# Eramurra Solar Salt Project

## Intertidal Benthic Communities and Habitat Report

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# Executive Summary

Leichhardt Salt Pty Ltd (LS) propose to develop the Eramurra Solar Salt Project (ESSP) in the Cape Preston East area, Western Australia (WA). The Proposal will produce high purity industrial grade sodium chloride salt from seawater via solar evaporation and crystallisation. Supporting infrastructure includes seawater intake, bitterns outfall, desalination plant and groundwater bores, power supply and other infrastructure.

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 for BCH 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 Eramurra Solar Salt Project in relation to intertidal BCH.

A desktop review has been undertaken to identify existing information available regarding the extent and distribution of intertidal BCH. This review identified the need for updated habitat mapping across the study area. A supervised classification of 3-band satellite imagery (Landsat) was undertaken to produce a preliminary BCH map across four established intertidal Local Assessment Units (LAUs). The boundaries of intertidal habitats and mangrove associations were then verified via ground-truthing infield surveys, which included analysis of data collected by aerial survey (via helicopter), and other studies such as quantitative and qualitative mangrove and fauna assessment, and algal mat sampling. The infield surveys were conducted in May 2020 and June 2021.

These studies resulted in the development of detailed intertidal BCH maps, showing the extent of BCH in an established series of LAUs across the proposed Ponds and Infrastructure Development Envelope (PIDE) and the Marine Development Envelope (MDE). The location of the PIDE and MDE suggests that most direct disturbance will occur in the central to eastern part of the intertidal study area (LAU2 – LAU4). This area predominantly comprises Terrestrial Vegetation (not intertidal BCH), inland mudflats, samphire shrubland and algal mats. A section of Regionally Significant Mangrove Area (RSMA) located within LAU1 and LAU2 occurs across both the PIDE and MDE.

In October 2024, addressing EPA comments, additional survey efforts were undertaken to enhance the spatial resolution and statistical validation of BCH within each intertidal LAU (LAU1 – LAU4). These surveys provided refined delineation of key habitats and improved the accuracy of BCH assessments. The updated mapping has contributed to a more precise understanding of habitat distribution and conditions.

The BCH assessment found that within the four established LAUs, the intertidal area was dominated by mudflats / algal mats, including both seaward (foreshore) and inland, this community made up approximately 2,157 ha or 17.0% of the study area. Other BCH with substantial coverage included samphires (10.9%) and mangroves (7.2%). Terrestrial Vegetation (not considered an intertidal community) was classified as 'other' for the purpose of this assessment and was included in broadscale mapping within LAUs. This community made up 53.5% of the four LAUs, a large portion of which will be directly impacted by the PIDE. Further details on Terrestrial Vegetation can be found in Phoenix (2025).

Mangrove assemblages, particularly the closed canopy (CC) functional group, represent the most productive, structurally complex and ecologically diverse BCH within the study area, and as such, they are deemed the most ecological significant BCH across the study area. This CC group are dominated by *Avicennia marina* communities (Am) and make up the greatest spatial area of mangrove (85% of overall mangrove). The Am3 (Scattered) association dominates the landward fringe comprising 50.2% of the total area of mangroves, followed by 25.9% for Am2 (Landward) and 17.1% for Am1 (Seaward Edge). The mixed association comprising *Rhizophora stylosa* and *A. marina (*Rs/Am) occupies 3.7% of the total area of mangroves. Approximately 85% of the total mapped mangrove habitat occurs within LAU1 (54.8%) and LAU2 (29.9%) which are located within the designated EPA RSMA #9 (EPA 2001). Mangrove communities were typically healthy with no signs of stress or anthropogenic impacts.

Fauna compositions within mangrove areas found a total of 1,095 organisms from seven taxa within 42 fauna quadrats at 21 individual sites. Recorded fauna counts were significantly higher within LAU4 (n – 949) when compared to LAU1 (n – 64) and LAU2 (n – 82). Overall, these results suggest that the dominant taxa were Mollusc (n-716) followed by Crustaceans (n-363) and *Periophthalmus* (mudskipper) (16). Interestingly, the mangrove structure at LAU4 is notably smaller and less complex than those found in LAU1 and LAU2. Fauna surveys for LAU1 and LAU2 were conducted in May 2020, while comparable surveys in LAU4 were undertaken in May 2021. It is likely that the recorded difference in organism numbers was a result of variable conditions (wind, heat, humidity, and sunshine), known to impact organism activity, rather than actual spatial variation.

Algal mat analysis identified six taxa recorded across the study area, dominated by filamentous cyanobacteria *Lyngbya sp*. then *Coleofasciculus chthonoplastes* and *Schizothrix spp*. Algal mats surveyed for this project were considered representative of other algal mat habitats within the Pilbara region, including the Mardie coastline (O2 Marine 2020a), Exmouth Gulf (Biota 2005) and south of Onslow (Paling 1990, URS 2010). Algal mats are known to play an important role in nutrient and carbon cycling. However, their overall significance on surrounding intertidal BCH is not well documented. O2 Marine undertook a nutrient flux study to investigate the role algal mats play on nutrient levels within mangrove and creek systems following tidal inundation. The results were largely inconclusive, with intra-site variability making conclusions difficult. Following completion of the WAMSI Mardie Salt Marine Research program (proposed for release mid 2025), contemporary information around the ecological role, value and function of algal mats will be incorporated into the Proposals EIA and management accordingly.

Mudflats were typically located immediately adjacent (both seaward and landward) of mangal communities and generally have 'Terrestrial Vegetation' as the landward limit. The most continuous and extensive Mudflat areas within the study area exist seaward of mangrove or beach/foredunes, extending out towards the intertidal macroalgae/seagrass/rock platform communities. These areas were generally classified as flat, fine sand with shell, and are predominantly devoid of biotic cover except for the occasional macroalgae and crab burrows. Samphire shrubland and samphire shrublands including Algal mat made up 1,815.3 ha or 10.1% of the intertidal study area, and was generally the most landward intertidal BCH, often found between inland mudflats and Terrestrial Vegetation.

## Acronyms and Abbreviations

| Acronym | Description |
|---|---|
| % | Percentage |
| °C | Degrees Celsius |
| AGB | Above-ground biomass |
| AHD | Australian height datum |
| Am1 | *Avicennia marina* Seaward Edge |
| Am2 | *Avicennia marina* Behind Am1 |
| Am3 | *Avicennia marina* scattered |
| Am/Ca | *A. marina / C. australis* (Scattered) |
| BCH | Benthic Communities and Habitat |
| BoM | Bureau of Meteorology |
| burrows/m$^2$ | Number of burrows per square metre |
| Ca | *C. australis* (Scattered) |
| CC | Closed canopy |
| CLA | Cumulative Loss Assessment |
| cm | Centimetres |
| CP | Cape Preston |
| CPA | Cape Preston East |
| DBCA | Department of Biodiversity, Conservation and |
| DBH | Diameter Breast Height |
| DNS | Did not survey |
| EIA | Environmental Impact Assessment |
| ENSO | El Nino Southern Oscillation |
| EP Act | *Environmental Protection Act 1986* |
| EPA | Environmental Protection Authority |
| EPBC Act | *Environmental Protection and Biodiversity Act 1999* |
| ESD | Environmental Scoping Document |
| ESSP | Eramurra Solar Salt Project |
| GDA | Geocentric Datum of Australia |
| GLpa | Gigalitres per annum |
| GPS | Global Position System |
| ha | Hectares |
| HAT | Highest astronomical tidal level |
| HDAM | High Density Algal Mat |
| HISF | High Intertidal Salt Flat |
| km | Kilometres |
| IOD | Indian Ocean Dipole |
| Km$^2$ | Square Kilometre |
| LAU | Local Assessment Unit |
| LAT | Lowest astronomical tidal |
| LDAM | Low Density Algal Mat |

| Acronym | Description |
|---|---|
| LS | Leichhardt Salt Pty Ltd |
| m | Metres |
| MDE | Marine Development Envelope |
| MGA | Map Grid of Australia |
| mm | Millimetres |
| MS | Ministerial Statement |
| mS/m | MilliSiemens per metre |
| $m^2$ | Square metres |
| $m^3$ | Cubic metres |
| MLWN | Mean Low Water Neap |
| MLWS | Mean Low Water Spring |
| MHWN | Mean High Water Neap |
| MHWS | Mean High Water Spring |
| MSL | Mean Sea Level |
| OBIA | Object-Based Image Analysis |
| P | Statistical *P*-value |
| PIDE | Pond and Infrastructure Development Envelope |
| PPA | Pilbara Ports Authority |
| QGIS | Quantum Geographic Information System |
| RF | Random Forest |
| Rs1 | *R. stylosa* (Continuous cover) |
| Rs2 | *R. stylosa* (Scattered) |
| Rs/Am | Mixed canopy *Rhizophora stylosa/Avicennia marina* |
| RSMA | Regionally Significant Mangrove Area |
| RTK | Real Time Kinematic |
| SC | Scattered community |
| SOI | Southern Oscillation Index |
| WA | Western Australia |
| WAMSI | Western Australia Marine Science Institution |

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# 1. Introduction

Leichhardt Salt Pty Ltd (Leichhardt) is seeking to develop the Eramurra Solar Salt Project (ESSP), a solar salt project east of Cape Preston, approximately 55 km west-southwest of Karratha in the Pilbara region of WA (Figure 1). The Proposal is an evaporative solar project that utilises seawater to produce raw salt as a feedstock for dedicated processing facilities that will produce a 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 Proposal content description is provided in Table 1 and the Proposal content elements (e.g. development, action, activities or processes) are summarised in Table 2. The Proposal development envelopes are shown in Figure 2.

Table 1: Short Summary of the Proposal

| | |
|---|---|
| **Project 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.<br><br>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 2 | 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 2 | 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 2 | Disturbance of no more than 100 ha within the 285 ha Dredge Spoil Disposal Development Envelope. |
| Operational Elements | | |
| Bitterns discharge | Figure 2 | 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 2 | Approximately 400,000 $m^3$ |

The export of salt is proposed 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 ESSP. The ESSP 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 360ppt salinity) will be generated in any given year and up to 0.59 GL (at 360ppt 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.

O2 Marine was engaged by the proponent to undertake marine environmental investigations to help identify environmental risks of the ESSP, 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.

## 1.2. Scope and Objectives

The scope of this report is to address the relevant work requirements outlined by Preston (2022) in the Eramurra Solar Salt Project - Environmental Scoping Document (ESD). Table 3 outlines the specific requirements from the ESD that are required to be covered by this Intertidal BCH report.

This document provides an account of the intertidal BCH of the Proposal area using desktop investigations and site-specific surveys. The report will provide a basis for an Environmental Impact Assessment (EIA) of the intertidal BCH, with reference to a range of proposal related information such as historical loss of BCH, coastal stability, hydrodynamic, groundwater and surface water modelling and engineering design.

Specific application of the desktop and survey data presented in this report includes:

- Description of the current understanding of the ecological role and value of the intertidal BCH in the Proposal area
- Preparation of detailed intertidal BCH maps and description of the effort in the field to ground-truth and validate the predicted distributions, and
- Review of any tenure, conservation, ecological or social values of the BCH that should be considered.

The specific objectives of this report are to address the ESD Items outlined within Table 3.

