaward margins of tidal channels and creeks. Mangrove height and density typically decreases with distance from mean water level due to increased soil salinity and decreased tidal inundation. Upper intertidal areas are a mosaic of samphires and other salt marsh plants, cyanobacterial mats and large areas of bare substrate.

1.2. Purpose and Relevant Guidelines

This report presents an assessment of the mangrove, salt marsh and cyanobacterial mat habitats of the intertidal zone in and around the Port Hedland Harbour that will potentially be impacted by the proposed Outer Harbour Development.

The intertidal zone in and around the Port Hedland Harbour typically supports several types of Benthic Primary Producer Habitat (BPPH). Benthic Primary Producers (BPP) associated with these habitats (such as mangroves, salt marshes and cyanobacterial mats) are recognised as contributing to important ecological functions and environmental services (EPA 2001, 2004). Consequently, the Environmental Protection Authority (EPA) has produced two Guidance Statements (EPA 2001, 2004) and these provide advice on the considerations that must be addressed by any proposed development that may impact negatively upon the suite of environmental services and ecological functions supported by BPPH. Guidance Statement No.1 (EPA 2001) defines the boundaries of the Local Assessment Unit (LAU)[2] (**Figure 1-2**), which is used for the assessment of potential impacts as required by Environmental Assessment Guideline (EAG) No.3 (EPA 2009).

The objectives of this intertidal BPP impact assessment report are to:

- summarise the findings of an assessment of the intertidal BPPH areas that may be impacted by the proposed Port Hedland Outer Harbour Development;
- provide a classification of vegetation associations with the area of potential impact, based on the intertidal BPPH assessment;

[2] Also known as the Port Hedland Industrial Area Management Unit, as identified in EPA (2001) Guidance Statement 1.

- describe the current knowledge of the ecological function of the mangrove vegetation associations, salt marsh habitats and cyanobacterial mat habitats that may be impacted by the proposed development;
- determine the historical and cumulative losses of mangrove BPPH within the relevant LAU; and
- identify expected and potential impacts on mangrove, salt marsh and cyanobacterial mat BPPH.

In addition, the report discusses key features of the ecological functions (fauna, primary productivity) of the various mangrove habitats, focussing on the relative value of different mangrove vegetation associations. This information forms the basis of the assessment of 'high value' and 'low value' areas of mangrove vegetation that allowed the delineation of areas of 'high value' during the field survey. The potential relative values of salt marsh and cyanobacterial mats in comparison to mangroves in the LAU are also estimated.

The intertidal BBPH field survey (SKM 2009a) is designed to be read in conjunction with this impact assessment to provide the reader with necessary background information. The field survey data, aerial imagery and existing information where available, were used to compare the areas where the infrastructure will impact upon intertidal BPPH with the general character and distribution of similar BPPH elsewhere in the LAU.

A key component of the assessment of the significance of the potential impacts required estimation of historical and cumulative losses for each mangrove vegetation association and for mangrove habitat overall. This is addressed in a supporting document (SKM 2009b).

A separate Mangrove Management Plan (SKM 2009c) has been developed to mitigate potential impacts to mangroves throughout the proposed program of works. Key points of the Management Plan are summarised in **Section 6** of this document.

Figure 1-2 Port Hedland Industrial Area management unit

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2. Existing Environment

Compared to other areas in the Pilbara region, the mangrove, salt marsh and tidal flats of Port Hedland are relatively well known and many elements of the ecology, distribution and classification of these habitats have been described in detail. Important references include:

- Flora: Semeniuk et al. (1978); Paling et al. (2003);
- The influence of geology and geomorphology on the different intertidal habitats: Semeniuk (1993a, 1994, 2007a);
- Vegetation associations: Beard (1975); Craig (1983); Semeniuk (2007a); Paling et al. (2003); and
- Fauna: Jones (2004).

The distribution of mangroves, salt marsh plants and bare tidal flats in the upper intertidal areas of Port Hedland Harbour is a mosaic that reflects a variety of factors and these have been described in detail by Semeniuk (1993b, 1994). Interspersed among the intertidal habitats are many ‘islands’ of supra tidal vegetation (Paling et al. 2003) where the elevation is high enough to allow colonisation by terrestrial plants. The characteristics of terrestrial vegetation present on and adjacent to the disturbance footprints are not covered in this report.

Cyanobacterial mats are recognised as a typical feature of the intertidal zone along most of the Pilbara coastline, but there is little existing data on the distribution and ecology of these mats at Port Hedland. Thus a conceptual model for the ecological requirements of cyanobacterial mats at Port Hedland has been developed (SKM 2009d), and field studies and mapping techniques are being developed to provide more reliable estimates of the potential spatial and temporal characteristics of the distribution of cyanobacterial mats in the region.

2.1. Mangrove Vegetation Associations

The mangrove vegetation associations of the entire harbour area including the area of interest for this project have been recently described and mapped by SKM (2009b) and the classification is derived principally from the classification system of Semeniuk (2007a), but has been simplified to the following categories by reference to Paling et al. (2003). The mangrove vegetation associations are:

1) *Avicennia marina* (scattered) – comprising scattered individuals of the mangrove *Avicennia marina*, often with scattered samphires, but without high densities;
2) *Avicennia marina* (closed canopy, landward edge) – a forest/scrub comprising the typical zone of mangroves immediately behind the mixed association of *Avicennia marina* and *Rhizophora*

stylosa and often up to 100 m in width or more and characterised by a decrease in vegetation height with increasing height on the shore.

3) *Avicennia marina/Rhizophora stylosa* (closed canopy) – a forest/scrub comprising a transitional zone between closed canopy forest close to the seaward edge of main channels and extending to landward along small channel banks.
4) *Rhizophora stylosa* (closed canopy) – a forest/scrub comprising a relatively narrow zone, often only a few trees wide, behind the seaward *Avicennia marina* fringe and lining steep banks on small channels.
5) *Avicennia marina* (closed canopy, seaward edge) – a forest comprising large, mature, multi-stemmed *Avicennia marina* on the seaward edge of the main channels and sheltered small bays.

Photographs depicting typical habitat in each of the above mangrove associations are shown in **Plate 2-1**. Other mangrove associations that were noted by SKM (2009a), such as the seaward fringe of *Aegiceras corniculatum*, the landward edge fringes of *Ceriops australis*, the mixed associations of *Avicennia marina*, *Ceriops australis*, *Aegialitis annulata*, and the rare occurrences of *Osbornia octodonta* and *Bruguiera exaristata*, cannot be accurately mapped due to their narrow and scattered distribution on the periphery of the major vegetation associations.

Within the area defined as the LAU (EPA 2001) (**Figure 1-2**) the relative proportions of the mangrove associations were mapped in 2008 by SKM (2009b), and are presented in **Table 2-1**.

- **Table 2-1: Proportions of each of the Major Mangrove Vegetation Types in the Port Hedland Industrial LAU, based on 2008 Satellite Imagery**

Vegetation Association	2008 total (ha)	% of total
Avicennia marina (closed canopy, seaward edge)	220	8.33
Rhizophora stylosa (closed canopy)	589	22.32
Rhizophora stylosa/Avicennia marina (closed canopy)	89	3.37
Avicennia marina (closed canopy, landward edge)	1,027	38.90
Avicennia marina (scattered)	715	27.08
Totals	**2,640**	**100**

Source: SKM (2009b)

SKM

a. *Avicennia marina* (scattered).

b. *Avicennia marina* (closed canopy, landward edge).

c. *Avicennia marina* (closed canopy, landward edge) viewed from above.

d. *Avicennia marina/Rhizophora stylosa* (mixed, closed canopy).

e. *Rhizophora stylosa* (closed canopy).

f. *Avicennia marina* (closed canopy, seaward edge).

- **Plate 2-1: Examples of the Mangrove Associations used for the Vegetation Classification**

One important aspect of the distribution of these vegetation associations is the integrity of their relative positions in the intertidal zone (SKM 2009b). Throughout the LAU, the zonation of the mangrove vegetation associations within the intertidal is fairly consistent and is related to increasing height within the intertidal zone. Typically, the vegetation associations occur in the order listed in **Table 2-1**; i.e., closed canopy *Avicennia marina* on the seaward margins occurs in the lowest intertidal position, through to scattered *Avicennia marina* in the upper intertidal areas.

2.2. Salt Marsh Vegetation

Review of the literature (Oceanica 2006, Paling et al. 2003) shows that in relation to the distribution of salt marsh plants in north-western Australia, the word samphire has been used to describe all species of salt marsh plant that grow within a maritime influence (i.e. are occasionally flooded by tidal water). More correctly it appears the term should be used to refer to members of the Chenopodiaceae tribe Salicornieae (Datson 2002), but in Australia the term has come to be used to refer to all the salt marsh plants present and the habitat supporting these plants, apparently because these habitats are typically dominated by members of the tribe Salicornieae.

In temperate regions of the world, the lower intertidal areas typically support highly productive stands of salt marsh (Adam 1995). In the Australian tropics, however, these areas are exclusively occupied by mangroves, and salt marsh areas are instead found in the mid to upper intertidal zones (Adam 1995).

Adam (1995) notes that salt marshes in northern Australia, although extensive, are species poor, with frequently less than ten vascular plant species in their total flora. Within the LAU, the salt marsh areas are largely dominated by one species of samphire, *Tecticornia halocnemoides* (recorded as *Arthrocnemum halocnemoides* or *Halosarcia halocnemoides* in earlier studies).

Adam (1995) notes that in the Australian tropics, the lower areas of the intertidal, which typically support the most productive stands of salt marsh in temperate regions of the world, are exclusively occupied by mangroves and therefore tropical salt marsh is a feature of the mid to upper intertidal zones.

2.3. Cyanobacterial Mats

Cyanobacteria are blue-green algae that obtain their energy through photosynthesis. There are many aquatic and terrestrial forms of cyanobacteria, which are considered an important component of the nitrogen cycle as they have the ability to fix atmospheric nitrogen.

Cyanobacteria are a common feature of intertidal zones throughout the world and have been found to occur in extensive mats on intertidal mud flats in highly saline conditions along the north-west Australian coastline (Paling 1986). Cyanobacterial mats are often found in association with, or in close proximity to, mangroves and salt marsh habitats in tropical and subtropical regions (Sheppard et al. 1992).

