Eramurra Solar Salt Project

Subtidal Benthic Communities and Habitat Report

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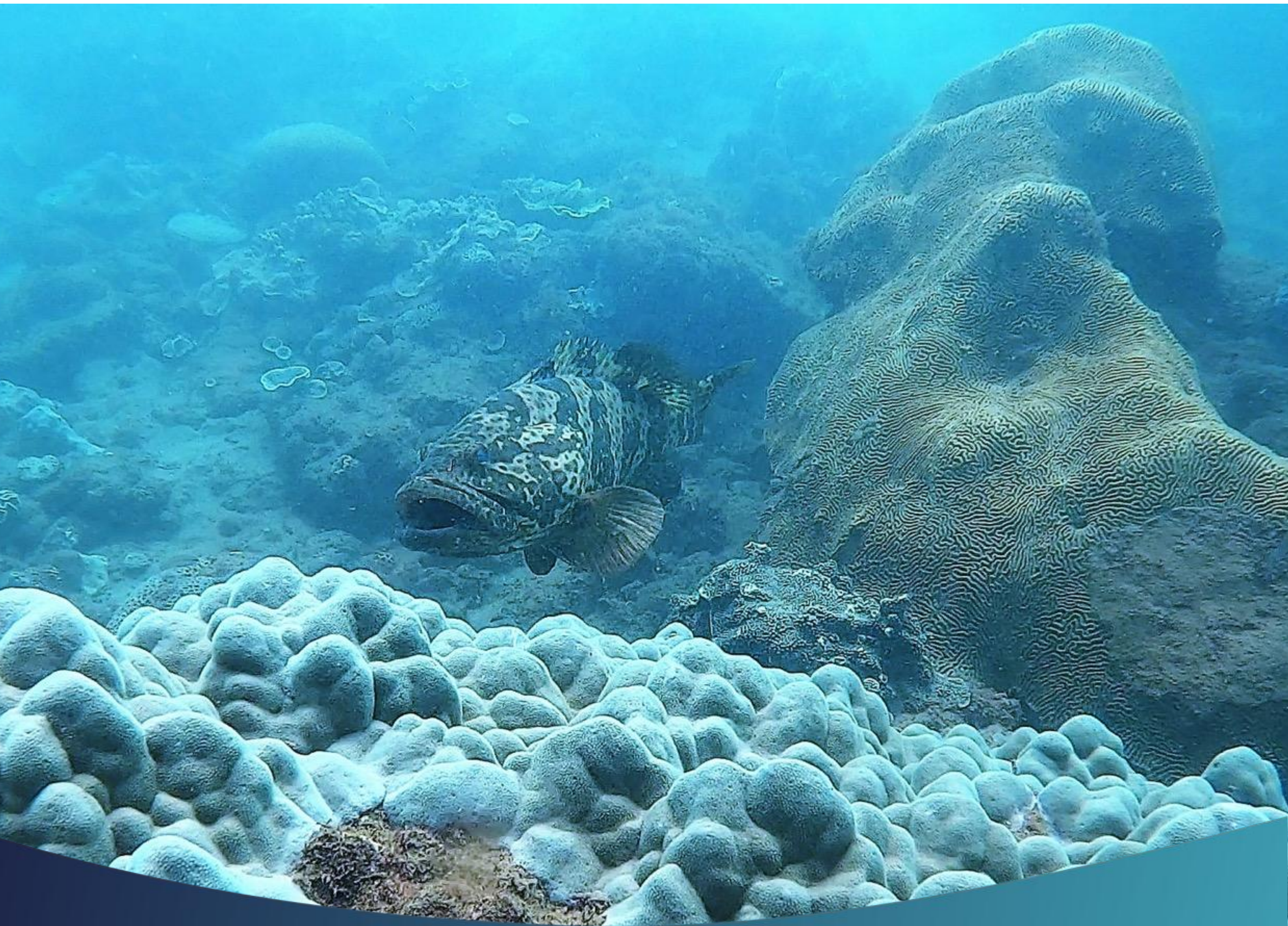

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Version Register

Version	Status	Author	Reviewer	Change from Previous Version	Authorised for release (Signed and dated)
Draft	A	D. Ryan	T. Hurley R Flugge		
Rev	0	T. Hurley	J. Abbott	Client comments	
Rev	1	S.W. Martin	J. Abbott	Client Comments	
Rev	2	J. Abbott	C. Lane	Included information about revised offshore dredge spoil area.	
Rev	3	J. Abbott	C. Lane	Address client comments	
Rev	4	J. Abbott	C. Lane	Address client comments	
Rev	5	J. Abbott	C. Lane	Update BCH calculations from revised mapping	
Rev	6	P.Bouvais	A. Gartner J. Abbott	Update BCH mapping from revised methodology	
Rev	7	P.Bouvais	J. Abbott	Adress client comments	

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Executive Summary

Leichhardt Salt Pty Ltd (LS) propose to construct and operate the Eramurra Solar Salt Project (the Proposal), a solar salt project to extract an average production rate of 5.2 Million tonnes per annum (Mtpa) of high-grade salt (sodium chloride (NaCl)). The Proposal is located approximately 55 km west-southwest of Karratha in the Pilbara region of Western Australia (WA), and will use a series of concentration ponds, crystallisers and processing plant to export a salt product to vessels via a trestle jetty.

The *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Cth) and *Western Australian Environmental Protection Act 1986* (EP Act) govern the environmental approval process. This process aims to support environmentally sustainable development while protecting environmental values. Benthic communities and habitat (BCH) is a key environmental factor to be considered during environmental impact assessment under the *EP Act (WA)*. The objective is *'to protect benthic communities and habitats so that biological diversity and ecological integrity are maintained'*. The scope of this report is to address the relevant work requirements determined by the Environmental Scoping Document (ESD) for the Proposal.

A desktop review has been undertaken to identify existing information available regarding the extent and distribution of subtidal BCH. Five (5) separate field surveys were undertaken between July 2018 and October 2024 to validate and build upon the existing mapping of BCH within established Local Assessment Units (LAUs) in order to better describe the subtidal BCH in this area. The BCH mapping fieldwork involved two (2) primary survey techniques: Sidescan Sonar and Drop/Tow Camera. Targeted subtidal BCH surveys were also undertaken by scuba divers within coral and seagrass communities to measure the health and condition of these BCH within the Proposal area. The condition of seagrass was measured in surveys undertaken during separate seasons in July 2020 (dry season) and March 2021 (wet season). Coral communities are less seasonally ephemeral and were instead measured for annual changes in coral cover and health with surveys performed in July 2020 and June 2021.

This study has resulted in the development of a high-level subtidal BCH map, outlining the presence of BCH in an established series of LAUs around the proposed Marine Development Envelope (MDE), and at the proposed offshore dredge spoil area. Additionally, benthic community health monitoring programmes for seagrasses and corals which were established by earlier investigations have been continued and updated. The development of this BCH map will allow the subsequent environmental impact assessment to take place and will also allow the identification of any further coral or seagrass monitoring sites should the need arise.

The location of the MDE suggests that most direct disturbance will occur in the western part of Regnard Bay, extending offshore between Cape Preston and South West Regnard Island. Large areas of bare sand BCH is likely to occur in the direct Proposal footprint (area of direct loss), as well as in the more distant area of indirect impact. Macroalgae, filter feeder and coral are present within the direct Proposal footprint (area of direct loss), as well as in the more distant area of indirect impact. A preliminary assessment of the MDE suggests that, although these identified habitats occur within the direct Proposal footprint, the primary areas of coral and seagrass will be avoided.

The detailed broad scale and targeted mapping undertaken as part of this study has, in general, shown that the BCH of the Cape Preston East vicinity are analogous to those which are ubiquitous across the inner continental shelf of the Pilbara. The distribution of BCH is however complex, due to the highly varied substrate

that comprises areas of bare sediment, low relief limestone with sand veneer, and outcropping rocky structures and islands. In the Cape Preston East area, as is common elsewhere, bare sediment dominates with patches of sessile organisms occurring where the geomorphic and oceanographic conditions allow.

Two (2) coral sites monitored within the MDE recorded low (3.3-7.4%) and moderate (20.2-22.9%) hard coral cover which were dominated by turf algae on hard substrate interspersed with patches of sand. Comparably, coral cover at three (3) sites east and west of the MDE ranged between 15.2% and 38.8% with generally lower proportion of soft sandy substrate. The coral composition was dominated by *Turbinaria*, *Porites* and *Acropora* at three (3) sites (sites 1, 2 & 4) whilst remaining sites comprised a relatively diverse assemblage. Seagrass cover was low within all seven (7) sites monitored, ranging between 0.04% and 3.01%. The cover was typically higher in July 2020 than recorded in March 2021, although the cover during both surveys was very low resulting in small changes being difficult to validate. Most seagrass cover consisted of *Halophila decipiens* and *H. ovalis*, while *Halodule* sp. and *Syringodium* sp. were also recorded within quadrats at some sites. Seagrass habitats were generally mixed with low cover of macroalgae and the occasional ascidian, coral and sponge.

South West Regnard Island, North East Regnard Island and beaches on the mainland near the MDE represent critical nesting habitat for turtle species (flatback, green and hawksbill turtles) and seabirds (Fairy Tern and Wedge-Tailed Shearwater). Seagrasses and macroalgae provide essential habitat and food sources for dugong, fish, turtles, and benthic invertebrates. In addition, with coral reefs and filter feeders, these BCH support a biodiversity of marine fauna that attract higher order predators for foraging such as conservation significant coastal dolphins, turtles and sea snakes. Macroalgae habitat such as the *Sargassum* dominated reefs within the Proposal area have also been suggested to form an important stage of the lifecycle for key commercial and recreational fishery species such as the blue-spot emperor (*Lethrinus hutchinsi*).

Investigations at the proposed offshore dredge spoil area in March 2023, identified a flat benthos, comprised entirety of sand. The majority of the survey area was classified as 'bare', with a central and south-east patch of sparse filter feeders (mixed habitat) making up 0.4% of LAU 11.

In October 2024, additional survey efforts were undertaken to enhance the spatial resolution and statistical validation of BCH within the MDE. These surveys focused on LAUs 1 through 6, providing refined delineation of key habitats and improving the accuracy of BCH assessments. The updated mapping has contributed to a more precise understanding of habitat distribution and condition, particularly within LAU 6, which is identified as the area most likely to be impacted by the proposed activities.

Acronyms and Abbreviations

Acronyms and Abbreviations	Description
BC Act	*West Australian Biodiversity Conservation Act 2016*
BCH	Benthic communities and habitat
BIA	Biologically Important Area
CALM Act	*West Australian Conservation and Land Management Act 1982*
CATAMI	Collaborative and Automated Tools for Analysis of Marine Imagery
Cth	Commonwealth
DBCA	Department of Biodiversity, Conservation and Attractions
DII	Depth Invariant Index
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
EP Act	*West Australian Environmental Protection Act 1986*
EPBC Act	*Commonwealth Environmental Protection and Biodiversity Act 1999*
ESD	Environmental Scoping Document
EVI	Enhanced Vegetation Index
GL	Gigalitre
GLpa	Gigalitres per annum
GPS	Geographic Positioning System
ha	Hectares
LAT	Lowest Astronomical Tide
LAU	Local Assessment Units
LS	Leichhardt Salt Pty Ltd
M^2	Meters squared
M^3	Meters cubed
MDE	Marine Development Envelope
MNES	Matters of National Environmental Significance
MS	Ministerial Statement

Acronyms and Abbreviations	Description
Mtpa	Million tonnes per annum
NaCl	Sodium chloride
NDAVI	Normalized Difference Aquatic Vegetation Index
NDWI	Normalised Difference Water Index
O2M	O2 Marine Pty Ltd
OBIA	Object Based Image Analysis
OMA	Offshore Mooring Area
PP	Pilbara Ports
Proposal	Eramurra Solar Salt Project
QGIS	Quantum Geographic Information System (mapping software package)
RMS	Root Mean Squared
SCUBA	Self-Contained Underwater Breathing Apparatus
SE	Southeast
SSII	Submerged Seagrass Identification Index
StdE	Standard Error
WA	Western Australia
WAMSI DSN	Western Australian Marine Science Institution Dredging Science Node
WAVI	Water Adjusted Vegetation Index

Figures

Tables

1. Introduction

Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop the Eramurra Solar Salt Project (the Proposal), a solar salt project east of Cape Preston, approximately 55 km west-south-west of Karratha in the Pilbara region of Western Australia (WA; Figure 1).The Proposal is an evaporative solar project that utilises seawater to produce raw salt as a feedstock for reprocessing to high purity salt. The Proposal aims for average annual production rates of 5.2 million tonnes per annum (Mtpa). To meet this production, the following infrastructure will be developed:

- Seawater intake, pump station and pipeline
- Concentration ponds totalling approximately 10,000 ha
- Crystallisers, totalling approximately 1,900 ha
- Drainage channels and bunds
- Process plant and product dewatering facilities
- Water supply (desalination plant)
- Bitterns disposal pipeline and outfall
- Pumps, pipelines, roads, and support buildings including offices and communications facilities
- Workshops and laydown areas
- Landfill, and
- Other associated infrastructure.

A general description of the of the Proposal is provided in Table 1, while the Proposal content elements (e.g. development, action, activities or processes) are summarised in Table 2. and shown in Figure 2 .

Table 1: Summary of the Proposal

Proposal Title	Eramurra Solar Salt Project
Proponent Name	Leichhardt Salt Pty Ltd
Short Description	Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop a solar salt project in the Cape Preston East area, approximately 55 kilometres (km) west-southwest of Karratha in Western Australia (WA) (the Proposal). The Proposal will utilise seawater and evaporation to produce a concentrated salt product for export. The Proposal includes the development of a series of concentration ponds, crystallisers and processing plant. Supporting infrastructure includes bitterns outfall, drainage channels, product dewatering facilities, desalination plant, pumps, pipelines, power supply, access roads, administration buildings, workshops, laydown areas, landfill facility, communications facilities and other associated infrastructure. The Proposal also includes dredging at the Cape Preston East Port and both offshore and onshore disposal of dredge spoil material.

Table 2: Location and proposed extent of physical and operational elements

Element	Location	Proposed Extent
Physical Elements		
Pond and Infrastructure Development Envelope – Concentration ponds and crystallisers. Process plant, desalination plant, administration, water supply, intake, associated works (access roads, laydown, water supply and other services).	Figure 1	Disturbance of no more than 12,201 ha within the 20,157 ha Ponds and Infrastructure Development Envelope.
Marine Development Envelope – Seawater intake and pipeline, dredge channel, bitterns pipeline, outfall diffuser and mixing zone.	Figure 1	Disturbance of no more than 53 ha within the 703 ha Marine Development Envelope.
Dredge Spoil Disposal Development Envelope – Disposal location for dredge spoil.	Figure 1	Disturbance of no more than 100 ha within the 285 ha Dredge Spoil Disposal Development Envelope.
Operational Elements		
Bitterns discharge	Figure 1	Discharge of up to 5.9 Gigalitres per annum (GL pa) of bitterns within a dedicated offshore mixing zone within the Marine Development Envelope
Dredge Volume	Figure 1	Approximately 400,000 m^3

The export of salt is planned to be via a trestle jetty. The jetty and associated stockpiles will be located at the Cape Preston East Port approved by Ministerial Statement (MS) 949. Dredging will be undertaken as part of this Proposal to remove high points at the Cape Preston East Port. Dredged material will either be disposed of at an offshore disposal location, or onshore within the Ponds and Infrastructure Development Envelope. The Cape Preston East Port jetty and associated stockpiles are excluded from the Proposal. The Proposal will produce a salt concentrate according to the following processes:

- Seawater will be pumped into the first concentration pond and commence progressive concentration by solar evaporation as it flows through successive concentration ponds
- Salt is deposited onto a pre-formed base of salt in the crystallisers
- Salt will be removed from the drained crystallisers by mechanical harvesters and stockpiled adjacent to the processing facilities
- Salt concentrate will be trucked to the trestle jetty approved by MS 949 for export, and
- A maximum of 5.4 GL of bitterns (at 360 ppt salinity) will be generated in any given year and up to 0.59 GL (at 360 ppt salinity) in a peak summer month. The bitterns will be diluted 1:1 mass ratio with local seawater prior to discharge via ocean outfall diffuser within the Marine Development Envelope (MDE).

O2 Marine (O2M) was engaged by the proponent to undertake marine environmental investigations to help identify environmental risks of the Proposal, establish baseline conditions, help facilitate the environmental approvals process, and guide appropriate monitoring and management to minimise potential impacts to the marine environment during construction and operations.

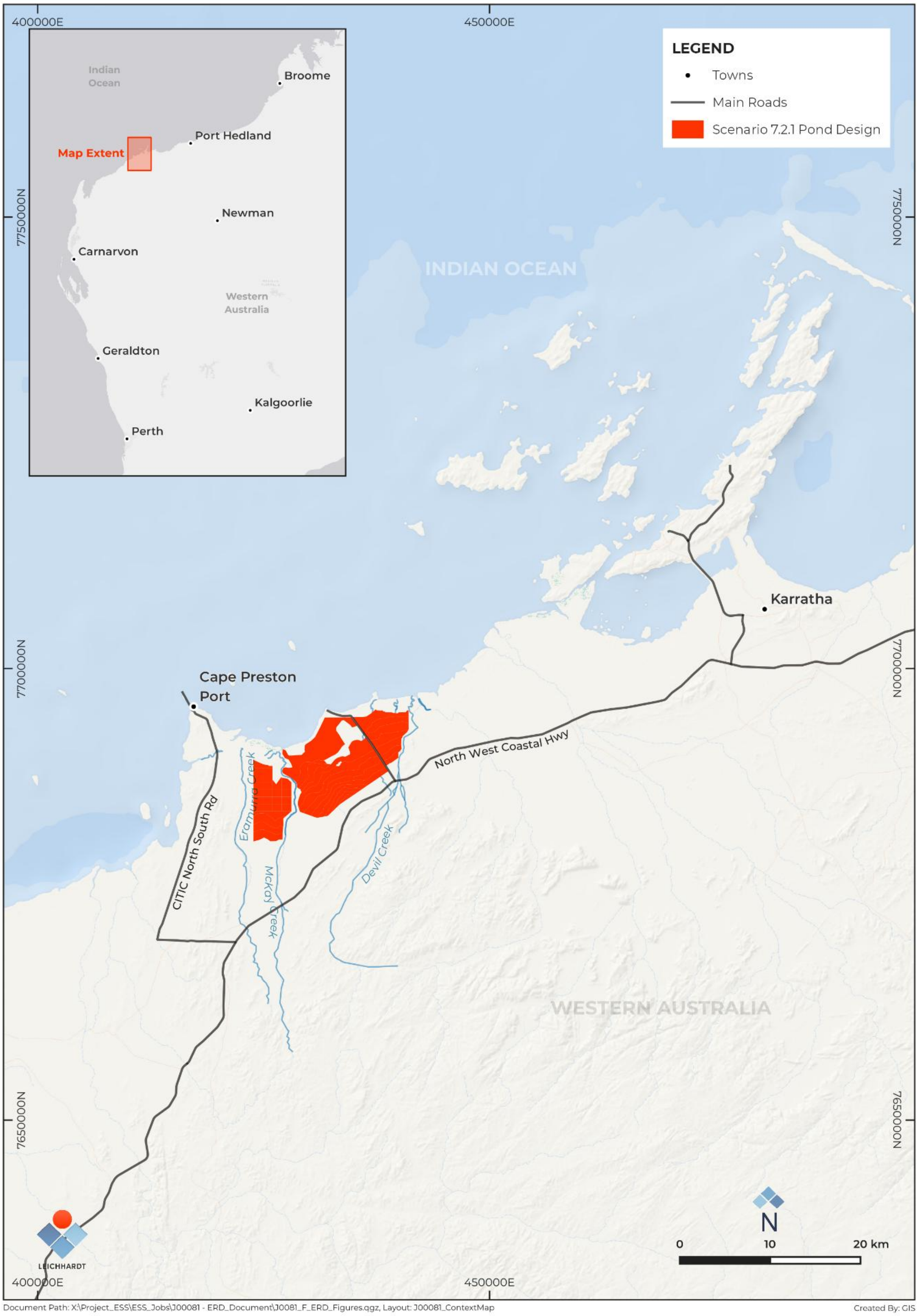


Figure 1: Proposal location and marine element

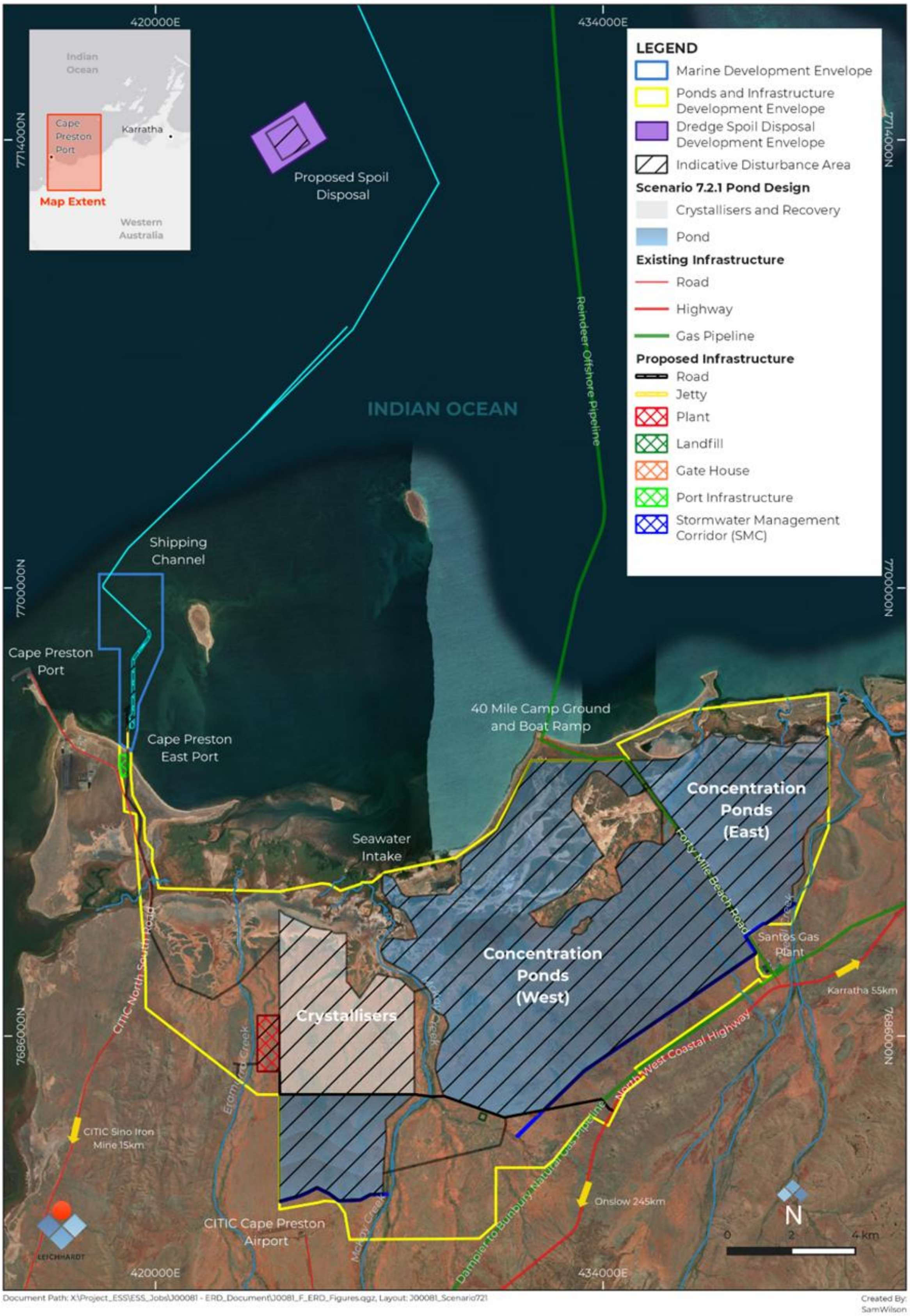


Figure 2: Project Development Envelope

1.1. Scope and Objectives

The scope of this report is to address the relevant work requirements determined by the Environmental Scoping Document (ESD) for the Proposal, which was prepared by Preston Consulting (2022).

This document will specifically address the tasks which pertain to subtidal benthic communities and habitats (BCH), through a combination of literature review, desktop assessment and multiple site-specific surveys. This work will become the basis for an Environmental Impact Assessment (EIA) of the Proposal on subtidal BCH. A separate report has been prepared to characterise the intertidal BCH (O2M 2025a), which has been defined for this Proposal as occurring above the lowest astronomical tide (LAT). Table 3 outlines the specific requirements from the ESD that are the focus of this report.

Table 3: Work Items relevant to subtidal Benthic Communities and Habitats identified in the Environmental Scoping Document (Preston Consulting 2022).

ESD Item	Requirement	Relevant Report Section
Item 1	Undertake a BCH targeted presence / absence field survey within proposed disturbance areas (including offshore dredge spoil disposal areas if they are to be used) and potential indirect impact areas (including dredge and bitterns disposal areas of impact) to determine if any key BCH (seagrass, macroalgae (*Sargassum*), filter feeders and corals) exist in these areas. If key BCH is located within proposed disturbance areas, a survey extension will be undertaken to identify a more suitable alignment or area of disturbance. Survey output: high level BCH map of the surveyed areas and a health assessment to determine the current status of the BCH.	Section 5.1.1 and 5.2.2 Figure 18
Item 2	Undertake a detailed BCH field survey within the final proposed disturbance areas and potential indirect impact areas (including dredge and bitterns disposal areas of impact). Survey other areas (that are not directly impacted) less intensively to form the basis for potential control monitoring sites. A BCH map will be developed which depicts community composition condition and abundance in each relevant LAU. Mapping in relation to dredge impacts should be in accordance with the EPA's Technical Guidance – Environmental impact assessment of marine dredging proposals (EPA 2021b).	Section 5.1.1 and 5.2.2 Figure 18
Item 3	Undertake a local bathymetry survey for the bitterns outfall location.	Section 5.3.2.1
Item 4	Develop appropriate LAUs in consideration of: a) Existing LAUs for the Sino Iron Project and Cape Preston East ports	Section 4 Figure 4

ESD Item	Requirement	Relevant Report Section
	b) Distribution, extent and condition of subtidal and intertidal BCH c) Management boundaries (e.g. regionally significant mangrove areas) d) Bathymetry, and e) Coastal geomorphology.	
Item 8	Undertake subtidal BCH surveys including an assessment of seasonal variation in the presence/absence of seagrass communities and their role in supporting MNES, and the spatial and temporal variation of BCH (including but not limited to seagrass communities).	Seasonal variation Section 5.3 MNES linkages assessed in Marine Fauna Desktop Study Report (O2M 2025b)
Item 23	Identify any critical linkages between important marine fauna and sea and shore birds, and key BCH that are likely to be impacted.	MNES linkages assessed in Marine Fauna Desktop Study Report (O2M 2025b)
Item 28	Undertake a BCH cumulative loss assessment in accordance with the EPA's Technical Guidance – Protection of BCH (EPA 2016a). As a minimum, the cumulative loss assessment should include: a) Clearly defined LAUs (Refer to Item 4) b) Description and mapping of the BCH present in the LAUs (Refer to Item 4) c) Identification of any tenure, conservation, ecological or social values associated with the BCH present in the LAUs d) An estimate of the spatial extent of each BCH type that was originally present within each LAU (i.e. prior to European disturbance) e) An estimate of the spatial extent of each BCH that is currently present within the LAUs f) Identification of the area of each BCH type that would suffer 'recoverable impacts' and 'irreversible loss' if the Proposal is implemented (results to be expressed as percentages of pre-existing conditions for each BCH type), and	Within Cumulative Loss Assessment Report (O2M 2025c). The foundations to address items b, c, & e are discussed within this document.

ESD Item	Requirement		Relevant Report Section
	g)	Comparison of the total area of each BCH type that would suffer 'irreversible loss' against the original BCH extent within the LAUs.	

1.2. Legislation and Regulatory Guidance

This study has been completed in accordance with the relevant state and federal legislation, and technical guidance statements that are applicable to the Pilbara. The relevant legislation, specific to BCH, includes:

- *Commonwealth Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- *Western Australian Environmental Protection Act 1986* (EP Act)
- *Western Australian Biodiversity Conservation Act 2016* (BC Act), and
- *Western Australian Conservation and Land Management Act 1982* (CALM Act).

The Environmental Protection Authority (EPA) provides guidance on how an EIA will be evaluated when determining whether or not an assessed proposal may be implemented. The EPA uses environmental principles, factors and associated objectives as defined within the Statement of Environmental Principles, Factors and Objectives (EPA 2021a) as the basis for assessing whether a proposal's impact on the environment is acceptable. These principles, factors and objectives therefore underpin the EIA process.

Environmental Principles

The objective of the EP Act is to protect the environment of the State and identifies five (5) environmental principles to achieve this. The third principle, *conservation of biological diversity and ecological integrity*, is directly relevant to subtidal BCH and will therefore be a fundamental consideration for the Proposal EIA.

Environmental Factors and Objectives

The EPA lists 13 environmental factors, which are organised into five (5) themes, including Sea, Land, Water, Air and People. The environmental factors are those parts of the environment that may be impacted by an aspect of a proposal. An environmental objective has been established for each environmental factor. The EPA will then make judgements against these objectives on whether the environmental impact of a proposal may be significant. BCH was identified by the EPA as one (1) of the key environmental factors for the Proposal. The objective for BCH is *'to protect benthic communities and habitats so that biological diversity and ecological integrity are maintained'*.

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

- Technical Guidance – Protection of Benthic Communities and Habitats (EPA 2016a)
- Environmental Factor Guideline – Benthic Communities and Habitats (EPA 2016b)

- Technical Guidance – Environmental Impact Assessment of Marine Dredging Proposals (EPA 2021b).

1.3. Related Documents

This report will specifically address the objectives and ESD work requirements specifically relating to subtidal BCH impact assessment, and will be used in conjunction with the following documents relevant to the Proposal:

- Intertidal Benthic Communities and Habitat Report (O2M 2025a)
- Conservation Significant Marine Fauna Desktop Study (O2M 2025b)
- Benthic Communities and Habitat Cumulative Loss Assessment Report (O2M 2025c)
- Metocean Field Data Collection Programme: Data Report (O2M 2022a)
- Sediment Analysis Report (O2M 2022b).

2. Tenure, Conservation, Ecological or Social Values

2.1. Tenure Values

The MDE area occurs within the marine boundary of the Port of Cape Preston (Figure 3). The MDE area currently resides within the Port of Cape Preston (CP) boundaries (see Figure 3). CP is declared under the *Shipping and Pilotage Act 1967* (WA) and administered by the Department of Transport (DoT). CP was created for CITIC-Pacific's Sino Iron Project export facilities at Cape Preston and is located several kilometres west of the of the ESSP development envelop. Under Tranche 2 of the State Government's 2014 port governance reform, regulation of CP will transition to the *Port Authorities Act 1999* (PAA) and responsibility for oversight of the port from the DoT to the regional port authority, the Pilbara Ports Authority (PPA), at some future stage.

The MDE is located within the greenfield Port of Cape Preston East (CPE) (see Figure 3). In 2008, the State Government secured 6,147ha of land at Cape Preston for the development of a future multi-user export port. A variation to the *Iron Ore Processing (Mineralogy Pty Ltd) Act 2002* (SAA) resulted in the excision of the land back to the State. In May 2017, a reserve 'for port purposes' was created over the CPE land and seabed areas with a Management Order in favour of PPA.

The CPE land area is largely undeveloped, apart from grazing cattle and minor clearing for tracks and pastoral activities. A road, causeway and bridge were constructed in the north-western portion of CPE in 2010 by CITIC-Pacific, as part of its Sino Iron Project. This infrastructure was subsequently bequeathed to the State (PPA), as per the variation to the SAA, to be used as common user infrastructure facilitating access to both the Sino Iron Project export facilities in CP and the future CPE port facilities.

The proposed port waters for CPE will be created by excising a portion of the existing CP port waters and State waters to facilitate transhipping routes, anchorages and the construction of marine infrastructure for CPE; and vested in the PPA. The State has agreed the boundary amendments to the ports and the declaration process for CPE is progressing.

2.2. Conservation Values

The Proposal occurs in close proximity to two islands, North East Regnard and South West Regnard Island, in the Pilbara Islands Nature Reserve, which encompasses 29 islands off the Pilbara coast (Figure 3). The surrounding coastal marine waters are classified as 'general use zone' and are not a part of the reserve. The islands within the Great Sandy Reserve are considered conservation significant breeding and resting places for migratory and resident shorebirds and seabirds, and marine turtles. The islands are recognized as Nature Reserves which are protected and managed by the Department of Biodiversity, Conservation and Attractions (DBCA).

The marine and coastal environment of the Dampier Archipelago/Cape Preston region, with its unique combination of offshore islands, intertidal and subtidal reefs, mangroves, macroalgal communities and coral reefs, was identified in the report prepared by the Marine Parks and Reserves Selection Working Group as having very significant conservation values (MPRSWG 1994). In December 1997, the WA Government, following advice provided by the WA Marine Parks and Reserves Authority (MPRA), announced the Dampier Archipelago/Cape Preston region as priority areas for the establishment of marine conservation reserves under the CALM Act. Studies were undertaken to assess the area's biological and economic resources, and social values and an Indicative Management Plan was prepared for the proposed Dampier Archipelago Marine Park and Cape Preston Marine Management Area in 2005 (CALM 2005). However, planning for the marine conservation reserves for the Dampier Archipelago/Cape Preston region did not proceed.