Table 3: Benthic Communities and Habitat Objectives from the Environmental Scoping Document – Eramurra Solar Salt Project, specific to the Intertidal region (Preston 2022).

| ESD Item | Requirement | Report Section |
|---|---|---|
| ESD Item 4. | Develop appropriate Local Assessment Units (LAUs) in consideration of:<br>a) Existing LAUs for the Sino Iron Project and Cape Preston East ports.<br>b) Distribution, extent and condition of benthic communities and habitat (BCH):<br>c) Management boundaries (e.g., Regionally significant mangrove areas).<br>d) Bathymetry; and<br>e) Coastal geomorphology. | Section 4<br>Figure 10 |
| ESD Item 5. | Undertake an intertidal habitat field survey to produce local and regional scale maps of algal mats, mangroves, samphire, and bare areas, as well as a list of species found. The survey will include:<br>a) Detailed mapping of the boundary of key habitat such as mangroves and algal mats.<br>b) Regional assessment of key habitat such as mangroves and algal mats to determine the importance of the habitats impacted by the Proposal.<br>c) Health assessment to determine the status of the habitat; and<br>d) Expert advice on the significance of the habitats impacted by the Proposal from a local and regional perspective. | a) Figure 13<br>b) Section 6<br>c) Section 6<br>d) Section 7 & 9 |
| ESD Item 6. | Revise design and subsequent Development Envelope boundaries if possible, to minimise direct impacts to key BCH. | Addressed in Cumulative Loss Assessment Report |
| ESD Item 7. | Conduct detailed intertidal BCH mapping within the LAUs to ensure that any impact calculations are accurate. | Figure 13<br>Appendix A |
| ESD Item 21. | Assess the likely dependency of the intertidal BCH on nutrient inflows from upslope/upstream and predict the impacts of changes in nutrient loading, to algal mat, mangrove, samphire and other intertidal BCH and include the predicted impacts in the BCH cumulative loss assessment described in Item 28. | Section 9 and Appendix F |
| ESD Item 23 | Identify any critical linkages between important marine fauna and sea and shore birds, and key BCH that are likely to be impacted. | Section 7 and 9 |
| ESD Item 27 | Provide figures of the proposed disturbance and predicted indirect impact to BCH; | Addressed in Cumulative Loss Assessment Report |
| ESD Item 29 | Assess the functional ecological values and significance of BCH in relation to arid-tropical mangrove communities (Guidance Statement 1 – Protection of Tropical Arid Zone mangroves along the Pilbara Coastline. (EPA, 2001b)). | Section 2 and Section 9<br>Potential impacts and influence to be assessed during the CLA Report |

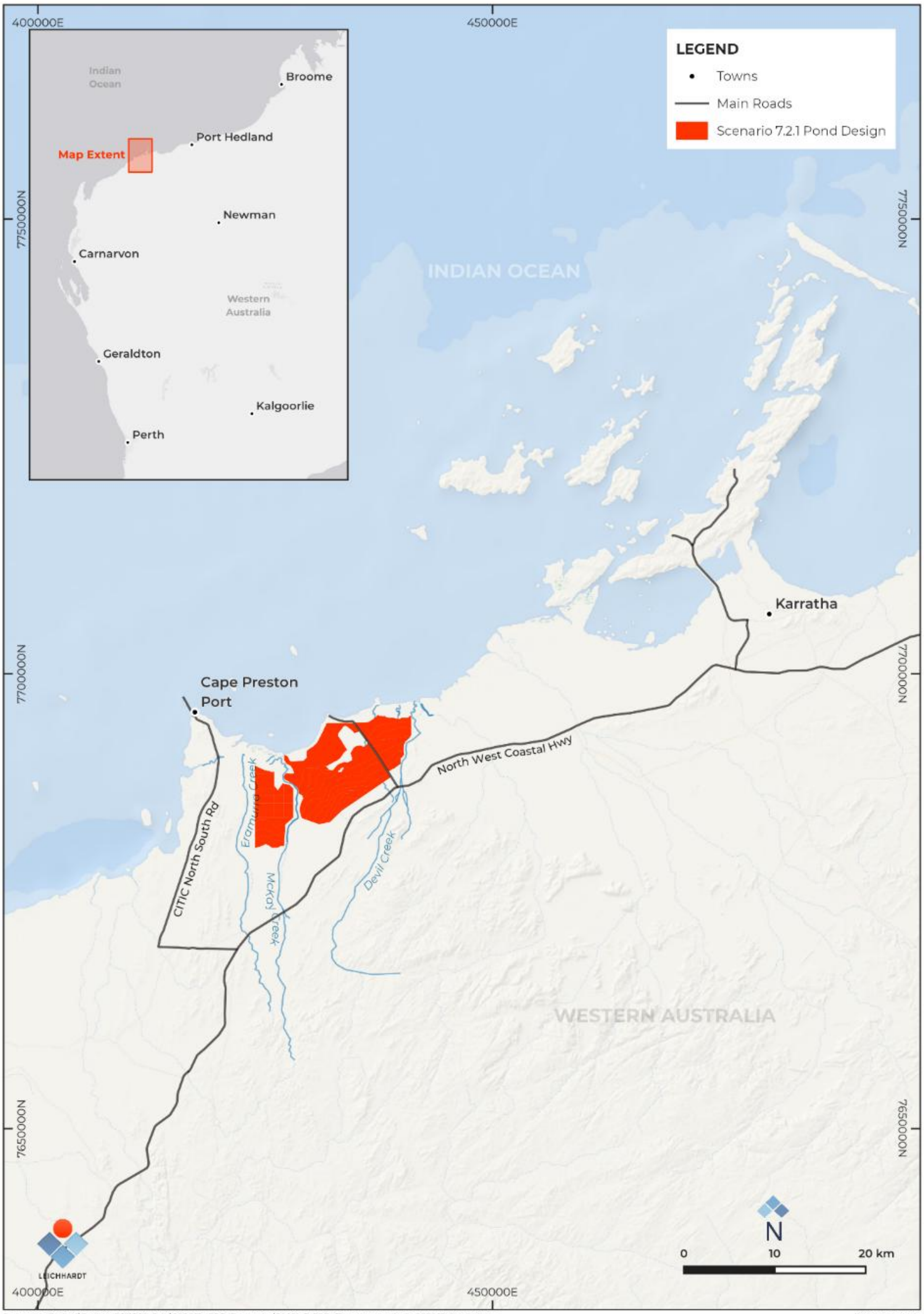
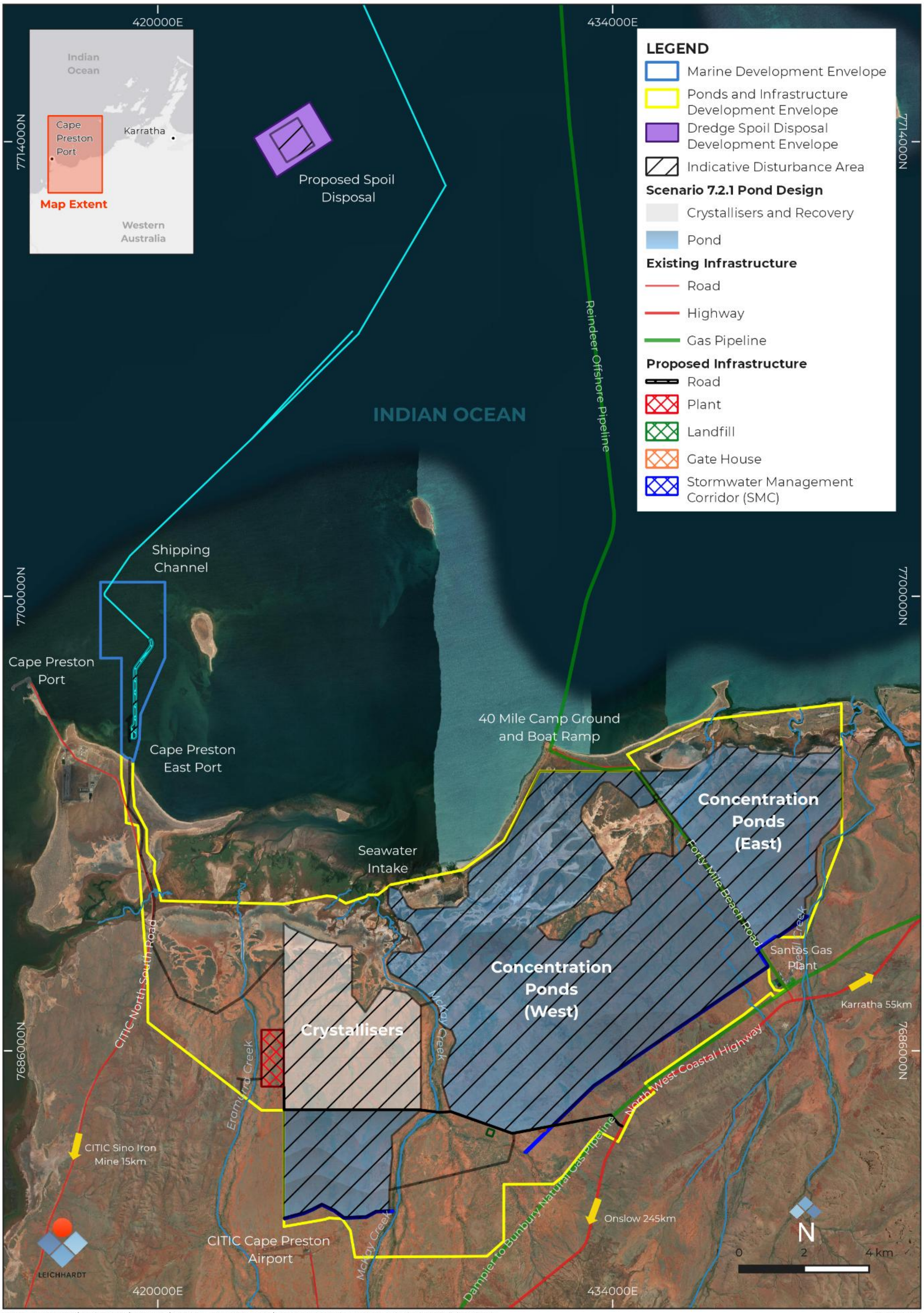



Figure 1: Regional Overview



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Created By: SamWilson

Figure 2: Proposal Development Envelopes

# 2. Tenure, Conservation and Social Values

## 2.1. Statutory and Policy Framework

In WA there are several legislative acts, both State and Federal, which guide the conservation of intertidal BCH. These include:

- *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act);
- *Environmental Protection Act 1986* (EP Act);
- *Biodiversity Conservation Act 2016* (WC Act); and
- *Conservation and Land Management Act 1984* (CALM Act).

## 2.2. Conservation Areas

In WA, the conservation of ecologically significant marine, estuarine or terrestrial ecosystems may be managed through reserves established under the *Conservation and Land Management Act 1984*. No conservation areas were identified within the ESSP study area. However, a designated Regionally Significant Mangrove Area (RSMA) does exist within the study area, and is discussed in Section 2.3.2. There are no implications from any of the proposed Commonwealth Marine Reserves for the ESSP Proposal due to the coastal location contained completely within state waters.