Specifically, it has been noted that the mats may be found between the mangrove and samphire dominated zones of the upper intertidal areas that occur in the Pilbara region (Paling et al. 2003). In this region, they have been observed to occur on the landward side of mangroves where no other vegetation exists, with the exception of two halophytic samphire genera (Paling 1986). Tidal flushing in areas of mat development is restricted by a landward levee and a sill of sediment at the seaward side, which effectively creates a ponding effect.

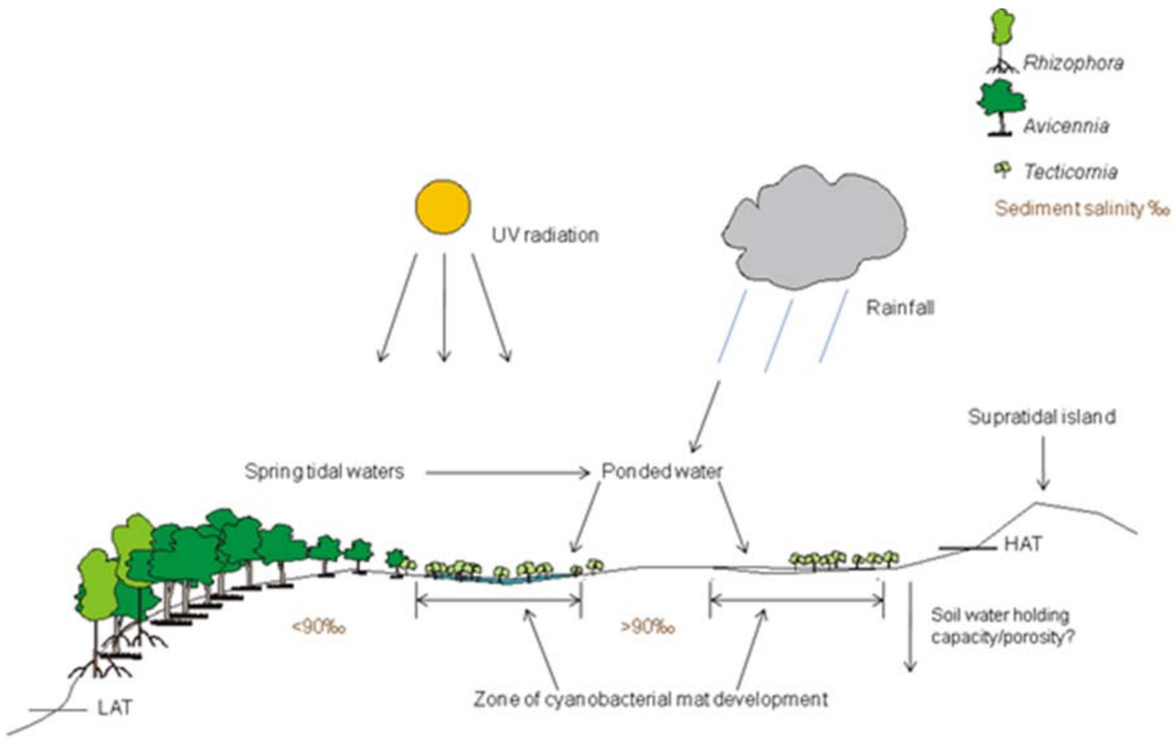
Cyanobacteria are typically distributed throughout the intertidal zone, including the substrate under mangroves and salt marsh plants (Alongi 2009), but only develop into mats in the areas of open canopy beneath mangroves and salt marsh plants and the open tidal pan, where sufficient light reaches the substrate. Mats are formed by the trapping of sediment between successive layers of cyanobacteria. In most areas where cyanobacteria form mats, there are periods when the mats dry out (Sheppard et al. 1992) and then become active again in response to tidal inundation and/or rainfall (Paling and McComb, 1994).

In the Pilbara region, cyanobacterial mat communities are commonly found to have between one and three genera present (Paling 1986). Paling (1986) concluded that the low species number found in mats on the Dampier Archipelago is attributable to stress. In particular, soil/sediment moisture content, salinity and temperature are considered primary environmental drivers of stress and reduced diversity in cyanobacterial mat communities. Species commonly found in these conditions include *Microcoleus*, *Phormidium*, *Lyngbya*, *Oscillatoria* and *Aphanocapsa*, all of which are non-heterocystic[3] forms of cyanobacteria. The genera *Oscillatoria*, *Phormidium* and *Microcoleus* have been observed in the Pilbara region (Paling 1986) and are widespread in these habitats.

A number of environmental factors (**Figure 2-1**) are considered to influence the occurrence, distribution and productivity of cyanobacterial mats in the Port Hedland coastal region: tidal influence (period of inundation), hydrological regime (rainwater inputs), sediment influx, drainage (runoff, soil water holding capacity/porosity), temperature, salinity gradient, light and grazing (Paling 1986). Specifically, it appears that a requirement for sunlight and a susceptibility to herbivory precludes mat formation under closed canopy forest of mangroves and also from areas where samphires are dense. Mats also form where the less frequent tidal inundation of the mid to upper intertidal zone produces high soil salinities and low soil moisture sufficient to reduce the presence of potential grazers. Lastly, there is usually a requirement for some surface ponding to occur, requiring local topography and soil types that retain moisture from tidal inundation and/or rainfall. Most of the intertidal zone at Port Hedland drains relatively freely after inundation and/or

[3] A heterocyst is a specialised nitrogen-fixing cell formed by some filamentous cyanobacteria, which facilitates nitrogen fixation in an oxygen-free environment. Non-heterocystic cyanobacteria do not have heterocysts and not all non-heterocystic bacteria can perform nitrogen fixation.

water is rapidly evaporated. The likely requirements for cyanobacterial mat formation are captured as a conceptual model in **Figure 2-1**.



- **Figure 2-1: Conceptual Model Depicting Potential Environmental Drivers for Cyanobacterial Mat Communities Formation between Lowest Astronomical Tide (LAT) and Highest Astronomical Tide (HAT)**

3. Ecological Functions of Different Intertidal BPP

The different mangrove vegetation associations and other intertidal BPP present in the EPA defined LAU are expected to show functional differences across a range of ecological elements. Key ecological elements include faunal diversity and primary productivity. In this section, faunal associations are compared between mangrove vegetation types and discussion is also provided for samphires and cyanobacterial mats.

For the purpose of comparing ecological function, mangrove associations have been grouped into two generalised functional groups:

- closed canopy mangrove forest; and
- sparse *Avicennia marina* (with or without samphires).

With reference to the mangrove associations used in the vegetation classification (**Section 2** of this report), the four mangrove associations that have been grouped together as closed canopy mangrove forest are:

- *Avicennia marina* (closed canopy, landward edge);
- *Avicennia marina*/*Rhizophora stylosa* (closed canopy);
- *Rhizophora stylosa* (closed canopy); and
- *Avicennia marina* (closed canopy, seaward edge).

The description of closed canopy areas of mangroves provided by Semeniuk (2007a) is of ‘low forest to scrub’ and the broad category as defined applies to a range of vegetation heights and physical appearance, reflecting variation in factors such as substrate type, frequency of inundation and soil salinity. The majority of closed canopy mangrove forest along the channels of the harbour is better described as ‘low forest’ rather than ‘scrub’ and the single-species stands of both *Avicennia marina* and *Rhizophora stylosa* along the larger channels usually contain some relatively large trees (in the Port Hedland context). The best examples of closed canopy mangrove forest reflect their proximity to mean sea level and frequent tidal inundation.

Compared to mangrove trees growing at higher levels on the shore in this LAU, such as sparse *Avicennia marina*, the trees of the closed canopy mangrove forest are generally better developed with larger trunks, greater canopy height and more continuous canopy cover.

In the Port Hedland Harbour region, the sparse *Avicennia marina* habitat occurs on areas of mid-intertidal mudflat and is often a mixed association of shrub-like *Avicennia marina* trees and samphires, most commonly *Tecticornia halocnemoides* (SKM 2007). These areas represent a gradient between the 'true' mangrove forests at lower shore heights and the upper intertidal areas that are typically occupied by only samphires and cyanobacterial mats.

These areas are typically a mosaic of bare mudflat interspersed with patches of samphires and patches of mangrove. Often the mangroves tend to be associated with very small channels draining the tidal flat and these channels are typically only a few centimetres deep, drying quickly once the tide begins to recede, but there are also areas where both mangroves and samphires are truly intermixed with each other.

Relative to the closed canopy mangrove forest these areas have a much lower above-ground biomass and the mangroves are often <1 m in height. Density of trees and of samphires can vary widely in this BPPH type, with mangrove in higher densities near shallow drainage channels and depressions where the frequency of tidal inundation is higher. Tree density is very low when measured per hectare as even along the drainage channels where trees are densely packed; the band of trees is rarely more than one or two trees wide.

3.1. Fauna Associated with Mangroves

There is a large body of literature on the ecology of fauna associated with mangroves and it is generally recognised that many species and genera present in the mangroves of north (Davie 1982, 1985; George & Jones 1982; von Hagen & Jones 1989; Hanley 1988, 1993a, 1993b, 1997; Hanley & Banks 1995; Hanley & Couriel 1992; Metcalf & Glasby 2008) and north-western (Hanley 1995; Wells 1983, 1984) Australia are widely distributed throughout the Indo West Pacific region (Davie 2004; Frith et al 1976; Houbrick 1991; Reid 1986; Sasekumar 1974; Ng & Sivasothi 2001).

Earlier surveys of mangroves in the LAU (SKM 2007, 2009a) revealed a generally low diversity of mangrove benthic invertebrate fauna when compared with areas of coastline both north and south of Port Hedland (J. Hanley, pers comm. 2009).

The earlier surveys of fauna in Port Hedland were not quantitative, but focussed on the presence/absence of the large, conspicuous and generally widespread elements of the benthic invertebrate fauna associated with mangroves, including the large species of molluscs and crustaceans that are both easy to find and identify in the field (SKM 2009a).

