Mardie Project - Benthic Communities & Habitat

Cumulative Loss Assessment

CLIENT: Mardie Minerals Limited

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O2 MARINE

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Version Register

Version	Status	Author	Reviewer	Change from Previous Version	Authorised for Release (signed and dated)	
0	Final	R. Stevens C. Lane	N. Dixon L Wynne R. Hanley	Incorporated comments from Client review	C. Lane	20/05/2019
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Transmission Register

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Acronyms and Abbreviations

Acronyms/Abbreviation	Description
%	Percentage
AGB	Above-ground biomass
AHD	Australian height datum
BCH	Benthic Communities and Habitats
CC	Closed canopy
CLA	Cumulative Loss Assessment
DMP	Dredge Management Plan
DomGas	Domestic gas pipeline
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
EPOs	Environmental Protection Outcomes
ERD	Environmental Referral Document
ESD	Environmental Scoping Document
GLpa	Gigalitre per annum
ha	Hectares
km	Kilometers
Km^2	Square kilometer
ktpa	Kilo tonnes per annum
LAU	Local Assessment Unit
LEPA	Low Ecological Protection Area
m	Meters
MEQMP	Marine Environmental Quality Management Plan
Mtpa	Million tonnes per annum
MTs	Management Targets
MSL	Mean Sea Level
NaCl	Salt / Sodium Chloride
SC	Scattered
SoP	Sulphate of Potash
SPL	Species Protection Level
SSC	Suspended sediment concentration
t	tonnes
ZoHI	Zone of High Impact
ZoI	Zone of Influence
ZoMI	Zone of Moderate Impact

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1. Introduction

1.1. Project Description

1.1.1. Short Summary of the Proposal

Table 1 Short Summary of the Proposal

Proposal Title	Mardie Project
Proponent Name	Mardie Minerals Pty Ltd
Short Description	Mardie Minerals Pty Ltd is seeking to develop a greenfields high quality salt and sulphate of potash (SOP) project and associated export facility at Mardie, approximately 80 km south west of Karratha, in the Pilbara region of WA. The Proposal will utilise seawater to produce a high purity salt product, SOP and other products derived from sea water. The Proposal includes the development of a seawater intake, concentrator and crystalliser ponds, processing facilities and stockpile areas, bitterns disposal pipeline and diffuser, trestle jetty export facility, transhipment channel, drainage channels, access / haul roads, causeway, desalination (reverse osmosis) plant, borrow pits, pipelines, and associated infrastructure (power supply, communications equipment, offices, workshops, accommodation village, laydown areas, sewage treatment plant, landfill facility, etc.).

1.1.2. Proposal Description

Mardie Minerals Pty Ltd (Mardie Minerals) seeks to develop the Mardie Project (the proposal), a greenfields high-quality salt project in the Pilbara region of Western Australia (**Figure 1**). Mardie Minerals is a wholly-owned subsidiary of BCI Minerals Limited.

The proposal is a solar salt project that utilises seawater and evaporation to produce raw salts as a feedstock for dedicated processing facilities that will produce a high purity salt, industrial grade fertiliser products, and other commercial by-products. Production rates of 4.0 Million tonnes per annum (Mtpa) of salt (NaCl), 100 kilo tonnes per annum (ktpa) of Sulphate of Potash (SoP), and up to 300 ktpa of other salt products are being targeted, sourced from a 150 Gigalitre per annum (GLpa) seawater intake. To meet this production, the following infrastructure will be developed:

- Seawater intake, pump station and pipeline;
- Concentrator ponds;
- Drainage channels;
- Crystalliser ponds;
- Trestle jetty and transhipment berth/channel;
- Bitterns disposal pipeline and diffuser;
- Processing facilities and stockpiles;
- Administration buildings;
- Accommodation village,
- Access / haul roads;
- Desalination plant for freshwater production, with brine discharged to the evaporation ponds; and

> Associated infrastructure such as power supply, communications, workshop, laydown, landfill facility, sewage treatment plant, etc.

Seawater for the process will be pumped from a large tidal creek into the concentrator ponds. All pumps will be screened and operated accordingly to minimise entrapment of marine fauna and any reductions in water levels in the tidal creek.

Concentrator and crystalliser ponds will be developed behind low permeability walls engineered from local clays and soils and rock armoured to protect against erosion. The height of the walls varies across the project and is matched to the flood risk for the area.

Potable water will be required for the production plants and the village. The water supply will be sourced from desalination plants which will provide the water required to support the Project. The high salinity output from the plants will be directed to a concentrator pond with the corresponding salinity, or managed through the project bitterns stream.

A 3.4 km long trestle jetty will be constructed to convey salt ($NaCl$) from the salt production stockpile to the transhipment berth pocket. The jetty will not impede coastal water or sediment movement, thus ensuring coastal processes are maintained.

Dredging of up to 800,000 m^3 will be required to ensure sufficient depth for the transhipper berth pocket at the end of the trestle jetty, as well as along a 4 km long channel out to deeper water. The average depth of dredging is approximately 1 m below the current sea floor. The dredge spoil is inert and will be transported to shore for use within the development.

The production process will produce a high-salinity bittern that, prior to its discharge through a diffuser at the far end of the trestle jetty, will be diluted with seawater to bring its salinity closer to that of the receiving environment.

Access to the project from North West Coastal Highway will be based on an existing public road alignment that services the Mardie Station homestead and will require upgrading (i.e. widening and sealing).

The majority of the power required for the project (i.e. approximately 95%) is provided by the sun and the wind, which drives the evaporation and crystallisation processes. In addition, the Project will require diesel and gas to provide additional energy for infrastructure, support services and processing plant requirements.

The proposal will be developed within three separate development envelopes. The boundaries of these development envelopes are shown in **Figure 2** and described in **Table 2**.

Table 2 Location and proposed extent of physical and operational elements

Element	Ref.	Proposed Extent
Physical Elements		
Ponds & Terrestrial Infrastructure Development Envelope – evaporation and crystalliser ponds, processing facilities, access / haul road, desalination plant, administration, accommodation village, quarry, laydown, other infrastructure.	Fig. 2	Disturbance of no more than 11,142 ha within the 15,667 ha Ponds & Terrestrial Infrastructure Development Envelope.
Marine Development Envelope – trestle jetty, seawater intake and pipeline, bitterns pipeline.	Fig. 2	Disturbance of no more than 7 ha within the 53 ha Marine Development Envelope.
Dredge Channel Development Envelope – berth pocket, channel to allow access for transhipment vessels, bitterns outfall diffuser, bitterns dilution seawater intake.	Fig. 2	Disturbance of no more than 55 ha within the 304 ha Dredge Channel Development Envelope.
Operational Elements		
Desalination Plant discharge	Fig. 2	Discharge to concentrator ponds or to bitterns stream.
Dredge volume	Fig. 2	Dredging is only to occur within the Dredge Channel Development Envelope. Dredging of no more than 850,000 m3 of material from the berth pocket and high points within the transhipment channel, with the material to be deposited within the Ponds & Infrastructure Development Envelope.
Bitterns discharge	Fig. 2	Discharge of up to 3.6 gigalitres per annum (GLpa) of bitterns within a dedicated offshore mixing zone.

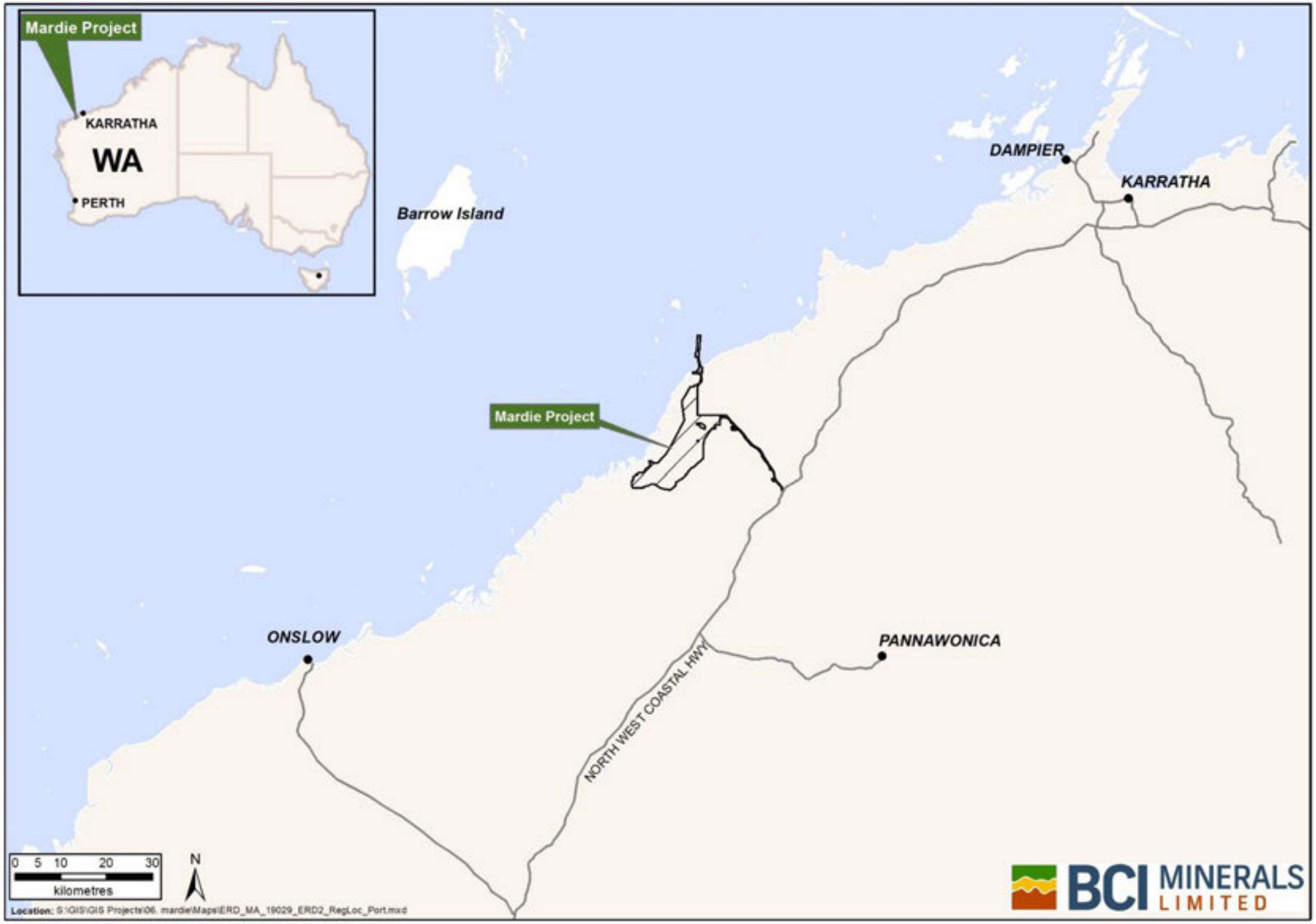


Figure 1 **Mardie Proposal Regional Location**

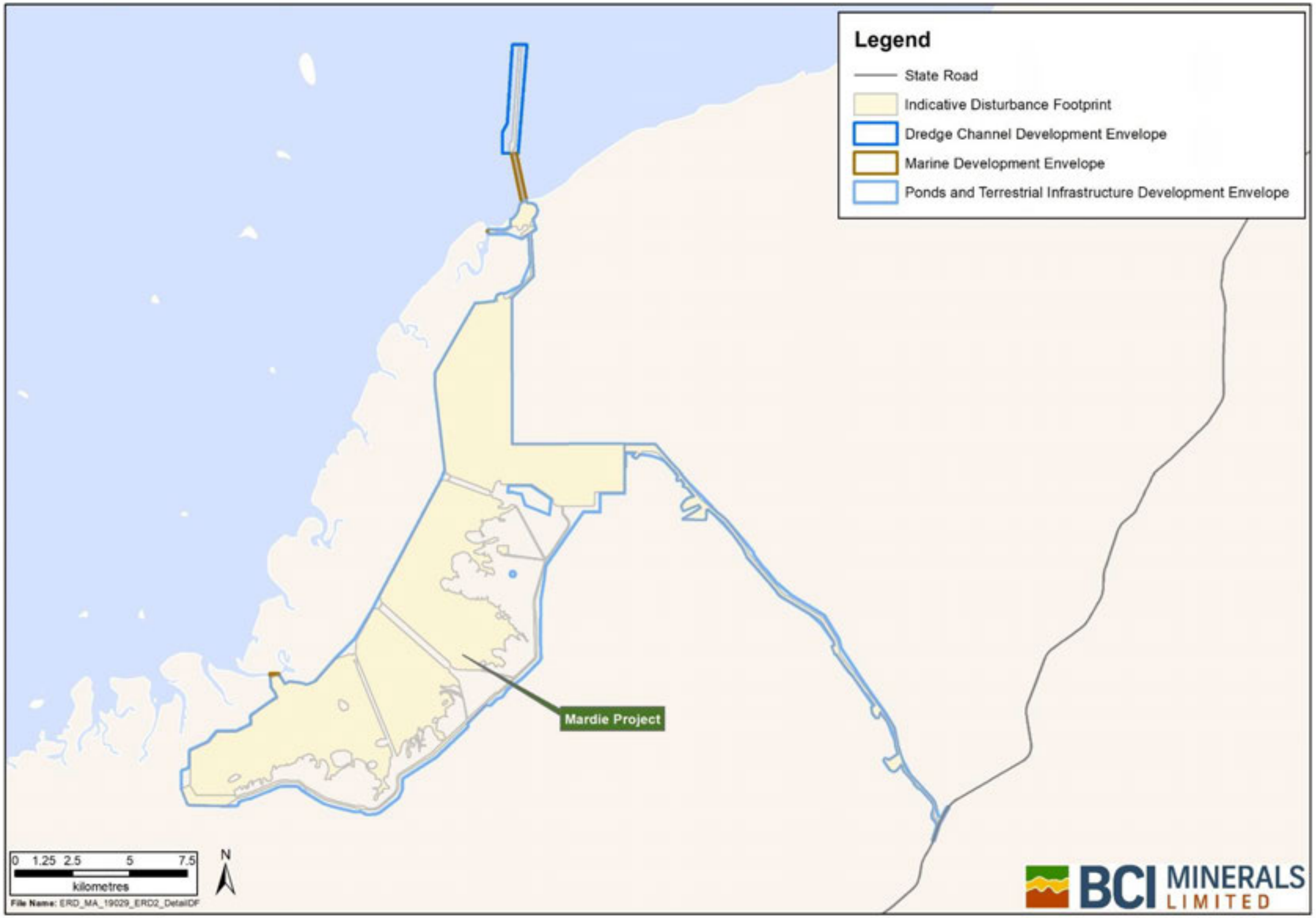


Figure 2 **Mardie Proposal Development Envelopes: Marine, Ponds and Terrestrial Infrastructure and Transhipment Corridor**

1.2. Scope and Objectives

This report outlines the benthic communities and habitat cumulative loss assessment (CLA) undertaken for the Mardie Project.