## 2.3. EPA Position and Guidelines

### 2.3.1. Benthic Communities and Habitats

The EPA have identified BCH as one of the key environmental factors that may be impacted by an aspect of a proposal or scheme requiring an environmental assessment under Part IV of the *Environmental Protection Act 1986*. EPA (2016) released the Environmental Factor Guideline – Benthic Communities and Habitats (EPA 2016a) with the objective to 'protect benthic communities and habitats so that biological diversity and ecological integrity are maintained.' To assist with the Environmental Impact Assessment process for BCH, the EPA developed Technical Guidance – Protection of Benthic Communities and Habitats (EPA 2016). EPA (2016) essentially sets out a framework for the assessment of proposals that may have a direct or indirect impact on BCH whilst outlining the principles required to be considered by a proponent when designing and developing projects, and during the impact assessment process. The guideline is spatially based and requires the establishment of Local Assessment Units (LAUs) to be identified for which BCH maps are developed and cumulative loss assessments undertaken based upon project specifics. The guideline identifies an eight-step process required for BCH assessment of a proposed development project.

This report has been developed to achieve steps 1-3 of this guideline which include:

1. Present the proposed LAUs (Figure 10, Section 4, Appendix A and Appendix B)
2. Spatially identify and map the current BCH present within proposed LAUs (Figure 17), Section 6, Appendices A, B, C and D)
3. Identify tenure caveats or conservation, ecological or social values (Section 2)

Steps 4-8 will be addressed in the ESSP Cumulative Loss Assessment Report (O2 Marine 2025); these steps included:

4. Spatially calculate BCH areas within proposed LAUs present prior to European settlement
5. Spatially assess present vs original BCH areas within proposed LAUs
6. Spatially calculate how much more BCH will be lost as a result of the Proposal
7. Spatially calculate the total amount of BCH loss as a result of the Proposal
8. What are the consequences for biological diversity and ecological integrity if the Proposal proceeds.

### 2.3.2. Regionally Significant Mangrove Area #9

The ESSP intertidal study area includes a section of mangrove that is considered regionally significant within the Pilbara region. This 'Regionally Significant mangrove Area #9" (RSMA #9) is outlined in the EPA Advice: Protection of Tropical Arid Zone mangroves Along the Pilbara Coastline (EPA 2001a), and spatially shown below in Figure 10. EPA (2001a) is a guidance statement developed by the EPA to provide advice to proponents, and the public generally, about the minimum requirements for environmental management which the EPA would expect to be met when the Authority considers a proposal during the assessment process. It specifically addresses the protection of tropical arid zone mangroves, habitats and dependant habitats along the Pilbara coastline, stretching from Cape Keraudren at the end of the Eighty Mile Beach to Exmouth Gulf (EPA 2001a). The guidelines contained within the Guidance Statement are based on a report titled Selection of mangrove Stands for Conservation in the Pilbara region of Western Australia – A Discussion (Semeniuk, 1997) (unpublished).

The designation of mangrove areas is based on the following criteria that address significance:

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

Semeniuk (1997) determined these areas to be of 'very high conservation value' based on coastal type, habitat, species diversity and plant form (EPA 2001a). RSMA #9 is ranked by Semeniuk (1997) to have: international, national and regional significance, unusual biodiversity or occurrence of uncommon species, and mangrove stands that explicitly exhibit mangrove/habitat relationships.

The remaining mangroves along this part of the Pilbara coast, although not "regionally significant", are also regarded as important and considered to be of high conservation value. As per EPA (2001a), four types of management areas have been identified for which guidelines have been prepared, they are summarised in Table 4.

Table 4: Mangrove management areas and associated guidelines (EPA 2001a).

| | Mangrove areas of very high conservation value (designated “regionally significant”) | Mangrove areas of high conservation value |
|---|---|---|
| Mangrove areas outside designated industrial and associated port areas | Guideline 1<br>Areas: 1, 2, 3, 4, 6, 7, 8, 12 13, 14, 16, 17, 18, 19, 20, 21, 22 | Guideline 2<br>All other mangrove areas outside designated industrial and associated port areas |
| Mangrove areas inside designated industrial and associated port areas | Guideline 3<br>Areas: 5, 9, 10, 11, 15 | Guideline 4<br>All other mangrove areas inside designated industrial and associated port areas |

RSMA #9 falls under Guideline 3 (Table 4), the objective of this guideline states: ‘*no development should take place that would significantly reduce the mangrove habitat or ecological function of the mangroves in these areas’* (EPA 2001b).

Under Guideline 3, proposals will be expected to meet the following performance objectives for an assessment of acceptability by the EPA:

- demonstrate a significant understanding of the mangrove systems, in terms of habitats, dependent habitats and ecological functions, which are likely to be affected if development is implemented;
- with the above understanding, evaluate how the mangrove system (the mangroves, habitats, dependent habitats, ecological function and ecological processes which sustain the mangrove habitats) would be affected and the environmental significance of any such impacts, including cumulative impacts;
- demonstrate that the proposed development adopts good engineering design and 'best practice' processes for minimising potential environmental impacts and maintains the ecological function and overall biological value and environmental quality of the area; and
- demonstrate that all feasible and prudent alternative (industry siting) to impacting detrimentally on mangroves have been considered.

This document identifies the intertidal BCH across the study area (including mangroves). It will discuss extent and percent coverage across LAUs and the study area, ecological function, and the significance of key BCH. The potential impacts to intertidal BCH as a result of the ESSP are discussed in the Cumulative Loss Assessment Report (O2 Marine 2025.

## 2.4. Social and Cultural Significance

Certain areas of the study area (e.g., Gnoorea Point) hold social value in relation to the regular recreational use of the area. Camping, fishing and birdwatching activities have been undertaken in this area for many years. It is not expected that the ESSP will have direct impacts on the camp grounds at Gnoorea Point. However, small impacts to recreational fishing/bird watching activities may result as part of the proposed development in the creek/mangrove area within LAU2. The remaining areas of impact are considered remote and unlikely to have impacts on social values of the area.

Stakeholder consultation outcomes and Cultural heritage importance of the site is covered separately in the Environmental Review Document and therefore not assessed herein.

# 3. Existing Environment

## 3.1. Overview

Regional factors that shape the coast include the coastal setting, climate, and tidal range. The coastal setting describes factors such as the coastal geomorphology and geology, Quaternary geological history, the relationship of the coast to the differing types of hinterland and oceanographic setting. These factors determine the coastal processes, the sediments, and the stratigraphy. Important aspects of the climate are rainfall, evaporation, cyclonic activity, and wind. Tidal range determines the extent of tidal habitat and coastal processes.

## 3.2. Climate and Wind

The Pilbara is an arid region with pronounced wet and dry seasons, influenced by the Indonesian-Australian monsoon and the meridional migration of the equatorial and subtropical pressure belts. The wet season (November-April) is characterised by high temperatures, higher than average rainfall, and lower atmospheric pressures (over the land). The dry season (May to October) is characterised by warm temperatures, clear skies, limited thunderstorm activity, very low rainfall, and higher atmospheric pressures. Over 1991-2020 the maximum daily temperatures at Mardie (closest available station with historic statistics) averaged 34.0 °C, with the monthly average peaking at 37.9 °C in January and falling to 28.3 °C in July (Figure 3).

During the southeast monsoon (approximately the dry season), winds are predominantly easterly to southerly, coincident with the trade winds (Figure 4). During the northwest monsoon (approximately the wet season) winds are predominantly west to south-westerly (Figure 4). These seasonal trends are modulated year-round by a diurnal land-sea breeze system, which intensifies in the wet season.

The region is exposed to tropical storms and cyclones during the wet season. The Karratha to Onslow coastline is the most-cyclone prone section of the Australian coast, with one cyclone making landfall every two years on average. Cyclones affecting the Pilbara typically form in the tropical waters between the Kimberley and the Timor Sea and intensify as they propagate westward and poleward, though tracks of significant cyclones impacting Cape Preston within the last 30 years are varied Figure 5. In addition to tropical storms, troughs of low pressure also bring rain, strong winds, and sharp changes in wind direction.

The annual average rainfall is only 315 mm, though this value can be exceeded in a single day during an extreme tropical storm (Figure 3). The mean monthly rainfall (top section in Figure 3) has a bimodal distribution with one peak in February and a second peak in June. Tropical storms dominate this first peak, while frontal systems from the south can contribute to the rainfall in the middle of the year. Very little rain falls between August and October (Figure 3). The maximum daily rainfall per month is displayed in the middle graph of Figure 3, while the monthly mean maximum daily temperature (red) and monthly mean minimum daily temperature (blue) are shown in the bottom graph.

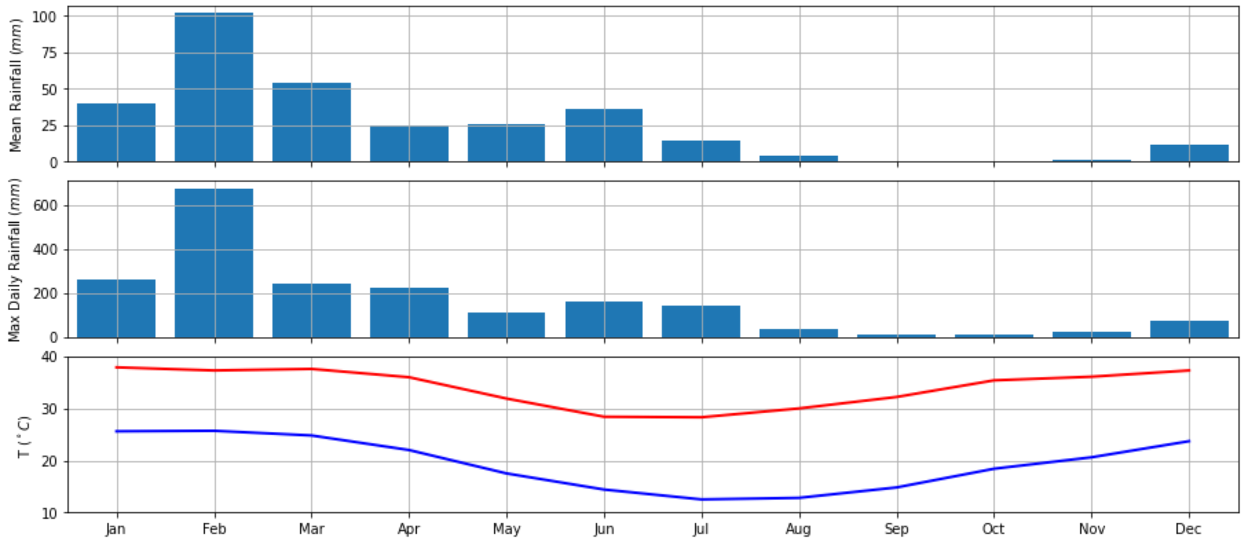



Figure 3: Climate Statistics for BOM Mardie weather station over ten years of 1991 to 2020.