2.3. Ecological Values

Ecological values of the Dampier Archipelago/Cape Preston region were described in CALM (2005) and a summary of those values are listed in Table 4.

Table 4: Summary of the ecological values for the Dampier Archipelago/Cape Preston region from CALM (2005)

Value	Description
Geomorphology	A complex seabed and island topography consisting of islands, islets, headlands, beaches, mudflats, rocky shores, platforms, intertidal and subtidal reef systems, sheltered lagoons and embayment's and deep channels and drop-offs.
Sediment quality	The sediments of the proposed reserves are generally undisturbed and are essential to the maintenance of a healthy ecosystem.
Water quality	The majority of the waters of the proposed reserves are relatively pristine and are essential to the maintenance of a healthy marine ecosystem.
Coral reef communities	Intertidal and subtidal reef systems, bommies and pavements with a high diversity of hard corals.
Mangrove communities	There are six species of mangrove found in the proposed reserves and extensive mangrove communities line over 50% of the mainland shore. Many of these communities are considered to be of international significance.
Macroalgal and seagrass communities	Extensive subtidal macroalgal and seagrass communities, which are important primary producers and refuge areas for fishes and invertebrates occur within the proposed reserves.
Subtidal soft bottom communities	Extensive sand and silt substrates that support a variety of invertebrate species both in and on the sediments.
Intertidal sand and mudflat communities	The intertidal sand and mudflat communities of the proposed reserves are primary producers and have an abundance of invertebrate life, which provides a valuable food source for shorebirds.
Rocky shore communities	Rocky shores are a major shoreline habitat of the proposed reserves and provide shelter for a variety of intertidal organisms, which in turn provide a valuable food source for shorebirds.
Turtles	Green, hawksbill, loggerhead, and leatherback turtles are of special conservation status and are all found in the proposed reserves. It is likely that most of the sandy

Value	Description
	beaches are used for turtle nesting and Rosemary Island has been identified as the focus for hawksbill turtle nesting in Western Australia.
Marine mammals	Eight species of toothed whale, four species of baleen whale and the dugong have been recorded from the proposed reserves. The humpback whale passes through the area during its annual migration.
Seabirds	The proposed reserves are a significant rookery for seabird and provide important feeding and resting areas for migrating shorebirds.
Finfishes	A diverse finfish fauna of approximately 736 species contributes significantly to the biodiversity of the proposed reserves.
Invertebrates	A high diversity and abundance of invertebrate fauna within the proposed reserves is an important food source for a variety of marine animals including migratory birds and fishes.

2.4. Social Values

Gnoorea Point, adjacent to 40 Mile Beach, is a natural, coastal camping area managed by the City of Karratha that occurs immediately adjacent to the Ponds and Infrastructure Development Envelope. The camp area offers a natural boat ramp, public toilets for day users and sullage disposal points. Recreational fishing from the shoreline or small boat is the most common activity undertaken by visitors.

Native Title Determination of the Proposal area identifies the Yaburara and Mardudhunera people who hold claim, but only the Mardudhunera were found to hold native title and as such are the Traditional Owners of the area. The Determination enables Traditional Owners to undertake cultural and spiritual activities including camping, hunting, fishing, collecting bush medicine and other plants and animals, and imparting knowledge through being on Country. CALM (2005) describes social values of the Dampier Archipelago/Cape Preston region which are summarised in Table 5.

Table 5: Summary of the social values for the Dampier Archipelago/Cape Preston region from CALM (2005)

Value	Description
Aboriginal heritage	Shell middens, artefacts and rock art remain as testimonies to a rich history of Aboriginal habitation dating back 20,000 years. There is still a strong Aboriginal identity in the region today and the area is culturally and recreational significant to Indigenous people.
Maritime history	The Dampier Archipelago/Cape Preston region has a history of European contact dating from 1628, which includes pearling, whaling and fishing for turtles.
Nature-based tourism	The ecological values of the area offer a wide range of attractions and opportunities for visitors, with popular visitor activities including diving, fishing, and wildlife appreciation.

Value	Description
Commercial fishing	The region is used by commercial fishers targeting prawns, finfish and sharks. On a smaller scale sea cucumbers, molluscs and aquarium fish are also targeted.
Aquaculture	The environment of the proposed reserves support the culture of pearls, algae, red claw crayfish and aquarium fishes, and have potential for future development of aquaculture industries in the future.
Pearling	The warm water temperatures, high nutrient levels, protection from wave damage, and relatively shallow water in parts of the proposed reserves provide optimal conditions for the production of pearls.
Ports and shipping	The high level of shipping activity in the area is expected to increase with the addition of future port facilities and the expected increase in tonnage of the nearby Dampier Port.
Industry	Petroleum, iron ore export and salt production are the major industries, which operate in and adjacent to the proposed reserves.
Recreational activities	The warm climate, island scenery, abundance of wildlife and pristine environment provides for a range of recreation activities including boating, diving and surface water sports.
Recreational fishing	Line fishing, netting and spearfishing are used by fishers to target a variety of pelagic and reef finfish species, mud-crabs, crayfish and other invertebrates.
Seascapes	Panoramic vistas of azure waters, offshore islands, reefs, mangroves and beaches are major aesthetic attractions of the proposed reserves.
Scientific research	The pristine nature and wide variety of the habitats and communities of the proposed reserves combined with the wide range of human activities including heavy industry, ports and shipping, commercial fishing and recreational activities within the proposed reserve provide unique opportunities for ecological and social research.
Education	The unique array of ecological and social values within the proposed reserves combined with the easy access and close proximity of the proposed reserves to regional centres provides opportunities for community education about the marine environment.

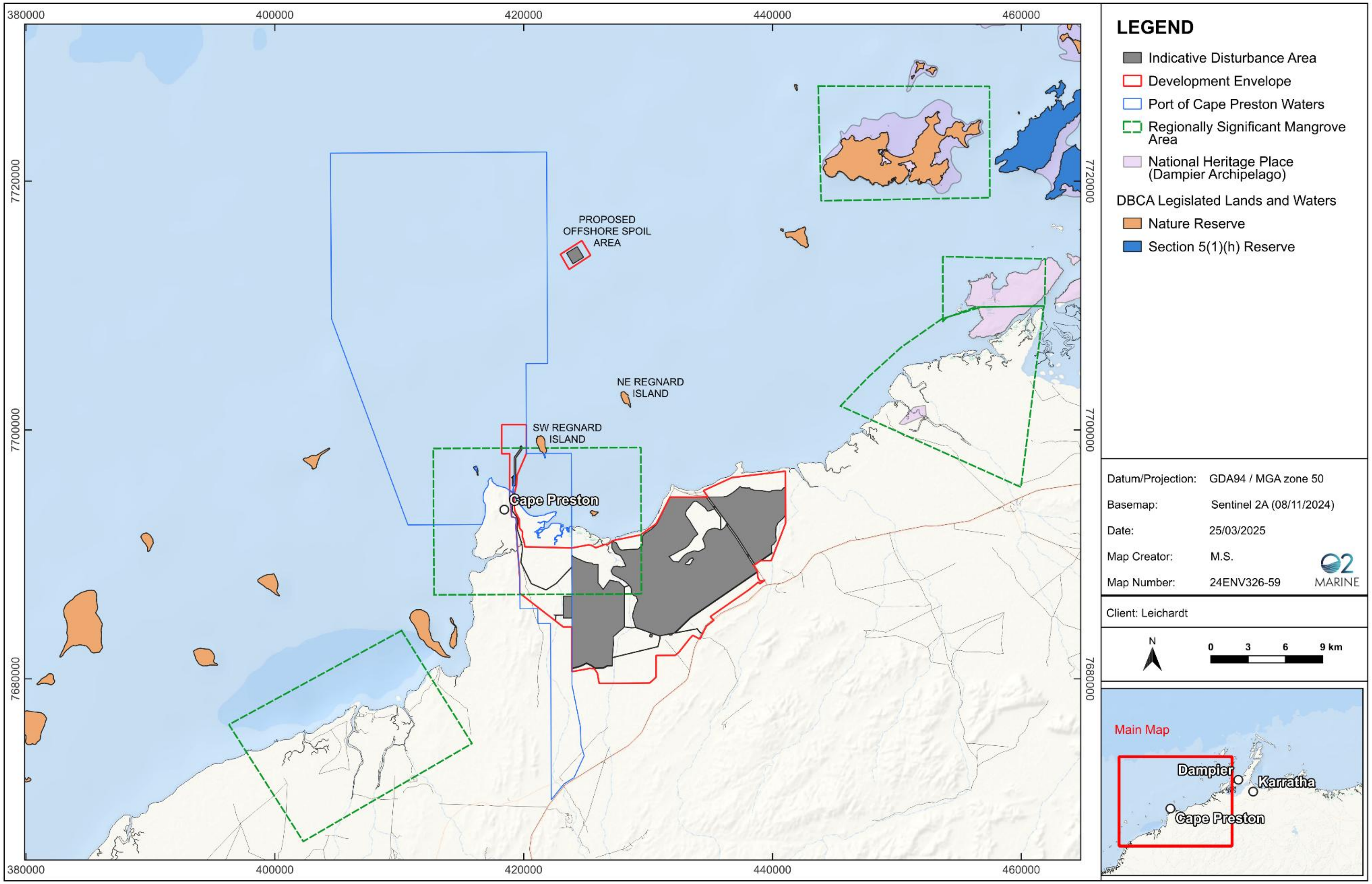


Figure 3: Location of tenure, conservation, ecological and social boundaries in the Proposal area.

3. Existing Environment

3.1. Overview

O2M undertook a comprehensive desktop assessment of the subtidal BCH in the Proposal area as a preliminary component of this study. The review focussed on surveys undertaken for previous coastal development projects in the Pilbara and relevant scientific journal literature on subtidal BCH in the adjacent region. In particular, the literature review sought to identify existing subtidal BCH mapping of the Proposal area and adjacent areas to assist in spatially characterising the distribution of subtidal BCH and to define the significance, environmental values, ecological integrity and biodiversity of BCH in the Proposal area.

3.2. Climate and Oceanography

The Pilbara is characterised as an arid region, with pronounced wet (December to June) and dry (August to November) seasons. The Pilbara experiences an average annual rainfall of approximately 275.3 mm, which is dominated by wet season tropical storms. Recent data indicates significant variability in rainfall patterns, with some areas receiving less than 250 mm annually. Maximum daily temperatures at nearby Mardie have shown recent increases, with the region experiencing prolonged heatwave conditions and temperatures frequently reaching the low to mid-forties. Maximum daily temperatures at nearby Mardie reached a monthly average of 37.9°C in January, falling to 27.8°C in July (BOM 2025). Winds range from easterly to south-easterly in the dry season to west and south-westerly in the wet season, when the area is also exposed to intense tropical storms and cyclones (with an average of one (1) landfall cyclone every two (2) years). Sea temperature varies from 18°C in the cooler months to a maximum of 31.5°C during the wet season, and inshore salinities may reach levels around 37 ppt (CALM 2005).

Wave energy in the area is typically relatively low, except during cyclones, with typical directions of west to south-west from May to July, and east to north-east between September to February (O2M 2022a). Various currents operate in the vicinity of the study area and are typically dominated by tides on the inner shelf. At the proposal site, tides are semidiurnal with a mean spring tidal range of approximately 3 m, and a maximum range of 4.5 m.

3.3. Geomorphology and Sediments

The Pilbara comprises a very broad and shallow continental shelf, which ranges from around 100 km wide in the west to 300 km wide in the east (Heap and Harris 2008). According to James et al. (2004), shallower (continental shelf) deposits comprise mixed sediments, including both modern terrigenous (river derived) and carbonate (biogenic) materials, as well as the often coarse preserved remains of ancient sediments (relict intraclasts).

Between North-West Cape and the Dampier Archipelago, numerous small bedrock islands lie in shallow water and introduce heterogeneity in the ambient hydrodynamic conditions (O2M 2022a) along the coastline, which in turn promotes heterogeneity in marine habitats. The Pilbara continental shelf is strongly influenced by the presence of limestone features that have been deposited during periods when the sea-level was lower and remain on the modern seabed as partially buried (reef veneer) or completely exposed rocky reef systems

(LeBrec et al. 2022). These often-complex features vary greatly in morphology, state of weathering and bathymetric profile. LeBrec et al. (2022) identified that the seabed in the vicinity of the Regnard Islands to the 20 m isobath features a series of submerged ancient strandplains. The authors do not characterise the inner bay itself, though the satellite derived bathymetry product of LeBrec et al. (2021) indicates several distinct systems of ridges within the bay.

The oceanography of the region, including cyclone events, internal tides and ocean currents, play an important role in regulating sediment transport, deposition and erosion (James et al. 2004). Marine sediments are mobilised and deposited through the action of wave and tides, whereas terrigenous sediments are delivered to the coast episodically through flood plains and river deltas - the largest river within Regnard Bay being the Maitland River to the east of the proposed site.

The local coastline is characterised by extensive beaches, mud flats, mangroves and tidal creeks seaward of an ancient hard-rock terrain. Cape Preston East has a beach coastline as far as the sandbar connecting Great Sandy Island to the cape. Behind this sand bar the shoreline consists of tidal creeks, mangrove habitat and extensive algal mudflats. Cyclones, and the associated extreme high-water levels, waves, and freshwater discharge are likely to be the most significant driver of coastal geomorphic changes in the inner bay (Eliot et al. 2013, LeProvost 2008).

3.4. Benthic Habitats

Early mapping work by Bancroft et al (2000) and Lyne et al. (2006) broadly described the subtidal habitat of the Pilbara region as being predominately sand (56%) and silt (18%), followed by macroalgae (16%). Sand habitat included sparse macroalgae, seagrass, soft corals, sponges, and a diverse array of other benthic invertebrates, whereas silt typically did not contain any vegetation. Reefs represent ~10% of the subtidal habitat area within the Pilbara region, whereas sponges and other filter feeders may occur within coral reef, macroalgae, sand, and seagrass habitat types (Bancroft et al 2000).

Campey and Gilmour (2000) mapped the communities in the near vicinity of Cape Preston, deriving six (6) habitat types, including bare sand, sand/algae, sparse coral/mixed algae/sponges/sand/rubble, medium coral cover/mixed algae, high coral cover/mixed algae, and sand/silt. The study described the importance of macroalgae (*Sargassum*) and compiled a species diversity list for the locality.

The distribution of habitats was further mapped by CALM (2000), Maunsell (2006) and URS (2008), summarised in LeProvost (2008), primarily using diver surveys and aerial inspections. This work identified the areas of highest live coral cover, specifically 3-5 km southwest of Cape Preston, 4 km north-east of Cape Preston (South West Regnard Island), and 5 km east of Cape Preston. These coral areas were described by LeProvost (2008) as being 'regionally significant'.

Subsequently, GHD (2013) undertook a more detailed benthic habitat investigation in the Cape Preston East area, building on the LeProvost (2008) study. This work identified sparse coral, sparse to dense macroalgae, algal pavements with filter feeders and sand/rubble in the vicinity of the proposed Proposal area.

Besides coral and seagrass communities (see below) the shallow marine environments of the Pilbara harbour a diverse range of other benthic invertebrates, including ascidians, sponges, hydrozoans and soft corals, however little is known about their distribution and abundance. Soft corals in the genera *Sarcophyton*, *Lobophytum*, *Sinularia*, and *Nepthea* are abundant, as are hydrozoans, particularly *Millepora* (WorleyParsons

2009a, b). Assemblages of ascidians, sponges, hydroids, and anemones are found among the communities of hard corals in different habitats. Large communities of other benthic organisms also exist outside the distribution of hard corals. For example, in deeper waters with strong currents and soft substrata are large communities of filter feeders, particularly soft corals, gorgonians, hydroids and sponges. Along the coastline, the mangrove communities are the largest single unit of relatively undisturbed arid zone habitat in the world (EPA 2001).

There is little known about the distribution and abundance of sponges and other filter feeders in the immediate vicinity of the Proposal area. However, the area beyond the tip of Cape Preston is predicted to contain the highest density of sponges (Irciniidae and Raspailiidae) and colonial ascidians within the region (Pitcher et al. 2016). In addition to filter feeders, the area is predicted to contain the highest density of mantis shrimps in the region (Pitcher 2016).

Olsen et al. (2019) described the physiographic extent of the marine algae of the Pilbara coastline, identifying 188 macrophyte species; 60% were Rhodophyta (commonly referred to as red algae), whereas Phaeophyceae (commonly referred to as Brown algae) made up 67% of the biomass. Macrophyte assemblages did not show any broad-scale patterns, but a number of key drivers were identified, including sea surface temperature, salinity, and sediment uniformity. Two (2) of the main predictors of macrophyte abundance and species richness were rugosity and coral cover rather than herbivory, unlike what has been demonstrated for many reefs globally. Availability of space therefore appears to be a major factor for the density and cover of algae on these reefs and it is possible that macrophytes benefit from periodic disturbances as they can free up space through physical removal of organisms.

3.5. Hard Coral Communities

The communities of corals in the Pilbara are more speciose than those within any other region of WA, including Ningaloo Reef and the Rowley Shoals (Veron and Marsh 1988). At least 223 scleractinian species from 57 genera have been recorded, of which approximately half belong to the families Acroporidae and Faviidae. Many species are thought to be in low abundance and to be widespread among Indo-Pacific reefs. However, the extent to which rare or endemic species exist within the region is largely unknown. The diversity of corals is theoretically lower at inshore reefs, due to extreme conditions such as sedimentation and the growth of macroalgae, and also at the furthest offshore reefs, due to wave energy and the dominance of species such as plating *Acropora*. Outer coastal reefs and those on the leeward sides of islands may be the most speciose (Simpson 1988). Although the inshore and coastal reefs generally have the lowest cover of corals, these can vary dramatically among locations and are often dominated by a few species of *Turbinaria*, *Porites*, *Goneastrea*, *Pavona*, *Favites*, *Favia* and *Caulastrea*, in addition to macroalgae, sponges and zoanthids. The suite of species recorded suggests that there are marked cross-shelf differences in the composition of Pilbara communities. For example, at inshore sites near the Passage Island group (Onslow coastline), *Turbinaria, Favites, Platygyra, Goniopora* and *Lobophyllia* were the most abundant genera and there is very little representation of *Acropora* and *Pavona* (Z T Richards pers comm 2022). At Barrow/Montebello Islands, the most abundant genera were *Acropora*, *Montipora* and *Porites*. These differences in community composition are most likely due to wave exposure and the level of suspended particulate matter in the water column (Marsh 1997, Blakeway and Radford 2005).

Surveys prior to the development of the Cape Preston jetty identified 50 species of corals from 11 families in the immediate vicinity the future jetty (Campey and Gilmour 2000). The area beyond the tip of Cape Preston was described as high coral cover (Acroporidae, Dendrophyllidae, Faviidae) and highly diverse habitat with low algal cover and many other benthic invertebrates, with the highest coral cover on the northern side of Preston Island. The tip of Cape Preston featured rocky shore with low coral (including *Turbinaria* and *Favia*) and high algal cover along with many other benthic invertebrates. Offshore areas are the most speciose, as inshore reefs tend to favour specific genera (e.g., *Turbinaria*, *Porites*, and *Favites*) that tolerate increased macroalgal competition, turbidity, and sedimentation (Gilmour et al. 2006, Richards and Rosser 2012). Given the environmental conditions at inshore sites, they tend to have lower coral cover compared to offshore reefs (Gilmour et al. 2006).

In 2012, coral monitoring surveys were conducted between Preston Island and South West Regnard Island (GHD 2013) at the same sites used for numerous previous targeted coral surveys (WorleyParsons 2009b, URS 2008, SKM 2008). Monitoring at these sites were repeated in this study and site locations are presented in Section 5.3, Figure 13. Hard coral cover at these sites typically ranged from 4.9 to 49.8% while macroalgal cover ranged from 29.5 to 77.0%. Coral cover was highest at site 3 (50%) on the eastern side of South West Regnard Island, followed by site 2 (27%) south of South West Regnard Island, site 4 (10%) east of the Sino Iron port facility, site 1 (9%) 1.5 km offshore between Preston Island and South West Regnard Island, and site 5 (5%) between Preston Island and South West Regnard Island (0.4 km offshore). The 2012 survey determined that the sites were quite distinct: Sites 1, 4, and 5 had high cover of Dendrophyllidae (e.g. *Turbinaria*) while site 3 was dominated by Faviid corals and site 2 was dominated by Poritidae and Mussidae. A regional survey in 1999 found similar benthic habitats at these locations, characterising site 2 as reef (*Porites* bommies) with hard substrate and sand and characterising site 3 as reef with ~50% coral cover of massive *Favites* and *Platygyra*.

WorleyParsons (2009b) undertook a comparative health assessment of the corals in the Cape Preston region, the Dampier Region and placed them in context with the broader reefs of WA and the Great Barrier Reef. This study noted that the corals present in the Cape Preston (and Dampier) areas are of species and growth forms that are typically more resistant to bleaching and sedimentation and are thereby mostly in good health.

3.6. Seagrass Communities

A total of seven (7) species of seagrass have been described throughout the Pilbara, and sites that contain five (5) or more species, such as Exmouth Gulf, are considered to be of relatively high richness, and two (2) or less being considered low (Vanderklift et al. 2017). *Halophila ovalis* is the most ubiquitous species in the Pilbara. Seagrass exists throughout the region but often doesn't appear in large-scale habitat descriptions as the seagrass is typically very sparse and/or ephemeral. For example, Bancroft et al (2000) merged the seagrass class within the coral reef and sand habitat classifications. Regionally, sparse seagrass cover (of <1%) was observed at several sites around the Barrow Islands, but not in other areas of the Pilbara (Bancroft et al 2000). Seagrass coverage of 0-7% was observed near Onslow in September 2011 but virtually disappeared by December 2011 (Chevron 2013).

Only qualitative observations of seagrass exist near the Proposal area. Campey and Gilmour (2000) noted only one (1) species of seagrass, *Syringodium isoetifolium* (on the Cape Preston spit), and sparse *Halophila* sp. at North East Regnard Island and north Regnard Bay. This indicates that both perennial and ephemeral seagrass habitat could occur in the Proposal area. Three (3) species were identified in the nearby Mardie Project area (*Halophila spinulosa*, *Halodule uninervis* and *Syringodium isoetifolium*.).

4. Local Assessment Units

Section 4.2 of EPA (2016a) outlines the requirement to clearly define spatially based Local Assessment Unit (LAUs) within which potential cumulative losses for BCH can be calculated, assessed, and presented. LAUs must be location specific, assessed on a case-by-case basis and consider local aspects of bathymetry, substrate type, exposure, currents, and biological attributes such as habitat types. EPA (2016a) suggests that LAUs should notionally be established in units of approximately 50 km^2. LAUs for this Proposal were based on consideration of the following factors:

- Existing LAUs for the Sino Iron Project and Cape Preston East ports
- Distribution, extent and condition of subtidal and intertidal BCH
- Management boundaries (e.g. regionally significant mangrove areas)
- Bathymetry, and
- Coastal geomorphology.

A total of 13 LAUs were developed for the Proposal. LAUs 1–4 are relevant to the intertidal zone but also extend into the subtidal zone, while LAUs 5–13 are relevant to the subtidal zone.

LAUs 1-13 were conservatively developed to spatially encompass all potential Proposal impacts. At the time of setting the LAUs, the dredge/disposal design was not finalised, thus, the total LAU area is likely to be larger than any Proposal related impacts. A description for each of the proposed subtidal LAUs, as well as the area presented in hectares and a percentage of the overall study area, is presented in

Table 6. The areas for each LAU for the Proposal are displayed in Figure 4.

Table 6: Description and spatial area (ha) for each proposed subtidal LAUs and the percentage of the total study area.

LAU	Area	Description
LAU1	5,921.75 ha (1.02%)	• Subtidal BCH area (1,363 ha) • Nearshore LAU characterised by sand and algae-dominated limestone pavement in depths <3 m • Contains existing Marine Management Unit on both side of Cape Preston • Port of Cape Preston port waters boundary too close to edge of MDE, so eastern boundary extended to approximate predicted Zone of Moderate Impact area • From LAT to 3 m depth contour, • Cape Preston is a significant geomorphological feature.
LAU2	3,790.12 ha (1.17%)	• Subtidal BCH area (1,564 ha) • Nearshore LAU characterised by sand and algae-dominated limestone pavement in depths <5 m • From LAT to 5 m depth contour, • The Great Sandy Island Nature Reserve is a significant geomorphological feature.
LAU3	4,499.96 ha (1.03%)	• Subtidal BCH area (1,371 ha) • Nearshore LAU characterised by sand and algae-dominated limestone pavement in depths <5 m

LAU	Area	Description
		• Contains existing Marine Management Unit on both side of Cape Preston • Port of Cape Preston port waters boundary too close to edge of MDE, so eastern boundary extended to approximate predicted Zone of Moderate Impact area • From LAT to 5 m depth contour, • Geomorphology relatively low gradient and featureless seabed.
LAU4	3,772.47 ha (0.74%)	• Subtidal BCH area (990 ha) • Nearshore LAU characterised by sand and algae-dominated limestone pavement in depths <5 m • Contains existing Marine Management Unit on both sides of Cape Preston • Port of Cape Preston port waters boundary too close to edge of MDE, so eastern boundary extended to approximate predicted Zone of Moderate Impact area • From LAT to 5 m depth contour, • Geomorphology relatively low gradient and featureless seabed.
LAU5	2,660 ha (2.00%)	• Nearshore LAU characterised by algae dominated limestone pavement and coral reefs in depths <5 m, including previously recognised regionally significant reefs • Contains existing Marine Management Unit on east side of Cape Preston • Port of Cape Preston port waters boundary • From LAT to 10 m depth contour, • Cape Preston significant geomorphological feature.
LAU6	8,129 ha (6.05%)	• Nearshore LAU characterised by sand, shallow seagrass, and reef platforms off Cape Preston and South West Regnard Island supporting coral and macroalgae in depths <5 m, including previously recognised regionally significant coral reefs • Contains existing Marine Management Unit on west side of Cape Preston • Port of Cape Preston port waters boundary too close to edge of MDE, so eastern boundary extended to approximate predicted Zone of Moderate Impact area • From LAT to 10 m depth contour, • Cape Preston and South West Regnard Island significant geomorphological features.
LAU7	7,815 ha (5.82%)	• Nearshore LAU characterised by silt/coarse sand and reef platform surrounding North East Regnard Island supporting coral and macroalgae in depths <5 m • Eastern boundary extended to approximate predicted Zone of Influence area • From LAT to 10 m depth contour, • North East Regnard Island and small shoal ~6 km north north-east on subtidal reef platform significant geological features.
LAU8	9,618 ha (7.22%)	• Mid-shelf LAU characterised by bare sand • Port of Cape Preston port waters boundary on east and west • Bathymetry from 10 m to 15 m depth contours, • Geomorphology relatively low gradient and featureless seabed.

LAU	Area	Description
LAU9	5,350 ha (4.02%)	• Mid-shelf LAU characterised by bare sand • Port of Cape Preston port waters boundary on west • Bathymetry from 10 m to 15 m depth, • Geomorphology relatively low gradient and featureless seabed.
LAU10	7,606 ha (5.71%)	• Mid-shelf LAU characterised by sand, occasional shoals possibly supporting macroalgae and filter feeders • Port of Cape Preston port waters boundary on east and west • 20 m depth contour forms northern boundary • Bathymetry from 8 m to 20 m depth, • Geomorphology relatively low gradient and featureless seabed with occasional shoals and steep gradient from 10 m to 20 m on outer shelf.
LAU11	6,080 ha (4.56%)	• Mid-shelf LAU characterised largely by bare sand, occasional shoals possibly supporting macroalgae and filter feeders • Port of Cape Preston port waters boundary on west • 20 m depth contour forms northern boundary • Bathymetry from 6 m to 20 m depth, • Geomorphology relatively low gradient and featureless seabed with occasional shoals steep gradient from 10 m to 20 m on outer shelf.
LAU12	22,482 ha (16.88%)	• Offshore LAU characterised by bare sand • Port of Cape Preston port waters boundary on north, east and west • Bathymetry from 20 m to ~30 m depth contours, • Geomorphology relatively low gradient and featureless seabed.
LAU13	5,886 ha (4.42%)	• Offshore LAU characterised by bare sand • Port of Cape Preston port waters boundary on north and west • Bathymetry from 20 m to ~30 m depth contours, • Geomorphology relatively low gradient and featureless seabed.

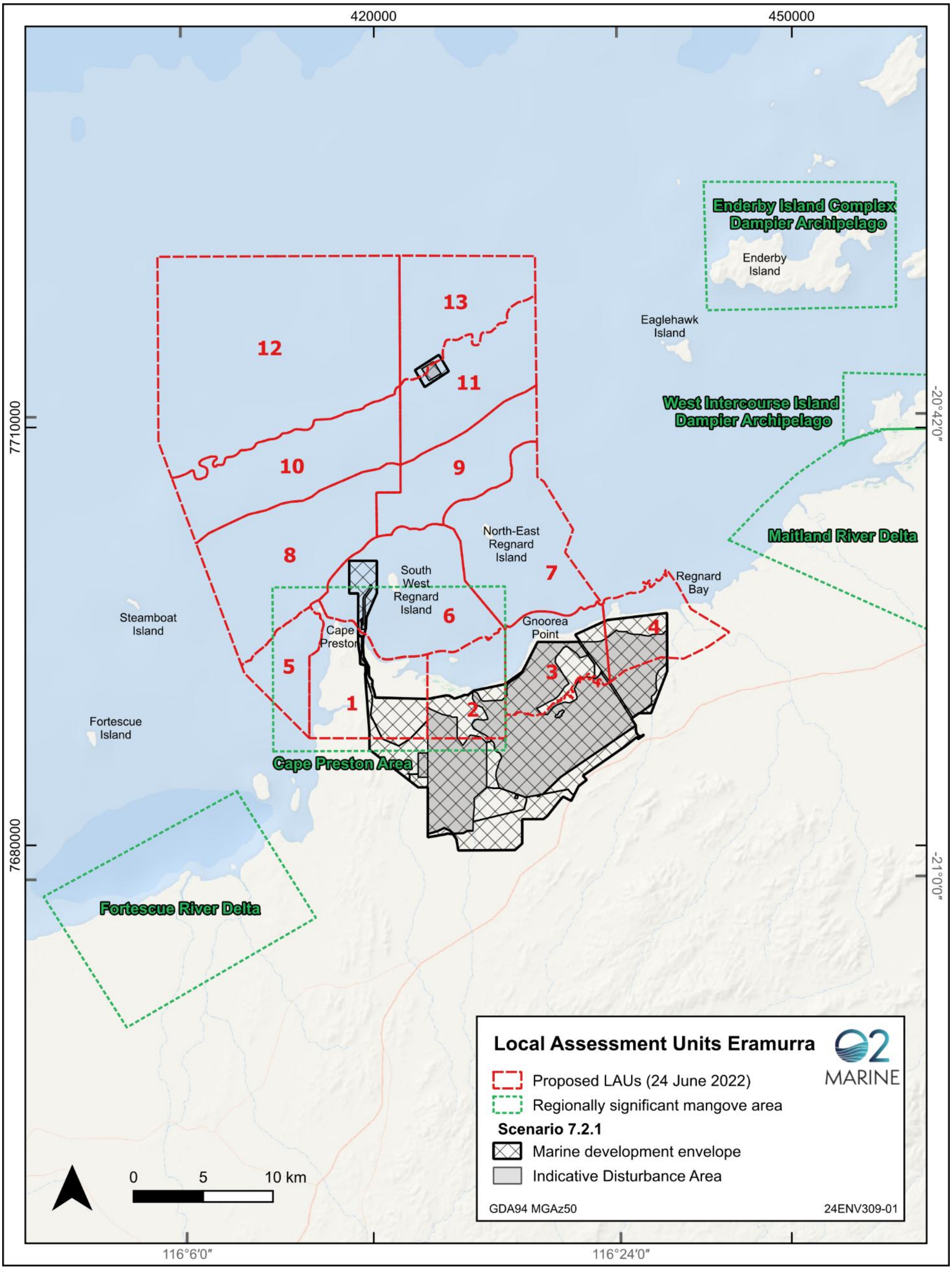


Figure 4: Local Assessment Units (LAUs) for the Proposal

5. Methodology

This assessment of subtidal BCH primarily focuses on the nearshore coastal zone including and adjacent to the Proposal MDE. The assessment draws on relevant information collected for wider regional nearby projects (within 100 km), and from site specific field studies undertaken from 2017 to 2024. The spatial area of the extent of the study area therefore enables consideration of all potential direct and indirect impacts of the Proposal on BCH. For the purpose of this assessment, the subtidal nearshore coastal zone is defined as extending from the lowest astronomical tide (LAT) of the Cape Preston East coast to the 20 m bathymetric contour, and includes several small coastal islands.

5.1. Review of historical data and BCH surveys

5.1.1. Historical data

Consistent with the requirements stipulated in the Proposal ESD (Preston Consulting 2022), Leichhardt commissioned an investigation to characterise and map the subtidal BCH within the proposed LAUs. An initial desktop review identified that previous maps have been generated presenting the extent and distribution of subtidal BCH in the general Proposal vicinity (Bancroft et al 2000, Lyne et al 2006, LeProvost 2008, GHD 2012). Bancroft et al (2000) and Lyne et al (2006) provide shapefiles of broadscale low resolution mapping across a broader area of the Pilbara, while LeProvost (2008) and GHD (2012) provided BCH maps for the Sino Iron Project and the Cape Preston East Project respectively. These maps provided fine-scale detail, relevant to the immediate Proposal area. Guidance within EPA (2021b) encourages utilisation of the available information to consolidate and improve knowledge of these habitats. A summary of the previous datasets relevant to this work is provided in Table 7.