The marine benthic community at Mardie is known to support a sparse but diverse range of intertidal and subtidal BCH, including primary producer habitat such as coral, seagrass and mangroves both within and adjacent to the proposed development at Mardie. The scope of this BCH CLA Report is to address the relevant work requirements outlined by Preston (2018) in the Mardie Project - Environmental Scoping Document (ESD). **Table 3** outlines the specific requirements from the ESD that are to be addressed by this BCH CLA Report.

Table 3 Environmental Scoping Document Requirements Addressed in this Report

ESD Item	Requirement	Report Section
ESD Item 1	Develop appropriate Local Assessment Units (LAUs) in consideration of: Intertidal and sub-tidal BCH mapping; Management boundaries (i.e. Regionally significant mangrove areas); Bathymetry; and Coastal geomorphology.	Section 2
ESD Item 17.	Identify the proposed activities and the potential scale and significance of direct and indirect impacts to BCH.	Section 1 Section 3 Section 4 Section 5 Section 6
ESD Item 19.	Evaluate the combined direct and indirect impacts to BCH, after demonstrating how the mitigation has been considered and applied. Predictions shall: a) Align with the approaches and standards outlined in Technical Guidance - Protection of BCH (EPA, 2016c); b) Involve application of contemporary scientific information on pressure response pathways, bio-indicators, thresholds, tolerance limits and resilience (resistance and recovery potential) of BCH types in relation to dredging pressures; c) Consider any spatial and temporal variability of BCH types within the study area and how this effects the predicted impacts; d) Consider annual seasonal variability in nearshore current patterns and how this affects the predicted sediment plume and loss of BCH; e) Consider historic cumulative impacts to BCH within the LAUs; f) Include a description of the severity and duration of reversible impacts, and the consequences of impacts on, and risks to, biological diversity and ecological integrity at local and regional scales; g) Include an estimate of the level of confidence underpinning predictions of residual impacts; and h) Give consideration to plausible events with the potential to significantly impact BCH including the introduction of marine pests, breached levee walls, hydrocarbon and other spills, and extreme episodic events (e.g. tropical lows and cyclones).	a) All Sections b) Section 4.1 Section 4.3 c) Section 3.2 O2 Marine 2020a/b d) Baird 2020a e) Section 5 f) Section 5 Section 6 g) Section 5 h) Section 4.3
ESD Item 21.	Provide figures of the proposed disturbance and predicted indirect impact to BCH.	Figure 3 Figure 4 Figure 5 Figure 6 Figure 8

1.3. Legislation and Regulatory Guidance

This study has been aligned with relevant state and federal legislation and technical guidance that will be applicable to BCH in the Project area. The relevant legislation specific to BCH, includes:

- Commonwealth *Environmental Protection and Biodiversity Act 1999* (EPBC Act);
- West Australian *Conservation and Land Management Act 1982* (CALM Act);
- West Australian *Environmental Protection Act 1986* (EP Act);
- West Australian *Biodiversity Conservation Act 2016* (BC Act); and
- West Australian *Fish Resources Management Act 1994* (FRM Act).

The EPA provides guidance on how an Environmental Impact Assessment (EIA) will be evaluated when determining whether or not an assessed proposal may be implemented. The EPA uses environmental principles, factors and associated objectives as defined within the Statement of Environmental Principles, Factors and Objectives (EPA 2018) as the basis for assessing whether a proposal's impact on the environment is acceptable. These principles, factors and objectives therefore underpin the EIA process.

1.3.1. Environmental Principles

The object of the EP Act is to protect the environment of the State and identifies five environmental principles. The third principle of the conservation of biological diversity and ecological integrity is directly relevant to subtidal BCH and is therefore a fundamental consideration for an EIA.

1.3.2. Environmental Factors and Objectives

The EPA list 13 environmental factors, which are organised into five themes: Sea, Land, Water, Air and People. The environmental factors are those parts of the environment that may be impacted by an aspect of a proposal. An environmental objective has been established for each environmental factor. The EPA will then make judgements against these objectives on whether the environmental impact of a proposal may be significant. The BCH was identified by the EPA as one of the key environmental factors for the Project. The objective for BCH is *'to protect benthic communities and habitats so that biological diversity and ecological integrity are maintained'*.

The EPA provides the following guidelines to explain how impacts on BCH are considered during EIA and to set out the type and form of the information that should be presented to facilitate the assessment of impacts on BCH in Western Australia's marine environment:

- Technical Guidance – Protection of Benthic Communities and Habitats (EPA 2016a);
- Environmental Factor Guideline – Benthic Communities and Habitats (EPA 2016b);
- Technical Guidance – Environmental Impact Assessment of Marine Dredging Proposals (EPA 2016c); and
- Guidance Statement for the Protection of Tropical Arid Zone Mangroves Along the Pilbara Coastline (EPA 2001).

2. Local Assessment Units

Section 4.2 of EPA 2016a outlines the requirement to clearly define spatially based LAUs within which cumulative losses for BCH can be calculated, assessed and presented. LAUs are required to be location specific, assessed on a case by case basis and consider local aspects of bathymetry, substrate type, exposure, currents, biological attributes such as habitat types. EPA (2016a) suggests that LAUs should typically be established in units approximately 50 km^2. As the Mardie Project area encompasses approximately 45 km of coastline, proposed LAUs were predominately based upon the following factors:

- Coastal geomorphology;
- Bathymetry;
- Aspect (direction the coastline faces) as relevant to exposure;
- BCH type and condition; and
- 'Regionally significant' mangrove management area boundaries.

Based upon the above criteria and the results identified through the BCH mapping and field survey ground-truthing, seven LAUs have been proposed. LAU boundaries are presented in **Figure 3** whilst total areas are presented within **Table 4**.

A brief summary of the justification for each of the five proposed LAUs for the intertidal BCH assessment is provided below:

- LAU1:
  - Intertidal BCH area (5,392 ha/53.92 km^2);
  - Predominantly NNW facing coastline;
  - North-eastern boundary is determined by the by the southern boundary of the Fortescue River Regionally Significant Mangrove Area;
  - Eastern and western boundaries are determined by the extent of intertidal BCH
  - LAU is characterised by a large dunal complex with associated terrestrial vegetation extending along the coastal fringe of the algal mat from the SW to NE;
  - BCH consists primarily of intertidal mudflats and a algal mat community extending from the southern boundary and continuing into the Fortescue River Delta. Some samphires occur surrounding the algal mat in the south of the LAU; and
  - No mangrove BCH are present.
- LAU2:
  - Intertidal BCH area (5,784 ha/57.84 km^2);
  - Predominantly WNW facing coastline;
  - North-eastern boundary is determined by the northern extent of mangrove BCH and runs adjacent to the project footprint prior to where algal mat BCH occurs to the north;
  - Eastern boundary typically follows the western extent of samphire communities prior to the low lying supratidal algal mat community occurs;
  - BCH consists of mangrove and samphire BCH surrounding an unknown, considerably sized creek system behind primary foredune in the north which makes way for a series of smaller creeks lined with fringing mangroves interspersed by samphire communities; and

  - Mangrove BCH typically declines with distance south.
- LAU3:
  - Intertidal BCH area (4,450 ha/44.50 km^2);
  - Western border aligns with the western extent of the large algal mat community from the north to the southern border;
  - Eastern border runs adjacent to the project (northern half) and the western extent of intertidal BCH (southern half); and
  - LAU characterised by a low-lying area of contiguous algal mat which extends along the western boundary and increases in width with distance south. This is flanked by supratidal mudflats along the eastern extent which make way for samphire BCH communities mixed with terrestrial communities in the central east and terrestrial vegetation in the south.
- LAU4:
  - Intertidal BCH area (4,724 ha/47.24 km^2);
  - Coastline faces WNW in the north and N in the south forming a shallow embayment and intertidal delta;
  - Southern boundary is aligned to the Robe River Regionally Significant Mangrove Area and (approximately) with the Peter Creek East / Robe River Secondary Coastal Compartment boundary;
  - BCH is similar to LAU-1, however tidal creek systems become increasingly complex in the south and support more extensive mangrove communities which are interspersed by samphire communities;
  - Mangrove BCH of generally of better quality in the south associated with the delta formation; and
  - Small portion of Project area historically affected by DomGas Pipeline.
- LAU5
  - Intertidal BCH area (9,171 ha/91.71 km^2);
  - Western boundary follows extent of contiguous algal mat from northern border and supratidal BCH to the southern border;
  - Eastern boundary follows the Project envelope;
  - Similar characteristics as LAU2 however, the intertidal zone extends further from coast, the proportional extent of mudflats is greater and algal mats lower and samphire communities occur only at the southern border;
  - Eastern boundary is flanked by terrestrial vegetation along the entire boundary; and
  - Small portion of Project area historically affected by DomGas Pipeline.
- LAU6
  - Intertidal BCH area (6,181 ha/61.81 km^2);
  - NW facing coastline;
  - Located entirely within the Robe River Regionally Significant Mangrove Area;
  - Borders the northern extent of a coastal dune system in the west and the Robe River Regionally Significant Mangrove Area boundary in the east;
  - Eastern boundary also aligns with the Peter Creek East / Robe River Secondary Coastal Compartment boundary;
  - LAU excludes all tributaries and mangrove areas of the Robe River; and

  - Mangrove BCH represents the best quality in the Project area.
- LAU7
  - Subtidal BCH area (7,574 ha/75.74 km^2);
  - NNW facing coastline;
  - Extends from the foreshore mudflat at the Lowest Astronomical Tide Line (Southern boundary) to approximately the 8 m Isobath (Northern boundary);
  - Eastern boundary of the LAU is aligned to the Western boundary of the Fortescue River Regionally Significant Mangrove Area;
  - Western boundary of the LAU is aligned to the change in aspect of the coastline from NNW to NW;
  - LAU is characterised by gently sloping, bare silt / sand substrate with areas of low relief, sand veneer over limestone pavement, which typically support sparse to moderate cover of filter feeders, macroalgae, seagrass and coral species; and
  - LAU specifically excludes BCH associated with the nearshore islands, which tend to support more diverse and better-quality coral and macroalgal BCH communities than is present within the LAU.

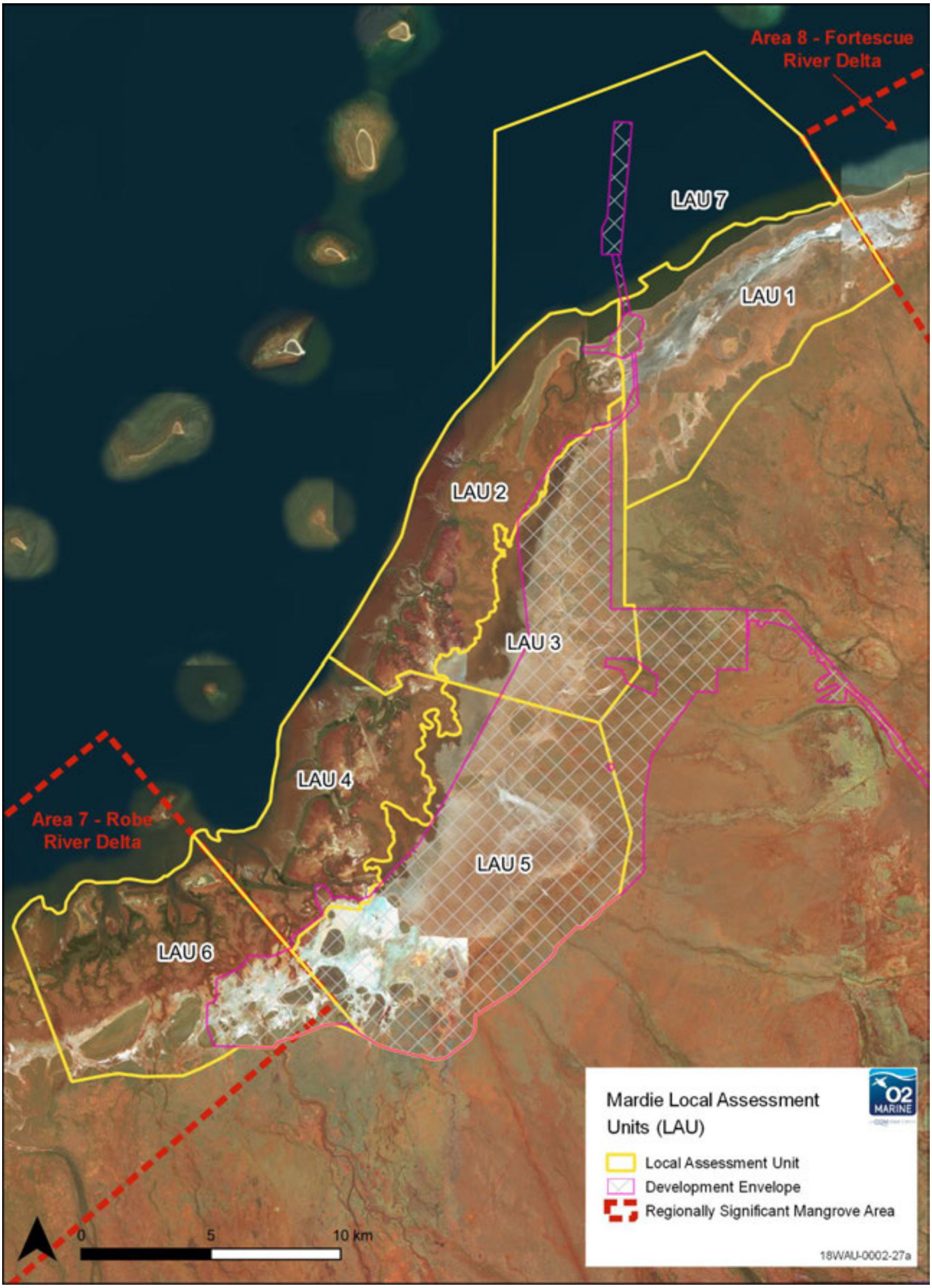


Figure 3 **Local Assessment Units for BCH overlaid against the Mardie Project Development Envelope and Regionally Significant Mangrove Areas 7 and 8.**

3. Benthic Communities & Habitat Mapping

3.1. Benthic Communities & Habitat

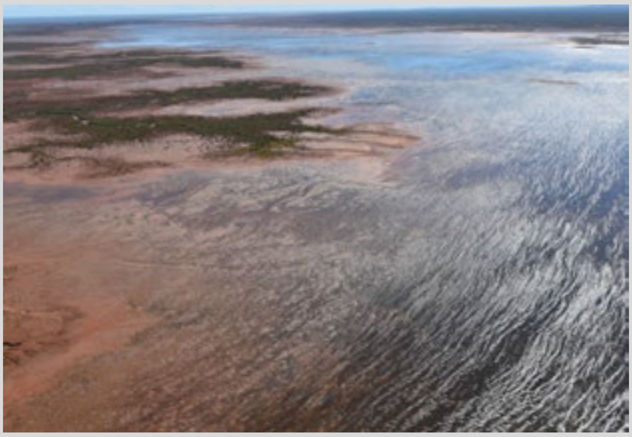
Extensive surveys of the subtidal and intertidal BCH were undertaken within and adjacent to the Project area (O2 Marine 2020a; O2 Marine 2020b; Phoenix 2019; Stantec 2018). Sixteen BCH classes were identified and mapped, including seven intertidal and nine subtidal BCH classes. The extent and distribution of these BCH classes is shown on **Figure 4**. The total area (Expressed in hectares and as a percentage of the total in each LAU) of each BCH class within each LAU is presented in **Table 4** and a brief description of each BCH class is provided in **Table 5.**

Table 4 Area (ha / %) of the Benthic Communities and Habitat within each LAU. Note all figures rounded to the nearest whole number.