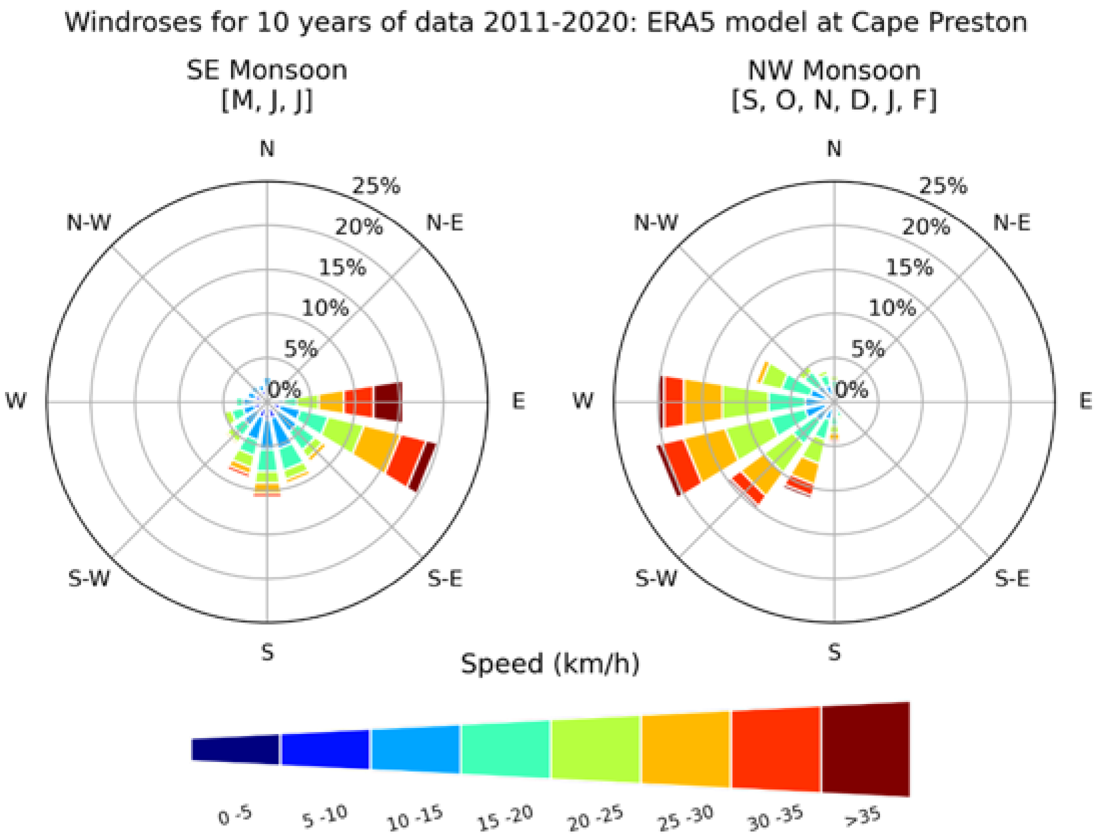



Figure 4: Wind Rose plots for SE Monsoon (left) and NW Monsoon Months (right) based on analysis of the 10 years of modelled data from near Cape Preston.

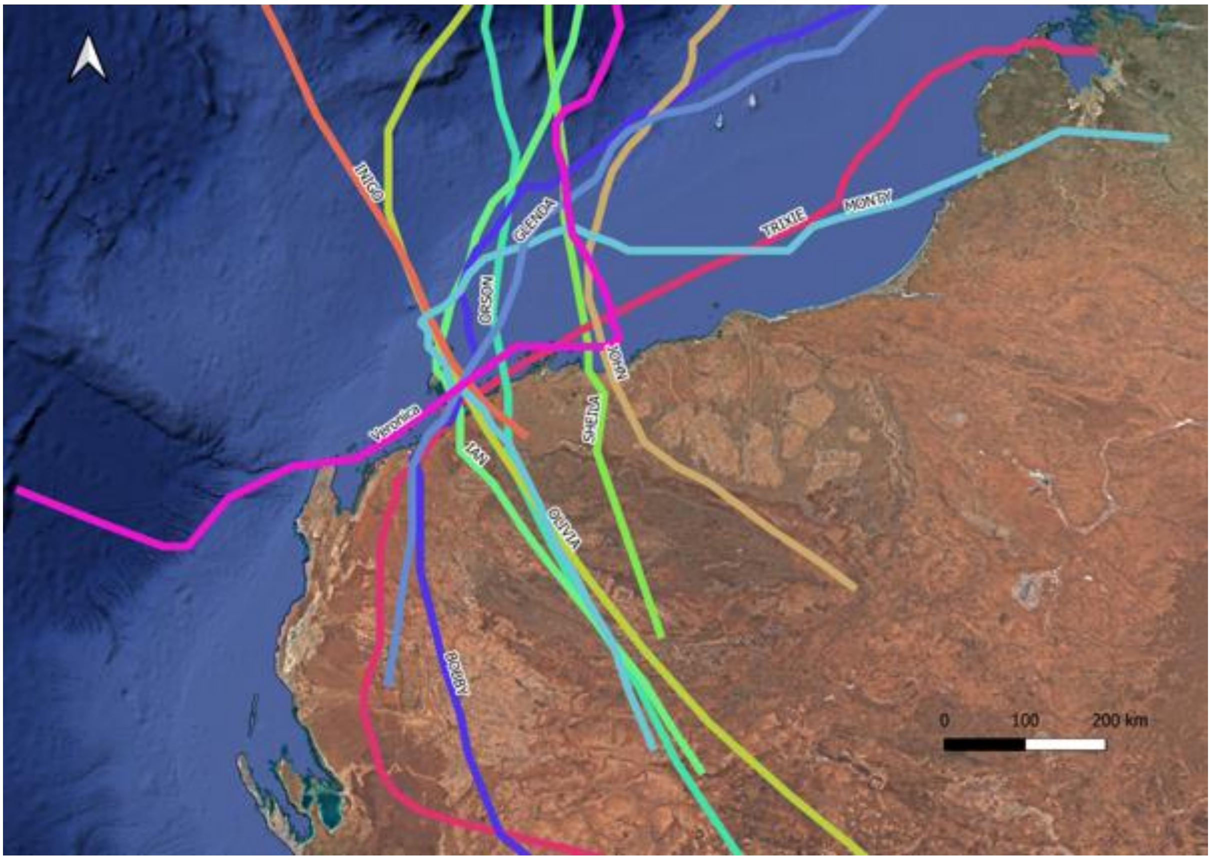



Figure 5: Tracks of notable cyclones impacting Cape Preston from the last 30 years.

### 3.2.1. Drivers of climate variability

Over short timescales (i.e., decades), the main driver of interannual climate variability in Northern Australia and the Pilbara region is the El Nino Southern Oscillation (ENSO). The positive phase of ENSO, known as La Nina, is characterised by a strengthening of the trade winds over the tropical Pacific (Figure 6). This intensification drives more warm water over the western Pacific, leading to less stable atmospheric conditions and increased rainfall over northern and eastern Australia, warmer than average conditions over the Cape York Peninsula, and cooler than average conditions over southern Australia. The negative phase, El Nino, has approximately opposite effects. Compared to the Pacific coast, the effects of ENSO over the Pilbara coast are less dramatic, and often less consistent, though La Nina years are linked to an increase in both the number and intensity of tropical cyclones in the Pilbara, despite distance from the direct effects of the Pacific Ocean trade winds.

The Indian Ocean Dipole (IOD) is another empirically defined oscillation which impacts interannual climate in the Indian ocean, modulating the effects of ENSO. A negative IOD reflects an intensification of the standard atmospheric circulation in the upper Indian Ocean. This is associated with warmer ocean temperatures and increased atmospheric instability over northern Australia, reinforcing La Nina conditions. Conversely, a positive IOD reflects a weakening or disruption to this circulation, associated with more stable atmospheric conditions over northern Australia, reinforcing the effects of El Nino.

The contemporary warming trend in the ocean and atmosphere (global warming) are another source of long-term climate variability, though significant effects are generally measured (and predicted) over timescales larger than the life of many engineering projects.

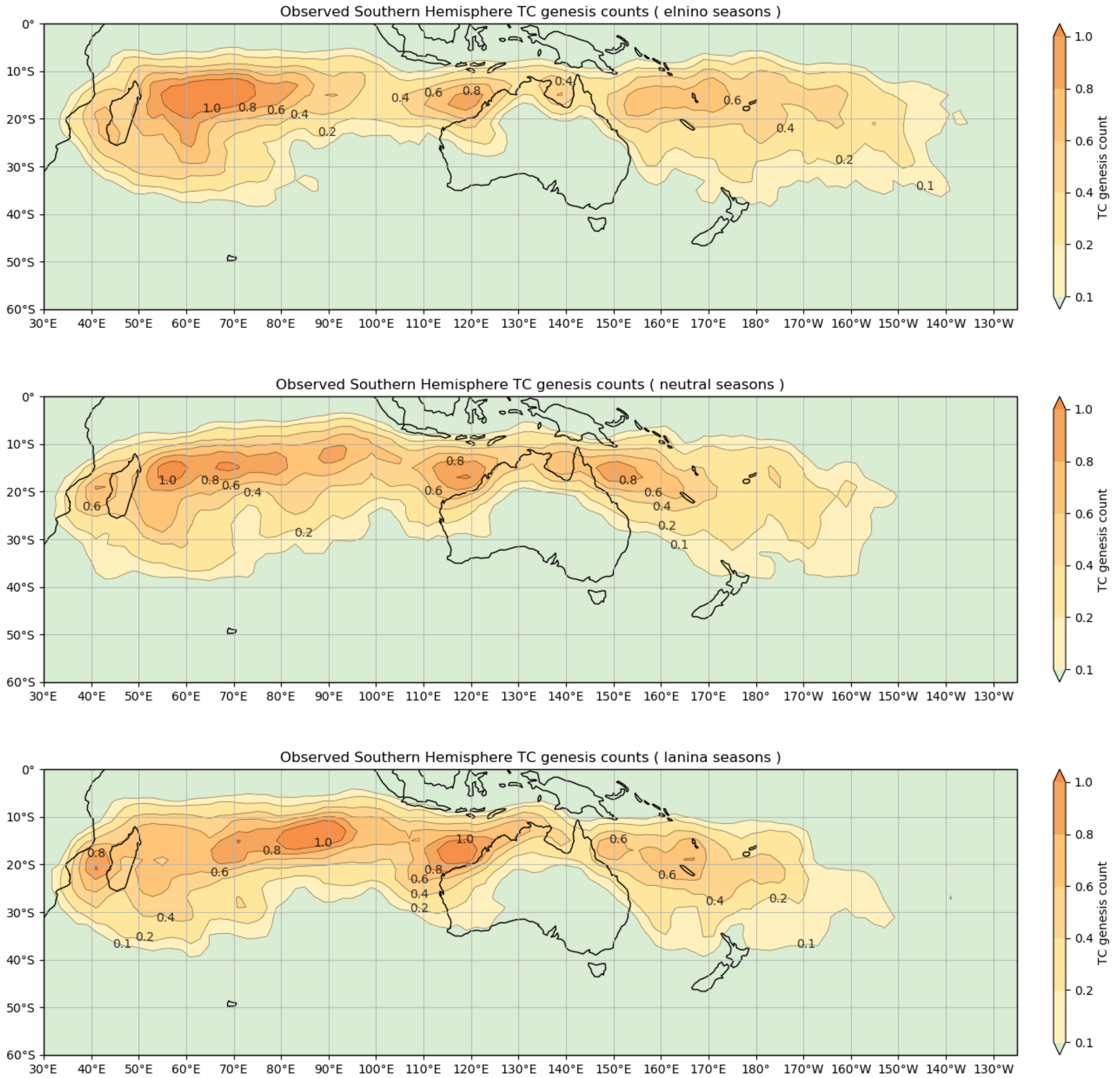



Figure 6: Tropical Cyclone genesis for El Nino (top), Neutral (middle) and La Nina (bottom) seasons (source: BOM 2022)

### 3.2.2. Temporal context of the present observations

The ENSO and IOD states for the recent period are shown in Figure 7 and Figure 8 respectively, with respect to longer term records of the indices. The 2020-2021 wet season was characterised by mild La Nina conditions and a neutral IOD, while the 2021 dry season was characterised by neutral ENSO conditions and a mild negative IOD. The Southern Oscillation Index (SOI) is one indicator of the state of the El Nino Southern Oscillation, with large positive conditions (blue region) indicating La Nina conditions, large negative values (red region) indicating El Nino conditions (Figure 7).