Table 7: Previous relevant benthic community habitat maps and datasets.

Study	Area Covered	Comment
Bancroft et al (2000)	Montebello/Barrow islands and the Dampier Archipelago/Cape Preston region, Western Australia	Field surveys encompassing the proposed marine conservation reserve areas carried out from the 14-25 June 1999 and 22-25 May 2000. The field surveys were undertaken aboard the CALM Marine Conservation Branch Research Vessel RV Bidthangara.
Lyne et al (2006)	North West Cape to Port Hedland and from the coast to the 200 m isobath.	North West Shelf Joint Environmental Management Study aimed to collate and integrate data on habitats for the region of the North West Shelf. Provides maps and statistical descriptions of key ecosystems and habitats designed to assist the process modelling of the ecosystem and impacts of uses, as well as directly supporting planning and management by Western Australian agencies and industries.
Leprovost (2008)	Area west of Cape Preston extending	Prepared for Sino Iron Project. Based on a review of past mapping in the area (Bancroft et al 2000, Maunsell 2006, URS 2008) and recent field surveys and aerial inspections by URS. High detail surrounding

Study	Area Covered	Comment
	to South West Regnard Island.	Cape Preston and the regionally significant coral areas near South West Regnard.
GHD (2013)	Cape Preston East area, narrow swath inshore in the MDE.	Prepared for the Cape Preston East Project. Benthic habitat survey of breakwater and trestle area. High detail shapefile delineating nearshore sparse coral and macroalgae habitats.
Aerial Imagery	Shallow inshore areas only.	Low tide images useful for identifying nearshore, intertidal and shallow subtidal features. Not suitable for BCH identification beyond the 10m depth contour.
Satellite Derived Bathymetry (LeBrec et al. 2021)	0-20 m depth over entire LAU areas	Useful for identifying broader geomorphic features such as depth contours, reef edge transitions and larger seabed bedforms.

5.1.2. BCH surveys

The above-mentioned historical data was used to inform a series of field campaigns, where the objective was to verify historic data, produce updated maps and assessment of BCH and assess seasonal variation. The historical field survey effort is summarised in Table 8 and focusses on validating/assessing BCH at greatest risk of impact from the Proposal activities.

Two separate BCH studies (2022 and 2023) assessed several offshore dredge spoil disposal ground options for the Proposal. The area surveyed during the latest study (2023), was selected as the preferred option and is included in this Proposal (Figure 2 and Figure 5). The BCH studies across the Proposal LUAs included three (3) primary survey techniques:

- Sidescan sonar to capture textural information over a series of broad swaths through the study area, and
- Drop camera to determine in detail the type of benthic communities present, and 'ground truth' the sidescan data.
- Targeted diver surveys over known coral and seagrass habitats to assess seasonal variation.

O2M conducted targeted subtidal BCH surveys to assess coral health and abundance in July 2020 and June 2021, while the condition of seagrass was measured in surveys undertaken during separate seasons (in July 2020 (dry season) and March 2021 (wet season).

Table 8: Summary of field surveys undertaken prior to the current benthic habitat mapping

Survey	Dates	Number of Sites	Purpose
Survey 1	23-25 July 2018	125 camera tows	Pre-feasibility drop camera investigative transects
Survey 2	2-7 March 2021	20 sidescan transects 18 camera tows	Offshore drop camera sites and sidescan sonar transects. Broad scale habitat assessment using sparse transects.
Disposal Ground / Mooring Area Assessment	19-22 March 2022	100 camera tows 3 spoil ground areas and 2 mooring sites (complete sidescan coverage)	Spoil ground and mooring area sidescan sonar and drop camera work. Small scale habitat assessment of targeted locations. Note* Disposal ground areas now superseded
Coral 1	14 – 18 July 2020	5 monitoring sites	First survey visiting previously established monitoring sites.
Coral 2	3 – 6 June 2021	5 monitoring sites	Second survey visiting previously established monitoring sites.
Seagrass 1	27 – 29 July 2020	7 monitoring sites	First survey during the dry season.
Seagrass 2	22 – 25 March 2021	7 monitoring sites	Second (repeat) survey during the wet season.
Disposal Ground Assessment (current proposal)	21st – 23 March 2023	Complete sidescan coverage. 15 camera tows.	Revised spoil ground location. Sidescan sonar and drop camera work. Small scale habitat assessment of targeted locations.

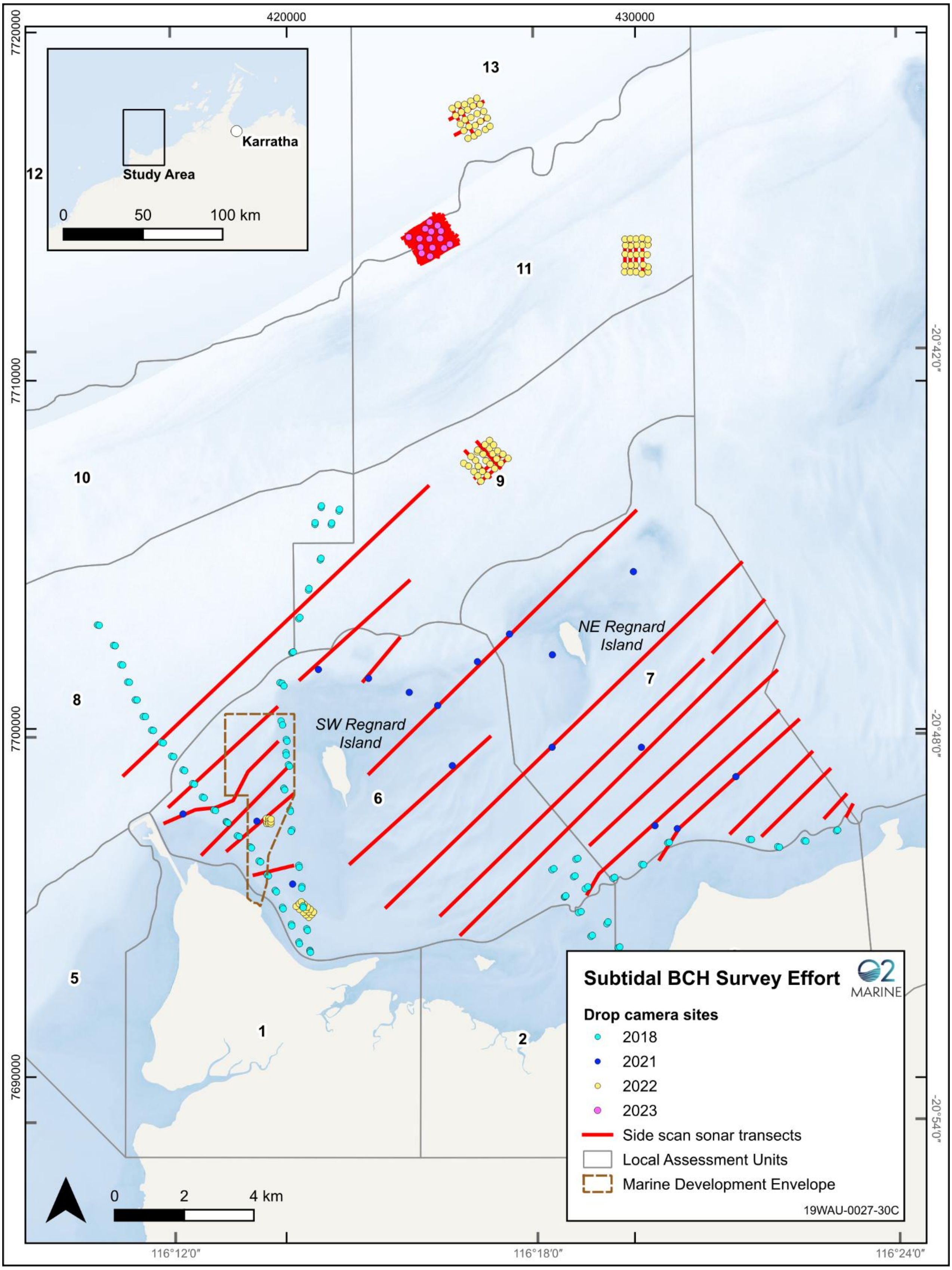


Figure 5: Side scan sonar and drop camera survey locations and effort for the previous subtidal BCH mapping.

5.2. Revised Assessment of BCH Extent and Distribution

In response to comments received from the EPA requiring improved spatial resolution and statistical validation of subtidal BCH communities, Leichardt commissioned an additional BCH survey which was carried out in October 2024. The revised survey methodology incorporated a combination of targeted towed video surveys, diver assessments, and remote sensing techniques to provide higher accuracy habitat delineation. The survey specifically focused on LAUs 1, 2, 3, 4, 5, and 6, enhancing previous BCH habitat mapping by refining the boundaries of coral reef, seagrass, macroalgae, and other subtidal habitats.

The revised benthic habitat maps presented in the report were generated using conventional remote sensing data, ground truthing and machine learning techniques; Figure 6 presents an overview of the approach to benthic habitat mapping, showing the four stages of the Project (pre-field/desktop tasks, in-field tasks, data processing and analysis, and reporting) and the activities/tasks associated with each stage.

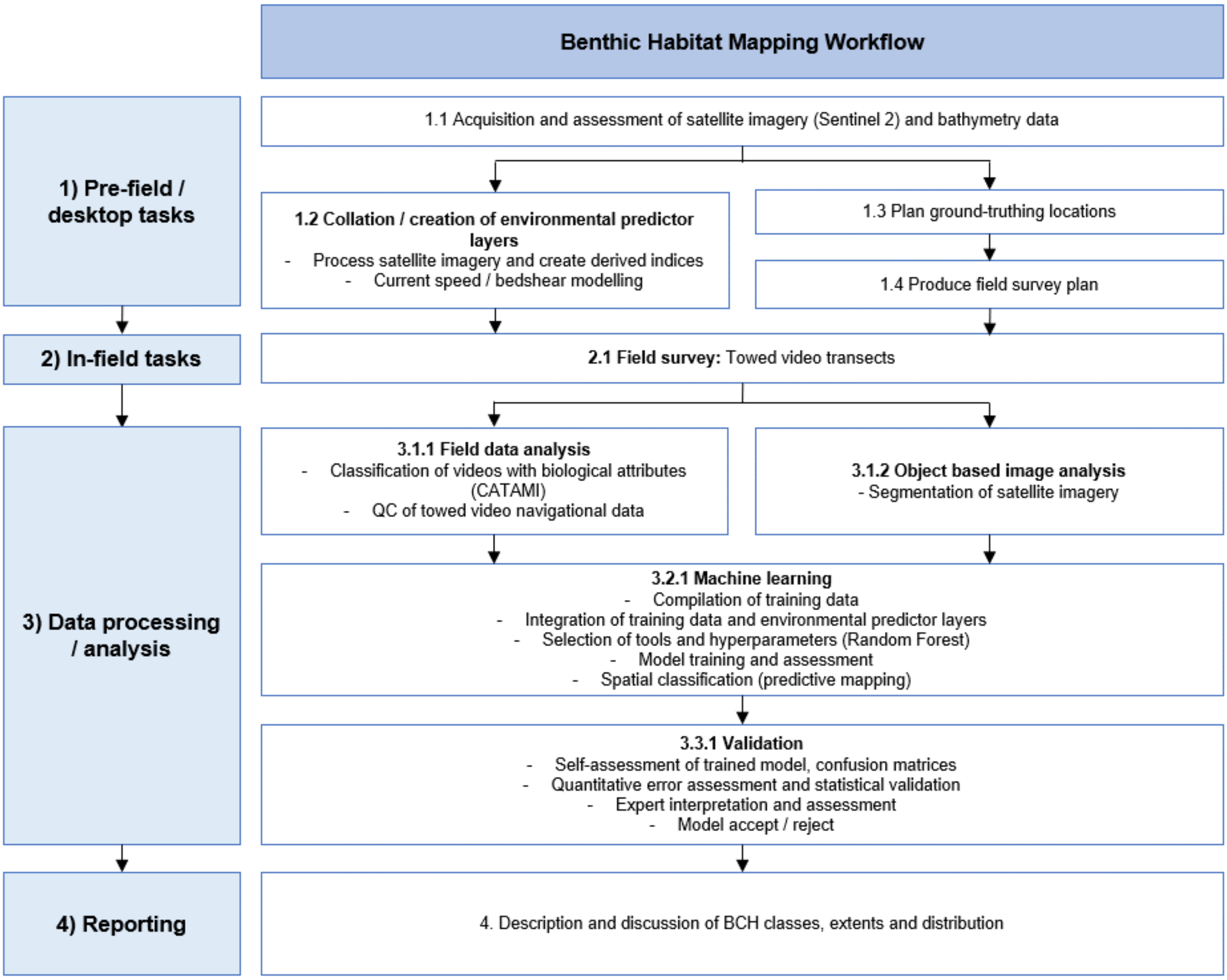


Figure 6: Breakdown of project stages and associated tasks

5.2.1. Acquisition of Satellite Imagery

Images from the Sentinel-2 satellite system (10 x 10 m grid cell resolution) have been reliably used for benthic habitat mapping and have been shown to produce high accuracy in vegetated environments optically shallow water substrate sites at a reasonably high spatial resolution (Wicaksono et al., 2021).

Image selection primarily focussed on identifying periods of low ocean turbidity and minimal sea state as close as possible to the period of 2024 ground truth data acquisition (Section 5.2.2, Table 9). A suitable Sentinel 2 image was obtained for the date 26/8/2024, which had low tide and sea state as well as clear atmospheric conditions.

5.2.2. Ground Truth Survey

5.2.2.1. Determining Ground-Truth Locations

To obtain the primary ground-truth dataset for this study, predetermined transects were identified prior to the field survey (Figure 7), comprising of targeted and randomly generated locations (~50% of each), where

- targeted transects were positioned to verify the nature of benthic features of visible in satellite imagery and bathymetric data, and
- randomly generated transects were haphazardly positioned to ensure that diverse habitat types are well represented, reducing potential bias from under- or over-sampling certain classes.

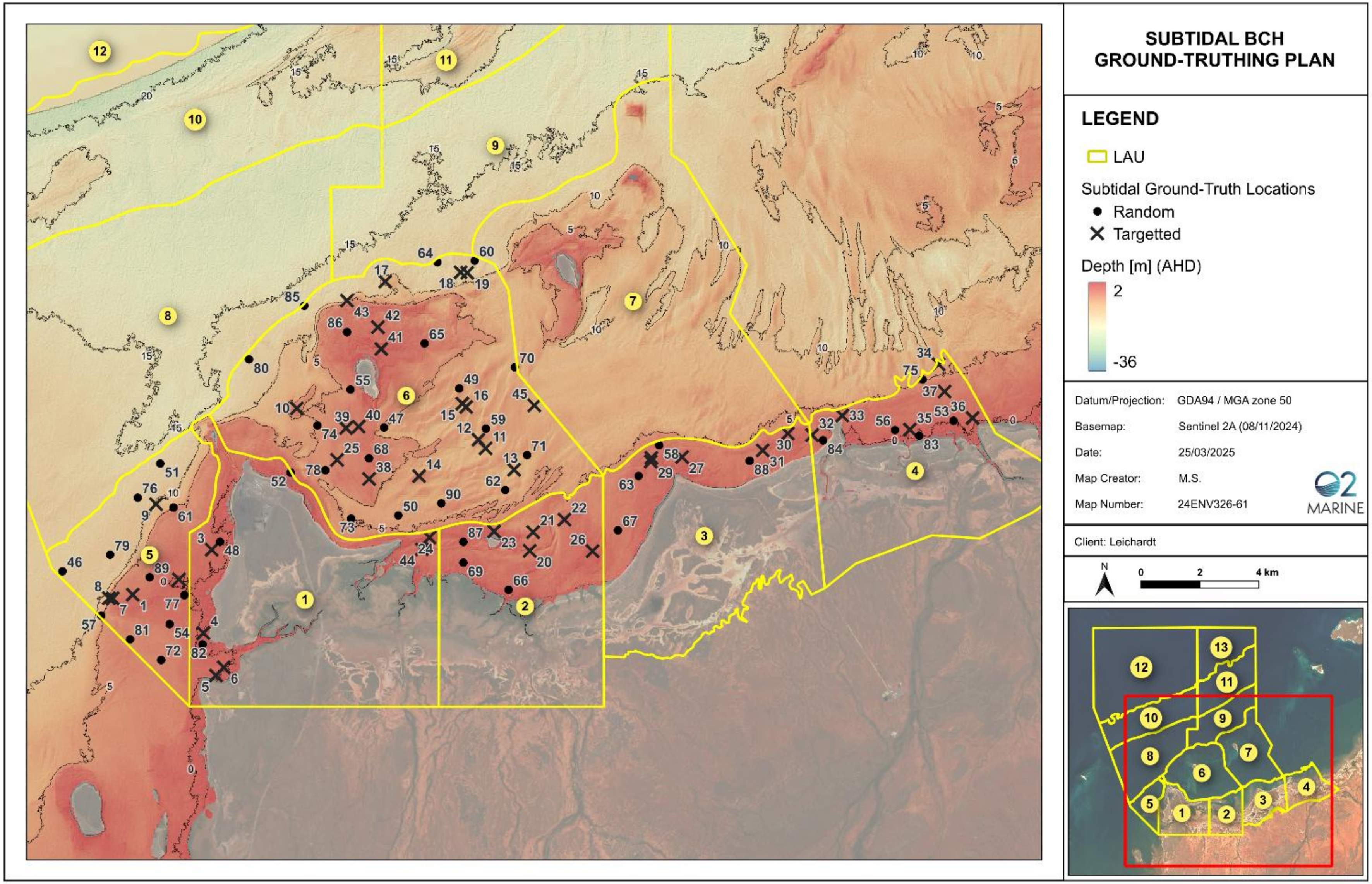


Figure 7: Planned ground-truthing locations

5.2.2.2. Timing and Location

Ground-truth survey acquisition was carried out by O2M across 3 (three) days, between the 23rd and 25th of October 2024. Survey days were selected based on targeting optimal weather conditions and vessel availability. The survey took place onboard a locally operated 7.5 m charter vessel, *'Willie'*. Daily survey effort is outlined in Table 9. For 10 sites too shallow for vessel operations, high-definition aerial photography was captured at low tide using a drone. The drone was flown at very low altitudes (approximately 5 m) to maximise image resolution.

Table 9: Daily survey effort for towed video and drone

Survey Date	Recording Method	Towed Video Transects
20/10/2024	Drone Imagery	10
23/10/2024	Towed Video	18
24/10/2024	Towed Video	45
25/10/2024	Towed Video	12
	TOTAL	85

5.2.2.3. Equipment

The primary towed video camera (TVC) system used for the ground truth survey was a Spot X SQUID real-time subsea high definition (HD) video camera (Figure 8a). A Spot X Pro Squid 3 (Figure 8b) was provided by O2M for two survey days (Table 9). Both systems are operated using the Helm video app on a topside unit, where a live video feed can be viewed, and settings can be adjusted. Global Positioning System (GPS) positioning was recorded on a GlobalSat BU 353S4 receiver, and backup tracks were recorded on a handheld Garmin GPS.

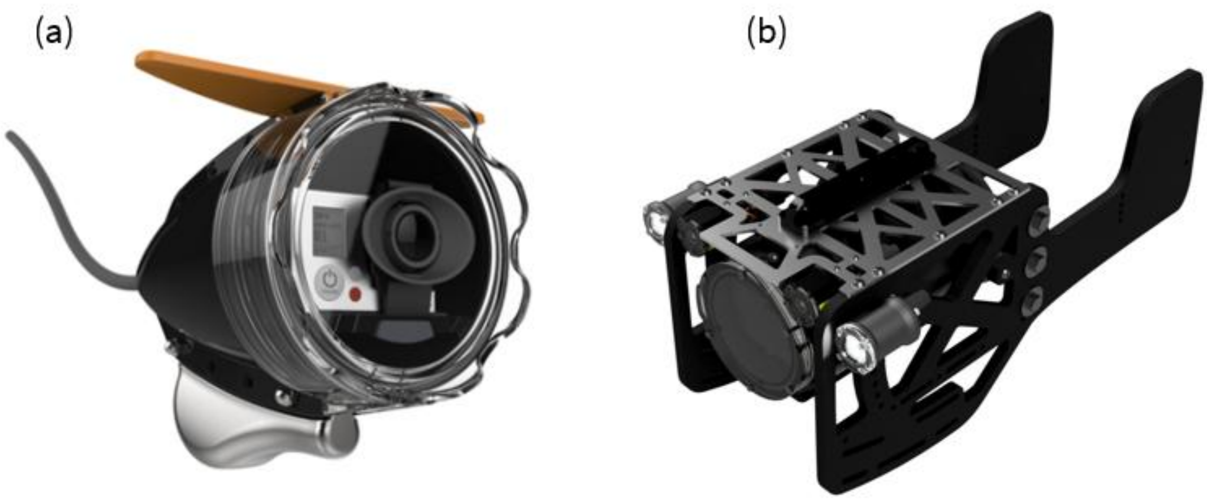


Figure 8: Towed video systems used in the ground-truth survey: a) Spot X Squid, b) Spot X Pro Squid 3

During the survey, the camera was flown at a depth of approximately 0.5 m above the seabed, with the operator recording between 30 seconds to a minute (30 - 60 m) of benthic video footage at each transect. Vessel speed ranged between 1-2 knots to allow for the acquisition of good-quality imagery.

The following information was recorded on field sheets at each targeted location:

- date and time
- GPS coordinates
- water depth (m)
- dominant BCH type
- comments to aid post-processing.

For areas too shallow for vessel operation, a Mavic 3 Multispectral RTK (Real-Time Kinematic) drone (Figure 9) was employed to collect photogrammetry data. Aerial photography was conducted during low tide to maximise exposure of benthic habitats. The Mavic 3 Multispectral captured both high-definition RGB (visible) and multiband imagery (near-infrared, red, red edge, and green).

Before mobilisation, pre-determined flight plans were uploaded to the drone's operating system. These plans included grid patterns over each target site, ensuring sufficient image overlap (minimum 75% both vertically and horizontally) for orthomosaic image production. During drone operations, the altitude was maintained at approximately 5 m above the seabed. Similar data to that recorded for the towed video surveys was documented on field sheets at each targeted location.

Figure 9: Mavic 3 Multispectral RTK Drone

5.2.2.4. Classification of TVC Footage

Ground truthing videos were initially assessed for quality, and any transects with poor visibility (e.g. high turbidity obscuring the identification of biota) were discarded. Video imagery was visually analysed by a qualified marine scientist using TransectMeasure software and classified into habitat classes following the Collaborative and Automated Tools for Analysis of Marine Imagery (CATAMI) standard classification scheme for scoring marine biota and physical characteristics (Althaus et al, 2013) from underwater imagery which includes:

- Relief
- Substrate
- Bedforms
- Visual estimate of cover of benthic flora and fauna, and
- The dominant and sub-dominant taxa.

An overview of the CATAMI classification system used by image analysts to score drop camera video transects is shown in Table 10.

A quality assurance and control check of the classifications was conducted by an experienced marine scientist specialising in benthic taxonomy and habitat classifications, including verification of percent cover estimates and species identification.

The TransectMeasure data output was synced with the GPS track log, as well as the corresponding auxiliary information (time, depth), to attribute the appropriate BCH characteristics at each point location. GPS offsets and cable lengths, which were recorded during the field survey, were applied to the transects to obtain the most accurate positioning of data. Navigation from each transect was checked for quality control in QGIS.

Table 10: Classifications based on CATAMI used by image analysts to score drop camera video transects

Physical		Relief		Substrate Type		Bedforms		Total Cover		Main BCH categories		BCH sub-categories
V	Veneer	F	Flat	M/S	Mud/silt	N	None	1	Bare (<1%)	BS	Bare Substrate / Unvegetated	
C	Consolidated (Hard)	L	Low (<1 m)	FS	Fine sand	B	Bioturbated	2	Sparse (1-3%)	FF	Filter feeders	FF - Black & Octocorals FF - Mixed FF - Other FF - Sponges
S	Unconsolidated (Soft)	M	Moderate (1-3 m)	CS	Coarse sand	2D	Ripples / Waves	3	Low (3-10%)	HC	Hard Corals	HC - Attached HC - Free-Living
		H	High (>3 m)	Cob	Cobbles			4	Moderate (10-25%	MA	Macroalgae	MA- Encrusting MA- Branching MA- Filamentous MA- Mixed MA- Other Macroalgae MA- Rhodoliths MA- Sargassum
		W	Wall	P/G	Pebble/Gravel	3D	Ripples	5	High (25%-75%)	SG	Seagrass	SG – Ephemeral SG – Mixed SG - Other / Unknown SG - Perennial
				B	Boulders			6	Dense (>75%)	Ot	Others	OT- Crustacea OT- Echinoderms OT- Molluscs OT- Other OT- Worms OT- Drift Algae / Wrack
				Inf	Infrastructure							

5.2.3. Data Processing and Analysis

5.2.3.1. Environmental Predictor Layers

Environmental predictor layers are datasets that act as proxies for habitat distribution. By sampling the values of these layers at the known locations of habitats (ground-truthing data), profiles of the physical characteristics of each habitat type can be assembled and, as such, used to predict the distribution of these habitats across the area of interest.

Environmental predictor layers are derived from three main sources:

- Bathymetric data
- Satellite imagery
- Bedshear (Modelled).

Bathymetric-derived layers

Bathymetric information for this study was derived from a bathymetric dataset of the entire North West Shelf (Figure 10). This dataset is based on an empirically calibrated Sentinel-2 satellite derived bathymetry study undertaken by LeBrec et al. (2021). The product has a grid cell resolution of 10 x 10 m, making it ideal for mapping large regions such as the study area. The dataset was cropped to cover the full extents of the study area. Preliminary data analysis was undertaken using a topographic gridding and sun-shading tool, highlighting terrain features. Derivatives are obtained by calculating, for each pixel in a primary data layer, a summary statistic from the values of all surrounding pixels within a defined neighbourhood (Olaya and Conrad 2009; Fisher et al., 2017; Wilson & Gallant 2000).

Several bathymetric-derived indices were used as environmental predictor layers (Table 11). Derivatives are obtained by calculating, for each pixel in a primary data layer, a summary statistic from the values of all surrounding pixels within a defined neighbourhood (Olaya & Conrad 2009; Fisher et al. 2017; Wilson & Gallant 2000).

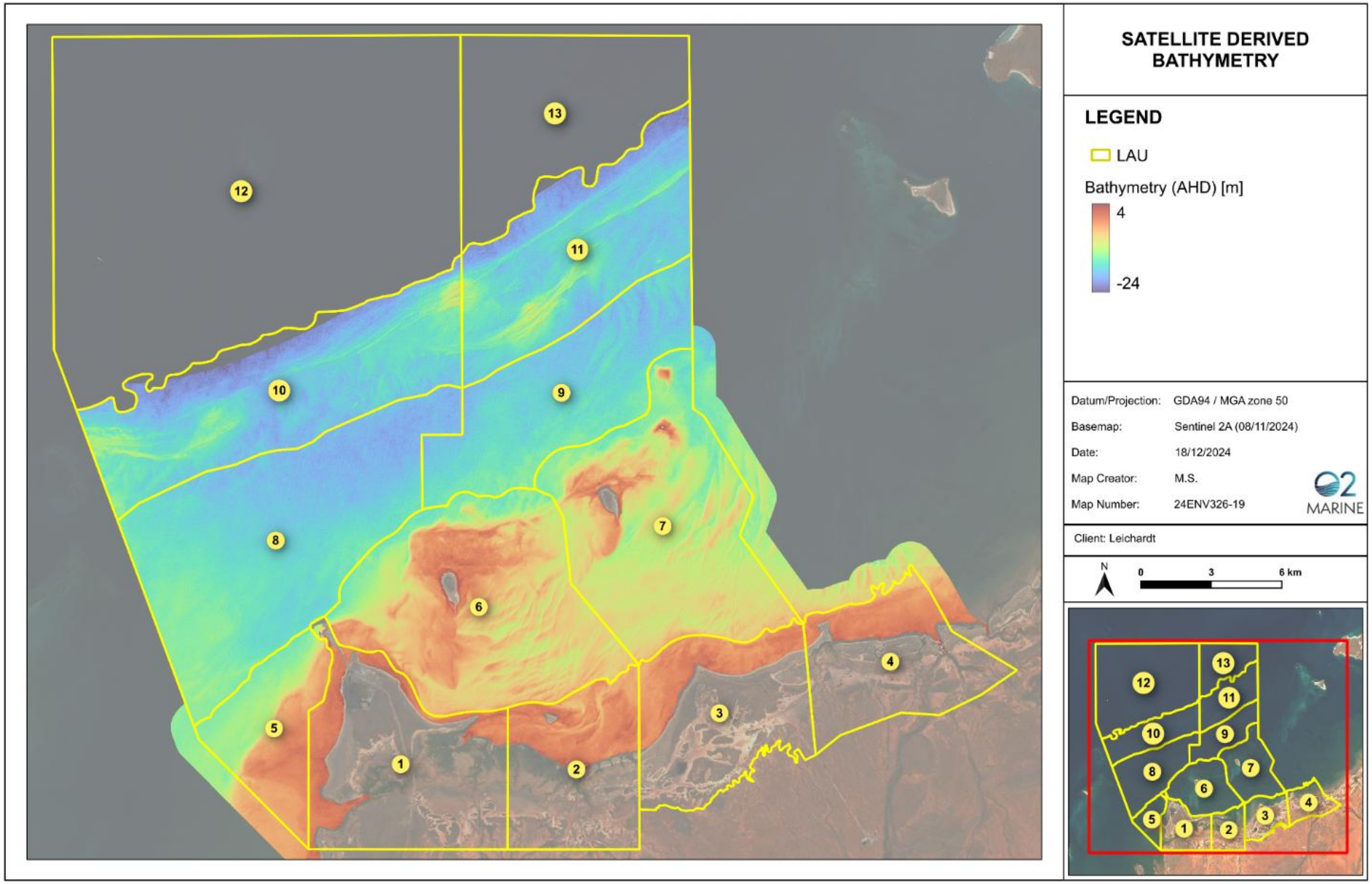


Figure 10: Satellite derived bathymetry data used in analysis. Dataset from LeBrec et al.(2021).

Table 11: Bathymetric-derived indices used as environmental predictor layers

Environmental Predictor Layer	Comment	Reference
Depth	Satellite Derived Bathymetry. Depth in mean sea level (MSL)	LeBrec et al. (2021)
Slope	Terrain slope (Horns method)	Florinsky (2016)
Aspect	Orientation of slope	Wilson & Gallant (2000)
Ruggedness/Roughness	Local topographic relief	Riley et al., (1999)
Relative Topographic Position Index	Elevation of a cell relative to its neighbouring cells (e.g. peak or pit)	Lindsay (2014), Lindsay et al (2015); Newman et al., (2018)
Curvedness	Root Mean Squared (RMS) of maximal and minimal curvatures, measures the magnitude of surface bending, regardless of shape	Koenderink and van Doorn, (1992); Florinsky (2017)
Openness (positive)	Angular value derived from the average horizon visible from each cell.	Yokoyama et al., (2002)

Satellite-derived layers

An initial multiband image was selected from a large number of Sentinel 2A scenes, during a period of relatively low ocean turbidity and minimal sea state (image date 28 August 2024). Individual satellite bands were compiled (Table 12) for use as environmental predictor layers. The effects of sun glint were removed using the methods described by Hedley et al. (2005).

The effect of water depth on benthic reflectance values was compensated for using a simple linear regression, following the methodology of Lyzenga (1978) and Green et al. (2000), using:

$X_i = -\ln(R_i - R_i^{deep})$, where:

- R_i is the pixel reflectance in band i, and

- R_i^{deep}, is the deep-water reflectance in that band.

A ratio of Bands 2 and 3 was used to maximise water penetration, computed from sample pixels over the same bottom type at different depths, and a reference deep-water sample.

Furthermore, satellite remote sensing instruments can obtain an optical measurement of water turbidity as it increases the backscattering of light (Pisanti et al. 2022). Multiple studies have found correlation between the in-situ measurements and the individual bands known to be most sensitive to water turbidity, namely Sentinel bands blue (B2), green (B3), red (B4). The index ratio showing the best correlation was:

$$\frac{(B3 \times B4)}{B2}$$

While a site-specific regression against field samples was not possible, this band ratio provides a good approximation of relative turbidity. These indices were calculated for all cloud-free images for the years 2022-2024, and the median value of all time periods was calculated for each raster cell in the study area to inform the machine learning process.

Table 12: Satellite bands and derived indices used as environmental predictor layers

Environmental Predictor Layer	Derivation	Comment	Reference
B02	Sentinel 2 band (490 nm)	Blue band	N/A
B03	Sentinel 2 band (560 nm)	Green band	N/A
B04	Sentinel 2 band (665 nm)	Red band	N/A
DII23	Sentinel 2	$\frac{\text{Blue}}{\text{Green}}$	Lyzenga (1978)
DII24	Depth Invariant Ratio	$\frac{\text{Blue}}{\text{Red}}$	Lyzenga (1978)
DII34	Sentinel 2	$\frac{\text{Green}}{\text{Red}}$	Lyzenga (1978)
Turbidity	Depth Invariant Ratio	$\frac{\text{Green} \times \text{Red}}{\text{Blue}}$	Pisanti et al. (2022)

Bed shear stress

Hydrodynamic conditions, such as exposure to waves and currents, have been shown to effect benthic community habitat distribution though their influence on sediment grainsize and mobility, and seabed disturbance (Post et al. 2006). Hydrodynamic influence on benthic habitats can be best quantified through bed shear stress, which is a measure of the frictional force exerted on the seabed by flowing water (Ashmore & Gardner 2008).