The number of these species present typically ranged from four to eight (SKM 2009a), but at one site 20 species were recorded under closed canopy forest. The list of species recorded is presented here in **Table 3-1** to demonstrate that when the local environmental conditions are favourable, the number of species of benthic invertebrates and the community composition is similar to that seen at other locations on the north-west coast (J. Hanley, pers comm. 2009).

Although the list of species in **Table 3-1** is typical of what might be found in many mangrove stands on the north-western coast, the high number of species and relative abundance at this site compared to other sites surveyed in Port Hedland (SKM 2007) is thought to be a consequence of an altered pattern of drainage in an area of mangroves on Finucane Island. The drainage pattern has been altered by the insertion of a road and culverts, which appear to have increased the retention time of water on outgoing tides, providing a longer period of inundation at this site than at nearby, unaltered sites of similar elevation in the intertidal zone (SKM 2009a).

- **Table 3-1: Fauna Observed in Closed Canopy Mangroves near Site F9 (Finucane Island)**

Species	Abundance[1]
Terebralia semistriata (mud whelk)	abundant
Terebralia palustris (mud whelk)	abundant
Terebralia sulcata (mud whelk)	abundant
Telescopium telescopium (mud whelk)	abundant
Cerithidea largillierti (mud whelk)	common
Nerita ?balteata (mollusc)	present
Nerita oualensis? (mollusc)	present
Littoraria articulata? (mollusc)	present
Onchidium daemilli (mollusc)	abundant
Saccostrea cucculata (mollusc)	present, common in patches near Mean Sea Level (MSL)
Neosarmatium meinerti (crab)	common
Parasesarma spp. (crab)	abundant
Perisesarma spp. (crab)	abundant
Metapograpsus frontalis (crab)	common
Uca flammula (crab)	common
Uca elegans (crab)	present – drier margins, open areas
Scylla spp. (crab)	present
Clibanarius longitarsus (hermit crab)	present
Epixanthus dentatus (crab)	present
Thalassina anomala (mud lobster)	common

[1]Present (1–5 individuals in vicinity), common (5-20 individuals in vicinity) abundant (more than 20 individuals in vicinity)
Source: SKM (2009a)

Given the different mangrove associations present in the intertidal zone of the Port Hedland Harbour, it can be expected that the fauna will show differences in species distribution, diversity and abundance in response to the same environmental conditions that influence the distribution, diversity and abundance of flora, such that fauna will decrease in diversity and abundance moving away from the tidal channels in response to rising salinity and less frequent tidal inundation.

3.1.1. Fauna of Closed Canopy Mangrove Forest

Compared to other mangrove trees growing at higher levels on the shore in this LAU, such as sparse *Avicennia marina*, the trees of the closed canopy mangrove forest are generally better developed with larger trunks, greater canopy height and more continuous canopy cover. All of these features are important in providing suitable niches for fauna. Johnstone (1990) documented eight species of bird that are largely dependent on mangroves in the Pilbara region where the mangroves form the only closed canopy forest in the region. All species are able to utilise more than one type of mangrove and all eight species of birds typically forage widely in all mangrove vegetation types and some also use samphires and tidal flats.

For some bird species, the presence of closed canopy forest and particularly larger trees appears to be critically important and this is reflected in discrete distributions that match the distribution of closed canopy mangrove forests (Johnstone 1990). For example, the presence of large hollow trunks in the seaward *Avicennia marina* zone provides suitable nesting sites for the collared kingfisher, *Todiramphus chloris*, which is apparently absent from areas of the coast which lack large *Avicennia marina* (Johnstone 1990). Similarly, the bar-shouldered dove (*Geopelia humerilis*) is widely distributed in north and north-western Australia where it is commonly found associated with a range of vegetation assemblages, but in the Pilbara this species is largely restricted to closed canopy mangrove forest for suitable nesting and roosting sites (Johnstone 1990). Johnstone (1990) also notes that birds such as the mangrove robin (*Eopsaltria pulverulenta*) and mangrove golden whistler (*Pachycephala melanura*) are heavily dependent on the presence of closed canopy forest, with the mangrove robin particularly dependent on *Rhizophora stylosa*.

The diversity of invertebrates and other mangrove associated fauna is typically higher in closed canopy forests in the tropics (Robertson et al. 1992; Hanley 1993a). The presence and degree of shading of the forest floor appears to affect the relative abundance of some crab species (Nobbs 2003) such as *Uca flammula*, which was abundant under all types of closed canopy mangrove forest surveyed (SKM 2007). A survey of fauna (SKM 2007) also noted that different species of fiddler crabs were associated with closed canopy mangrove forest in Port Hedland Harbour and that these animals were generally more abundant in these areas when compared with the more open *Avicennia marina* scrub. It should be noted however that fiddler crab distribution and abundance is likely to be the result of a combination of factors including the frequency of tidal inundation, vegetation present, substrate type and salinity, rather than the presence of closed canopy mangrove forest alone.

Survey of the closed canopy mangrove forests at Harriet Point in Port Hedland (SKM 2007) concluded these areas supported a comparatively low diversity of benthic invertebrates and epifauna, and that sites both north and south of Port Hedland were known to support higher diversity (J. Hanley, pers comm. 2009). The almost total absence of typical large and conspicuous mangrove-associated molluscs such as *Telescopium telescopium*, *Terebralia* spp., neritids and littorinids was notable (SKM 2007). The comparatively low diversity may be related to the low levels of litter on the forest floor, as it appears a large proportion of nutrient capital may be stored in dead roots below the forest floor (Alongi et al. 2000, 2003) rather than on the surface where it might be more easily accessed by grazing and deposit feeding invertebrates.

3.1.2. Fauna of Sparse *Avicennia marina* (With or Without Samphires)

The fauna associated with areas of sparse *Avicennia marina* is low in both diversity and abundance compared with closed canopy mangrove forests. Many of the eight species of bird associated with mangroves do use these areas to forage for food (Johnstone 1990), but given the lower density of vegetation it is likely that a relatively small proportion of time is spent foraging in sparse *Avicennia marina* compared to within closed canopy mangrove forests. Other species of birds that are not restricted mostly or entirely to mangroves would use these areas to forage and include a variety of insectivores, waders and herons (Johnstone 1990).

Very few species of benthic invertebrate fauna have been observed in areas of sparse *Avicennia marina* (SKM 2009a). The most common was the large sesarmid crab *Neosarmatium meinerti*, which usually digs its burrows under canopies of *Avicennia marina* trees (Dahdouh-Gebas et al. 1999). This habitat type is important as foraging habitat for fishes and crustaceans such as prawns and crabs that enter the area on suitable high tides. These areas are unlikely, however, to support the same abundance and diversity of fauna found in closed canopy mangrove forest as they are not inundated for as long or as often, and are further from channels (Thomas & Connolly 2001).

3.2. Fauna Associated with Salt Marsh

The salt marsh habitat is dominated by the samphire *Tecticornia halocnemoides* and (SKM 2007, 2009a) reported very few benthic invertebrate species from these areas at Port Hedland. No molluscs or insects were recorded, and the only crustacean commonly encountered was the sesarmid crab *Neosarmatium meinerti*. Areas of bare mud support the fiddler crab, *Uca elegans*, and this species appears to favour open areas devoid of shade (Nobbs 2003). It is, however, unclear whether the amount of shade is important to this species, possibly because shading may restrict the production of algae and/or cyanobacteria, or whether a lack of shade is correlated with a particular height on the shore (Jones 2004).

The lack of fauna on the substrate is most likely related to the harsh environmental conditions faced by marine invertebrates at this height on the shore. Tidal inundation is infrequent and for short durations and the pore water and soil salinities are high. Recent surveys of soil water salinity for BHP Billiton Iron Ore's RGP5 monitoring program (SKM 2009e) demonstrated that at the edge of tidal flats behind mangroves, soil salinity was in the range of 60 to 70‰ (parts per thousand) and at these levels most intertidal organisms are excluded. The exception appears to be species such as the crabs *Neosarmatium meinerti* and *Uca elegans*, both of which are capable of digging deep burrows to reach depths where soil moisture is higher and salinities are closer to that of seawater.

3.3. Fauna Associated with Cyanobacterial Mats

The areas of cyanobacterial mats observed at Port Hedland have mostly been surveyed during dry season conditions (SKM 2007) and all portions of mats observed were dormant with no signs of any invertebrate associates.

However, during the recent setup of the mangrove monitoring program (SKM 2009e), areas of live, actively photosynthesising mats were observed at a number of sites around the harbour, but no evidence of organisms feeding on the mats was found. Samples of mat were collected from several sites and were examined under microscope for evidence of micro-invertebrates, but none were observed. The apparent absence of a cohort of invertebrates that can feed on the mats is consistent with observations made elsewhere (Stahl 2000). Although tolerant to high salinities of up to 300‰ (Sheppard et al. 1992), the species diversity in cyanobacterial mats is known to decrease as soil salinity increases. While these conditions are considered sub-optimal for cyanobacteria, mats may occur because at high salinities there is an absence of grazing by metazoans (animals such as crabs and molluscs), whereas in more benign conditions such as lower in the intertidal zone the presence of significant grazing prevents accumulation of biomass and binding of sediment (Stahl 2000).

3.4. Environmental Services Provided by Different Intertidal BPP

The Organisation for Economic Co-operation and Development (OECD 2008) defines environmental services as:

- disposal services which reflect the functions of the natural environment as an absorptive sink for residuals;
- productive services which reflect the economic functions of providing natural resource inputs and space for production and consumption; and
- consumer or consumption services which provide for physiological as well as recreational and related needs of human beings.

The range of environmental services provided by different intertidal BPPHs at Port Hedland include, but are not limited to, primary productivity, biodiversity (both floral and faunal), nutrient trapping and maintenance of water quality, protection against storm surge and erosion, and the recreational amenity value associated with fishing.