Despite the presence of La Nina, cyclone impacts in the Pilbara region were very mild during the 2020-2021 cyclone season. The only storms reaching cyclone classification were TC Marian (21 February – 9 March 2021), and the interacting systems Seroja (3 – 12 April 2021) and Odette (3 – 10 April 2021), though each of these reached full intensity far to the west of Cape Preston. In addition to these extreme events there were numerous other weaker tropical storms in the region (e.g., TL02U 6 – 12 December 2000; TL08U 15 – 23 January 2001, and TL12U 28 January – 5 February 2001).

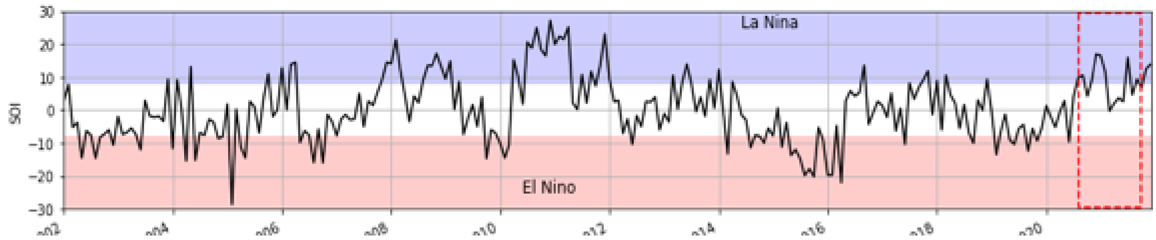



Figure 7: Monthly Southern Oscillation Index (SOI) from 2002 to 2021.

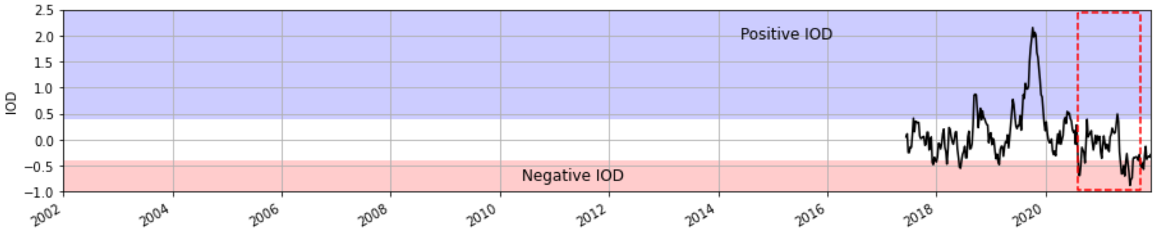



Figure 8: Monthly Indian Ocean Dipole Index from (IOD) 2017 to 2021.

## 3.3. Geomorphology

The Pilbara has a very broad continental shelf, ranging from around 100 km at the western extent to 300 km in the east. To the west (i.e., offshore from Barrow Island) the shelf breaks gradually onto the Exmouth Plateau, while in the east (i.e., offshore from the Rowley Shoals), the shelf breaks much more rapidly into deeper waters. Barrow Island, the Montebello Islands, and the shoals to the south of Barrow are significant features of the inner shelf that influence waves, tidal currents, and wind driven circulation in the region. Between North-West Cape and the Dampier Archipelago, many smaller islands lie inside the 30 m depth contour, providing further shelter for the coastline. These islands introduce heterogeneity in the ambient hydrodynamic conditions along the coast, which in turn promotes heterogeneity in the marine habitat.

Regnard Bay is bound by Cape Preston to the west and the Dampier Archipelago to the east. Offshore, the bay is bound by a series of islands (e.g., Southwest Regnard, Northeast Regnard and Eaglehawk Islands), the line of which mark a step change in bathymetry from the relatively shallow bay to the deeper waters offshore. Cape Preston has been extended and fortified by the construction of the Cape Preston marine offloading facility. The consequences for sediment fluxes into the bay are unknown.

LeBrec *et al*. (2021) characterise the seabed between the Regnard Islands and the 20 m isobath as a submerged sandplain. The authors do not characterise the bay itself, though the satellite derived bathymetry product of LeBrec *et al*. (2021) indicates several distinct systems of ridges within the bay. The region behind (i.e., to the south of) Southwest Regnard Island is particularly shallow, which is expected to introduce complex friction controlled tidal flows through the channel to the west.

The mainland Pilbara coastline is characterised by extensive beaches, mud flats, mangroves, and tidal creeks seaward of an ancient hard-rock terrain. Marine sediments are delivered and deposited through the action of wave and tides, while 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. Island coastlines are predominantly rocky marine sediments. A beach coastline stretches east from Cape Preston through to an intertidal sandbar connecting Great Sandy Island. Behind this sand bar, the shoreline consists of tidal creeks, mangrove habitat and extensive algal mats. Cyclones, and the associated extreme high-water levels, waves, and freshwater discharge are likely to be a significant driver of coastal geomorphic changes in the region (Elliot *et al* 2013).

## 3.4. Water levels

Water levels along the Pilbara coast are dominated by the semidiurnal lunisolar tides, with the eastern Pilbara classified as macro-tidal, and the western Pilbara as meso-tidal (Table 5). At the ESSP site the mean spring tide range exceeds 3 m, and the maximum tide range is approximately 4.5 m. The presence of Barrow Island and the shallow waters to the south strongly affect the westward propagation of semidiurnal and diurnal tidal energy, introducing complex non-linear tidal flows to the west of Barrow Island.

Wind, pressure and wave-setup in the Pilbara are typically low in comparison to the tidal variability, though they can be significant under tropical cyclone forcing, particularly in partially closed water bodies (i.e., marine embayment). Appreciable inundation of coastal areas occurs under these conditions, and wave action can be highly destructive. No long-term records of water levels within Regnard Bay to estimate peak storm water levels.

Table 5: Tidal Planes at Dampier, Barrow Island, Onslow and Cape Preston [datum mean sea level].

| Water level | Onslow [m] | Dampier [m] | Cape Preston [m] | Barrow Island West [m] | Barrow Island East [m] |
|---|---|---|---|---|---|
| HAT | 1.29 | 2.46 | 2.25 | 1.30 | 2.20 |
| MHWS | 0.85 | 1.76 | 1.71 | 0.89 | 1.50 |
| MHWN | 0.26 | 0.46 | 0.38 | 0.26 | 0.41 |
| MSL | 0 | 0 | 0 | 0 | 0 |
| MLWN | -0.25 | -0.46 | -0.38 | -0.25 | -0.40 |
| MLWS | -0.84 | -1.48 | -1.45 | -0.94 | -1.33 |
| LAT | -1.29 | -2.66 | -2.19 | -1.32 | -2.21 |

## 3.5. Ocean Currents

Instantaneous currents on the inner shelf are dominated by barotropic tides, with wind-driven currents, steric currents and continental shelf waves playing a lesser role (Godfrey and Mansbridge, 2000; Condie and Andrewartha, 2008; Ridgway and Godfrey, 2015; Sun and Branson, 2018). Persistent large-scale currents (e.g., the Holloway current) are typically constrained to water depths greater than 100 m. Sub-tidal circulation is seasonally variable, and driven predominantly by winds (Condie and Andrewartha, 2008). During the wet season these low-frequency wind-driven currents typically flow towards the east, while in the dry season they typically flow towards the west.

## 3.6. Waves

Waves on the Pilbara shelf can be broadly classified into three primary generation mechanisms: Southern Indian Ocean swell, locally generated wind-waves, and tropical cyclone waves. Indian ocean swells lose appreciable energy as they refract around Northwest Cape and onto the Northward facing Pilbara coastline. Though consistently mild, this swell climate is stronger in the dry season owing to stronger Indian Ocean swells in the winter months. Non-cyclonic waves are thus dominated by high-frequency wind waves. These seas vary appreciably in magnitude, period, and direction along the Pilbara coastal waters, but typically have a north-westerly aspect in the wet-season, and a north-easterly aspect in the dry season (Figure 9). The largest waves are associated with cyclone forcing, and again vary greatly across the coast, influenced by the proximity, intensity, and travel speed of the cyclone.

Little is known of the wave climate within Regnard Bay itself, though it is expected that the Cape, Archipelago and Regnard Islands would provide some natural protection from waves propagating onshore. Shoaling and dissipation of waves will vary appreciably as a function of the tide. The impact of cyclonic waves on the study site will be dependent on the storm-enhanced water level.

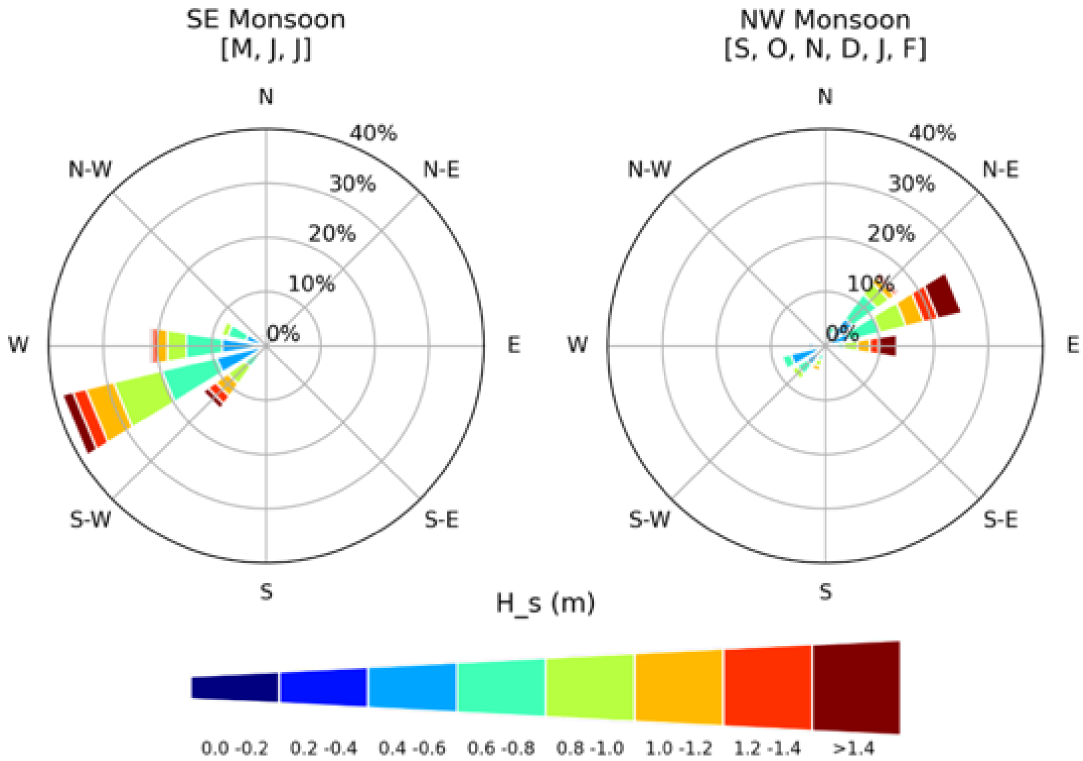



Figure 9: Wave conditions offshore of Cape Preston for the SE Monsoon (left) and NW Monsoon (right) based on 10 years of modelled data.

