ASSESSMENT OF MANGAL AND ALGAL COMMUNITIES FOR THE MARDIE SOLAR SALT PROJECT

PREPARED FOR BCI MINERALS LTD

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MWH now part of Stantec

QUALITY STATEMENT

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Executive Summary

BCI Minerals Ltd (BCI) commissioned Stantec Australia Pty Ltd (Stantec) to complete an assessment of mangal (mangroves) and algal mat communities (the Assessment) for the proposed Mardie Solar Salt Project (the Project). The Project is located between Dampier and Onslow, along the Pilbara coastline of Western Australia. Mangroves and algal mats are classified as benthic communities and habitat (BCH), which are regulated by the Environmental Protection Authority (EPA).

The aim of the Assessment was to identify the potential impacts and risks from the Project to inform the pre-feasibility team. Specific objectives were to:

- gain a preliminary understanding of mangrove and algal mat communities;
- provide environmental criteria for engineering design;
- identify Project constraints for mangrove and algal mat communities; and
- recommend future studies to support the Project.

The Assessment comprised two field surveys (reconnaissance and targeted surveys), and a desktop review of available and relevant literature, supported by preliminary hydrological modelling. In the Study Area, broad habitat zonation, including mapping and analysis of mangroves, algal mats and samphires was undertaken, to provide regional context. The Study Area was extensive, and covered approximately 75 km of coastline, extending 20 km south of Robe River, and north to the Fortescue River (**Figure ES1**). The Project Area comprised a smaller, central portion of the Study Area (approximately 20 km of coastline).

Three mangrove species were identified within the Study Area, comprising *Avicennia marina*, *Ceriops australis* and *Rhizophora stylosa*. These are distributed in other tropical regions globally, and are widespread along the Pilbara coastline. Mangal communities were sparse near the Fortescue River, becoming more prevalent in the southern parts of the Project and Study Areas.

Algal mats were dominated by filamentous cyanobacteria including *Microcoleus* and *Lyngbya*, while *Calothrix* and *Schizothrix* were also common. Diversity was comparable with global communities and the Pilbara coast. Algal mats occurred within a relatively nominal elevation of between 1.1 to 1.3 m (20 cm) Australian Height Datum (AHD). They were classified as either contiguous (thick and extensive) or fragmented (thin and patchy). Contiguous mats were characteristic of the Project Area and also occurred in the northern and southern parts of the Study Area.

Database searches indicated there were no flora or communities of conservation significance in the Study Area, relevant to the Assessment. However, the southern part of the Project Area is adjacent to Mangrove Management Boundary 7 (Robe River Delta), designated 'regionally significant' by the EPA. BCI have specifically avoided impacts to mangroves within the Project Area.

The results of the Assessment, along with the literature review, were used to redefine the engineering design of the Project, with the understanding that:

- the relationship between mangroves and algal mats requires further investigation;
- tidal inundation modelling needs refining to determine its influence on algal mats and subsequent connectivity to the marine environment; and
- while hinterland flows occur from minor ephemeral creeks and are infrequent, they still contribute to the hydrological regime.

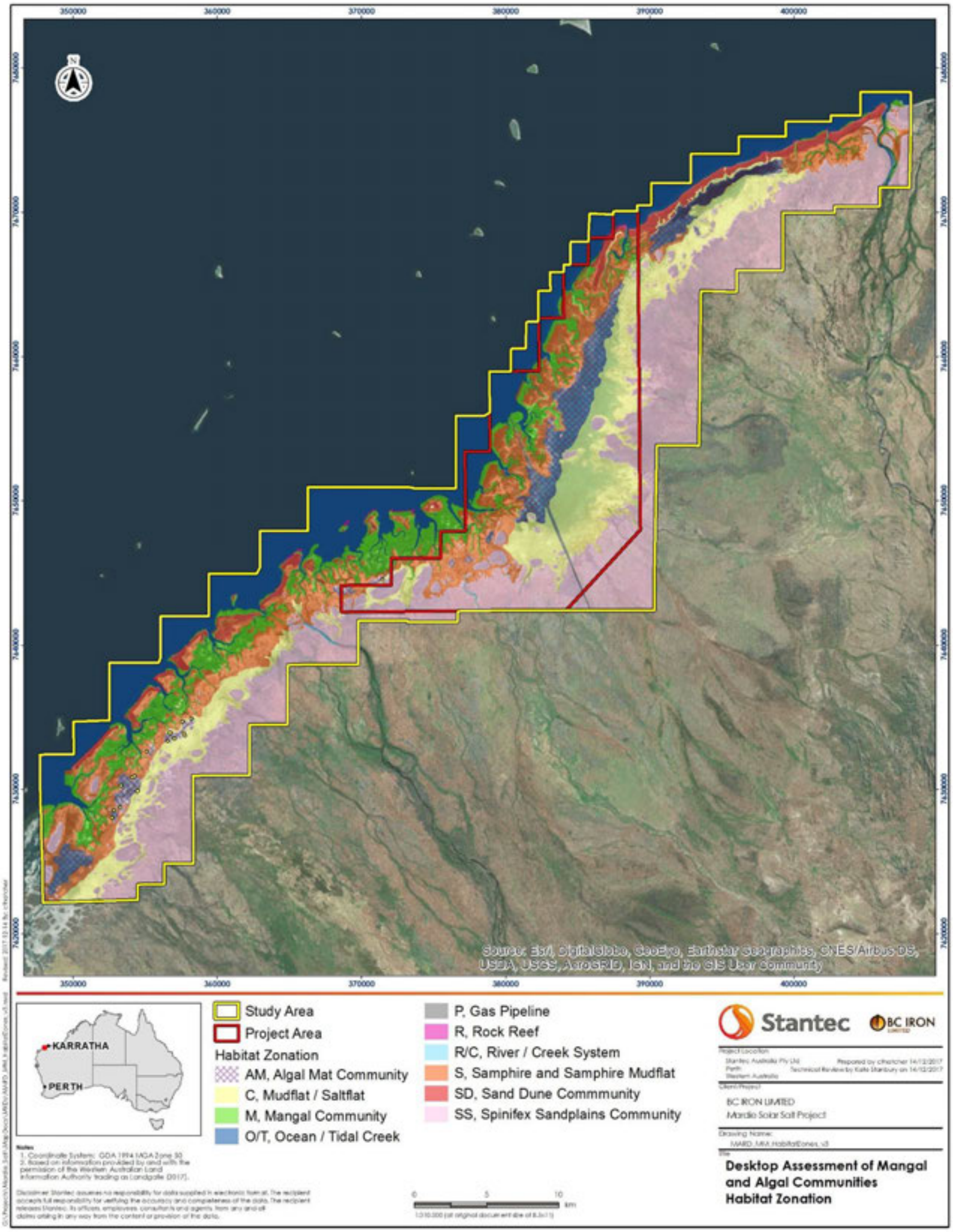


Figure ES1: Habitat zonation of the Study and Project Areas for the Mardie Solar Salt Project.

The engineering design of the Project was considered in the context of avoiding and/or minimising impacts to mangroves and algal mats, in an attempt to maintain biological diversity and ecological integrity, aligning with EPA technical guidance. Avoidance of the largest portion of algal mat within the Project Area was the environmental criteria used, with any removal to occur from the northern and southern extremities of the Project Area (491 ha or 18%). Preliminary justification for this removal of algal mats is as follows:

- a substantial area of algal mats will remain within the Study Area (4053 ha or 89%) and Project Area (2162 ha or 82%);
- comparatively, the Onslow Salt Project disturbed approximately 350 ha or 20% of algal mats, and the Anketell Port Project less than 50 ha, equivalent to more than 30% of algal mats;
- removal of some contiguous algal mat in the southern part of the Project Area aligns with previous disturbance from the installation of the Chevron gas pipeline;
- removal of some fragmented algal mats in the southern part of the Project Area, as they are typically thinner, patchier, and smaller than contiguous algal mats;
- based on preliminary hydrological modelling by RPS, the inundation of algal mats may be limited; and
- nutrients such as nitrogen produced by algal mats may be utilised internally for growth, and with the low frequency of inundation, may provide limited support to mangroves.

The engineering design of the Project has undergone several revisions to implement a range of mitigation measures, to reduce the risk to mangroves and algal mats, and endeavour to maintain biological diversity and ecological integrity including:

- a substantial reduction in the size of the Project Area through the surrender of tenement E08/2399 (4808 ha or 30% of tenure under lease at the time), to avoid mangroves in the Robe River Delta;
- a further reduction in the Project Area (3000 ha or 29%), to avoid algal mats;
- no stockpiling of bitterns;
- no clearing, dredging or other maritime disturbance associated with a local port facility, with salt to be exported from a designated port, via a planned extension to the proposed Cape Preston East Port;
- re-location of the seawall landward, with a 300 m buffer to algal mats (equivalent to the narrowest band of algal mat), to maintain the tidal inundation regime and the north-south distribution of hinterland flows;
- installation of corridors (channels 300 m wide), designed to maintain hinterland and tidal creek flows and connectivity, to specifications that will reduce velocity and the build-up of water along the seawall; and
- engineering design to allow algal mats to migrate landwards towards the seawall and along corridors, in response to predicted sea level rise over the life of the Project (0.2 m over 50 years).

The aim of future studies related to mangrove and algal mat communities will be to:

- refine hydrological modelling, including on-ground observations and data collation, to verify the tidal inundation regime of the algal mats;
- undertake hydrogeological modelling, to understand potential changes to BCH;
- undertake comprehensive BCH baseline studies, and refine the preliminary zonation mapping for mangroves, samphires and algal mats;
- undertake marine fauna baseline studies, to determine marine fauna associated with mangroves and algal mats, in relation to the tidal inundation regime; and
- liaise with the EPA to define local assessment units (LAUs) for the assessment of BCH.

BCI have proactively considered the engineering design of the Project to address constraints relating to mangroves and algal mats. Further refinement may be required following the outcomes of baseline studies.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1. Introduction and Objective

BCI Minerals Ltd (BCI) commissioned Stantec Australia Pty Ltd (Stantec) to complete an Assessment of mangal (mangroves) and algal communities (the Assessment) for the proposed Mardie Solar Salt Project (the Project). Mangroves and algal mats are classified as benthic communities and habitat (BCH), and are regulated by the Environmental Protection Authority (EPA).

An overview of the scope of the Assessment is provided in **Table 1-1**, which outlines the key tasks and objectives, Study and Project Areas, EPA technical guidance, and limitations. The aim of the Assessment was to identify the potential impacts and risks from the Project to inform the BCI pre-feasibility team.

Table 1-1: Overview of the scope of the Assessment.

Assessment Components	Brief Description
Aim	To identify the potential impacts and risks posed to mangal and algal communities from the Project, providing recommendations for future monitoring and investigation
Objectives	• gain a preliminary understanding of mangrove and algal mat communities • provide environmental criteria for engineering design • identify Project constraints for mangrove and algal mat communities • recommend future studies to support the Project
Key Tasks	• two field surveys; one reconnaissance survey and one targeted survey • database searches (flora and vegetation only) and literature review • regional context and understanding of ecological values (diversity and function) • laboratory analysis of algal mat samples (local and regional) • mapping and estimates of algal and mangal communities and preliminary habitat zonation • impact assessment (direct and indirect), outlining project constraints and risk. • mitigation measures and recommendations for optimal Project Area, with scientific justification • recommendations for future monitoring and investigation (including scheduling)
Study Area	Study Area: 82,833 ha Project Area: 26,005 ha
EPA Technical Guidance	Environmental Protection Authority. (2016). Technical Guidance: Protection of benthic communities and habitats. Western Australia Environmental Protection Authority. (2001). Guidance Statement No. 1: Protection of tropical arid zone mangroves along the Pilbara coastline, Western Australia.
Limitations	Scope specific to mangal and algal communities, excluding the marine environment and associated impacts, such as bitterns discharge. Preliminary habitat zonation, which was based on aerial surveying, supported by ground-truthing.

1.1 Project and Study Areas

The Project is located in the north of Western Australia, within the Pilbara region, approximately 70 km southwest of the Port of Cape Preston East, between the towns of Onslow and Dampier (**Figure 1-1**). The Project Area covers up to 26,005 ha, and comprises three granted exploration tenements; E08/1849, E08/2740, and E08/2741 (**Figure 1-2**), with two additional exploration tenements pending; E08/2836 and E08/2943. Approximately 25% of this area may be utilised for solar salt production, with the Project likely to produced 3 to 3.5 million tonnes per annum of sodium chloride salt from seawater, via a series of evaporation ponds and crystallisers (**Figure 1-2**).

Solar salt production is proposed on the saltflats and mudflats of the coastal environment within the Project Area. For the purposes of the Assessment, the Study Area comprised 82,833 ha, extending across a 75 km stretch of coastline; 20 km south of the Robe River, and north to the Fortescue River. The Project Area comprised a smaller, central portion of the Study Area, occupying approximately 20 km of coastline.

1.2 Applicable Legislation and Technical Guidance

The Assessment has been aligned with relevant state and federal legislation and technical guidance that will be applicable to the Project, in order to receive regulatory approval. A complete list of legislation and guidance that may apply to the Project is provided in **Appendix A**. However, specific to BCH, this includes:

- *Environmental Protection and Biodiversity Act 1999* (EPBC Act);
- *Environmental Protection Act 1986* (EP Act);
- *Wildlife Conservation Act 1950* (WC Act); and
- *Conservation and Land Management Act 1982* (CALM Act).

Under the EP Act, the EPA also provide several environmental factor guidelines and associated objectives relevant to the Project including:

- *Benthic Communities and Habitats – Objective:* to protect BCH so that biological diversity and ecological integrity are maintained.
- *Coastal Processes – Objective:* to maintain the geophysical processes that shape coastal morphology so that the environmental values of the coast are protected.
- *Marine Environmental Quality – Objective:* to maintain the quality of water, sediment and biota so that environmental values are protected.
- *Marine Fauna – Objective:* to protect marine fauna so that biological diversity and ecological integrity are maintained.

Key EPA technical guidance aligning with the EP Act and relevant to the Project also includes:

- Technical Guidance – Protection of Benthic Communities and Habitats (EPA 2016a).
- Guidance Statement for Protection of Tropical Arid Zone Mangroves along the Pilbara Coastline (**EPA** 2001).
- Technical Guidance – Protecting the Quality of Western Australia's Marine Environment (EPA 2016b).

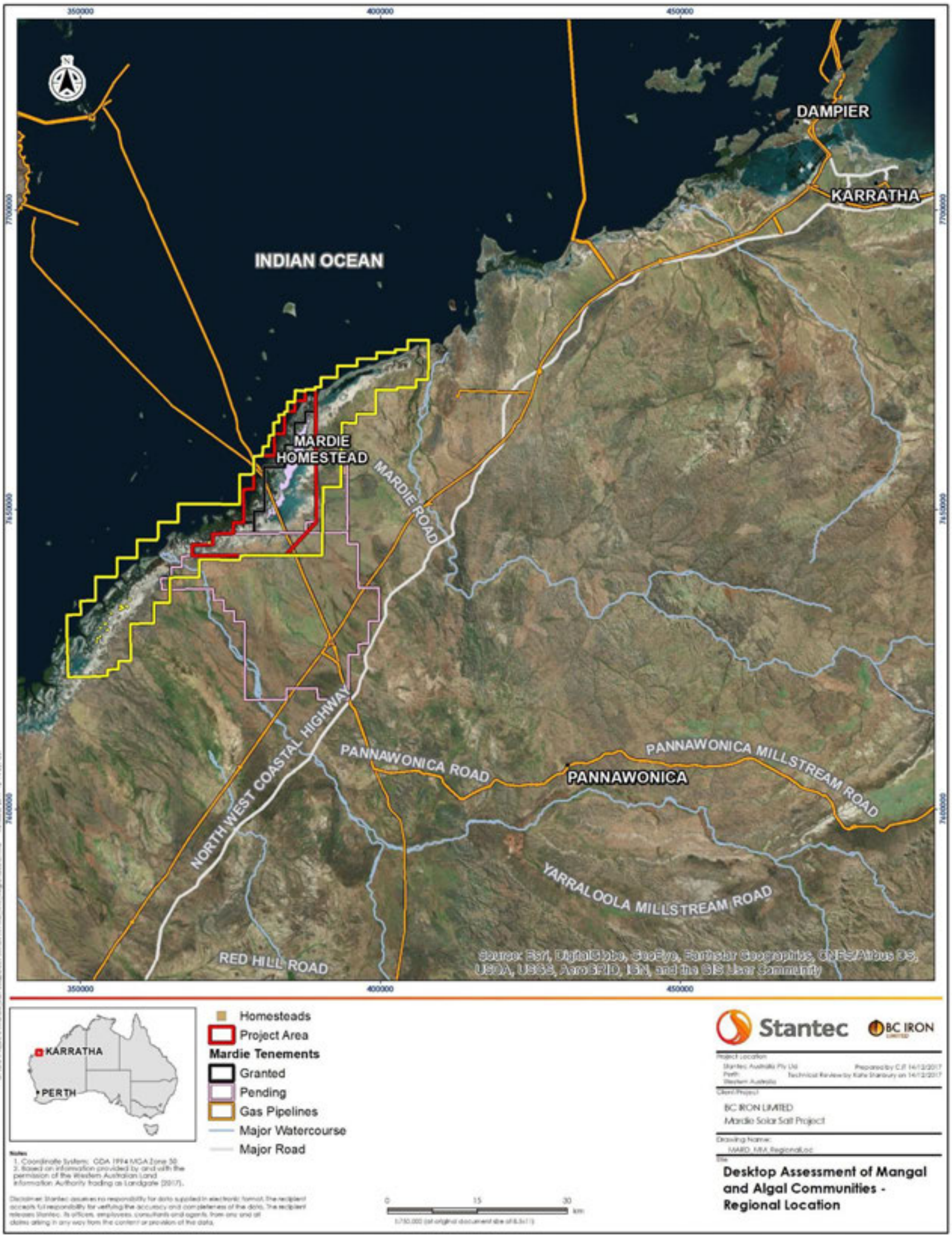


Figure 1-1: Regional location of the Study Area and Project Area, in the Pilbara region of Western Australia.

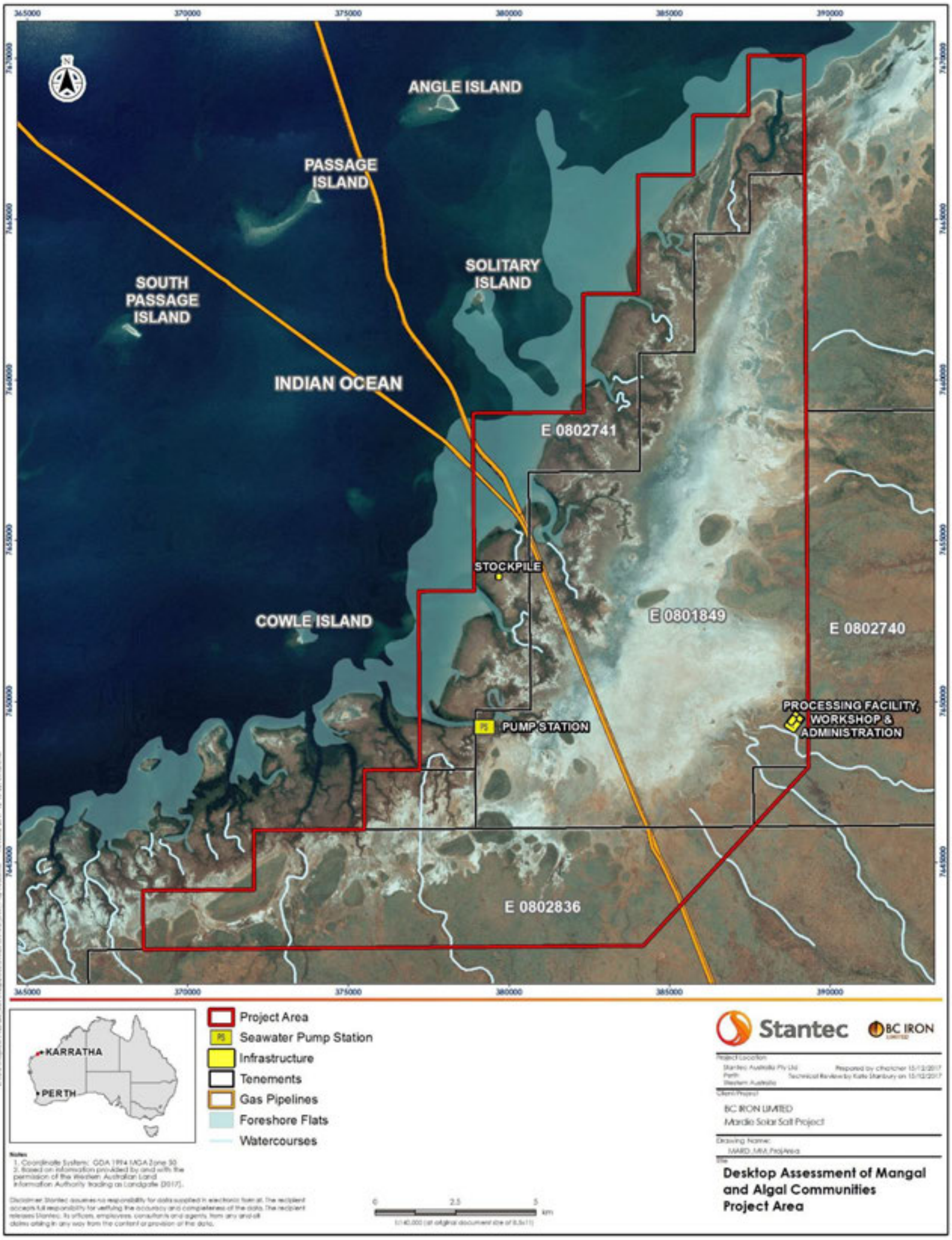


Figure 1-2: Project Area indicating preliminary location of infrastructure.

2. Biogeographical Context

The Project Area is located within the Pilbara bioregion, as defined by the Interim Biogeographical Regionalisation for Australia (IBRA) classification system (Thackway and Cresswall 1995). Based on the IBRA classification system, the Pilbara bioregion is further classified into four sub-regions (McKenzie *et al.* 2009), of which the Project Area falls within the Roebourne subregion (**Figure 2-1**).

The Roebourne subregion is described as quaternary alluvial and older colluvial coastal and sub-coastal plains with grass savannah of mixed bunch and hummock grasses with dwarf shrub steppe of *Acacia stellaticeps* or *A. pyrifolia* and *A. inaequilatera*. The uplands are dominated by spinifex (*Triodia* species) hummock grasslands, while the ephemeral drainage lines support *Eucalyptus victrix* or *Corymbia hamersleyana* woodlands. The marine alluvial flats and river deltas support samphire (*Tecticornia*), marine couch (*Sporobolus virginicus*) and mangal communities (Kendrick and Stanley 2001).

2.1 Land Systems

The Project Area intersects four land systems (Van Vreeswyk *et al.* 2004); the Littoral, Horseflat, Onslow and Yamerina (**Table 2-1**, **Figure 2-2**). Of these, the Project Area is predominantly located within the Littoral land system (69%), which occurs in association with the saline and clay flats between the seaward margin and the terrestrial spinifex sandplains. The remaining land systems occupy approximately 30% of the Project Area, comprising mostly the Onslow land system (22%) and includes sandplain dunes supporting spinifex grasslands.

Table 2-1: Land systems associated with the Project Area.

Land System	Description	Percentage (%)
Littoral	Bare coastal mudflats (unvegetated), samphire flats, sandy islands, coastal dunes and beaches, supporting samphire low shrublands, sparse acacia shrublands and mangrove forests.	69
Onslow	Sandplains, dunes and clay plains supporting soft spinifex grasslands and minor tussock grasslands.	22
Horseflat	Gilgaied clay plains supporting tussock grasslands and minor grassy snakewood (*Acacia xiphophylla*) shrublands.	1.5
Yamerina	Flood plains and deltaic deposits supporting tussock grasslands, grassy woodlands and minor halophytic low shrublands.	0.5
Ocean	NA	7
	Total	**100**

Figure 2-1: Location of the Project Area within the Pilbara bioregion and Roebourne sub-region.

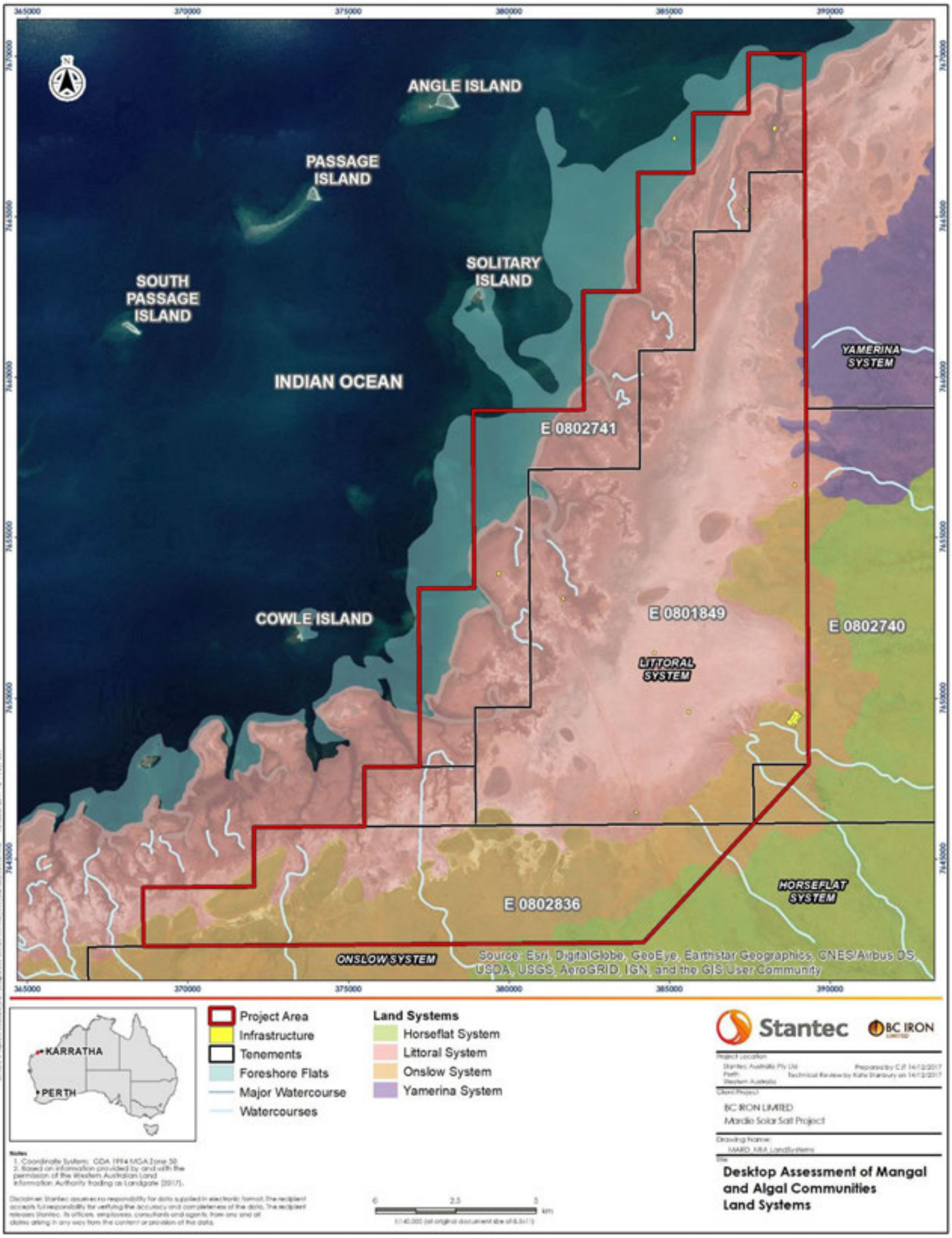


Figure 2-2: Land systems associated with the Project Area.