A hydrodynamic and spectral wave model of the Pilbara coastline, capable of quantitatively describing the combined interaction of waves and tidal energy with the seabed, has been made available for use in this study (O2 Metocean 2022a). Winds near the study area were reviewed to identify a 7-day window that may have led to potentially strong seabed shear stress over the two-month, dry season period available for modelling. The hydrodynamic and spectral wave model was run over the selected 7-day period and its results analysed to derive the following maps:

- Maximum significant wave height – nonsynchronous
- Maximum horizontal bed particle velocity at seabed – nonsynchronous
- Maximum bed shear stress – nonsynchronous
- 4-hourly snapshots of bed shear stress during the strongest wind event observed within the two-month, dry-season period available for modelling.

Values were extracted at the model 400-500 m horizontal native resolution and linearly interpolated onto a 50 m by 50 m grid for further analysis (Figure 11).

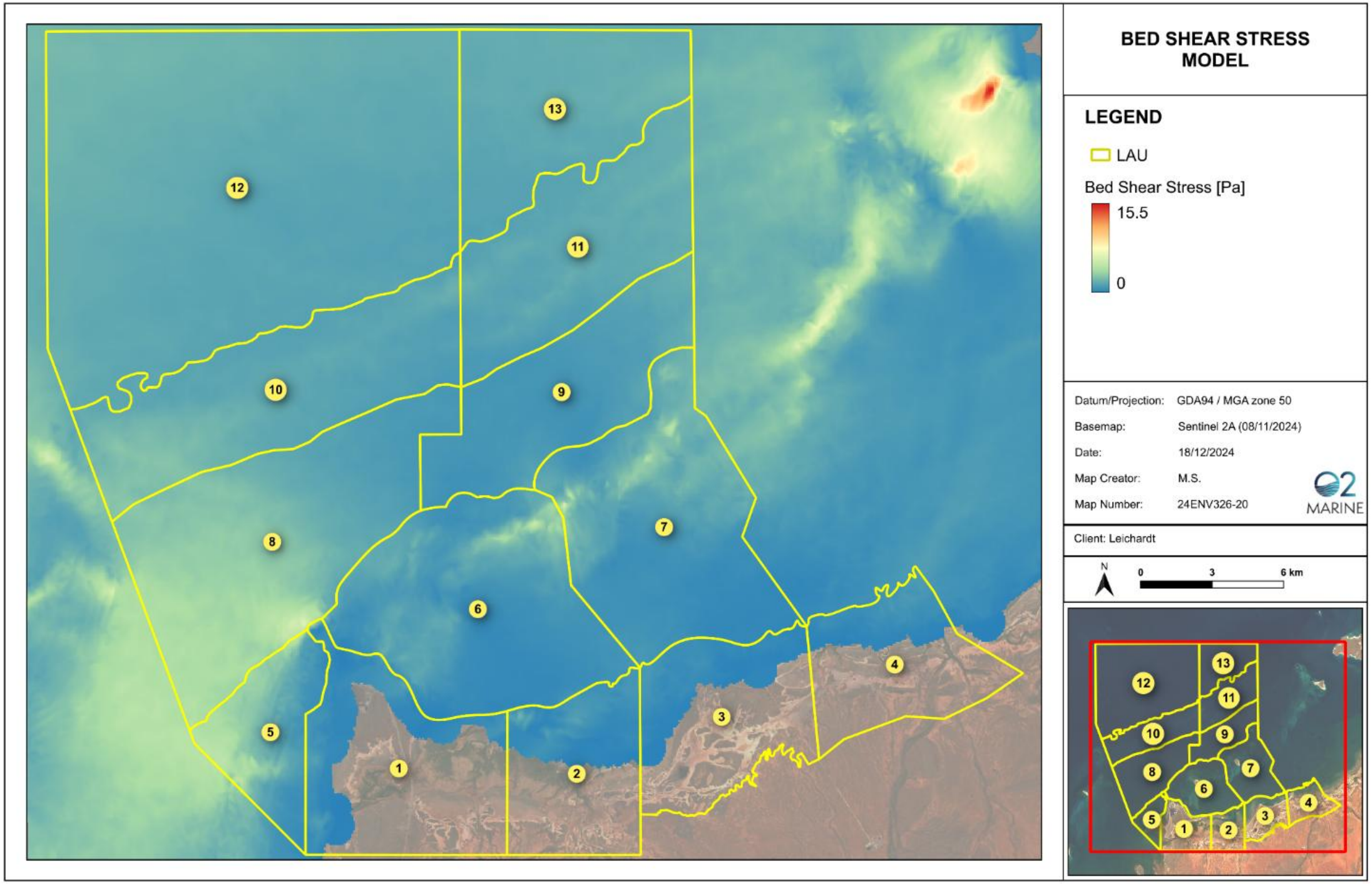


Figure 11: Bed shear stress model

5.2.3.2. Training Data for Machine Learning

Training data is an input dataset used to inform a machine learning model. The primary dataset used as training data was derived from the towed video captured during the October 2024 BCH survey. To supplement the primary dataset, multiple datasets from various sources were compiled to be used as training data for the predictive habitat model (Table 13). Habitats which were considered highly variable, featuring ephemeral vegetation, were solely represented in the most recent datasets. Older datasets were solely used for identification of habitats which can be considered permanent such as coral reefs and filter feeder habitats.

Table 13: Datasets used as 'training data' for predictive habitat mapping

Survey	Dates	Number of Sites	Survey Rational
Survey 1	23-25 July 2018	125 camera tows	Pre-feasibility drop camera investigative transects
Survey 2	2-7 March 2021	20 sidescan transects 18 camera tows	Offshore drop camera sites and sidescan sonar transects. Broad scale habitat assessment using sparse transects.
Disposal Ground / Mooring Area Assessment	19-22 March 2022	100 camera tows 3 spoil ground areas and 2 mooring sites (complete sidescan coverage)	Spoil ground and mooring area sidescan sonar and drop camera work. Small scale habitat assessment of targeted locations. Note* Disposal ground areas now superseded
Coral 1	14 – 18 July 2020	5 monitoring sites	First survey visiting previously established monitoring sites.
Coral 2	3 – 6 June 2021	5 monitoring sites	Second survey visiting previously established monitoring sites.
Seagrass 1	27 – 29 July 2020	7 monitoring sites	First survey during the dry season.
Seagrass 2	22 – 25 March 2021	7 monitoring sites	Second (repeat) survey during the wet season.
Disposal Ground Assessment	21st – 23 March 2023	Complete sidescan coverage. 15 camera tows.	Revised spoil ground location. Sidescan sonar and drop camera work. Small scale habitat assessment of targeted locations.
Survey 3	23rd- 26th October 2024	75 camera tows and 10 drone transects	Revised ground-truthing dataset across the extent of project envelope

5.2.3.3. Object-based Image Analysis

In order to integrate different scale ground truthing point observations, 50 m bedshear model data and 10 m Sentinel 2 data products, an object-based image analysis (OBIA) technique was employed. OBIA is a method of image analysis that groups pixels into meaningful objects (polygons) based on spectral, shape and neighbourhood properties (Hossain & Chen 2019). This allows integration of data of different scales, reduction of speckle noise, and faster processing times. These polygons, which vary in shape and size, can then be attributed with ground truthing and environmental predictor layer statistics, and subsequently subjected to classification techniques. Segmentation was undertaken on a high-resolution image of the study area using a mean-shift algorithm.

5.2.3.4. Supervised Classification and Mapping

The supervised classification method used utilises Random Forest; an ensemble learning method for supervised classification that operates by constructing a large number (600) of decision trees during training. RF classification uses a combination of 'tree' predictors, where each tree depends on the values of a random vector sampled independently for all trees in the 'forest'. Multiple trees are generated at each node, with classes being assigned through a majority vote (Breiman 2001). The random forest classification technique has been successfully applied in numerous benthic habitat mapping studies involving the use of bathymetry and its derivatives, and other related work (Brown et al., 2011; Hasan et al., 2012).

The known locations of identified benthic habitats are used to query the available background environmental layers. Once a signature set has been developed for each confirmed habitat location, the machine learning algorithm then interrogates the entire dataset and attempts to identify other 'suitable' background signature combinations which might also indicate the existence of the habitat.

Supervised data classification was undertaken in a Python-based software environment, using the range of tools available in (Lindsay 2014). The classification was then applied to the entire dataset, allowing the algorithm to assess the band spectral values for each pixel cell.

For validation and error assessment, a stratified randomly selected 'bootstrap' subset of data was withheld from the training dataset; 80% of original data pixels were used to train the model, and the remaining 20% 'out-of-bag' dataset was then used by the model to evaluate its own performance. This process was then repeated 20 times using different randomly selected subsets. A further field data split of randomly stratified data was used to derive a confusion matrix (assessment of misclassification) and precision, recall and F-score statistics (Stehman & Foody 2019).

The classification was undertaken on every image subset order to capture variation in habitat distribution. Classified images were then integrated for presentation using a fusion of classification (majority vote) procedure to identify the most important classes for each raster cell. This method resulted in the creation of a 'no majority' class, where no clear majority occurred for a particular cell. These areas may be considered mixed or transitional habitats (Table 14).

Table 14: Mapping classifications

BCH Classification		Description
Unvegetated Sediment		Bare, undifferentiated sediment with no apparent structure or minor ripple features/bioturbation. Sparse (< 3 %) to no biota.
Hard Coral Dominated Habitat	Coral and Macroalgae	Coral reef dominated substrate, with high structural complexity and live coral. High cover of red/brown/green algae of varied proportions.
Filter Feeders Dominated Habitat	Sparse Filter Feeders	Varied non-hard coral filter feeders on a sand / silt substrate. Substrate is unconsolidated or semi consolidated (pavement with veneer). Assemblages dominated by combinations of sponges, ascidians, bryozoans, soft corals or molluscs.

BCH Classification		Description
	Filter Feeders on Low Relief Reef	Varied non-hard coral filter feeders on a consolidated (low relief reef) or semi-consolidated (pavement with veneer) substrate. Assemblages dominated by combinations of sponges, ascidians, bryozoans and soft corals. Macroalgae is also prevalent.
	Pinna bicolor beds	Benthic habitats dominated by the high density of the razor clam, *Pinna bicolor* on a sand / silt substrate. Substrate is unconsolidated or semi consolidated (pavement with veneer). Assemblages
Macroalgae Dominated Habitat		Macroalgae-dominated vegetation on sediment or pavement substrate. Including sparse assemblages of seagrass or filter feeders.
Habitat with Seagrass Present	Low Density Seagrass	Low (3 – 10 %) to medium (10 – 25 %) density of seagrass on a mostly sand or silty substrate, including potential minor ripple features/bioturbation.
Mixed Habitat		Habitat with no dominant biota. May include varied compositions of filter feeders, macroalgae and seagrass.

5.3. Assessment of Seasonal Variation

In accordance with ESD Item 8 (see Section 1.1) Leichhardt were required to further investigate seasonal variation in the presence/absence of seagrass communities and their role in supporting MNES, and the spatial and temporal variation of BCH (including but not limited to seagrass communities). To achieve this aim, O2M carried out the following lines of investigation:

- BCH extent change assessment using remotely captured imagery
- In situ sampling of BCH
    - Inter-annual assessment of trends in coral health using video imagery captured in situ, and
    - Inter-seasonal assessment of trends in seagrass cover using video imagery captured in situ.

5.3.1. Remote Sensing Analysis

O2M conducted a preliminary desktop analysis using remote sensing techniques to assess seasonal variation in vegetation coverage within seagrass and macroalgal assemblages. This investigation utilised Sentinel-2 satellite imagery to analyse temporal changes in benthic habitat coverage, leveraging its high revisit frequency and moderate-resolution multispectral data to evaluate seabed dynamics.

The methodology involved accessing and analysing a large dataset of Sentinel-2 images using vegetation enhancement techniques to detect changes in marine vegetation extent. Specific monitoring polygons, primarily within LAUs 1 to 4 (Figure 12), were selected based on previous habitat distribution mapping conducted during the 2024 field surveys. The spatial extent of these polygons and their associated habitats are summarised in Table 15.

Two to three sites were selected from the shallow intertidal/subtidal regions of each LAU, with a primary focus on seagrass and macroalgae habitats for the preliminary study. Additionally, extra sites were selected for sampling from the satellite imagery to save potential future work, relating to mangrove, cyanobacterial mats, and extensive offshore filter feeder (*Pinna bicolor*) deposits.

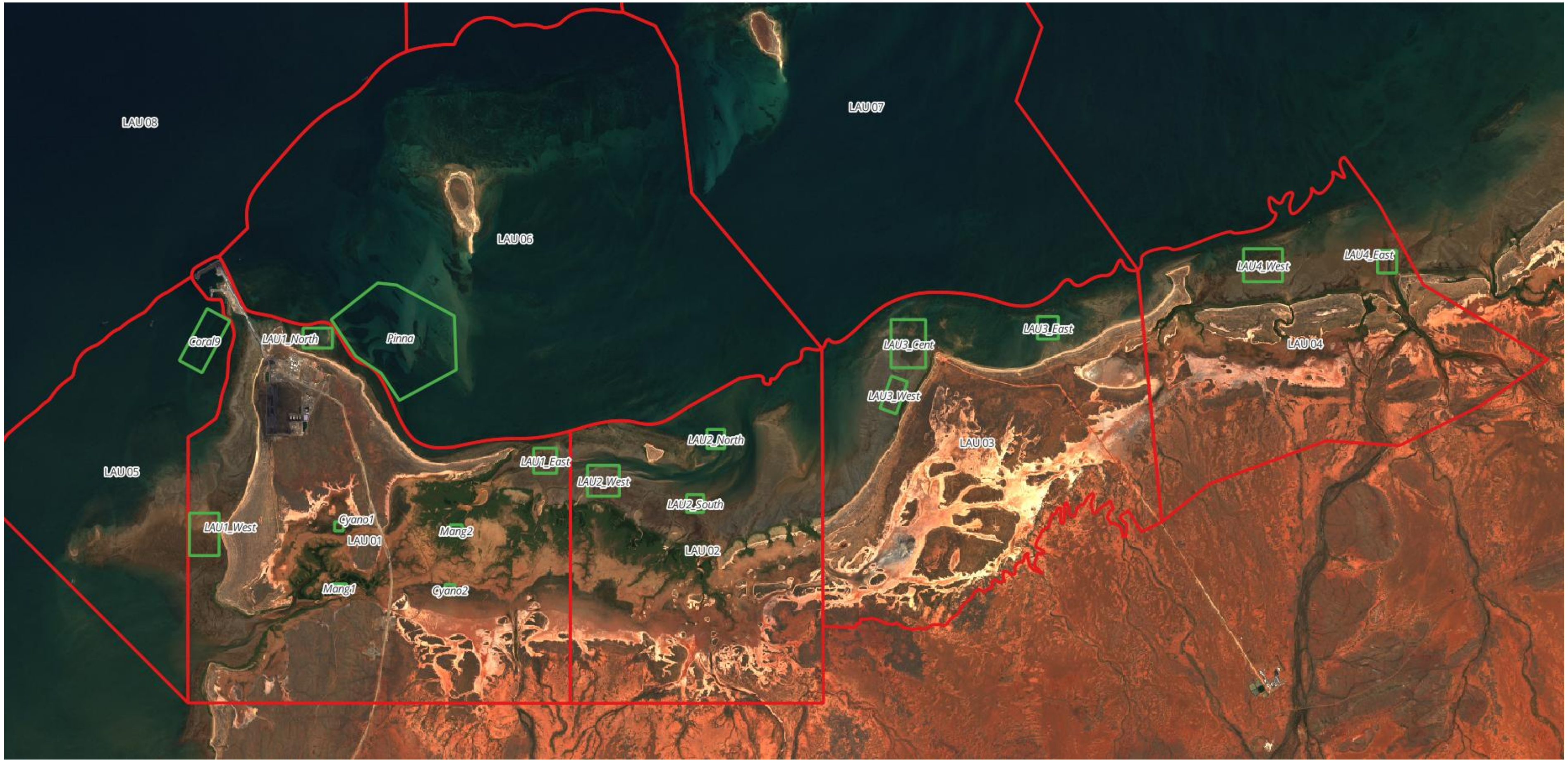


Figure 12: Selected sites for the preliminary study assessing seasonal changes in vegetation coverage.

Table 15: Description and spatial area (ha) for each selected site included in the preliminary study assessing seasonal variation.

Monitoring Area	LAU	Area (ha)	Habitat	Comment
LAU1_East	1	28.41	Ephemeral Seagrass & Macroalgae	
LAU1_West	1	61.78	Ephemeral Seagrass	
LAU1_North	1	28.66	Possible Ephemeral Seagrass & Macroalgae	
Cyano1	1	3.81	Cyanobacterial	Out of scope for preliminary study
Cyano2	1	4.90	Cyanobacterial	Out of scope for preliminary study
Mang2	1	6.50	Mangrove	Out of scope for preliminary study
Mang1	1	5.43	Mangrove	Out of scope for preliminary study
LAU2_South	2	14.85	Ephemeral Seagrass	
LAU2_North	2	16.71	Ephemeral Seagrass & Macroalgae	
LAU2_West	2	48.25	Ephemeral Seagrass	
LAU3_West	3	28.70	Possible Ephemeral Seagrass	
LAU3_East	3	23.24	Possible Ephemeral Seagrass & Macroalgae	
LAU3_Cent	3	81.75	Possible Ephemeral Seagrass & Macroalgae	
LAU4_East	4	21.25	Ephemeral Seagrass & Filter Feeders	

Monitoring Area	LAU	Area (ha)	Habitat	Comment
LAU4_West	4	63.16	Possible Ephemeral Seagrass & Macroalgae	
Coral9	5	74.88	Coral Monitoring Site 9 and 14	Out of scope for preliminary study
Pinna	6	449.19	Pinna Monitoring Zone	Out of scope for preliminary study

Image Selection and Pre-Processing

Sentinel-2 Level 2A atmospherically corrected images between 01/01/2019 and 10/12/2024 were inspected to identify suitable datasets for analysis. Selection criteria included:

- Cloud cover (automated filtering using Band 1), with zero tolerance for cloud in the study area
- Tide height (low tide images only)
- Sea state (low)
- Turbidity (high water clarity preferred).

Given the tropical arid climate of the study region, with distinct wet (January–March) and dry (July–September) seasons, images were categorised accordingly. A total of 55 time periods were analysed for each monitoring polygon. The selected spectral bands for processing are listed in Table 16.

Table 16: Spectral bands selected from each satellite image.

Band	Centre Wavelength (nm)	Name
B02	490	Blue
B03	560	Green
B04	665	Red
B05	705	Red Edge 1
B06	740	Red Edge 2
B08	842	Near Infra Red
B08A	865	Narrow band veg. indicator

Vegetation Indices

A suite of established vegetation indices was calculated to assess seasonal fluctuations in submerged vegetation coverage. These indices were applied across all selected time periods using automated Python processing scripts. The primary indices used are outlined in Table 17.

Once indices were calculated, derivative statistics including mean, standard deviation, median, and percentiles were computed for each monitoring region. Results were then plotted and analysed to assess seasonal trends and detect potential environmental changes or anthropogenic impacts on seagrass and macroalgae communities.

Table 17: List of vegetation indices used for the preliminary study

Index	Derivation	Comment
Basic Normalised Difference Vegetation Index (NDVI)	(B08-B04)/(B08+B04)	Often used for assessing the presence and health of vegetation, but must be applied cautiously for submerged vegetation due to water interference.
RedEdge NDVI	(B08-B05)/(B08+B05)	Modified NDVI, often used for assessing dense vegetation, and better for seagrass delineation.
Normalised Difference Aquatic Vegetation Index (NDAVI)	(B08-B02)/(B08+B02)	Less affected by water absorption because the blue band penetrates water more effectively. Works well in shallow, clear waters where seagrass, algae, or other aquatic plants are present
Wide Dynamic Range Vegetation Index (WAVI)	(1+0.5)x(B08-B02)/(B08+B02+0.5)	Reduces saturation in dense vegetation while enhancing sparse vegetation detection, useful in aquatic scenarios.
Submerged Seagrass Identification Index (SSII)	B05/(B04+0.00001)	Allows for better detection of seagrass by emphasizing subtle changes in vegetation reflectance while minimizing the influence of water and sediment.
Enhanced Vegetation Index. (EVI)	2.5 * ((B08 – B04) / B08 + 6 * B04 - 7.5 * B02 + 1)	Reduces atmospheric and water effects compared to NDVI, making it better for aquatic vegetation.
Normalised Difference Water Index (NDWI)	(B03-B08)/(B03+B08)	Primarily used to delineate water bodies but can also identify seagrass by contrasting vegetation against open water.

5.3.2. *In situ* sampling of BCH

5.3.2.1. Field Sampling Methods and Approach

In total, five (5) previously established coral monitoring sites were targeted during the October 2024 field survey (WorleyParsons 2009b, URS 2008, SKM 2008, GHD 2012), and seven (7) seagrass monitoring sites were selected from the Survey 1 drop camera survey, undertaken in July 2018. The selected monitoring sites were chosen to complement and verify data from historic surveys, and to assess the status of benthic communities in areas that are predicted to be impacted by the Proposal (e.g. intake and outfall sites and direct Proposal footprint). The location and description of these monitoring sites is provided in Table 18 and Figure 13.

Table 18: Targeted coral and seagrass monitoring surveys sites (after GHD 2013).

Site	Location	Description	Depth (CD)	Lat (°)/ Northing (m)	Long (°)/ Easting (m)
Coral 1	1.5 km offshore within 100 m of proposed jetty	Coral, sponge, and soft coral habitat on sand and limestone veneer pavement. Dominated by Dendrophylidae	5.3	-20.82578	116.22580
Coral 2	1.5 km SE of South West Regnard Island	Large coral bommies dominated by Poritidae and Mussidae	3.5	-20°827306	116°255944
Coral 3	E side of South West Regnard Island	Shallow fringing reef with high coral cover dominated by Faviidae	0.5	-20.814500	116.250444
Coral 4	E side of Sino Iron port facility	Coral and macroalgae habitat on limestone rock substratum dominated by Dendrophylidae, Faviidae, and Acroporidae	6.0	-20.821167	116.200111
Coral 5	0.4 km offshore within 100 m of proposed jetty	Coral and macroalgae habitat on limestone rock dominated by Dendrophylidae	2.5	-20.83771667	116.2226
Seagrass E14a	1 km W of South West Regnard Island	Sand with patchy sparse to moderate seagrass and occasional macro algae	6.0	-20.80745	116.23175
Seagrass E16a	1.5 km SW of South West Regnard Island	Sand with patchy sparse to moderate seagrass and occasional macro algae	4.5	-20.81908333	116.2322333
Seagrass E16b	1.5 km SW of South West Regnard Island	Sand overlying limestone platform with sparse to moderate seagrass, macroalgae and sessile invertebrates	4.5	-20.81953333	116.2322333
Seagrass ERASG2	4 km SE of South West Regnard Island	Sand, patchy sparse seagrass and sessile invertebrates	5.5	-20.8507	116.26153

Site	Location	Description	Depth (CD)	Lat (°)/ Northing (m)	Long (°)/ Easting (m)
Seagrass I13b	5 km E of 40 Mile Beach Campground	Sand with patchy sparse to moderate seagrass and occasional macro algae	6.5	-20.84193333	116.3080667
Seagrass W7a	2.5 km E of Cape Preston jetty	Sand with patchy sparse seagrass and occasional macro algae	5.1	-20.82868333	116.22105
Seagrass W8a	2 km E of Cape Preston jetty	Sand with sparse seagrass, filter feeders and macroalgae	6.0	-20.82581667	116.2175667

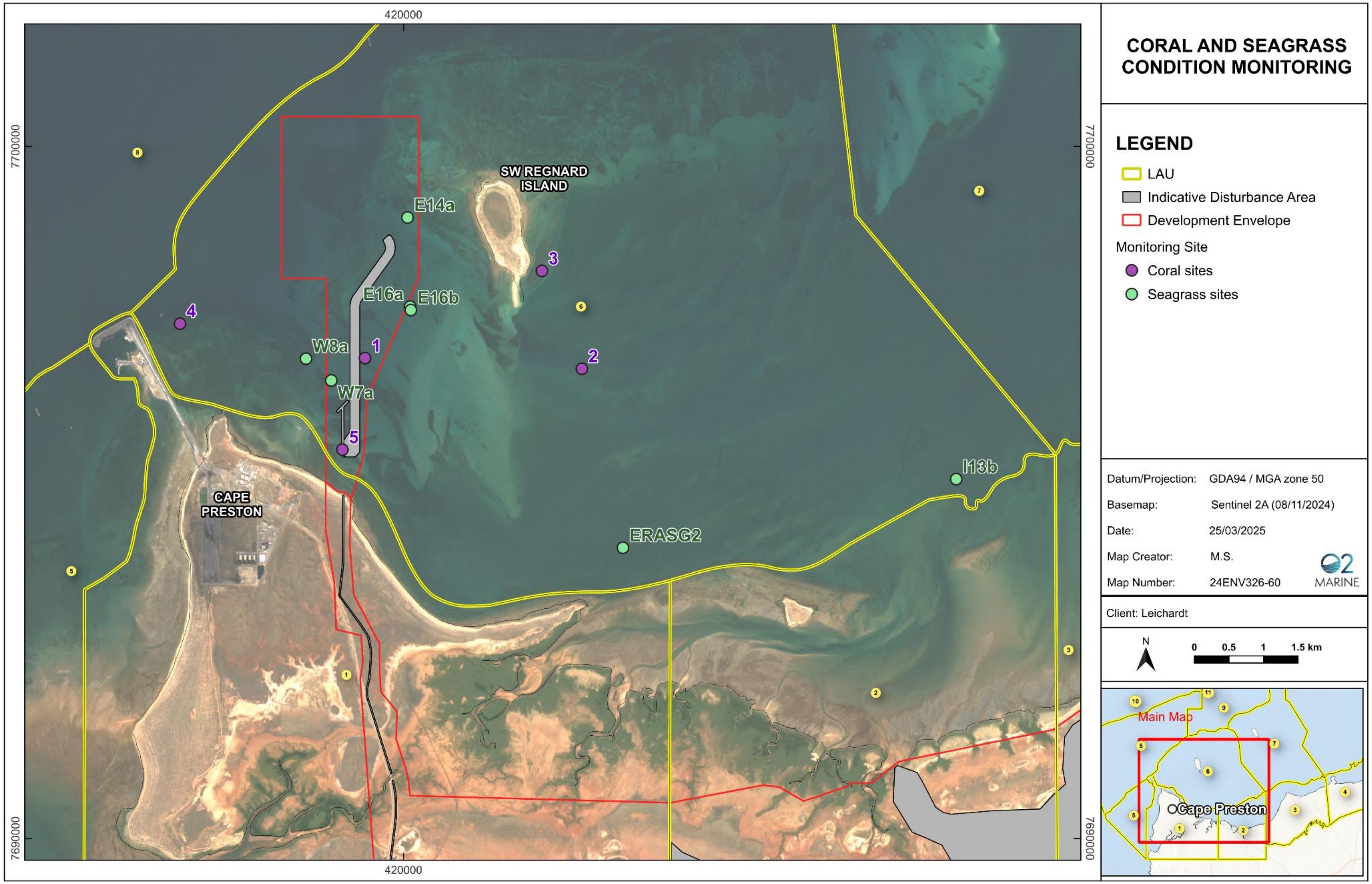


Figure 13: Subtidal BCH (coral and seagrass) monitoring locations

At each of the five (5) coral monitoring sites, a shot weight (8) and surface float were used to mark the central point of the monitoring site, with coordinates being recorded with a handheld GPS. From this central point, a fiberglass measuring tape was used to measure 5 x 20 m long transects across the coral communities. The five (5) transects were spaced radially at approximately evenly spaced intervals (72° apart) from the central shot weight.

Once the tape was positioned, a diver swam along each transect and obtained a series of clear photographs using an underwater digital still camera, at approximately 1 m above the seafloor. Using the measuring tape as reference, the diver was able to record a series of 1 x 1.3 m overlapping images along the transect length for later analysis. In this way, benthic cover images were collected at each monitoring location comprising a total seabed area of approximately 130 m^2 (i.e. 5 transects x 20 m long x 1.3 m wide).

The nominated survey method was designed to adequately describe the abundance (as percentage cover) and diversity of the benthic community at each site. This technique was designed to detect any composition and health differences between sites and can also be repeated to detect temporal changes. The method also provides a rapid assessment that does not rely on any infrastructure to remain in the marine environment.

Seagrass cover was measured at seven (7) sites, two (2) locations west (W7a, W8a) and three (3) locations east (E14a, E16a, E16b) of the proposed shipping channel, within or immediately outside the MDE, and two (2) nearshore locations further east in Regnard Bay at ~4 km (ERASG2) and 9 km (I13b) adjacent to the onshore Proposal area. Depths at monitoring locations were recorded during the 2018 drop camera survey as ranging from 4.5 m to 6 m. At each site, three (3) 50 m transects were established radiating from a central point. Transects were surveyed using SCUBA and photographs of 25 x 25 cm quadrats were taken every metre along the transect. Cover was visually estimated to ~1% within each photograph primarily for seagrass types, and also recorded ascidians, corals, macroalgae, and sponges. Seagrass was identified to genus-level (e.g. *Cymodocea* sp., *Halodule* sp., *Halophila* sp., *Syringodium* sp.) or species-level where possible (e.g. *Halophila decipiens*, *Halophila ovalis*, *Halophila spinulosa*). To capture seasonal changes in seagrass cover, transects were surveyed twice: once in the dry season (July 2020) and again in the following wet season (March 2021).

5.3.2.2. Data analysis – Coral Cover

Benthic cover images were analysed to provide an assessment of the benthic community at each of the five (5) coral monitoring sites. Multiple images (15) were chosen at random from each of the five (5) transects at each site (i.e. a total of 75 images per site; or a total area of ~97.5 m^2). Benthic cover at each site was assessed by plotting 25 points over each frame in a 'stratified-random' distribution for assessment with CoralNet. This image analysis method is appropriate for the objectives of this study and is consistent with those used in other Pilbara benthic habitat assessment projects in a similar manner to Stoddart and Stoddart (2005).

During the image analysis, benthic taxa were recorded within CoralNet and grouped based on the following classifications:

- All hard corals were identified and grouped at the family level;
- All other observed benthic taxa were broadly classified (i.e. Algae, Hard substrate, other invertebrates, Rubble, Soft substrate);

- An assessment of coral health was provided;
- The percentage cover of each benthic group for each of the five (5) transects was used to calculate a mean value for each site; and
- The above classifications are consistent with those used in similar studies to describe marine benthic communities in the Pilbara and therefore are amenable to comparisons with previous studies.

5.3.2.3. Data analysis - Seagrass Cover

For the seagrass monitoring sites, desktop *post-hoc* analysis of the still images from each transect was undertaken using a visual estimate of the composition of the various BCH types within each 25 x 25 cm quadrat. Every quadrat image was individually assessed through an image viewing application, with filter enhancements being made when the visual quality was limited. The images were captured in high resolution in order for a closer inspection of the smaller or unidentified features within the quadrat through the zoom function. The CATAMI system was utilised for classification, with the cover of each biotic feature being recorded to the highest taxonomic level practicable. The BCH biotic cover data for each image was compiled in Excel to provide the estimate percent cover summary statistics for each transect and site. The broad classifications utilised includes Macroalgae, Seagrass, Coral and Non-Coral. The mean percent cover data for each site (and StdE) and the level of change in mean cover between surveys were then presented in tabular and graphical form.

6. Results

6.1. Bathymetry of Regnard Bay

The 20 m bathymetric contour in the vicinity of Cape Preston and Regnard Bay lies well offshore, approximately 13 km seaward of the tip of Cape Preston, and is oriented in a northeast-southwest direction (Figure 14). Immediately landward of this contour, a series of parallel and arcuate ridges can be seen, rising from approximately 15 m water depth to less than 10 m, and separated by narrow channels (these correspond to the strandplain features described by LeBrec et al. (2022)).

Inshore of these features, a relatively low gradient and featureless seabed dominates up to the 10-12 m isobath. At this depth, the seabed shoals quickly to 5 m depth, forming a platform that delineates Cape Preston and South West Regnard Island. This platform is well developed around Cape Preston and South West Regnard Island (forming the basis for coral communities in that area) and a smaller platform is located around North East Regnard Island.

Shoreward of South West and North East Regnard Islands, the seabed remains relatively shallow and shows evidence of complex bedform features related to tidal scour and sediment movement. In the eastern portion of Regnard Bay, tidal sand banks and channels become more pronounced, whereas in the west of the bay between South West Regnard Island and Cape Preston, the bathymetry is characterised by tidal scour. The shoreline merging into the intertidal zone and tidal creeks is relatively broad and shallow.

The local bathymetry surrounding the bitterns outfall location is presented in Figure 15. The outfall and associated diffusers are located beyond the end of the jetty with the jetty orientated north to target a naturally scoured depth depression for the dredge area (Figure 15). The jetty crosses the lower intertidal and shallow subtidal zones to a depth of -4 m LAT. The position of the jetty infrastructure occurs in a location where the width of this shallow platform is reduced compared to broader sections along the coastline. The diffuser is located in depths ranging from -4 m to -6 m LAT.