# 4. Local Assessment Units

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

- Existing LAU boundaries for the Sino Iron Project and Cape Preston East Port
- Regionally significant mangrove management area boundaries
- Coastal geomorphology
- Bathymetry
- Aspect (direction the coastline faces) as relevant to exposure, and
- BCH type and condition.

A total of 12 LAUs were developed for the Proposal, four of which (LAU1 – LAU4) are relevant to the intertidal zone based on the above criteria and the results identified through the BCH mapping and field survey ground-truthing. Table 6 provides the area for each of the proposed intertidal LAUs, including a percentage of the overall study area. Figure 13 displays all intertidal LAUs for the Proposal. Detailed, individual figures of each intertidal LAU (LAU1 – LAU4) are included in Appendix A.

Table 6: Spatial areas for each proposed intertidal LAU in hectares and their percentage of the intertidal study area.

| | LAU1 | | LAU2 | | LAU3 | | LAU4 | | Intertidal Study Area | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % | ha | % |
| Area | 5,918 | 33% | 3,787 | 21% | 4,481 | 25% | 3,771 | 21% | **17,956** | **100%** |

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

- LAU1:
  - Intertidal BCH area (5,918 ha)
  - Existing LAU and mangrove protection area #9 boundary
  - Incorporates a west and north-east facing coastline and wraps around Cape Preston
  - LAU is characterised by a large river delta system in the lower western edge and two smaller river deltas in the north-east. The river delta in the north east becomes mudflats and then algal mats in the central to lower east boundary
  - A large portion of the LAU is terrestrial vegetation, including coastal sand dunes and spinifex sandplains
  - BCH is characterised by mangrove communities along the main rivers and delta, which is supported by thin ribbons of samphire and surrounded by algal mats and mudflats/saltflats inland and an intertidal bay with extensive foreshore mudflats.

- LAU2:
    - Intertidal BCH area (3,787 ha)
    - Predominantly north facing coastline
    - Northern boundary is determined by the -5m LAT bathymetry isobath
    - Eastern boundary is determined by the extent of the main mangrove community occurring within the sheltered bay behind Gnoorea Point and Great Sandy Island and the eastern extent of the river delta system occurring here
    - BCH is characterised by mangrove communities along the main rivers and delta, which are supported by thin ribbons of samphire and surrounded by algal mats and mudflats/saltflats inland and an intertidal bay with extensive foreshore mudflats
    - A series of terrestrial islands interspersed with the algal mat and mudflats/saltflats in the eastern central portion, and
    - Mangrove BCH typically declines with distance east.
- LAU3:
    - Intertidal BCH area (4,481 ha)
    - Coastal aspect is north-west up to Gnoorea Point and then north to the eastern border
    - Southern border typically follows the southern extend of intertidal zone
    - LAU characterised by a low-lying area of algal mats and mudflats/saltflats interspersed with terrestrial islands through the centre. A sandy beach and rocky shoreline extends from the west to the east, with a thin mangrove fringe extending approximately 50% of the north western facing shoreline up to Gnoorea Point
    - A large portion of the LAU comprises terrestrial vegetation including a long sand dune complex along the full northern shoreline and spinifex sandplains throughout the central terrestrial islands and along the landward extent of intertidal BCH.
- LAU4:
    - Intertidal BCH area (3,771 ha)
    - Coastline typically faces north with an anvil shaped headland in the far west
    - Southern boundary typically follows the southern extend of intertidal zone, whilst the eastern zone completes the LAU past the development envelope
    - LAU comprises a series of small intertidal creeks which drain into low lying mudflats and algal mats along the southern extents
    - Mangrove communities occur along the edges of intertidal creeks and the foreshore from the western headland to the eastern border
    - The central portion of the LAU is characterized by extensive algal mats and mudflats/saltflats with some terrestrial islands in the western half and a fresh water river delta in the east. BCH is similar to LAU1, however tidal creek systems become increasingly complex in the south and support more extensive mangrove communities which are interspersed by samphire communities
    - Terrestrial coastal sand dune communities occur along the northern coastline between intertidal rivers and mangroves, whilst spinifex sandplains occur landward of mudflats/saltflats.

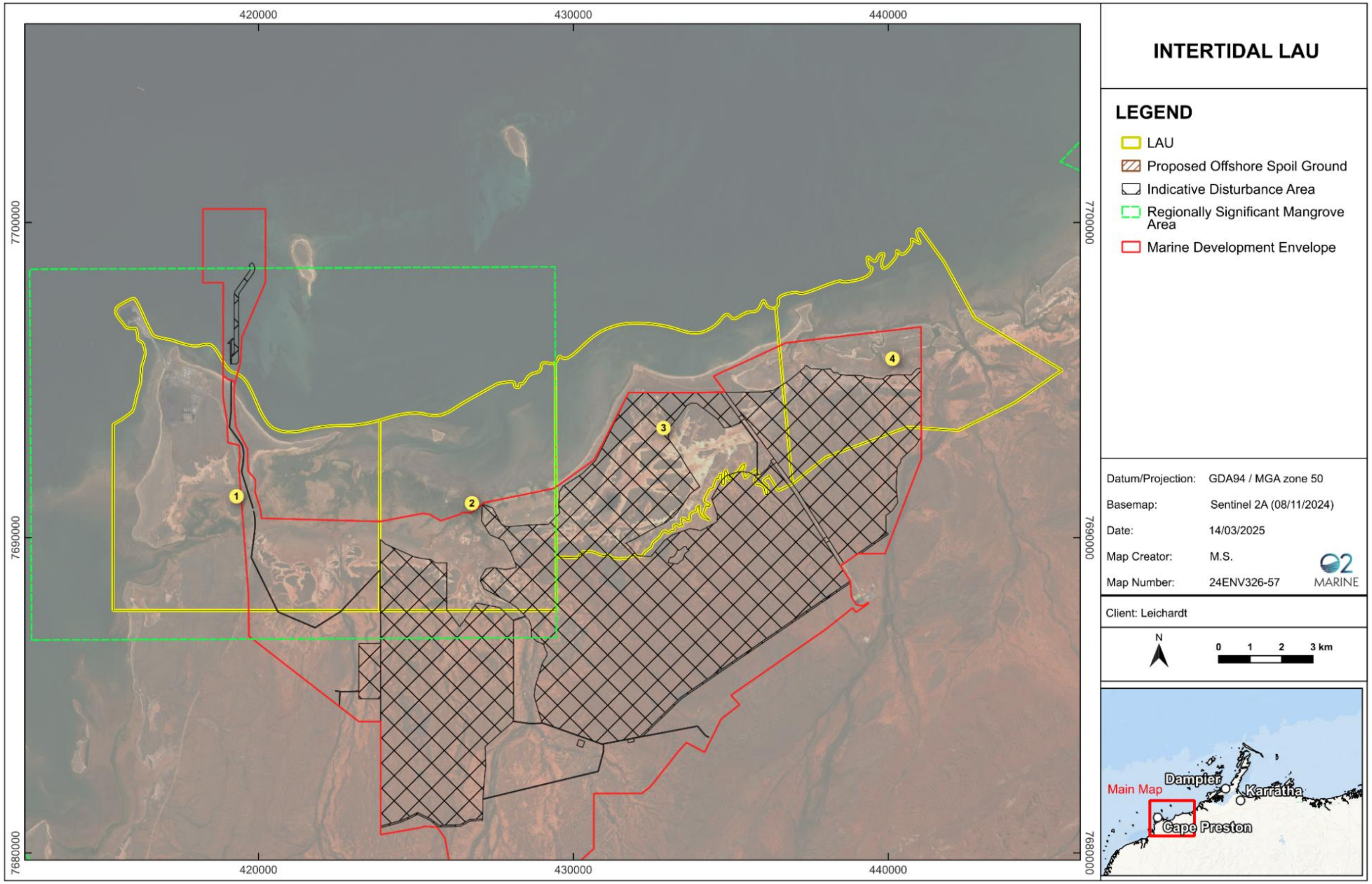



Figure 10: Intertidal LAUs and Regionally Significant Mangrove Area #9.

# 5. Survey Methodology

## 5.1. Study Area

The assessment of intertidal BCH primarily focusses on the coastal zone extending from the existing Sino Iron causeway in the west and extending east along the northern shore to the Strelley River West in the east. This intertidal area has been assessed through four LAUs. RSMA #9 is located across two LAUs in the west of the study area. Within this management area exists the Cape Preston Causeway Management Unit[1] which extends from Bangemall Creek in the west to Eramurra Creek in the east and is presented in Figure 13 as LAU 1. LAU 2 – LAU4 extend to the eastern extent of the development footprint and incorporate the strip of coastline from the foreshore mudflats of the lowest astronomical tidal level (LAT) to the intertidal habitats of highest astronomical tidal level (HAT). This intertidal zone typically extends ~5 km north to south within each LAU.

Figure 1 presents the study area regional location, and Figure 10 provides an overview of the study area, proposed intertidal LAUs, and the proposed indicative disturbance footprint.

## 5.2. Desktop Review

LS commissioned several studies to characterise, map and understand the environmental value and significance of intertidal BCH within and adjacent to the Proposal area. This information was also used to inform and optimise Proposal design, to ensure minimal impact on intertidal BCH.

O2 Marine completed a comprehensive desktop review of the intertidal BCH in the Study area as a preliminary component of this investigation, using information derived from surveys undertaken for previous coastal development projects in the Pilbara, relevant scientific journal literature on intertidal BCH in the Pilbara region, and other studies commissioned by Leichhardt Salt as part of the Project development.

Studies completed as part of the Proposal that were reviewed during the preparation of this report included:

- Phoenix (2025). Detailed flora and vegetation survey of the Eramurra Solar Salt Project. Phoenix Environmental Sciences Pty Ltd, Osborne Park, WA. Report prepared for Leichhardt Salt Pty Ltd
- Phoenix (2023). Detailed terrestrial fauna and Migratory Shorebird surveys for the Eramurra Solar Salt Project. Phoenix Environmental Sciences Pty Ltd, Osborne Park, WA. Report prepared for Leichhardt Salt Pty Ltd
- O2 Marine (2022a). Eramurra Solar Salt Project – Turtle Nesting Study. Prepared for Leichhardt Salt Pty Ltd
- O2 Marine (2022b). Eramurra Solar Salt Project – Metocean Data Acquisition Report. Prepared for Leichhardt Salt Pty Ltd, and
- O2 Marine (2022c). Eramurra Solar Salt Project – Coastal Inundation Studies. Unpublished report prepared for Leichhardt Salt Pty Ltd.