BCH Class		LAU1		LAU2		LAU3		LAU4		LAU5		LAU6		LAU7		TOTAL	
		ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)
Total area of LAU		5,392	12%	5,784	13%	4,450	10%	4,724	11%	9,171	21%	6,181	14%	7,574	18%	***43,277***	***100%***
Intertidal BCH																	
Algal Mat		857	16%	0	0%	1,300	29%	0	0%	1,259	14%	43	1%	-	-	***3,459***	***10%***
Foreshore Mudflat/Tidal Creeks		401	7%	2,133	37%	0	0%	1,596	34%	0	0%	883	14%	-	-	***5,014***	***14%***
Mangroves (Closed Canopy)	*A. marina* (Seaward edge)	0	0%	95	2%	0	0%	113	2%	0	0%	116	2%	-	-	***325***	***1%***
	R. stylosa (Behind Am)	0	0%	2	0%	0	0%	28	1%	0	0%	135	2%	-	-	***164***	***<1%***
	R. stylosa / A. marina (Closed canopy mixed)	0	0%	37	1%	0	0%	77	2%	0	0%	177	3%	-	-	***291***	***1%***
	A. marina (Landward edge)	0	0%	79	1%	0	0%	151	3%	0	0%	273	4%	-	-	***503***	***2%***
Mangroves (Scattered)	*A. marina* (Scattered)	0	0%	750	13%	0	0%	751	16%	0	0%	827	13%	-	-	***2,327***	***7%***
Rocky Shores		<1	<1%	6	0%	0	0%	0	0%	0	0%	53	1%	-	-	***59***	***<1%***
Samphire/Samphire Mudflats		149	3%	2,030	35%	264	6%	1,533	33%	471	5%	1,546	25%	-	-	***5,993***	***17%***
Sandy Beaches		22	<1%	10	0%	0	0%	0	0%	0	0%	0	0%	-	-	***32***	***<1%***
Mudflat/Saltflat		2,260	42%	339	6%	2,069	46%	429	9%	4,775	53%	636	10%	-	-	***10,509***	***29%***
Other terrestrial habitats (included for information purposes)		1,702	32%	304	5%	817	18%	0	0%	2,502	28%	1,496	24%	-	-	***6,820***	***19%***
Cleared Areas		0	0%	0	0%	0	0%	46	1%	164	2%	0	0%	-	-	***200***	***<1%***
Subtidal BCH																	
Bioturbated Sand	Bare Substrate	-	-	-	-	-	-	-	-	-	-	-	-	6,745	89%	***6,745***	***89%***
	Sand / Sparse (<5%) Macroalgae	-	-	-	-	-	-	-	-	-	-	-	-	82	1%	***82***	***1%***
	Sparse (<5%) Cover	-	-	-	-	-	-	-	-	-	-	-	-	113	1%	***113***	***1%***

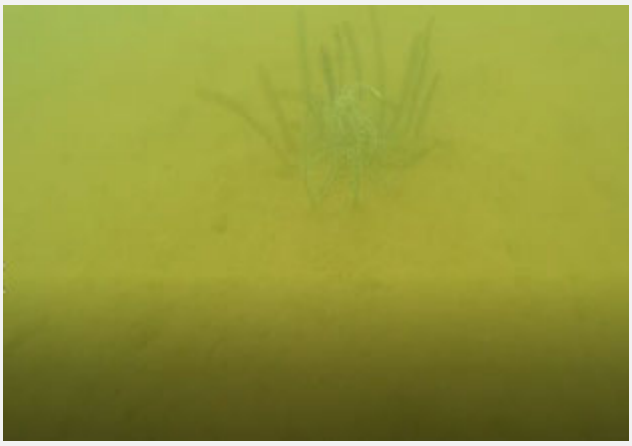
BCH Class		LAU1		LAU2		LAU3		LAU4		LAU5		LAU6		LAU7		TOTAL	
		ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)
Filter Feeder / Macroalgae / Seagrass	Low (5-10%) Cover	-	-	-	-	-	-	-	-	-	-	-	-	445	6%	***445***	***6%***
Coral / Macroalgae	Low (5-10%) Cover													71	1%	***71***	***1%***
	Moderate (10-25%) Cover													92	1%	***92***	***1%***
	Dense (>25%) Cover – Macroalgae Dominated													<1	<1%	***<1***	***<1%***
	Dense (>25%) Cover – Coral Dominated													25	<1%	***25***	***<1%***

Table 5 Description of the Benthic Communities and Habitat of the Mardie Coastline

BCH Class	Description (Area)	Example Image
Intertidal BCH		
Algal Mat	**Algal Mat** Algal mats are typically green to grey or black, and either contiguous or fragmented. 11 species were identified with filamentous cyanobacteria *Microcoleus sp*. and *Lyngbya sp* the dominant species. Algal mat communities extend over 3,400 ha and comprise ~10% of the total mapped intertidal BCH area. They predominantly occur in two major communities within the central and northern sections of the study area. They occur within a relatively nominal elevation of 1.1 – 1.3 m AHD which is lower than the adjacent seaward BCH where they form vast shallow lakes at high tides (>1.2m).	
Foreshore Mudflat/Tidal Creek	**Foreshore Mudflat/Tidal Creek** A variety of benthic habitat types from flat fine to coarse sands, flat mud, sparse to high macroalgae, and low to moderate seagrasses were identified occurring within Foreshore Mudflats/Tidal Creeks. Foreshore Mudflats/Tidal Creeks occur over 5,000 ha and comprise ~14% of the total mapped intertidal BCH area. Tidal creeks are typically well established within the southern coastal LAUs (Robe River Delta) and become sparser in the northern coastal LAUs. Foreshore mudflats extend over a wider area through the central coastal LAUs with subtidal region much closer to the coastline in the northern and southern LAUs.	

BCH Class	Description (Area)	Example Image
Mangrove	**CC Mangroves** CC mangroves comprise the greater structural complexity, typically higher seaward mangrove associations. *Avicennia marina* dominate the species with *Rhizophora stylosa* the sub dominant species. CC mangrove communities extend over 1,280 ha and comprise ~4% of the total mapped intertidal BCH area. They are very well established within LAU6, with ~46% of their total area represented. CC mangroves occur as ribbons along the coastline and fringing tidal creeks, with more vast forest occurring within the southern coastal LAUs, particularly LAU6 within the boundary of the Robe River Delta.	
	SC Mangroves SC mangroves comprise the least structural complexity, typically lower landward mangrove associations. *Avicennia marina* dominate the species with *Ceriops australis* also observed. SC mangrove communities occur over 2,300 ha and comprise ~7% of the total mapped BCH area. SC mangroves are the most extensive mangrove functional groups representing over 64%. They are typically located on the landward extents extending over wide intertidal mudflat areas with comparable spatial extents occurring within each of the three LAUs.	
Rocky Shoreline	**Rocky Shoreline** Rocky shorelines within the study area were typically low relief rock platforms generally with little to low associated flora and fauna. Macroalgae were identified as the dominant communities with minimal juvenile hard corals, oyster stacks and some soft corals also present. Rocky shorelines occur over 59 ha comprising <1% of the total mapped BCH area. They are only located within LAU2 and LAU6.	NA

BCH Class	Description (Area)	Example Image
Samphire/Samphire Mudflat	**Samphire/Samphire Mudflat** Samphire/Samphire Mudflats are distributed over more than 5,900 ha, comprising approximately 17% of the mapped intertidal BCH. They are typically located on the landward extent of Mangroves, whilst through the centre of the study site occur on the seaward extent of Algal Mats, with several smaller communities in LAU1 and LAU3 seaward of terrestrial vegetation. By area they are the greatest in LAU2 and lowest in LAU1.	
Mudflat/Saltflat	**Mudflat/Saltflat** Mudflat/Saltflats are extremely low in biodiversity and support little to no associated fauna or flora due to their characteristic high salinities. Mudflat/Saltflats are the dominant intertidal BCH extending over 10,509 ha and comprising ~29% of the total mapped BCH area. They are most dominant through the supratidal LAUs (3 & 5) representing over 83% of their total distribution. They typically occur on the higher intertidal gradients on the landward extent of Samphire's or Algal Mats.	
Sandy Beach	**Sandy Beach** Sandy beaches are typically flat, low energy, low profile beaches backed by gently rising dunes. Sandy beaches are only located within LAU1 and LAU2 representing 32 ha in total and comprising <1% of mapped BCH. They are found extending from the northern extent of LAU1 into the northern LAU2 they continue along the coast for approximately 2.5 km west of the northernmost creek mouth.	
Subtidal BCH		

BCH Class	Description (Area)	Example Image
Bare / Bioturbated Sand	**Bare Substrate** Typically comprises of silt or sand with no or occasional very sparse macroalgae. Silt areas often comprised of bioturbation (burrows formed by living organisms). Sand areas often contain traces of shell grit. This habitat comprises 89% of the subtidal BCH within LAU7 and is also widely dispersed across the region.	
	Sand / Sparse (<5%) Macroalgae Fine silt/sand and bioturbated bedform with a very patchy distribution of macroalgae and invertebrates. Macroalgae (Phaeophyta) was the dominant cover, but was very sparse, generally comprising <1% of the overall cover. Class was differentiated from the other macroalgal classes due to the very sparse nature of the cover and the much finer grained, and often bioturbated sediments. This habitat comprises 1% of the subtidal BCH within LAU7. Outside of LAU7, it was also observed on the eastern fringing waters of Round Island, whilst the largest contiguous area was observed closer to the mainland in the shallow waters between Angle Island and the mainland.	
Filter Feeder / Macroalgae / Seagrass	**Sand / Sparse (<5%) Filter Feeder Cover** Sparse filter feeder habitat occurs where the relief is flat and is associated with fine to coarse sands. Although only present in sparse densities (<5% Cover), hydroids are most common where there is no bedform, whilst sponges occur where there is some bioturbation. This habitat comprises 1% of the subtidal BCH within LAU7 and is widely dispersed throughout the region.	

BCH Class	Description (Area)	Example Image
	Low (5-10%) Cover Macroalgae / Filter Feeders Flat to low relief constituting either fine to coarse sands, including shell grit on occasions. Macroalgae, hydrozoan and sponge species are equally dispersed throughout this habitat although benthic cover is low (3-10%). Occasional very sparse (<1%) cover of *Halophila sp*. seagrass was also observed at some locations. This habitat comprises 6% of the subtidal BCH within LAU7 and follows a patchy distribution throughout the region. Outside of LAU7, this habitat was also observed in small patches fringing the shallow waters of Long Island, Mardie Island and close to the mainland.	
Coral / Macroalgae	**Low (5-10%) Cover Coral** Flat to low relief rock and rubble with coarse sand. Low (3-10%) cover of soft and hard corals, including *Faviidae, Dendrophyllidae, Mussidae and Octocroals*. Sparse macroalgae was also present. This habitat comprises 1% of the subtidal BCH within LAU7. Outside of LAU7 this habitat was also found fringing Mardie Island and in small isolated patches between Angle Island and the mainland. It was generally recorded in waters between 1-3 m depth.	
	Moderate (10-25%) Cover Low to moderate relief rock and rubble/coarse sand. Low to moderate cover (3 – 25%) of soft and hard corals with macroalgae. Corals largely consisted of *Faviidae, Poritidae*, and Octocorals, while *Phaeophyceae* dominated the macroalgae communities. This habitat class comprises only 1% of the subtidal BCH within LAU7. However, outside of LAU7, it was recorded in larger areas in fringing shallow waters south of Mardie Island and adjacent to the mainland coast.	

BCH Class	Description (Area)	Example Image
	Dense (>25%) Cover Macroalgae Dominated This habitat class occurs on low relief substrate with fine to coarse sands and areas of exposed limestone reef. Dense assemblages (>75%) of macroalgae and hydrozoan species predominately in waters at depths of 2.2m-4.0m. This habitat also supported sparse juvenile corals (*Faviidae, Dendrophyllidae, Mussidae)* with occasional larger coral (*Poritidae*) bommies (1-2m diameter). This habitat class comprised <1% of the subtidal BCH in LAU7. It was also identified outside of LAU7 in the waters fringing the eastern outer edge of Long Island, Round Island and Sholl Island.	
	Dense (>25%) Cover Coral Dominated Low relief limestone reef and rubble substrate which supports high coral cover (25%-75%) of diverse coral species, including *Faviidae, Dendrophyllidae, Mussidae, Portitidae*, and Octocoral species. This habitat class was only recorded at one location in LAU7 and, as such, comprises only <1% of the subtidal BCH within LAU7. However, it was also recorded outside of LAU7, in a much larger area, fringing the Northern edge of Mardie Island.	

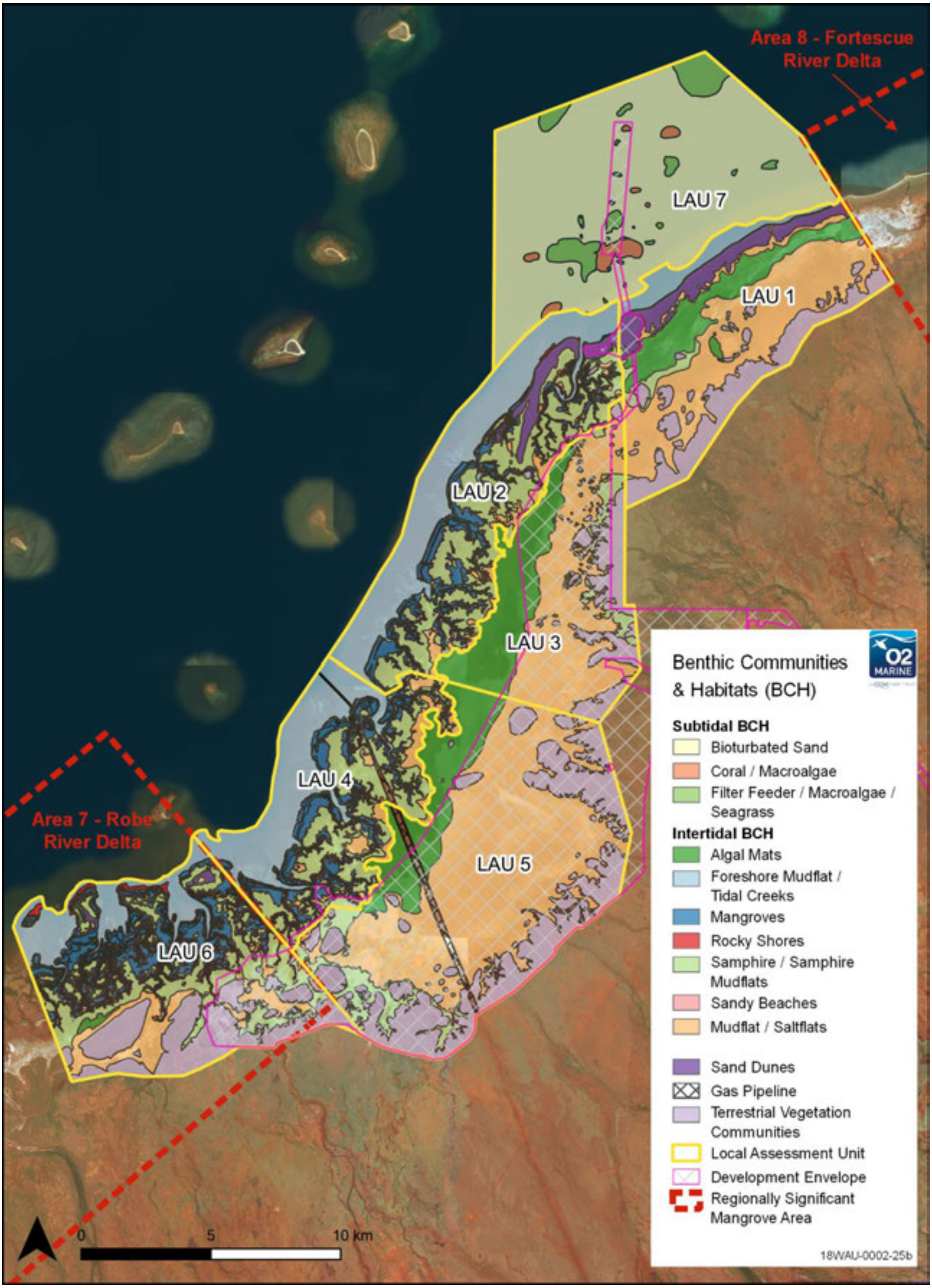


Figure 4 **Benthic Communities and Habitat of the Mardie Coastline**

3.2. Local & Regional Values

3.2.1. Conservation Values

In WA the conservation of ecologically significant marine, estuarine or terrestrial ecosystems may be managed through reserves established under the CALM Act. The coastal habitats within the Mardie Project study area have not been identified as containing significant ecological communities warranting protection through the introduction of marine or terrestrial reserves.