3.4.1. Closed-Canopy Mangrove Forest

Stands of closed canopy mangrove forest are located between the seaward edge and the mid-tidal level of the shore and these stands are among the most productive in the harbour (Alongi et al. 2005). At a species level, *Rhizophora stylosa* is more productive than *Avicennia marina* although both species are at the upper end of the range of estimates of productivity (in terms of both leaf litter production and photosynthetic rates) for these species elsewhere. The estimates of productivity are surprising as there is no doubt these arid-zone trees are under considerable stress (Alongi et al. 2005) and it might have been expected that their productivity would be at the lower end of the scale, reflecting the combination of latitude, rainfall and vegetation height that has elsewhere been shown to be highly correlated with productivity (Saenger & Snedaker 1993) measured as litterfall.

The primary productivity of closed canopy mangrove forests in the Port Hedland Harbour is higher than the other types of mangrove associations present (Alongi et al. 2005) and so, given that primary productivity is an important source of organic carbon in food chains both within the mangrove and externally (tidal creeks, coastal waters), then the ecological value per unit area of closed canopy mangrove forest would be high relative to other types of mangroves. However, while the relationship between nearshore fisheries and mangrove systems is often stated to be important (reviewed by Robertson et al. 1992 and Saenger 2002) there is a large range of local variation dependent on a variety of local factors, such as whether the mangrove system acts as a source or a sink for nutrients, and the complexity of trophic webs (Manson et al. 2005; Hanley 2007).

Another environmental service provided by the closed canopy mangrove forests is the provision of habitat for fishes and other organisms (prawns, crabs) that swim up onto the flooded areas during high tides seeking shelter and food. The value of this service is variable and dependent on a number of factors such as pneumatophore density, which provides habitat complexity (Bloomfield & Gillanders 2004; Thomas & Connolly 2001; Lewis & Gilmore 2007). It is likely that areas of closed canopy mangrove forest are more important than other areas because they:

- lie close to the channels which provide a refuge at low tide;
- are structurally complex;
- are flooded on all high tides; and
- are flooded for longer periods compared to areas higher in the intertidal zone.

The provision of suitable areas of habitat for roosting, nesting and foraging by avifauna has been discussed in the earlier section on fauna associated with closed canopy mangrove forests (**Section 3.1.1**). The structural complexity provided by closed canopy mangrove forest provides other benefits including windbreak, storm protection and some degree of shoreline protection (Saenger 2002) and maintenance of tidal channel depths and contours (Wolanski 2006).

3.4.2. Sparse *Avicennia marina* (With or Without Samphires)

Sparse *Avicennia marina* habitat would provide many of the environmental services provided by closed canopy mangrove forests, although the relative degree of contribution would be lower.

Although no productivity data exist for sparse *Avicennia marina* habitat, it can be reasonably assumed that productivity would be lower than closed canopy mangrove forest due to lower above-ground biomass of plants. Therefore, although sparse *Avicennia marina* areas would contribute to the food chain through production of organic carbon, as does closed canopy mangrove forest, the rate of contribution would be considerably lower. Furthermore, since little or no accumulation of leaf litter has been observed in areas of sparse *Avicennia marina* (SKM 2009a), it is assumed that leaf litter production would be very low compared to closed canopy mangrove forests and is unlikely to be exported to adjacent habitats in any appreciable amounts.

Birds and crabs forage for food within areas of sparse *Avicennia marina*, although many species spend a greater proportion of time foraging in closed canopy mangrove forests where prey species are generally more abundant. Foraging by fish and aquatic invertebrates is restricted to suitable high tides that allow such species to enter higher intertidal areas.

3.4.3. Salt Marsh

The accurate determination of potential primary productivity from salt marsh requires recognition of an important difference between Australian and overseas marshes, namely that salt marshes around much of the Australian coast occupy the upper intertidal and are typically dominated by samphires. Even at their lowest limit on the shore, tropical Australian marshes are not subject to daily flooding by tides (Adam 1995). In physiological terms, the habitat of tropical Australian marshes is more stressful than that of temperate salt marsh plants such as *Spartina alterniflora*, with greater fluctuation in salinity and higher maximum salinities. This greater stress is likely to lower the maximum potential productivity (Adam 1995).

3.4.4. Cyanobacterial Mats

Cyanobacterial mats are rich in organic matter, nitrogen and phosphorus, and reduce erosion by binding and stabilising the substrate (Paling 1986, Paling et al. 1989). They play an important role in the nitrogen cycle through atmospheric nitrogen fixation, which later becomes available in the food web through grazing and/or decomposition as organic nitrogen (Paling and McComb 1994). Subsequently, they have the potential to act as a biofertiliser for mangroves, which may aid in their sustainability and persistence.

3.5. Assignment of Relative Value to Intertidal BPP

3.5.1. Mangroves

The preceding overview of the two general functional groups of mangroves demonstrates that the range and scale of environmental services provided by each appears to be negatively correlated with height in the intertidal zone. There is a general trend of increasing stress in the intertidal zone moving from Mean Sea Level (MSL) to the uppermost limit of the tide at Highest Astronomical Tide (HAT) as soil moisture content falls and soil salinity rises. This impacts on the vegetation and is reflected in the distribution, diversity, size, density and productivity of the floristic components. Similar trends are seen among the fauna found in the intertidal zone, particularly those species that appear to be wholly or partially dependent on the presence of benthic primary producers.

Differences in the ecological function and provision of environmental services are expected when comparing different mangrove types. As an example, differences in biodiversity would be expected although there may be instances where some level of overlap exists, particularly in areas where two different mangrove associations are adjacent to each other, or where the density and structure of the vegetation is similar between habitats.

Differences in the ecological function and provision of environmental services are also expected when comparing different stands of the one type of mangrove association, as it cannot be assumed that all areas would be equivalent on an areal basis. For example, different stands of closed canopy *Avicennia marina* would be expected to have different contributions on a per unit area basis, reflecting local-scale variation in the environmental and physiological conditions within stands.

The most useful summary of the relative value of specific stands of mangroves in the Port Hedland Harbour may be provided by the adoption of a convenient metric such as above ground biomass (AGB). The data compiled by Alongi et al. (2005) and Clough et al. (1997) have shown considerable variation in estimates of AGB at Port Hedland with a marked decline in AGB moving landward from the edge of tidal channels.

The available data on the abundance and diversity of benthic invertebrates associated with mangrove vegetation in Port Hedland suggests a strong correlation with AGB despite generally low numbers of organisms.

Using the metric of AGB per unit of area, the relative value of the mangrove vegetation associations (from highest to lowest) at Port Hedland would be:

1. *Rhizophora stylosa* (closed canopy);
2. *Avicennia marina* (closed canopy, seaward edge);
3. *Avicennia marina*/*Rhizophora stylosa* (closed canopy);
4. *Avicennia marina* (closed canopy, landward edge); then
5. *Avicennia marina* (scattered) with or without samphires.

The relative value of stands of the first three types of mangrove vegetation is likely to be almost equivalent. The fourth category, *Avicennia marina* landward does represent a significantly lower value category based on AGB, and the last category *Avicennia marina* (scattered) typically has 10–20% of the AGB of the more highly valued closed canopy vegetation associations.

3.5.2. Salt Marsh

The use of the AGB metric as a measure of the relative value of salt marsh area that is dominated by samphires can allow a comparison of these BPPH with nearby mangrove vegetation. However, there are few published estimates in the literature of the AGB of tropical salt marsh such as that found at Port Hedland.

Alongi (1997) reports that mangrove AGB is typically greater than that of salt marsh, but also cautions that AGB is not always a good measure of underlying primary productivity. The highest levels of AGB recorded for salt marsh plants are around 2000 g DW m^{-2}, which is some 20 t DW ha^{-1}, but these values are for salt marshes that are not dominated by samphires. At Port Hedland it is likely that typical AGB of the samphires per unit of area is less than this, given that coverage is not continuous over the substrate in most places and that the samphire dominated salt marsh is typically found higher in the intertidal zone (Adam 1995). The likely level of AGB is expected to be similar to that estimated for the scattered *A. marina* vegetation type at Port Hedland and is therefore much lower than that of the closed canopy forest areas.

3.5.3. Cyanobacterial Mats

In terms of a relative contribution to local ecological functions and environmental services, the application of the AGB metric as used for mangroves and salt marsh may not be justified if it can be shown that primary productivity from mats is high relative to production from equivalent areas of mangrove. However that is considered to be unlikely given that active primary production is restricted to those relatively short periods when a combination of tidal inundation and rainfall are present (**Figure 2-1**). In some years, the lack of rainfall at Port Hedland may mean there are large areas of tidal flat which have no activity. For these reasons, cyanobacterial mats are considered here to be the least important of the intertidal BPPH in terms of inputs to ecosystem level function in the LAU.

3.6. Field Surveys of the Intertidal Environment

Field surveys were undertaken to provide data on the flora, fauna and to develop relative ‘ecological values’ for the potential impact areas associated with the Outer Harbour Development. Detailed descriptions of the flora, fauna and any other relevant observations (e.g. hydrological patterns) from each site are provided in SKM (2009a). Sixteen sites (**Figure 3-1**) were selected to provide sufficient baseline information to undertake an assessment and to evaluate the data against the significant body of information already documented in previous studies as referenced above.

Each site was surveyed by informal line transects which were aligned parallel and perpendicular to shorelines. The alignment of transects enabled zonation patterns of BPP to be recorded and verified against those initially identified using aerial photography. Along each transect, the flora and fauna species present, their height and condition (flora only) and relative abundance was recorded (SKM 2009a). Photographs of typical species and/or habitats were taken at each site.

Figure 3.1 - Proposed Infrastructure and Location of Intertidal Survey Sites

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4. BPPH Classification and Distribution

The BPPH present within the area which will be impacted by the proposed corridor comprises intertidal creek banks and tidal flats. These habitats support mangroves, samphires (salt marsh) and cyanobacterial mats.

4.1. Mangrove Vegetation Classification and Distribution

A map showing the distribution of the mangrove associations that together comprise the mangrove BPPH is provided in **Figure 4-1**.

The distribution of the mangrove vegetation associations is typical of that recently mapped for the entire LAU (SKM 2009b). The map (**Figure 4-1**), does not show the locations of the other species present (*Aegiceras corniculatum*, *Ceriops australis*, *Osbornia octodonta*, *Aegialitis annulata* and *Bruguiera exaristata*) because they occur either as single trees on the landward edge, or occupy a band of the intertidal zone so narrow that it cannot be shown accurately at the scale of the map. None of these species are found within the footprint of the proposed causeway.