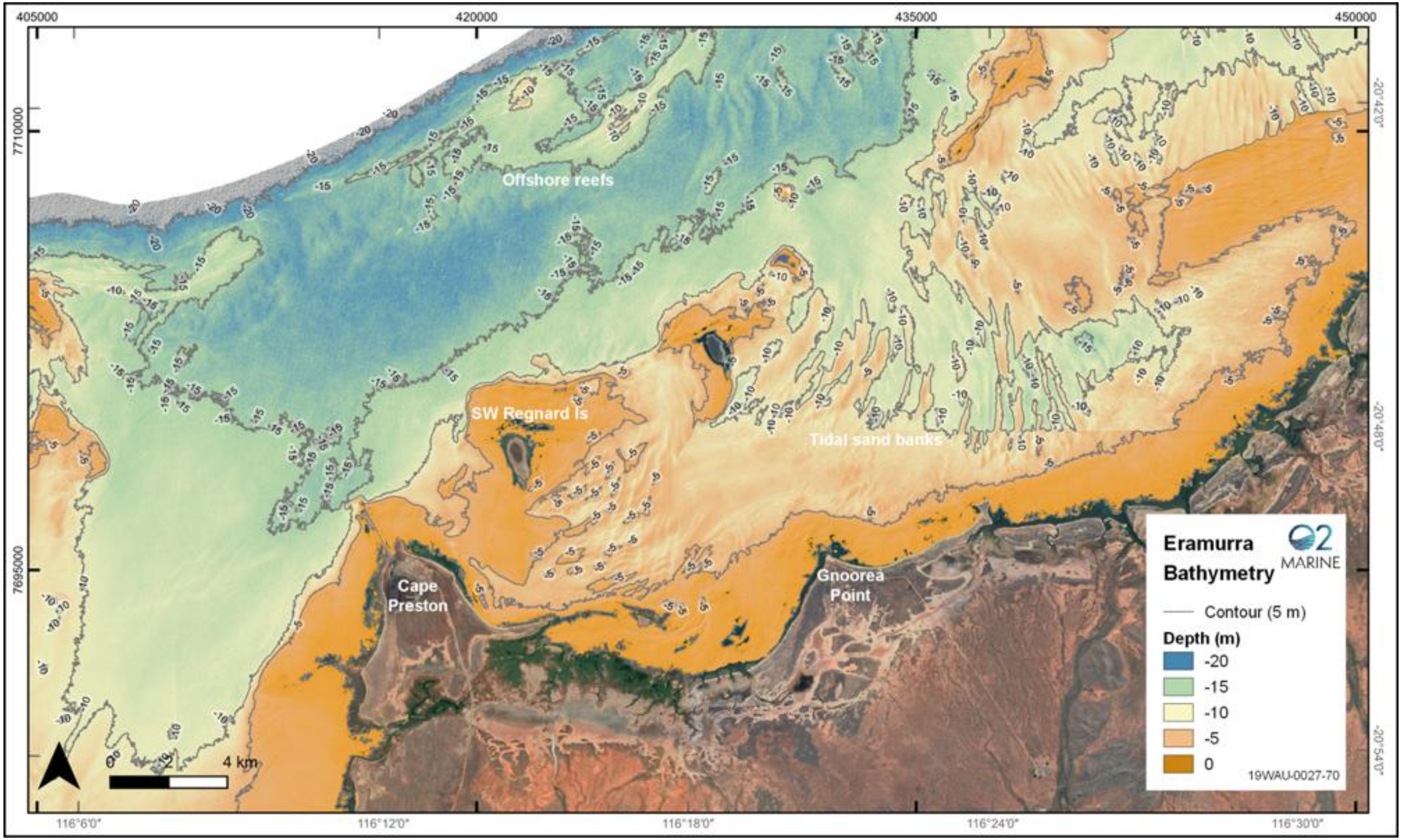


Figure 14: Bathymetry of Regnard Bay (based on satellite bathymetry, after LeBrec et al. 2021, relative to LAT). Image by Google (2022).

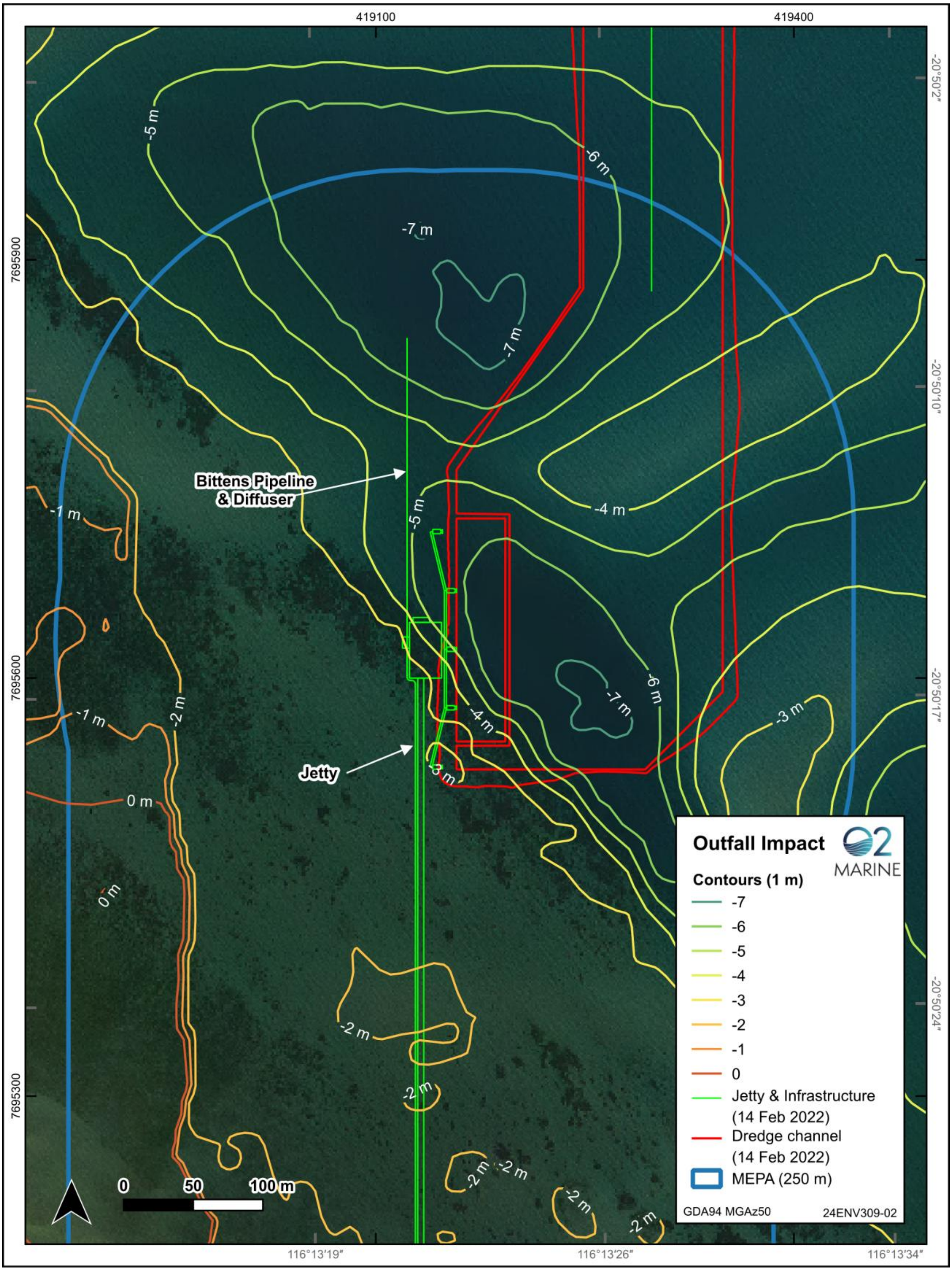


Figure 15: Local bathymetry around the bitterns outfall location.

6.2. Habitat Ground Truthing

A total of 14,827 ground truth points were extracted from the 2024 towed video imagery and classified with biological attributes (Table 19, Table 20, Figure 16 and Figure 17). Note that due to the scale of the maps relative to the length of the transects, Figure 16 and Figure 17 do not reveal habitat and substrate changes across transects. The purpose of these figures is to provide an overview of the dataset, and classifications observed at each transect on these maps should not be considered completely representative of the broader BCH type at each location.

The dominant substrate within the Proposal MDE (Figure 16 and Figure 17) was bare substrate (predominantly unconsolidated coarse sand with shell fragments) accounting for 79.7% of all classified points (11,812 points; Figure 16; Table 19). Rocky flat and low relief reefs with a sediment veneer were observed in 15.9% of the points, mostly on the western side of Cape Preston, and near Gnoorea and 40 Mile beach. Notably, Hard substrates, (low relief and moderate relief) constituted 4.3% of classified points, typically distributed close to mainland and north of South West Regnard Island, while mud/silt substrates were minimally represented (0.1%, 16 points). These substrates provided the foundation for the observed benthic habitat classifications.

Bare substrate, predominantly unconsolidated coarse sand, was the dominant habitat class, representing 32.4% of all classified points (4,814 points; Table 20). This habitat type was prevalent in offshore regions and sandy areas within LAUs 1 to 4.

Seagrasses were observed at 18.0% of the total classified points (2,659 points). Ephemeral seagrasses dominated (14.2%, 2,103 points), while perennial and mixed seagrasses contributed 3.4% and 0.4%, respectively. Dense cover (>75%) was recorded for 52% of seagrass observations, followed by high cover (25–75%) at 28% (

Table 21). The densest seagrass meadows were concentrated in shallow, protected zones near the mainland, particularly within LAU 6. Sparse seagrass were observed in mixed assemblages with macroalgae.

Macroalgae accounted for 29.8% of all classified points (4,429 points), with mixed macroalgae dominating. Dense cover (>75%) was observed in 36.3% of macroalgae points, followed by moderate cover (10–25%) at 28.9%, and high cover (25–75%) at 24.6% (

Table 21). Macroalgal assemblages occurred in areas with moderate to high substrate complexity, with *Sargassum* sp. being the dominant taxon. Dense patches were observed along the coastal and nearshore reef platforms, particularly in LAUs 5 and 6.

Hard corals represented 6.1% of the total classified points (902 points). Of these, 52% were classified as dense (>75%) cover, and 48% as high (25–75%) cover. Hard corals were primarily associated with reef structures in LAUs 5 and 6, including fringing reefs and isolated limestone outcrops. Dominant genera included Acropora and Porites, which were often observed in association with macroalgae.

Filter feeders accounted for 13.8% of the total classified points (2,046 points). Dense cover (>75%) was observed in 56.4% of these points, followed by high cover (25–75%) at 14.2%. Notable habitats included *Pinna bicolor* beds, concentrated within LAU 6, forming east-west bands adjacent to Cape Preston and extending toward Regnard Island. These assemblages were associated with hard substrates and sand veneers, contributing to habitat heterogeneity.

LAUs 1 to 4 are characterised by nearshore subtidal habitats dominated by algae-covered limestone pavement and sandy substrates. Sparse macroalgae and bare sediment were the primary habitats, with limited seagrasses recorded, likely due to substrate conditions or hydrodynamics. Ground-truthing highlighted the presence of low-density filter feeders, such as sponges and ascidians, on rubble and cobble substrates in certain areas, contributing to habitat heterogeneity. Typically, these LAUs exhibited comparatively much lower habitat complexity compared to other units.

Ground-truthing at LAU 5 revealed a mix of bare sediment, macroalgal-dominated substrates, and scattered coral habitats. Dense macroalgal assemblages were observed in shallow reef zones with moderate to high substrate complexity, while coral habitats were sparsely distributed and associated with reef edges.

Ground-truthing at LAU 6 indicated the presence of seagrasses concentrated in shallow, sheltered regions. Seagrass was commonly found in mixed assemblages with macroalgae, enhancing habitat diversity. Sparse coral habitats were observed along the edges of reef platforms, and *Pinna bicolor* beds were identified as a dominant component of the filter feeder community. These beds extended across sandy substrates with hard patches, forming east-west bands adjacent to Cape Preston and Regnard Island

Table 19: Statistics relating to substrate classifications assigned to the 2024 towed video and drone footage data

Substrate	Towed Video		Drone Footages	
	Number of points classified	Percentage of all points classified (%)	Number of points classified	Percentage of all points classified (%)
Mud / Silt (<64 um) [M/S]	16	0.1		0.0
Coarse Sand (with shell fragments) [S.C]	11812	79.7	221	36.2
Flat [V.F]	1277	8.6	161	26.4
Low (<1 m) [V.L]	1083	7.3	89	14.6
Rock - Low (<1 m) [R.L]	504	3.4	139	22.8
Rock - Moderate (1-3 m) [R.M]	135	0.9		0.0
TOTAL	14827	100	610	100

Table 20: Statistics relating to biotic classifications assigned to the 2024 towed video data

Classification		Towed Video		Drone Footages	
		Number of points classified	Percentage of all points classified (%)	Number of points classified	Percentage of all points classified (%)
Bare	Bare Substrate	4814	32.4	221	36.2
Filter Feeders	Black and Octocorals	3	0.0		0.0
	Mixed	1022	6.9	26	4.3
	Other	1	0.0		0.0
	Pinna bicolor bed	1020	6.9		0.0
Hard Coral	Hard coral	902	6.1		0.0
Macroalgae	Filamentous	150	1.0		0.0
	Mixed	4279	28.8	363	59.5
Seagrass	Ephemeral	2103	14.2		0.0
	Mixed	53	0.4		0.0
	Perennial	503	3.4		0.0
TOTAL		14827	100	610	100

Table 21: Summary of cover type classification points (highest to lowest) assigned to the 2024 towed video and drone footage data.

Classification	Cover type	Number of points classified	Percentage of classified points (%)
Filter Feeders (2,046 classified points)	Dense (>75%)	1154	56.4
	High (25%-75%)	290	14.2
	Bare (<1%)	263	12.9
	Moderate (10%-25%)	209	10.2
	Sparse/Low (1%-10%)	107	5.2
Hard Corals (902 classified points)	Dense (>75%)	471	52.2
	High (25%-75%)	431	47.8
Macroalgae (4429 classified points)	Dense (>75%)	1609	36.3
	Moderate (10%-25%)	1282	28.9
	High (25%-75%)	1090	24.6
	Sparse/Low (1%-10%)	280	6.3
	Bare (<1%)	168	3.8
Seagrass (2,659 classified points)	Dense (>75%)	1373	51.6
	High (25%-75%)	763	28.7
	Moderate (10%-25%)	340	12.8
	Bare (<1%)	171	6.4
	Sparse/Low (1%-10%)	12	0.5

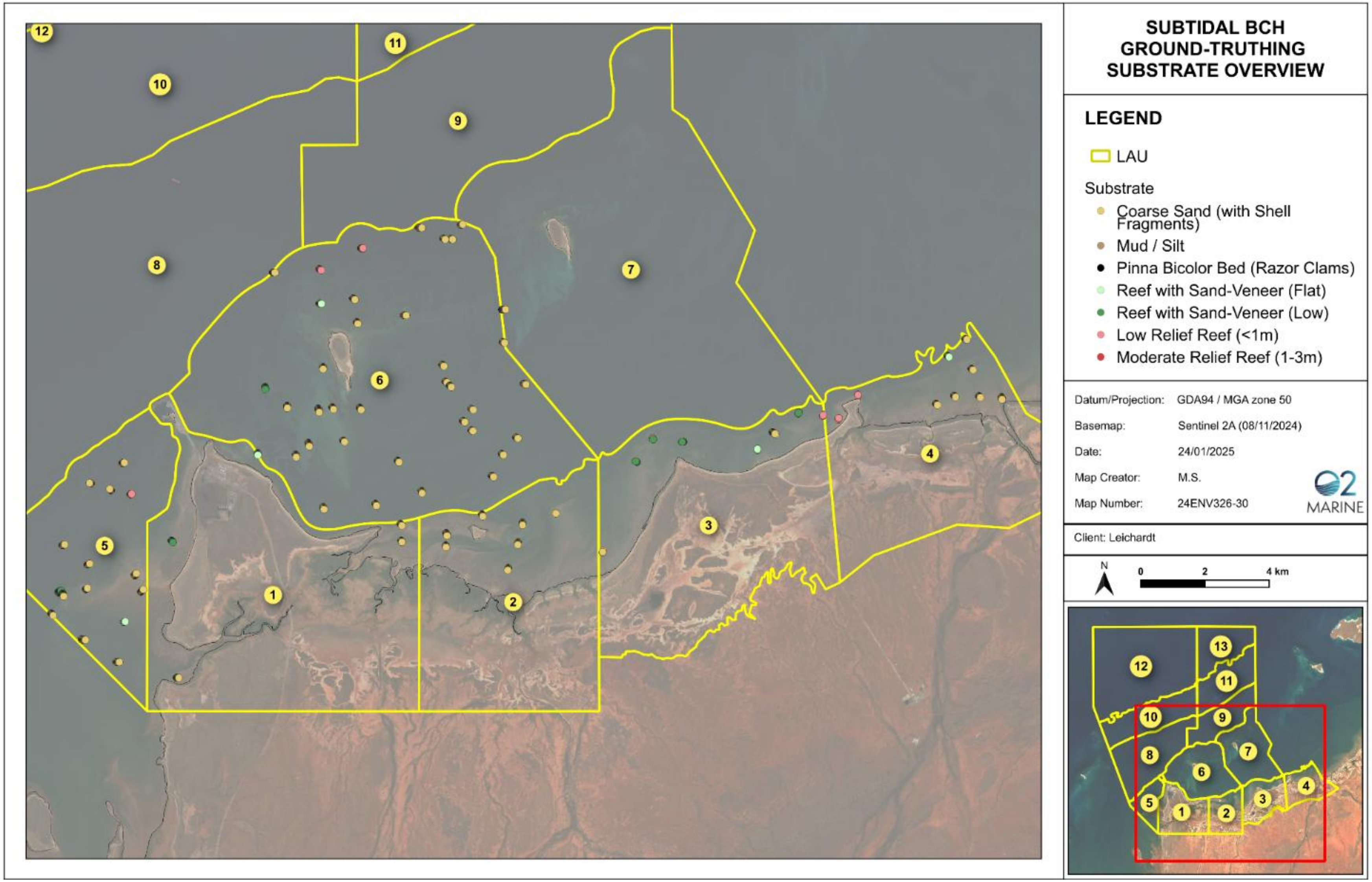


Figure Note: Due to mapping scale, and comparatively short towed video transect lengths, it is not possible to display all classified points along each transect.

Figure 16: Overview of towed video and assigned substrate classifications.

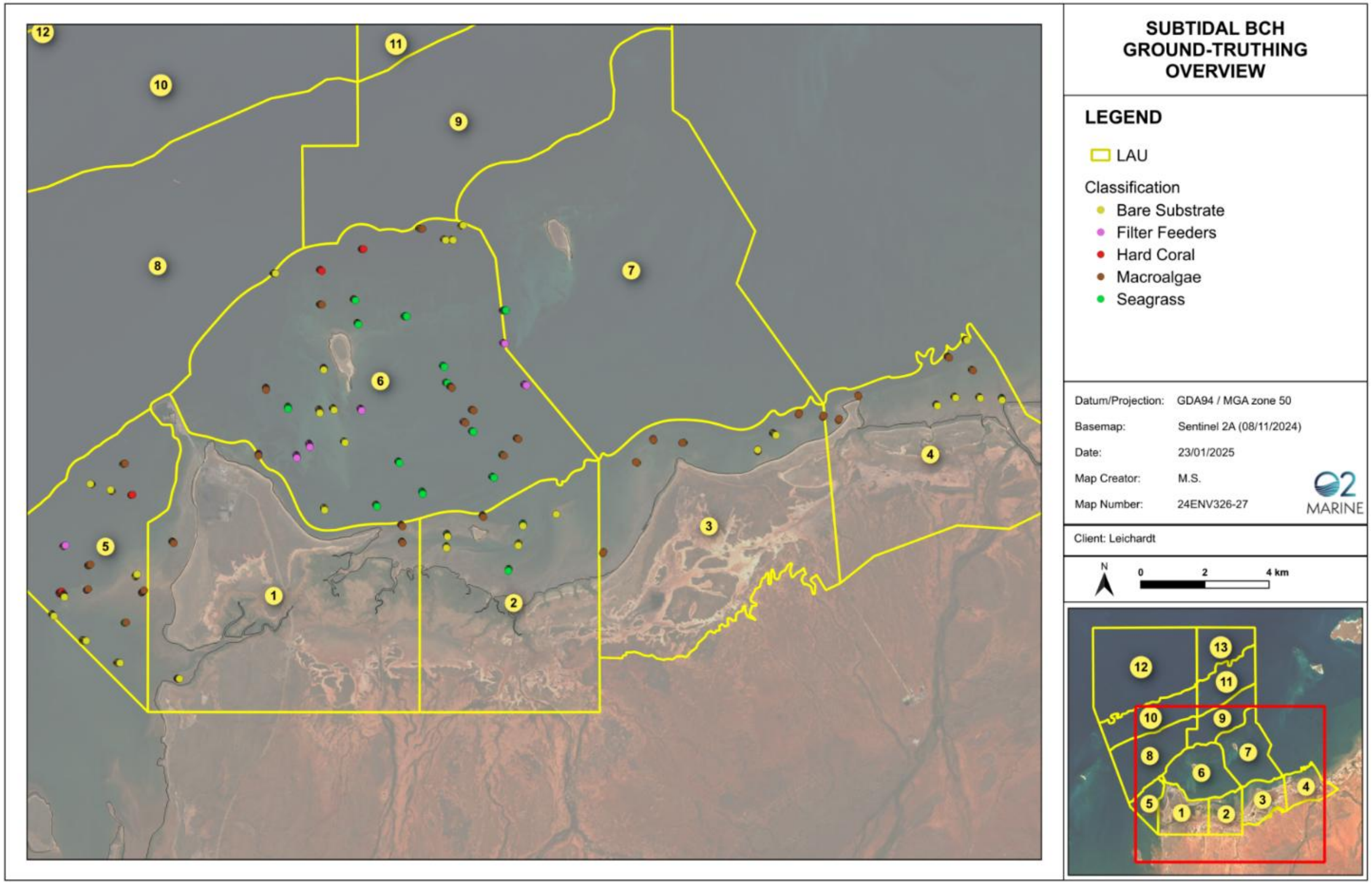


Figure Note: Due to mapping scale, and comparatively short towed video transect lengths, it is not possible to display all classified points along each transect.

Figure 17: Overview of towed video transects and assigned habitat classifications.

Table 22: Habitat classifications assigned to 2024 towed video

Class	Description	Example Images	
Bare Substrate	Areas of bare substrate, devoid of biota. Predominantly unconsolidated (sand / mud), but also includes instances of consolidated substrates.		
Filter Feeders	Filter feeders (sponges, sea whips, gorgonians, sea fans, feather stars, ascidians) with sparse/low (1 – 10%) to dense (> 75%) coverage, generally growing over sand, rubble, reef with sand veneer, or exposed reef.		

Class	Description	Example Images	
Macroalgae	Area of macroalgae (brown algae and other), with sparse/low (1 – 10%) to dense (> 75%) coverage. Growing on both unconsolidated (sand / mud) and consolidated (boulders, gravel, rock) substrates.		
Seagrass	Seagrass of elliptical (*Halophila sp.*) or strap-like form (*Halodule sp., Thalassia sp., Syringodium sp., Cymodocea sp.*) with sparse/low (1-10%) to dense (>75%) coverage, growing on sandy substrate.		
Hard Corals	Hard and soft corals of varied forms growing on rocky reef with flat to moderate (1 – 3 m) relief, or rubble., with high (25 – 75%) to dense (> 75%) coverage		

Class	Description	Example Images	
Mixed Assemblage – Macroalgae Dominated Habitat	Area of mixed assemblage dominated by seagrass (*Halophila sp., Halodule sp., Thalassia sp., Syringodium sp., or Cymodocea sp.*) generally growing over sand.		
Mixed Assemblage – Seagrass Dominated Habitat	Area of mixed assemblage dominated by macroalgae (brown and other macroalgae), filter feeders (sponges, hydroids, and sea whips) and/or hard and soft coral, generally growing over rocky reef with flat to high (> 3 m) relief, or rocky rubble.		

6.2.1. Key Habitat Classifications

A random forest classification procedure undertaken on the composite stack and training dataset provided a coherent dominant class habitat map, which comprised six final classes mapped across a total area of 935.2 km^2 (Table 23, Table 24 and Figure 18). The updated mapping and classification techniques have refined the boundaries of seagrass and macroalgae habitats, leading to improved habitat delineation. Higher-resolution mapping has identified additional filter feeder and hard coral habitats that were previously unmapped. The enhanced coverage of naturally occurring mixed subtidal habitat (transition habitats) and the identification of additional coral assemblages highlight the value of the updated methodologies.

6.2.1.1. Unvegetated Soft Sediment

The survey determined that the majority (69.4%) of benthic habitat within the Proposal MDE was characterised by unvegetated soft sediment (Figure 18 & Figure 19). This substrate dominated areas with little to no biota, particularly in zones beyond the 5 m (MSL) contour. Unvegetated soft sediment was prominent in LAUs 8, 9, 10, 11, 12, and 13, where it represents more than 50% of the mapped area in each unit. In LAUs 1, 2, 3, 4, 5, and 6, it accounts for 27% to 61% of the mapped area (Figure 19).

6.2.1.2. Habitat with Seagrass Present

Vegetated sediments and habitats (Figure 20, Figure 21) were widespread within the Proposal area, with high-density seagrass areas, accounting for 51.6% of classified seagrass points, restricted to shallow, sheltered zones below 2 m (MSL). Low densities seagrass were the most common benthic primary producer type over the unconsolidated sediments in zones above 2 m (MSL). The largest area of seagrass was found in LAU 6, comprising 1,446 ha (18%). LAU 7 contains 399 ha (5%), followed by LAU 2, with 225 ha (14%). Smaller patches of seagrass are visible in LAUs 3 (70 ha, 5%), 4 (66 ha, 7%), and 1 (110 ha, 8%), providing additional connectivity between vegetated habitats across the Proposal area.

6.2.1.3. Macroalgae Dominated Habitat

Macroalgae-dominated habitats appear to be associated with outcropping low-relief reef and were widely distributed across the Proposal area. Prominent distributions were found in LAUs 1 and 4, with the largest areas of macroalgae comprising 521 ha (38%) and 316 ha (32%), respectively. Smaller but notable patches were recorded in LAUs 2, 3, 5, 6, and 7, contributing to the overall habitat diversity. These habitats were characterized by coarse branching macroalgae, such as *Sargassum* sp., and were typically located closer to shorelines, particularly in LAUs 1, 4, and 5.

6.2.1.4. Hard Coral Habitat

Hard coral habitats (Figure 22) were primarily observed near limestone reef features and areas with higher topographic complexity, such as emergent shoals or isolated reef patches, as indicated by bathymetry and habitat mapping data. These habitats were generally found in depths ranging from -5 m to -15 m, as shown in the bathymetry map. The highest densities of coral appear to be associated with reef structures around SW Regnard Island in LAU 6 (1,750 ha, 22%) and LAU 7 (1,573 ha, 20%), followed by significant areas in LAU 5 (301 ha, 11%). Smaller patches were also observed in LAUs 1, 2, 3, and 4.

6.2.1.5. Filter Feeder Dominated Habitat

Filter feeder habitats (Figure 23), ranging from sparse to dense coverage, include bivalves, sponges, ascidians, bryozoans, and soft corals. These communities were distributed across various depths and are often associated with sediments and reef structures partially covered by sand veneers. Filter feeder-dominated habitats were most extensive in LAUs 7 (2,960 ha, 38%), LAU 8 (3,463 ha, 36%), and LAU 10 (3,742 ha, 49%), with substantial areas also present in LAU 6 (2,097 ha, 26%) and LAU 5 (299 ha, 11%). Smaller areas of filter feeder habitats occur in LAUs 1, 2, 3, and 4.

6.2.1.6. Mixed Subtidal Habitat

These are generally a 'no majority' class, where no clear majority occurred for a particular data collection point. These areas are often transitional habitats, and generally included a combination of macroalgae (brown and other macroalgae), filter feeders (sponges, hydroids, and sea whips) and/or hard and soft corals.

Table 23: Total area of each BCH classification across the Proposal MDE

BCH Classification	Area (ha)	Area (km^2)	Percentage of mapped area (%)
Unvegetated Soft Sediment	56104.6	561.0	69.4
Hard Coral Habitat	3806.5	38.1	4.7
Filter Feeder Dominated Habitat	15484.7	154.8	19.2
Macroalgae Dominated Habitat	2066.5	20.7	2.6
Habitat with Seagrass Present	2441.3	24.4	3.0
Mix Subtidal Habitat	923.5	9.2	1.1
Total	93523	935.2	100.0

Table 24: Subtidal benthic communities and habitat types, including the areas mapped (in ha) that occur within each LAU.