There are no implications from any of the proposed Commonwealth Marine Reserves for the Mardie project due to the coastal location contained completely within State Waters.

EPA position and Guidelines

Whilst no formal reserves have been established, a discussion paper by Semeniuk (1997) was presented to the EPA, whereby the subsequent Guidance Statement for protection of tropical arid zone mangroves along the Pilbara coastline No1 was developed and issued (EPA 2001). Semeniuk's (1997) assessment on a global scale noted:

> 'This region represents the most arid coast in Australia, and. from a global perspective presents a heterogeneous mix of coastal types in a generally depositional system'; and
> that Western Australia does not support any unusual endemic or restricted mangrove species. All mangrove species within Western Australia are common and widespread elsewhere, either in northern Australia, or in the Indo-Pacific region proximal to northern Australia, and so in this sense, the mangroves in Western Australia are not globally significant.

Semeniuk (1997) presented an argument for a series of areas of regionally significant mangrove formations based upon:

> the extent or rarity of the habitat;
> the internal diversity of the habitat;
> the ecological significance of a given stand; and
> the nationally to internationally significant features of a given site.

EPA 2001 identified:

> 'The mangroves along the Pilbara coastline are the largest single unit of relatively undisturbed tropical arid zone habitats in the world',
> 'average tree height is smaller, species diversity relatively lower and the associated flora and fauna communities less complex when compared with the mangrove communities of the wet tropics.'

Based upon Semeniuk (1997) EPA (2001) identified a series of regionally significant mangrove areas which are considered to be 'very high conservation value'. Two areas relevant to the Mardie Project have been identified by (EPA 2001) as regionally significant areas: Robe River (Area 7) and Fortescue River (Area 8) deltas. The boundaries of these two regionally significant mangrove areas as the relate to the Mardie Project are presented in **Figure 4**. Mangroves within these designated areas are classified under '*Guideline 1 – Regionally significant mangroves – Outside designated industrial areas or* *associated port areas*', whilst all other mangroves within the study area fall under '*Guideline 2 – Other mangrove areas – Outside designated industrial areas or associated port areas'.*

From EPA 2001:

> *The EPA's operational objective for Guideline 1 areas is that no development should take place that would adversely affect the mangrove habitat, the ecological function of these areas and the maintenance of ecological processes which sustain the mangrove habitats, and*
> *The EPA's operational objective for Guideline 2 areas is that no development should take place which would cause unacceptable impacts on the mangrove habitat, the ecological function of these areas and the maintenance of ecological processes which sustain the mangrove habitats.*

3.2.2. Regional Significance

Intertidal habitats assessed within the Mardie Project area were found to be commonly distributed throughout the wider Pilbara region, with many having distributions either within the Australian tropics or internationally. Many species identified during the assessment are also typically found within a broader geographical distribution. Of particular significance within the study area, as identified within the Mardie Project ESD (Preston 2018), are the Algal Mats and Mangrove associations. Samphire's and their particular regional significance are presented within a separate appendix attached to the Environmental Referral Document (ERD).

Mangroves

Mangrove communities were dominated across the study area by *A. Marina*, with *R. stylosa* common in surveyed seaward communities with several observations of *C. australis* occurring in landward associations. About 60 species of mangrove trees belong to several botanical families; eight in the Americas, 40 species in Asia, and 13 in Africa (Holgium *et. al.* 2001). Of the 40 recorded Asian species nine have been identified within the Pilbara region, 19 within the Kimberley region, 32 in the Darwin region and 39 in northern Queensland (Duke 2006). Internationally Brazil, Indonesia, and Australia have the largest representative areas of mangrove communities (Holgium *et. al.* 2001). Within WA, mangrove habitats and assemblages have been widely assessed and seven recognised sets of Mangrove biogeographic regions or coastal sectors have been identified (Semeniuk et al. 1978, Johnstone 1990 and Semeniuk 1993). These are characterised by distinctive climatic and geomorphic settings and follow the decrease in species richness evident from north to south (URS 2010).

The Kimberley region of north west Australia has climatic and geomorphological aspects which support high Mangrove species and association diversity and habitat types. The region is characterised by a tropical climate, has a large tidal variation and variable wave energy which has allowed Mangroves to develop floristic, physiognomic and structural formations ranging from relatively simple to complex associations across a vast range of coastal habitat types (Cresswell and Semeniuk 2011). Opposingly, the Pilbara has a tropical arid climate, lower tidal variations and whilst there are some major creeks, typically they are much smaller, and estuaries are poorly developed. This has led to lower species richness occupying a reduced variation of assemblages and accordingly associations are far less complex than those further north in the Kimberley region (URS 2010). Additionally, the intertidal characteristics are remarkably different between the Kimberley and Pilbara regions, with the Pilbara region being characterised by large expanses of Mudflats/Saltflats and Algal Mats along the landward margins of intertidal zones. These areas in the Kimberly are typically associated with several species of mangrove, which are excluded from the Pilbara by hypersaline conditions. These differences in Mangrove assemblages are common throughout Northern Australia and have been extensively studied and zonation patterns described (Semeniuk et al. 1978, Semeniuk 1993, Duke 2006). The Mangrove assemblages associated with the Mardie coastline are characteristic of the described Pilbara (nearshore) bioregion.

Of the nine known species of Mangroves from the Pilbara region, this survey identified three, with previous surveys nearby identifying an additional two species at this local scale. The species recorded in this survey have broad distributions across northern Australia (Duke 2006). The two most common species are broadly distributed throughout the Asia-Pacific region (*R. stylosa*) and the wider Indo-Pacific region (*A. marina*) (Duke 2006; IUCN 2017a, b). These two species are characteristic of the regional area (Johnstone 1990; Kenneally 1982; Semeniuk 1994) and have no current conservation significance (Florabase 2019). The dominant Mangrove species, *A. marina* is extremely common along the WA coast occurring across the greatest range. Internationally *A. marina* is widely distributed with populations occurring across New Zealand, South-East Asia, Japan, Southern China, Pacific, India and East Africa (WORMS, 2019). *R. stylosa* is also widely distributed with populations occurring throughout South-East Asia, southern China, Japan and the Pacific (WORMS, 2019). *C. australis* is more limited in its geographic distribution with communities recorded from Papua New Guinea and tropical northern Australia (WORMS, 2019).

Algal Mats

Microbial or cyanobacterial mats, commonly referred to as Algal Mats, are a geographically widespread and ubiquitous intertidal BCH type common to estuarine and inter – and subtidal marine environments (Paerl *et al.* 1993). They are typically found existing asynchronously of other organisms, occupying mudflats and saltflats, and are exposed to extreme variations in salinity, temperature and moisture (SØrensen *et al.* 2005, SKM 2011). Algal mats vary widely in appearance, ranging from barely perceptible mucilagenous coatings on sand, mud and organic debris to well-developed, accreted, multilayered 'leathery' carpets dominating lagoonal, reef, mud and sandflat as well as saltmarsh systems (Paerl *et.* al 1993). Algal mats are generally dominated by cyanobacteria, have many nitrogen fixing taxa and possess a range of unique physiological traits enabling them to occupy these extreme environments (SØrensen *et al.* 2004, SØrensen *et al.* 2005). Local studies within the Pilbara have identified Algal Mats dominated by cyanobacteria, generally comprised of a combination of several genera. The genera identified within the Mardie study are not unique to the study area, or Pilbara region, and are recognised by a variety of species distributed throughout the Indo-Pacific region. The Algal Mats of the Mardie region were dominated by cyanobacteria *Microcoleus sp.* and *Lyngbya sp* and reported to be only slightly variable across the study area.

3.2.3. Functional Ecological Values

Productivity and Nutrient Cycling

It is widely acknowledged that structural complexity, productivity and associated AGB characteristic of distinct BCH associations are represented by functional differences with respect to the ecological services which they provide. High-level ecological elements include relative primary productivity, the associated heterotrophic relationships (secondary productivity of grazers and predators) this supports, which depending upon the structural complexity, primary productivity rates and AGB may in turn support a large and intricate food web.

Whilst subtidal BCH such as coral reefs and seagrass communities can be significant contributors to primary productivity, they represent a tiny proportion of the Mardie Project area <1% and any contributions are likely to be negligible by comparison to the more complex and extensive mangrove BCH.

The seaward to landward characteristics within intertidal BCH typically correlate with an initial sharp decline with respect to ecological functionality, structural complexity and AGB, and then a gradual decline therein through to the terrestrial communities. For example, initially the CC mangrove communities, which represent the most productive, structurally complex and ecologically diverse BCH with in the Mardie Project study area, make way to the second most diverse BCH, the SC mangroves. SC mangroves, due to their lower structural complexity and typically scattered nature, are less ecologically valuable in terms of both primary and secondary productivity. Functional ecological diversity, structural complexity and AGB continue to decline further landward next represented by the low and scattered Samphire BCH, then Mudflats, Algal Mats and finally the Saltflats, which in turn support lower and lower ecological value, with the exception of Algal Mat primary productivity, although as presented below, this is likely to be supplementary rather than essential. Whilst less important in terms of net primary productivity, Foreshore Mudflats have been identified to support BCH habitats such as macroalgae and seagrasses in varied abundances. These ecosystems are likely to be far less productive in comparison to subtidal BCH, due to the more extreme environments (exposure to terrestrial climate during times of exposure (i.e. neap tides)) in which they are found whereby they are restricted in their ability to thrive. Foreshore Mudflats, do however, support a wide array of secondary productivity as identified by Phoenix (2018b).

Intertidal BCH, primarily CC Mangroves, are well understood to play key roles in primary and secondary productivity, and nutrient and carbon cycling in coastal environments. Intertidal BCH provide varying levels of organic matter in the form of vegetative litter and are active sinks for dissolved nitrogen, phosphorous, carbon and silicon. Detritus serves as an important nutrient source and forms the basis of an extensive coastal food web. In addition, intertidal BCH ecosystems serve as shelter, feeding, nursery and breeding zones for crustaceans, molluscs, fish, and resident and migratory birds. The importance of these ecological functions delivered by intertidal BCH are directly proportional to the structural complexity, AGB and their spatial distributions. As described above this therefore presents the case that the seaward BCH communities (i.e. CC Mangroves, Foreshore Mudflats, SC Mangroves, seaward Samphires) present, by far, the most ecologically valuable communities within the Mardie Study area, particularly the CC mangroves which individually represent the single most valuable BCH within the study area.

The species richness of primary and secondary producers associated with arid zone intertidal BCH communities are low compared with tropical communities in higher rainfall zones, and the variety of habitats is also more limited. This net result is a comparably low level of biodiversity, although abundance of associated fauna can attain quite high numbers.

Primary and Secondary Production

In the Mardie Project area, the most significant contributors to primary and secondary production are the Mangrove and Cyanobacterial Communities. It is noted that, whilst Seagrass and Coral communities can provide an import role in primary and secondary production, their contribution in the context of the Mardie Project area is considered to be negligible due to their sparse and limited abundances.

Mangrove Communities

Mangrove communities are recognised as highly productive ecosystems that provide large quantities of organic matter to adjacent coastal waters in the form of detritus and live animals. Recent research has identified primary productivity of tropical Mangroves as rivalling those of tropical terrestrial forests, however Alongi (2009b) concluded that not all Mangrove habitats are highly productive, particularly arid zone or those stunted, sparse association types typical of landward associations (i.e. SC communities). Mangrove leaves and wood consist mainly of lignocellulose components that are degradable by microorganisms (Holgium *et. al.* 2001). Degradation of fallen mangrove vegetation starts immediately after its colonization by fungi and bacteria, and may last for 2–6 months, or more for degradation of the wood (Holgium *et. al.* 2001). The degradation of mangrove vegetative material produces detritus, which is rich in energy and contains a large active microbial population (Holgium *et. al.* 2001). As well as being an important food source, Boto and Bunt (1981, 1982) estimated that up to 46% of the primary productivity of an Australian mangrove ecosystem was exported to coastal waters through tidal movement as particulate organic matter. The main source of primary productivity are the seaward CC mangrove associations as these were calculated to have the greatest biomass of all habitat types within the study area, and therefore represent the highest ecologically valuable habitat within the Study area.

Primary productivity within Mangrove habitats is not just limited to the Mangrove trees themselves, many studies have also investigated the microbial activity of associated soils. Soils in which mangroves grow are typically composed of thick organic matter mixed with sediment, are anaerobic except for the sediment surface, and supports highly productive microphytobenthos which fix significant amounts of nitrogen. The higher the AGB associated with the mangrove community, the higher the associated microbial activity is. Therefore, as with AGB related to nutrient export, the CC mangroves also support a far greater net primary productivity of associated microbial activity.

Other primary producer sources occurring within Mangrove communities are epiflora and bacteria residing on vegetation or detritus and tidal phytoplankton imported from coastal waters. The magnitude of organic matter exported from mangrove areas depends on the biomass and extent of the mangrove ecosystem, the frequency and duration of tides, the size of the draining channel(s), the frequency and magnitude of rains, and the inflow of fresh water. In the Pilbara the main export mechanisms is essentially tidal movements due to low rainfall.