2.2 Surface Geology

The Pilbara has moderately high relief with a number of ranges, river valleys and peneplains which fall away to form a gently sloping coastal plain along the northern boundaries of the region (Van Vreeswyk *et al*. 2004). The Project Area intersects four geological units (**Table 2-2**, **Figure 2-3**) (Geoscience Australia 2013) and predominantly comprises estuarine and delta deposits (Qe; >50%), made up of coastal silt and evaporate deposits, and estuarine, lagoonal and lacustrine deposits. The remainder of the Project Area is Quarternary colluvial sediment regolith (Qrc), Holocene alluvial sediment regolith (Qa), and Pleistocene beach sand and sand dunes (Qdc) (38% combined).

Table 2-2: Surface geology and their extent within the Study Area.

Code	Description	Proportion of Project Area (%)
Qe	Coastal silt and evaporate deposits; estuarine, lagoonal, and lacustrine deposits.	53
Qrc	Quarternary colluvial sediment regolith comprising colluvium, sheetwash, talus; gravel piedmonts and aprons over and around bedrock; clay-silt-sand with sheet and nodular kankar; alluvial and aeolian sand-silt-gravel in depressions and broad valleys in Canning Basin; local calcrete, reworked laterite.	20
Qa	Holocene alluvial sediment regolith comprising channel and flood plain alluvium; gravel, sand, silt, clay, locally calcreted.	16
Qdc	Pleistocene beach sand, sand dunes, coastal dunes, beaches, and beach ridges; calcareous and siliceous, locally shelly and/or cemented (beach rock); locally reworked.	2
Ocean	NA	9
	Total	**100**

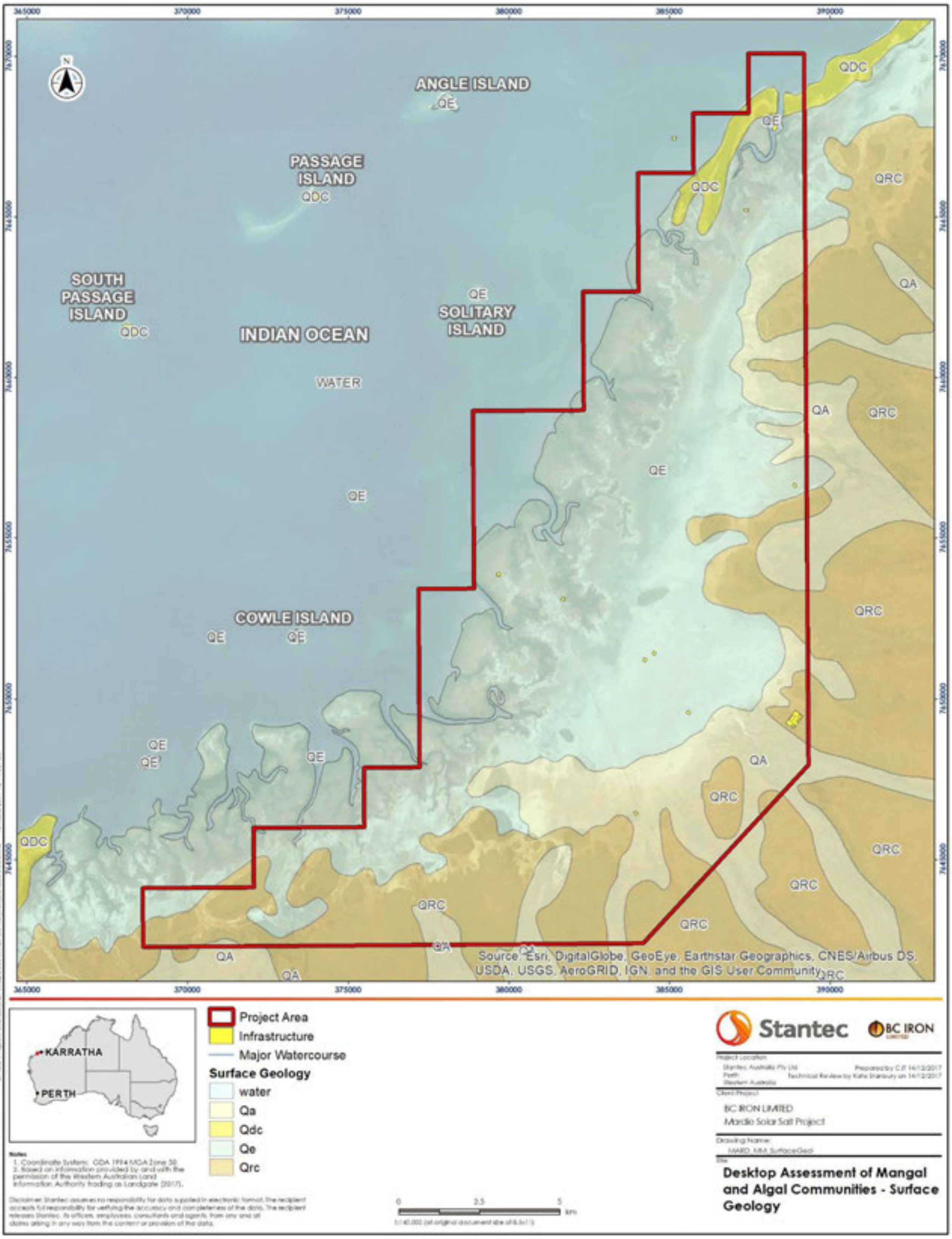


Figure 2-3: Surface geology associated with the Project Area.

2.3 Vegetation System

The Project Area lies within the Onslow Coastal Plain vegetation system (Beard 1975), which comprises five vegetation system associations (**Table 2-3**, **Figure 2-4**). The majority of the Project Area is located within the Onslow Coastal Plain 127, comprising bare areas and mudflats (69%). The remainder of the Project Area is mostly the Onslow Coastal Plain 601 (25%), and includes sedgelands and hummock grasslands. Of the five vegetation system associations, only Onslow Coastal Plain 43 has any of its current extent classified within IUCN Class I to Class IV reserves (**Table 2-4**). The remainder of the associations are not formally protected within reserves that meet IUCN criteria.

Table 2-3: Vegetation system associations and their extent within the Study Area

Vegetation System	System Code	Description	Proportion of Project Area (%)
Onslow Coastal Plain	127	Bare areas: mudflats	69
	601	Mosaic: Sedgeland; various sedges with very sparse snakewood / Hummock grasslands, shrub-steppe; kanji over soft spinifex	25
	117	Hummock grasslands, grass steppe; soft spinifex	1
	600.1	Sedgeland: sedges with open low tree savanna; *Eucalyptus* sp. aff *aspera* over various sedges	0.5
	43	Low forest; mangroves (Kimberley) or thicket; mangroves (Pilbara)	<0.1
Ocean	NA	NA	4
		Total	**100**

Table 2-4: Vegetation system associations remaining across various scales for Onslow Coastal Plain 43.

Scale	Pre-European Extent (ha)	Current Extent (ha)	Extent Remaining (%)	% Extent Protected in IUCN Reserves
State	6305.56	4114.30	65.25	2.48
Bioregion	4,675.21	4,081.67	87.30	2.31
Subregion	4,675.21	4,081.67	87.30	2.31
LGA	4,325.44	3,050.88	70.53	2.48

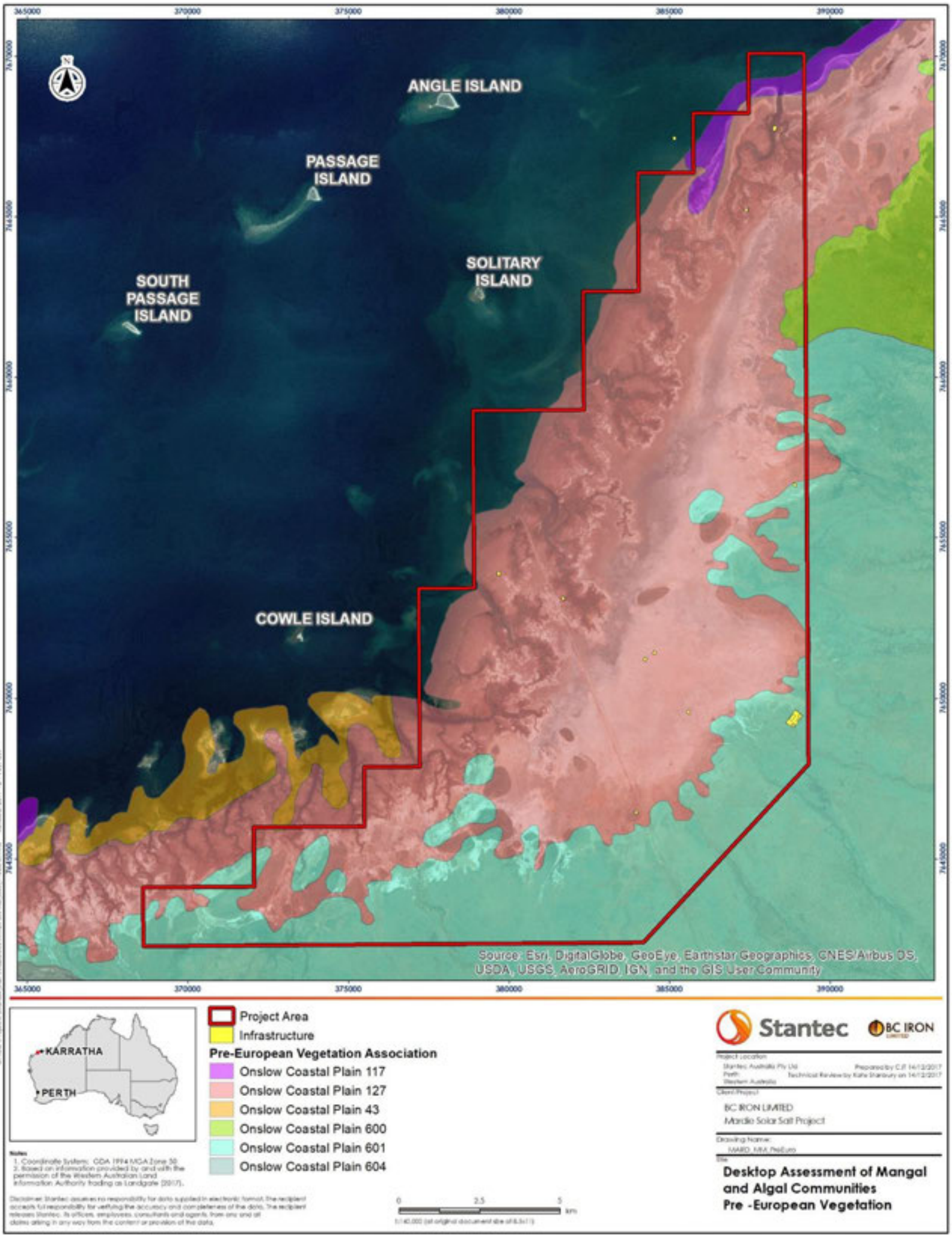


Figure 2-4: Vegetation system associations within the Project Area.

2.4 Climate

The Project Area is located in the Pilbara bioregion, which is characterised by a semi-arid climate, averaging a daily maximum temperature of 35°C between October and March each year. Rainfall is highly variable and episodic reflecting infrequent tropical monsoonal weather systems and the highest frequency of tropical lows and cyclones in Australia. Despite this, the overall average rainfall is only 250 mm per year, which combined with the hot climate, results in a very high net evaporation rate (DPIRD 2017).

The nearest Bureau of Meterology (BoM) weather station to the Project Area is Mardie Station. Mean maximum temperatures are highest in January (~38°C), and mean minimum temperatures are lowest in July (~12°C) (**Figure 2-5**). The long-term average rainfall for Mardie Station is 277 mm, the majority of which occurs in February (>60 mm) and March (>45 mm) (**Figure 2-5**). However, substantial variation in rainfall between years results from cyclonic weather events or tropical lows in the north of the state. The average annual pan evaporation is between 3,200 and 3,600 mm per year (BoM 2017).

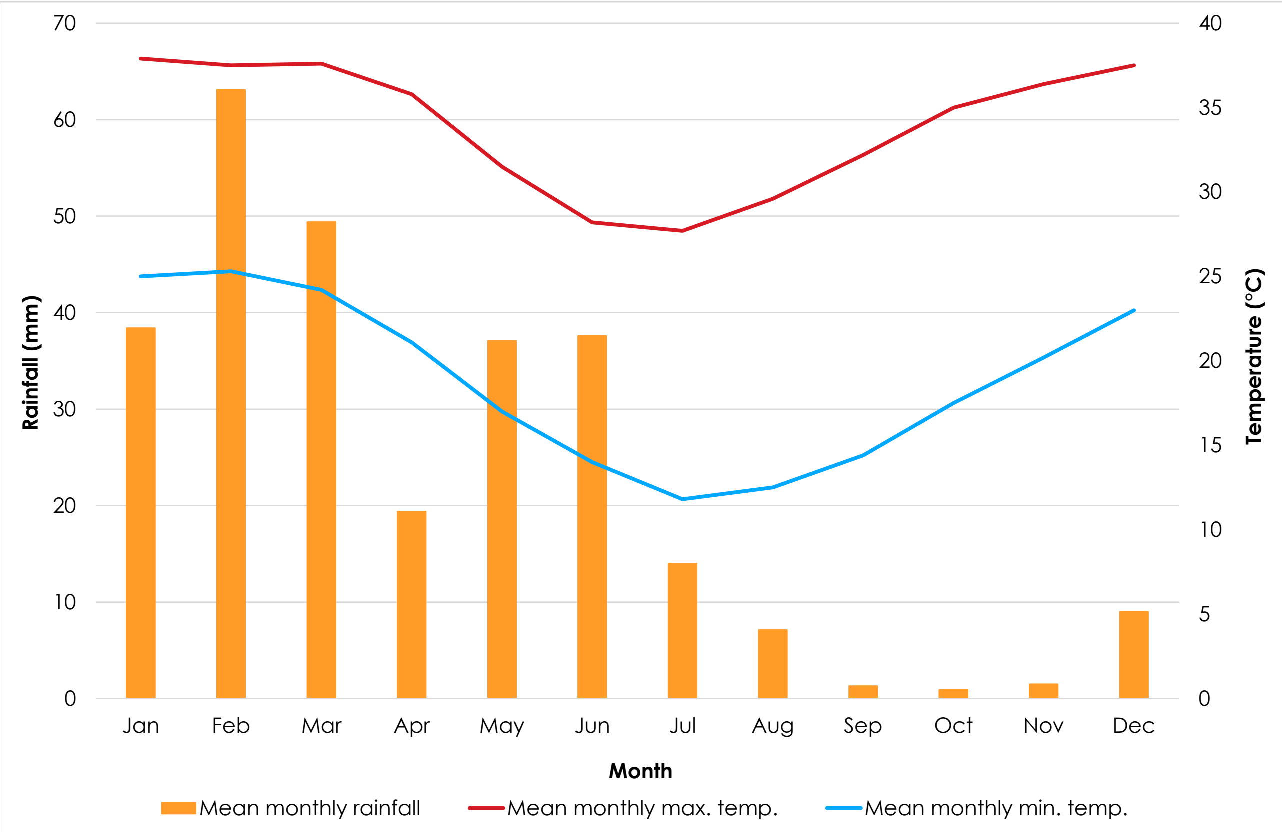


Figure 2-5: Average long-term climate statistics for Mardie Station (Source: BoM 2017).

3. Coastal Processes

The coastal zone is dynamic and influenced by processes seaward to the point at which waves interact significantly with the seabed, extending to the landward limit of tides, waves, and wind-blown coastal dunes (Kaiser *et al.* 2011). It is affected by coastal processes, which are defined as any action of natural forces involving the interaction between natural structures and geophysical processes such as wind, wave speed and direction (EPA 2016b). These processes can be cyclic or episodic, which can change the morphology of the coastline at varying rates (EPA 2016b).

The coastal zone can support rich ecosystems, with ecological productivity favoured by shallow waters, high light intensity, nutrient inputs, tidal inundation regime, wave flushing, and the range of available habitats (Kaiser *et al.* 2011). Specifically, within the intertidal zone, the extent and structure of BCH is primarily influenced by the tidal inundation regime, which affects connectivity to the marine environment (EPA 2016b).

3.1 Tidal Inundation Regime and Surface Hydrology

The Pilbara coastline encompasses a diverse suite of intertidal habitats, featuring limestone barrier islands, complex delta systems, tidal creeks and sandy beach plains (Semeniuk 1994). It represents a heterogenous coastal system (Semeniuk 1993;1994), subject to a combination of fluvial and shoreline accretion processes, sedimentary deposits, sand aprons around islands, alluvial fans and tidal creeks that extend almost 2 km inland (Paling *et al.* 2008).

In contrast, hinterland rivers and creeks are subject to intermittent or irregular, flows, typically associated with episodic tropical cyclones (Kenneally 1982; Paling *et al.* 2008; Semeniuk 1994). This causes flash flooding, marked river discharge of sediment into the coastal plain, the accumulation of spits, erosion and dispersion of coastal sediments (Semeniuk 1994).

The coastal environment in the vicinity of the Project Area functions as a 'reverse estuary', characterised by a complex network of tidal creeks, which protrude onto the extensive intertidal salt flats (Penrose 2011). This results in a unique type of estuary that may be found in arid regions where there is little to no freshwater input and the flow is inverted from usual conditions. In these environments the head of the estuary becomes hypersaline and salinity increases from the mouth of the estuary upstream to the landward limit of the tide (Simier *et al.* 2004).

Recent hydrological modelling for the Project Area indicates mean neap tide levels vary approximately +/- 0.5 m from the mean sea level, and spring tide levels vary approximately +/1.8 m. There is also a difference in tide levels between the north and the south due to changes in elevation. The highest (HAT) and lowest astronomical tides, which are the highest and lowest tidal levels which can be predicted to occur under average meteorological conditions, vary by approximately +/-2.4 m from mean sea level. The highest HAT in the Project Area is RL 2.4m (RPS 2017). There is also a difference in tide levels between the northern and southern ends

The region is prone to widespread inundation from storm surges and infrequent, high intensity rainfall. Storm surges from cyclones can also cause a raised mound of seawater to make landfall, extending up to 50 km across, and several metres higher than the normal tide. This scenario is amplified when a severe cyclone crosses the coast with a gently sloping seabed at high tide (RPS 2017). Rainfall of up to 296 mm in a 24 hour period has been known to coincide with intense tropical lows during summer months, or cold fronts during winter months (BoM 2017; RPS 2017).

The estimated 100 year still water sea level for the Project Area, based on various return periods (recorurrence intervals) was RL 4.2 to 4.3m, approximately 2 m higher than HAT. The 10 year estimated sea level is 3.5 to 3.7 m, 1.3 m higher than the HAT. These sea levels would flood the coast within the Project Area for several kilometres beyond that of the mean sea level (RL 0 m) location (RPS 2017).

The Project Area is located between the Robe River and Fortescue River, with several creeks in between, including Peter and Trevarton Creeks (**Figure 3-1**), which are smaller ephemeral channels that drain from the Hamersley Ranges into the mudflats and saltflats of the Project Area (Phoenix Environmental 2017; RPS 2017). Fortescue River has the largest catchment (18,360km^2), compared to Robe River (7,100km^2), while the local creek catchments are typically less than 100 km^2, with the exception of Peter Creek (188 km^2) (RPS 2017). Flow in the lower Fortescue River is seasonal and generated primarily by rainfall runoff from the river catchment, with the highest flows occurring between December and March. Low or no flow is typically experienced from July through to November (CloudGMS 2017). More broadly, the hydrological regime of the hinterland creeks associated with the Project Area are characterised by seasonal rainfall and there appears to be few, if any, permanent waterbodies (Phoenix Environmental 2017).

Figure 3-1: Regional hydrology of the Project Area, indicating hinterland creek systems.

4. Climate Change

The effects of climate change on coastal and marine environments typically include a rise in sea levels, increased atmospheric and oceanic temperatures, reduced oceanic pH and increases in the frequency and incidence of extreme weather events (Semeniuk 1994). In Australia, predicted sea level rise may be in the order of 2 to 3.8 mm per year between now and 2100 (Ward *et al.* 2016), equivalent to a potential increase of up to 190 mm. Concurrently, atmospheric temperatures for Australia are projected to increase 0.4 to 1.4˚C by 2030 (Paice and Chambers 2016).

In the Pilbara, the extent and consequences of climate change and sea level rise will depend on local weather patterns, geomorphology, hydrological regimes, and anthropogenic modification, if relevant (Semeniuk 1994; Ward *et al.* 2016). The intertidal and coastal zones are expected to be most affected by sea level rise, due to the lower elevation. The extent of changes in this zone will depend on the ability of the ecosystem to adapt to rising water levels, and the rate of change to hydrological regimes (Semeniuk 1994; Ward *et al.* 2016). The potential effects of rising sea levels include coastal erosion, changes to sedimentary processes and the redistribution of benthic habitats (Semeniuk 1994; Ward *et al.* 2016).

The physiological stresses associated with altered hydrological regimes will be much less significant in ecosystems adapted to fluctuations of inundation and desiccation. Mangrove forests for example, have the potential to migrate landwards in response to rising sea levels (Kathiresan and Rajendran 2005; Semeniuk 1994; Ward *et al.* 2016). However, this would depend on the rate of sea level rise and the suitability of the biogeomorphology. While specific to localised habitat, estimates of sea level rise of up to 90 mm over a 100 year period have been suggested as potentially tolerable for some mangrove forests (Kathiresan and Rajendran 2005).

Elevated atmospheric temperatures and may intensify evapotransporation rates and increase salinity profiles in intertidal habitats. For mangroves, increased warming may also increase habitat distribution into higher latitudes and increase productivity. However, adverse effects include changes in species composition and the disruption of phenological patters may also change (Gilman *et al.* 2008). There may also be negative impacts due to heat stress and increased salinity (Kathiresan and Rajendran 2005; Ward *et al.* 2016).

For microbial communities, warmer atmospheric temperatures and increased atmospheric carbon dioxide may have a strong effect on metabolism and growth rates, and selectively favour cyanobacterial growth, allowing for increases in distribution. Changing weather patterns may also impact nutrient mobilisation and salinity within coastal and marine environments, key factors likely to influence species composition, dominance and persistence (Paerl *et al.* 2011).

5. Nutrient Cycling

Nutrient input, cycling and export in coastal and marine environments is fundamental to ecosystem function. The movement of key elements such as nitrogen, phosphorous and carbon, which cycle between inorganic and organic forms, is well studied for mangroves, and less so for algal mats (Biota 2005; Penrose 2011). Nitrogen and phosphorus are vital for the growth of photosynthetic organisms, and primary production is limited when nutrients are in short supply (Reef *et al.* 2010). The production, cycling, and conservation of nutrients is influenced by biological and coastal processes (Hyndes *et al.* 2013; Reef *et al.* 2010).

Typically, nitrogen is considered a limiting nutrient in marine environments (Paerl *et al.* 1993). Inputs into the euphotic zone (light penetrating) result from fluxes of deep water upwelling, hinterland flows, atmospheric deposition and marine nitrogen fixation (Hyndes *et al.* 2013). In the coastal environment, allochthonous (from elsewhere) inorganic nutrient inputs, which may include nitrate and ammonia, occur via fluvial processes, rainfall events, surface runoff and wind driven dust from hinterlands (Semeniuk 1993). High primary production in coastal zones can also provide a large source of autochthonous (*in situ*) organic matter that contributes to marine secondary production (Hyndes *et al.* 2013).

The nitrogen cycle is driven by complex microbial transformations, including nitrogen fixation, assimilations, nitrification and denitrification, of which mangrove forests and algal mats have a key role. Nitrogen fixation is the process whereby molecular atmospheric nitrogen gas (N_2) is converted to biologically available forms of nitrogen. This process is dependent on the presence of prokaryotic bacteria, including cyanobacteria, and a variety of heterotrophic, photoautotrophic and chemoautotrophic bacteria and high light flux (Reef *et al.* 2010).

Microbial communities in these habitats firstly convert nitrogen into ammonium (NH_4+), which is the main form of inorganic nitrogen in sediment. Through nitrification (combining ammonium with oxygen), organic nitrogenous compounds (nitrite or nitrate) are produced, which can be utilised by mangroves (Reef *et al.* 2010). The conversion of atmospheric nitrogen into organic nitrogen by algal mats also provides a mechanism for the export of nitrogen into the marine environment during high spring tides, or from hinterland flows after large rainfall events (Lee and Joye 2006). Nitrogen fixation and export forms the basis of connectivity and productivity in coastal and marine environments (Hyndes *et al.* 2013).

Mangroves have adapted scylerophyllous evergreen leaves to aid nutrient conservation and cycling. Resorption of nutrients also occurs prior to leaf fall (Reef *et al.* 2010). Decomposition of fallen leaves is facilitated by microbial activity, which also contributes to nutrient cycling (**Figure 5-1**). Macrofaunal assemblages associated with mangroves are also important contributors to nutrient cycling and export. Faecal matter from terrestrial organisms (such as birds and bats) provide a source of nitrogen and phosphorous. Crabs can consume 30 to 80% of mangrove litter fall (secondary production), contributing to carbon cycling through herbivory (**Figure 5-1**, as well as producing faecal matter, with subsequent nutrient release via microbial breakdown (Biota 2005).

Cyanobacteria in algal mats may account for almost all of the organic carbon in the sediment of the coastal zone (Stal *et al.* 1984). Grazing by invertebrates at high tides transports this carbon and other nutrients into the marine environment (Penrose 2011). As seawater usually contains low amounts of nitrogen, it is likely that nitrogen fixation also plays a significant role in the development of algal mats (Stal *et al.* 1984). Organic nitrogen produced by algal mats can then be assimilated internally for growth (Stal 2001), or exported and utilised by mangroves or other marine organisms (Biota 2005).