BCH	LAU1	LAU2	LAU3	LAU4	LAU5	LAU6	LAU7	LAU8	LAU9	LAU10	LAU11	LAU12	LAU13
Unvegetated Soft Sediment	671 ha (49%)	960 ha (61%)	811 ha (59%)	492 ha (50%)	1,473 ha (55%)	2,215 ha (27%)	2,493 ha (32%)	6,161 ha (64%)	4,113 ha (77%)	3,869 ha (51%)	4,461 ha (73%)	22,495 ha (100%)	5,890 ha (100%)
Hard Coral Habitat	8 ha (0.6%)	18 ha (1%)	91 ha (7%)	65 ha (7%)	301 ha (11%)	1,750 ha (22%)	1,573 ha (20%)	-	-	-	-	-	-
Filter Feeder Dominated Habitat	15 ha (1%)	21 ha (1%)	10 ha (0.8%)	16 ha (2%)	299 ha (11%)	2,097 ha (26%)	2,960 ha (38%)	3,463 ha (36%)	1,240 ha (23%)	3,742 ha (49%)	1,622 ha (27%)	-	-
Macroalgae Dominated Habitat	521 ha (38%)	277 ha (18%)	348 ha (25%)	316 ha (32%)	363 ha (14%)	223 ha (3%)	18 ha (0.2%)					-	-
Habitat with Seagrass Present	110 ha (8%)	225 ha (14%)	70 ha (5%)	66 ha (7%)	125 ha (5%)	1,446 ha (18%)	399 ha (5%)	-	-	-	-	-	-
Mix Subtidal Habitat	38 ha (3%)	61 ha (4%)	41 ha (3%)	35 ha (4%)	101 ha (4%)	332 ha (4%)	315 ha (4%)		-	-	-	-	-
Total (ha)	1362.95	1564.09	1370.93	989.70	2661.90	8062.89	7758.21	9623.79	5353.28	7610.41	6083.35	22495.42	5890.25

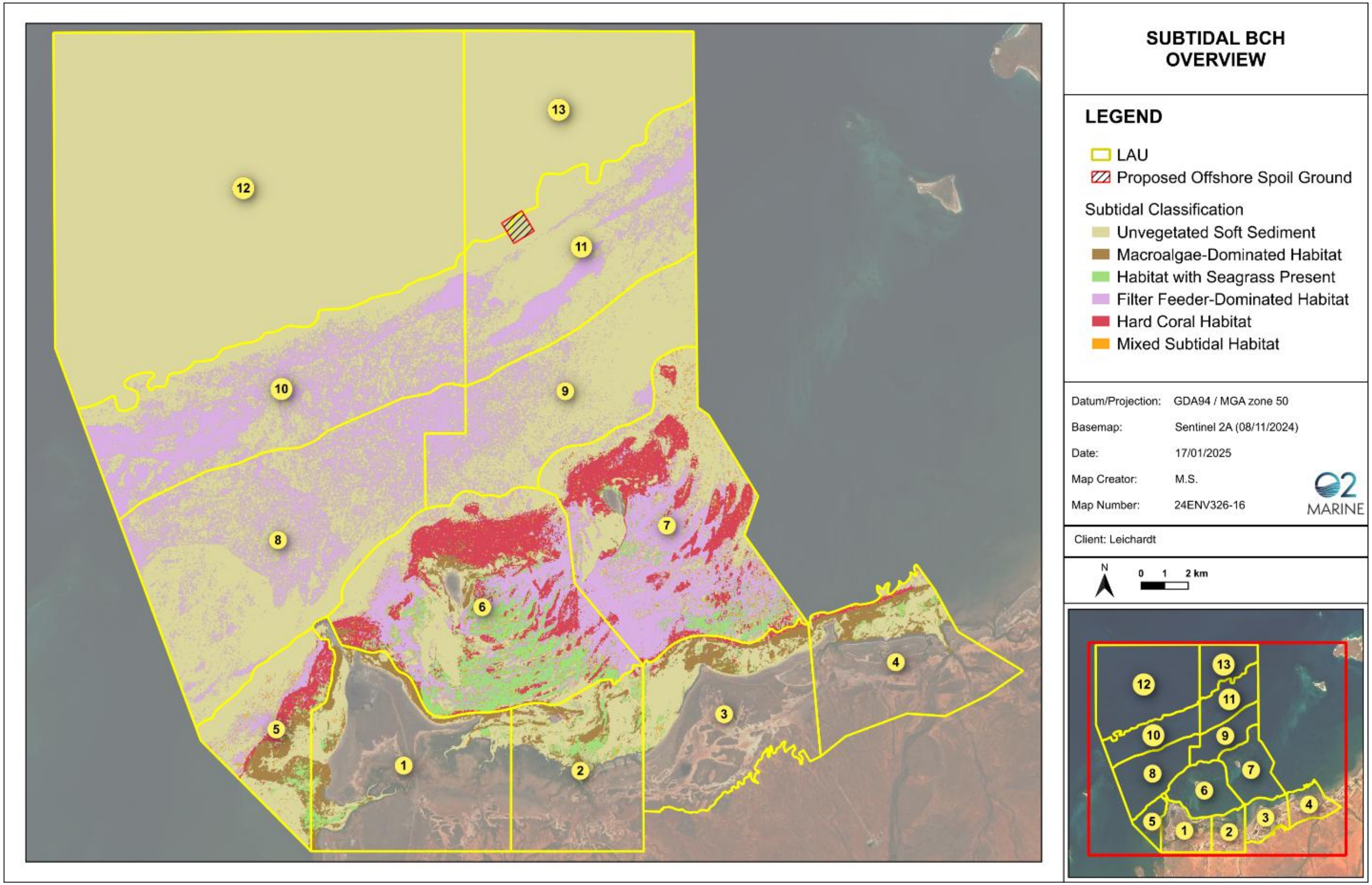


Figure 18: Broad Scale Benthic Habitat Classifications for the Subtidal LAUs

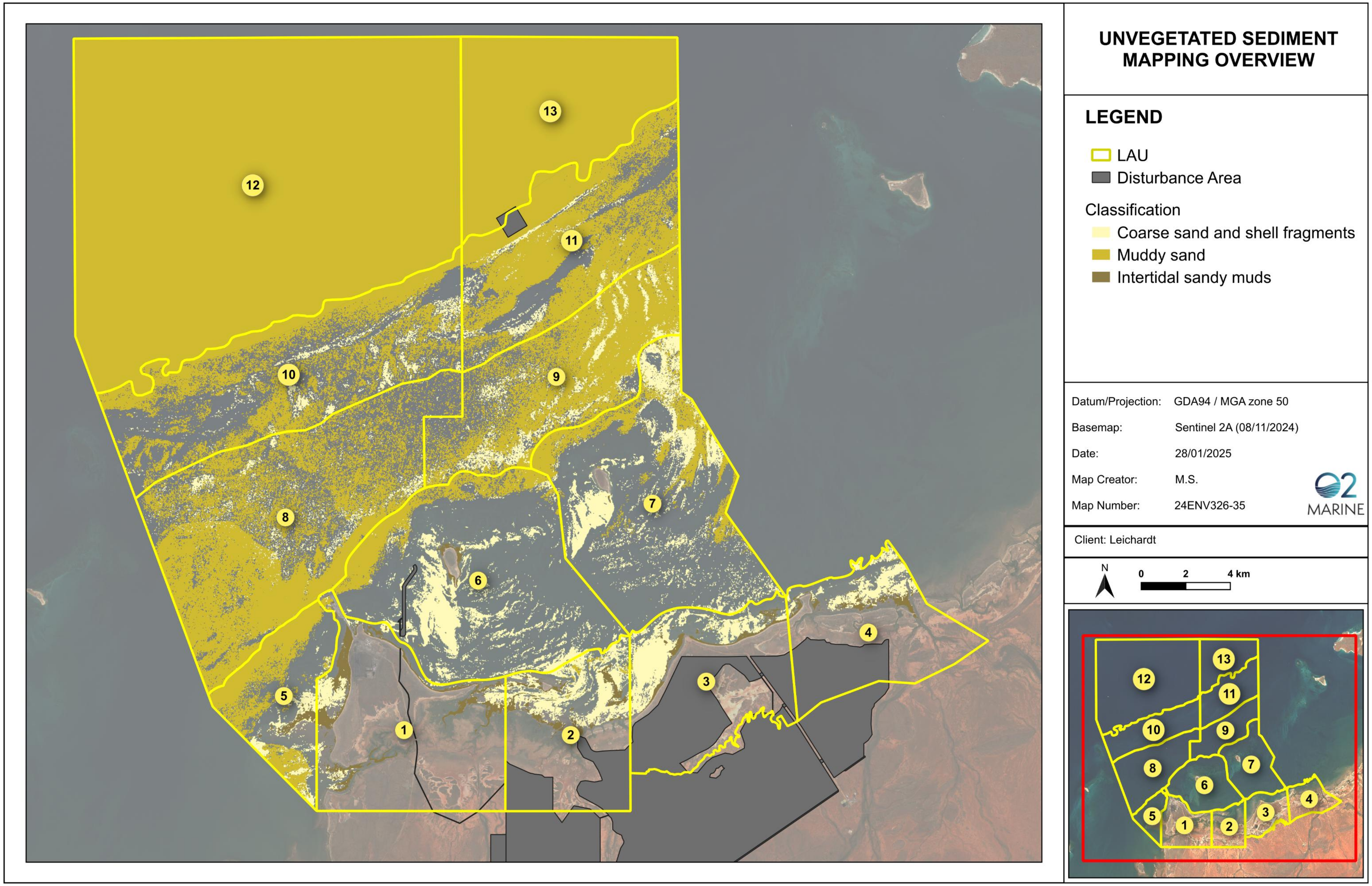


Figure 19: Unvegetated Sediment Mapping Overview

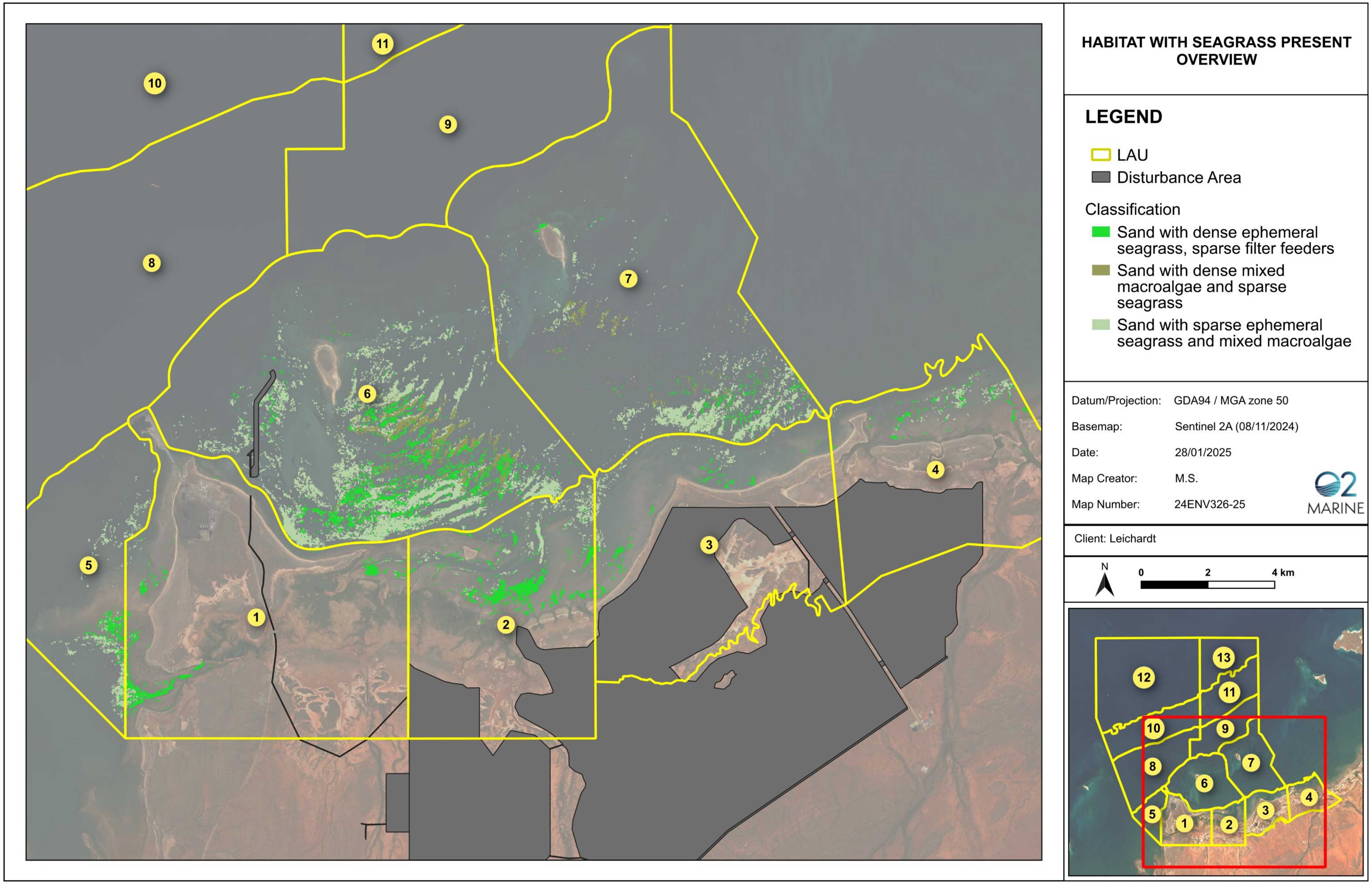


Figure 20: Seagrass Habitat Overview

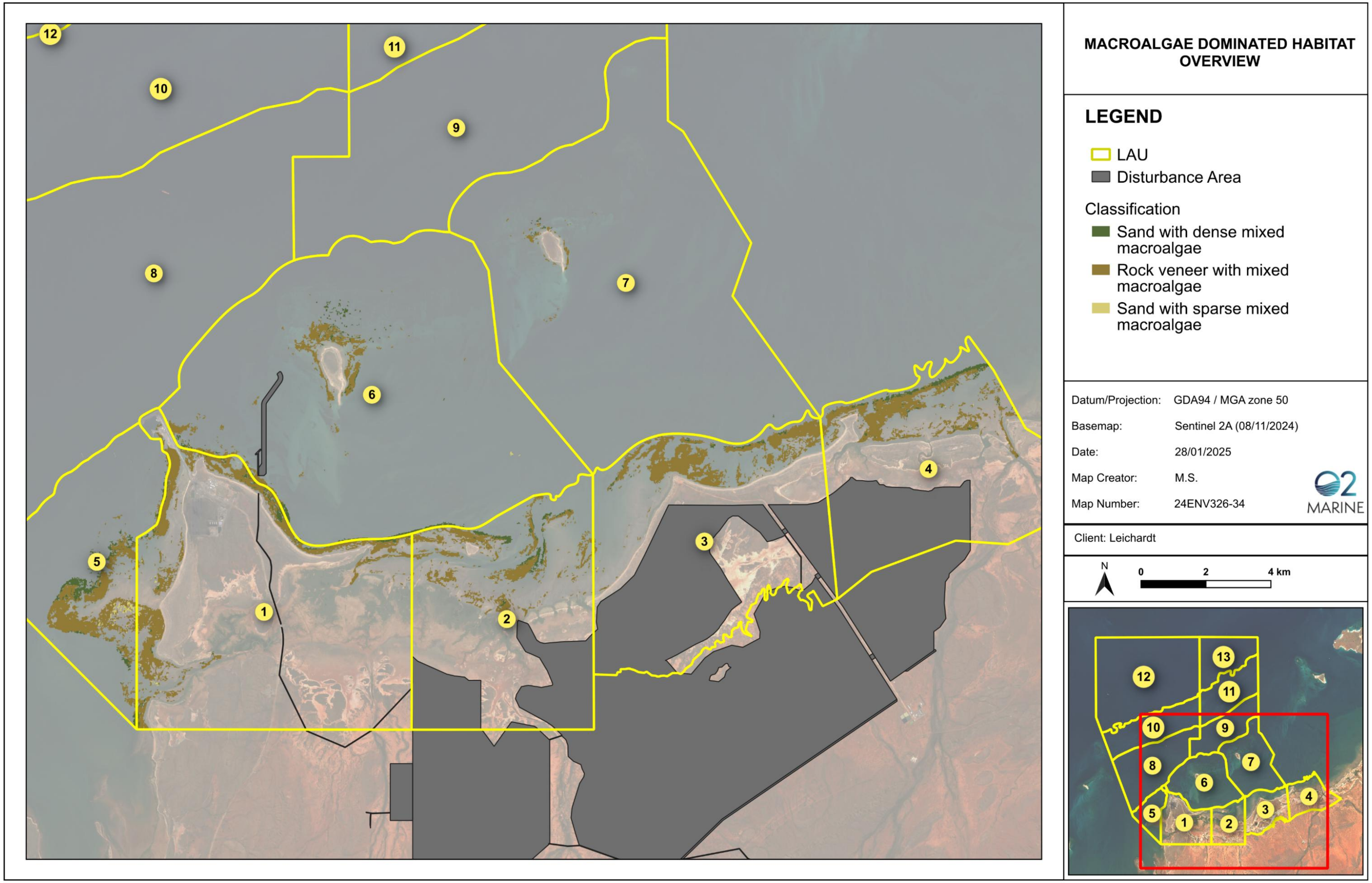


Figure 21: Macroalgae Dominated Habitat

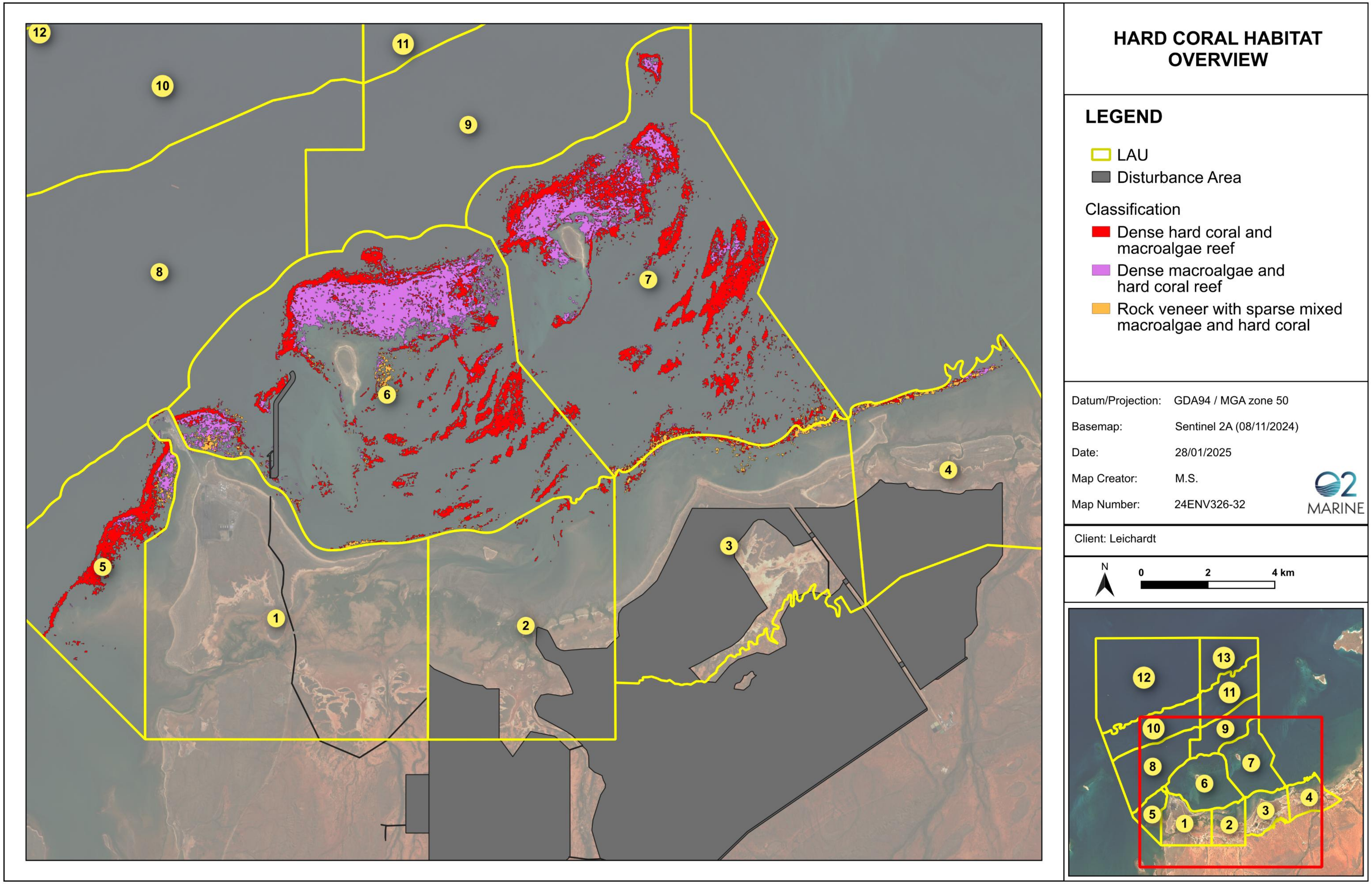


Figure 22: Hard Coral Habitat Overview

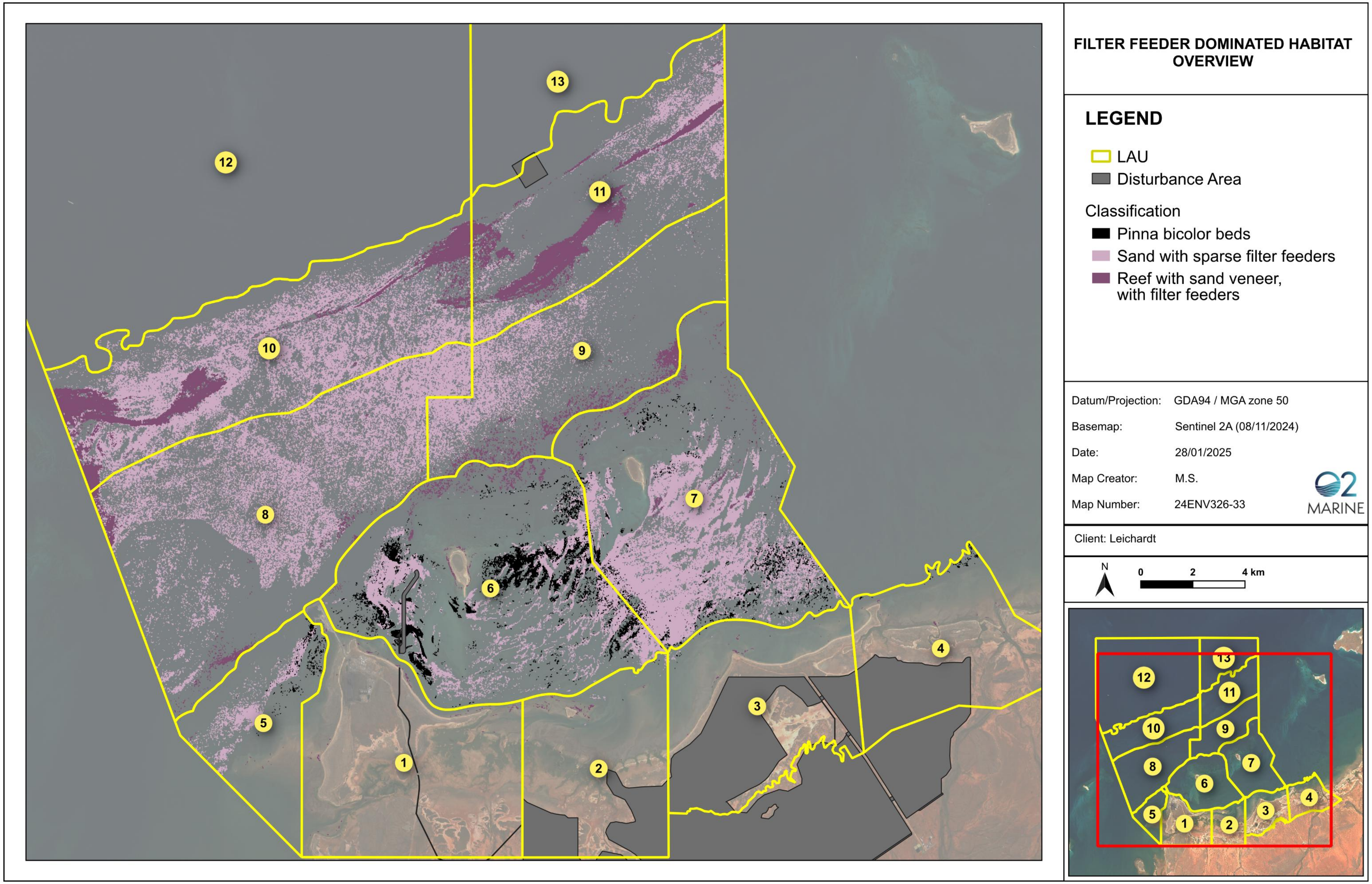


Figure 23: Filter feeders Dominated Habitat Overview

6.2.2. Mapping Validation

On completion of the model training, validation metrics were generated to assess the performance of the classifier across different habitat types. The confusion matrix and class statistics (Table 25) presents a detailed account of the model's predictive accuracy, with the rows indicating reference (true) labels and the columns depicting the labels predicted by the model.

Table 25: Confusion matrix (misclassification assessment)

		MODEL PREDICTION				
		Bare Sediment	Hard Coral Habitat	Filter Feeder Dominated Habitat	Macroalgae Dominated Habitat	Habitat with Seagrass Present
TRAINING DATA	Bare Sediment	97.3	0.1	0.7	1.0	0.3
	Hard Coral Habitat	1.8	85.8	7.8	1.8	0.3
	Filter Feeder Dominated Habitat	5.6	0.8	91.9	0.5	0.1
	Macroalgae Dominated Habitat	3.7	6.5	1.0	86.7	1.3
	Habitat with Seagrass Present	6.8	1.2	1.3	3.3	85.7

The calculation of accuracy is derived from the confusion matrix, which compares actual vs. predicted classifications. Indicators of accuracy include key performance metrics used in classification tasks to evaluate the accuracy of a model:

- True Positives: correctly predicted as positive for each class.
- True Negatives: correctly predicted as negative i.e. not belonging to a particular class.
- False Positives: incorrectly predicted as positive.
- False Negatives: incorrectly predicted as negative.
- Precision: measures the proportion of true positive predictions out of all positive predictions made (True positives/(True Positives + False Positives)), indicating how many of the predicted positive instances are actually correct.
- Recall (also known as sensitivity): measures the proportion of true positive predictions out of all actual positive instances (True positives/(True Positives + False Negatives)), reflecting the model's ability to identify all relevant cases.
- F-score: the harmonic mean of precision and recall, providing a single metric that balances both aspects. It is particularly useful in scenarios where both false positives and false negatives are critical.

Table 26 provides a summary of the classification performance metrics (Precision, Recall, F-Score) across different benthic habitat classes. High precision was observed in classes such as ‘sand with sparse mixed macroalgae’, ‘sand with dense perennial seagrass and mixed macroalgae,’ and ‘intertidal sandy muds,’ reflecting highly accurate predictions for these habitats. However, high precision often came with a tradeoff in recall, as seen in some classes, reflecting the model’s tendency to correctly predict positive cases selectively but miss a portion of true positives. Habitats such as ‘muddy sand, bare’ and ‘intertidal sandy muds’ achieved both high recall and F-scores, indicating strong overall performance in identifying these classes comprehensively and accurately.

Table 26: Subtidal Class statistics

Class	Precision		Recall		F-Score		Comment
	Mean	SD	Mean	SD	Mean	SD	
Bare Sediment	0.93	0.03	0.98	0.01	0.95	0.02	High precision and high recall, indicating the model effectively identifies most cases, most instances of these habitat.
Hard Coral Habitat	0.92	0.06	0.88	0.08	0.90	0.06	
Filter Feeder Dominated Habitat	0.88	0.06	0.93	0.03	0.90	0.03	
Macroalgae Dominated Habitat	0.89	0.05	0.87	0.08	0.88	0.05	
Habitat with Seagrass Present	0.98	0.01	0.87	0.04	0.92	0.02	

The overall accuracy of the model ensemble was 0.66 (moderate to high), with a combined Kappa value of 0.63, indicating a good agreement beyond chance between predicted and observed classifications. Kappa values closer to 1 suggest better agreement, and this value reflects a reliable classification model for the study area.

The resulting habitat map covered the entire study area and accurately delineated BCH types based on training data and environmental predictor layers. Bare Sediment dominated the mapped area, consistent with ground-truthing observations, with vegetated BCH types (Macroalgae and Seagrass) occupying relatively smaller but ecologically significant extents. Filter Feeder and Hard Coral habitats were distributed more heterogeneously, often associated with reef structures and areas of higher bathymetric complexity.

Validation against prior mapping efforts indicates a refinement in BCH delineation, attributed to enhanced resolution and classification techniques. The increased accuracy and detailed representation of biotic classes underscore the efficacy of integrating machine learning methods with comprehensive ground-truthing data.

6.3. Offshore Disposal Ground Assessment

Two separate investigations were undertaken at several offshore disposal areas, in order to determine the most suitable location where environmental impacts would be minimized, and that suited project design and feasibility. The revised and current offshore dredge spoil area was surveyed in March 2023, and was found to comprise of unvegetated soft sediment, with patches of sparse to low (1 - 10%) filter feeders (mixed habitat), refer Figure 18.

6.4. Habitat Status Within Key Impact Area (LAU 6)

The classification of BCH during field surveys initially involved characterizing the density of benthic cover with the intent of describing the condition of communities. Based on supplementary BCH assessments conducted by O2M, additional survey efforts in LAUs 1, 2, 3, 4, 5, and 6 have provided improved spatial resolution and statistical validation of BCH within the Marine Development Envelope (MDE). The updated mapping has refined the delineation of key habitats, including coral reefs, seagrass, macroalgae, and filter feeder communities. While Figure 18 to Figure 23 present the BCH assessment across the broader LAUs, Figure 24 specifically illustrates the distribution of BCH within LAU6, the area most likely to be disturbed by the Proposal activities. Detailed habitat descriptions specific to LAU 6, including targeted coral and seagrass surveys within the LAU are provided below.

The macroalgae and filter feeder habitats within the Proposal MDE and adjacent areas have been identified as comprising high to dense cover, occurring over low to moderate limestone reef, or flat to low-relief sandy veneer on limestone platform or rubble (Table 22). These habitats represent the predominant community type within the study area, though they often consist of mixed communities in varying compositions. Filter feeders include sponges and various octocorals, while macroalgae is dominated by *Sargassum* spp. in variable abundance, with additional contributions from green (Chlorophyta), brown (Phaeophyta), and red (Rhodophyta) algae, as well as benthic invertebrates

The coral habitat was observed to contain low to moderate benthic cover, typically occurring on more exposed or complex reef structures. Coral cover remains generally low, dominated by *Turbinaria* sp. and Faviid corals, though patches of higher coral cover and diversity were identified through refined mapping efforts in specific locations. The revised surveys in LAU 6 have provided enhanced delineation of coral reef boundaries, with updated density characterisations presented in Figure 22 and Figure 24.

Seagrass/macroalgae communities in the Proposal vicinity appear to contain low to moderate benthic cover, consisting of sparse to low-density seagrass interspersed with patches of macroalgae, coral, filter feeders, or evidence of bioturbation. The seagrass habitat occurs on flat-relief coarse sand, which, according to sediment studies, typically overlays shallow hard substrate within the MDE (O2M 2022b). The dominant seagrass species observed include *Halophila* spp. and *Syringodium*, with further details on seagrass distribution and seasonal variations discussed in Section 6.4.1.

Further field validation of the community composition and abundance of coral and seagrass classified BCH within LAU6 have been targeted within specific locations identified in Section 6.4.1.

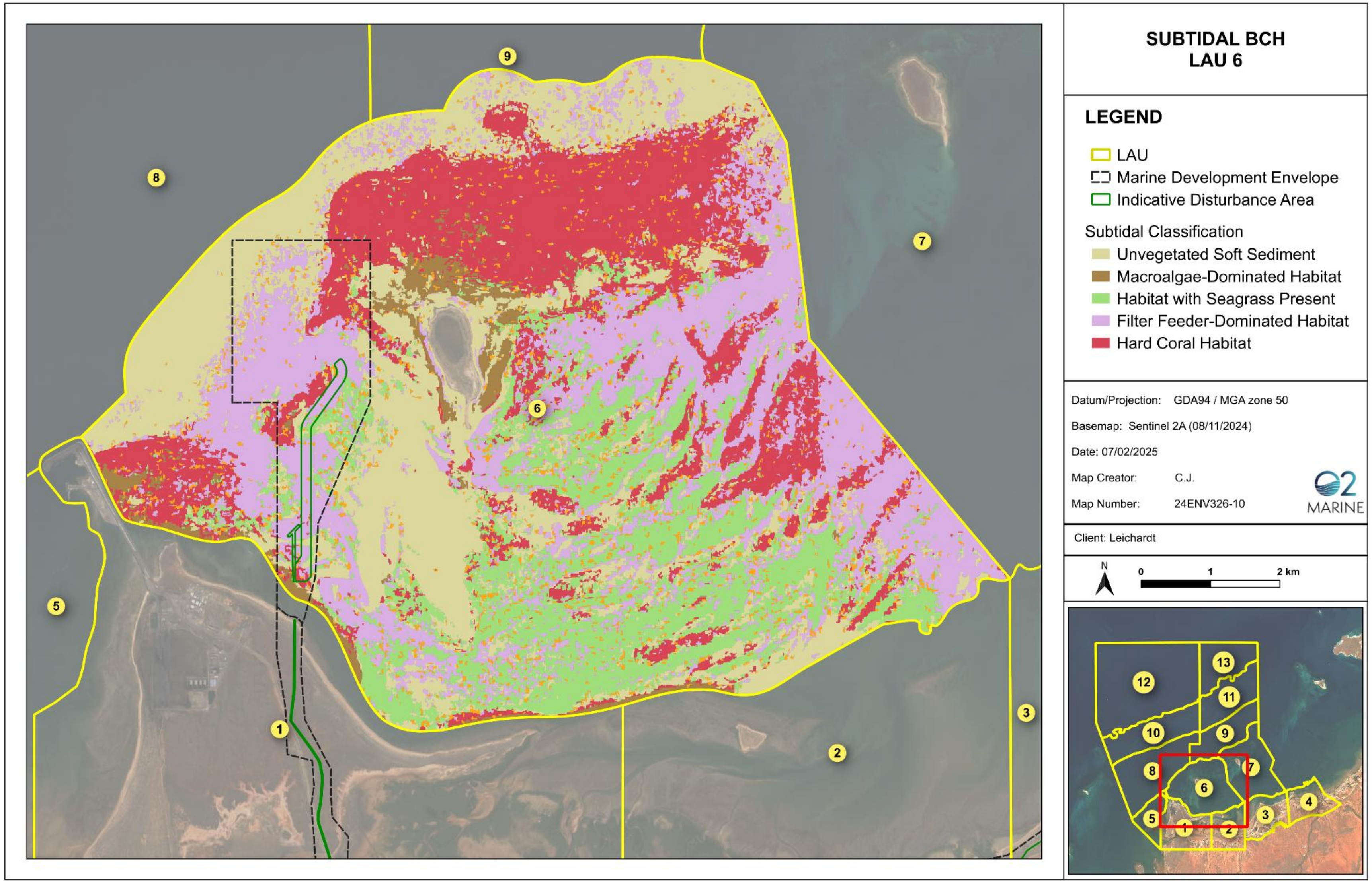


Figure 24: The distribution of BCH within LAU6.

6.4.1. Targeted Subtidal BCH Health Surveys

6.4.1.1. Coral Cover

Mean hard coral cover in 2020 and 2021 at monitoring locations (see Figure 13) ranged from 3.3% to 38.8% (Figure 25). Coral cover was highest at Site 3 close to South West Regnard Island and lowest at Site 5 nearshore within the MDE. All sites recorded Algae as the dominant functional group, predominantly comprised of turf algae. Soft substrate cover was lowest at Site 3 (2.5-3%) and highest at Site 1 (20.9-23.2%).

There was a general trend of an increasing proportion of turf algae cover and a decreasing proportion of hard coral cover between 2020 and 2021 across all sites (Figure 25). The coral cover loss at each site ranged between 2.4% at Site 3 and 6.4% at Site 2.

The coral community composition varied among sites (Figure 26). Site 1 was almost exclusively Dendrophyllidae; Site 2 was predominately Poritidae; Site 3 was a relatively balanced community of Agariciidae, Lobophyllidae, Merulinidae, and Poritidae; Site 4 was predominately Acroporidae; and at Site 5, the most abundant families were Dendrophyllidae, Poritidae and Acroporidae.

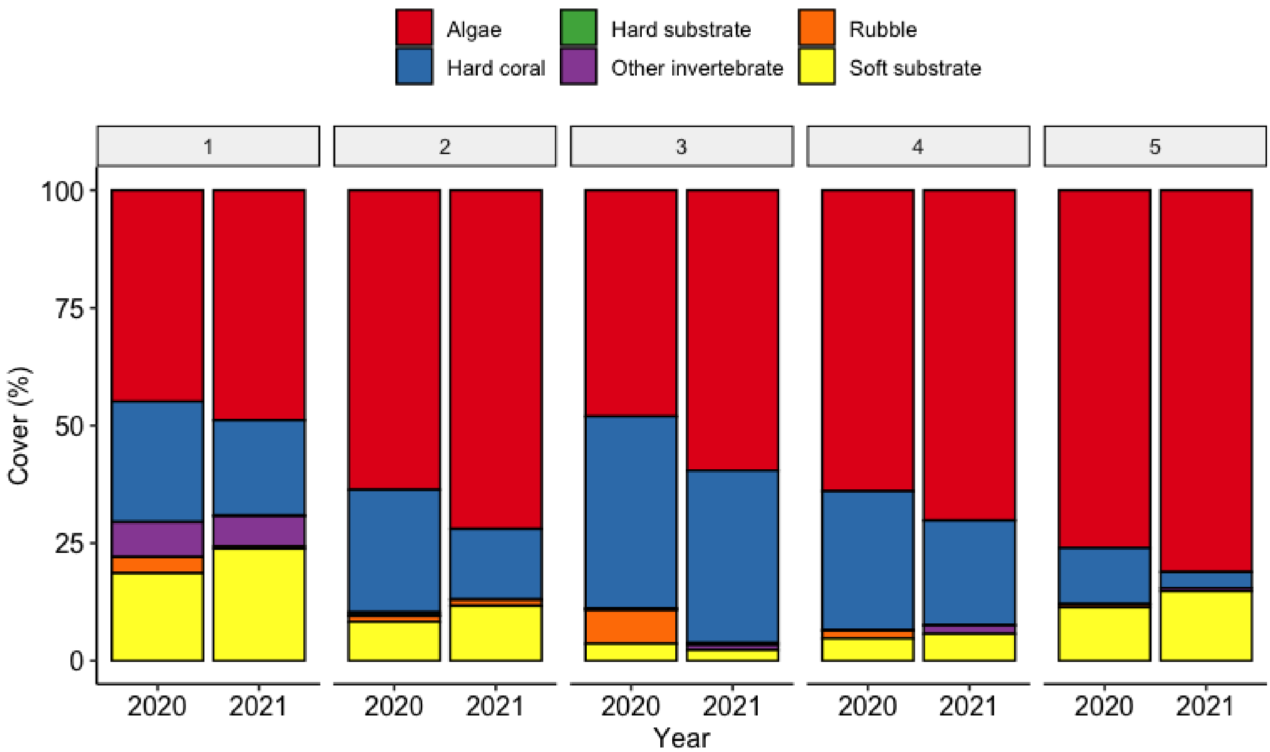


Figure 25: Benthic percent cover of functional groups at each site (1-5) in 2020 and 2021.