A review of worldwide mangrove investigations undertaken by Holgium *et. al. (*2001) identified that of approximately 120 species examined, at least one third were detritivores. The review found these species to include crustaceans, molluscs, insect larvae, nematodes, polychaetes, along with several fish species. Most of the animals associated with secondary productivity are either surface dwelling or burrowing grazers and detritivores. These species have the important role of breaking down organic matter into its nutrient component and redistributing that material within the ecosystem, essentially recycling the nutrients for use by the Mangroves or more widely into the coastal ecosystem.

Nitrogen Fixing Cyanobacteria (Including Algal Mats)

Many studies have inferred the importance Algal Mats play as an important nutrient source in Pilbara intertidal BCH through their nitrogen fixing properties in an otherwise nitrogen deficient system (Paling et al. 1989, Paling and McComb 1994, Biota 2005, URS 2010, Stantec 2018). However, there have been limited studies quantifying specific nitrogen fixing and export loads for BCH classes or the indirect impacts on BCH and coastal environments due to loss, removal or degradation of these communities, particularly in tropical arid zones of the Pilbara region.

Primary productivity that occurs within Algal Mats is directly related to the nitrogen fixing characteristics of the cyanobacteria that dominate the species composition within this BCH type. Whilst there are specific areas located within the study area assigned to the BCH classification Algal Mat, it is widely understood that nitrogen fixing cyanobacteria are present within most intertidal BCH, particularly Mangroves (Paerl *et al.* 1993, Alongi 1994, Holgium *et. al.* 2001 and Alongi 2009b), though there is little in the literature through which a direct comparison can be determined with respect to distinct BCH types and their respective nitrogen fixing or export loads. Whilst the predominately cyanobacterial Algal Mat communities are likely to be more productive, they are by no means the only source of nitrogen fixation within intertidal systems.

In mangrove ecosystems, high rates of cyanobacterial nitrogen fixating have been associated with dead and decomposing leaves or pneumatophores (aerial roots), the rhizosphere soil, tree bark, cyanobacterial mats covering the surface of the sediment, and the sediments themselves (Paerl *et al.* 1993 and Holgium *et. al.* 2001). In Indian estuarine mangrove ecosystems, high rates of dinitrogen fixation were found associated with the roots of seven different mangrove species (Senguputa and Chaudhuri 1991), whilst in Florida's mangroves, dinitrogen fixation was associated with the roots of all three mangrove species present (Holgium *et. al.* 2001). Nitrogen fixation was also found to take place by bacteria associated with decomposing leaves, the rhizosphere, and superficial sediments in a mangrove ecosystem in a southern Australian community and thought to supply about 40% of the annual nitrogen requirement (Holgium *et. al.* 2001).

A soil chemistry study undertaken by Soilwater Group (2019 – Unpublished data) investigated the chemical properties of soils across the study site providing a comparison between Algal Mats, Mudflats/Saltflats and 'crusts' present within the study area. The results concluded the following:

- Elevated Colwell Potassium, Extractable Sulphur and Total Organic Carbon associated with the Algal Mat material, compared to the typical surface crust that forms on the mud flats, suggesting a more 'biological' component to Algal Mats.
- Algal Mat material contains appreciably higher salinity than the normal surface crust and the surrounding soils.
- No difference in mineralised nitrogen between the Algal Mat material and the typical surface crust, and these are similar to the surrounding soils, although the mud flat soils contain appreciably higher Colwell Phosphorous.

Based on these results and the spatial distribution it would be difficult to establish a firm connection between nutrient sharing between Algal Mats and Mangroves. Mangroves are likely to be able to get all relevant nutrients from the surrounding soils on the mud flat, tidal migration of nutrients from surrounding Samphires or through nitrogen fixing processes occurring within localised soils. Algal Mats may therefore represent a surface accumulation or concentration of potassium, sulphur and organic matter, and it is likely they do not influence the surrounding area.

Algal Mats do not directly support additional sources of primary productivity within their habitats and export negligible nutrients in the form of detritus due to their physiology and associated inundation regimes. Algal Mats are limited in their ability to export dissolved organic nitrates and ammonia to tidal, surface or ground water exchanges, and depending upon associated hydrology nutrient exporting would vary considerably.

Algal mats support a limited number of grazing heterotrophs that are associated with adjacent BCH along seaward edges. During certain tides or seasons these heterotrophs migrate from their associated BCH to the edges of Algal Mats whereby they graze directly on the ‘crust’. In terms of supported heterotroph biomass, Algal Mats provide these opportunistic grazers with supplementary primary productivity source and do not solely support them as opposed to Mangroves or Samphire BCH.

Nutrient Pathways

Whilst primary productivity within Mangroves are widely understood and investigated, there is limited understanding of the direct pathways between BCH and the primary productivity associated with Algal Mats. Within the Mardie Project study area, the identified pathways for Algal Mat communities to export organic nitrogen are tidal, surface or groundwater flows or direct grazing. In comparison to grazing within seaward BCH, this contribution is negligible and warrants no further discussion.

Inundation studies undertaken as part of the Mardie Project have identified that Algal Mats occur within depressions, or at lower elevations than seaward and landward habitats (RPS 2019). During incoming tides (>1.2 m) oceanic water flows up through tidal creeks emptying into these depressions, however during receding tides this water becomes trapped remaining within the depression. This remaining water either evaporates, resulting in the high salinities which characterise this BCH, or migrates down into groundwater. Net reverse tidal flow from the depression is understood to be minor, and realistically would occur as a steady decant, rather than mixed flow or flush.

During large low-pressure systems, associated with heavy rainfall, the surrounding catchments may fill and begin to flow through drainage channels into the study area. Depending upon which catchment, these flows are either directed straight through natural drainage channels and tidal creeks into coastal waters (in the southern LAUs) or into the vast depressions where Algal Mats occur whereby, as with tidal inflows, water becomes trapped and subject to either evaporation, or migration into groundwater.

Once trapped within the depressions water, whether oceanic or fresh, are only able to exit via groundwater or evaporation. Hydrogeological studies undertaken for the Mardie Project suggest that groundwater flows are minimal to static within these depressions and the surrounding claypans.

It must therefore be assumed that the greatest proportion of water that enters these systems exit via evaporation, with any dissolved nutrients remaining in the system. As there are limited pathways available for nitrogen accumulated through cyanobacterial activity within Algal Mat systems, export loads are therefore considered to be low, particularly when compared with the combined nutrient exports associated with the seaward BCH. Not only are these BCH more structurally complex with higher associated AGB and their own cyanobacterial communities, they are frequently inundated therefore providing connectivity and a mechanisms for nutrient export to adjacent coastal waters.

Biomass and Primary Productivity

Across the study area there is a dominant seaward to landward trend whereby BCH with the highest AGB occurs along the seaward edge and typically decreases between BCH type as the increasing stress of higher salinities support reducing AGB until the BCH becomes Saltflats whereby no organisms are supported. AGB is directly related to productivity and where there is higher AGB net productivity is also at its highest, along with all the ancillary benefits these BCH provide such as erosion protection, shelter and refuge, food, nursery and breeding habitats.

The subtidal BCH supports very low AGB in the context of the Mardie Project with >95% of the mapped subtidal BCH area supporting only bare to sparse (<5%) cover of BCH.

Along the seaward edge CC mangrove communities represent the highest AGB across all BCH types. These communities support complex communities and regulate nutrient and carbon cycles which support wider coastal food webs. CC communities are also the most structurally complex and robust resulting and their delivery of a wide range of ecological functions that the remaining BCH types do not provide. CC mangroves support a range of marine invertebrate and vertebrate communities which utilise the mangroves during high tides for breeding, feeding, shelter, hunting, or as nursery areas for juvenile stages. Mangrove communities are also known to support a wide range of terrestrial vertebrates, particularly shoreline birds, that lower biomass BCH types do not.

As the seaward communities become more scattered, less structurally complex and support lower AGB, the level of ecological functions they provide also reduces. The ecological functionality of SC mangroves is reduced from CC mangroves; Samphire's represent a further reduction in functional ecology which continues through Mudflats, Algal Mats and finally the Saltflats which support no organisms or provide no productivity to surrounding BCH.

Whilst Algal Mats are identified to contribute, albeit vastly reduced, nutrients to support primary productivity of adjacent BCH, they do not support, nor provide any additional associated ecological functionality.

Targeted faunal surveys undertaken by Phoenix (2018b) identified faunal diversity being higher within the seaward BCH and declining with distance from the coast. This trend was very strong between migratory shoreline birds present during these periods and the more structurally complex seaward intertidal BCH classes through which they use for shelter and foraging during their visiting periods. Total observed faunal diversity was also higher within associated seaward BCH, particularly Foreshore Mudflats, Mangroves and Samphires. Most interesting is the high faunal diversity observed within Foreshore Mudflats and Mangroves with respect to their low associated total areas.

3.3. Pre-European Extent

The Pre-European extent of the subtidal and intertidal BCH types are presented for each LAU in **Table 6**.

Due to the remote nature and historical land-uses the Mardie Project area is considered representative of pre-European settlement with the exception of a gas pipeline easement extending in a north-west to south-east direction from northern LAU4 through to south-eastern LAU5 (**Figure 4**). This has resulted in the direct loss of associated BCH over an area of ~200 ha, or <1% of the study area. The main loss of BCH attributable to this easement is:

- Algal mats – 63 ha from LAU5;
- Foreshore Mudflats/Tidal Creeks – 3.4 ha from LAU4;
- CC Mangroves – 0.2 ha from LAU4
- SC Mangroves – 1.1 ha from LAU4;
- Samphires/Samphire Mudflats – 39.3 ha from LAU4; and
- Mudflats/Saltflats – 1.6 ha from LAU4 and 91 ha from LAU5.

Site observations and aerial photography indicates some recovery occurring along certain sections of this easement, particularly within the western extent.

In the absence of historical information on subtidal BCH prior to commercial trawling which may have occurred in the area, it has been assumed there has been no historical loss of BCH within LAU7 and therefore this region is considered representative of pre-European settlement and subject only to natural temporal variability.

Table 6 Benthic Communities and Habitat Pre-European Extent (Area expressed hectares & % of pre-existing BCH). Red text indicates the BCH impacted by the gas pipeline easement. Note all figures rounded to the nearest whole number.

BCH	LAU1		LAU2		LAU3		LAU4		LAU5		LAU6		LAU7		Total Area	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Intertidal BCH																
Algal Mat	857	100%	0	-	1,300	100%	0	-	1,323	95%	43	100%	-	-	***3,523***	***98%***
Foreshore Mudflat/Tidal Creeks	401	100%	2,133	100%	0	-	1,600	100%*	0	-	883	100%	-	-	***5,013***	***100%****
CC Mangrove	0	-	212	100%	0	-	369	100%*	0	-	700	100%	-	-	***1,282***	***100%****
SC Mangrove	0	-	750	100%	0	-	752	100%*	0	-	826	100%	-	-	***2,327***	***100%****
Rocky Shores	0	100%	6	100%	0	-	0	-	0	-	53	100%	-	-	***59***	***100%***
Samphire Mudflat	149	100%	2,030	100%	264	100%	1,572	97%	471	100%	1,546	100%	-	-	***6,032***	***99%***
Sandy Beaches	22	100%	10	100%	0	-	0	-	0	-	0	-	-	-	***32***	***100%***
Mudflat/Saltflat	2,260	100%	339	100%	2,069	100%	431	100%*	4,866	98%	636	100%	-	-	***10,509***	***99%***
Other Terrestrial Habitats	1,702	100%	304	100%	817	100%	0	-	2,511	100%*	1,496	100%	-	-	***6,830***	***100%****
Subtidal BCH																
Bioturbated Sand	-	-	-	-	-	-	-	-	-	-	-	-	6,827	100%	***6,827***	***100%***
Filter Feeder / Macroalgae / Seagrass	-	-	-	-	-	-	-	-	-	-	-	-	559	100%	***559***	***100%***
Coral / Macroalgae	-	-	-	-	-	-	-	-	-	-	-	-	189	100%	***189***	***100%***

* Whilst there is identified historical loss associated with the pipeline easement, the calculated percentages are so small they display as 100% when rounded to the nearest whole figure.

4. Potential Impacts

4.1. Mitigation

During pre-feasibility stages of project conception and design, a variety of environmental studies were undertaken. The aim of these studies were typically to identify environmental characteristics of the proposed Mardie Project area to allow this information to feed into project design and engineering. In response, the project design footprint has been refined to avoid the high and medium complex BCH types with a variety of factors being implemented to reduce both direct and indirect effects.

Specific considerations addressed during the design phase include:

- The marine disturbance footprint has been optimised to avoid impacts to known high value BCH areas such as dense cover coral and seagrass habitats;
- The Pond disturbance footprint has been optimised to minimise impacts to mangroves, algal mats and samphire BCH and is primarily positioned on Mudflats / Salt flat BCH, which represent the poorest quality and/or ecological functionality within the intertidal BCH types present in the project area;
- Any mangrove losses associated with the footprint have been positioned in areas associated with lower quality SC habitat resulting in minimal net reduction of overall mangrove biomass;
- Loss of the more structurally complex CC mangrove communities has been restricted to two small areas and design of the infrastructure at these locations has undergone several modifications to minimise loss of Mangrove BCH. These two areas include:
  - Intake Creek sea water extraction infrastructure (LAU4), and
  - Trestle jetty construction for offshore export facility in the north (LAU2).
- Construction methodology for the trestle jetty using a ‘top-down’ method, whereby the piles are driven from above, using the previous piles as support. This eliminates the requirement for a construction access road and reduces the direct disturbance to just the footprint of each pile; and
- Positioning of the trestle jetty has been identified over bare substrate to avoid direct loss or shading impacts to key subtidal BCH.

4.1.1. Dredge Management Plan

The Dredge Management Plan (DMP) developed for the Proposal includes project specific Management Targets (MTs) to mitigate the potential impacts on BCH and subsequently ensure that the EPA’s objective for BCH is met and the predicted Environmental Protection Outcomes (EPOs) are achieved. The project specific MTs for BCH include:

- Dredge works do not occur outside the approved area of disturbance. Manage dredging activities to minimise turbid plumes and sedimentation.
- Manage vessel bunkering, chemical storage and spill response to minimise impacts to the marine environment.
- Manage project vessels activities to prevent IMP impacts on the environment.

For each of the above project specific MTs, a comprehensive set of management actions and environmental performance measures have been established and are described in the DMP.

4.1.2. Marine Environmental Quality Management Plan

The Marine Environmental Quality Monitoring and Management Plan (MEQMMP) developed for the Proposal, includes project specific MTs to mitigate the potential impacts on BCH as a result of waste bitterns discharge and operational activities, and subsequently ensure that the EPA's objective for BCH is met and the predicted EPOs are achieved. The EPOs for Marine Environmental Quality include:

- Maintain a Low Level of Ecological Protection (80% SPL) as designated based on modelled predictions of the bitterns plume which determined that a 90% SPL would be achieved at the LEPA/MEPA boundary (Baird 2020);
- Maintain a Moderate Level of Ecological Protection (90% SPL) designated for all waters (excluding the LEPA areas) based on modelled predictions of the bitterns plume which determined that a 99% SPL would be achieved at the MEPA/HEPA boundary (Baird 2020);
- Maintain a High Level of Ecological Protection (99% SPL) within:
  - 250 m surrounding the small vessel facility in the northern creek;
  - 250 m surrounding the seawater abstraction facility in the southern creek; and
  - For all other areas not identified as Low, Moderate or Maximum
- Maintain a Maximum Level of Ecological Protection for all other areas not designated above.