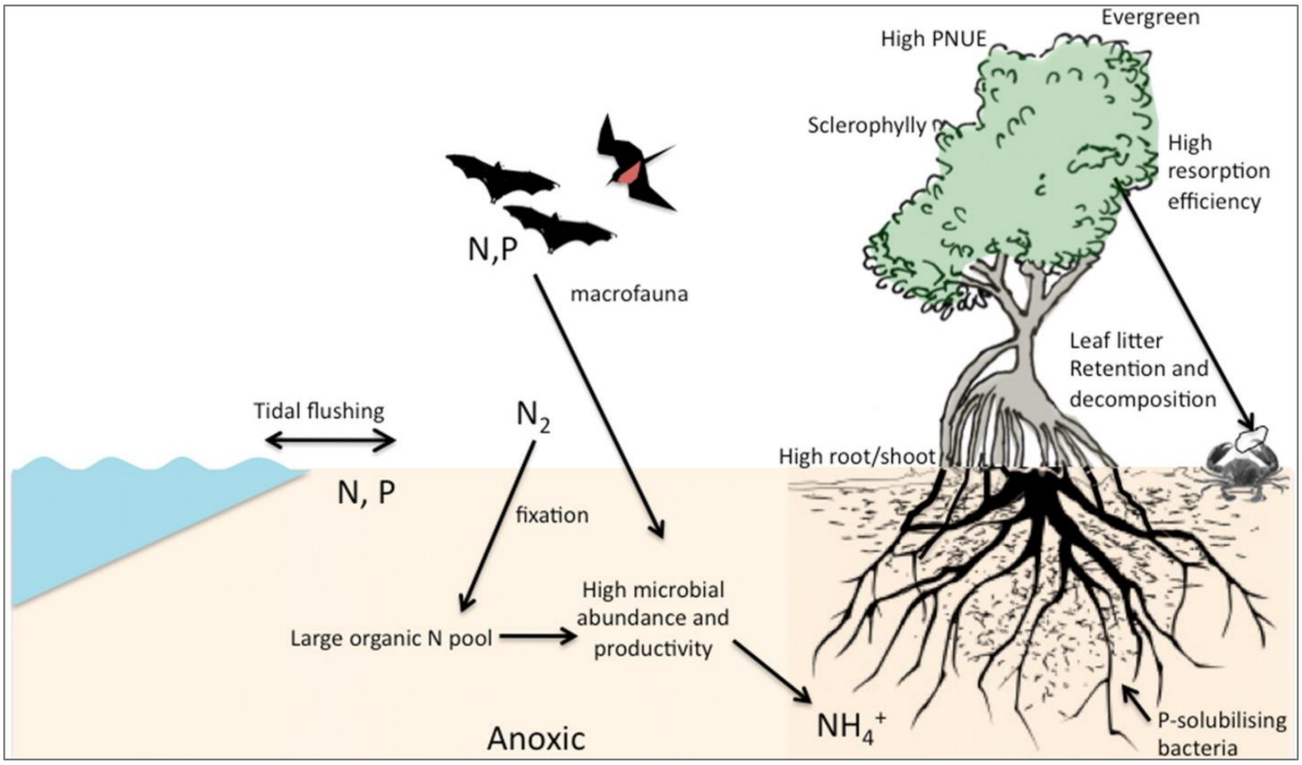


Figure 5-1: Schematic diagram of major nutrient inputs and nutrient conservation mechanisms (PNUE is the photosynthetic nitrogen-use efficiency index) for mangrove forests (Source: Reef *et al.* 2010).

6. Benthic Communities and Habitats

BCH are defined as biological communities that inhabit the seabed, including substrates within the subtidal and intertidal zones, which are important to primary or secondary production. These communities typically contain light-dependent, photosynthetic taxa found growing on or within benthic habitats ranging from unconsolidated sand material, to limestone or igneous rock. BCH examples include coral reefs, rocky reefs dominated by algal communities, seagrass beds and mangroves. In addition, algal mats and salt marshes associated with subtidal or intertidal sandflats or mudflats, as well as microphytobenthos (MPB; microalgae that live amongst sediment particles) are also classified as BCH (EPA 2016a;b).

BCH can occupy the subtidal (fully submerged), intertidal (periodic tidal inundation), and supratidal (occurring above the high tide mark) zones (**Figure 6-1**). They are important for maintaining the integrity of marine ecosystems and for contributing to the supply of ecological services. They support biological diversity by providing structurally complex and diverse habitat and increasing food resources, and can influence the nutrient status of the environment (EPA 2016a).

However, it is recognised that the functional ecological value of BCH varies, dependent on factors such as species diversity, structural complexity, productivity and seasonality. For this reason, greater significance may be placed on BCH dominated by structurally complex primary producers such as algal reef community, compared to more simplistic primary producers such as algal mats (EPA 2016a).

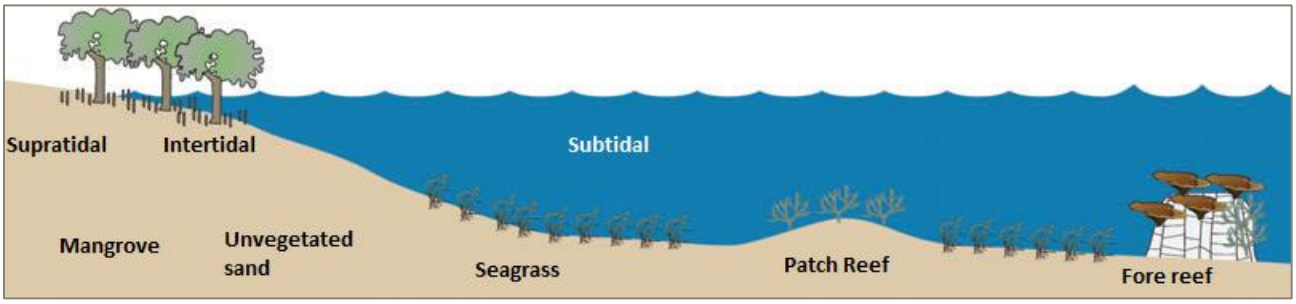


Figure 6-1: Schematic of typical tropical coastal habitat zonation (Source: Hydnes *et al.* 2012).

6.1.1 Mangroves

Mangrove is an ecological term for a distinct vegetated sea-edge forest habitat of plants which dominate vegetation in saline, tidal wetlands along wet and arid tropical regions of the world (Duke and Schmitt 2015). Mangrove forests typically occupy habitat in the upper intertidal zone, between mean sea level and high tide (Duke and Schmitt 2015). They are highly productive and functionally linked to neighbouring ecosystems, promoting primary and secondary production in the euphotic zone (Gilman *et al.* 2008; Hyndes *et al.* 2013; Reef *et al.* 2010). Mangroves are valued for the range of anthropogenic and environmental services they provide, and in many parts of the world are considered culturally important (Ewel *et al.* 1998). They are a source of harvestable goods (fuel, timber and food), and contribute to ecosystem regulating services such as erosion protection, flood control, storm protection, wave attenuation, climate regulation, detoxification, nutrient cycling, pollution control. In addition, mangroves can increase biodiversity, with their unique root-network providing habitat and refugia, typically forming nursery areas and feeding grounds for marine invertebrate and vertebrate fauna (Duke and Schmitt 2015; Ewel *et al.* 1998).

Mangroves have a number of morphological and physiological adaptations to cope with variable and high salinity, waterlogged anoxic sediment and tidal fluctuations. These features include exposed air-breathing roots (pneumatophores), and salt-excreting glands on their leaves. Their leaves also have specialised adaptations to conserve water, such as a thick waxy cuticle or dense hairs that reduce transpiration. The propagules of mangroves are typically dispersed in water (and are often viviparous; germinating prior to detaching from the parent plant), and are buoyant to increase dispersal capabilities (Reef *et al.* 2010; Duke, 2015; Nguyen *et al.* 2015).

Salinities in mangrove habitat can range from seasonally fresh to hypersaline (Nguyen *et al.* 2015), with variations controlled by the hydrological regime, evapotranspiration and rainfall. Interspecific variances in salinity tolerance strongly influence forest structure and the community composition. Mangroves are poor competitors in non-saline areas, restricting their landward distribution (Reef *et al.* 2010).

Nutrient availability limits growth and production in mangrove forests, with changes closely dependent on plant assimilation and microbial mineralisation (Kathiresan and Rajendran 2005). While organic nitrogen is low in marine environments, microbial communities transform inorganic nitrogen into forms available for utilisation by mangroves. Repeated inundation from tidal and hinterland flows also promotes primary production of mangroves by mixing nutrients locked in the sediment (Boto 1982).

Within Western Australia, mangroves are estimated to cover an area of approximately 252,000 ha (Paling *et al.* 2008). They form a distinct, fragmented, fringing community spread across four biogeographic regions; tropical subhumid, tropical semi-arid, tropical arid and subtropical arid (Kenneally 1982; Semeniuk 1993). Nineteen species have been identified across the state (Duke and Schmitt 2015), with distribution and species diversity broadly correlated to temperature and rainfall (Galloway, 1982). The diversity and expanse of mangroves are greatest in the Kimberley, with a marked decrease south of the Exmouth Gulf (Kenneally 1982).

Mangroves along the Pilbara coastline represent the largest single unit of relatively undisturbed tropical arid zone habitats in the world (**EPA** 2001). Within this region seven species are recognised (Paling 2003), which represent four families (Biota 2005). These mangrove species exhibit strong zonation, related to factors such as salinity (including groundwater salinity), sediment erosion and deposition, nutrients, extreme high temperatures, tidal inundation regime, cyclonic events and plant interactions (Biota 2005; Kenneally 1982; Lovelock *et al.* 2009; Lovelock *et al.* 2011).

Mangroves in the Pilbara region have an above ground biomass of 80/120 megagrams per hectare (Mg/ha) (Hutchinson *et al.* 2014), which is comparatively lower than the wet tropics, due to extreme water and salinity stresses (**EPA** 2001). However, this productivity is associated with a diverse array of crustaceans, molluscs and fish. Mangrove forests in the region also provide important corridors for migration to the marine environment, and are known to support a rich birdlife (Kenneally 1982). Along the Pilbara coastline, mangroves are also typically backed by saltflats (Kenneally 1982), which may support algal mat communities.

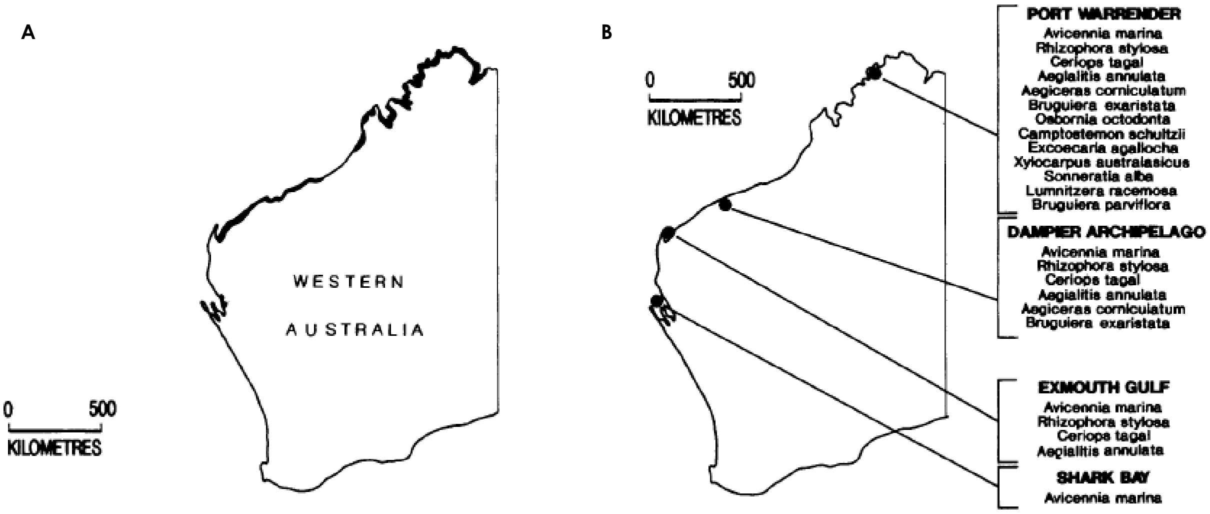


Figure 6-2: Western Australian coastline indicating; (A) mangrove distribution (shaded black), and (B) changes in species composition (Source: Semeniuk 1994).

6.1.2 Algal Mats

Algal mats, also known as microbial or cyanobacterial mats, are geographically widespread, ubiquitous and highly productive components of coastal and marine environments (Paerl *et al.* 1993). They comprise different functional groups of microorganisms, which represent a structural and physiological unit (Van Gemerden 1993). In coastal environments, algal mats occupy saltflats and mudflats, and can extend across large areas (Potts and Whitton 1977). These are typically considered extreme environments, as they are exposed to strong variations in salinity, temperature and desiccation, with low nutrient availability. This means they are able to occupy zones where most other organisms are excluded (Sørensen *et al.* 2005; Stal 2001).

Algal mats are typically dominated by cyanobacteria, commonly known as blue-green algae (Sørensen *et al.* 2004). Cyanbacteria prefer fine sediment and high light transmission, adhering to material through sticky extracellular polymers (Stal 2001). They possess a range of unique and highly adaptable physiological traits including tolerance to extreme conditions, ability to store phosphorus, light capturing ability across a range of wave lengths, and buoyancy (Carey *et al.* 2012; Sørensen *et al.* 2004). They also have relatively few nutritional requirements, with many taxa able to fix their own nitrogen.

The ability of cyanobacteria to fix atmospheric nitrogen means they are not dependent on organic nitrogen sources, which are often in limited supply (Paerl *et al.* 1996). Both heterocystous (containing specialised cells for fixing nitrogen) and some non-heterocystous taxa are capable of fixing nitrogen. Growth of cyanobacteria therefore tends to be controlled by nutrient uptake and rates of intracellular assimilation, rather than by photosynthetic rates (Carey *et al.* 2012). Cyanobacteria enrich the sediments with organic matter, which becomes available to other organisms. Secondary metabolites or organic compounds produced by cyanobacteria may also be important for ecosystem function (Stal 2001).

In the Pilbara region of Western Australia, extensive algal mats occur in the intertidal zone, along saltflats and mudflats, landward of mangroves. They typically comprise filamentous cyanobacteria, with key influential factors including elevation, tidal inundation regime, salinity and habitat stability (Biota 2005; Paling 1989; Penrose 2011). While limited studies are available, algal mats in this region appear to have an important role in nutrient cycling (Penrose 2011). They may also provide a source of nutrients to mangrove forests and the marine environment (Lee and Joye 2006; Paling 1989; Penrose 2011). The latter occurs via grazing and detrital pathways, by marine invertebrate and vertebrate fauna (Penrose 2011; Revsbech and Jorgensen 1983). However, these associations are dependent on the frequency and duration of tidal inundation which creates connectivity between coastal and marine ecosystems.

7. Methods and Approach

7.1 Database Searches and Literature Review

Database searches were undertaken by Stantec and Phoenix Environmental Sciences (the results of which were provided to Stantec). The searches were undertaken to generate a list of conservation significant flora, ecological communities, or vertebrate fauna previously recorded within, or in the vicinity of, the Study and Project Areas.

Four database searches (**Table 7-1**) were conducted at state, federal and international levels (**Appendix B-C**). State and Federal searches were completed within a radius of approximately 50 km of the Study Area. These results were cross referenced against the IUCN Red List database. The search outputs were then refined as those relevant to mangroves and algal mat communities. Literature relevant to solar salt production, mangroves and algal mats was also reviewed, including regulatory information, reports, journal articles and book sections as part of the Assessment.

Table 7-1: Database searches conducted for the Assessment.

Regulatory Department	Database	Biological Group	Level
Department of Biodiversity, Conservation and Attractions	Threatened and Priority Ecological Communities	Flora and Fauna	State
Department of Biodiversity, Conservation and Attractions	Threatened and Priority Flora	Flora	State
Department of Biodiversity, Conservation and Attractions	Threatened and Priority Fauna	Fauna	State
Department of the Environment and Energy	Protected Matters Search Tool	Flora/Fauna	Federal
IUCN	IUCN Red List 2008	Flora/Fauna	International

7.2 Field Surveys

Two field surveys were undertaken as part of this Assessment. The first of these was a reconnaissance survey completed in August 2017, which was restricted to the Project Area. This occurred along a stretch of approximately 20 km of coastline, and was undertaken by experienced botanist Clinton van den Bergh. The second survey was conducted in October 2017, and included a targeted survey of the Project Area to refine initial mapping efforts. The survey area was also extended to include a 75 km stretch of coastline, which ranged from 20 km south of Robe River, and north to the Fortescue River (Study Area), for increased regional context. The targeted survey was completed by Clinton van den Bergh and experienced algologist Dr Fiona Taukulis.

The field surveys were used to aid preliminary mapping and habitat zonation of mangal and algal mat communities. Both surveys consisted of aerial surveying and mapping from a helicopter, supported by ground-truthing. Geo-referenced imagery was also captured at five and 10 second intervals across the Study Area, using a GoPro Hero 5. A summary of tasks undertaken during the field surveys included:

- approximately 18 broad transects (seaward to landward) of the Study Area were established to delineate habitat zonation and identify changes in mangrove and algal mat communities;
- ocean shoreline, tidal creeks and river systems were assessed, along which the species diversity of mangal communities was estimated and mapped, prior to ground-truthing (samphire communities were also broadly identified);
- areas parallel to the coastline, targeting subtidal, intertidal and supratidal zones were surveyed to identify and map algal mats, with representative samples of algal mats collected for laboratory analysis;
- targeted ground-truthing of algal mats was undertaken, focussing on the southern part of the Project Area; and
- hummock grasslands beyond the supratidal zone were broadly recorded and mapped.

7.3 Laboratory Analysis of Algae

In the laboratory, a thin section of algal mat sample was mounted onto a glass microscopy slide, and rehydrated with a small amount of deionised water, to which a glass coverslip was added. The slides were examined using a compound microscope at a maximum of 400X magnification, to gain an understanding of species composition and dominance. The algae identified were recorded, and a broad ranking system was applied to assess dominance. Identification was undertaken to genus or species level, using relevant taxonomic guides and literature, by Dr Fiona Taukulis and Dr Erin Thomas. In addition, expert algal taxonomist Associate Professor Jacob John from Curtin University (Western Australia), was consulted for verification of some taxa.

7.4 Mapping and Habitat Zonation

Digitation of habitat zones based on the field surveys was undertaken using the georeferenced photos, available satellite aerial imagery and ground-truthing data. Approximately ten different habitats were assigned; nine natural and one anthropogenic (the Chevron LNG gas pipeline), with no further delineation undertaken. For example, the Spinifex Sandplains community comprised numerous vegetation types, however was grouped into one broad habitat. The habitat zonation was undertaken by Clinton van den Bergh, while the digitisation and mapping was completed by experienced GIS consultants Sarah Annison and Clare Thatcher.

7.5 Assumptions and Limitations

The following assumptions and limitations apply to this Assessment:

- the scope of work was limited to the coastal environment and targeted manrove and algal mats, excluding the marine environment, and associated impacts, such as bitterns disposal;
- the mapping and habitat zonation is considered preliminary, supported by ground-truthing; and
- algal mat mapping and sampling outside of the Project Area is considered preliminary.

8. Results and Discussion

8.1 Database Searches

The Study Area is located approximately 115 km north of the Exmouth Gulf, of which the eastern side supports significant conservation values that are recognised internationally and nationally. The eastern Exmouth Gulf is considered to be a Wetland of National Importance listed under the Directory of Important Wetlands in Australia (DIWA); Exmouth Gulf East Wetland (WA007) (Australian Nature Conservation Agency 1993). It is described as an outstanding example of a northwest Australian tidal wetland system, with well-developed tidal creeks, extensive mangrove swamps and broad saltflats (Australian Nature Conservation Agency 1993).

Database searches also identified four Priority Ecological Communities (PECs) within 45 km of the Study Area. The four PECs are associated with subterranean or terrestrial environments listed at a state level (**Appendix B**). The two subterranean invertebrate communities identified are restricted to the pisolitic hills and mesas of the Robe Valley, while the Sand Sheet vegetation is poorly known, with its nearest occurrence being near the Mesa A mine site. The Horseflat Land System occurs on the south eastern boundary of the Project Area (**Figure 2-2**), and potentially represents a PEC (**Appendix B**). Therefore PECs are unlikely to represent an issue for the Project.

There were no conservation significant flora identified from the database searches that are known to occur within the Study Area. The nearest records of conservation significant flora (*Goodenia nuda* P4, *Acacia glaucocaesia* P3 and *Owenia acidula* P3) were near the Mardie Homestead, approximately 5 km to the east of the Study Area boundary. While no conservation significant flora were found, two species; *Goodenia nuda* and *Acacia glaucocaesia* were considered likely occur, with an additional 14 species considered to possibly occur (**Appendix C**).

No mangrove species were listed as being of conservation significance (threatened) at a state or federal level within the Study Area, according to database searches (**Appendix C**). The three mangal species identified from the Study Area, *Rhizophora stylosa, Avicennia marina* and *Ceriops australis*, are categorised as Least Concern under the 2008 IUCN Red List, with a decreasing population trend across their state, national and global extents (IUCN 2017a;b;c). There were also no mangrove species of 'other significance' (relictual species, unique or unusual species or communities, or species located at the extremities of their range) found within the Study Area.

While acknowledging that there are no unusual endemic or restricted mangrove species along the Pilbara coastline, the EPA provides specific guidance on mangrove protection in this area, in relation to potential development. The criteria for areas of conservation are based on ecological values, as well as coastal type, habitat, species diversity and plant form. In this context, the southern portion of the Project Area has been classified as a mangrove area of high conservation value (Mangrove Management Boundary 7; Robe River Delta), and is designated 'regionally significant' by the EPA (**Figure 8-1**) (EPA 2001). The EPA are committed to provide these mangrove formations with the highest degree of protection, with respect to geographical distribution, biodiversity, productivity and ecological function. In addition, where developments are proposed in these areas, the EPA will adopt a presumption against finding the proposals environmentally acceptable (EPA 2001).

Database searches for conservation significant fauna identified numerous marine fauna and migratory shorebird species listed at a state, federal and international level, which are known to occur within the vicinity of the Study Area (**Appendix D**). Marine fauna of conservation significance comprise fish, sharks, rays, marine mammals and reptiles, listed under the various state and federal acts. Of these, five marine turtles; Green Turtle (Vulnerable, Migratory), Hawksbill Turtle (Vulnerable, Migratory), Flatback Turtle (Vulnerable, Migratory), Leatherback Turtle (Endangered, Vulnerable and Migratory) and Loggerhead Turtle (Endangered and Migratory) (**Appendix D**), have been recorded from the coastline of the Study Area, and would typically use mangrove habitat for feeding, resting and breeding (Pendoley and Fitzpatrick 1999).

Migratory shorebirds may also utilise mangroves in the Study Area for feeding, roosting, resting and breeding (Johnstone 1990), and were identified during database searches (**Appendix D**). However, there is only one record (Oriental Pratincole; Migratory) from the Study Area. To the south of the Project Area (42 km), at the mouth of a tidal creek, an Eastern Great Egret (Migratory) and Bar-tailed Godwit (Migratory) have also been recorded. The Rainbow Bee-eater (Migratory), Greater Sand Plover (Vulnerable), Whimbrel (Migratory) and Common Greenshank (Migratory) are also known from the Fortescue River, north of the Project Area (**Appendix D**).

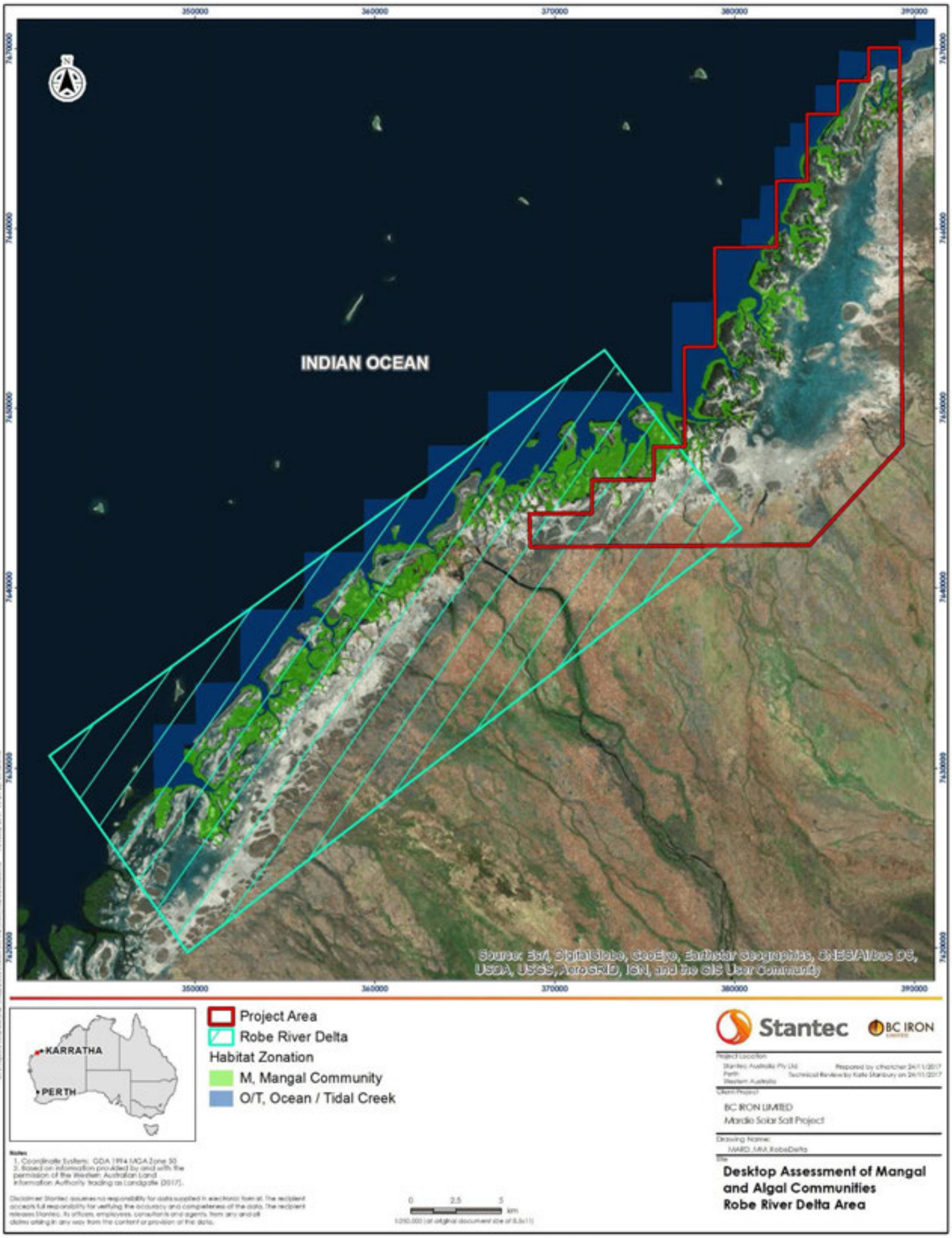


Figure 8-1: Location of the Project Area in relation to Mangrove Management Boundary 7 (Robe River Delta), a designated 'regionally significant' area (Source: EPA 2001).