4.2. Samphire Vegetation and Distribution

Samphire vegetation lies at a higher level in the intertidal zone than mangroves and is dominated in the Port Hedland region by one species, *Tecticornia halocnemoides*. The plants are typically scattered across the tidal flat, with bare areas of tidal flat between individual plants. The substrate under individual plants is often slightly higher in elevation than the surrounding flat (1–2 cm). This is most obvious when a thin layer of water is lying over the surrounding tidal flat and suggests that either the plants are conducive to active accretion of sediment around their roots, or conversely, that the tidal flat is eroding but the plants mitigate erosion of sediment from beneath them.

As noted earlier (**Section 3.2**), the environment where samphires are found in Port Hedland is harsh and the areas of samphires are typically comprised of scattered plants from 10 to 40 cm in height. These areas often grade into the scattered *Avicennia marina* zone without a clear distinction between the two types of vegetation association. For this reason, accurate mapping of the boundaries of samphires and the scattered *Avicennia marina* vegetation association is problematic.

Within the area under or near the proposed causeway, there are scattered samphires present on Finucane Island in a zone bounded by the access road that leads to the western tip of the island and by the mangroves on the seaward side. In addition, scattered samphires are present on the mainland, on the western side of the old conveyor causeway. The scattered samphires are confined to one small area to the north of the BHP Billiton Iron Ore RPG5 Dredge Material Management Area (DMMA; **Figure 5-1**), approximately 1–1.5 km south-west of site SWCW3.

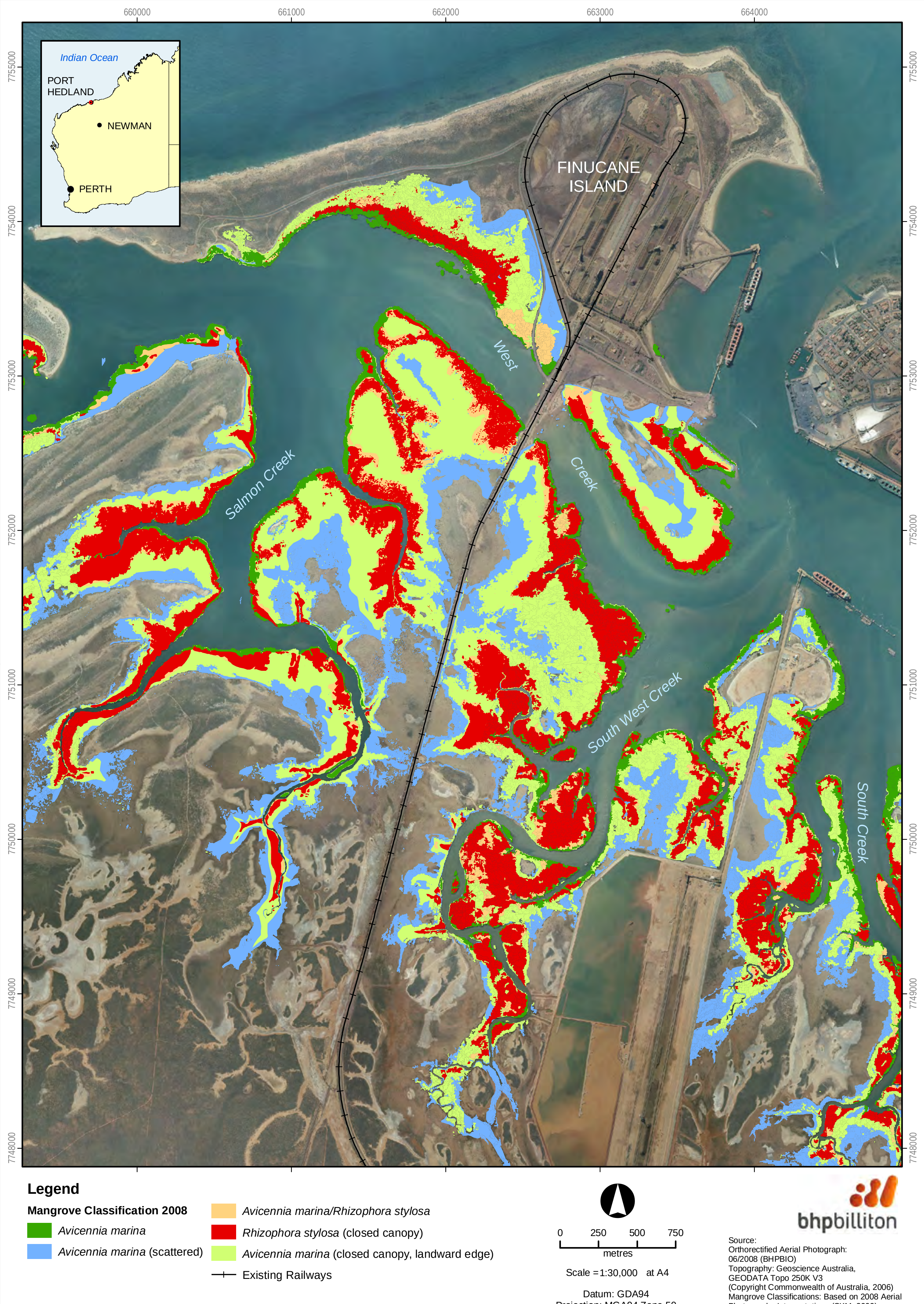

Figure 4.1 - Distribution of mangrove vegetation associations

4.3. Cyanobacterial Mats

The accurate mapping and delineation of cyanobacterial mats has not been undertaken in the Port Hedland region to date. Recent investigations of aerial imagery were undertaken to determine if the presence of cyanobacterial mats could be identified by a specific spectral signature (or set of signatures), but the results were inconclusive. Training of image analysis requires positive identification of mats at specific locations so that the spectral signature of these areas can be used to search for similar signatures elsewhere. The results obtained to date show conclusively that the image analysis cannot accurately delineate the spectral signatures unique to cyanobacterial mats from the limited data set of confirmed mat locations. There are very few locations where mats have been confirmed, and because mats are not always present or active, it is not certain that the mat location will have had active mats in the image available for analysis. Another factor is the state of the tide, where any layer of water over the tidal flat areas which might support mats confounds the analysis.

It is important to note that mats are restricted both spatially and temporally to areas where conditions are conducive to their formation, and may not form at all in dry years.

Within the area of interest, under or near the footprint of the proposed causeway, there is one small area where the presence of a cyanobacterial mat was confirmed during survey work to set up the monitoring sites for the RGP5 mangrove monitoring program (SKM 2009a). An area of bare tidal pan immediately north of the DMMA reclamation area (**Figure 5-1**) and west of the existing conveyor causeway includes a shallow depression of about 0.25 ha in size and this area had a cyanobacterial mat in late January 2009.

5. Historical and Cumulative Losses

This section provides an assessment of the losses of BPPH in the intertidal areas in and around Port Hedland from previous and planned development projects. It is important to understand, however, that BPPH are rarely static ecosystems and that gain and loss in area coverage will occur naturally. The assessment of losses presented here recognises the dynamic nature of the BPPH in the LAU (**Figure 1-2**).

The assessment presented here is restricted to the habitats supporting mangroves. During an intertidal survey of the potential area of impact, other intertidal BPPH such as salt marsh/samphire flats and cyanobacterial mats were recorded (SKM 2009a) and their contribution to ecological processes is described in **Section 3** of this report. However, due to the limitations in determining historical extent and cumulative losses for BPPH other than mangrove habitats, they have not been included in this assessment.

5.1. LAU and Relevant Regulatory Framework

The EPA (2001) has designated the Port Hedland Industrial LAU (**Figure 1-2**) as the appropriate LAU for mangrove and other BPP communities in the Port Hedland Harbour area. This LAU has been used here for estimations of the historical and cumulative losses of mangroves associated with the proposed Port Hedland Outer Harbour development, of which the terrestrial component lies entirely within the specified LAU.

Coastal areas are divided in EPA Environmental Assessment Guideline No. 3 into six categories ranging from areas considered to have very high conservation value (Category A) to development areas (Category E) where it is recognised there is, or will be, substantial coastal and marine infrastructure development that may impact on BPPH (EPA 2004). A set of cumulative loss thresholds is specified for each category and is shown in **Table 5-1**.

The threshold of cumulative loss for Category E Development Areas is 10%, which is applicable to the Port Hedland Industrial LAU as defined by the EPA (2001). For development areas along the State's coastline where cumulative loss is already well in excess of 10%, another category (F) has been specified for these areas and the cumulative loss threshold is set at 0% net damage/loss (plus offsets). This means that any further losses will only be acceptable if a suitable suite of offsets is provided by the proponent.

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- **Table 5-1: Categories of Protection and Cumulative Loss Thresholds Guidelines**

Category	Description	Cumulative loss threshold (percentage of original BPPH within a defined LAU)
A	Extremely special areas	0%
B	High protection areas other than above	1%
C	Other designated areas	2%
D	Non-designated areas	5%
E	Development areas	10%
F	Areas where cumulative loss thresholds have been significantly exceeded	0% net damage/loss (+Offsets)

Source: EPA (2004)

The EPA (2009) also define cumulative impact 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 (approximately 200 years before present). Cumulative impacts in this context do not include changes to benthic primary producer habitat caused by natural disturbances such as severe storms or effects of freshwater inundation from river flow, or climate change. Port Hedland has been subjected to several cyclones over the past 35 years (BoM 2010) and it is therefore important to recognise that the mangrove and other BPP communities in the Port Hedland Harbour area would be affected by these and other natural events.

5.2. Previous Historical Loss Estimates

Recent infrastructure projects in the Port Hedland Harbour have required the calculation of estimates of historical and cumulative loss of BPPH as part of the approvals process. Two of the larger, recent projects are Fortescue Metals Group's (FMG) development of Anderson Point, and the development of Utah Point on Finucane Island by the Port Hedland Port Authority (PHPA). Both of these projects used Paling et al. (2003) as the basis for their estimates of historical loss of mangroves that occurred as a consequence of industrial development in the port.