Table 27: Mean percent cover (± StdE) of BCH classifications at each site in the coral targeted surveys (2020-2021). Means were calculated from the average cover on each transect across 2020 and 2021 surveys (n=5).

Site	Survey	Algae (%)	Hard coral (%)	Hard substrate (%)	Other invert. (%)	Rubble (%)	Soft substrate (%)
1	2020	47.2 (4.0)	22.9 (2.7)	0.1 (0.1)	0	2.0 (0.6)	20.9 (3.2)
	2021	49.5 (4.1)	20.2 (2.0)	0.1 (0.1)	6.4 (1.0)	0.5 (0.3)	23.2 (4.4)
2	2020	67.0 (5.2)	21.6 (6.9)	0.3 (0.2)	0	1.3 (0.6)	9.6 (2.0)
	2021	71.9 (4.3)	15.2 (5.7)	0	0.2 (0.1)	1.3 (0.8)	11.4 (2.0)
3	2020	53.7 (0.9)	38.8 (1.7)	0.4 (0.3)	0	3.5 (0.7)	3.0 (1.4)
	2021	59.5 (1.5)	36.4 (1.9)	0.6 (0.6)	1.0 (0.7)	0	2.5 (1.7)
4	2020	67.2 (2.9)	25.6 (2.6)	<0.1 (<0.1)	0	0.8 (0.2)	5.4 (2.1)
	2021	70.4 (3.1)	21.8 (3.2)	0.1 (0.1)	1.8 (0.4)	0	5.9 (2.8)
5	2020	78.2 (4.2)	7.4 (1.6)	0	0	0.3 (0.1)	13.7 (4.7)
	2021	80.3 (5.7)	3.3 (0.7)	0	0.7 (0.5)	0	15.7 (5.5)

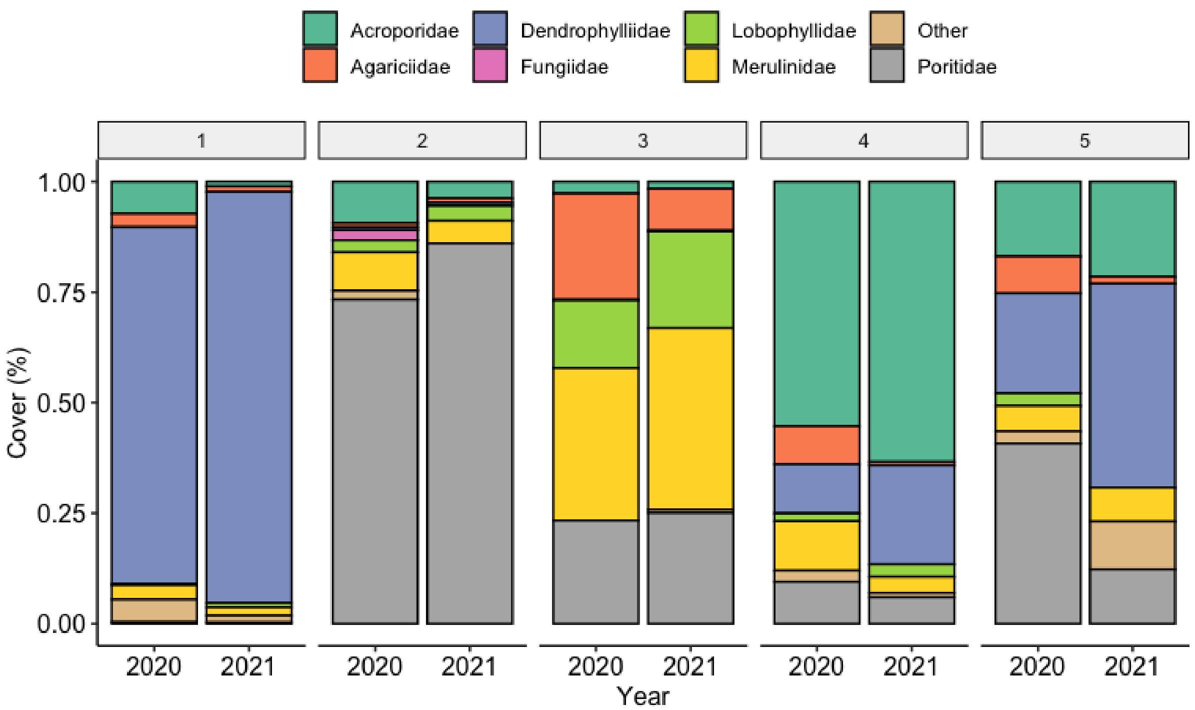


Figure 26: Percent composition of hard coral families at each site (1-5) in 2020 and 2021. Values represent the proportion of hard coral cover shown in Figure 25. The least abundant coral families (Euphillidae and Pocilloporidae) were pooled as "Other".

When compared to a previous survey at these sites from GHD (2013), Algae continued to be the dominant functional group at sites 1, 2, 4 and 5 (Table 28). Hard coral cover was previously dominant at Site 3 at a mean of 51.8% (GHD 2013), which had declined to between 36.4%-38.8% during surveys in 2020-2021. Conversely, Algae cover increased from 29.5% in 2012 (GHD 2013) to between 53.7% and 59.5% in 2020-2021.

The dominant corals at sites 1, 2 and 5 (Table 28) have remained consistent with that recorded in 2012 (GHD (2013). Differences in the dominant coral taxa between 2012 (GHD 2013) and 2020-2021 are partly related to recent changes in taxonomic guidance provided from the World Register of Marine Species (http://www.marinespecies.org/) and of Scleractinia (http://www.marinespecies.org/scleractinia/) in May 2018. The family Faviidae which was previously identified as dominant at Site 3 in 2012 (GHD 2013) has since been split into multiple different family groups based on more recent taxonomic studies of molecular phylogeny (Huang et al. 2011). One (1) of these family is the Merulinidae, which was listed as dominant in 2020-2021.

Site 4 was previously composed of between 24.3% and 28.2% cover of Acroporidae, Dendrophyllidae and Faviidae defined as 'Mixed community'. In 2020-2021 surveys Acroporidae cover averaged from 14.0% to 14.83% cover, comprising between 57.9% and 64.2% of hard coral. This is primarily attributable to an increase in hard coral cover at Site 4 from 10.4% in 2012 (GHD 2013) to between 21.8% and 25.6% in 2020-2021 through Acroporidae coral taxa. An increase in coral cover from 11.7% to 14.4% since 2012 (GHD 2013) was also observed at Site 1 although the dominant coral family has not changed.

Table 28: Changes in the dominant functional group and coral families between 2012 and 2020-2021. 2012 data are summarised from GHD (2013). Changes between surveys in 2012 and 2020-2021 are underlined.

Site	Dominant functional group		Dominant coral family	
	2012 (GHD, 2013)	2020-2021	2012 (GHD, 2013)	2020-2021
1	Algae	Algae	Dendrophyllidae	Dendrophyllidae
2	Algae	Algae	Poritidae	Poritidae
3	Hard coral	Algae	Faviidae	Merulinidae
4	Algae	Algae	Mixed community	Acroporidae
5	Algae	Algae	Low coral cover mixed community	Low coral cover mixed community

6.4.1.2. Seagrass Cover

Seagrass represented from 0.07% to 3.01% of the benthos at all seagrass monitoring sites, with large areas of bare sand substrate between (Figure 27). Seagrass formed the highest cover of any benthic biota at almost all sites, notwithstanding, it still occurred in typically very low densities even by regional standards (i.e. mean cover was < 5 % at all sites (Figure 27). Low density cover of other benthic invertebrates such as ascidians, corals and sponges were occasionally recorded (Table 29).

Total benthic cover of benthic biota varied between July 2020 and March 2021 (e.g. W8a in Figure 27), indicating that there may be high temporal variability at these sites, with seagrass cover lower in March 2021 than in June 2020 at all sites except E16b (Figure 27). Site W8a experienced the largest decline from ~4% to close to 0% in *H. decipiens* and *H. ovalis* cover, whereas other sites dropped by between 0.5% and 3.0%. Seagrass increased by 0.1% at Site E16b which was composed predominantly of *H. decipiens*.

Most seagrass cover consisted of *H. decipiens* and *H. ovalis*, while *Halodule* sp. and *Syringodium* sp. represented low cover at several sites. Some sites exhibited changes in seagrass composition between July 2020 and March 2021, including E14a, I13b, ERASG2 and W8a. In general, sites in March 2021 were composed of fewer seagrass species than in July 2020.

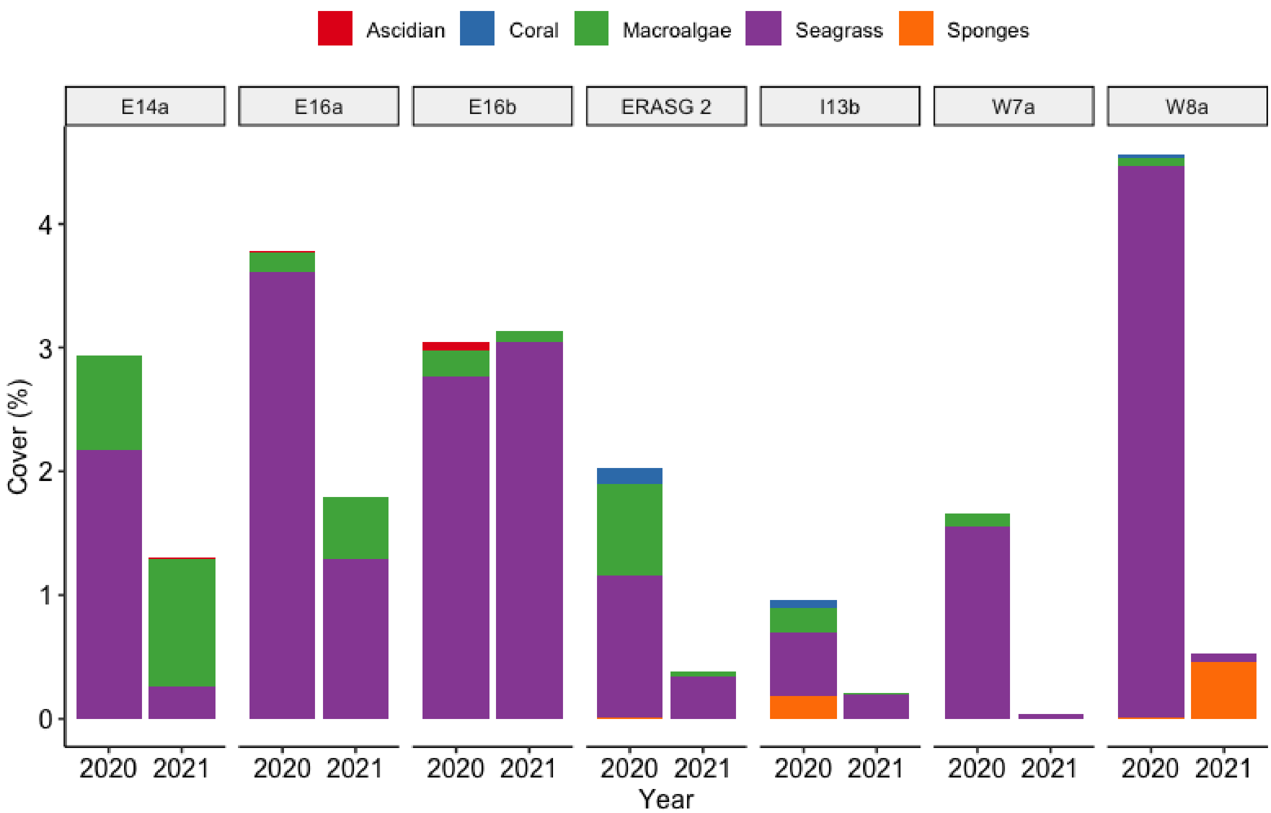


Figure 27: Percent cover of functional groups (ascidians, corals, macroalgae, seagrass, and sponges) at targeted seagrass sites in July 2020 and March 2021.

Table 29: Mean percent cover (± StdE) of BCH classifications at each targeted seagrass site across both surveys (2020-2021). Means were calculated from the average cover on each transect across 2020 and 2021 surveys (n=3).

Site	Survey	Ascidian (%)	Hard coral (%)	Macroalgae (%)	Seagrass (%)	Sponges (%)
E14a	2020	0	0	0.89 (0.32)	1.22 (0.21)	0
	2021	0.03 (<0.01)	0	1.03 (<0.01)	0.27 (<0.01)	0
E16a	2020	0.01 (0.01)	0	0.32 (0.18)	2.47 (0.47)	0
	2021	0	0	0.49 (<0.01)	1.35 (<0.01)	0
E16b	2020	0.03 (0.01)	0	0.15 (0.02)	2.89 (0.34)	0
	2021	0	0	0.09 (<0.01)	3.01 (<0.01)	0
ERASG2	2020	0	0.07 (0.04)	0.40 (0.07)	0.78 (0.18)	0
	2021	0	0	0.03 (<0.01)	0.37 (<0.01)	0
I13b	2020	0	0.03 (0.02)	0.11 (0.03)	0.36 (0.16)	0.09 (0.08)
	2021	0	0	0	0.21 (<0.01)	0
W7a	2020	0	0	0.05 (0.01)	0.72 (0.23)	0
	2021	0	0	0	0.04 (<0.01)	0
W8a	2020	0	0.01 (0.01)	0.03 (0.01)	2.17 (0.23)	0.24 (0.23)
	2021	0	0	0	0.07 (<0.01)	0.54 (<0.01)

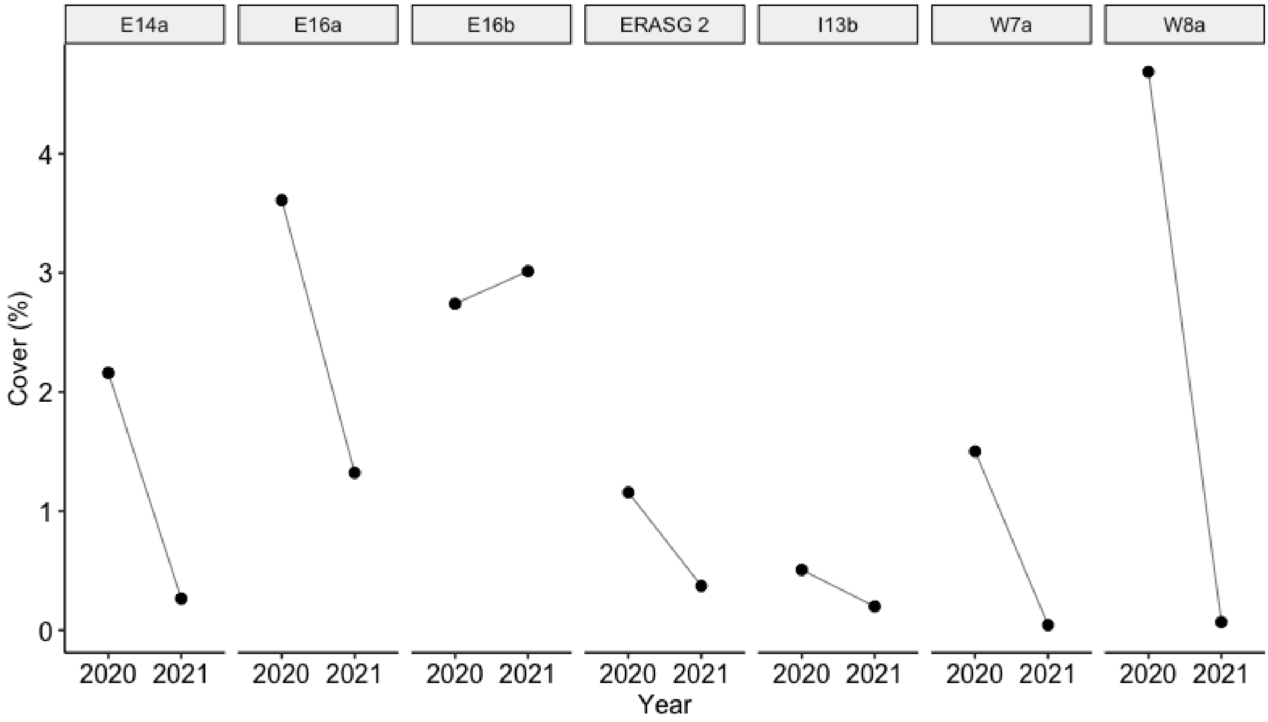


Figure 28: Change between July 2020 and March 2021 in seagrass cover (% area) at targeted seagrass sites. Points represent means of three (3) transects at each site.

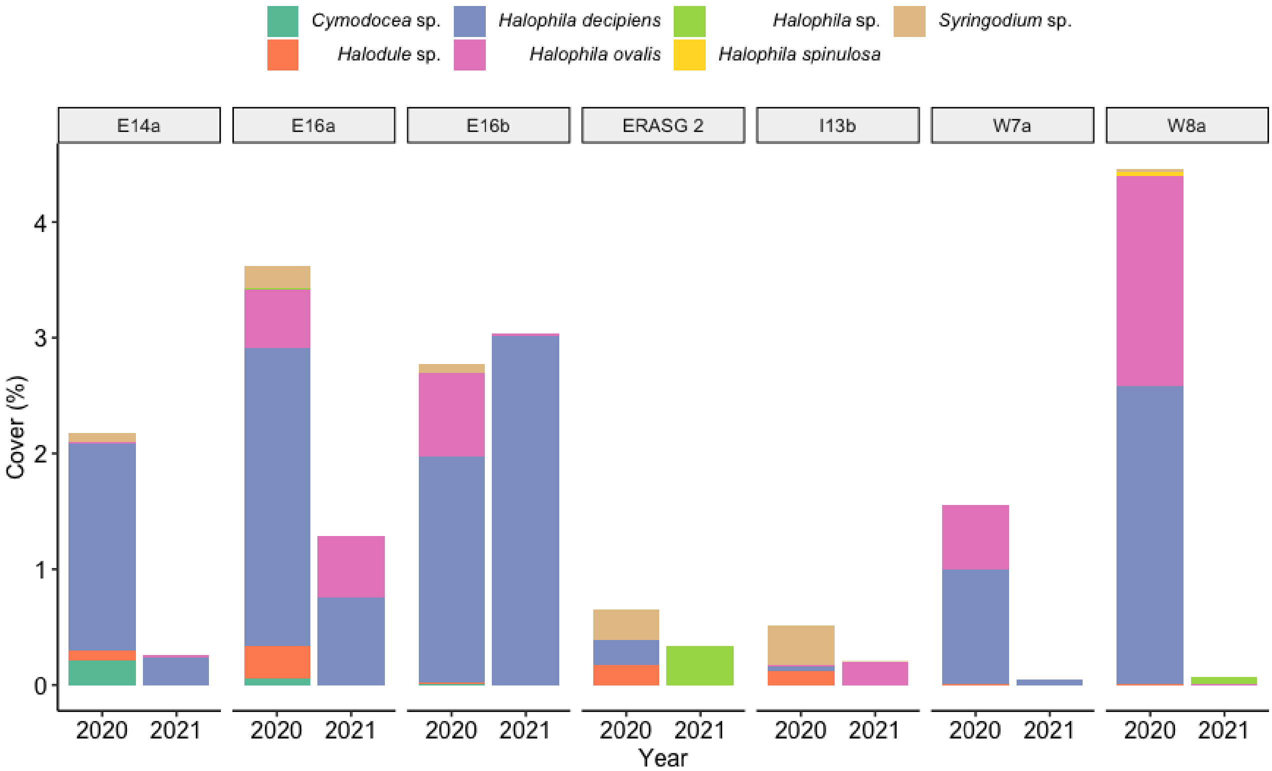


Figure 29: Seagrass cover (% area) by species (*Cymodocea* sp., *Halodule* sp., *Halophia decipiens*, *Halophila ovalis*, *Halophila* sp., *Halophila spinulosa*, *Syringodium* sp.) in July 2020 and March 2021.

6.5. Seasonal Variation in Seagrass Extent

The assessment of 55 time-series multispectral satellite images from 2019 to 2024 for multiple monitoring sites around Cape Preston indicated little discernible environmental change in benthic habitat beyond seasonal fluctuations in seagrass extent based on presence or absence of seagrass. The most sensitive / useful indicators for detecting variability in the extent of seagrass on the seafloor were found to be the Enhanced Vegetation Index (EVI) and the Water Adjusted Vegetation Index (WAVI)/Normalized Difference Aquatic Vegetation Index (NDAVI), whereas the least variable indicator was the Submerged Seagrass Identification Index (SSII).

Table 30 provides a summary of trends for each monitoring site, confirming that very localised seasonal fluctuations in seagrass distribution were observed, but there were no substantial long-term changes in overall extent detected. The most notable trend was an overall increase in vegetative density or cover at LAU1_East and LAU2_West; although while LAU1_West and LAU1_North exhibited periodic fluctuations in EVI and NDAVI values, no long-term trends were discernible. LAU2_South displayed significant fluctuations in EVI without corresponding changes in other indices, suggesting variability in extent is unrelated to benthic vegetation shifts. LAU3_West, LAU3_Cent, and LAU3_East exhibited slight variations in WAVI/NDAVI but no discernible patterns. LAU4_East and LAU4_West showed high variability in EVI and WAVI, with little indication of consistent long-term changes.

These patterns are illustrated in Figure 30, which reinforces the conclusion that most seasonal changes were minor and that the distribution and extent of benthic vegetation remained largely stable across the monitoring period. Notably, LAU3_Cent experienced a large negative spike in EVI during the 2020 wet season, while LAU2_West exhibited NDAVI/WAVI fluctuations likely influenced by residual sediment wetness.

Overall, the assessment confirms that there were no major long-term environmental changes, with observed fluctuations being primarily seasonal and driven by natural cycles.

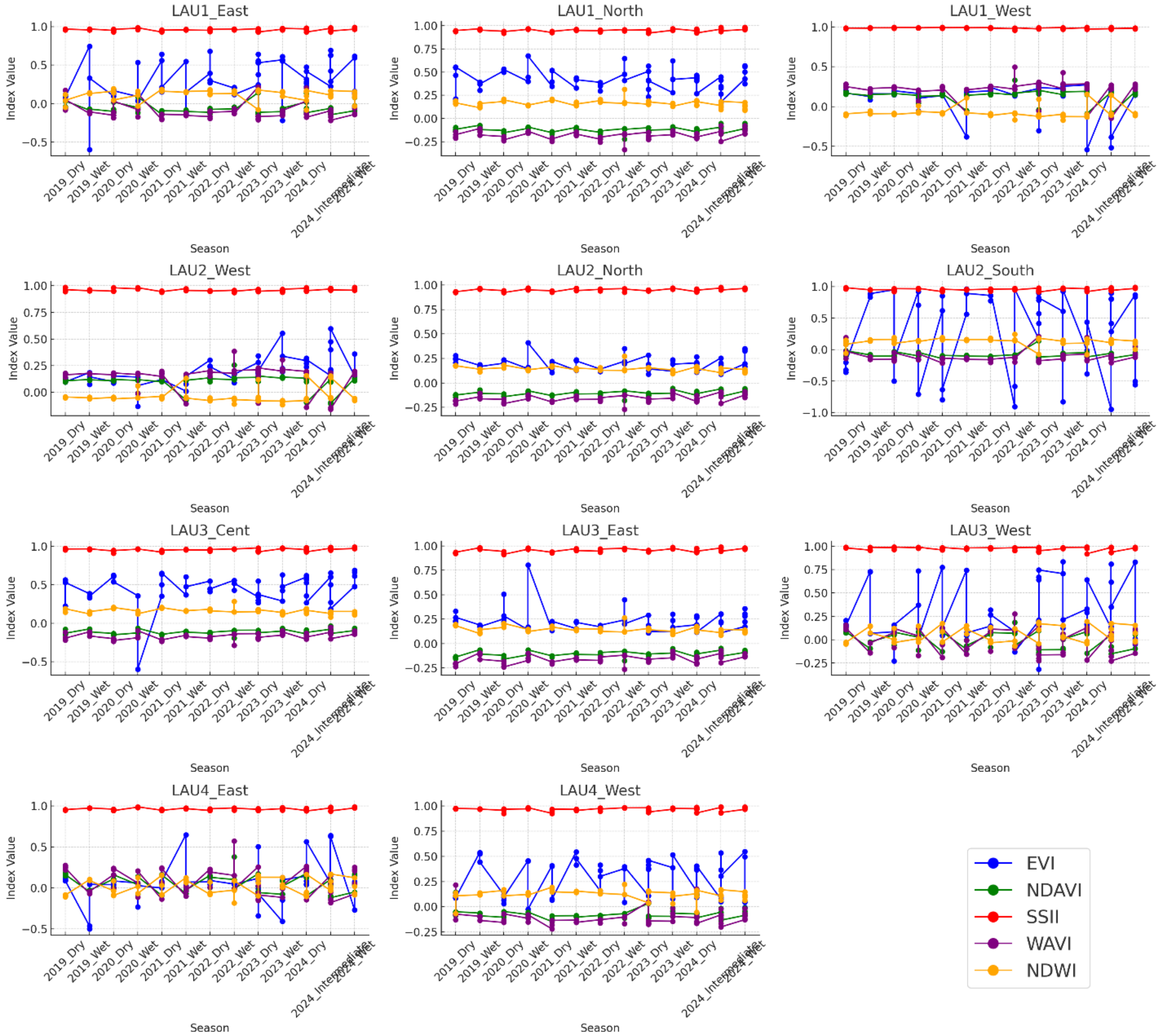
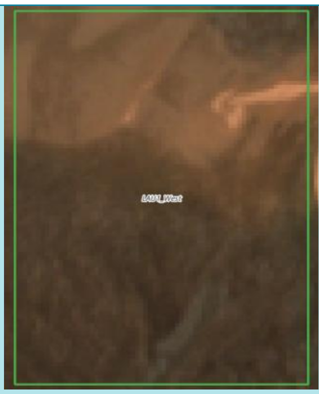
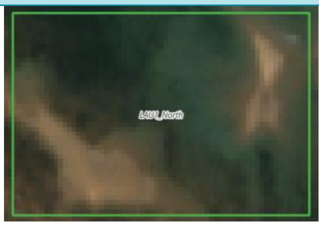


Figure 30: Summary of vegetation indices (EVI, NDAVI, SSII, WAVI, and NDWI) across all monitoring sites from 2019 to 2024.

Table 30: Summary of monitoring area trends, including total area, representative image, and observed patterns in vegetation indices.

Monitoring Area	LAU	Area (ha)	Example Image (26/8/ 2024, True Colour)	Summary
LAU1_East	1	28.41		Shows upward but noisy trend in EVI across the monitoring period. SSII relatively stable, and some seasonal fluctuation in other indices noted.
LAU1_West	1	61.78		No long term trends are readily discernible, however some three large fluctuations occur which are probably due to image wetness (as concurrent spikes in NDWI are seen).
LAU1_North	1	28.66		Slight seasonal variation on WAVI/NDAVI however little long term change.
LAU2_South	2	14.85		Large fluctuations in EVI with relatively small magnitude change in other variables – unexplained.
LAU2_North	2	16.71		Slight seasonal variation on WAVI/NDAVI however little long term change.

LAU2_West	2	48.25		Slight upward trend in EVI suggesting slight but variable vegetation gain. NDAVI/WAVI fluctuations again probably attributable to residual sediment wetness.
LAU3_West	3	28.70		Large fluctuations in EVI with slight seasonal variation on WAVI/NDAVI.
LAU3_East	3	23.24		Large spikes in EVI noted in association with wet season periods. Similar slight seasonal variation in WAVI/NDAVI.
LAU3_Cent	3	81.75		Slight seasonal variation on WAVI/NDAVI however little long term change. Large negative spike in EVI during 2020 wet season.

LAU4_East	4	21.25		High variability in EVI and WAVI but little potential seasonal relationships.
LAU4_West	4	63.16		High variability in EVI and WAVI but little potential seasonal relationships.

7. Discussion

This study has resulted in the development of a high-resolution BCH map, illustrating the distribution of BCH across an established series of LAUs within the Proposal footprint. Using advanced machine learning techniques, extensive ground-truthing, and environmental predictor datasets, this mapping provides a comprehensive overview of subtidal habitats, ensuring robust data for environmental impact assessment and long-term monitoring.

The distribution and community structure of benthic primary producers can be influenced by range of complex environmental factors, including temperature, light availability, wave exposure, depth, sediment type, currents, and latitude. These factors drive spatial and temporal variability in habitat extent and condition, shaping the ecological dynamics within the study area.

The Proposal MDE is located in the western part of Regnard Bay, extending offshore between Cape Preston and South West Regnard Island. The mapped BCH within the Proposal area predominantly comprises large expanses of bare sediment, interspersed with areas of coral, macroalgae, seagrass, and filter feeders. Bare sediment, primarily composed of coarse sand with shell fragments, dominates in mid-shelf and offshore regions, while vegetated and reef-associated habitats are more localised and influenced by substrate availability and geomorphic complexity.

7.1. Subtidal Habitats of Cape Preston East and Regnard Bay

The Regnard Bay and Cape Preston East area forms a wide, shallow embayment bordered to the west by Cape Preston and to the north by South West and North East Regnard Islands. Due to tidal flow and minor platform reef development, the seabed of the Bay has developed a complex topography, showing evidence of tidal scour, reef accumulation (around South West Regnard Island), and unstable tidal sand banks in the east (Eliot et al., 2013).

The broad-scale and targeted mapping undertaken as part of this study provides a detailed delineation of BCH types across varied substrates, including areas of bare sediment, low-relief limestone with sand veneer, and outcropping rocky structures and islands. The BCH in the Cape Preston East vicinity are analogous to those found across the inner continental shelf of the Pilbara (Bancroft et al 2000, CALM 2000, Chevron 2015), though this study highlights refined spatial distributions and classifications. Bare sediment dominates the Proposal area, although patches of sessile organisms, such as filter feeders and coral assemblages, were found to occur in areas where geomorphic and oceanographic conditions allow.

The local bathymetry surrounding the bitterns outfall location indicates the diffuser is positioned in depths ranging from -4 m to -6 m LAT. These depths align with areas of bare sediment. The position of the jetty infrastructure, where the width of the shallow intertidal/subtidal platform is reduced compared to other areas along the coast, was chosen to allow for improved dilution, reduced dredging requirements, and minimal impacts on adjacent BCH.

7.1.1. Bare Sand and Silt Habitat

The dominant BCH that occurs in the Pilbara subtidal zone is bare sediment, typically dominated by coarse calcium carbonate silty sands (Bancroft et al 2000). As expected, this habitat type was identified as the most common type in the Eramurra study area, where there appears to be a gradual change from coarser sediments in the west (including in the development footprint) through to finer silts in the east. This pattern is likely to be associated with tidal sediment movement (noting assessment of sediment types was visual only and further testing of sediment size fractions would be required to verify this assertion). Silty sands closer to the shore have previously been found to support a lower density of sessile invertebrates compared to coarser sands, although silty sands are typically more bioturbated. This prevalent trend, noted elsewhere in the Pilbara (Chevron 2014, 2015), was also observed within the Proposal area.

The updated mapping results identify three key sub-classifications of sediment types in the Proposal area:

- Intertidal Sandy Muds, found in nearshore areas subject to tidal influences, supporting microphytobenthic algae and contributing to local productivity.
- Muddy sand, bare, predominantly in the eastern parts of the Proposal area, associated with tidal sediment deposition and reduced hydrodynamic energy.
- Coarse sand and shell fragments, dominating the mid-shelf and offshore zones, with minimal colonisation by sessile organisms due to high levels of sediment movement.

While unvegetated habitats are typically areas targeted by Proponents for development (due to their lower ecosystem value relative to benthic primary and secondary producer habitats), it is reasonable to note that , this type of BCH can support microphytobenthic algal communities and sometimes diverse benthic infauna, depending on depth and other environmental variables (PHPA 2010). Notwithstanding, this environment, particularly where coarse well-sorted sediments dominate, is likely to experience high levels of disturbance due to wave, current, and cyclone action. Consequently, these areas often do not provide good habitat for slower-growing colonising sessile organisms, though patches of mixed filter feeders were identified within the disposal ground assessments.