8.2 Review of Approvals for Solar Salt Projects

Information on environmental approvals for existing solar salt projects in the Pilbara region was reviewed, in relation to potential BCH impacts (**Table 8-1, Figure 8-2**). Information was available for six approved projects (including expansions to existing projects). However, as these approvals pre-date 1999, they provide limited contextual information relevant to this Project.

Of the more recent project proposals, the Yannarie Solar Salt Project was rejected in 2008, and the Ashburton Salt Project is currently under assessment (**Table 8-1, Figure 8-2**), both of which are located in the Exmouth Gulf. The Yannarie Solar Salt Project was rejected based on uncertainty regarding potential environmental risks, and loss of biodiversity and ecosystem services in an area of national importance. Part of this project area is now incorporated into the Ashburton Salt Project.

For the information available, typical environmental concerns raised by the EPA included:

- maintenance of hydrological regimes (including tidal and hinterland flows);
- impacts to biodiversity and ecosystem services;
- loss of BCH habitat (including mangroves and algal mats);
- impacts to marine fauna (including fish stocks) and birds;
- changes to nutrient cycling in the coastal and marine environment; and
- fragmentation of marine habitat and loss of connectivity.

Additional concerns that are not applicable to this Project included environmental impacts associated with:

- shipping and port infrastructure; and
- stockpiling.

Specific to mangal and algal communities, areas previously approved for clearing have ranged from 0 ha, to 50 ha for mangroves and up to 380 ha for algal mats. However, anecdotal evidence suggests historic impacts to mangroves along the Pilbara coast may have been more substantial, with more than 100 ha cleared for individual projects. In addition, of relevance to this Project, is that assessment by the EPA is currently undertaken on a case-by-case basis, adhering to technical guidance and the regulatory framework.

Table 8-1: Summary of solar salt projects and regulatory approvals, relating to BCH, in the Pilbara region (ordered by date from most recent).

Project/Proponent	Proximity to Project (km)	Project Background	Preliminary Environmental Factors	EPA Conclusions	EPA Approval Status	Date of Approval
K+S: Ashburton Salt Project	140 (SW)	Proposed to build a new salt facility 40km SW of Onslow and 50km from the rejected Yannarie Solar Salt Project. The project is expected to operate between 40-100 years **Production:** 3.5mtpa (proposed)	• BCH • Marine and terrestrial fauna • Environmental quality of marine and inland waters • Rehabilitation and decommissioning • 50ha mangrove clearance • 200ha algal mat clearance	Proposal referred for Public Environmental Review in November 2016, based on the premise that detailed assessment was required to determine the extent of the direct and indirect impacts, including long-term impacts and management.	In process	Outcome expected in 2019
Straits Salts: Yannarie Solar Salt, East Coast of Exmouth Gulf	210 (SW)	Proposed construction and operation of new salt facility, requiring 17,765ha of salt flat for ponds. Facility sought dredging a 1.6km shipping channel. Levee walls were proposed to be set back 100m from algal mats and created from 3 million cubic metres of clay from hinterlands. Proposal was located within the Exmouth Gulf East wetland (WA007) which is listed as being of national importance in the Directory of Important Wetlands in Australia. The project had a 60 year expected life span with only 10 years of bitten storage. **Production:** 4.19mpta	• Loss of mangrove and algal mat habitat • Marine and terrestrial fauna • Environmental quality of marine and inland waters • Marine productivity and nutrient cycling • Eutrophication and release of heavy metals • Alterations to geomorphology of coastal zone • Mapped >11,000ha mangroves • 2ha mangrove clearance • 17ha algal mat clearance • 17ha seabed dredging for channel	Proposal deemed to have unacceptable environmental risks due to the following: • Loss of biodiversity and wetland values in an area of national importance and fragmentation of a critically important Benthic Primary Producer Habitat (BPPH)(now referred to as BCH) • Loss of ecosystem goods and services as salt pond blocking distributional adjustments of mangrove and algal mat habitat • Considerable uncertainty of sustainable management of ongoing production >1 million m^3 of bitterns annually, and concerns of incidental or chronic pollution to biota • Negative changes to nutrient cycling, flux and export to productive coastal environment • Potential eutrophication from releasing acids and heavy metals stored in sediments during dredging activity	×	Rejected in July 2008
Shark Bay Salt Joint Venture: Shark Bay Solar Salt Field Enhancements	880 (SW)	Shark Bay Solar Salt project originally operated under the Shark Bay Solar Salt Industry Agreement Act, 1983. Proposed expansion of ponds systems at Useless Inlet to increase production. Irrevocable alterations to construct ponds were proposed to increase from 18% to 34% to the Useless Inlet area, enclosing 2,600ha land adjacent to the existing primary production ponds. **Production:** 1.2mtpa (proposed increase from 0.65m)	• Fragmentation of marine habitat and loss of connectivity • Loss of biodiversity • Protection of mangroves and rehabilitation for disturbed areas • Coastal productivity • Coastal fish stocks • Seepage/bitterns disposal • Environmental impacts of increased shipping • 2,600ha habitat alteration	The proposal was found to be environmentally acceptable based on the premise that mitigation measures could be applied to manage potential impacts. Key recommendations included: • Proponent to reach agreement on compensation to affected fishing industries prior to commencement; • Environmental Management Programme to evidence on-going environmental management; • Avoid direct and indirect impacts to mangroves on and off-site; • Rehabilitate disturbed areas • Decommissioning and rehabilitation plan completion six months prior to end of project	✓	21 July, 1992
Rio Tinto: Onslow Solar Salt Project	90 (SW)	Proposed changes to project to increase production by 1mpta. Modifications included decrease in haulage washing and rate; addition of three crystalliser ponds; decrease in bitterns discharge volume; correction of water use units. **Production:** 2.5mtpa	• BCH • Marine and terrestrial fauna • Environmental quality of marine and inland waters • 380ha algal mats cleared	The proposal was approved under section 45C in 2013. It was determined that there should be no permitted significant direct or indirect impacts arising from the project that could threaten viability of mangrove and algal mat systems.	✓	26 June, 1997
Gulf Holdings: Onslow Solar Salt Project (Stage 1)	90 (SW)	In 1989 the proponent proposed construction and operation of solar salt project on coastal flats near Onslow. Necessary seawater pumping from Beadon Creek and discharge or bitterns into Middle Creek. Required use of 7,700ha tidal flats. **Production:** 1.5mtpa	• Loss of mangrove and algal mat habitat • Maintenance of hydrological regimes for mangrove and algal mats • Introduction of non-native species from ballast water and oil spills in the shipping channel • Eutrophication from bitterns • 230ha algal mat clearance	Proposal deemed environmentally acceptable and the following key recommendations formed part of commitments: • Construction and management should not cause loss or detriment to mangrove or algal mat • Construction of a floodwater channel through condenser ponds for freshwater overland flows to empty into Beadon Creek as they did naturally; • Pumps should be turned off during certain periods of the tidal cycle to prevent desiccation of tidally wetted areas inhabited by mangroves and algal mats	✓	14 August 1991

Project/Proponent	Proximity to Project (km)	Project Background	Preliminary Environmental Factors	EPA Conclusions	EPA Approval Status	Date of Approval
				• Monitoring of offsite mangroves and algal mats necessary • Bitterns discharge regime should be altered or an ocean outfall constructed to prevent loss of mangroves due to partially diluted bitterns reaching upstream on the rising tide		
Leslie Salt Project: Expansion of Ponds, Port Hedland	290 (NE)	Acquired by Rio Tinto in 2001. Located 30 km east of Port Hedland, previously occupying approximately 6,000ha. The facility had already resulted in the loss of 169.3ha of mangroves (8.9% of regional resource) though recruitment in new areas gained 32.8ha. The proposal was for an expansion of 0.5mtpa requiring a new concentration pond covering 1,600ha. **Production:** 2.75mtpa (increased from 2.25mtpa)	• Mangrove habitat • Maintenance of freshwater floodout regime • Location of new pump facility • Bitterns discharge regime • Rehabilitation of disturbed areas • Establishment of Environmental Management Programme • Clearance or fragmentation of sandplain areas • Decommissioning plan • 210ha algal mat clearance	Subject to modifications to pond design, all issues could be resolved by proponent's commitments and the project was deemed environmentally acceptable. Key recommendations included: • Avoidance of mangroves with exception to 0.2ha at second intake pump; • Commitment to avoid indirect loss of BCH; • Monitoring commitments for effect of discharge of bitterns on mangroves, and; • Implementing of a monitoring plan for shorebirds in consultation with Royal Australasian Ornithologists Union;	✓	21 June, 1991
Dampier Salt: Lake MacLeod Salt Field	500 (SW)	Established by Texada in the 1960's it was acquired by Rio Tinto in 1978. In 1997 Rio Tinto proposed to commence extraction of gypsum by creating new borrow pits, new bores, increased shipping, new roads and improve power sources. The lake is recognised nationally and internationally as an important habitat for wetland birds. **Production:** 1mtpa	• Maintenance of local hydrological regimes • Critical bird habitat • BCH • Loss of mangrove habitat and marshland • Marine and terrestrial fauna • Social and cultural • 212ha clearance 43ha/year	Proposal deemed environmentally acceptable and the following key recommendations formed part of commitments: New borrow pits are exhausted and are incorporated in rehabilitation	✓	10 February 1993
Dampier Salt: Lake McLeod Salt Field	95 (NE)	Established in 1967, the proposal was to increase production by re-dissolving and using existing waste salt and installing three new 0.5mtpa stages to more productively utilise the area. The proposal was for an area of former mud flat that had already been disturbed by salt operations. **Production:** 4mtpa (increased from 2.5mtpa)	• Limited environmental impacts, outside of existing impacts.	Residual impacts determined to be insignificant. Key recommendations included: • Monitoring of discharge flow to identify scouring or sedimentation; • Remove excavated material from seawater storage pond and use it to either build up mudflat areas contained by levees and road causeways, between Banana Island and the mainland or as backfill base in appropriate eastern lease area borrow pits, before replacing topsoil; • Seed seawater storage pond area with mangroves and samphire, and; • Monitoring of vegetation establishment.	✓	23 November, 1990

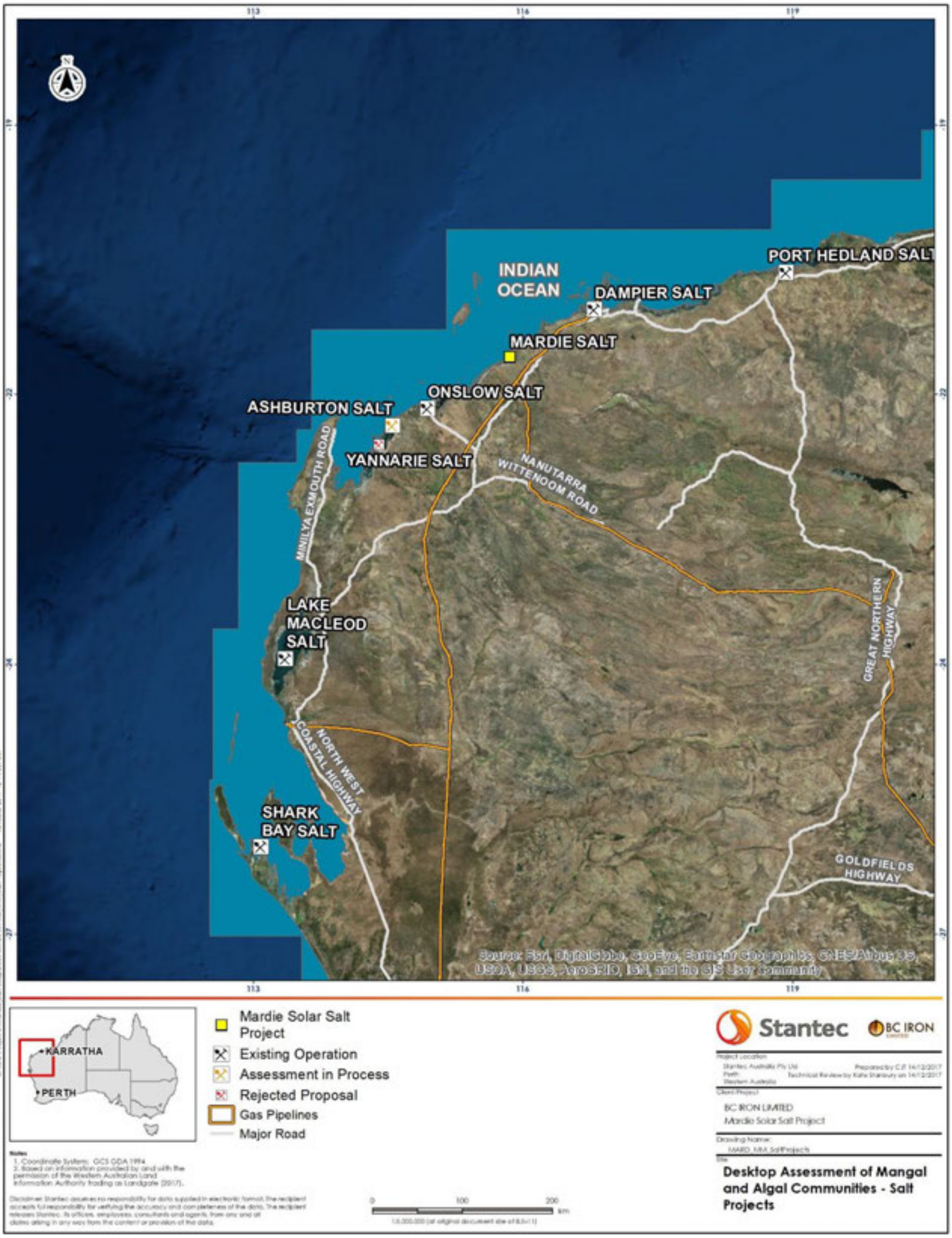


Figure 8-2: Location of solar salt projects in relation to the Mardie Solar Salt Project.

8.3 Preliminary Mapping and Habitat Zonation

8.3.1 Overview

During the Assessment, BCH, including mangal and algal communities within the Study Area were broadly mapped, showing distinct zonation. The majority of coastal habitat comprised Samphire and Samphire/Mudflat Community and Mudflat/Saltflat (excluding Ocean/Tidal Creek and Spinifex Sandplain Community), which together accounted for over 30% of the Study Area (13,111 and 12,880 ha, respectively). In comparison, the Mangal Community, and the Algal Mat Community represented 9.5 and 5.5% of the Study Area, respectively (7,849 and 4,544 ha, respectively) (**Table 8-2**). Within the Project Area, the Mudflat/Saltflat habitat comprised 7,020 ha (27%), the Samphire and Samphire/Mudflat Community 5,755 ha (22%), the Algal Mat Community 2,653 ha (10%), and the Mangal Community 2,159 ha (8%) (**Table 8-2**).

The Mangal Community (**Plate 8-1**) was primarily distributed along the ocean shoreline and tidal creeks, forming bands of various thickness (**Figure 8-3**). Samphire habitat typically occurred behind the mangroves (**Plate 8-1**), while algal mats intermittently occupied the subsequent intertidal zone along low-lying saltflats and mudflats (**Plate 8-2**). Approximately 28 and 58% of mangroves and algal mats, respectively, occurred within the Project Area relative to the Study Area (**Table 8-2**). Behind the algal mats, Mudflat/Saltflat was prevalent, bordered by Spinifex Sandplain Community (**Plate 8-2**), considered a terrestrial vegetation association (**Figure 8-3**).

The zonation observed during the Assessment was considered typical of most parts of the Pilbara coastline, with mangrove forest commonly backed landward by extensive saltflats (Johnstone 1990; Kenneally 1982; Paling *et al.* 2003; Semeniuk 1994). In addition, previous studies of the Exmouth Gulf have identified three large-scale geomorphic units that include the intertidal mangrove system along the shoreline and extensive saltflats, interspersed with areas of terrestrial supratidal land (sandplain/dune system) on saltflats within the intertidal zone (DC Blandford and Associates 2005). Extensive algal mats were also found to occur beyond the tidal limit of the mangroves on mudflats within the Gulf (Biota 2005).

Table 8-2: Summary of habitat zonation with the Study Area (SA) and Project Area (PA) for the Assessment.

Habitat Zonation	Portion of SA (ha)	% SA	Portion of PA (ha)	% PA	% PA relative SA
Ocean/Tidal Creek	14,960	18.1	2,203	8.5	-
Rock Reef	110	0.1	16	0.1	-
Sand Dune Community	2,331	2.8	242	0.9	-
Mangal Community	7,849	9.5	2,159	8.3	27.5%
River/Creek System	89	0.1	25	0.1	-
Samphire & Samphire/Mudflat Community	13,111	15.8	5,755	22.1	-
Algal Mat Community	4,544	5.5	2,653	10.2	58.4%
Mudflat/Saltflat	12,880	15.5	7,020	27.0	-
Gas Pipeline	218	0.3	204	0.8	-
Spinifex Sandplains Community	26,741	32.3	5,729	22.0	-
Total	**82,833 ha**	**100%**	**26,005 ha**	**100%**	**-**

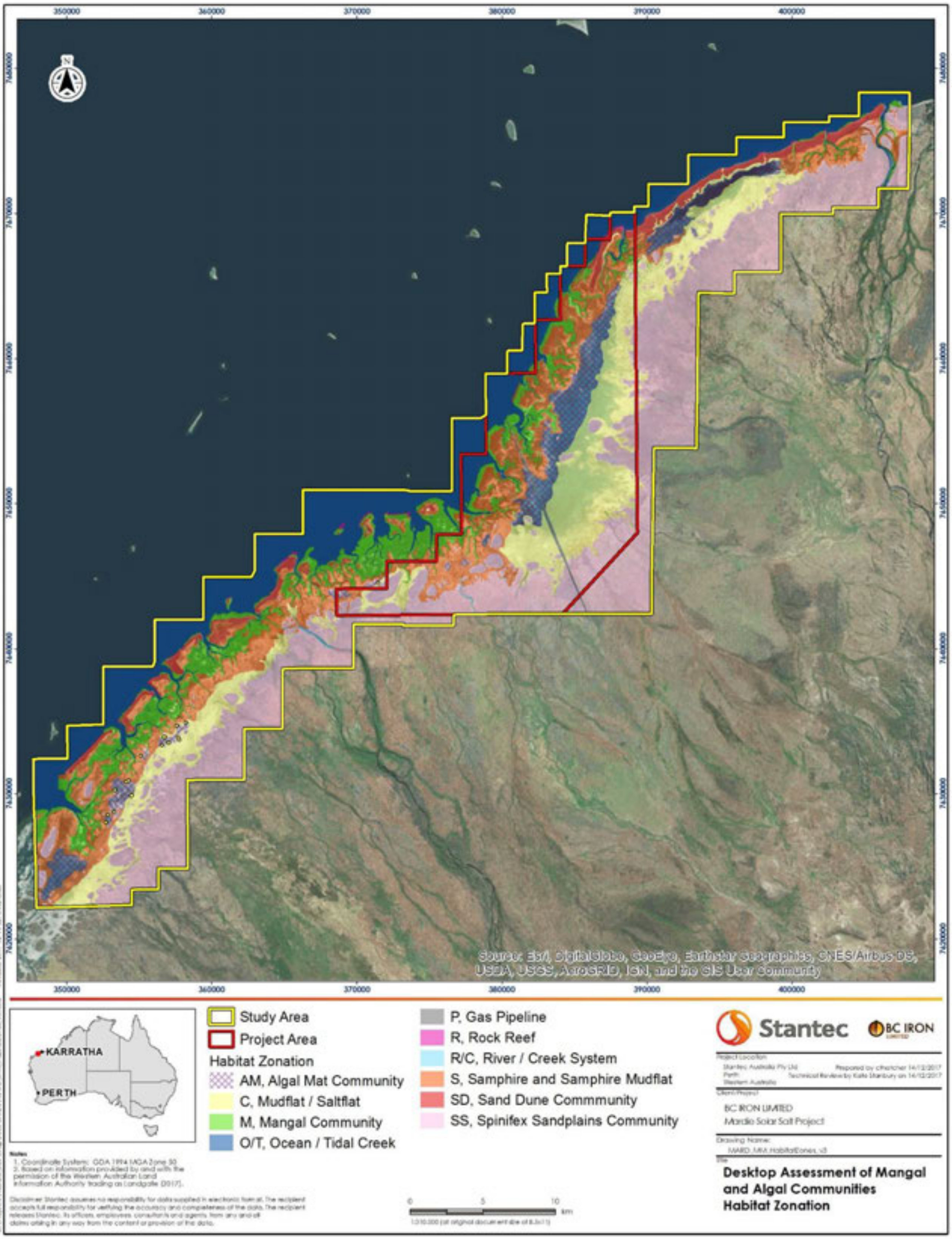


Figure 8-3: Habitat zonation of the Study Area and Project Areas for the Assessment.

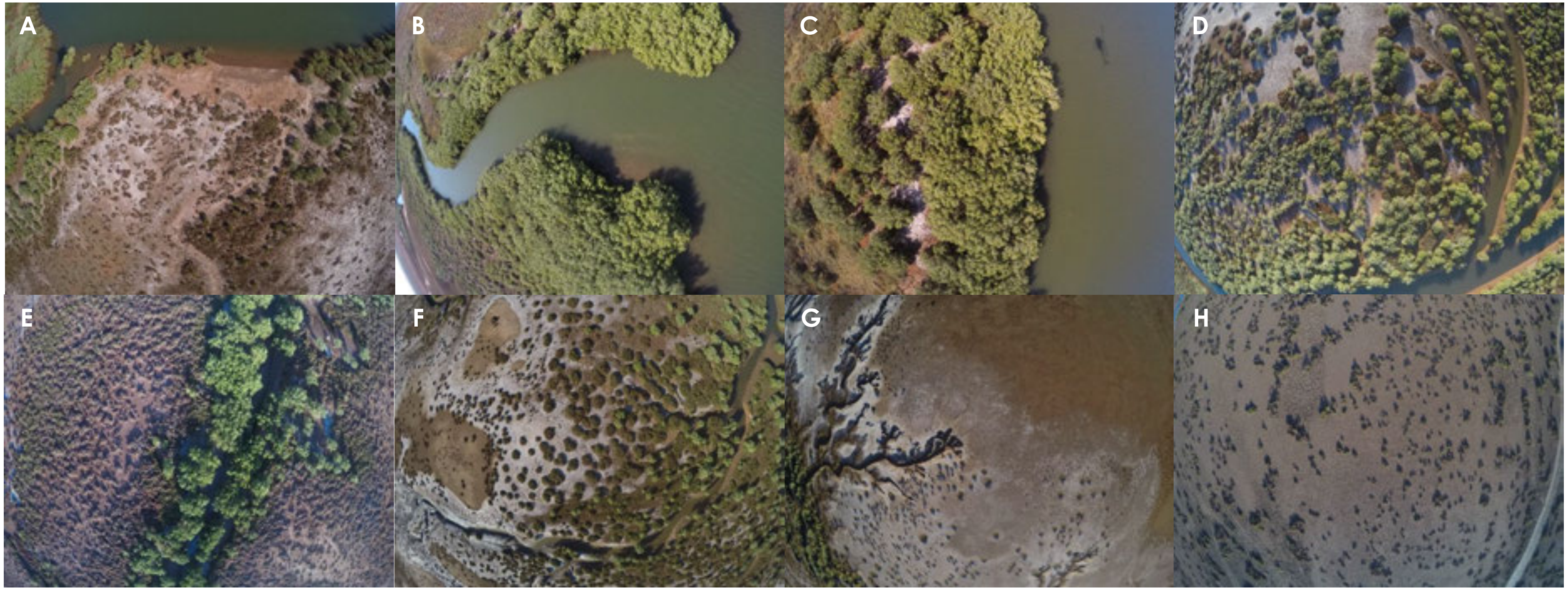


Plate 8-1: (A - E) Mangal communities along the ocean shore and tidal creeks, and (F - H) samphire communities along the landward edge of tidal creeks, within the Study Area.

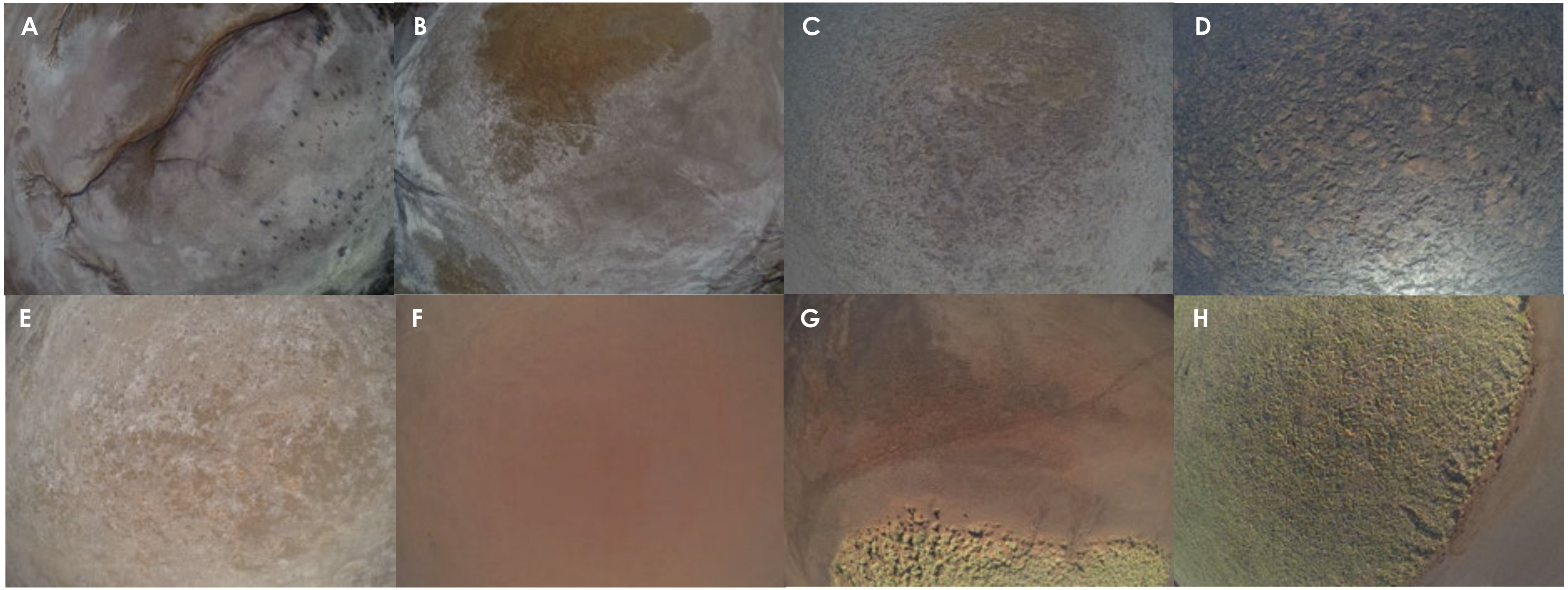


Plate 8-2: (A – B) Samphires along the landward edge of tidal creek, (C – E) algal mats along saltflats and mudflats, (F) mudflats, and (G – H) mudflats along the edge of spinifex sandplain (terrestrial environment), within the Study Area.