[1] Management Units are now referred to as Local Assessment Units

Recent project development impact assessments that have occurred within similar coastal environments within the local Pilbara region included:

- Mardie Project Environmental Impact Assessment (Preston Consulting, 2020) including the Intertidal BCH and Cumulative Loss assessment technical appendices (O2 Marine, 2020a and O2 Marine, 2020b)
- Cape Preston East – Multi Commodity Export Facility Environmental Impact Assessment – (Preston Consulting, 2012)
- Gorgon Domestic Gas Pipeline Mainland Environmental Impact Assessment – Chevron (2015)
- Wheatstone Project Environmental Impact Assessment (URS, 2010)
- Onslow Solar Salt Project Environmental Impact Assessment (Paling, 1990), and
- Yannarie Salt Project Environmental Impact Assessment (Biota, 2005).

The above documents and other relevant literature were reviewed to achieve the following aims:

- Identify existing and historical mapping of the Proposal area, adjacent potentially impacted areas, and reference areas to temporally and spatially characterise the known distribution of intertidal BCH within the study area;
- Identify data gaps, and determine if further surveys are required for the Proposal approvals;
- Identify if any or all the intertidal BCH has tenure caveats or conservation, ecological or social values that should be considered;
- Identify previous developments that may have resulted in historical loss of intertidal BCH in the Proposal area; and
- Evaluate the environmental values and significance of intertidal BCH of the Proposal area.

### 5.2.1. Desktop Review of Intertidal Surveys

#### 5.2.1.1. Previous Intertidal BCH Surveys

Previous intertidal studies undertaken in the area largely focused on areas to the west of Cape Preston, or along the tip of the Cape Preston peninsular. HGM (2001) undertook a biological study for Austeel Pty Ltd as part of their iron ore mine and export project, which included the assessment of terrestrial vegetation and fauna communities around Cape Preston. Whilst the studies focussed on terrestrial areas, broad mapping of intertidal areas stretching approximately 2 km west of Cape Preston was completed to include bare beaches, tidal mud flats, foredunes and backing dunes and mangals. The small amount of mangroves surveyed during this study were found to be dominated by *Avicennia marina* and/or *Rhizophora stylosa,* which were observed to be in very good to excellent condition (no sign of disease, yellowing leaves or anthropogenic impacts). Bancroft et al. (2000) provides broadscale mapping of mudflats, salt marsh and mangrove communities along a large stretch of coastline from Fortescue River to Point Sampson (east of Karratha). The study identifies high level shoreline habitats comprising of beach, beach plus rocky shores, and mangal in the area stretching from west of Cape Preston through to 40 Mile Beach.

#### 5.2.1.2. Desktop review results

The desktop review identified that further investigations into the environmental values and significance of the more structurally complex intertidal BCH would be required for Proposal approvals (i.e. mangrove and samphire communities). In addition, a nutrient study was designed to quantify the importance of algal mats with respect to their significance of nutrient export into the surrounding marine environment to support primary productivity and the nearshore food web.

O2 Marine were commissioned to undertake two targeted mangrove and algae BCH investigations and a nutrient flux investigation, as well as refining and validating existing BCH mapping data for the purposes of facilitating environmental impact assessment.

## 5.3. Intertidal BCH Mapping

In October 2024 further survey effort was completed to enhance the spatial resolution and statistical validation of BCH within each intertidal LAU (LAU1 – LAU4). This survey provided refined delineation of key habitats and improved the accuracy of BCH assessments. The updated mapping has contributed to a more precise understanding of habitat extent and distribution.

This predictive habitat mapping study utilised a supervised classification approach involving an extensive multi-stage workflow (Figure 11). Supervised classification techniques make use of artificial intelligence algorithms to statistically compare environmental predictor layers, such as satellite imagery, with known locations of ecological interest. This 'bottom-up' approach utilizes *in situ* ground-truthing data to organise and segment spatially continuous environmental data, allowing classification at precise taxonomic levels, from specific species to broader biotopes (Breiman, 2001; Brown et al., 2011; Hasan et al., 2012). A series of background environmental layers were compiled, derived from Sentinel 2 satellite imagery. High resolution drone imagery was also obtained in order to construct a ground-truthing dataset to verify the distribution of intertidal and terrestrial habitats of interest.

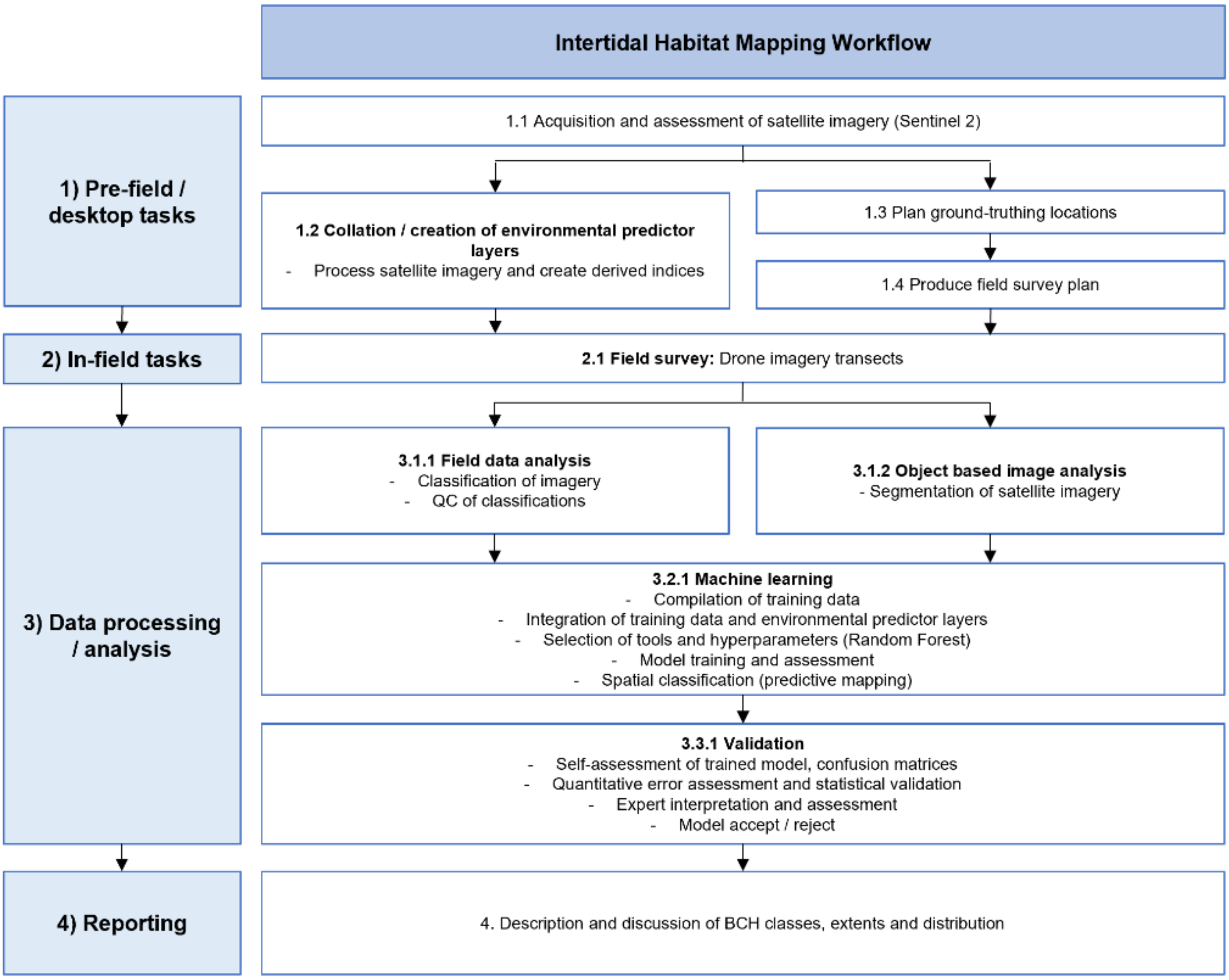



Figure 11: Workflow used for predictive habitat mapping of the onshore environment

### 5.3.1. Field Data

#### Acquisition

Aerial drone photography was conducted in October 2024 to collect ground-truthing data for validating intertidal habitat mapping. Fifteen drone missions were undertaken across intertidal zones within LAU1 – LAU4 (Figure 13) (Table 7). A transect approach was identified as the most effective method for capturing imagery of different habitat types, with flight paths positioned perpendicular to the elevation contours. Imagery was collected across areas approximately 1500 m in length and 200 m in width, ensuring adequate image overlap for orthomosaic generation. The drone used for the survey was a Phantom 4 Real Time Kinematic (RTK) (Figure 12).

Figure 12: Drone used in field survey - Phantom 4 RTK

Table 7: Dates of acquisition of drone imagery transects

| Date | Flight missions |
|---|---|
| **19/10/2024** | LAU2-1, LAU2-2, LAU2-4, LAU3-2, LAU3-3, LAU3-4, LAU4-1 |
| **20/10/2024** | LAU3-1, LAU4-3, LAU4-2, LAU4-4 |
| **23/10/2024** | LAU1-3, LAU1-2, LAU1-1 |
| **24/10/2024** | LAU1-4 |