4.2. Direct Impacts

4.2.1. Direct Irreversible Loss - Marine Development Envelope

Dredging

Dredging of the berth pocket and transhipment channel will result in direct *irreversible loss* of 47.5 ha of vegetated subtidal BCH (**Table 7**), comprising:

- 8 ha (1.4%) of Filter Feeder / Macroalgae / Seagrass BCH; and
- 8.8 ha (4.7%) of Coral / Macroalgae BCH.

A further 31 ha (<1%) of Bare 'unvegetated' substrate will also be directly impacted as a result of dredging (**Table 7**). However, this area will still remain classified as bare substrate after the completion of dredging and so has not been considered further in the cumulative loss assessment. **Figure 6** presents the spatial area of direct impacts for subtidal BCH.

Pile Driving

The 2.2 km long trestle jetty will be approximately 8 m wide to accommodate a roadway, conveyor and other services. It will be constructed with 18 m spans across twin 900 mm diameter piles using a 'top-down' method, whereby the piles are driven from above, using the previous piles as support. Construction of the Trestle Jetty will therefore result in direct *irreversible loss* of subtidal BCH in the immediate vicinity of each pile. The estimated BCH direct *irreversible loss* calculated for this assessment is highly conservative as it factors the entire Trestle Jetty footprint as a direct loss, rather than only the direct loss associated with the spatial area of each pile.

Pile driving will result in an additional loss of BCH (i.e. outside the already calculated subtidal BCH loss within the ZoHI worst case) including:

- 0.02 ha (<0.1%) of Filter Feeder / Macroalgae / Seagrass BCH; and
- 0.04 ha (<0.1%) of Coral / Macroalgae BCH.

A further 4.7 ha (<0.1%) of Bare 'unvegetated' substrate will also be directly impacted as a result of dredging (**Table 7**).

As the Trestle Jetty impact area does not intersect with any substantial area of corals or seagrasses, shading impacts to these BCH types has not been considered in this assessment.

Table 7 Direct Impacts to Subtidal BCH within LAU5 (Area expressed in hectares & % of BCH type within LAU). Note all figures rounded to the nearest whole number.

BCH Class	BCH Subclass	LAU7 ha	Direct Impact – Dredging ha (%)	Direct Impact – Pile Driving
Bare / Bioturbated Sand	Bare Substrate	6,823	31 (<1%)	5 (<1%)
	Sand / Sparse (<5%) Macroalgae	82	0 (0%)	0 (0%)
	Sub Total	***6,827***	***31 (<15)***	***5 (<1%)***
Filter Feeder / Macroalgae / Seagrass	Sparse (<5%) Cover	113	0 (0%)	0 (0%)
	Low (5-10%) Cover	445	8 (4.7%)	<1 (<1%)
	Sub Total	***559***	***8 (4.7%)***	***<1 (<1%)***
Coral / Macroalgae	Low (5-10%) Cover	71	0.1 (<1%)	<1 (<1%)
	Moderate (10-25%) Cover	92	8.7 (4.6%)	<1 (<1%)
	Dense (>25%) Cover – Macroalgae Dominated	<1	0 (0%)	0 (0%)
	Dense (>25%) Cover – Coral Dominated	25	0 (0%)	0 (0%)
	Sub Total	***188***	***9 (5%)***	***<1 (<1%)***

4.2.2. Direct Irreversible Loss - Ponds Development Envelope

Construction of the evaporation and crystalliser ponds, processing plant, desalination plant, administration, accommodation camp and associated works (access roads, laydown, etc.) will result in direct *irreversible loss* of 8,260 ha of intertidal BCH, comprising ~23% of the total LAU areas.

Direct loss areas resulting from the project indicative disturbance footprint have been calculated and are presented below (**Table 8**).

Mudflat/Saltflats represent the single greatest BCH direct loss occurring within the Ponds Development Footprint with a total of 78% of this BCH to be lost. Algal mats represent the second greatest direct loss with 25% of this type of BCH within the project area. The third greatest loss is Samphire/Samphire Mudflats with a loss of 16% of this type of BCH. Zero to negligible losses occur to Rocky Shores, Sandy Beaches, CC and SC Mangroves and Foreshore Mudflats/Tidal Creeks.

Table 8 Direct Intertidal BCH Loss Calculations within each LAU (Area expressed in hectares & % of BCH type lost within LAU). Note all figures rounded to the nearest whole number.

BCH Class	LAU1		LAU2		LAU3		LAU4		LAU5		LAU6		Direct Impact	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Algal Mat	10	1%	0	-	452	35%	0	-	416	33%	1	3%	***880***	***25%***
Foreshore Mudflat/Tidal Creeks	2	0%	0	0%	0	-	0	0%	0	-	0	0%	***2***	***0%***
CC Mangrove	0	-	0	0%	0	-	0	0%	0	-	0	0%	***0***	***0%***
SC Mangrove	0	-	1	0%	0	-	12	2%	0	-	4	1%	***17***	***1%***
Rocky Shores	0	0%	0	0%	0	0%	0	-	0	-	0	0%	***0***	***0%***
Samphire Mudflat	8	5%	15	1%	216	82%	57	4%	322	68%	335	22%	***954***	***16%***
Sandy Beaches	0	0%	0	0%	0	0%	0	0%	0	-	0	-	***0***	***0%***
Mudflat/Saltflat	5	1%	45	13%	1775	86%	24	6%	4355	91%	208	33%	***6412***	***78%***
Total	***20***	***1%***	***61***	***1%***	***2443***	***67%***	***94***	***2%***	***5093***	***78%***	***549***	***12%***	***8260***	***23%***

Mangrove Biomass

As a proportion of the total biomass calculated within the study area (226,703 t) (O2 Marine 2020a), direct mangrove losses from the Mardie project infrastructure are negligible (<1%). **Table 9** presents the calculated direct loss figures for Above Ground Biomass (AGB) of CC and SC mangroves.

Table 9 Estimates of Mean Above Ground Biomass Lost from Direct Removal (Biomass expressed tonnes per hectares & % of biomass lost). Note all figures rounded to the nearest whole number.

BCH	LAU2		LAU4		LAU6		Total Biomass	
	T	%	T	%	T	%	T	%
CC Mangrove	0	0%	3	0%	0	0%	**3**	**0%**
SC Mangrove	11	0%	483	2%	184	1%	**678**	**1%**
Total	**11**	**2%**	**486**	**71%**	**184**	**27%**	**682**	**<1%**

4.3. Indirect Impacts

4.3.1. Indirect Dredge Plume Impacts on Subtidal BCH

Indirect impacts to subtidal BCH are likely to be caused due to increased suspended sediment concentration (SSC), resulting in increased turbidity, reduction in available benthic light and localised increase in sedimentation.

In accordance with guidance provided in EPA (2016c), a dredge plume impact assessment was undertaken to develop predictions of the Zone of Influence (ZoI), Zone of Moderate Impact (ZoMI) and Zone of High Impact (ZoHI) for BCH in the vicinity of the dredging (Baird 2020a). The modelling results for the ZoMI and ZoHI, including best and worst-case outcomes are presented in **Figure 5**.

Within the Mardie Project area, the BCH at most risk from indirect dredging related impacts include coral, macroalgae and seagrass BCH, whereas filter feeder communities have been shown to be tolerant to dredging related impacts (Wahab *et al.* 2019). Although seagrass was present within the Mardie Project area, it was only present in very low densities (i.e. typically <1% cover) as a subdominant taxa within the Filter Feeder / Macroalgae / Seagrass BCH.

Benthic light conditions in the Mardie area were shown in O2 Marine (2020d) to naturally exceed the tolerance limits for corals published in Jones *et al.* (2019). Therefore, threshold values were not considered to be suitable for impact assessment. However, given the high volume of fines (i.e. up to 80%) present in the dredge material it was considered that sedimentation, rather than benthic light reduction, posed the greatest risk to Coral BCH occurring within the Project area. Therefore, the SSC and sedimentation tolerance limits for coral as published in Jones *et al.* (2019) were selected as the most appropriate thresholds to derive the separate zones of impact (i.e. ZoMI & ZoHI). Indirect impacts to bare substrate were not predicted as a result of dredging.

Indirect Irreversible Loss

Baird (2020a) identified that the sedimentation thresholds were exceeded beyond the dredge footprint for both the best- and worst-case model scenarios, typically in the southern half and adjacent to the berth pocket. For the purpose of the CLA, the worst case ZoHI for SSC was used to determine the extent of predicted indirect *irreversible loss* of subtidal BCH as a result of dredging. The area of *irreversible loss* (i.e. ZoMI) for each BCH type are displayed in **Figure 6,** and presented in **Table 10**.

The following estimated *irreversible loss* are predicted to subtidal BCH as a result of indirect dredging impacts:

- 27 ha (5%) of Filter Feeder / Macroalgae / Seagrass BCH; and
- 35 ha (18%) of Coral / Macroalgae BCH.

These predicted *irreversible loss* are considered to be relatively conservative, as the threshold values used were derived from a clear water coral reef environment (i.e. Barrow Island). As stated in Jones *et al.* (2019), these absolute threshold values may not be applicable to more marginal reef sites, such as the turbid reef zones in the Mardie Project area. Nevertheless, the Jones *et al.* (2019) threshold values are based on the latest scientific understanding of coral pressure response pathways and as such are considered appropriate for impact assessment purposes. However, Jones *et al.* (2019) notes that studies are currently underway to derive thresholds for turbid water coral communities, which may be able to be used to inform monitoring and management to ensure that recoverable impacts to the Mardie nearshore reef systems are minimised.

Although the subtidal BCH present in the Mardie area are tolerant to turbid conditions (i.e. Mean 14.2 NTU and 90^{th} percentile 29.5 NTU) (O2 Marine 2020d), O2 Marine (2019c) identified a considerably high proportion of fines (i.e. up to 80%) present within nearshore sediments likely to be mobilised and released during dredging activities. These fine sediments pose the greatest risk to vulnerable life history stages for corals, such as fertilisation and settlement (Negri et al. 2019). In particular, the resulting film of fine sediment that will be present on substrate considered suitable for settlement may result in delayed recovery of the affected coral BCH areas, such that the coral BCH within the ZoHI may not recover within 5 years and so should be considered as *irreversible loss*.

Indirect Recoverable Impacts

For the purpose of the CLA, the worst case ZoMI for SSC was used to determine the extent of predicted indirect *recoverable impacts* to subtidal BCH as a result of dredging. The area of *recoverable impact*s (i.e. ZoMI) for each BCH type are shown on **Figure 6** and presented in **Table 10**.

The following estimated *recoverable impact*s are predicted to subtidal BCH as a result of indirect dredging impacts:

- 133 ha (24%) of Filter Feeder / Macroalgae / Seagrass BCH; and
- 69 ha (36%) of Coral / Macroalgae BCH.

As with the indirect *irreversible loss,* the estimated *recoverable impacts* to subtidal BCH are also considered to be relatively conservative due to the threshold values used in the modelled predictions.

Table 10 **Indirect Irreversible Loss (ZoHI) and Recoverable Impacts (ZoMI) to subtidal BCH as a result of Dredging. Note all figures rounded to the nearest whole number.**

BCH Class	BCH Subclass	LAU7 ha	Indirect Irreversible Loss ha (%)	Indirect Recoverable Impacts ha (%)
Filter Feeder[1] / Macroalgae / Seagrass	Sparse (<5%) Cover	113	1 (<1%)	56 (10%)
	Low (5-10%) Cover	445	25 (4%)	76 (14%)
	Sub Total	***559***	***27 (5%)***	***133 (24%)***
Coral / Macroalgae	Low (5-10%) Cover	71	5 (3%)	45 (24%)
	Moderate (10-25%) Cover	92	30 (16%)	22 (12%)
	Dense (>25%) Cover – Macroalgae Dominated	<1	<1 (<1%)	36 (<1%)
	Dense (>25%) Cover – Coral Dominated	25	0 (0%)	1 (<1%)
	Sub Total	***188***	***35 (18%)***	***69 (36%)***

[1] Filter feeders within Filter Feeder / Macroalgae / Seagrass mixed BCH are unlikely to be impacted from the indirect effects from high levels of SSCs and sedimentation from dredge-generated sediments.

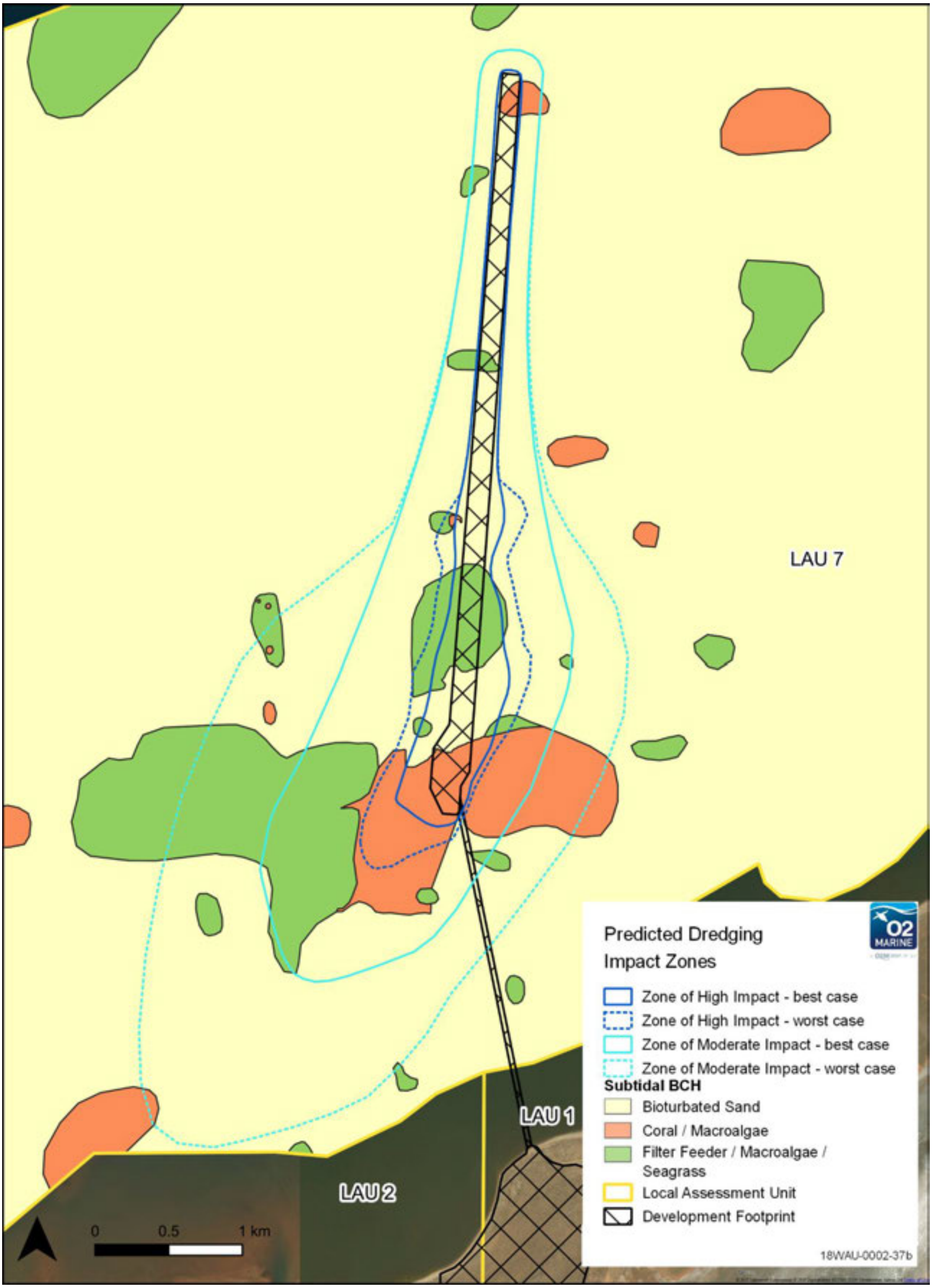


Figure 5 Predicted Likely Best- and Worst-Case Dredging Impact Zones (i.e. ZoMI & ZoHI) overlaid on Subtidal BCH