8.3.2 Mangal Communities

8.3.2.1 Distribution and Species Composition

During the Assessment, mangroves were broadly mapped throughout the Study Area (**Figure 8-3**). The distribution of mangal communities occurred along the ocean shore and tidal creeks, considered typical of Pilbara coastline (Johnstone 1990; Kenneally 1982; Semeniuk 1994). The largest extent of mangroves occurred in the southern part of the Study Area, where thicker stands were present (**Figure 8-3**). Within the Project Area, narrower bands were associated with tidal creeks. In the northern part of the Study Area, mangroves were restricted by the presence of a large sand dune, and predominantly occurred along the edges of the Fortescue River.

There are seven species of mangroves that are known to occur along the Pilbrara coast, including *Avicennia marina*, *Rhizophora stylosa*, *Ceriops australis*, *Aegialitis annulata*, *Aegiceras corniculatum*, *Osbornia octodonta* and *Bruguiera exaristata* (Pilbara Ports Ref). Within the Study Area, three of these species were identified; *Avicennia marina*, *Ceriops australis* and *Rhizophora stylosa* (**Plate 8-3**). All three species have broader distributions across Asia-Pacific (IUCN 2017). They are also characteristic of the tropical arid biogeographic zone of Western Australia (Johnstone 1990; Kenneally 1982; Semeniuk 1994), and are not considered conservation significant (Florabase 2017).

A. marina (White Mangrove) occurs along the length of the Western Australian coastline (**Figure 8-4**), associated with intertidal zones of mudflats or sandy flats. *C. australis* and *R. stylosa* are both found in northern Western Australia, across the Pilbara and Kimberly coasts (**Figure 8-4**). *R. stylosa* occurs on tidal flats and along the landward edge of mangal communities, and proliferates in mid-intertidal exposed areas (Clarke *et al.* 2001; Duke 2006) (Florabase 2017). *C. australis* generally forms near the supratidal margin of well-drained consolidated clays (Well 1982). Typically, the Study Area was dominated by *Avicennia marina* and *Ceriops australis*, with discrete stands of *Rhizophora stylosa*.

8.3.2.2 Associations

Mangroves form associations based on dominant growth form and species, and their position in the landscape (ESCAVI 2003). In the Pilbara, nine mangal associations are generally recognised (Paling *et al.* 2003), which have been simplified to five associations for mapping purposes, and include:

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

During the Assessment, all five of these mangal associations were recorded in the Study Area, with a further two, localised associations added, including:

- *Ceriops australis* (scattered); and
- *Avicennia marina* / *Ceriops australis* (low open).

While mangal associations were not mapped within the Study Area, their distribution was broadly described as part of the Assessment (**Table 8-3**). The most widespread mangal associations were *Avicennia marina* (closed canopy, landward edge) and *Avicennia marina* (scattered). While both associations were extensive in the Project Area, and in the southern portion of the Study Area, *Avicennia marina* (closed canopy, landward edge) occurred in larger bands of 200 m to 400 m across.

Plate 8-3: (A – C) *Ceriops australis,*, (D – F) *Avicennia marina*, and (G – I) *Rhizophora stylosa* within the Study Area.

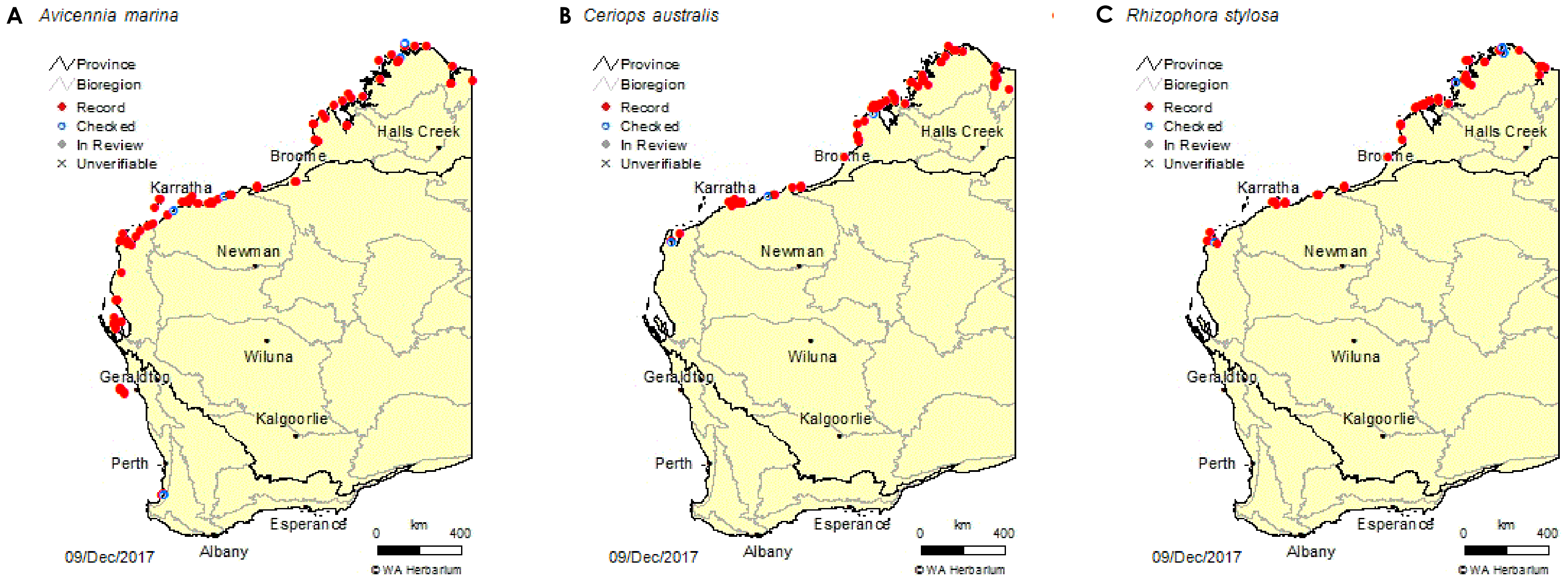


Figure 8-4: Western Australian distribution of mangrove species identified from the Study Area during the Assessment (Source: Florabase 2017).

Table 8-3: Mangrove species associations occurring within the Study Area (yellow highlight indicates localised association added).

Association	Description	Location in the Study Area
Avicennia marina (closed canopy, seaward edge)	A forest comprising large, mature, multi-stemmed *A. marina* on the seaward edge of the main channels and sheltered small bays	Observed in association with the larger tidal creek systems and along the seaward edge of the entire Study Area, excluding the northern portion and other minor pockets. Generally extended between 5 m to 100 m landward from the tidal creek or shoreline edge.
Rhizophora stylosa (closed canopy)	A forest/scrub comprising a relatively narrow zone, often only a few trees wide, behind the seaward *A. marina* fringe and lining steep banks on small channels	Observed as pockets on the seaward edge of larger tidal creek systems and bays surrounded by a closed canopy of *A. marina*. This association occurred mainly in the south, with isolated occurrences in the central portion.
Rhizophora stylosa / Avicennia marina (closed canopy)	A forest/scrub comprising a transitional zone between closed canopy forest close to the seaward edge of main channels and extending to landward along small channel banks	Observed in the transitional zone between the closed canopy of *A. marina* and the closed canopy of *Rhizophora stylosa*.
Avicennia marina (closed canopy, landward edge)	A forest/scrub comprising the typical zone of mangroves immediately behind the mixed association of *A. marina* and *Rhizophora stylosa* and often up to 100 m in width or more and characterised by a decrease in vegetation height with increasing height (above MSL) on the shore	Observed on the landward side of the closed canopy of *A. marina* on the seaward edge association. This association was extensive in the central and southern portion of the Study Area, with some occurrences extending 200 m to 400 m across.
Avicennia marina (scattered)	Comprising scattered landward individuals of the mangrove *A. marina*, often with scattered samphires, but without high densities	Observed on the landward edge of the mangal community, along minor tidal creek systems and mudflats. Ranged in height from 0.5 m to 1.5 m with varying densities. This association was found across a large area, with greater occurrence in the central and southern portions of the Study Area.
Ceriops australis (scattered)	Isolated occurrences of *Ceriops australis* in localised areas on the landward edge of the mangroves and along minor creek systems moving up the landscape.	Observed as isolated pockets on the landward edge of the mangal community. This association was small in size and rarely exceeded more than 50 to 100 m across.
Avicennia marina / Ceriops australis (low open)	Occurred on the landward edge of the mangroves and along minor creek systems.	Observed in areas on the landward side of the mangal communities and across the transition zones between *A. marina* and *Ceriops australis* associations. This association was relatively common in the central and southern portions of the Study Area.

8.3.2.3 Environmental Factors

Mangrove zonation can be highly localised, and is influenced by a range of factors. These include geomorphology, coastal processes (particularly tidal inundation regime), sediment and groundwater properties, climate (cyclonic events), and predation of propagules (Biota 2005; Duke and Schmitt 2015; Feller and Sitnik 1996; Kathiresan and Rajendran 2005; Lugo and Snedaker 1974).

In the Pilbara, elevation and the associated tidal inundation regime affects groundwater salinity in mangrove sediment. Receding tides expose sediment, and together with high temperatures and evaporation rates, cause a steady increase in groundwater salinity, until the next incoming tide flushes and recharges the intertidal zone (Biota 2005; Semeniuk 1983). Individual mangrove species are also known to have specific tolerance limits to environmental factors, including salinity (Biota 2005). Freshwater input from hinterland flows and groundwater seepage can also be important in reducing salinities and delivering nutrients to mangroves (Semeniuk 1983).

A. marina is a hardy, pioneer species, with a high tolerance to salinity, aridity and water temperature (Duke and Schmitt 2015; Nguyen *et al.* 2015). It can dominate in hypersaline conditions, and has been recorded in salinities of up to 85,000 mg/L (**Table 8-4**), with an optimum of 30,000 mg/L, close to seawater (Duke and Schmitt 2015; Nguyen *et al.* 2015). This species has also been recorded from a broad range of temperatures (Duke *et al.* 1998), with peak photosynthesis occurring between 28 to 32˚C (Gilman *et al.* 2008; Kathiresan and Rajendran 2005; Ward *et al.* 2016). As a pioneer species, *A. marina* is efficient at trapping sediment, enabling settlement in conditions where fluvial sediment loading is low (Ewel *et al.* 1998; Nguyen *et al.* 2015).

C. australis is also known to tolerate hypersaline conditions of up to 72,000 mg/L (**Table 8-4**), with an optimal growth rate of between 40,000 to 50,000 mg/L (Bridgewater 1982). *C. australis* also favours drier conditions (**Table 8-4**), with reduced growth rates observed during prolonged periods of inundation (Duke *et al.* 2001; Smith 1988) . In comparison to *A. marina* and *C. australis*, *R. stylosa*, while being salt tolerant (Duke *et al.* 2001), and able to persist up to 74,000 mg/L (Bridgewater 1982), has a lower salinity optima of less than 30,000 mg/L (**Table 8-4**). In addition, unlike *C. australis* and *A. marina*, it does not flourish in dry conditions (Duke *et al.* 2001).

Studies investigating pre-establishment mortality of *Avicennia* spp., *Ceriops* spp., and *R. stylosa* have also shown that when all three species occur together, *R. stylosa* seedlings has the greatest mortality rate (>70%). High seedling mortality has been attributed to a range of factors including herbivory, drought and salinity stress (Upadhyay and Mishra 2012). These three species also have varying preferences for substrate and inundation regime (**Table 8-4**), and nutrient requirements, which influences their establishment and distribution.

Table 8-4: Summary of mangrove species characteristics, relevant to the Assessment.

Key Species	Salinity (mg/L)	Temperature (C°)	Substrate Composition	Inundation Regime
Avicennia marina (Grey mangrove)	Max: 85,000[1] Opt: 15-30,000[1]	Max: 40[2] Opt: 28-32[7]	Aerobic soils, fine stones or rocks coral ramparts, sand, loams[2]	Seaward and landward, permanent to regular to infrequent[2]
Ceriops australis	Max: 72,000[4] Opt: 40,000-50,000[3]	Max: N/A Opt: 28[3]	Aerobic soils, fine silts, clays[4]	Landward, infrequent, spring high tides, intolerant to lengthy inundation[4]
Rhizophora stylosa	Max: 74,000[4] Opt: 8,000-26,000[5]	Min: 16[6] Max: N/A Opt: 20-28[5]	Aerobic soils; fine stones or rocks, coral ramparts, sand, loams[5]	Seaward, regular to permanent, intolerant of dry sediment[5]

References: 1 – Robertson & Alongi, 1992; 2– Duke et al. 1998; 3 – Smith, 1988; 4 – Bridgewater, 1982; 5 - Duke, 2006; 6 – Hutchings and Saenger, 1987; 7 – Ward et al. 2016.

8.3.3 Algal Mats

8.3.3.1 Distribution and Morphology

During the Assessment, algal mats were mapped throughout the Study Area and were classified as contiguous or fragmented (**Figure 8-5**). They occurred within the intertidal zone, and approximating the supratidal zone, having developed along saltflats and mudlfats. The distribution was considered comparable with algal mat zonation previously documented from the Pilbara coast (Biota 2005; Paling 1989; Penrose 2011).

The most extensive contiguous algal mats occurred within, and to the north of the Project Area. The largest of these was within the Project Area (2536.5 ha), and to the north of the Project Area (909.1 ha) (**Figure 8-5**). Contiguous algal mats also occurred outside of the Project Area (although within the Study Area), which were smaller in size (<500 ha). Fragmented algal mats were present in the southern portion of the Project Area (central fragmented), ranging from 1 to 66 ha in size (**Figure 8-5**). Fragmented algal mats were also recorded south of the Project Area (1 to 3 mm), within the Study Area.

Contiguous algal mats were extensive, thicker (1 to 5 mm) and more cohesive than fragmented algal mats, and were characterised by a smooth appearance (**Plate 8-4**). Contiguous algal mats also exhibited folding in some instances, associated with disturbance from strong winds or movement by seawater. Fragmented algal mats were smaller, thinner (1 to 3 mm) and patchier, and often appeared more pustular (**Plate 8-4**). As well as clay material, fragmented algal mats were associated with rockier substrates. Previous studies in the Pilbara (Biota 2005) have documented similar variations in appearance and morphology to this Assessment.

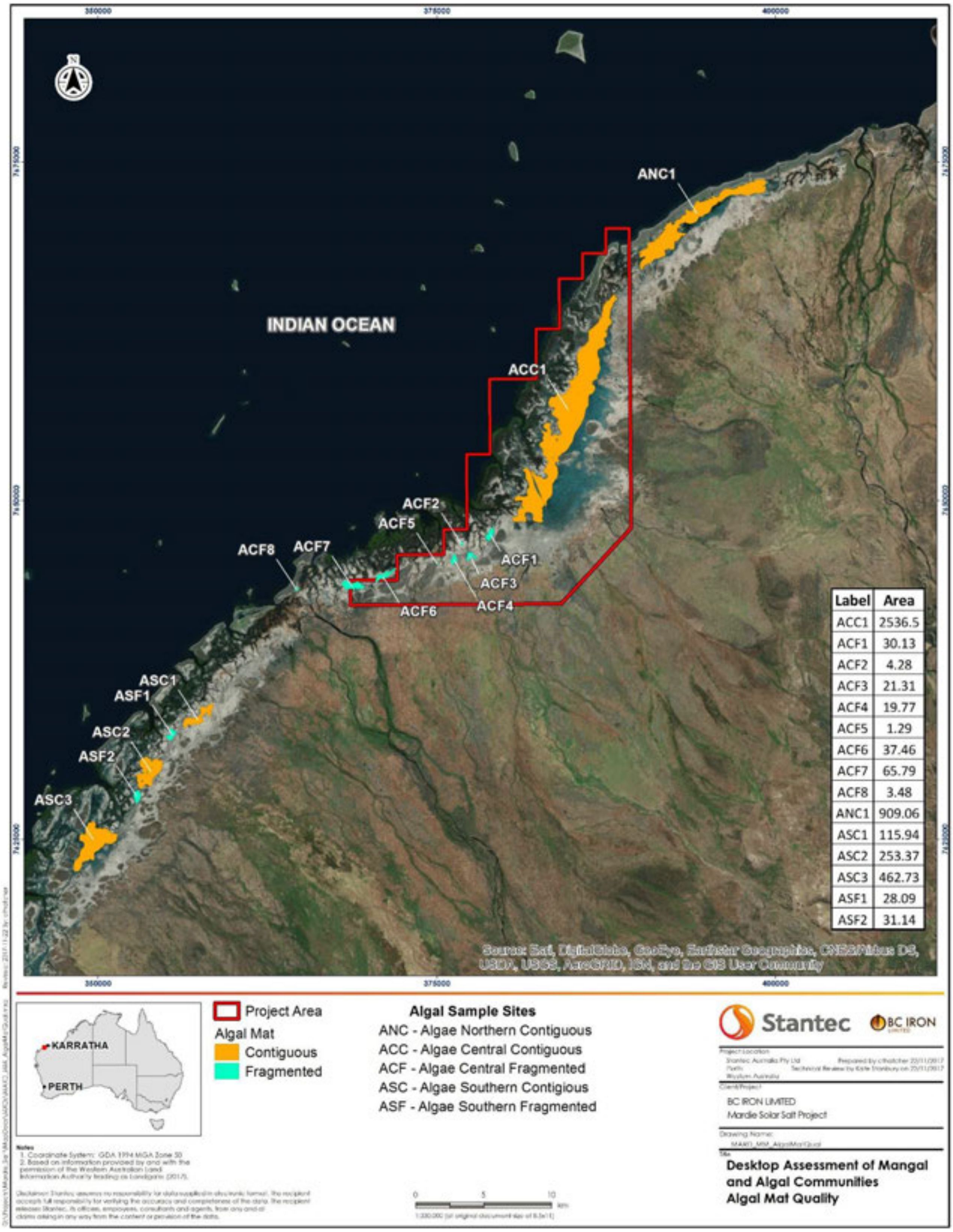
Algal mat colour ranged from green, to grey or black, related to differing levels of hydration. Algal mats, are known to vary widely in appearance; from barely perceptible mucilaginous coatings on sand, mud and organic debris, to well-developed, multilayered 'leathery' carpets dominating lagoonal, reef, mudflats, and saltmarsh ecosystems (Paerl *et al.* 1993).

8.3.3.2 Species Composition and Diversity

The composition of algal mats identified during the Assessment comprised mostly filamentous cyanobacteria (blue-green algae) (**Appendix E**), consistent with microbial communities of intertidal zones around the world (Paerl *et al*. 1983; Stahl *et al*. 1984; 2001, Biota 2005), and including Western Australia (Penrose 2011). Cyanobacteria were typically attached to fine clay material, underlain by a black anoxic layer, which was intermittently evident, and likely associated with sulphur or sulphate-reducing bacteria (Stahl *et al*. 1984).

A total of 11 taxa were recorded from algal mats throughout the Study Area (**Table 8-5**), with comparable composition between contiguous and fragmented algal mats (ranging from seven to nine taxa). Algal assemblages also showed little variation inside and outside of the Project Area, along the length of coastline of the Study Area. The filamentous cyanobacteria *Microcoleus* sp. and *Lyngbya* sp. were the most widespread and dominant components of the algal mats (Plate 8-5), genera which are also characteristic of coastal regions of the USA and Mexico (Paerl *et al.* 1993), and the Pilbara (Biota 2005; Paling *et al*. 1989) and south-west of Western Australia (John *et al.* 2009).

The filamentous cyanobacteria *Calothrix copulorum, Oscillatoria* sp. and *Schizothrix* sp. (**Plate 8-5**) were also relatively common in the Study Area (**Table 8-5**), and are associated with marine and saline environments globally (Fan *et al.* 2015; Potts and Whitton 1977), and in Western Australia (Biota 2005; Handley 2003). Minor algal mat constituents included several filamentous cyanobacteria (*Anabaena and Spirulina*), coccoid cyanobacteria (*Cyanothece* sp., *Merismopedia* sp. and *Synechococcus* sp.), and diatoms (*Navicula* sp.). Cyanobacteria and diatom genera are frequently recorded from microbial communities (Fan *et al.* 2015; Jing and Liu 2012; Paerl *et al.* 1993), including the Pilbara coastline (*Actis* 2005; Chevron 2017; Handley 2003; John *et al.* 2009; Paling 1989).



Label	Area
ACC1	2536.5
ACF1	30.13
ACF2	4.28
ACF3	21.31
ACF4	19.77
ACF5	1.29
ACF6	37.46
ACF7	65.79
ACF8	3.48
ANC1	909.06
ASC1	115.94
ASC2	253.37
ASC3	462.73
ASF1	28.09
ASF2	31.14

Figure 8-5: Contiguous and fragmented algal mats mapped throughout the Study Area.

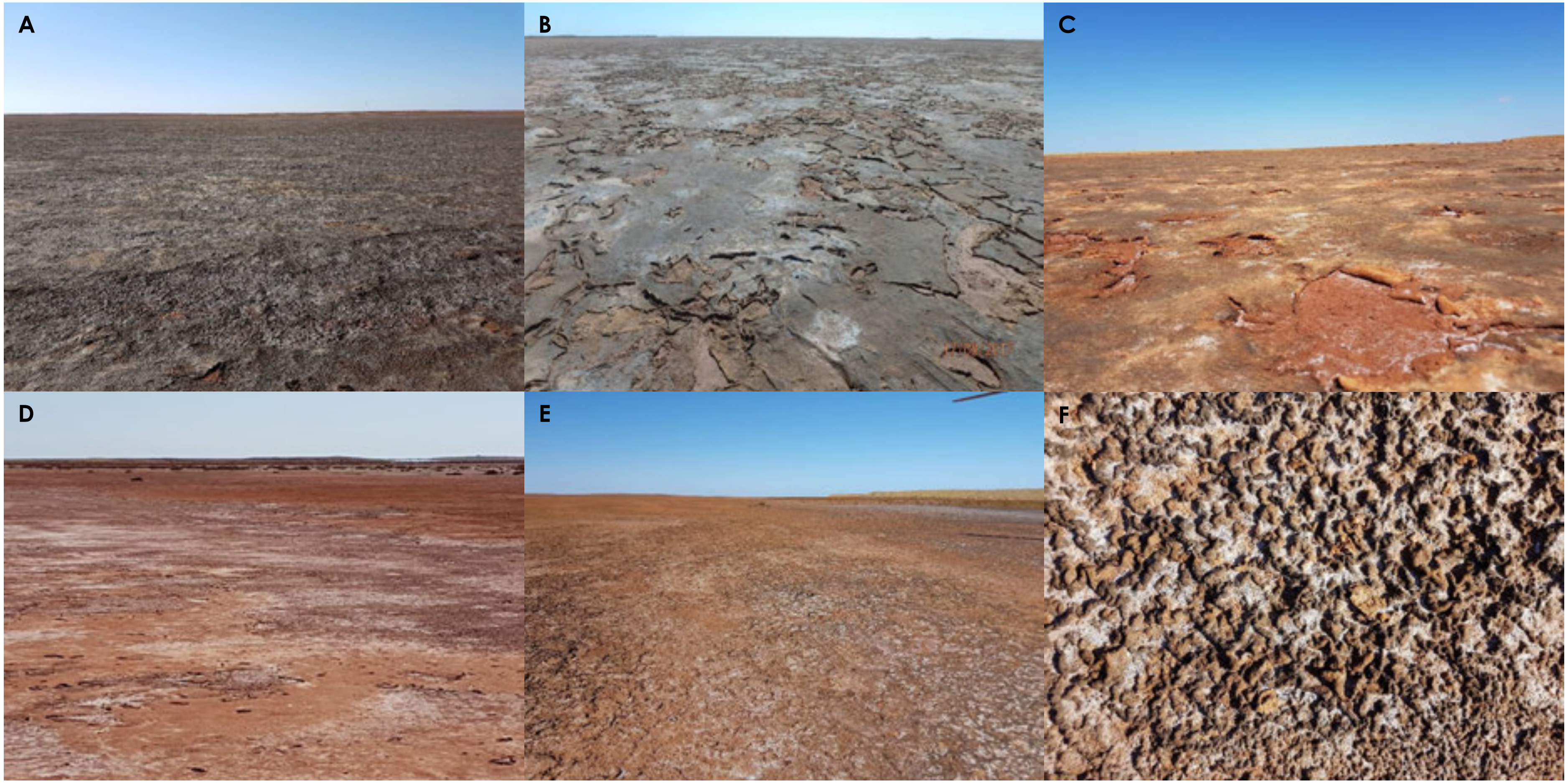


Plate 8-4: (A – C) Contiguous mats in the northern portion of the Study Area, central Project Area and southern portion of the Study Area, respectively (thick, smooth and cohesive), and (D – F) fragmented mats in the southern part of the Project Area (patchy and pustular).

Table 8-5: Summary of taxa recorded from algal mats during the Assessment.

Algal Taxa	Project Area		Study Area	
	Central Contig.	Central Frag.	North Contig.	Southern Contig.
Bacillariophyta				
Navicula sp.	●●	●	●	
Cyanophyta				
Anabaena sp.	●●	●	●	●
Calothrix scopulorum	●●	●●●	●	●●●
Cyanothece sp.	●●		□	
Lyngbya sp.	●●●	●●●	●●●	●●●
Merismopedia sp.				●
Microcoleus spp.	●●●	●●●	●●●	●●●
Oscillatoria spp.	●	●●●		●●●
Schizothrix spp.	●●	●	●●	●
Spirulina sp.	●●	●	●	
Synechococcus sp.				●
Diversity	9	8	7	8
Thickness	1-5mm	1-3mm	1-5mm	1-5mm

Key: ●=rare, ●●=common, and ●●●=abundant Note: not all algal mats were sampled.