7.1.2. Macroalgal Habitat

Macroalgal communities require light for photosynthesis and are therefore restricted to areas where depth and turbidity levels are within tolerable limits. In the shallow waters of the inshore Pilbara continental shelf, turbidity and suspended sediment often become the limiting factors for macroalgal distribution. These communities also require hard substrates for attachment. This requirement is less of a limitation in the Pilbara environment due to the natural cementation of sediments (Jones and Desrochers 1992) and the prevalence of limestone reef/pavement, which occurs from the intertidal zone to the continental shelf break (LeBrec et al. 2022).

Field and remote sensing data collected during the current investigation confirms the distribution of macroalgal habitats across LAUs 1 to 6, highlighting their association with rocky reef platforms and low-relief limestone substrates. Furthermore, ground truth data demonstrated that that dense macroalgae is dominated by brown algae (*Sargassum* spp.) in shallow, well-lit areas. Smaller components of green algae (*Caulerpa* sp., *Halimeda* sp.) and red algae (Rhodophyta) contribute to assemblage complexity, though their distribution and densities appear more limited.

Recent mapping refinements indicate that macroalgal habitats occur in distinct bands, particularly in shallow waters adjacent to 40 Mile Beach and between South West and North East Regnard Islands. These areas also appear to support sparse colonies of hard coral and filter feeder habitat.

Macroalgae are critical to the productivity of marine ecosystems for their role in the provision of habitat for invertebrates, fish, and birds, and serve as both a food source and a contributor to decomposition processes.

Some species, such as *Halimeda*, act as sediment producers, while other forms of macroalgae, like Rhodophyta, contribute to the cementation and binding of materials with calcium carbonate, creating functional habitats for other organisms (Jones and Desrochers 1992).

7.1.3. Mixed Filter Feeder Habitat

Marine habitats on the continental shelf of the Pilbara are often characterised by assemblages of filter feeder communities dominated by a highly diverse assemblage of sponges, ascidians, and other organisms. These assemblages create three-dimensional structures on the seabed that provide suitable habitat for a range of other organisms (Fromont et al. 2016). Filter feeder assemblages dominate in areas where there is suitable substrate for attachment, particularly limestone veneer and ancient shoreline deposits, and where waters are too turbid or deep for significant competition from other communities (e.g., macroalgae; Abdul Wahab et al. 2019). These substrates are ubiquitous in the Pilbara and, as confirmed by the updated mapping, filter feeders cover significant tracts of marine habitats, particularly in deeper waters and areas with sand veneers over hard substrates.

The updated mapping results identify specific subcategories within filter feeder habitats, refining their classification and spatial understanding:

- *Pinna bicolor* beds, observed in shallow to moderate depths, typically associated with areas of hard substrate and sand veneer. These beds provide structural habitat for a range of other benthic organisms
- Sand veneer with dense filter feeders, occurring where a thin layer of sand overlays hard substrates, supporting dense assemblages of sponges, ascidians, and other filter feeders, and
- Sand with sparse filter feeders, identified in areas with minimal substrate complexity, often transitional zones between bare sediment and more structured habitats.

Ecologically, filter feeders such as sponges can significantly influence water quality and substrate conditions and provide nutrition and vital habitat for many other organisms. Sponges are efficient filter feeders and play a critical role in linking the pelagic environment to the benthos through nutrient cycling and are increasingly recognized as key contributors to ecosystem services. The updated mapping reaffirms the importance of Filter Feeders as key contributors to ecosystem services, including enhancing biodiversity and stabilising substrates.

7.1.4. Seagrass Habitat

Seagrasses, comprising entirely small ephemeral species, were found in the protected inshore regions of Regnard Bay, occurring in three distinct subcategories based on density and associated biotic communities:

- Sand with dense ephemeral seagrass, sparse filter feeders, predominantly found in LAUs 1, 2, 5, and 6.
- Sand with dense mixed macroalgae and sparse seagrass, observed in LAUs 1, 2, and 5.
- Sand with sparse ephemeral seagrass and mixed macroalgae, distributed more broadly across LAUs 1 to 6.

Seagrass habitats appear to be primarily concentrated in shallow waters less than 5 m below LAT, with notable coverage in LAU 6 (1,446 ha, 18%), followed by LAU 7 (399 ha, 5%) and LAU 2 (225 ha, 14%). Smaller patches are present in LAUs 3 and 4. The map highlights the presence of seagrass communities along the shoreline between Cape Preston and Gnoorea Point and between South West Regnard Island and Cape Preston.

The densities of seagrasses found in the current investigation are consistent with observations across the Pilbara (Vanderklift et al. 2017). Coverage proportions rarely exceeded 5%, which aligns with regional trends (generally 10-15 %, Vanderklift et al. 2017) where dense seagrass meadows are uncommon compared to southern Australian waters (Vanderklift et al. 2017). No significant areas of seagrass were observed further offshore.

7.1.5. Coral Habitat

The coral habitats of Cape Preston and Regnard Bay appear distributed across multiple LAUs, with notable densities in LAUs 5, 6, 7, and 9 and additional occurrences in LAUs 1, 2, 3, and 4.

The updated mapping identifies three subcategories of coral habitat within the study area:

- Dense Hard Coral and Macroalgae Reef found extensively in LAUs 6, 7, and 9, with isolated patches also present in LAUs 2 and 3. These habitats are dominated by significant coral cover interspersed with macroalgae
- Dense Macroalgae and Hard Coral Reef, which appears concentrated in LAUs 6, 7, and parts of 9, with smaller areas in LAU 4. These habitats occur in transitional zones with a higher proportion of macroalgae relative to coral cover, and
- Rock Veneer with Sparse Mixed Macroalgae and Hard Coral that were observed in LAUs 5, 6, 7, and 9, with smaller patches in LAUs 1, 2, and 4. These habitats feature sparse coral growth mixed with ephemeral biota such as macroalgae. They were commonly found on shallow rock outcrops and sand veneer, particularly in more turbid environments.

Corals were not found in muddier areas of the inner bay, with the exception of a narrow band of low-cover, inshore corals identified within MDE in LAU 7. The highest coral densities were observed on the reef platform surrounding South West Regnard Island, particularly in LAUs 6 and 7, as well as in isolated patch reefs in LAU 5 (e.g., Sites 2/3). These areas exemplify developing coral reef platforms likely formed from slow-growing and sediment-tolerant species. As noted by WorleyParsons (2009a, b), such reefs showcase the resilience of coral species adapted to high sedimentation and low growth rates.

Smaller patches of coral habitat in LAUs 1, 2, 3, and 4 were found on nearshore limestone pavements, rocky substrates, and mixed communities. These habitats, though less extensive, enhance ecological connectivity and contribute to the overall biodiversity of the area.

7.2. Seasonal Variation

The results of this study indicate that benthic habitats in the monitored area appear largely stable over time, with only very localised seasonal fluctuations in BCH distribution and extent observed in the timeframes investigated. The stability of key indicators such as the Submerged Seagrass Identification Index (SSII) suggests that submerged seagrass beds did not undergo major distribution shifts, most likely reflecting the semi-protected hydrodynamic conditions of the near-shore environment. The most useful indicators for assessing seasonal variation were the Enhanced Vegetation Index (EVI) and the Water Adjusted Vegetation Index (WAVI)/Normalized Difference Aquatic Vegetation Index (NDAVI), which effectively captured periodic fluctuations and trends in vegetative cover.

The periodic fluctuations noted in LAU1_West, LAU1_North, and LAU2_South most likely correspond with natural environmental cycles, noting the species types are dominated by ephemerals which have well known seasonal variability due to their reproductive strategies and rapid productivity. While some sites demonstrated an increase in cover, notably LAU1_East and LAU2_West, these changes were not consistent across all monitored locations.

Seasonal variability appears to be the dominant driver of fluctuations in benthic habitat indices. The absence of long-term directional change suggests that the current environmental conditions, including hydrodynamic processes and sediment dynamics, have not led to major alterations in benthic vegetation.

7.3. Benthic Community Health

7.3.1. Status of Seagrasses in Regnard Bay

In this study, a decrease of seagrass cover was observed at most monitoring sites between 2020 and 2021, , although the proportion decline (1-3 %) aligns with changes in density – representing natural variation - reported by others in the region (Vanderklift et al. 2017)

A total of seven (7) seagrass species have been described throughout the Pilbara, and sub-regional areas with five (5) species have been previously considered as having relatively high species richness (e.g. Exmouth Gulf, Vanderklift et al. 2017). Various species of seagrass were identified in the study area, including three (3) species of *Halophila* (*decipiens*, *ovalis* and *spinulosa*), *Cymodocea* sp., *Halodule* sp., and *Syringodium* sp. The greater diversity of ephemeral species reported in this investigation compared to the number of species reported previously for nearby locations, e.g. just one species by Campey and Gilmour (2000) around Cape Preston Island (Campey and Gilmour 2000), most likely reflects the much greater survey effort in the present investigation rather than a regional ecological shift. This, and the ephemeral nature of seagrasses in the Pilbara, suggests that the seagrasses of Regnard Bay are likely representative of many other parts of the Pilbara coast.

7.3.2. Status of Corals in Regnard Bay

The proportion of hard corals across the five (5) coral sites surveyed during 2020 and 2021 recorded cover ranging from 3.3% to 38.8%. Highest cover was recorded adjacent to South West Regnard Island, although coral density generally decreases moving inshore into more turbid waters. Previous studies have determined that over 50 coral species may be found in the near vicinity of Cape Preston, with over 360 species in total known across the broader Pilbara bioregion (Campey and Gilmour 2000). Each of the coral communities surveyed were distinctive among sites.

LeProvost (2008) identified three (3) regionally significant coral communities in the vicinity of Cape Preston with > 50 % cover and in parts up to 100% live coral cover comprised primarily of large colonies of massive species such as *Porites*, *Favites*, *Lobophylia* and *Goniastrea*. These major reefs were located:

- approximately 3 – 5 km to the southwest of Cape Preston
- 4 km to the east-north-east of Cape Preston on the southeast end of SW Regnard Island, and
- 5 km east of Cape Preston.

A survey of five (5) coral communities within the area of Cape Preston East, which included two regionally significant reefs to the east of Cape Preston described above, was undertaken by GHD in 2012 (GHD 2013). Repeated monitoring of these same survey sites in 2020-2021 within this study indicates the reefs were largely dominated by the same coral types almost a decade later. However, the Faviid-dominated community recorded in 2012 at site 3 (close to South West Regnard Island) had increased in macroalgae cover which is now also dominant. Additionally, the mixed 2012 community of site 4 (adjacent to the Cape Preston rock wall) was more recently seen to now be dominated by Acroporidae. The proportion of hard coral was observed to decline from 2020 to 2021 at several sites. This was replaced by a relative increase in turf algal cover (as described above).

The reasons behind observed changes are likely complex, although trends are likely attributable to recent impacts from Tropical Cyclone (TC) Damien, which made landfall as a strong Category 3 severe tropical cyclone over the Dampier/Karratha region on 8 February 2020. In addition, marine heatwave conditions were also recorded in summer 2021 associated with a La Niña event which places thermal stress causing subsequent bleaching on coral communities. Therefore, any reductions in health measures of the reefs since 2012 may be a function of shorter-term climatic conditions rather than permanent shift.

Most corals observed in the Proposal area appeared in a good state of health during surveys in 2020/2021, with no obvious signs of coral stress (e.g. bleaching, sediment smothering, disease, predation, mucous production). The good health of corals is likely attributable to the fact that many of the species present are sediment tolerant, and non-tolerant species are mostly absent.

7.4. Critical Linkages of Benthic Communities to Marine Fauna

The types of BCH identified in the Proposal area have known ecological value in supporting life cycle requirements for conservation significant species, most notably as nesting habitat, food sources or foraging areas for various marine fauna. As such, linkages and the particular value of BCH occurring the Proposal area were further investigated and reported in a Conservation Significant Marine Fauna Desktop Study by O2M (2025b). While not diminishing their ecological value, the study determined that none of the BCH identified in this study were unique, with all BCH found types found to be ubiquitous along the Pilbara coastline. This desktop study also investigated the value of the BCH in the Proposal area in consideration of its relative importance for supporting conservation significant fauna. Biologically Important Areas (BIAs) are spatially defined zones where aggregations of individuals of a species are known to display biologically important behaviours such as breeding, foraging, resting or migration (DCCEEW 2022). A summary of BIAs within the Proposal area is presented in Table 31.

Fossette et al. (2021) used aerial photogrammetry to identify flatback turtle nesting activity occurs at South West Regnard Island, while other turtle nesting activity (i.e. species not specified) was identified to occur at North East Regnard Island and also on the beach immediately East of the MDE (O2M 2025b). The BIAs suggest green and hawksbill turtles may also nest on beaches in the area. The islands also provide critical breeding habitat for seabirds, with some activity also possibly occurring on the mainland sandy beaches. In particular, the Proposal area is identified as a breeding BIA for the Fairy Tern and Wedge-Tailed Shearwater. The area represents migratory habitat for the Humpback Whale which is generally not relevant to BCH.

Seagrasses provide essential habitat and a food source for dugong, fish, turtles, and benthic invertebrates (Vanderklift et al. 2017). Macroalgae are consumed by herbivorous fishes, crabs, sea urchins, zooplankton and turtles. Algae also "leak" organic carbon into the water, where it is consumed by bacteria, in turn consumed by a variety of filter feeders (Borowitzka and Larkum 1986).

BCH such as seagrasses, macroalgae, coral reefs and filter feeders support a biodiversity of marine fauna that attract higher order predators for foraging such as coastal dolphins, turtles and sea snakes. Two (2) species of sea snakes, the short-nosed sea snake (*Aipysurus apraefrontalis*) and the leaf-scaled sea snake (*Aipysurus foliosquama*) are likely or known to exist within habitats found in the Proposal area (O2M 2025b). The Australian humpback dolphin is suggested to predominantly occur within shallower coastal waters likely associated with foraging opportunities at coral reefs and shoals (Hanf et al. 2022).

Key species of the inshore sector of the Northern Demersal Scalefish Fishery (also important species for recreational fishing) such as the blue-spot emperor (*Lethrinus hutchinsi*) are associated with reef habitats (Newman et al. 2004). The blue-spot emperor is common in nearshore reef habitats in the Pilbara and is commonly caught and discarded by commercial line fishers. Macroalgae habitat such as the *Sargassum* dominated reefs that were recorded in the Proposal area have been suggested to form an important stage of the lifecycle for the blue-spot emperor. The need to obtain more detailed information on crucial aspects of the biology of these key target species has been identified as a priority to rationalise appropriate conservation actions (Newman et al. 2004).

Table 31: Biologically Important Areas that spatially overlap with the Marine elements of the Proposal.

Species	Type	Marine Component
Humpback whale	Migration	Nearshore and offshore
Flatback turtle	Inter-nesting	Nearshore and offshore
Green turtle	Inter-nesting	Nearshore and offshore
Hawksbill turtle	Nesting	Offshore
Fairy tern	Breeding	Nearshore and offshore
Wedge-tailed shearwater	Breeding	Nearshore and offshore

8. Conclusion

The extensive habitat mapping and monitoring undertaken in this study establish a strong foundation for assessing project-related impacts on benthic communities. The dataset generated can be used to quantify changes in BCH over time, support cumulative impact evaluations, and contribute to the broader regional understanding of habitat stability and variability.

The subtidal BCH mapping and monitoring study made the following findings:

- Regnard Bay and the Cape Preston East area forms a wide, shallow embayment with a complex topography, showing evidence of tidal scour, reefal accumulation, and unstable tidal sand banks
- A total of 93,523 ha of seabed BCH was mapped, which included 56,105 ha bare sand, 3807 ha subtidal coral reef, 15,485 ha mixed filter feeders, 2,067 ha subtidal macroalgae, 2,441 ha seagrass and 924 ha mixed subtidal classes
- Although the types of BCH listed above are known to provide ecological value and are likely to support various marine fauna, they are ubiquitous along the Pilbara coastline
- The preliminary study to assess seasonal variations in vegetation cover within seagrass and macroalgae communities indicated little discernible environmental change in benthic habitat beyond seasonal fluctuations
- Targeted hard coral surveys determined that there has been a slight increase of macroalgal cover between the dry season of 2020 and the wet season of 2022, however, in general the community composition observed in other surveys (2012) remains intact
- Targeted seagrass surveys indicated that while overall seagrass coverage is very low, multiple species of seagrass can be found in the area, including *Cymodocea* sp., *Halodule* sp., *Halophia decipiens*, *Halophila ovalis*, *Halophila* sp., *Halophila spinulosa*, and *Syringodium* sp., and
- Surveys of the proposed offshore disposal ground and nearshore anchorages show areas of bare sediment and mixed filter feeder communities which are common in the Pilbara marine environment.

9. References

Abdul Wahab, M.A., Radford, B., Fromont, J.. (2019). *The diversity and distribution of mesophotic benthic invertebrates at Ningaloo Reef, Western Australia*. Mar. Biodiverse. 49, 2871–2886 (2019). https://doi.org/10.1007/s12526-019-01015-0

Althaus F., Hill N., Edwards L., Ferrari R. (2013). *CATAMI Classification Scheme for scoring marine biota and substrata in underwater imagery – A pictorial guide to the Collaborative and Annotation Tools for Analysis of Marine Imagery and Video (CATAMI) classification scheme*. Version 1, http://catami.org/classification; 20 June 2022.

Ashmore, P. E., and T. Gardner (2008), Unconfined confluences in braided rivers, in River Confluences, Tributaries and the Fluvial Network, edited by S. Rice, A. Roy, and B. L. Rhoads, pp. 119 – 143, Wiley, Chichester, U. K.

Bancroft K.P., Sheridan M.W. and Davidson J.A. (2000). *Developing broadscale habitat maps for the Montebello/Barrow Islands and the Dampier Archipelago/Cape Preston regions*. Data Report MRI/PI/MBI & DAR-34/2000. August 2000. Marine Conservation Branch, Department of Conservation and Land Management, Fremantle, Western Australia. (Unpublished report)

Blakeway D. and Radford B. (2005) 'Scleractinian corals of the Dampier Port and Inner Mermaid Sound: species list, community composition and distributional data', in Stoddart JA and Stoddart SE (eds) *Corals of the Dampier Harbour: their survival and reproduction during the dredging programs of 2004*. MScience Pty Ltd., Perth.

Borowitzka L.J., Larkum A.W.D. (1986) *Reef algae*. Oceanus 29:49-54

Bureau of Meteorology, 2025, Climate statistics for Australian locations, Mardie. http://www.bom.gov.au/climate/averages/tables/cw_005008.shtml

Breiman, L. (2001) Random Forests. Machine Learning, 45:5-32. Kluwer Academic Publishers. Manufactured in The Netherlands.

Brown, C.J., Smith, S.J., Lawton, P., Anderson, J.T. (2011). Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. Estuarine, Coastal and Shelf Science, 92:502-520.

CALM (2000) *Regional Perspective Dampier Archipelago / Cape Preston*. Department of Conservation and Land Management, Perth, Western Australia.

CALM (2005) *Indictive Management Plan for the proposed Dampier Archipelago and Cape Preston Marine Management Area*. Marine Conservation Branch: Department of Conservation and Land Management, Perth, Western Australia.

Campey M.L. and Gilmour J.P. (2000) *Baseline survey of benthic marine communities of Cape Preston and Preston Island*. Report prepared for Halpern Glick Maunsell Pty Ltd.

Chevron (2013) *State of the Marine Environment Baseline Surveys Report, Wheatstone Project*. Chevron Australia.

Chevron (2014) *Gorgon Project: Offshore Domestic Gas Pipeline Installation Management Plan: Summary*. Doc. No: G1-NT-PLNX0001302, Chevron Australia.

Chevron (2015) *Wheatstone Project Mid-term State of the Environment Report*. Chevron Australia.

DCCEEW (2022) *Conservation Values Atlas*, retrieved from: https://www.environment.gov.au/webgis-framework/apps/ncva/ncva.jsf, Accessed 20 June 2022. Department of Climate Change, Energy, the Environment and Water.

Eliot I., Gozzard B, Eliot M, Stul T and McCormack G. (2013) *Geology, geomorphology & vulnerability of the Pilbara coast, in the shires of Ashburton, East Pilbara and Roebourne, and the town of Port Hedland, Western Australia*. Report to The Western Australian Department of Planning by the Geological Survey of Western Australia, December 2013, Report 161-01-Rev 0.

EPA (2001) *Protection of Tropical Arid Zone Mangroves Along the Pilbara Coastline*. Environmental Protection Authority, Western Australia.

EPA (2016a) *Technical Guidance: Protection of Benthic Communities and Habitats*. Environmental Protection Authority of Western Australia, Perth, Western Australia.

EPA (2016b) *Environmental Factor Guideline: Benthic Communities and Habitats*. Environmental Protection Authority of Western Australia, Perth, Western Australia.

EPA (2021a) *Statement of Environmental Principles, Factors and Objectives*. Environmental Protection Authority of Western Australia, Perth, Western Australia.

EPA (2021b) *Technical Guidance Environmental impact assessment of marine dredging proposals*. Environmental Protection Authority of Western Australia, Perth, Western Australia.

Fisher, R., Hobgen, S., Mandaya, I., Riwu Kaho, N., Zulkarnain (2017) Satellite image analysis and terrain modelling: A practical manual for natural resource management, disaster risk and development planning using free geospatial data and software. SAGA GIS 4+, Version 2, June 2017, Copyright Charles Darwin University, Universitas Nusa Cendana dan Universitas Halu Oleo.

Florinsky, I. (2016). Digital terrain analysis in soil science and geology. Academic Press.

Florinsky, I. V. (2017). An illustrated introduction to general geomorphometry. Progress in Physical Geography, 41(6), 723-752.

Fossette, S., Loewenthal, G., Peel, L., Vitenbergs, A., Hamel, M., Douglas, C., Tucker, A., Mayer, F., and Whiting, S. (2021). *Using aerial photogrammetry to assess stock-wide marine turtle nesting distribution, abundance and cumulative exposure to industrial activity Remote sensing*, 2021, 13, 1116.

Fromont, J., Abdul Wahab, M.A., Gomez, O., Ekins, M., Grol, M., Hooper, J.N.A. (2016) *Patterns of Sponge Biodiversity in the Pilbara, Northwestern Australia*. Diversity 2016, 8, 21. https://doi.org/10.3390/d8040021

GHD (2012) *Cape Preston East Project: Marine Benthic Primary Producer Habitat Survey*. Report prepared for Iron Ore Holdings Ltd by GHD, December 2012.

GHD (2013) *Cape Preston East Project: Marine Benthic Community Assessment*. Report prepared for Iron Ore Holdings Ltd by GHD, Jan 2013.

Gilmour J.P., Cooper T.F., Fabricius K.E. and Smith L.D. (2006) *Early warning indicators of change in the condition of corals and coral communities in response to key anthropogenic stressors in the Pilbara, Western Australia*. Australian Institute of Marine Science

Google, CNES / Airbus, Landsat / Copernicus, Maxar Technologies (2022) Accessed 20 June 2022

Green, E., Mumby, P., Edwards, A., and Clark, C. (2000). Remote Sensing: Handbook for Tropical Coastal Management (United Nations Educational, Scientific and Cultural Organization (UNESCO)).

Hanf, D., Smith, J., Hodgson, A. J., Kobryn, H., Bejder, L. B. (2022) *Dolphin distribution and habitat suitability in coastal north Western Australia: Applications of a broadscale, opportunistic dataset.*

Hasan, R.C., Ierodiaconou, D. and Monk, J. (2012) Evaluation of four supervised learning methods for benthic habitat mapping using backscatter from multi-beam sonar. Remote Sensing, 4(11), pp.3427-3443.

Heap A.D. and Harris P.T. (2008) *Geomorphology of the Australian margin and adjacent seafloor*, *Australian Journal of Earth Sciences*, 55(4), 555-585.

Hedley, J.D., Harborne, A.R., and Mumby, P.J. (2005). Technical note: Simple and robust removal of sun glint for mapping shallow-water benthos. Int. J. Remote Sens. 26, 2107–2112.

Hossain, M.D., Chen, D. (2019) Segmentation for Object-Based Image Analysis (OBIA): A review of algorithms and challenges from remote sensing perspective. ISPRS Journal of Photogrammetry and Remote Sensing, 150, 115-134. https://doi.org/10.1016/j.isprsjprs.2019.02.009.

Huang, D., Licuanan, W.Y., Baird, A.H.(2011). *Cleaning up the 'Bigmessidae': Molecular phylogeny of scleractinian corals from Faviidae, Merulinidae, Pectiniidae and Trachyphylliidae*. BMC Evol Biol 11, 37. https://doi.org/10.1186/1471-2148-11-37

IOH (2012) *Cape Preston East Project: Section 38 Referral – Supporting Information Document*. Prepared by Preston Consulting and Iron Ore Holdings.

James N.P., Bone Y., Kyser T.K., Dix G.R. and Collins L.B. (2004) *The importance of changing oceanography in controlling late Quaternary carbonate sedimentation on a high-energy, tropical, oceanic ramp: north-western Australia*, *Sedimentology*, 51(6), 1179-1205.

Jones B. and Desrochers A. (1992) Shallow platform carbonates, in *Facies Models: Response to Sea Level Change*. Geological Association of Canada, Ontario, pp. 277-302.

Koenderink, J. and van Doorn. (1992) Surface shape and curvature scales. Image and Vision Computing, vol. 10, pp. 557-564,

LeBrec, U., Paumard, V., O'Leary, M. J., and Lang, S. C. (2021) *Towards a regional high-resolution bathymetry of the North West Shelf of Australia based on Sentinel-2 satellite images, 3D seismic surveys and historical datasets*, *Earth Syst. Sci. Data*, 13, 5191-5212.

LeBrec, U., Riera, R., Paumard, V., O'Leary, M.J., Lang, S.C. (2022) *Morphology and distribution of submerged palaeoshorelines: Insights from the North West Shelf of Australia*, *Earth Science Reviews*, 224, 103864.

LeProvost (2008) *Sino Iron Project Marine Management Plan*. Prepared for CITIC Pacific Mining Management Pty Ltd in association with LeProvost Environmental, GEMS, URS Australia and CP Mining Management Pty Ltd.

Lindsay, J.B. (2014). The Whitebox Geospatial Analysis Tools project and open-access GIS. Proceedings of the GIS Research UK 22nd Annual Conference, The University of Glasgow, 16-18 April, DOI: 10.13140/RG.2.1.1010.8962.

Lindsay, J.B., Cockburn, J.M.H., Russell, H.A.J. (2015) An integral image approach to performing multi-scale topographic position analysis. Geomorphology, 245: 51-61, doi: https://doi.org/10.1016/j.geomorph.2015.05.025

Lyne, V., Fuller, M., Last, P., Butler, A., Martin, M., Scott, R. (2006) *Ecosystem characterisation of Australia's North West Shelf*. Series: Technical report CSIRO. Marine and Atmospheric Research. North West Shelf Joint Environmental Management Study; no. 12.

Lyzenga, D.R. (1978) Passive Remote Sensing Techniques for Mapping Water Depth and Bottom Features. Applied Optics, 17, 379-383.

Marsh, L.M. (1997) 'Corals and other cnidarians', In: *Bowman Bishaw Gorman Survey of the intertidal shores of the eastern side of Barrow Island*. Report for West Australian Petroleum Pty Ltd by Bowman Bishaw Gorman and Murex Consultants.

Maunsell (2006) *Marine and Coastal Environmental Report*. Prepared for Mineralogy Pty Ltd by Maunsell, Perth, Western Australia.

MPRSWG (1994). A Representative Marine Reserve System for Western Australia. Report of the Marine Parks and Reserves Selection Working Group. Department of Conservation and Land Management, Perth, Western Australia.

Newman, D. R., Lindsay, J. B., and Cockburn, J. M. H. (2018). Evaluating metrics of local topographic position for multiscale geomorphometric analysis. Geomorphology, 312, 40-50.

Newman S. J, Young G. C and Potter I. C. (2004). *Characterisation of the inshore fish assemblages of the Pilbara and Kimberley coasts*. Department of Fisheries, Research Division, WA Marine Research Laboratories, North Beach.

O2M (2022a) *Eramurra Solar Salt Project: Metocean Field Data Collection Programme*. Report prepared by O2 Marine for to Leichhardt Salt Pty Ltd, Data Report R210219 RevD6.

O2M (2022b) *Eramurra Solar Salt Project: Sediment Analysis Report.* Report prepared by O2 Marine for Leichhardt Salt Pty Ltd by, Report Number: 19WAU-0027/R210087.

O2M (2025a) *Eramurra Solar Salt Project: Intertidal Benthic Communities and Habitat*. Report prepared by O2 Marine for Leichhardt Salt Pty Ltd, Report Number 19WAU-0027.

O2M (2025b) *Eramurra Solar Salt Project: Conservation Significant Marine Fauna Desktop Study.* Report prepared by O2 Marine for Leichhardt Salt Pty Ltd.

O2M (2025c) *Benthic Communities and Habitat Cumulative Loss Assessment Report*. Report in preparation by O2 Marine for to Leichhardt Salt Pty Ltd.

Olaya, V., Conrad, O. (2009) Chapter 12 Geomorphometry in SAGA. Developments in Soil Science, 33:293-308. DOI https://doi.org/10.1016/S0166-2481(08)00012-3

Olsen, Y. S., Mattio, L., Perez, A. Z., Babcock, R. C., Thompson, D., Haywood, M. D. E., Keesing, J., & Kendrick, G. A. (2019). *Drivers of species richness and abundance of marine macrophytes on shallow tropical reefs of north-western Australia*. Journal of Biogeography, 46(1), 170-184. https://doi.org/10.1111/jbi.13470

PHPA (2010) *South West Creek Dredging Approvals Benthic Habitats Survey Report*, 301012-01318-EN-REP-00016 October 2010.

Pisanti, A., Magri, S., Ferrando, I., Federici, B., (2022). Sea water turbidity analysis from Sentinel-2 images: atmospheric correction and bands correlation. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-4/W1-2022 Free and Open Source Software for Geospatial (FOSS4G) 2022 – Academic Track, 22–28 August 2022, Florence, Italy.

Pitcher, C. R., Miller, M., Morello, B., Fry, G., Strzelecki, J., McLeod, I., and Huisman, J. (2016). The Pilbara Marine Conservation Partnership.

Post, A.L., Wassenberg, T.J. and Passlow, V. (2006). Physical surrogates for macrofaunal distributions and abundance in a tropical gulf. Marine and Freshwater Research, 57(5), pp.469-483.

Preston Consulting (2022) *Eramurra Solar Salt Project: Environmental Scoping Document*. Prepared for Leichardt Industrials Pty Ltd by Preston Consulting Pty Ltd, 2022.

Richards Z.T. and Rosser N. (2012) *Abundance, distribution and new records of scleractinian corals at Barrow Island and Southern Montebello Islands, Pilbara (Offshore) Bioregion*, *Journal of the Royal Society of Western Australia*, 95, 155-165.

Riley, S. J., DeGloria, S. D., and Elliot, R. (1999). Index that quantifies topographic heterogeneity. Intermountain Journal of Sciences, 5(1-4), 23-27.

Simpson C.J. (1988) *Ecology of scleractinian corals in the Dampier Archipelago, Western Australia. Technical series (Western Australia*. Environmental Protection Authority); 1988, no. 23.

SKM (2008) *Cape Lambert Port B Development. Abundance and Distribution of Inter & Subtidal Benthic Habitats in the Cape Lambert Area: 2008 Survey*. Unpublished Report Prepared by SKM on behalf of Rio Tinto. September 2008. pp68. Sinclair Knight Merz.

Stehman, S. V., & Foody, G. M. (2019). Key issues in rigorous accuracy assessment of land cover products. Remote Sensing of Environment, 231, 1-23.

Stoddart, J.A. and Stoddart S.E. (Eds) (2005) *Corals of the Dampier Harbour: Their Survival and Reproduction During the Dredging Programs of 2004*. MScience Pty Ltd, Perth WA, 78pp.

URS (2008) *Cape Preston Benthic Habitats*. Unpublished report to CITIC Pacific Mining Management Pty Ltd by URS Australia Pty Ltd, Perth, WA. Report No. R1241, November 2008.

Vanderklift M., Bearham D., Haywood M., Lozano-Montes H., McCallum R., Mc Laughlin J., McMahon K., Mortimer N. and Lavery P. (2017) *Natural dynamics: understanding natural dynamics of seagrasses of the north west of Western Australia*. Report of Theme 5 - Project 5.3 prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 55 pp.

Veron, J.E., Marsh, L.M. (1988) *Hermatypic corals of Western Australia: records and annotated species list*, Records of the Western Australia Museum, No. 29.

Wicaksono, P., Wulandari, S.A., Lazuardi, W., Munir, M. (2021) Sentinel-2 images deliver possibilities for accurate and consistent multi-temporal benthic habitat maps in optically shallow water. Remote Sensing Applications: Society and Environment, 23, 100572 (https://doi.org/10.1016/j.rsase.2021.100572)

Wilson, J.P., Gallant, J.C. (2000): Primary Topographic Attributes. In: Wilson, J.P. & Gallant, J.C. [Eds.]: Terrain Analysis: Principles and Applications, John Wiley & Sons, p.51-85.

WorleyParsons (2009a) *Benthic Habitat Report: Dampier Marine Service Facility.* Prepared for Dampier Port Authority.

WorleyParsons (2009b) *Comparison of the Dampier Port Fringing Reef Benthic Community with nearby reef areas*. Unpublished Report to Dampier Port Authority, Dec 2009.

Yokoyama, R., Shirasawa, M., & Pike, R. J. (2002). Visualizing topography by openness: a new application of image processing to digital elevation models. Photogrammetric engineering and remote sensing, 68(3), 257-266.