A critical review of the estimates in Paling et al. (2003) identified a number of concerns with the estimates provided (SKM 2009b). Loss estimates compiled by Paling et al. (2003) were confined to those within the major creek system within the harbour (such as the infilling of East Creek by BHP Billiton Iron Ore), and did not include areas to the east or west which are still within the EPA's defined Port Hedland Industrial LAU (EPA 2001). Furthermore, no account was made of the areas where the then Cargill Salt facility (now Dampier Salt Limited) caused the loss of mangrove habitat. Findings from a review of data presented by Paling et al. (2003) are discussed by SKM (2009b).

Most recent project proposals (e.g. by FMG and PHPA) have relied heavily upon the loss estimates provided by Paling et al. (2003), and subsequently the loss estimates provided by the EPA in several Bulletins and Reports. This approach leads to loss estimates based on an original baseline of 2,676 ha (approved by the EPA) and the total of mangroves remaining within the LAUs is derived by subtraction of the approved losses for each successive development proposal. The most recent EPA Report

If this approach is adopted, then the historical and cumulative losses for mangroves in the Port Hedland Industrial LAU including the proposed Outer Harbour Development are as listed in **Table 5-2**.

- **Table 5-2: Historical and Cumulative mangrove losses associated with development in the Port Hedland Industrial LAU**

LAU	Mangrove extent[1]	Current extent of mangroves as defined by EPA	Sequential historical losses	Cumulative losses (%)
Port Hedland Industrial (154.3 km^2)	2,676 ha	2,378.9ha	Area of 297.1 ha lost due to existing development Proposed loss of 40 ha from PHPA South West Creek Development – 40.0 ha **Total Cumulative loss of 342.1 ha**	11.1 12.8
		2,333.9 ha	<u>*Worst-case loss scenario*</u>*:* Port Hedland Outer Harbour project: 27 ha **Total Cumulative loss of 369.1 ha**	13.8

[1]*Source: EPA 2011*

From an accounting perspective, the delineation of a baseline and subtraction of approved losses is sensible enough, but assumes that the baseline area of mangroves would remain static through time if it were not for the losses induced by development.

As mangroves are typically dynamic systems, it is unlikely that over a timespan of decades the total area of mangroves within the LAU would remain static (**Section 5.4**). As there is evidence of both accretion and erosion within mangrove stands in the LAU then it is not possible to predict whether the actual area of mangroves is more or less than that derived from the static accounting model shown in **Table 5-2**.

Therefore the historical and cumulative loss estimates for RGP6 and now the Outer Harbour Development have been recalculated using comprehensive data sets to determine whether the 10% loss threshold has already been exceeded by existing losses or will be exceeded.

5.3. Revised Historical Loss Estimates

Revised loss estimates were originally calculated over the period 1963 to 1993, which is similar to the period 1960 to 1992 investigated by Paling et al. (2003). The year 1963 was chosen for the

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estimation of a baseline because this is the first year when a complete coverage of the area by one set of aerial photographs was available. The use of one set of images for baseline removed the potential for errors inherent in using photographs, maps and other images of different scales and coverage. The level of error inherent in using several different formats of imagery can be considerable and exceed the total allowable level of loss of 10% for the LAU. The revised estimates were expanded to include the whole LAU, including the development of Cargill Salt's facility. Orthorectified images were classified using an unsupervised ISODATA algorithm; full details of the analysis methods and results by vegetation association are provided in SKM (2009a).

The revised loss estimates were then updated to provide a more current estimate of loss by the inclusion of datasets from 2008 (SKM 2009b). These images allow assessment of the losses associated with development up to and including the FMG development at Anderson Point, but do not include the losses from the PHPA Utah Point Development, PHPA South West Creek or the BHP Billiton Iron Ore RGP5 and RGP6 developments.

The total area of mangroves estimated to be present in 1963 is 2,699 ha, and this figure is similar to the official baseline of 2,676 ha adopted by the EPA (2005). Although the difference is trivial in the context of the overall area of the resource, a difference of 23 ha does have an impact upon the percentage of loss calculations. There are more substantial disparities in the estimates of historical losses associated with the infilling of East Creek and the construction of Cargill Salt's facility. The EPA (2005) and Biota (2007) both originally provided estimates of 253 ha of mangrove loss, comprising losses of 155 ha from the infilling of East Creek and 98 ha from the Cargill Salt development. Investigation of the 1963 and 2008 images allowed revised estimates for losses from these two developments, which are shown by mangrove vegetation association in **Table 5-3.** Cumulative losses from the East Creek (BHP) and Cargill Salt developments are estimated to be 155.7 ha and 146.3 ha, respectively, with the vegetation association *Avicennia marina* (scattered) having suffered the greatest losses. The boundaries of this particular vegetation association are difficult to define on the landward side of the mangrove distribution because the vegetation association is defined by scattered trees with either bare areas between trees and/or samphires. The issue of whether to include sparsely distributed outlying trees within the boundary of the vegetation association also contributes to a much less robust boundary delineation than that which can be applied to any of the closed canopy mangrove vegetation associations. Therefore the disparities between estimates of the amount of mangrove loss from the Cargill Salt development may be explained by the error in the estimates of areas of scattered *Avicennia marina*.

- **Table 5-3: Revised Cumulative Loss Estimates (in hectares) of Mangrove Associations due to the East Creek (BHP) and Cargill Salt Developments**

Vegetation Association	East Creek (BHP) (ha)	Cargill Salt (ha)	Cumulative Loss (ha)
Avicennia marina (closed canopy, seaward edge)	10.3	3.7	14.0
Rhizophora stylosa (closed canopy)	47.9	1.5	49.4
Avicennia marina/Rhizophora stylosa (closed canopy)	11.7	3.9	15.6
Avicennia marina (closed canopy, landward edge)	24.1	38.2	62.3
Avicennia marina (scattered)	61.7	99.0	160.7
Total	**155.7**	**146.3**	**302.0**

The 1963 and 2008 images were then examined to determine the cumulative loss within each type of vegetation association. The areal extent derived from interpretation of the images revealed that three of the five vegetation associations had increased in coverage since 1963, despite substantial losses from the infilling of East Creek. The greatest loss resulted from the removal of the mid-upper intertidal areas of scattered *Avicennia marina*, with 22.5% of this habitat lost since 1963 and up to 2008. It is important to note this vegetation association is considered to contribute the least of all the mangrove associations in terms of environmental services (**Section 3.5.1**).

The revised estimates of loss based upon the current status of mangroves present in 2008 (SKM 2009b) show that losses of mangroves to date have been offset to a large extent by gains in mangrove areas during the last 45 years. It is possible that some of the apparent gains in mangrove vegetation are due to errors in the estimates between 1963 and 2008 and there is no doubt that for the vegetation association *A. marina* scattered (**Table 5-4**) the delineation of landward boundaries of open canopy forest is problematic. However, a comparison of the areas of the closed canopy forest vegetation associations (**Table 5-4**), which are much more accurately delineated, shows that while there have been substantial losses of some vegetation associations, substantial gains have occurred such that the estimated net loss of mangroves between 1963 and 2008 is 2.2%.

- **Table 5-4: Cumulative Changes in Extent of Mangrove Associations in 1963 and in 2008**

Vegetation Association	1963 total (ha)	2008 total (ha)	% Cumulative losses or gains
Avicennia marina (closed canopy, seaward edge)	223	220	-1.3
Rhizophora stylosa (closed canopy)	570	589	+3.3
Rhizophora stylosa/Avicennia marina –(closed canopy)	126	89	-29.6
Avicennia marina (closed canopy, landward edge)	891	1,027	+15.3
Avicennia marina (scattered)	889	715	-19.6
Totals	**2,699**	**2,640**	**-2.2**

5.4. Evidence for Increases in Mangrove Extent

Mangrove-lined tidal creeks are dynamic systems and typically show evidence of both erosion and accretion of sediments and associated mangrove vegetation over time, often on the same creek.

The mangroves of the arid Pilbara coastline are not subject to the same erosive and depositional environments typical of estuaries in the wet tropics that produce substantial changes in the morphology of creeks and rivers over relatively short time frames (Woodroffe 1992; Saenger 2003). However, there is ample evidence of local erosion and deposition (Paling et al. 2003; Semeniuk 2007a) sufficient to provide some drivers of change in the distribution, extent and composition of mangrove vegetation inside the defined LAU.

Periodic events such as heavy rainfall runoff, strong waves and storm surges during cyclones also have the potential to quickly and substantially alter the morphology of the coastline and the many tidal creek channels in the defined LAU. These changes would often affect the viability of existing stands and also create new opportunities for colonisation.

The aerial photography from 1963, 1993 and 2008 was examined in detail for evidence of increases in the area of mangrove vegetation associations and for evidence of change in composition (SKM 2009b). While many areas of the mangroves within the LAU showed remarkable stability over a prolonged period of time, there is ample evidence of substantial increases in the areas of mangroves (SKM 2009b).

The gains in mangrove vegetation also include areas where new mangroves have formed and one of the most conspicuous of these is downstream of the Cargill Salt development where alterations to the creek channel have apparently created conditions suitable for colonisation by mangroves. There are several other large and conspicuous areas but most of the gains are small-scale and therefore difficult to readily identify on a large-scale image. At the finer scale, many areas of increase in mangrove vegetation are apparent, particularly the expansion of the *Avicennia marina* closed canopy forest on the landward edge (SKM 2009b).

None of these areas of active gain lie within the area to be impacted by the footprint of the proposed development.

5.5. Direct Loss of Mangrove BPPH Due to Outer Harbour Development

Predicted direct loss estimates due to construction of the infrastructure corridor have been determined for each mangrove vegetation association (**Table 5-5)**. Potential losses of mangrove BPPH in this disturbance envelope are considered to be an absolute worst case scenario.

As shown in **Figure 5-1**, the southern part of the proposed corridor will traverse the area of the DMMA A already approved for reclamation as part of the RGP5 proposal and now constructed and operational. The expected worst case scenario would result in a total loss of 27 ha of closed canopy and open canopy mangroves.