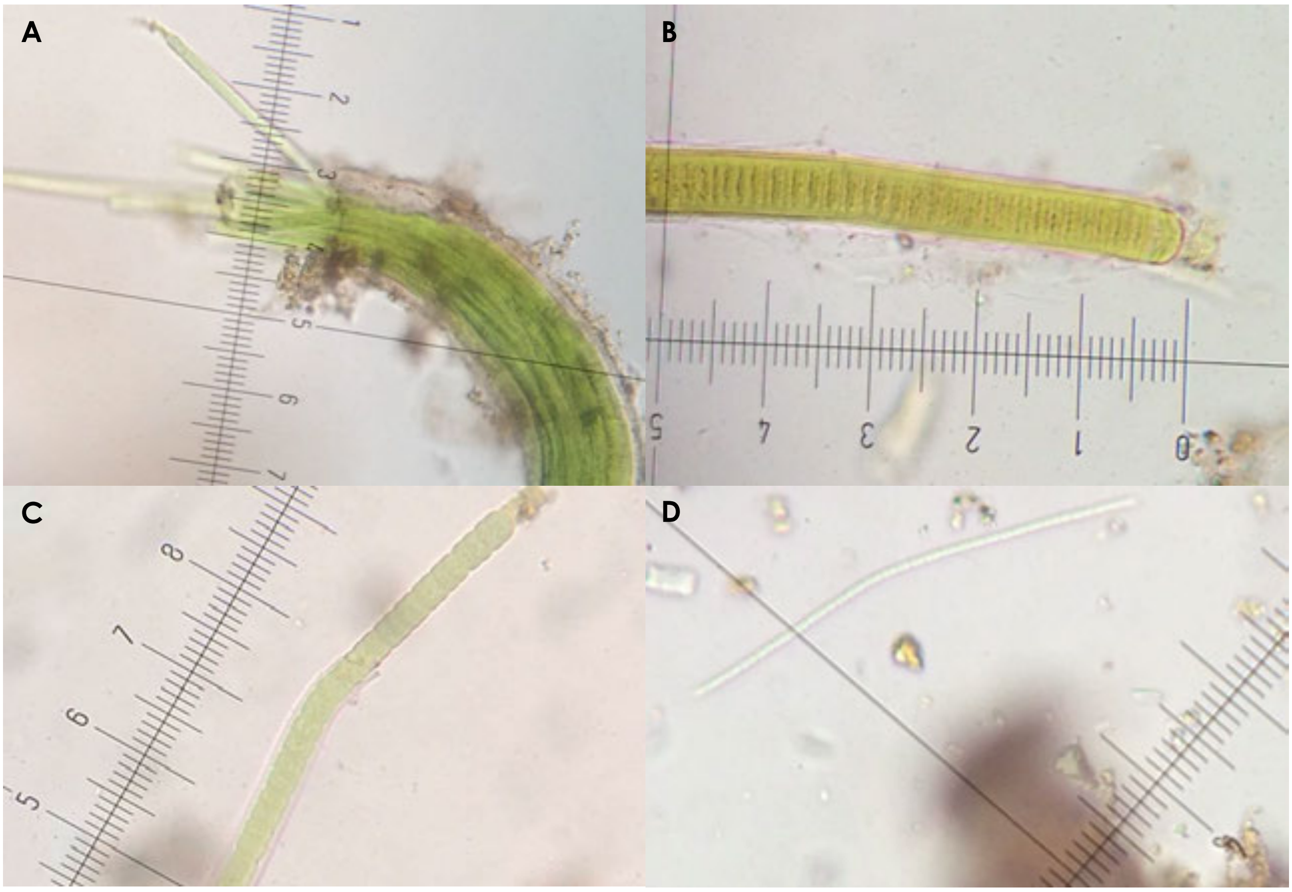


Plate 8-5: Dominant and common components of algal mats within the Study Area including (A) *Microcoleus*, (B), *Lyngbya*, (C) *Calothrix* and (D) *Schizothrix*.

8.3.3.3 Environmental Factors

Algal mats occupy specific habitat within the intertidal zone and may be influenced by a range of factors. This includes elevation, which affects the tidal inundation regime (Biota 2005). Within the Study Area, algal mats occurred within a relatively nominal elevation range of between 1.1 to 1.3 m AHD (0.2 m) (**Table 8-6**) based on digital elevation modelling. This is comparable to algal mats along the Exmouth Gulf, which are known to occupy a narrow tidal range of 1.3 to 1.4 m AHD (0.1 m) (Biota 2005). This corresponds to being completely submerged on average, 1 to 3% of the time (Biota 2005; Penrose 2011).

The distribution of algal mats may also be affected by salinity. It is well-documented that increases in salinity (Sanders 1979) and temperature (Tison *et al.* 1981; Wickstrom 1980) combine to form conditions that favour cyanobacteria (Paling *et al*. 1989). Previous studies have shown that tidal water inundates algal mats in the Pilbara at a salinity of between 35,000 and 40,000 mg/L (Paling 1989), with an upper limit of up to 85,000 mg/L (Chevron 2017). This likely reflects evapocentration of seawater pools associated with receding tides (**Table 8-6**), with algal mat surface temperatures reaching more than 40°C (Paling 1986). Increases in salinity are caused by the dissolution of salt crystallised on algal mats between tidal cycles. Salinity is also known to affect the growth rates of all cyanobacteria, which decreases at salinities above 100,000 mg/L (Paling 1989).

The dominant genera contributing to algal mats within the Study Area were non-heterocystous, filamentous cyanobacteria, comparable with previous studies of the Pilbara coast (**Table 8-6**). However, taxa such as *Microcoleus* and *Lyngbya*, are still capable of fixing substantial amounts of nitrogen (Paerl *et al.* 1993; Stal *et al.* 1984). In addition, algal mats in this region have been shown to fix nitrogen during tidal inundation, as well as when exposed. While active nitrogen fixation takes place over a wide range of salinities (Paling 1989), under experimental conditions, the highest nitrogen fixation rates occurred in algal mats at salinities of between 20,000 to 60,000 mg/L (Paling 1989). Rates of nitrogen fixation have also been found to be approximately ten times higher in the *Lyngbya* as opposed to *Microcoleus*-dominated mats (Bebout *et al.* 1993; Canfield and Des Marais 1993). While nitrogen fixation has been intensively studied in microbial mats, very little is known about the fate of the organic nitrogen produced (Fan *et al*. 2015), and in the context of utilisation in the broader marine environment (Penrose 2011).

Table 8-6: Summary of algal mat characteristics for this Assessment, in comparison to other projects.

Project	Dominant Genera	Morphology	Thickness (mm)	Elevation (m AHD)	Inund. Regime (%)	Upper Sal. (mg/L)	Tidal Range (m)
Yannarie Salt Project[1]	*Lyngbya* *Microcoleus* *Oscillatoria* *Schizothrix*	grey to black smooth to pustular	5-10	1.3-1.4	1-3	N/A	2-0
Wheatstone LNG Project[2]	*Oscillatoria*	grey to black smooth to pustular	5-10	N/A	1-3	60,000-85,000	2.6
Mardie Solar Salt Project	*Lyngbya* *Microcoleus* *Calothrix* *Oscillatoria* *Schizothrix*	green, grey to black smooth to pustular	1-5	1.1-1.3	N/A	NA	2.7

References: 1 – Biota 2005, 2– Chevron 2017.

8.3.4 Marine Fauna

Marine fauna observed along the nearshore ocean environment and tidal creeks were documented during the Assessment. Several sharks, rays, reptiles (including sea snakes, turtles and lizards), fish and mammalian fauna were recorded (**Table 8-7**). This included the Green Turtle (*Chelonia mydas)* listed as Vulnerable, Migratory and the Dugong, listed as Vulnerable, Specially Protected (**Appendix D**). Turtles will utilise feeding, resting, breeding, nesting or juvenile habitat of shallow intertidal reefs, tidal mangrove creeks and beaches. Dugongs will forage in important seagrass habitats, with large populations known from the Exmouth Gulf, south of the Study Area (Preen *et al.* 1997).

Tidal creeks that support mangroves are known as important nursery grounds for juvenile marine fauna, including teleost fish, observed during the field surveys, and other commercially important species including Penaeid prawns. Many of these species migrate to nearshore and offshore adult habitats (Robertson and Duke 1987). It is likely that other potentially conservation significant or commercially important species will be associated with the marine environment in the vicinity of the Project Area (**Appendix D**).

Table 8-7: Summary of marine fauna observed within the area of the Mardie Salt Project

Elasmobranchii (Orders)		
Carcharhinidae	**Myliobatidae**	
Whitetip Reef Shark *(Triaenodon obesus)*	Stingray	
Blacktip Reef Shark *(Carcharhinus melanoperus)*	Eagle Ray	
Grey Reef Shark (*Carcharhinus amblyrhnchos)*	**Rhinopristidae**	
Bull Shark *(Carcharhinus leucas)*	Shovelnose Ray	
Tiger Shark *(Galeocerdo cuvier)*	**Rajidae**	
	Giant Manta Ray *(Manta birostris)*	
	Reef Manta Ray *(Manta alfredi)*	
Reptilia (Families)		
Elapidae	**Squamata**	**Cheloniidae**
Hydrophiinae (Sea snakes)	Varanidae (lizards)	Green Turtle (*Chelonia mydas*)
Teleostei (Bony Fish) Families	**Mammalia Families**	
Serranidae	Odontoceti (Dolphins)	
Lutjanidae	Dugongidae (Dugong)	
Lethrinidae		
Mullidae		
Carangidae		
Siganidae		

9. Preliminary Impact Assessment

9.1 Project Constraints, Risk and Mitigation

9.1.1 Biological Receptors and Impacts

The development and operation of the Project has the potential to affect sensitive biological receptors within the coastal environment including mangroves, samphires, and algal mats. Direct impacts to these receptors include removal of habitat, which may potentially result in temporary or irreversible loss. Indirect impacts include effects on coastal processes. This may affect receptors within the coastal and marine environments in the vicinity of the Project, due to changes to factors such as the:

- hydrological regime (seaward and landward sides);
- hydrogeological regime;
- water and sediment quality, particularly salinity and nutrients;
- flow, erosion and depositional processes;
- trophic pathways and the broader marine food web;
- food resources and habitat provision; and
- migration and succession of BCH in response to climate change.

9.1.2 Preliminary Risk Assessment

A preliminary risk assessment was completed on mangroves, samphires and algal mats for the Project Area (**Table 9-1**), comprising inherent and residual risk rankings. The risk assessment accounted for the:

- key findings of the Assessment;
- potential direct and indirect development and operational impacts of the Project; and
- local and regional ecosystem context.

The inherent risk to samphires is considered ***low***, due to the likelihood that there are no species of conservation significance with a restricted distribution present in the Project Area, and that these communities are not considered BCH. The inherent risk to mangroves is also ***low***, with the proposed Project engineering design avoiding these communities, and avoiding or minimising indirect impacts. The inherent risk to algal mats in the Project Area is ***medium-high***, due to the potential for direct impacts on localised habitat. However, consideration of Project engineering design to maintain ecological integrity, and the completion of more detailed baseline studies to qualify impacts, may reduce this risk to ***low***. Mitigation recommendations and justification predominantly relating to algal mats is provided in subsequent sections.

Table 9-1: Summary of potential Project impacts, risk, mitigation and knowledge gaps (* outside scope however included for context).

Biological Receptor	Direct Impacts	Indirect Impacts	Inherent Risk / Justification	Mitigation Measures	Knowledge Gaps	Residual Risk
Mangroves	Degradation or loss of mangroves due to Project construction and operation Degradation or loss of significant BCH due to Project construction and operation	Degradation or loss of mangroves due to changes in the: • hydrological regime (seaward/landward) • hydrogeological regime • water and sediment quality • coastal processes including flow, erosion and deposition • trophic pathways, food resources and habitat provision, which may affect the marine ecosystem • habitat zonation, due to climate change, with potential migration landwards	***Low*** Direct Project impacts are not expected, with minmal indirect impacts, due to implementation of Project engineering design	Avoid or minimise impacts to mangal communities where possible, through consideration of Project design Maintain the hydrological regime and coastal processes where possible, via the installation of flow corridors throughout the Project Area, and locating the seawall at a suitable distance behind mangal communities. Undertake baseline studies of mangroves and tidal creeks, to inform the establishment of a monitoring and management plan during Project construction and operation Provide a suitable distance between the Project Area and mangroves, to allow for the migration of communities landwards in response to climate change Where impacts maybe required for Project construction and operation, consider environmental offsets (such as funding of research) or rehabilitation programs	Detailed mapping of current mangrove populations in Project and Study Areas Understanding of the response of mangroves to potential indirect Project impacts Understanding of the response of mangroves to potential impacts associated with climate change	***Negligible*** Verification of hydr Project engineering of direct and indirec
Samphires*	Degradation or loss of samphires due to Project construction and operation Loss of conservation significant species due to Project construction and operation	Degradation or loss of samphires due to changes in the: • hydrological regime (seaward/landward) • hydrogeological regime • water and sediment quality • coastal processes including flow and erosion and deposition • habitat zonation of samphires, due to climate change, with potential migration landwards	***Low*** Direct Project impacts appear minor, conservation significant species are unlikely to be restricted, and samphires are not considered BCH, however, mitigation measures to be implemented where possible	Avoid or minimise impacts to samphire communities where possible, through consideration of Project design Maintain the hydrological regime and coastal processes where possible, via the installation of flow corridors throughout the Project Area, and locating the seawall at a suitable distance behind samphire communities Undertake baseline studies of samphires, to determine potential conservation significance of species Provide a suitable distance between the Project Area and samphires, to allow for the migration of communities landwards in response to climate change Where impacts maybe required for Project construction and operation, consider environmental offsets (such as funding of research) or rehabilitation programs	Detailed mapping of current samphire populations in Project and Study Areas Understanding of potential conservation significant species and distribution Understanding of the role of samphires in relation to BCH	***Negligible*** Verification of abs significant species a and indirect impact
Algal Mats	Degradation or loss of algal mats due to Project construction and operation Degradation or loss of significant BCH due to Project construction and operation	Degradation or loss of mangroves due to changes in the: • hydrological regime (seaward/landward) • hydrogeological regime • water and sediment quality • coastal processes including flow, erosion and deposition • trophic pathways, food resources and habitat provision, which may affect the marine ecosystem • habitat zonation, due to climate change, with potential migration landwards	***Medium-High*** While BCI will aim to avoid or minimise direct impacts, the surface area required for the Project may require some disturbance of algal mats, however the risk of direct and indirect impacts can be reduced by implementing mitigation measures where possible	Avoid or minimise impacts to algal mat communities where possible, through consideration of Project design Maintain the hydrological regime and coastal processes where possible, via the installation of flow corridors throughout the Project Area, and locating the seawall at a suitable distance behind algal mat communities. Undertake baseline studies of algal mats, to inform the establishment of a monitoring and management plan during Project construction and operation Provide a suitable distance between the Project Area and algal mats, to allow for the migration of communities landwards in response to climate change Where impacts maybe required for Project construction and operation, consider environmental offsets (such as funding of research) or rehabilitation programs	Detailed mapping of current algal mat populations in Project and Study Areas Understanding of the importance and relationship of algal mats to the marine environment Understanding of the key factors regulating the growth, development and distribution of algal mats Understanding the response of algal mats to potential indirect Project impacts Understanding the response of algal mats to the potential impacts associated with climate change	***Low*** Verification of hydr connectivity to the with removal unlikel regional ecological

9.1.3 Mitigation Recommendations and Justification

The EPA's objective for BCH is to maintain biological diversity and ecological integrity, and as part of the approvals and regulatory framework, Environmental Impact Assessment (EIA) of mangroves and algal mats will be required for Project approval. As part of this process, mitigation of potential impacts is promoted to proponents in the following hierarchical order; ***Avoid, Minimise, Rehabilitate and Offset***. Specific to BCH, there are three principles outlined within the technical guidance that require consideration (EPA 2016a), comprising:

- Principle 1: Demonstrate consideration of options to avoid damage/loss of BCH;
- Principle 2: Design to minimise loss of BCH and justify unavoidable loss of BCH, and;
- Principle 3: Best practicable design/construction/management to minimise loss of BCH.

The EPA recognises that the functional ecological value of BCH varies, depending on factors such as species composition, spatial and temporal distribution, structural complexity, productivity, nutritional value and recovery potential. In particular, greater significance may be placed on BCH dominated by structurally-complex primary producers such as mangroves, compared to structurally-simple primary producers such as algal mats (EPA 2016).

However, it is recommended that an integrated approach to demonstrate adherence to these principles is undertaken by BCI. The following sections provide preliminary discussion and information in relation to these principles, which will form the basis of future studies and EIA. It is expected that following the completion of comprehensive baseline studies across all aspects of the coastal and marine environments, impact and risk associated with the Project will be revised.

AVOID

- *conserve areas of mangal and algal mat communities where possible, and their associated functional processes, such as hydrological and nutrient regimes.*
- *conserve tidal creeks and associated tidal movement, maintaining hydrological flows; key factors that influence mangal and algal mat communities.*
- *conserve hinterland creek flows and sheetflow areas where possible, which provide an important pathway for nutrient runoff to coastal and marine environments during intensive storm events.*

In a regional context, mangroves and algal mats from the Project Area had comparable species composition to the wider Pilbara coast, and intertidal regions globally. *Avicennia marina*, *Ceriops austalis* and *Rhizophora stylosa* comprised mangal communities, and demonstrated characteristic zonation and species associations (Kenneally 1982; Semeniuk 1993;1994). Algal mat taxa consisted of filamentous cyanobacteria; primarily *Lyngbya* and *Microcoleus*, often known to dominate microbial communities (Paerl *et al.* 1993; Paling 1989). This indicates that mangrove and algal mat communities were not considered unique to the Project Area.

Mangroves comprised 8% of the Project Area, and while not expected to be directly impacted by the development and operations, may be subject to minor indirect impacts. Mangroves have a well-documented role in the maintenance of coastal processes, through primary production, habitat provision, nutrient cycling, and soil formation (Ewel *et al.* 1998). In comparison, algal mats were estimated to comprise 10% of the Project Area, with potential direct impacts to a minor portion of habitat, required to accommodate evaporation ponds and crystallisers. Ecosystem services provided by algal mats include nutrient contribution, and as a food source for marine fauna. However unlike mangroves, their relationship to the marine environment is not well understood, with limited studies available (Penrose 2011). Regardless, in the context of the broader Study Area, extensive mangrove and algal mat habitat is present, reducing the potential for Project impacts on biodiversity and ecological integrity.

Algal mats occupy the intertidal zone, or habitat approximating the supratidal zone in the Pilbara (Biota 2005; Penrose 2011). In the Exmouth Gulf they occur within the range from 1.3 m to 2.7 m above the lowest astronomical tide (Lovelock *et al.* 2009). They are only intermittently connected to the marine environment, and are inundated for an average of six consecutive days on the highest of spring tides. This corresponds to a frequency of inundation that is approximately 30% of all tides on a yearly basis, with the mats being completely submerged for up to 3% of the time (Biota 2005; Penrose 2011). While the tidal inundation regime for the Project Area needs refining, preliminary hydrological modelling suggests a comparatively lower frequency (RPS unpublished data).

The importance of algal mats and connectivity to the marine environment has been established for the Exmouth Gulf (Penrose 2011), however, along the Pilbara coastline tidal range and inundation regimes show substantial variation. Preliminary hydrological modelling for the Project Area has shown there is a substantial difference in tidal variation north to south (up to +0.7m at the northern end of the Project Area), likely to influence the flow and expression of seawater along tidal creeks and saltflats (RPS unpublished data). In addition, based on geomorphology, there may also be a cyclical tidal inundation pattern, north to south across the Project Area. Verification of the tidal inundation regime will aid in determining the relationship between algal mats and the marine environment.

When submerged by seawater, herbivorous consumers of algal mats include gastropod molluscs (Al-Zaidan *et al.* 2003; Bauld *et al.* 1992), harpacticoid copepods (Fenchel 1998), and ocypodid crabs (France 1998; Rodelli *et al.* 1984), which support a range of predatory, juvenile fish (Penrose 2011). However, due to the potentially limited inundation regime of algal mats, alternative marine food sources also have an important role for these organisms. Terrestrial insects such as dipterans and trichopterans (Doi *et al.* 2006; Price 1975), are also known to feed directly on algal mats (Gerdes and Krumbein 1987; Gratton and Denno 2006; Pulich and Scalan 1987). The interaction of algal mats with various trophic levels for marine and terrestrial invertebrate and vertebrate fauna is not yet understood for the Project Area.

In the Exmouth Gulf, algal mats are known to contribute to between 5 and 15% of the total carbon fixed by primary producers (Lovelock *et al.* 2009). It is also estimated that annually they add 68 kg of nitrogen per hectare, or 547 tonnes of nitrogen, to the marine environment (Biota 2005). While this indicates that algal mats have an important functional role in facilitating trophic connectivity across intertidal and marine habitats (Penrose 2011), this relationship has not yet been determined for the Project Area.

Tidal and hinterland creek flows influence mangal and algal mat communities. The catchments of several hinterland creeks flow from the Hamersley Ranges; 6 Mile Creek, Trevarton Creek and Gerald Creek towards the southern end of the Project Area, while Peter Creek is also present in the vicinity of the Project Area (Kendrick and Stanley 2001; RPS 2017). Terrestrial inputs from these creeks, albeit infrequent, are recognised as important contributors to the carbon and nutrient budgets across coastal environments (Lovelock *et al.* 2011; Penrose 2011). This is also likely to apply to the Project Area, with the installation of flow corridors proposed as part of the engineering design, to maintain the hydrological regime, and associated coastal processes.

The corridors aim to preserve both tidal and hinterland flows, and have been designed based on hydrological modelling for the Project Area. They should also provide for sedimentary processes, and reduce the likelihood of impacts from erosion or deposition on mangroves and algal mats (Lovelock *et al.* 2011). The location of the seawall, set back 300 m from algal mats should minimise direct and indirect impacts from the Project, with the distance based on the narrowest growth band of contiguous algal mats in the Project Area. Previously, the EPA has rejected a proposed 100 m setback of the seawall for the Yannarie Project. The reasoning for this was that the distance did not provide a suitable precautionary approach allowing for sea level rise and edge effects on algal mats (EPA 2006). Hydrological modelling within the Project Area needs to be refined in relation to predicted sea level rise, however the proposed 300 m distance should prevent edge effects (J. John pers. comm. 2017).

MINIMISE

- *Removal of algal mats should occur from the northern and southern extremities of the Project Area if required, while avoiding the most extensive central section of contiguous algal mat (Section 5.2).*
- *Provide appropriate flow corridors that align with major tidal and hinterland creeks within the Project Area, to maintain the hydrological regime (accounting for changes in flow from climate change). The minimum width of the corridors should be at least 300 m, which corresponds to the narrowest width of contiguous algal mat in the Project Area.*
- *Locate the seawall behind the contiguous algal mats within the Project Area, to conserve this habitat. The optimal distance between the seawall and algal mats should be equal to the narrowest growth band of contiguous algal mats; 300 m. The location of the seawall should also take into the hydrological regime, and changes associated with climate change over the life of Project.*
- *Baseline studies should be undertaken to increase understanding of mangrove and algal mat ecology, and their connectivity and relationship to the marine environment. Key findings may be used to inform the development of management plans as required.*

The presence or absence, and relative abundance of mangroves adjacent to algal mats effects biodiversity and nutrient pathways. The presence of both habitat types has been shown to support an increased diversity of marine fauna in the Exmouth Gulf, which may increase the resilience of the environment to disturbance (Penrose 2011). This also applies to the Project Area, which is characterised by both mangal and algal mat communities, potentially increasing resilience if removal of a small portion of algal mats was required for Project development. The regional extent of algal mats outside of the Project Area is also considered to be substantial (an additional 1891 ha), and therefore may provide justification for the removal of a minor amount of algal mat, without causing adverse effects to the broader ecosystem.

Knowledge of organic matter exports associated with algal mats is generally poorly understood, and complicated by factors such as hydrology, climate, geomorphology, and the nutrients available (Kneib 2003). Organisms inhabiting extreme environments typically may not expend more energy than is required to sustain themselves (J. John pers. comm. 2017). Together with the potentially limited frequency of tidal inundation of algal mats in the Project Area, this indicates the relationship and connectivity to the marine environment may be more independent than the Exmouth Gulf in the Pilbara. However, verification of hydrological modelling is required to support this.

Studies have shown the rates of nitrogen fixation in algal mats vary substantially, and are largely dependent on the inundation regime (Joye and Paerl 1993). While the production of nitrogen by algal mats may be substantial, as demonstrated in the Exmouth Gulf (Biota Environmental Sciences 2005), the fate of this nitrogen is largely unknown (Fan *et al.* 2015). For example, algal mats may utilise the majority of the nitrogen they produce (J. John pers. comm. 2017), which allows them to persist on the saltflats, considered nutrient poor, extreme environments (Lee and Joye 2006; Lovelock *et al.* 2011; Vivanco Adame and Lovelock 2011). This would mean that net export rates of nitrogen to the marine environment may be lower in the Project Area.

While nutrient input from algal mats may also contribute to mangrove productivity (Lee and Joye 2006), there are lengthy stretches in the southern portion of the Study Area where algal mat presence is absent or limited, and the mangal community is thriving. Recent studies indicate that hinterland creek flows, while intermittent, appear to be an important source of nutrients that stimulate mangrove growth and productivity (Saravanakumar *et al.* 2008). In turn, the breakdown of mangrove leaves and detrital matter by bacteria in the sediment contributes nutrients to the marine environment (Biota 2005), where algal mats are absent. This suggests that mangroves within the Project Area may be more reliant on terrestrial nutrient inputs, and their own nutrient cycling processes, which are independent of algal mats.

Hinterland creek flows may play an important role in sustaining algal mats over the longer-term. In addition to providing nutrients, intermittent freshwater flows are likely to periodically hydrate and flush saltflats, preventing excessive salt accumulation. This is supported by satellite imagery from 2014, which shows a large extent of surface water covering saltflats within the Project Area (RPS unpublished data), likely followed a substantial rainfall and runoff event. The overnight dew point also generates moisture within algal mats, and in cooler weather causes small, shallow pools to form, which subsequently evaporate as temperatures increase. This process was actively observed within the Project Area.

Key factors likely to influence algal mats are known, and include elevation, inundation regime, salinity, stability, composition of the substrate and grazing by invertebrates (Biota Environmental Sciences 2005). However, these factors also vary substantially along the Pilbara coast. Therefore comprehensive baseline studies for the Project Area are required to understand the relationship between mangroves and algal mats, and connectivity to the marine environment. There is also limited understanding of the variables that are responsible for regulating algal growth, development and distribution, which affects the capacity of these communities to adapt, and cope with change. Baseline studies of algal mats will contribute to the current lack of ecological knowledge for the Project Area.

REHABILITATION AND OFFSETS

- *Consider environmental offsets such as funding of research programs on algal mats and trophic pathways in the vicinity of the Project Area, to increase understanding of the relationship to the marine environment.*
- *Consider implementation of adaptive management and monitoring programs over the life of the Project, assessing contiguous and fragmented mats inside and outside the Project Area. Also consider utilising flow corridors to monitor changes on mangal and algal communities over time.*
- *Investigate the potential to develop additional habitat conducive for algal mats within the Project Area, based on understanding of ecological requirements for growth and development.*

While there is a wealth of information on the ecology of mangroves in the Pilbara, there has been limited, detailed studies of algal mats (Penrose 2011). In the Exmouth Gulf, a diverse faunal assemblage access algal mats to feed during high spring tides. This includes an array of marine fauna, some of which may be recreationally and commercially important fish species, while juvenile penaeid prawns are supported via the detrital pathway. They are also potential prey for larger marine predators (Balcolme *et al.* Variation in fish diet between dry and flood periods in an arid zone floodplain river.). Therefore, understanding the contribution of mangroves and algal mats in relation to marine BCH (such as algae, epiphytes, corals and seagrasses) adjacent to the Project Area is important. This will increase understanding of trophic pathways and interactions, and allow for potential predictions of environmental changes over time.