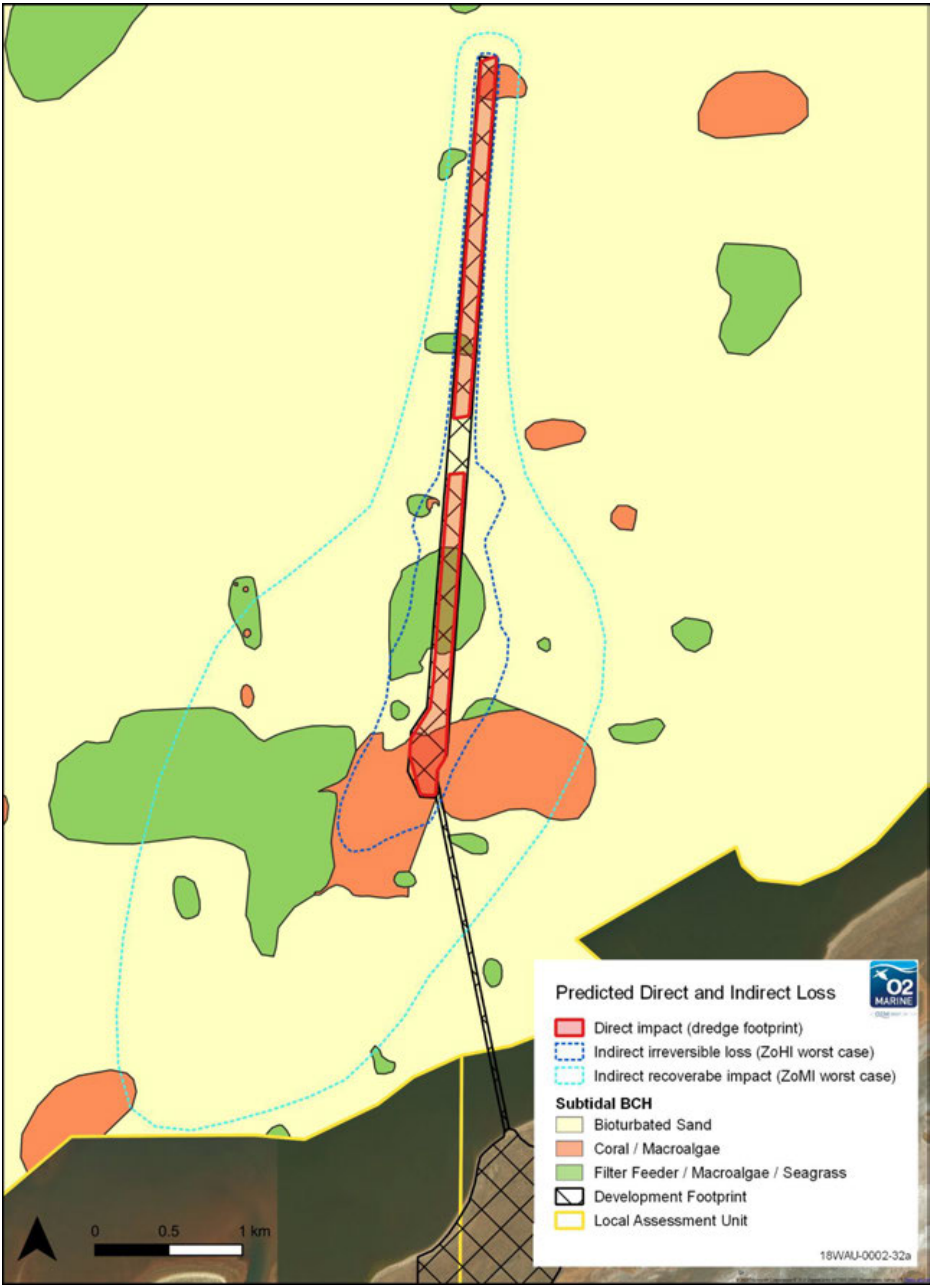


Figure 6 **Predicted area of Direct and Indirect Impacts to subtidal BCH from Dredging and Dredge related operations**

4.3.2. Indirect Bitterns Discharge Impacts on Subtidal BCH

Indirect impacts to subtidal BCH are likely to be caused due to the discharge of hyper saline waste bitterns, which will result in a plume with increased toxicity (O2 Marine 2019b) and salinity characteristics, along with alterations to natural physico-chemical parameters (i.e. lower dissolved oxygen) (Baird 2020).

In accordance with guidance provided in EPA (2016d), bitterns outfall modelling (Baird 2020) based upon whole of effluent toxicity testing (O2 Marine 2019b) was undertaken to predict the spatial boundaries of the LEPA and MEPA based upon achieving an 80% and 90% SPL, respectively, resulting from altered water quality due to bitterns discharge. The LEP areas are presented within **Figure 8**.

Within the Mardie Project area, the BCH at most risk from indirect bitterns plume related impacts include coral, macroalgae, filter feeders and seagrass BCH. The impacts upone these BCH types will vary in the indirect impact, being either plume toxicity impacts upon vulnerable life stages of certain species (in accordance with the specified SPL), or through alterations to the wayer quality through increased salinity or other physicochemical alterations (i.e. dissolved oxygen, pH etc.).

Indirect Irreversible Loss

Discharge of hyper saline waste bitterns is predicted to result in an indirect *irreversible loss* of the subtidal BCH within the Low LEP. Bitterns outfall modelling (Baird 2020) based upon whole of effluent toxicity testing (O2 Marine 2019b) indicates that a 90% Species Protection Level (SPL) will be achieved at the boundary of the LEPA/MEPA.

Within the LEPA *irreversible loss* of subtidal BCH is predicted as the indirect impacts from increased salinity and toxicity, and altered physico-chemical properties would likely result in a complete ecological community shift within the LEPA over time, therefore biological diversity and ecological integrity would not be maintained. However, the spatial area of the LEPA is entirely contained within the ZoHI (Worst Case) as presented in **Figure 7,** and, as such is already considered within direct impact calculations contained within **Table 7**.

Figure 7 **Dredge plume impact Zone of High Impact (Worst Case) and Levels of Ecological Protection areas established for the Bitterns discharge**

Indirect Recoverable Impacts

Indirect *recoverable impacts* to subtidal BCH would ordinarily occur within the MEPA. However, as with the *irreversible loss* identified within the section above, the MEPA spatial boundary is completed contained within the ZoHI (worst case) boundary (**Figure 7**), and therefore there are no predicted recoverable impacts resulting form the bitterns discharge.

4.3.3. Leaks or Spills of Hydrocarbons or Chemicals

Leaks or spills of hydrocarbons have the potential to impact on BCH communities. However, the Proponent will develop and implement environmental management plans incorporating controls to mitigate the risk of hydrocarbon spills to the marine environment. Therefore, the risk of any significant impacts as a result of hydrocarbon spill are considered to be very low and impacts are not predicted.

4.3.4. Introduction of Marine Pests

O2 Marine (2019a) identified the introduction of marine pests or invasive marine species to the Mardie Project area as a low risk. Therefore, no impacts to BCH are predicted as a result of this risk.

Figure 8 Bitterns Outfall Plume Dispersion showing 90%(LEPA/MEPA) and 99% SPL (MEPA/HEPA) boundaries.

4.3.5. Changes to the dynamics of nutrient flows and budgets

Based upon the studies undertaken during site investigations there is not predicted to be any significant alteration to nutrient flows and budgets.

Key points regarding nutrient budgets are outlined below:

> CC Mangroves and their related ecosystems (especially cyanobacterial communities) are the single most important contributor to the nutrient budget within the project area;
> A significant trend is identified with respect to decreasing biomass and productivity with respect to tidal elevation. Seaward mangrove communities with the highest associated biomass are the most productive with Saltflats characteristic of the highest tidal elevations and no biomass the least productive intertidal BCH; and
> Nutrient productivity from Algal Mats, whilst potentially high (although seasonal), has not been identified as a significant source within the system due to lack of connectivity with adjacent BCH.

The key points regarding nutrient flows are outlined below:

> Tidal inundation is the single most important mechanism with regards to connectivity for nutrient transport between BCH and coastal waters;
> Freshwater inputs, though potentially significant, are highly sporadic and therefore associated nutrient inputs are considered supplementary, not essential; and
> Groundwater flows through the study site are of negligible volumes and therefore not a strong driver of nutrient flows within the system.

The specific project footprint and design has been refined to avoid any direct, or indirect losses of the structurally complex, higher biomass and primary productivity BCH. By avoiding direct loss of these BCH, the impacts upon primary productivity and nutrient budgets within the study area have been minimised. Minor alteration to the tidal cycle (i.e. a time delay from current regime), with no predicted alteration to tidal inundation frequency or tidal heights is predicted, hence maintaining the single most important driver of nutrient flows between BCH and coastal waters.

Alterations to surface water flows from the project have also been avoided where possible and engineering designed to ensure surface water continues to be captured and flow to coastal waters, albeit through different pathways. Surface water flows are not considered to be essential within intertidal arid zone BCH primarily because of low annual rainfall with infrequent episodic flood events. The design and location of drainage channels, however, will ensure that tidal creek and coastal waters will still receive any supplementary nutrients that may derive from stormwater and rainfall run off. Therefore, no indirect effects are predicted from alterations to surface water flows from the project development.

4.3.6. Potential Movement of Hypersaline Groundwater as a Result of Hydrostatic Pressure of the Brine in the Salt Ponds

The results of groundwater modelling studies undertaken by SoilWater Group (2019) show there are not likely to be significant impacts upon BCH through the lateral movement of hypersaline groundwater emanating from the evaporation ponds. Key findings from the study include:

- Little to no lateral movement of groundwater between the vicinity of the proposed ponds and adjacent intertidal BCH due to the nature of the associated soils (very low permeability),
- Little to no increased lateral movement of groundwater resulting from pressure head of evaporation ponds due to:
    - Very low permeability of associated soils; and
    - Low pressure head due to shallow ponds.
- Little to no release of hypersaline water through pond floor/walls due to very low permeability.

More detail regarding groundwater and potential impacts from hypersaline water is contained within the report of studies undertaken by Soilwater Group and is presented as a separate appendix within the Environmental Referral Document. Please refer to this study for more information.

4.3.7. Prevention of Inland Movement of Habitats Due to Sea Level Rise

Inundation studies conducted by RPS (2019) have been summarised into a technical appendix presented within the Mardie Project Environmental Referral Document. A high-level summary of the predicted inundation effects from sea level rise is presented below:

- The Mardie project study area would still wet and dry, exposing current mangroves at lower tides and increasing inundation frequencies of algal mats;
- Current King Tides (2.2 m MSL) would occur at the same frequency of the current 1.2 m MSL tides), approximately >15 times per month, the current minimum tide required for algal mat inundation;
- Pond walls limit the eastern extent of King Tides plus 0.9 m (EPA 100yr sea level rise for coastal hazard assessment) resulting in higher water levels over seaward BCH during high tides; and
- Current mangrove areas will still be exposed at lower tides, a scenario that is consistent between modelling results with or without project infrastructure (i.e. Mardie project infrastructure will not result in different tidal cycles that would not occur naturally over this period).

As discussed within O2 Marine (2020a), there are several physical and chemical factors that affect the localised spatial distribution of key BCH within the Mardie project study area. BCH distributions are principally controlled by the effects of tidal inundation on soil salinity regulation. Sea level rise is predicted to alter the current physical and chemical dynamics which apply in each area of the intertidal zone that is currently occupied by BCH. The physical and chemical properties typical of each BCH type are highly dependent upon the current interrelationships that occur between tidal inundation and geomorphological structures at different heights on the shore. Understanding exactly how these interrelationships may alter over time due to rising sea levels is surrounded by a high degree of uncertainty and it cannot be assumed that BCH will migrate east (i.e. mangroves colonising saltflats or samphire mudflats) as sea levels rise. Rather, existing BCH will persist wherever conditions allow and colonise newly created environs, whereby chemical and physical properties offered are suitable for their respective tolerances (inundation, soil salinity, nutrient budgets, connectivity etc.). For example, mangrove communities typically occur as thin ribbons associated with tidal creeks, as these habitats provide the exact physical and chemical conditions required for colonisation. As sea levels rise, tidal creek systems are likely to also alter and with this some mangrove habitat may remain, whilst other areas are lost or created. However, if tidal creek systems do not retreat landwards, and the tidal plains currently comprising landward BCH do not offer the required chemical and physical condition mangroves require then their eastward retreat will be controlled by physico-chemical properties, not the presence of Mardie project infrastructure.

Thus, the mechanisms driving altered BCH through sea level rise will occur irrespective of Mardie project infrastructure. Whilst project infrastructure may reduce the available area for new BCH to occur, it cannot be predicted whether the chemical and physical properties characteristic of the current mudflats (i.e. where project infrastructure is proposed) would remain as they are or alter to become new BCH as sea levels rose. Whilst there are therefore predicted impacts upon the current spatial extents of mapped BCH due to sea level rise, the inclusion of project infrastructure is not expected to greatly impact upon net predicted results.

5. Cumulative Loss Assessment

The current spatial extent of each BCH type within each LAU is presented in **Table 11**. The current spatial extent is presented in hectares and is expressed as a percentage of pre-existing conditions (Section 3.3). The area of BCH type in the LAU impacted after the mitigation hierarchy has been applied has been calculated and is expressed within **Table 11** as *irreversible loss* and *recoverable impacts*, and expressed as percentages of pre-existing conditions (Section 3.3). A description of the expected severity and duration of the reversible impacts is discussed within Section 4.3. Total cumulative losses have been calculated and presented as hectares within **Table 11** and expressed as percentages of pre-existing conditions (Section 3.3).

In the absence of historical information on subtidal BCH prior to commercial trawling which may have occurred in the area, it has been assumed there has been no historical loss of BCH within LAU7, so cumulative loss of BCH is limited to the *irreversible loss* occurring from the current proposal.