The greatest loss would be in the *Avicennia marina* (scattered) habitat and the *Avicennia marina* (closed canopy, landward edge) mangrove habitat (**Table 5-5**). These two vegetation associations occupy the highest intertidal positions of the five mangrove habitats under consideration. Contribution to environmental services is considered to decrease with increasing shore height (see **Section 3.5.1**) and as such the conservation of low-intertidal mangrove habitat is of high importance. The closed canopy, seaward edge *Avicennia marina* forest in the low intertidal would be the least impacted of the mangrove vegetation associations, with an estimated loss of 1.5 ha, while the losses of high value stands of *Rhizophora stylosa* would be up to 5.5 ha (**Table 5-5**).

- **Table 5-5: Estimated Direct Loss of Mangrove Habitat within Footprint and Disturbance Envelope for Terrestrial Works proposed for the Port Hedland Outer Harbour Development**

Vegetation Association	Pre-impact extent (ha)[1]	Worst case (ha)
Avicennia marina (closed canopy, seaward edge)	223	1.5
Rhizophora stylosa (closed canopy)	570	5.5
Avicennia marina/Rhizophora stylosa (closed canopy)	126	2.0
Avicennia marina (closed canopy, landward edge)	891	7.0
Avicennia marina (scattered)	889	11.0
Total	**2699**	**27.0**

(1) Pre-impact extent (1963) derived from revised analysis as described in this report (**Section 5.3**)

Table 5-6 provides an estimate of the cumulative losses of mangrove habitat within the LAU. **Table 5-6** presents estimates of previous losses and also includes the approved losses for Utah Point (PHPA), RGP5 (BHP Billiton Iron Ore), RGP6 (BHP Billiton Iron Ore) and South West Creek (PHPA).

The calculation of actual net losses (2,699 ha – 2,640 ha = 59 ha) between 1963 and 2008 were made from an image set captured in 2008 where none of the approved mangrove losses for recent project proposals had yet occurred and therefore the total cumulative loss as at 2008 was 2.2% (59 ha/2,699 ha).

Since then, Utah Point (18.6 ha) and RGP5 (6.5 ha) have been approved and the projects have proceeded, and if the projected losses of mangroves for the South West Creek (40.0 ha) and RGP6 proposals (4 ha) are also approved, then the approved cumulative loss from existing net losses (59 ha), plus the approved losses since the 2008 image was captured (29.1 ha), means that the total cumulative loss is 4.7% (127.95 ha/2,699 ha). With the addition of the worst-case scenario for mangrove losses from the proposed Outer Harbour Development (27.0 ha), the cumulative loss of mangroves would rise to 5.9% (160.1 ha/2,699 ha).

The accuracy of measurements of total area of mangrove vegetation associations is distorted by the large error term inherent in the difficulties associated with the definition of scattered *Avicennia marina*, which comprises often large areas of bare tidal pan with a few sparsely distributed trees. Comparisons of areas of this vegetation association between 1963 and 2008 show there is remarkable stability in many areas, suggesting that the bare areas between the trees is not a suitable habitat for colonisation. Therefore, much of what is captured by the landward boundary of this association is not mangrove habitat and its inclusion in calculations provides an unacceptably large error term (SKM 2009b).

- **Table 5-6: Historical and Cumulative Loss of Mangrove BPPH in Port Hedland Industrial LAU using revised estimates**

LAU	1963 mangrove extent[1]	2008 extent of mangroves	Losses since 2008 mangrove area estimate	Cumulative losses (%)
Port Hedland Industrial (154.3 km^2)	2,699 ha	2,640 ha	▪ PHPA Utah Point – 18.6 ha ▪ BHP Billiton Iron Ore RGP5 – 6.5 ha ▪ BHP Billiton Iron Ore RGP6 – 4.0 ha ▪ RHIO 5 ha ▪ PHPA South West Creek – 40.0 ha **Cumulative loss since 2008 = 74.1 ha**	2.2% from 2008 estimate
		Current extent of mangroves 2,565.9 ha	*Worst-case loss scenario*: Port Hedland Outer Harbour project: 27 ha	5.9%

(1) Values are derived from revised analysis as described in this report (**Section 5.3**).

The processes leading to natural creation (and loss) of mangroves in the LAU are not yet understood well enough to determine rates of natural change and the scale or direction of potential future changes in the mangroves of the LAU.

It is important to understand that BPPH are dynamic ecosystems and that gain and loss in spatial coverage are natural processes. It is not scientifically defensible to assume that Port Hedland mangrove systems are static and to simply subtract coverage losses based on approved project clearances without accounting for recruitment and succession of habitats. There is a strong case to regularly revisit the calculations of historical loss, to investigate the underlying processes that may be continuing to provide new areas of mangroves within the LAU and to deal with any issues associated with mapping accuracy.

Given the difficulties associated with accurately delineating the landward boundary of scattered *Avicennia marina* and the relatively low value of this vegetation when compared with the closed canopy forests, it is strongly recommended that future investigations partition the mangrove vegetation into the vegetation associations used by SKM (2009b). This would then readily allow estimation of changes in high value mangroves and accurately identify potential impacts upon those mangrove vegetation associations.

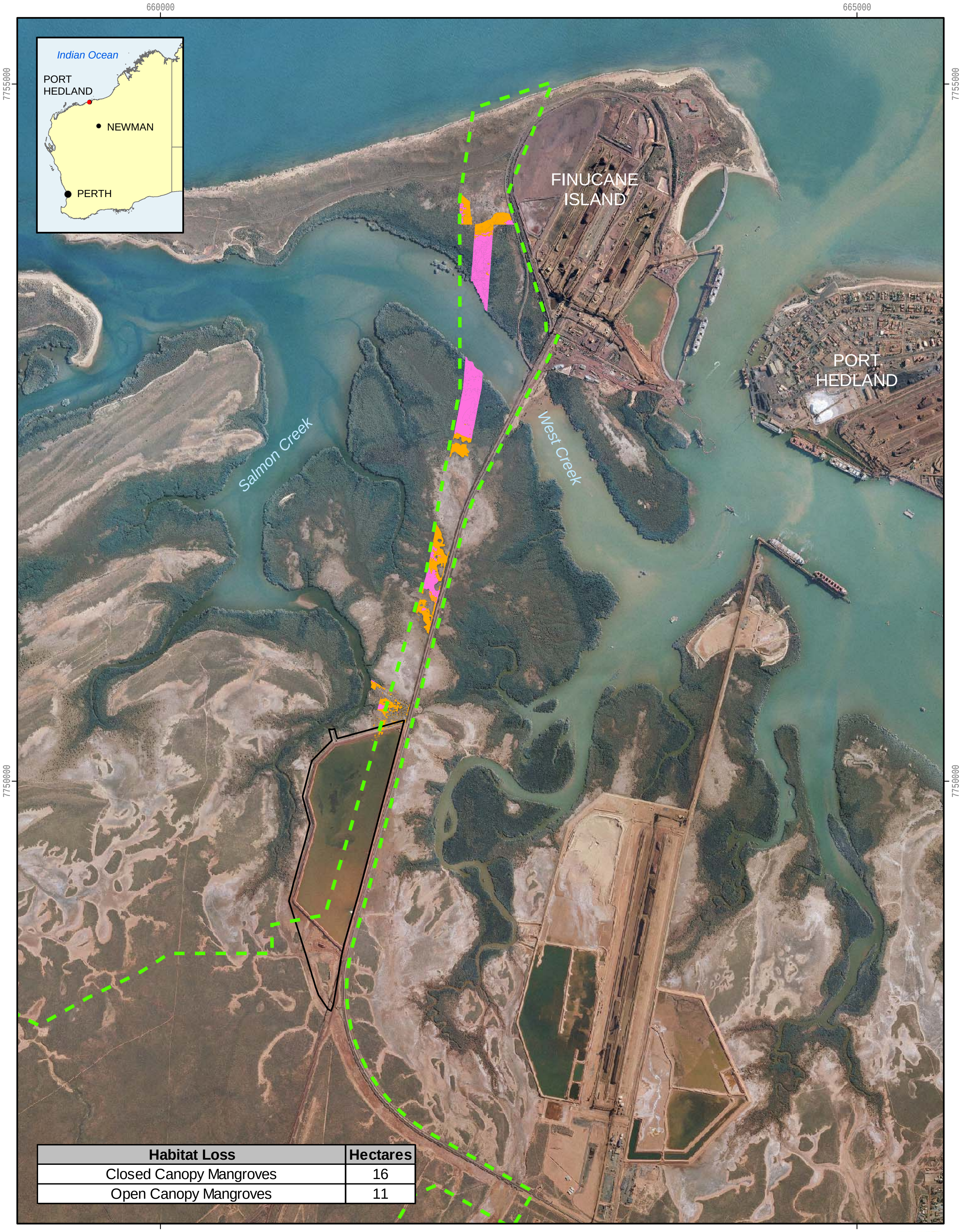
5.6. Loss of other BPPH

For the other BPP types present in the intertidal zone, the estimation of historical and cumulative losses is a more difficult exercise.

There is no currently accepted method for accurately delineating the distribution of cyanobacterial mats and this is the subject of ongoing investigations. An initial evaluation has been undertaken to describe the distribution of cyanobacterial mat communities in the LAU and multispectral imagery has indicated that 1,798 ha of mat may be present, but this number represents the results of a first pass classification algorithm, with no ground truthing undertaken to confirm this distribution and there are problems associated with the interpretation of the outputs from the classification (see **Section 4.3**). So this is likely to represent a gross overestimation of the total area that could support mats. Estimations of cyanobacteria areal coverage will continue to be investigated as part of ongoing BHP Billiton Iron Ore environmental studies.

Within the area of the footprint of the proposed causeway, the area of known cyanobacterial mat occupies no more than 0.25 ha. The area supporting the mats is perhaps larger in years when conditions are more favourable (i.e. heavier rainfall), but that cannot be confirmed at this point. Although there is no data available yet on potential historical and cumulative losses of this BPP and the habitat that supports it, the area of 0.25 ha is considered to be a small component of the overall areas of potential mat that may be present within the LAU (1,798.1 ha).