There has been a predicted sea level rise of between 0.2m (RPS unpublished data) to 0.9 m (IPCC 2013) in the Pilbara region over the next 50 years, which has the potential to impact on mangal and algal communities. While considered resilient to short and long-term stressors (Alongi 2008; Presiner *et al.* 2016), these communities will potentially migrate landwards (Kathiresan and Rajendran 2005; Semeniuk 1994; Ward *et al.* 2016). However, complex ecosystem dynamics, and often specific ecological preferences (Duke and Schmitt 2015; Ward *et al.* 2016), mean these predictions are based on broad assumptions. Implementing an adaptive monitoring program over the life of the Project would enable valuable scientific data to be collected and compared to baseline conditions. Changes associated with the Project, or climate change, may also be assessed.

There is also the potential to investigate the artificial creation of suitable habitat over the life of the Project that may be used to test the potential for algal mats to colonise rehabilitated areas. Algal mats are known to regenerate following intensive storm events (Lovelock *et al.* 2011), and have been observed recolonising areas previously disturbed for the installation of the gas pipeline in the southern portion of the Project Area. This reflects the resilience of these communities to disturbance. If suitable conditions can be simulated, including hydrology and substrate composition, then algal mats may be able to recolonise previously disturbed areas.

9.2 Environmental Criteria for Project Engineering Design

The results of the Assessment were used to redefine the engineering design of the Project, with the understanding that:

- the relationship between mangroves and algal mats requires further investigation;
- tidal inundation modelling needs refining to determine its influence on algal mats and subsequent connectivity to the marine environment; and
- while hinterland flows occur from minor ephemeral creeks and are infrequent, they still contribute to the hydrological regime.

Database searches indicated there were no flora or communities of conservation significance in the Study Area, relevant to the Assessment. However, the southern part of the Project Area is adjacent to Mangrove Management Boundary 7 (Robe River Delta), designated 'regionally significant' by the EPA. Therefore, BCI have specifically avoided impacts to mangroves within the Project Area (**Figure 9-1**).

The engineering design of the Project was also considered in the context of avoiding and/or minimising impacts to algal mats, in an attempt to maintain biological diversity and ecological integrity, aligning with EPA technical guidance. Avoidance of the largest portion of algal mat within the Project Area was the environmental criteria used, with any removal to occur from the northern and southern extremities of the Project Area (491 ha or 18%) (**Figure 9-1, Table 9-2**). Preliminary justification for this removal of algal mats is as follows:

- a substantial area of algal mats will remain within the Study Area (4053 ha or 89%) and Project Area (2162 ha or 82%) (**Figure 9-1, Table 9-2**);
- comparatively, the Onslow Salt Project disturbed approximately 350 ha or 20% of algal mats, and the Anketell Port Project less than 50 ha, equivalent to more than 30% of algal mats (**Table 9-3**);
- removal of some contiguous algal mat in the southern part of the Project Area aligns with previous disturbance from the installation of the Chevron gas pipeline;
- removal of some fragmented algal mats in the southern part of the Project Area, as they are typically thinner, patchier, and smaller than contiguous algal mats;
- based on preliminary hydrological modelling by RPS, the inundation of algal mats may be limited; and
- nutrients such as nitrogen produced by algal mats may be utilised internally for growth, and with the low frequency of inundation, may provide limited support to mangroves.

The engineering design of the Project has undergone several revisions to implement a range of mitigation measures, to reduce the risk to mangroves and algal mats, and endeavour to maintain biological diversity and ecological integrity including:

- a substantial reduction in the size of the Project Area through the surrender of tenement E08/2399 (4808 ha or 30% of tenure under lease at the time), to avoid mangroves in the Robe River Delta;
- a further reduction in the Project Area (3000 ha or 29%), to avoid algal mats;
- no stockpiling of bitterns;
- no clearing, dredging or other maritime disturbance associated with a local port facility, with salt to be exported from a designated port, via a planned extension to the proposed Cape Preston East Port;
- re-location of the seawall landward, with a 300 m buffer to algal mats (equivalent to the narrowest band of algal mat), to maintain the tidal inundation regime and the north-south distribution of hinterland flows;
- installation of corridors (channels 300 m wide), designed to maintain hinterland and tidal creek flows and connectivity, to specifications that will reduce velocity and the build-up of water along the seawall; and
- engineering design to allow algal mats to migrate landwards towards the seawall and along corridors, in response to predicted sea level rise over the life of the Project (0.2 m over 50 years).

Table 9-2: Proposed area of algal mat removal within the Project Area (PA) and Study Area (SA).

Project Infrastructure	Area of Algal Mat Removal			Proportion of Algal Mat Removal	
	Contiguous	Fragmented	Total	Total % in PA	Total % in SA
8378 ha	420 ha	71 ha	491 ha	18%	11%

Table 9-3: Summary of available information for previous algal mat removal, in comparison to the Project.

Project	Mapped Area (ha)	Area of Impact (ha)	Reference
Onslow Salt Project	2000 ha	380 ha (19%)	EPA 1997
Wheatstone LNG Project	866 ha	52 ha (6%)	Chevron 2006
Anketell Port Project	134 ha	41.5 ha (31%)	API Management 2011
Mardie Solar Salt Project*	2,653 ha in PA 4,544 ha in SA	491 ha (18% in PA / 11% in SA)	Stantec 2017

*= proposed area of impact, PA=Project Area, SA=Study Area

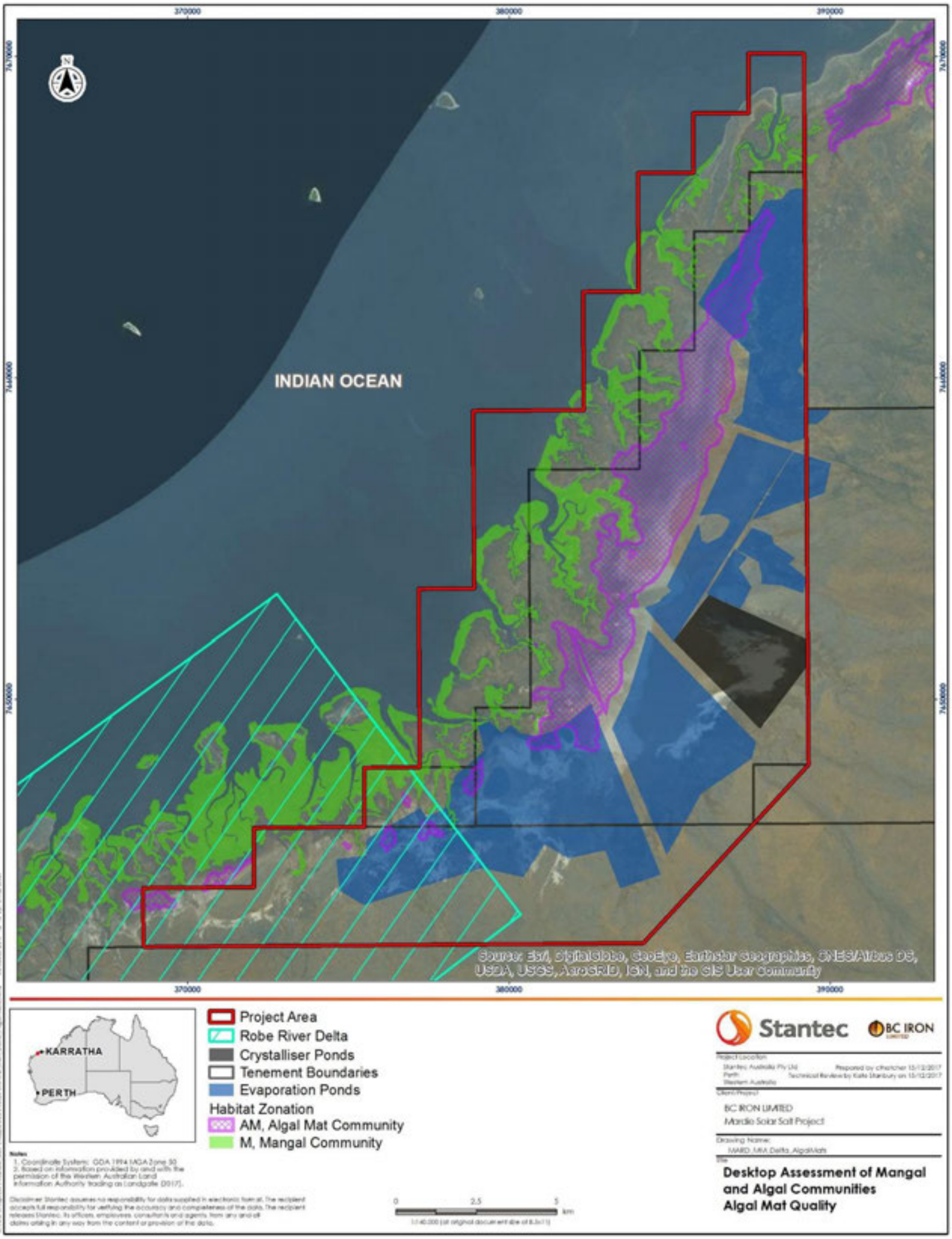


Figure 9-1: Proposed Project Area for solar salt production, in relation to area of algal mat removal.

10. Summary and Recommendations

The recommended mitigation measures provided within this Assessment aim to avoid and/or minimise potential impacts to mangal and algal communities within the Project Area. Impacts to mangroves will be avoided, while only minor disturbance to algal mats is proposed, to accommodate evaporation ponds and crystallisers. The proposed removal of a small portion of algal mats appears comparable to other projects in the Pilbara that have been approved by the EPA. BCI will also endeavour to maintain biological diversity and ecological integrity within the Project Area, through engineering design.

Future studies will be required to support the findings of this Assessment, the aims of which will be to:

- refine hydrological modelling, including on-ground observations and data collation, to verify the tidal inundation regime of the algal mats;
- undertake hydrogeological modelling, to understand potential changes to BCH;
- undertake comprehensive BCH baseline studies, and refine the preliminary zonation mapping for mangroves, samphires and algal mats;
- undertake marine fauna baseline studies, to determine marine fauna associated with mangroves and algal mats, in relation to the tidal inundation regime; and
- liaise with the EPA to define local assessment units (LAUs) for the assessment of BCH.

BCI have proactively considered the engineering design of the Project to address constraints relating to mangroves and algal mats. Further refinement may be required following the outcomes of baseline studies.

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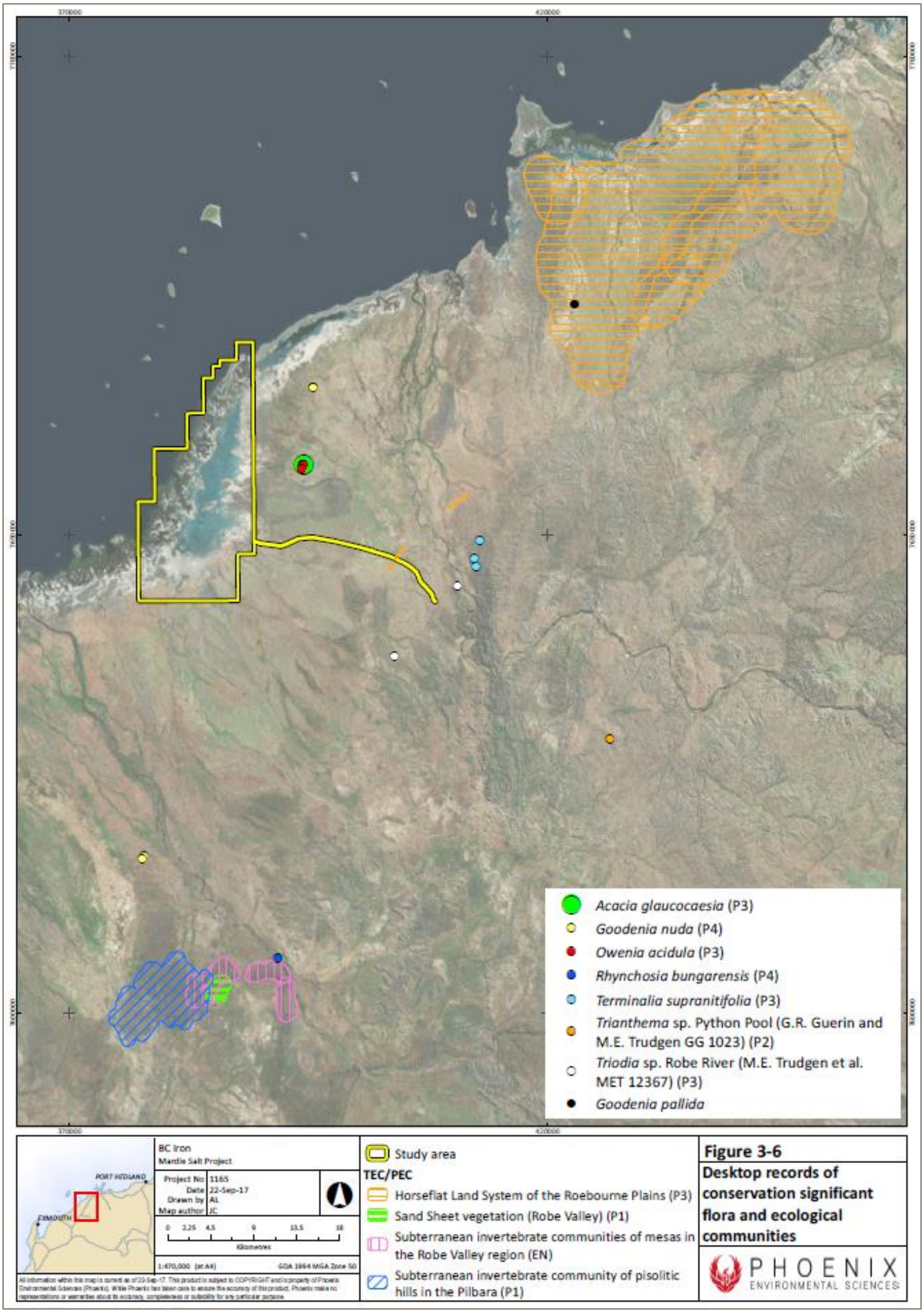
Appendices

Appendix A Applicable Legislation and Guidelines

Level	Title
International	*Convention for the Prevention of Marine Pollution from Ships (International) (1973) and Protocol (1978) (MARPOL 73/78)*
	Protection of the Sea (Prevention of Pollution from Ships) Act 1983
	Convention on Biological Diversity (1992)
	Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention) (1979)
	United Nations Convention on the Law of the Sea 1982
	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) 1982
Federal	*Environmental Protection and Biodiversity Conservation Act 1999 (refer to technical guidance and fact*
	Environmental Protection (Sea Dumping) Act 1981
	Protection of the Sea (Prevention of Pollution from Ships) Act 1983
	The Coastal Waters (States Powers) Act 1980 and Coastal Water (States Titles) Act 1980
	ANZECC and ARMCANZ Guidelines (2000)
State	*Environmental Protection Act 1986*
	Fish Resources Management Act 1994
	Conservation and Land Management Act 1984
	Conservation and Land Management Act 1984: Acts Amendment (Marine Reserves) Act 1997
	Land Act 1933 and the Land Administration Act 1997
	The Heritage Act WA 1990
	The Maritime Archaeology Act 1973
	Rights to Water and Irrigation Act 1914
	Western Australian State Sustainability Strategy
	Wildlife Conservation Act 1950

Appendix B PECs in Proximity to the Study Area

Community ID	Community Name and Description	Status
Robe Valley mesas	**Subterranean invertebrate communities of mesas in the Robe Valley region** A series of isolated mesas occur in the Robe Valley in the state's Pilbara Region. The mesas are remnants of old valley infill deposits of the palaeo Robe River. The troglobitic faunal communities occur in an extremely specialised habitat and appear to require the particular structure and hydrogeology associated with mesas to provide a suitable humid habitat. Short range endemism is common in the fauna. The habitat is the humidified pisolitic strata.	Priority 1
Sand sheet vegetation	**Sand Sheet vegetation (Robe Valley)** *Corymbia zygophylla* scattered low trees over *Acacia tumida* var. *pilbarensis*, *Grevillea eriostachya* high shrubland over *Triodia schinzii* hummock grassland. Other associated species include *Cleome uncifera, Heliotropium transforme*, *Indigofera boviperda* subsp. *boviperda*, and *Ptilotus arthrolasius*. Most northern example/expression of vegetation of Carnarvon Basin. Community is poorly represented type in the Pilbara Region, and not represented in the reserve system. Community contains many plant species that are at their northern limits or exist as disjunct populations. Vulnerable to invasion by weeds.	Priority 3
Robe valley pisolitic hills	**Subterranean invertebrate community of pisolitic hills in the Pilbara** A series of isolated low undulating hills occur in the state's Pilbara region. The troglofauna are being identified as having very short range distributions.	Priority 1
Horseflat land system	**Horseflat land system of the Roebourne Plains** The Horseflat Land System of the Roebourne Plains are extensive, weakly gilgaied clay plains dominated by tussock grasslands on mostly alluvial non-gilgaied, red clay loams or heavy clay loams. Perennial tussock grasses include *Eragrostis xerophila* (Roebourne Plains grass) and other *Eragrostis* spp., *Eriachne* spp. and *Dichanthium* spp. The community also supports a suite of annual grasses including *Sorghum* spp. and rare *Astrebela* spp. The community extends from Cape Preston to Balla Balla surrounding the towns of Karratha and Roebourne. This community incorporates Unit 3 (Gilgai plains), Unit 5 (Alluvial Plains) with some Unit 7 (Drainage Depressions) described in Van Vreeswyk et al. 2004.	Priority 3



(Source: Phoenix Environmental Sciences 2017)

Appendix C Conservation Significant Flora

Species	Family	Conservation Code			Habit[1]	Habitat[1]	Nearest Locality (km)	Likelihood
		EPBC Act	WC Act	DPAW				
Acacia glaucocaesia	Fabaceae			3	Dense, glabrous shrub or tree, 1.8-6 m high. Fl. yellow, Jul to Sep	Red loam, sandy loam, clay. Floodplains	5 to east	**Likely** Suitable habitat present with known records in close proximity
Goodenia nuda	Goodeniaceae			4	Erect to ascending herb, to 0.5 m high. Fl. yellow, Apr to Aug	Recorded from a variety of habitats	6 to east	**Likely** Suitable habitat present with known records in close proximity
Abutilon sp. Onslow (F. Smith s.n. 10/9/61)	Malvaceae			1	Prostrate to semi prostrate shrub with roundish hairy grey leaves and compartmentalised spiny fruit, growing up to 0.1 m tall.	Red-brown sand-plains and undulating plains. Known from grassland of Triodia lanigera with an overstorey of Acacia xiphophylla.	38 to south	**Possible** Suitable habitat may present within the spinifex plains
Eremophila forrestii subsp. *viridis*	Scrophulariaceae			3	Much-branched shrub, ca 1 m high. Fl. pink-cream, Aug	Recorded from heavy clays to skeletal soils	>75 to south west	**Possible** Known records occur within similar habitats and subregion
Euphorbia inappendiculata var. *inappendiculata*	Euphorbiaceae			2	Prostrate, much-branched, diffuse herb	Growing amongst hummock grassland of *Triodia epactia*	>75 to east	**Possible** Marginal habitat may present within the Project Area
Goodenia pallida	Goodeniaceae			1	Erect herb, to 0.5 m high. Fl. purple, Aug	Red soils	34 to east	**Possible** Suitable habitat present with known records in close proximity
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	Fabaceae			3	Erect shrub to 2 m, pink, red flowers. Leaves simple, symmetrically organised, crowded towards terminal branches.	Rivers, creeks, floodplains. Often associated with Acacia citrinoviridis or *Eucalyptus leucophloia* and *Eucalyptus ferriticola* over *Acacia maitlandii, Acacia pyrifolia, Acacia inaequilatera*, and an understorey of *Corchorus sidoides* and *Triodia pungens*.	17 to south east	**Possible** Marginal habitat present within Project Area
Owenia acidula	Meliaceae			3	Tree, 3-8 m high. Fl. white-brown/cream	Clay	4.8 to east	**Possible** Known records in close proximity, however it has been hypothesised these records are plantings
Rhynchosia bungarensis	Fabaceae			4	Compact, prostrate shrub, to 0.5 m high. Fl. yellow	Pebbly, shingly coarse sand amongst boulders. Banks of flow line in the mouth of a gully in a valley wall	37 to south	**Possible** Marginal habitat present within Project Area
Solanum albostellatum	Solanaceae			3	Shrub to 0.2 m	Plain, red-brown cracking clay loam.	>100 to east	**Possible** Marginal habitat may be present within the Project Area
Swainsona thompsoniana	Fabaceae			3	Small tufted compound-leaved annual herb with blue to mauve flowers	Gibber plains, crabhole plains and gilgai	>50 to east, south east	**Possible** Marginal habitat may be present within the Project Area
Tephrosia rosea var. Port Hedland (A.S. George 1114)	Fabaceae			1	Sprawling or erect shrub, densely tomentose sericeous in all parts	Coastal. Sandy areas and along ephemeral sandy rivers	>100 to east, north east	**Possible** Suitable habitat may be present within the Project Area
Teucrium pilbaranum	Lamiaceae			2	Upright shrub, 0.2 m high. Fl. white, May or Sep	Clay. Crab hole plain in a river floodplain, margin of calcrete table	>100 to east	**Possible** Marginal habitat may be present within the Project Area
Themeda sp. Hamersley Station (M.E. Trudgen 11431)	Poaceae			3	Tussocky perennial, grass-like or herb, 0.9-1.8 m high. Fl. Aug	Red clay. Clay pan, grass plain	>85 to north east	**Possible** Marginal habitat may be present within the Project Area
Trianthema sp. Python Pool (G.R. Guerin & M.E. Trudgen GG 1023)	Aizoaceae			2	Low growing succulent herb	Low-lying sandy areas on gibber plains	42 to south-east	**Possible** Marginal habitat may be present within the Project Area
Triumfetta echinata	Malvaceae			3	Prostrate shrub, to 0.3 m high. Fl. Aug	Red sandy soils. Sand dunes	>50 to south west	**Possible** Suitable habitat may be present within the Project Area

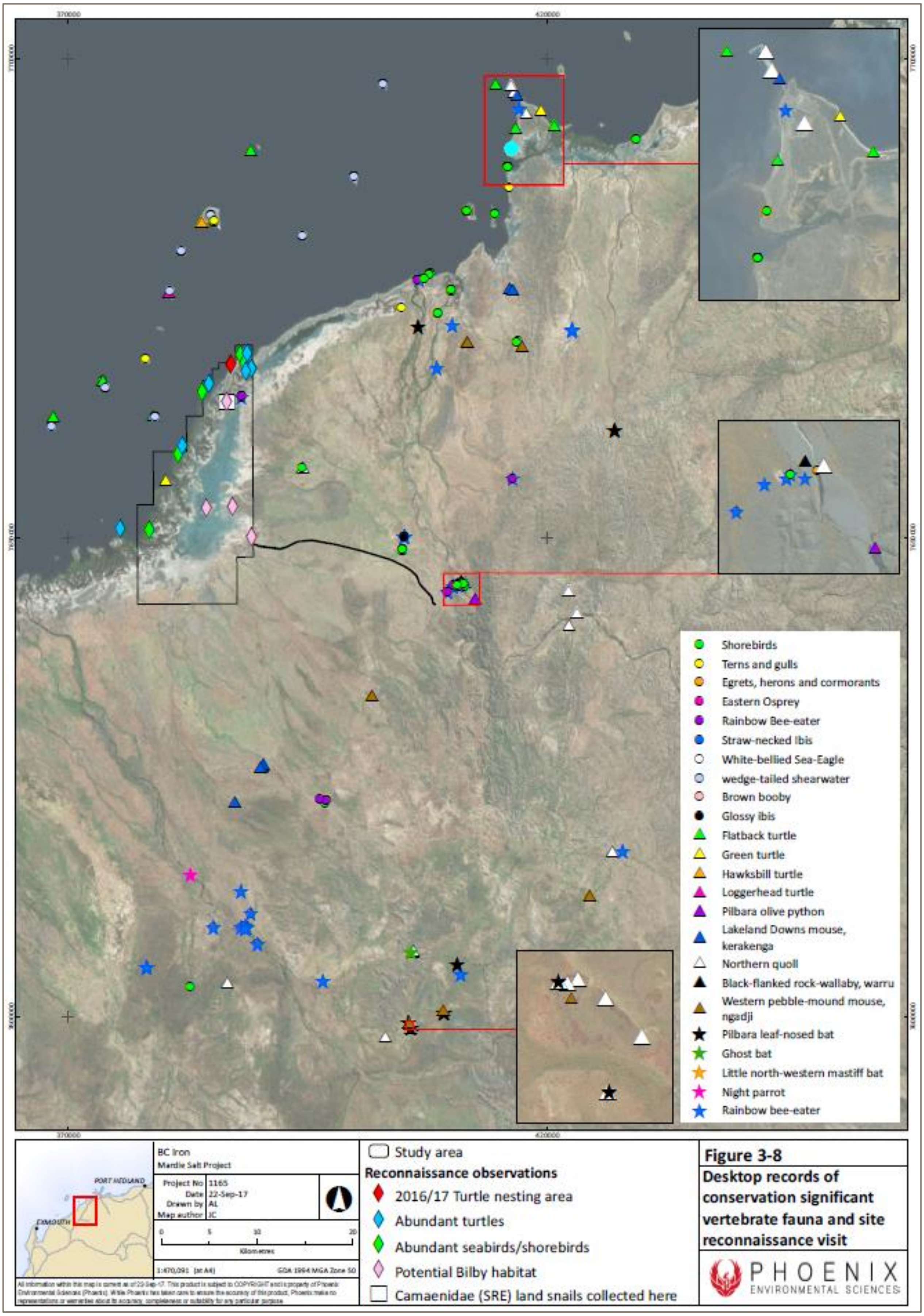
Species	Family	Conservation Code			Habit[1]	Habitat[1]	Nearest Locality (km)	Likelihood
		EPBC Act	WC Act	DPAW				
Acacia bromilowiana	Fabaceae			4	Tree or shrub, to 12 m high, bark dark grey, fibrous; phyllodes more or less glaucous & slightly pruinose; inflorescence in spikes. Fl. yellow/pink, Jul to Aug	Red skeletal stony loam, orange-brown pebbly, gravel loam, laterite, banded ironstone, basalt. Rocky hills, breakaways, scree slopes, gorges, creek beds	>100 to south east	**Unlikely** Habitat preferences not present within the Project Area
Acacia daweana	Fabaceae			3	Spreading shrub, 0.3-1.5(-2) m high. Fl. yellow, Jul to Sep	Stony red loamy soils. Low rocky rises, along drainage lines	>150 to east, south east	**Unlikely** Habitat preferences not present within the Project Area
Acacia subtiliformis	Fabaceae			3	Spindly, slender, erect shrub, to 3.5 m high, phyllodes green, new growth slightly viscid, resinous, aromatic; inflorescence in heads to 6 mm diameter; peduncles red. Fl. yellow, Jun	On rocky calcrete plateau	>300 to south east	**Unlikely** Habitat preferences not present within the Project Area
Adiantum capillus-veneris	Pteridaceae			2	Rhizomatous, perennial, herb or (fern), 0.1-0.2 m high, frond 1-2-pinnate; stipe blackish-brown, hard, glossy; sori marginal between sinuses, oblong	Moist, sheltered sites in gorges and on cliff walls	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Barbula ehrenbergii	Pottiaceae			1	Dark green.	On rock iron rich, weathered conglomerate.	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Bothriochloa decipiens var. *cloncurrensis*	Poaceae			1	Perennial, grass-like or herb, to 1.4 m high. Fl. green-yellow	Usually associated with floodplains, clays and seasonally wet grasslands where it occurs	>75 to south east	**Unlikely** Restricted and poorly known in the Pilbara
Calotis latiuscula	Asteraceae			3	Erect herb, to 0.5 m high. Fl. yellow, Jun to Oct	Sand, loam. Rocky hillsides, floodplains, rocky creeks or river beds	>100 to south east	**Unlikely** Habitat preferences not present within the Project Area
Calotis squamigera	Asteraceae			1	Procumbent annual, herb, to 0.21 m high. Fl. yellow, Jul	Pebbly loam	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Cladium procerum	Cyperaceae			2	Densely tufted perennial, grass-like or herb (sedge), 2 m high. Fl. Nov (?)	Perennial pools	>100 to north east	**Unlikely** Habitat preferences not present within the Project Area
Cucumis sp. Barrow Island (D.W. Goodall 1264)	Cucurbitaceae			2	Trailing or climbing herb. Deciduous	Hummock grasslands and on limestone outcrops	60 to north west	**Unlikely** Occurs on Barrow Island and near Exmouth
Dampiera anonyma	Goodeniaceae			3	Multistemmed perennial, herb, to 0.5(-1) m high. Fl. blue-purple, Jun to Sep	Skeletal red-brown to brown gravelly soil over banded ironstone, basalt, shale and jaspilite. Hill summits, upper slopes (above 1000m)	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Dampiera metallorum	Goodeniaceae			3	Rounded, multistemmed perennial, herb, to 0.5 m high. Fl. blue, Apr or Jun to Oct	Skeletal red-brown gravelly soil over banded ironstone. Steep slopes, summits of hills	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Dysphania congestiflora	Chenopodiaceae			3	Short-lived annual herb	Flats and margins of seasonally inundated flood plains and lake beds, on saline, deep, light-medium to heavy clay soils.	>350 to east, south east	**Unlikely** No known records in close proximity to the Project Area
Eragrostis sp. Mt Robinson (S. van Leeuwen 4109)	Poaceae			1	Tussock-forming perennial, grass-like or herb, to 0.3 m high. Fl. Sep	Red-brown skeletal soils, ironstone. Steep slopes, summits	>350 to south east	**Unlikely** Habitat preferences not present within the Project Area
Eremophila magnifica subsp. *magnifica*	Scrophulariaceae			4	Shrub, 0.5-1.5 m high. Fl. blue, Aug to Nov	Skeletal soils over ironstone. Rocky screes	>100 to south east	**Unlikely** Habitat preferences not present within the Project Area