All *calculated cumulative losses* of BCH are likely to be within the range of error inherent in mapping BCH.

Table 11 Benthic Communities and Habitat Cumulative Loss Assessment (Area expressed hectares & % of LAU). Note all figures expressed as the nearest whole number.

LAU	Loss Assessment	Intertidal BCH																Subtidal BCH					
		Algal Mat		Foreshore Mudflat/Tidal Creek		CC Mangroves		SC Mangroves		Rocky Shores		Samphire Mudflat		Sandy Beaches		Mudflat/Saltflat		Bare Bioturbated Sand		Macroalgae / Filter Feeder / Seagrass		Coral / Macroalgae	
		ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
LAU 1	Pre-European Extent	857	-	401	-	0	-	0	-	0	-	149	-	22	-	401	-	-	-	-	-	-	-
	Current Extent	857	100%	401	100%	0	-	0	-	0	-	149	100%	22	100%	401	100%	-	-	-	-	-	-
	Irreversible Loss	10	1%	2	0%	0	-	0	-	0	-	8	5%	0	-	5	1%	-	-	-	-	-	-
	Recoverable Impact	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	-
	Cumulative Loss	**10**	**1%**	**2**	**<1%**	**0**	**-**	**0**	**-**	**0**	-	**8**	**5%**	**0**	**0%**	**5**	1%	-	-	-	-	-	-
LAU 2	Pre-European Extent	0	-	2,133	-	212	-	750	-	6	0%	2,030	-	10	0%	339	-	-	-	-	-	-	-
	Current Extent	0	-	2,133	100%	212	100%	750	100%	6	100%	2,030	100%	10	100%	339	100%	-	-	-	-	-	-
	Irreversible Loss	0	-	0	0%	0	0%	1	0%	0	-	15	1%	0	0%	45	13%	-	-	-	-	-	-
	Recoverable Impact	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	-
	Cumulative Loss	**0**	**-**	**0**	**0%**	**0**	**0%**	**1**	**<1%**	**0**	**0%**	**15**	**1%**	**0**	**0%**	**45**	**13%**	-	-	-	-	-	-
LAU 3	Pre-European Extent	1,300	-	0	-	0	-	0	-	0	-	264	-	0	-	2,069	-	-	-	-	-	-	-
	Current Extent	1,300	100%	0	-	0	-	0	-	0	-	264	100%	0	-	2,069	100%	-	-	-	-	-	-
	Irreversible Loss	452	35%	0	-	0	-	0	-	0	-	216	82%	0	-	1,775	86%	-	-	-	-	-	-
	Recoverable Impact	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	-
	Cumulative Loss	**452**	**35%**	**0**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**216**	**82%**	**0**	**-**	**1,775**	**86%**	-	-	-	-	-	-
LAU 4	Pre-European Extent	0	-	1,600	-	369	-	752	-	0	-	1,572	-	0	-	431	-	-	-	-	-	-	-
	Current Extent	0	-	1,596	100%	369	100%	751	100%	0	-	1,533	97%	0	-	429	100%	-	-	-	-	-	-
	Irreversible Loss	0	-	0	-	0	-	12	2%	0	-	57	4%	0	-	24	6%	-	-	-	-	-	-
	Recoverable Impact	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	-
	Cumulative Loss	**0**	**-**	**3**	**<1%**	**0**	**0%**	**13**	**2%**	**0**	**-**	**97**	**6%**	**0**	**-**	**26**	**6%**	-	-	-	-	-	-
LAU 5	Pre-European Extent	1,323	-	0	-	0	-	0	-	0	-	471	-	0	-	4,866	-	-	-	-	-	-	-
	Current Extent	1,259	95%	0	-	0	-	0	-	0	-	471	100%	0	-	4,775	98%	-	-	-	-	-	-

LAU	Loss Assessment	Intertidal BCH																Subtidal BCH					
		Algal Mat		Foreshore Mudflat/Tidal Creek		CC Mangroves		SC Mangroves		Rocky Shores		Samphire Mudflat		Sandy Beaches		Mudflat/Saltflat		Bare Bioturbated Sand		Macroalgae / Filter Feeder / Seagrass		Coral / Macroalgae	
		ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
	Irreversible Loss	416	31%	0	-	0	-	0	-	0	-	322	68%	0	-	4355	89%	-	-	-	-	-	-
	Recoverable Impact	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	-
	Cumulative Loss	**479**	**36%**	**0**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**322**	**68%**	**0**	**-**	**4,446**	**91%**	-	-	-	-	-	-
LAU 6	Pre-European Extent	43	-	883	-	700	-	826	-	53	-	1,546	-	0	-	636	-	-	-	-	-	-	-
	Current Extent	43	100%	883	100%	700	100%	826	100%	53	100%	1,546	100%	0	-	636	100%	-	-	-	-	-	-
	Irreversible Loss	1	3%	0	-	0	-	4	1%	0	-	335	22%	0	-	208	33%	-	-	-	-	-	-
	Recoverable Impact	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	-
	Cumulative Loss	**1**	**3%**	**0**	**0%**	**0**	**0%**	**4**	**1%**	**0**	**0%**	**335**	**22%**	**0**	**-**	**208**	**33%**	-	-	-	-	-	-
LAU 7	Pre-European Extent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6827	-	559	-	189	-
	Current Extent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6827	100%	559	100%	189	100%
	Irreversible Loss	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104	1%	35	6%	44	23%
	Recoverable Impact	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	595	9%	133	24%	69	36%
	Cumulative Loss	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**104**	**1%**	**35**	**6%**	**44**	**23%**
TOTALS (All LAUs)	***Pre-European Extent***	**3,523**	**-**	**5,014**	**-**	**1,282**	**-**	**2,327**	**-**	**59**	**-**	**6,032**	**-**	**32**	**-**	**10,602**	**-**	**6827**	**-**	**559**	**-**	**189**	**-**
	Current Extent	**3,459**	**98%**	**5,014**	**100%**	**1,282**	**100%**	**2,326**	**100%**	**59**	**100%**	**5,993**	**99%**	**32**	**100%**	**10,509**	**99%**	**6827**	**100%**	**559**	**100%**	**189**	**100%**
	Irreversible Loss	**880**	**25%**	**2**	**0%**	**0**	**0%**	**17**	**1%**	**0**	**0%**	**954**	**16%**	**0**	**0%**	**6,412**	**77%**	**104**	**1%**	**35**	**6%**	**44**	**23%**
	Recoverable Impact	**0**	**0%**	**0**	**0%**	**0**	**0%**	**0**	**0%**	**0**	**0%**	**0**	**0%**	**0**	**0%**	**0**	**0%**	**595**	**9%**	**133**	**24%**	**69**	**36%**
	Cumulative Loss	**880**	**25%**	**5**	**<1%**	**0**	**0%**	**17**	**1%**	**0**	**0%**	**954**	**16%**	**0**	**0%**	**6,505**	**77%**	**104**	**1%**	**35**	**6%**	**44**	**23%**

6. Consequences

As outlined within Section 5 cumulative losses have been calculated and presented for the Mardie project. In this section cumulative losses are discussed and evaluated with respect to the potential consequences (i.e. impacts and risks) that the proposal can have on ecological integrity and biological diversity.

In accordance with EPA (2016a), the consequence of direct impacts to bare or unvegetated BCH are considered to be inconsequential with regards to impacting upon ecological integrity and biological diversity.

6.1. Mangroves

Irreversible loss of <1 ha (<1%) of CC Mangroves and 17 ha (1%) of SC Mangroves is predicted to occur as a result of the proposal.

O2 Marine (2020a) determined that the three species identified during this survey are known to have broader distributions across Asia-Pacific, are characteristic of the regional area and have no current conservation significance. Mangrove associations and functional groups identified are typical of mangrove communities within the regional Pilbara area along with the wider Pilbara and Canning coasts of North Western Australia.

O2 Marine (2020a) identified mangroves as being the highest ecologically important BCH within the Mardie Project study area, particularly CC mangroves, due to the range of ecological services in which they provide to adjacent BCH and coastal waters. All efforts have been made during the Mardie project design and engineering stages to maintain maximum mangrove biomass with <1% identified for direct removal and no net predicted indirect effects. Within LAU6, which intersects the Robe River Delta regionally significant mangrove area, zero cumulative losses of CC mangroves will occur. Therefore, the risk of impact to biological diversity and ecological integrity of mangrove communities is not considered significant.

6.2. Algal Mats

An *irreversible loss* of 880 ha (25%) of Algal Mats is predicted to occur as a result of the proposal.

O2 Marine (2020a) determined that the diversity and species composition of Algal taxa are representative of algal mat habitats occurring regionally within the Pilbara, whilst the taxa identified are typically those associated with algal communities found elsewhere in Australia and overseas. While mats are known to play an important role in nitrogen fixing within the Pilbara it is also the case that nitrogen fixing cyanobacteria are present within most intertidal BCH, including areas with mangroves. Whilst the predominately cyanobacterial Algal Mat communities form a higher standing biomass, the cyanobacterial communities associated with CC mangroves are likely to be higher in primary productivity (non-seasonal) and due to lower associated soil salinities also support significant secondary productivity (grazing by primary heterotrophs) and therefore play a more valuable ecological function within the system. Algal Mat communities as mapped, are limited in their ability to export significant nutrient loads due to their lack of connectivity via nutrient flow pathways. They provide limited primary productivity services to other BCH types within the intertidal zone.

The Mardie project design and engineering has been refined to minimise losses of mats and the predicted loss of 880 ha is not considered a significant risk to the ecological integrity and biological diversity of the BCH within the region.

6.3. Samphires/Samphire Mudflats

An *irreversible loss* of 954 ha (16%) of Samphires / Samphire Mudflats is predicted to occur as a result of the proposal. The functional ecological value and regional significance of this habitat is considered and assessed as part of the Terrestrial Flora and Vegetation impacts and are not discussed further within this CLA Report. Please refer to Phoenix (2019) for further detail regarding Samphire communities.

6.4. Coral / Macroalgae

An *irreversible loss* of 44 ha (23%) and *recoverable impact* of 69 ha (36%) of Coral / Macroalgae BCH is predicted to occur as a result of the proposal. Of the *irreversible loss* <1 ha (<1%) is classified as Dense (>25%) cover and is dominated by macroalgae, with the remainder classified as Low (5-10%) and Moderate (10-20%) Cover with 5 ha and 39 ha of *irreversible loss*, respectively.

O2 Marine (2020b) determined that similar Coral / Macroalgae BCH is well represented throughout the LAU and more broadly, whilst surrounding the offshore islands include much denser macroalgal and coral communities than within the LAU. This BCH was also previously mapped as occurring with the Filter Feeder / Macroalgae / Seagrass BCH from the Fortescue River mouth to the southern end of the Exmouth Gulf (Scott *et al.* (2006) and is extensively well represented throughout the region. Additionally, of the 44 ha of the Coral / Macroalgae BCH predicted to be lost, <1 ha consists of 'dense' coral or macroalgae therefore the highest value of this BCH type within the LAU is still retained.

The area of coral BCH within LAU7 represents marginal habitat and is unlikely to be a significant contributor to coral recruitment within the region. Rather, the high value, biologically diverse reefs with far denser colonisation surrounding the offshore islands, being the primary driver of long-term ecosystem health and sustainability of nearshore Pilbara coral communities in this area. Therefore, whilst this BCH provides suitable habitat for a variety of marine fauna species, the loss of 44 ha is not considered a significant risk to the ecological integrity and biological diversity of this BCH.

6.5. Filter Feeder / Macroalgae / Seagrass

An *irreversible loss* of 35 ha (6%) and *recoverable impact* of 133 ha (24%) of Filter Feeder / Macroalgae / Seagrass BCH is predicted to occur as a result of the proposal.

O2 Marine (2020b) determined that the Filter Feeder / Macroalgae / Seagrass BCH is well represented throughout the LAU and more broadly, this BCH was previously also mapped as occurring with the Coral / Macroalgae BCH from the Fortescue River mouth to the southern end of the Exmouth Gulf (Scott *et al.* (2006), and is extensively well represented throughout the region. Of the 35 ha of Filter Feeder / Macroalgae / Seagrass BCH mapped within the LAU none was identified as medium density or above, with all mapped densities being less than 10% benthic cover. Although this BCH is also known to provide suitable habitat for a variety of marine fauna species, the loss of 35 ha is not considered a significant risk to the ecological integrity and biological diversity of this BCH.

7. Conclusion

The Mardie Project will result in cumulative *irreversible loss* of the following BCH over the entire Mardie Project area (i.e. including all LAUs):

- 1 ha (<1%) of CC Mangrove;
- 17 ha (<1%) of SC Mangrove;
- 880 ha (25%) of Algal Mat;
- 954 ha (16%) of Samphires/ Samphire Mudflats;
- 35 ha (6%) of Filter Feeder / Macroalgae / Seagrass; and
- 44 ha (23%) of Coral / Macroalgae.

Recoverable impacts were also predicted for:

- 133 ha (24%) of Filter Feeder / Macroalgae / Seagrass; and
- 69 ha (36%) of Coral / Macroalgae.

Overall, the CLA determined that the impacts to subtidal BCH whilst measurable were unlikely to result in any risk of impacting biological diversity and ecosystem integrity. The subtidal BCH found within the study area were typically very low density, dominated by bioturbated sands. Where losses were identified these were typically to the lowest density of BCH mapped within the LAU. When compared with similar BCH types found more broadly within the region, these communities are considered attributed to lower biological diversity and are less important as the high value BCH found adjacent in higher densities and diversity, which are likely to support far greater primary and secondary productivity.

The intertidal BCH assessed within the Mardie Project study were found to be commonly distributed throughout the wider Pilbara region, with many having distributions within the Australian tropics and or internationally. All of the species identified during the assessment are also typically found within a broader geographical distribution.

The coastal habitats within the Mardie Project study area have not been identified as supporting significant ecological communities warranting protection through the introduction of marine or terrestrial reserves. There are no implications from any of the proposed Commonwealth Marine Reserves for the Mardie project as the coastal location is contained completely within State Waters. Whilst no formal reserves have been established two areas relevant to the Mardie Project have been identified by (EPA 2001) as regionally significant areas: Robe River (Area 7) and Fortescue River (Area 8) deltas.

Cumulative losses for CC and SC mangroves within the Mardie project study were calculated to be <1% of the total mangrove area and biomass, whilst within LAU4 (which intersects the Robe River Delta) cumulative losses will be incurred at 1% for SC mangroves. There are no predicted cumulative losses for CC mangroves in LAU4.

The pre-feasibility studies and environmental investigations have directed appropriate mitigation through the engineering and development phases of the Mardie project. This has ensured that the structurally complex BCH, which are required for ongoing support and maintenance of the biodiversity and ecological integrity and functionality within the study area, will not incur any significant cumulative losses. Where cumulative losses have been calculated, the impact upon biodiversity and ecological integrity is predicted to be negligible. The majority of the direct losses will be of BCH types that are both well represented elsewhere in the respective LAUs and the wider region and therefore the contribution of these BCH types to ecosystem functions, integrity and biodiversity will not be impaired.

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