Within the area of the footprint of the proposed causeway, the area of samphires has not been mapped accurately, primarily because of problems with defining the boundaries of a vegetation association where plants are scattered over tidal flats at low densities. At present there are no protocols for mapping boundaries of the samphire areas and that is the subject of ongoing investigation. The potential area of samphire habitat has not been estimated, due to the problem of assigning discrete boundaries which makes it difficult to accurately discriminate between bare tidal flat and samphire, and mixed samphire and scattered mangrove. The area of samphire within the footprint is also a small percentage of the area of total samphire BPPH within the LAU, based on the estimation of 758 ha by Paling et al. (2003); although it is acknowledged there has likely been substantial loss of this habitat type in the past, and further losses since 2003. Estimations of samphire areal coverage within the LAU continue to be investigated as part of ongoing BHP Billiton Iron Ore environmental studies.



Habitat Loss	Hectares
Closed Canopy Mangroves	16
Open Canopy Mangroves	11

Legend

DMMA A Construction Footprint

Vegetation Association (2008)

Closed Canopy Mangroves

Open Canopy Mangroves

0 200 400 600 800
metres

Scale = 1:35,000 at A4

Datum: GDA94

Projection: MGA94 Zone 50

PRELIMINARY

bhpbilliton

Source:
Orthorectified Aerial Photograph: 06/2008 (BHPBIO) Topography: Geoscience Australia, GEODATA Topo 250K V3 (Copyright Commonwealth of Australia, 2006)
Mangrove: Based on 2008 Reclass of PTHE_ORTHOREG_35K_0608.ecw

Figure 5-1 Estimated Loss of Mangrove Primary Producer Habitat from the Proposed Infrastructure Corridor

003/g106_WV05024_RevA

6. Mitigation and Management Measures

Mitigation and management measures to be used for the minimisation of impacts to intertidal BPPH during the Outer Harbour Development project have been drawn from the Mangrove Management Plan (MMP) developed for the project (SKM 2009c).

The MMP seeks to limit environmental impacts arising from the proposed Outer Harbour Development. Specifically, the objectives and applicable strategies of the MMP are:

Objective: to limit the direct loss of mangroves associated with construction of the infrastructure corridor to the approved footprint and buffer zone

- where practical, cleared material that is lost into the harbour will be collected;
- the disturbance area will be surveyed and delineated using coloured flagging (where practical); and
- clear briefings and instructions to contractors regarding the clearance procedures will be undertaken to minimise the disturbance area.

Objective: to avoid indirect impacts to the mangrove ecosystem of the Port Hedland Harbour associated with the Outer Harbour Development

- maintain unaltered tidal flushing patterns by insertion of necessary number and size of culverts as recommended by modelling;
- installation of rock armouring at the base of the channel crossing to contain fill and stabilise earth fill as it is placed; and
- minimisation of dust generation by watering dust sources, use of dust suppressants, restriction of vehicle movements and speeds, an induction program to make staff aware of the need to minimise dust emissions and reporting of any community complaints regarding dust levels.

Objective: to maintain the abundance, diversity, geographic distribution and productivity of mangrove communities at species and ecosystem levels

- restrict loss of habitat to the corridor footprint and buffer zone.

Monitoring will also be done to assist in the management of potential impacts on mangrove vegetation associations and will consist of the following four components; further detail is provided in the MMP.

6.1. Mangrove Mapping

Aerial photography and field surveys will be used to map the distribution and coverage of mangrove vegetation associations situated near the project footprint. Aerial photography will be ortho-rectified to allow for determination of mangrove cover. Mangrove mapping will be undertaken, prior to the commencement of the project to provide current information on mangrove distribution; at project milestones including the completion of clearing activities within the infrastructure corridor; and on completion of the project.

Mangrove distribution and cover will be compared to the baseline data to confirm that the area of direct disturbance of mangrove habitat does not exceed the approved limits.

6.2. Mangrove Health Surveys

Mangrove health surveys will be undertaken in an effort to ensure that any negative impacts are detected as soon as possible. This will consist of regular visual assessments to determine mangrove condition and detailed mangrove health surveys prior to dredging, after six months (following commencement of construction) and on completion of the project.

The health surveys will include looking at several parameters in 4 m x 4 m quadrats. More detail is contained in the MMP.

6.3. Monitoring of any Sediment Accumulation within Mangrove Vegetation Associations

Sedimentation will be monitored within mangrove communities to provide an early warning of any potential impacts. Sedimentation monitoring will be undertaken at the same monitoring and reference sites used in the mangrove health surveys. Monitoring will be via pegs planted and secured within the sediment along each transect, which will be revisited regularly. The detection of sedimentation is only possible at a coarse scale and would require sedimentation in the order of tens of centimetres.

6.4. Assessment of the Potential for Changes in Soil Salinity in the Vicinity of the Infrastructure Corridor

Soil salinity will be measured at the same sites used in the mangrove health surveys and compared with baselines values collected along transects across the intertidal zone profile (increasing distance from creek banks).

7. Synthesis

The objectives of this document were to assess the potential and known impacts on intertidal BPPH due to activities as proposed by the Outer Harbour Development. The assessment is robust, drawing on information available in the literature and baseline environmental data.

The BPPH present within the area which will be impacted by the proposed corridor comprises intertidal creek banks and tidal flats. These habitats support mangroves, samphires (salt marsh) and cyanobacterial mats.

The mangrove vegetation associations within the Port Hedland Industrial LAU have been separated into five categories; *Avicennia marina* (scattered) 27.1% of total mangrove area, *Avicennia marina* (closed canopy, landward edge) 38.9%, *Avicennia marina/Rhizophora stylosa* (closed canopy) 3.4%, *Rhizophora stylosa* (closed canopy) 22.3% and *Avicennia marina* (closed canopy, seaward edge) 8.3%. Throughout the LAU there is typically the same distribution of the vegetation associations across the intertidal, with zonation corresponding to increasing elevation above mean sea level. Occupying the lowest intertidal position is the seaward *Avicennia marina* closed canopy association, then having progressed through the other associations, scattered *Avicennia marina* occupies the highest (most landward) intertidal position.

Salt marsh vegetation associations are also known as samphires, which describes all species of salt marsh plant that grow within a maritime influence (that are occasionally flooded by tidal water). Within the LAU, the salt marsh areas are largely dominated by one species of samphire, *Tecticornia halocnemoides.* In the Australian tropics, the lower areas of the intertidal, which typically support the most productive stands of salt marsh in temperate regions of the world, are exclusively occupied by mangroves, and therefore tropical salt marsh is a feature of the mid to upper intertidal zones (Adam 1995).

Cyanobacterial mats (blue-green algae) are a common feature of intertidal zones throughout the world and have been found to occur in extensive mats on intertidal mud flats in highly saline conditions along the north-west Western Australian coastline (Paling 1986). Cyanobacterial mats are often found in association with, or in close proximity to, mangroves and salt marsh habitats in tropical and subtropical regions (Sheppard et al. 1992) and fix nitrogen from the atmosphere. However, they may not be present year-round.

These BPP at Port Hedland provide a range of environmental services that include, but are not limited to, primary productivity, biodiversity (both floral and faunal), nutrient trapping and maintenance of water quality, protection against storm surge and erosion, and the recreational amenity value associated with fishing.

The productivity of different BPP at Port Hedland may be influenced by a combination of latitude, rainfall and vegetation height that has elsewhere been shown to be highly correlated with productivity (Saenger & Snedaker 1993) measured as litterfall. Therefore, it is expected that habitats closest to the seaward edge the LAU may be more productive than those on the landward edge. Given that primary productivity is an important source of organic carbon in food chains both within the mangrove and externally (tidal creeks, coastal waters), then the ecological value per unit area of closed canopy mangrove forest would be high relative to other types of mangroves, samphires and cyanobacterial mats.

These habitats are ecologically valuable because of the habitat they provide. Mangroves provide habitat to several species of birds, whelks, crabs, lobsters and also to fish and prawns when inundated at high tide. The value of different categories of mangrove is also different as closed canopy associations may have greater habitat structure that is able to support a greater diversity and abundance of organisms.

The seaward mangroves may be of higher value than landward mangroves due to proximity to channels which provide a refuge at low tide, structural complexity that provides refuge at high tide, inundation and therefore access on all high tides and they are flooded for longer periods compared to areas higher in the intertidal zone.

The only fauna found in the samphire habitat were crabs. The lack of fauna is most likely related to the harsh environmental conditions faced by marine invertebrates at this height on the shore. Tidal inundation is infrequent and for short durations and the pore water and soil salinities are high, therefore crabs may be able to burrow deeper to reach sediment with greater moisture content.

The areas of cyanobacterial mats observed at Port Hedland have mostly been surveyed during dry season conditions (SKM 2007) and all portions of mats observed were dormant with no signs of any invertebrate associates. Similarly, when areas of live, actively photosynthesising mats were observed around the harbour, no evidence was found in the field of organisms feeding on the mats or microorganisms living within the mats.

The historical and cumulative losses of mangroves (the only BPP that could be accurately estimated) in the Port Hedland Industrial LAU were estimated using aerial photographs and estimates from previous and planned development projects. It is important to understand, however, that BPPH are rarely static ecosystems and that gain and loss in area coverage will occur naturally. The assessment of losses recognises the dynamic nature of the BPPH in the LAU.

The threshold of cumulative loss for Category E Development Areas is 10%, which is applicable to the LAU as defined by the EPA (2001). Substantial losses of some vegetation associations have occurred over the last 45 years but also some substantial gains (SKM 2009b) such that the estimated net loss of mangroves between 1963 and 2008, together with planned future development result in a cumulative loss of 4.7% (127.95 ha from a total of 2,699 ha). With the addition of the worst-case scenario for mangrove losses from the proposed Outer Harbour Development (27 ha), the cumulative loss of mangroves would rise to 5.7% (155 ha/2,699 ha).

The impact of these cumulative losses upon the ecosystem functions supported by mangroves and other BPP such as samphires and cyanobacterial mats is considered to be small. This is partly because the predicted loss of mangroves, although considered to be the most important driver of primary productivity in the intertidal zone, is relatively small in terms of the total area of mangroves within the LAU. Further, the predicted mangrove losses are largely comprised of scattered *Avicennia marina*, which has the lowest ecological value.

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