Species	Family	Conservation Code			Habit[1]	Habitat[1]	Nearest Locality (km)	Likelihood
		EPBC Act	WC Act	DPAW				
Eremophila magnifica subsp. *velutina*	Scrophulariaceae			3	Shrub, 0.5-1.5 m high. Fl. blue-purple, Aug to Sep	Skeletal soils over ironstone. Summits	>100 to south east	**Unlikely** Habitat preferences not present within the Project Area
Eremophila pusilliflora	Scrophulariaceae			2	Sub-shrub to 0.5m high	Recorded on low shrubland on gibber plains or from low scree slopes adjacent to plains	>250 to south, south east	**Unlikely** Habitat preferences not present within the Project Area
Eremophila sp. Hamersley Range (K. Walker KW 136)	Scrophulariaceae			1	Erect shrub to 2 m. Flowers white-cream-yellow-pink-purple.	Summit, steep rock slopes and scree, skeletal brown-red soil over banded ironstone.	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Eremophila sp. Snowy Mountain (S. van Leeuwen 3737)	Scrophulariaceae			1	Shrub to 1 m tall	Summit, high in landscape, skeletal red gritty soil over ironstone	>275 to south, south east	**Unlikely** Habitat preferences not present within the Project Area
Eremophila sp. West Angelas (S. van Leeuwen 4068)	Scrophulariaceae			1	Spindly whip shrub to 3 m tall	Summit of hill, high in landscape, steep rock slopes and scree, skeletal brown-red soil over ironstone	>350 to south east	**Unlikely** Habitat preferences not present within the Project Area
Eremophila youngii subsp. *lepidota*	Scrophulariaceae			4	Dense, spreading shrub, (0.2-)1-3 m high. Fl. purple-red-pink, Jan or Mar or Jun or Aug to Sep	Stony red sandy loam. Flats plains, floodplains, sometimes semi-saline, clay flats	>200 to west, south west	**Unlikely** No known records in close proximity to the Project Area
Eucalyptus lucens	Myrtaceae			1	(Mallee), to 4.5 m high, bark smooth, white, sometimes slightly powdery; leaves glossy green	Ironstone. Rocky slopes and mountain tops, high in the landscape	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Fimbristylis sieberiana	Cyperaceae			3	Shortly rhizomatous, tufted perennial, grass-like or herb (sedge), 0.25-0.6 m high. Fl. brown, May to Jun	Mud, skeletal soil pockets. Pool edges, sandstone cliffs	>150 to south east	**Unlikely** Habitat preferences not present within the Project Area
Geijera salicifolia	Rutaceae			3	Tree, 1.5-6 m high. Fl. white, Sep	Skeletal soils, stony soils. Massive rock scree, gorges	>150 to south east	**Unlikely** Habitat preferences not present within the Project Area
Hibiscus sp. Gurinbiddy Range (M.E. Trudgen MET 15708)	Malvaceae			2	Spindly upright shrub to 3 m tall. Bark light grey-brown fairly smooth. Flowers purple.	high in landscape, skeletal red-brown stony soil over massive ironstone	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Hibiscus sp. Mt Brockman (E. Thoma ET 1354)	Malvaceae			1	Shrub to 2 m. Flowers purple with dark violet centres.	Gullies/ gorges. Red - brown sand. Banded ironstone with ironstone gravel, pebbles, cobbles and mantle	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Indigofera gilesii	Fabaceae			3	Shrub, to 1.5 m high. Fl. purple-pink, May or Aug	Pebbly loam. Amongst boulders & outcrops, hills	>325 to south east	**Unlikely** Habitat preferences not present within the Project Area
Iotasperma sessilifolium	Asteraceae			3	Erect herb. Fl. pink	Cracking clay, black loam. Edges of waterholes, plains	>175 to east	**Unlikely** No known records in close proximity to the Project Area
Ipomoea racemigera	Convolvulaceae			2	Creeping annual, herb or climber. Fl. white	Sandy soils along watercourses	>125 to east	**Unlikely** No known records in close proximity to the Project Area
Lepidium catapycnon	Brassicaceae	VU		4	Open, woody perennial, herb or shrub, 0.2-0.3 m high, stems zigzag. Fl. white, Oct	Skeletal soils. Hillsides	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Livistona alfredii	Arecaceae			4	Tree-like monocot (palm), to 10 m high. Fl. cream, Jul to Sep	Edges of permanent pools	>100 to south east	**Unlikely** Habitat preferences not present within the Project Area
Oldenlandia sp. Hamersley Station (A.A. Mitchell PRP 1479)	Rubiaceae			3	Spreading annual, herb, 0.05-0.1 m high. Fl. blue, Mar	Cracking clay, basalt. Gently undulating plain with large surface rocks, flat crabholed plain	>75 to north east	**Unlikely** Habitat preferences not present within the Project Area
Oxalis sp. Pilbara (M.E. Trudgen 12725)	Oxalidaceae			2	Creeping annual herb to 0.2 m high. Leaves green above, purple below. Flowers yellow.	Red-brown pebbly/rocky loam amongst boulders.	>100 to south	**Unlikely** Habitat preferences not present within the Project Area

Species	Family	Conservation Code			Habit[1]	Habitat[1]	Nearest Locality (km)	Likelihood
		EPBC Act	WC Act	DPAW				
Pentalepis trichodesmoides subsp. *hispida*	Asteraceae			2	Upright perennial shrub, 60 cm x 30 cm. Yellow flowers.	Hillside. Red - brown gravel over ironstone/ stony brown clayey sand.	>75 to south east	**Unlikely** Habitat preferences not present within the Project Area
Pilbara trudgenii	Asteraceae			3	Gnarled, aromatic shrub, to 1 m high. Fl. Sep	Skeletal, red stony soil over ironstone. Hill summits, steep slopes, screes, cliff faces	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Pleurocarpaea gracilis	Asteraceae			3	Rounded shrub to 0.4 m with purple flowers.	Rocky slopes, ironstone outcropping.	>100 to south	**Unlikely** Habitat preferences not present within the Project Area
Rhagodia sp. Hamersley (M. Trudgen 17794)	Chenopodiaceae			3	Shrub to 1.5 m high. Fl. yellow	Alluvial plain. Red brown clay to loamy clay.	>175 to south east	**Unlikely** No known records in close proximity to the Project Area
Rostellularia adscendens var. *latifolia*	Acanthaceae			3	Herb or shrub, 0.1-0.3 m high. Fl. blue-purple-violet, Apr to May	Ironstone soils. Near creeks, rocky hills	>75 to south east	**Unlikely** Habitat preferences not present within the Project Area
Samolus sp. Fortescue Marsh (A. Markey & R. Coppen FM 9702)	Primulaceae			1	Low, erect perennial shrub	Marsh, freshwater pools, drainage lines	>200 to east	**Unlikely** Habitat preferences not present within the Project Area
Scaevola sp. Hamersley Range basalts (S. van Leeuwen 3675)	Goodeniaceae			2	Shrub, to 1 m high. Fl. Jul to Aug	Skeletal, brown gritty soil over basalt. Summits of hills, steep hills	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Sida sp. Barlee Range (S. van Leeuwen 1642)	Malvaceae			3	Spreading shrub, to 0.5 m high. Fl. yellow, Aug	Skeletal red soils pockets. Steep slope	>150 to south	**Unlikely** Habitat preferences not present within the Project Area
Sida sp. Hamersley Range (K. Newbey 10692)	Malvaceae			1	Upright shrub to 2 m tall, Fl. Orange	Base of ironstone cliffs, high in landscape, in skeletal red soil.	>125 to south	**Unlikely** Habitat preferences not present within the Project Area
Solanum kentrocaule	Solanaceae			3	Perennial shrub to 2 m high. Flowers purple, blue.	High in landscape, skeletal red-brown stony soil over massive ironstone of the Brockman Iron Formation.	>100 to south	**Unlikely** Habitat preferences not present within the Project Area
Tecticornia globulifera	Chenopodiaceae			1	Low perennial samphire shrub	Moderately saline flats on red-brown gritty clay	>250 to east, south east	**Unlikely** No known records in close proximity to the Project Area
Tecticornia medusa	Chenopodiaceae			3	Medium to tall perennial samphire shrub	Red-brown, gritty clay on saline alluvial plain	>250 to east, south east	**Unlikely** No known records in close proximity to the Project Area
Tecticornia sp. Christmas Creek (K.A. Shepherd & T. Colmer et al. KS 1063)	Chenopodiaceae			1	Low perennial samphire sub-shrub	Saline flats on red-brown clay	>250 to east, south east	**Unlikely** No known records in close proximity to the Project Area
Terminalia supranitifolia	Combretaceae			3	Spreading, tangled shrub or tree, 1.5-3 m high. Fl. green-yellow, May or Jul or Dec	Sand. Among basalt rocks	23 to east	**Unlikely** Habitat preferences not present within the Project Area
Tetratheca fordiana	Elaeocarpaceae			1	Dwarf shrub, 0.3-0.4 m high	Shale pocket amongst ironstone	>200 to south east	**Unlikely** Habitat preferences not present within the Project Area
Thryptomene wittweri	Myrtaceae	VU	VU	-	Spreading or rounded shrub, 0.5-1.5(-2.1) m high. Fl. white-cream, Apr or Jul or Aug	Skeletal red stony soils. Breakaways, stony creek beds	>250 to south east	**Unlikely** Habitat preferences not present within the Project Area
Triodia basitricha	Poaceae			3	Slightly resinous hummock grass, to 40 cm tall, soft. Inflorescences to 70 cm tall.	Skeletal red gritty alluvial soil amongst cobbles, large boulders and rocky screes, low in landscape.	>50 to south east	**Unlikely** Habitat preferences not present within the Project Area

Species	Family	Conservation Code			Habit[1]	Habitat[1]	Nearest Locality (km)	Likelihood
		EPBC Act	WC Act	DPAW				
Triodia sp. Karijini (S. van Leeuwen 4111)	Poaceae			1	Hummock grass 0.5-1 m high. Wiry tangled habit, soft foliage - not pungent	Summit, upper hillslopes, skeletal red gritty soil over massive banded ironstone of the Brockman Iron Formation.	>250 to south east	**Unlikely** Habitat preferences not present within the Project Area
Triodia sp. Mt Ella (M.E. Trudgen 12739)	Poaceae			3	Perennial, grass-like or herb, 0.4 m high	Light orange-brown, pebbly loam. Amongst rocks & outcrops, gully slopes	>350 to south east	**Unlikely** Habitat preferences not present within the Project Area
Triodia sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89)	Poaceae			1	Foliage non-resinous; orifice and sheaths densely woolly; inflorescence unbranched.	Occurs on rocky hillsides that are a mixture of metasandstone and chert.	>50 to south east	**Unlikely** Habitat preferences not present within the Project Area
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	Poaceae			3	Perennial hummock grass to 0.4 m high.	Red-brown loam on Banded Ironstone Formation. High in the landscape. Tops of mesas, summits	21 to east	**Unlikely** Habitat preferences not present within the Project Area
Vittadinia sp. Coondewanna Flats (S. van Leeuwen 4684)	Asteraceae			1	Annual herb to 1 m, flowers cream.	Plains, Red clay loam with some stone.	>350 to south east	**Unlikely** No known records in close proximity to the Project Area

1 – Habit and habitat information sourced from WAH (2017) and Rio Tinto and WAH (2015)



(Source: Phoenix Environmental Sciences 2017)

Appendix D Conservation Significant Marine Fauna

Common name	Species	Occurrence	EPBC Act	WC Act	*Fish Resources Management Act 1994*
Fish					
Braun's Pughead Pipefish	*Bulbonaricus brauni*	Possible	Marine		
Three-keel Pipefish	*Campichthys tricarinatus*	Possible	Marine		
Pacific Short-bodied Pipefish	*Choeroichthys brachysoma*	Possible	Marine		
Pig-snouted Pipefish	*Choeroichthys suillus*	Possible	Marine		
Cleaner Pipefish	*Doryrhamphus janssi*	Possible	Marine		
Flagtail Pipefish	*Doryrhamphus negrosensis*	Possible	Marine		
Queensland Grouper	*Epinephelus lanceolatus*	Occurs			Protected
Potato Cod	*Epinephelus tukula*	Occurs			Protected
Ladder Pipefish	*Festucalex scalaris*	Possible	Marine		
Tiger Pipefish	*Filicampus tigris*	Possible	Marine		
Brock's Pipefish	*Halicampus brocki*	Possible	Marine		
Mud Pipefish	*Halicampus grayi*	Possible	Marine		
Glittering Pipefish	*Halicampus nitidus*	Possible	Marine		
Spiny-snout Pipefish	*Halicampus spinirostris*	Possible	Marine		
Ribboned Pipehorse	*Haliichthys taeniophorus*	Possible	Marine		
Beady Pipefish	*Hippichthys penicillus*	Possible	Marine		
Western Spiny Seahorse	*Hippocampus angustus*	Possible	Marine		
Spiny Seahorse	*Hippocampus histrix*	Possible	Marine		
Spotted Seahorse	*Hippocampus kuda*	Possible	Marine		
Flat-face Seahorse	*Hippocampus planifrons*	Possible	Marine		
Three-spot Seahorse	*Hippocampus trimaculatus*	Possible	Marine		
Tidepool Pipefish	*Micrognathus micronotopterus*	Possible	Marine		

Common name	Species	Occurrence	EPBC Act	WC Act	*Fish Resources Management Act 1994*
Pallid Pipehorse	*Solegnathus hardwickii*	Possible	Marine		
Gunther's Pipehorse	*Solegnathus lettiensis*	Possible	Marine		
Robust Ghostpipefish	*Solenostomus cyanopterus*	Possible	Marine		
Rough-snout Ghost Pipefish	*Solenostomus paegnius*	Possible	Marine		
Double-end Pipehorse	*Syngnathoides biaculeatus*	Possible	Marine		
Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	Possible	Marine		
Straightstick Pipefish	*Trachyrhamphus longirostris*	Possible	Marine		
Sharks and Rays					
Narrow Sawfish	*Anoxypristis cuspidata*	Likely	Migratory		
Grey Nurse Shark	*Carcharias taurus*	Likely	Vulnerable Threat.	Rare	
White Shark	*Carcharodon carcharias*	Possible	Vul. Mig.	Rare	
Reef Manta Ray	*Manta alfredi*	Occurs	Migratory		
Oceanic Manta Ray	*Manta birostris*	Likely	Migratory		
Dwarf Sawfish	*Pristis clavata*	Occurs	Vul. Mig.		
Green Sawfish	*Pristis zijsron*	Breeding likely	Vul. Mig.	Vulnerable	
Whale Shark	*Rhincodon typus*	Possible	Vul. Mig.	Vulnerable	
Reptiles					
Horned Seasnake	*Acalyptophis peronii*	Possible	Marine		
Short-nosed Seasnake	*Aipysurus apraefrontalis*	Likely	Crit. End.		
Dubois' Seasnake	*Aipysurus duboisii*	Possible	Marine		
Spine-tailed Seasnake	*Aipysurus eydouxii*	Possible	Marine		
Olive Seasnake	*Aipysurus laevis*	Possible	Marine		
Stokes' Seasnake	*Astrotia stokesii*	Possible	Marine		

Common name	Species	Occurrence	EPBC Act	WC Act	*Fish Resources Management Act 1994*
Loggerhead Turtle	*Caretta caretta*	Feeding occurs	End. Mig.	End	
Green Turtle	*Chelonia mydas*	Breeding occurs	Vul. Mig.	Vulnerable	
Airlie Island Ctenotus	*Ctenotus angusticeps*	Likely	Vul. Threat.		
Leatherback Turtle	*Dermochelys coriacea*	Breeding likely	End. Mig.	Vulnerable	
Spectacled Seasnake	*Disteira kingii*	Possible	Marine		
Olive-headed Seasnake	*Disteira major*	Possible	Marine		
Turtle-headed Seasnake	*Emydocephalus annulatus*	Possible	Marine		
North-western Mangrove Seasnake	*Ephalophis greyi*	Possible	Marine		
Hawksbill Turtle	*Eretmochelys imbricata*	Breeding occurs	Vul. Mig.	Vulnerable	
Fine-spined Seasnake	*Hydrophis czeblukovi*	Possible	Marine		
Elegant Seasnake	*Hydrophis elegans*	Possible	Marine		
Spotted Seasnake	*Hydrophis ornatus*	Possible	Marine		
Olive Python	*Liasis olivaceus barroni*	Possible	Vul. Threat.		
Flatback Turtle	*Natator depressus*	Breeding occurs	Vul. Mig.	Vulnerable	
Yellow-bellied Seasnake	*Pelamis platurus*	Possible	Marine		
Marine Mammals					
Minke Whale	*Balaenoptera acutorostrata*	Possible	Marine		
Bryde's Whale	*Balaenoptera edeni*	Possible	Migratory		
Blue Whale	*Balaenoptera musculus*	Likely	Endangered	Rare	
Common Dophin	*Delphinus delphis*	Possible	Marine		
Dugong	*Dugong dugon*	Occurs	Vulnerable	Specially Prot.	
Southern Right Whale	*Eubalaena australis*	Possible	End. Mig.	Rare	

Common name	Species	Occurrence	EPBC Act	WC Act	*Fish Resources Management Act 1994*
Risso's Dolphin	*Grampus griseus*	Possible	Marine		
Humpback Whale	*Megaptera novaeangliae*	Occurs	Vul. Threat.	Rare	
Killer Whale	*Orcinus orca*	Possible	Migratory	Rare	
Indo-Pacific Humpback Dolphin	*Sousa chinensis*	Likely	Migratory	Priority 4	
Spotted Dolphin	*Stenella attenuata*	Possible	Marine		
Indian Ocean Bottlenose Dolphin	*Tursiops aduncus*	Likely	Marine		
Spotted Bottlenose Dolphin	*Tursiops aduncus*	Occurs	Migratory		
Bottlenose Dolphin	*Tursiops truncatus s. str.*	Occurs	Marine		
Birds					
Common Sandpiper	*Actitis hypoleucos*	Occurs	Migratory	Migratory	
Common Noddy	*Anous stolidus*	Possible	Migratory	Migratory	
Fork-tailed Swift	*Apus pacificus*	Likely	Migratory	Migratory	
Great Egret	*Ardea alba*	Likely	Migratory	Migratory	
Cattle Egret	*Ardea ibis*	Possible	Migratory	Migratory	
Wedge-tailed Shearwater	*Ardenna pacifica*	Breeding occurs	Migratory	Migratory	
Sharp-tailed Sandpiper	*Calidris acuminata*	Possible	Migratory	Migratory	
Red Knot	*Calidris canutus*	Possible	End. Mig.	Migratory	
Curlew Sandpiper	*Calidris ferruginea*	Possible	Crit. End. Mig.	Vun. Mig.	
Pectoral Sandpiper	*Calidris melanotos*	Possible	Migratory	Migratory	
Streaked Shearwater	*Calonectris leucomelas*	Possible	Migratory	Migratory	
Oriental Plover	*Charadrius veredus*	Possible	Migratory	Migratory	
Lesser Frigatebird	*Fregata ariel*	Likely	Migratory	Migratory	

Common name	Species	Occurrence	EPBC Act	WC Act	*Fish Resources Management Act 1994*
Oriental Pratincole	*Glareola maldivarum*	Possible	Migratory	Migratory	
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	Likely	Migratory	Migratory	
Barn Swallow	*Hirundo rustica*	Possible	Migratory	Migratory	
Bar-tailed Godwit	*Limosa lapponica baueri*	Possible	Vul. Mig.	Migratory	
Northern Siberian Bar-tailed Godwit	*Limosa lapponica menzbieri*	Possible	Crit. End.	Migratory	
Southern Giant-Petrel	*Macronectes giganteus*	Possible	End. Mig.	End. Mig.	
Rainbow Bee-eater	*Merops ornatus*	Possible	Migratory	Migratory	
Grey Wagtail	*Motacilla cinerea*	Possible	End. Mig.	Migratory	
Yellow Wagtail	*Motacilla flava*	Possible	Migratory	Migratory	
Eastern Curlew	*Numenius madagascariensis*	Possible	Crit. End. Mig.	Vun. Mig.	
Osprey	*Pandion haliaetus*	Breeding occurs	Migratory	Migratory	
Night Parrot	*Pezoporus occidentalis*	Possible	Endangered	Crit. End.	
Australian Fairy Tern	*Sternula nereis nereis*	Breeding likely	Vulnerable	Vulnerable	

Crit. – Critically, End – Endangered, Mig – Migratory, Prot. – Protected, Threat. – Threatened, Vul. – Vulnerable

Appendix E Algal Mats – Raw Data

Table E2: Taxa recorded from samples of algal mat in the Project Area during the Assessment.

Algal Taxa	Central Contiguous							
	ACC1(A)	ACC1(B)	ACC1(C)	ACC1(D)	ACC1(E)	ACC1(F)	ACC1(G)	ACC1(H)
Bacillariophyta								
Navicula sp.	●●		●				●	
Cyanophyta								
Anabaena sp.					●			●●
Calothrix sp.	●				●●	●●		●
Cyanothece sp.				●●				
Lyngbya sp.	●●	●●●	●●		●	●	●●●	●
Microcoleus spp.	●●●	●	●●●	●●●	●●●	●●●	●●●	●●●
Oscillatoria spp.		●						
Schizothrix spp.	●		●		●	●	●●	●●
Spirulina sp.	●						●●	●
Diversity	**9 taxa (3-6 taxa per sample)**							
Thickness Range	**1-5mm**							

Key: ●=rare, ●●=common, and ●●●=abundant

Table E2: Taxa recorded from samples of algal mat in the Project Area during the Assessment.

Algal Taxa	Central Fragmented											
	ACF1(A)	ACF2(A)	ACF3 (A)	ACF3 (B)	ACF3(C)	ACF4(A)	ACF4(B)	ACF4(C)	ACF5(A)	ACF6(A)	ACF7(A)	ACF8(A)
Bacillariophyta												
Navicula sp.		●									●	
Cyanophyta												
Anabaena sp.						●			●			
Calothrix scopulorum	●●	●	●●	●		●	●●	●	●	●●	●	●●
Lyngbya sp.	●●●	●●●	●	●●●	●●	●●	●●	●	●●●	●	●●●	●●
Microcoleus spp.	●●●	●●●	●●●	●●●	●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
Oscillatoria spp.				●	●							
Schizothrix spp.	●			●	●	●	●					
Spirulina sp.	●	●		●								
Diversity	**5**	**5**	**3**	**6**	**4**	**5**	**4**	**3**	**4**	**3**	**4**	**3**
Thickness	**1-3mm**											

Key: ●=rare, ●●=common, and ●●●=abundant

Table E3: Algal mats recorded from samples of the Study Area during the Assessment.

Algal Taxa	Northern Contiguous					Southern Contiguous		
	ANC1(A)	ANC1(B)	ANC1(C)	ANC1(D)	ANC1(E)	ASC1(A)	ASC1(B)	ASC2(A)
Bacillariophyta								
Navicula sp.				●				
Cyanophyta								
Anabaena sp.	●						●	
Calothrix scopulorum					●	●●●	●●●	
Cyanothece sp.								
Lyngbya sp.	●●●	●●●	●●●	●●●	●●●		●	●●●
Merismopedia sp.								●
Microcoleus spp.	●●	●●●	●●	●●●	●●●	●●	●●●	●●●
Oscillatoria spp.						●●●		
Schizothrix spp.	●	●●	●	●				●
Spirulina sp.			●					
Synechococcus sp.								●
Diversity	**4**	**3**	**4**	**4**	**3**	**3**	**4**	**5**
Thickness	**1-5mm**					**1-5mm**		

Key: ●=rare, ●●=common, and ●●●=abundant

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