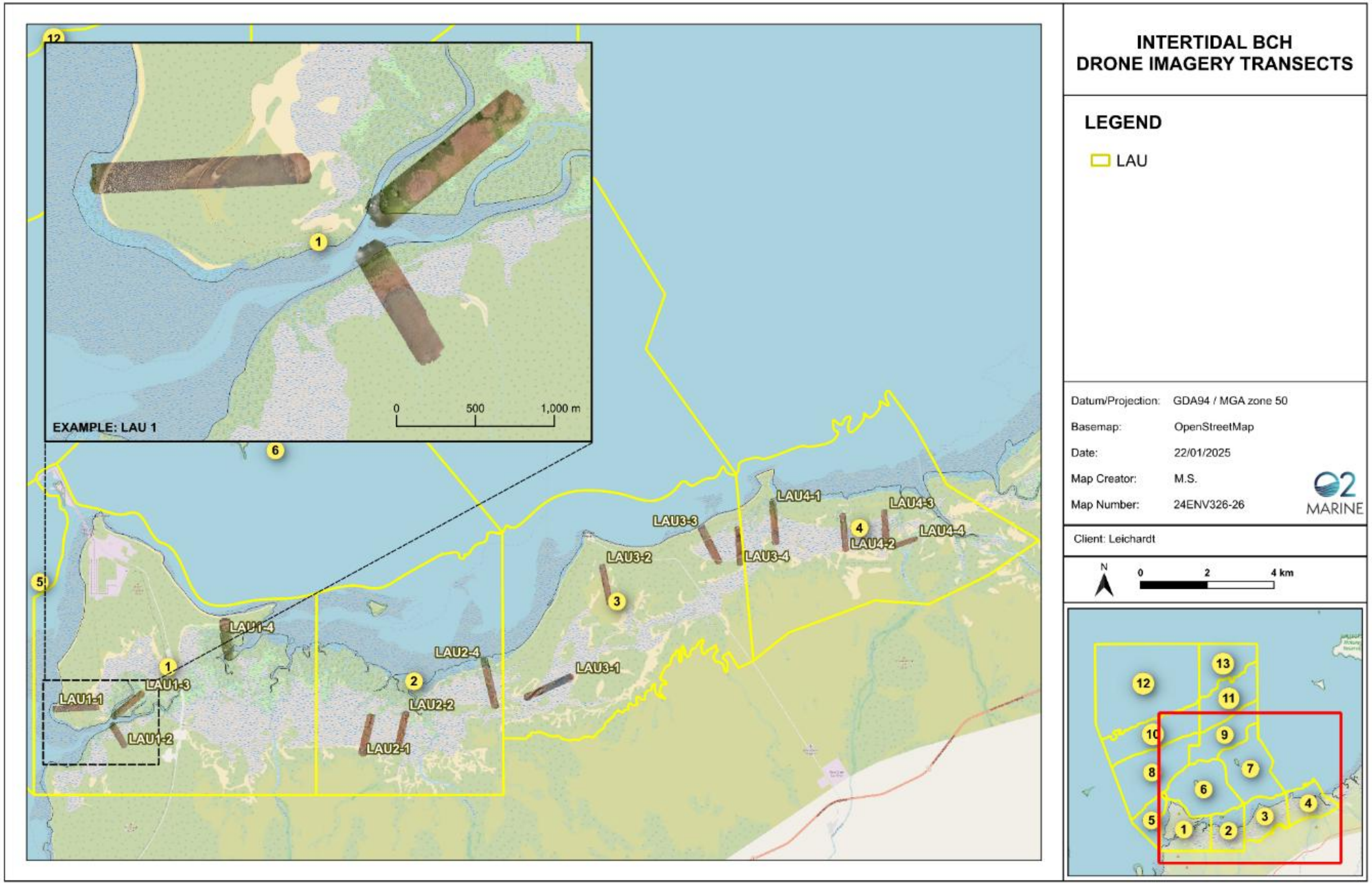



Figure 13: Drone survey effort over the study area (LAU1, LAU2, LAU3, LAU4) in October 2024.

## Imagery Processing

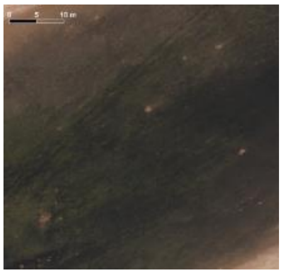
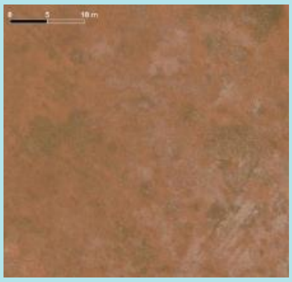
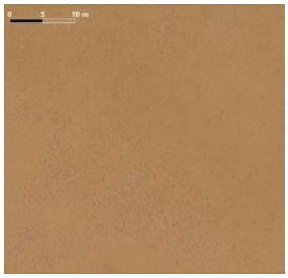
Images from each flight were imported into the processing software Pix4D Fields to generate orthomosaics. Following generation and QC of outputs. Orthomosaics were exported at a high resolution (2 cm) and georeferenced to Geocentric Datum of Australia (GDA94) Map Grid of Australia (MGA) Zone 50.

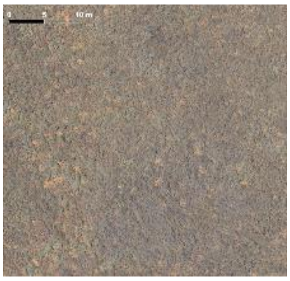
## Imagery Analysis

For each orthomosaic, three transects were created, each approximately 1300 m long and spaced 60 metres apart. Along these transects, 20 x 20 m 'windows' (example in Figure 14) were classified according to the categories outlined in Table 8.

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

Table 8: Classifications assigned to drone imagery

| Group | Class | Description | Example Image |
|---|---|---|---|
| Algal Mat | High Density Algal Mat (HDAM) | Area dominated by contiguous black, dark green or grey algal mat. |  |
| | Low Density Algal Mat (LDAM) | Algal mat with lighter colouring and/or fragmented mat features mixed with Bright Salt or with High Intertidal Salt Flat visible underneath. |  |
| Bare Intertidal Habitat | Bare / High Intertidal Salt Flat (HISF) | Flat surfaces at lower elevations that are subject to inundation and exposure by tide. These areas are absent of algal mat or vegetation. |  |

| Group | Class | Description | Example Image |
|---|---|---|---|
| Water | Water | Open ocean at edges of study boundary, water within creeks or submerged High Intertidal Salt Flat surfaces. Areas covered by water where land type underneath cannot be identified. |  |
| Terrestrial | Grassland | Grassland and dune vegetation e.g. spinifex, hummock/tussock grassland |  |
| | Terrestrial (Unvegetated) | Terrestrial areas that are absent of vegetation. |  |
| Mangrove | Am1 | Typically closed canopy cover and usually large, spreading trees, often with limbs that bend down onto the substrate. This community is usually only a few 10's of metres wide and backed by *Rhizophora* (Rs either in a monospecific stand or mixed association with Am) or *Avicennia* (Landward edge). |  |
| | Rs | Typically closed canopy and dense, occurring either at the seaward edge in bands a few 10's of metres wide or behind Am1 as sprawling forests or as fingers extending into the landward Am where there are narrow shallow tidal channels. |  |

| Group | Class | Description | Example Image |
|---|---|---|---|
| | Rs/Am | This is usually a transition zone between the Rs monospecific stands and the monospecific stands of the landward edge Am closed canopy, however also occurs at the seaward edge where trees are typically older and larger. *R. stylosa* / *A. marina* (closed canopy, mixed) was allocated where either species contributed approximately between 20% to 80% of the mangrove stand. |  |
| | Am2 | Typically the largest area of mangrove association and comprises trees that show a decline in height moving from seaward to landward and often backed by the scattered Am3 association. |  |
| | Am3 | The point where Am landward edge displays canopy gaps and these gaps eventually become larger in total area than the surrounding Am. Individual scattered mangroves were excluded if tree density was approximately less than five trees per 100 m2. |  |
| Samphire | Sam1 | Open samphire flats with sparse cover (<10%) inclusive of algal mats. These habitat classes occur in a transition area between algal mats and proper Samphire shrubland. A density gradient is evident, with increasing density of Samphire from Sam1 to Sam4. Sam1 and Sam2 are the only classifications that include algal mats. |  |
| | Sam2 | Open samphire flats with low cover (>10% <25%) inclusive of algal mats. These habitat classes occur in a transition area between algal mats and proper Samphire shrubland. A density gradient is evident, with increasing density of Samphire from Sam1 to Sam4. Sam1 and Sam2 are the only classifications that include algal mats. |  |

| Group | Class | Description | Example Image |
|---|---|---|---|
| | Sam3 | Samphire shrublands.<br>Sparse level of cover (< 50%) |  |
| | Sam4 | Samphire shrublands. Dense level of cover (>50%). |  |

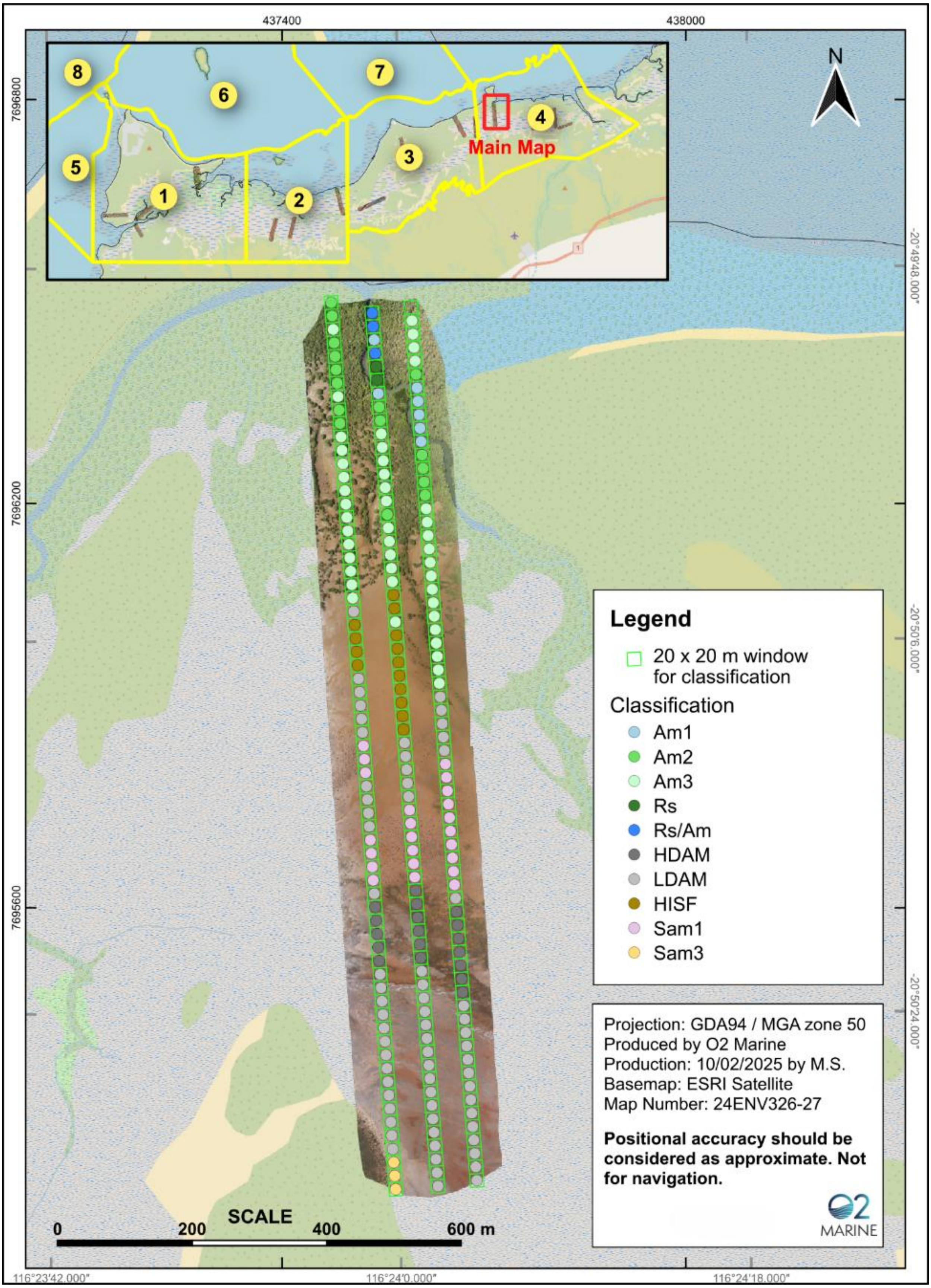



Figure 14: Drone image classification transect example

### 5.3.2. Acquisition of Satellite Imagery

Sentinel-2 is a multispectral satellite-based mission developed by the European Space Agency that systematically acquires optical imagery at high spatial resolution (most bands at 10 m) over land and coastal waters. Sentinel-2 can directly image variability in vegetated environments at a reasonably high spatial resolution (Wicacksono et al., 2021).

A single image (20/10/2024) was selected from a large number of Sentinel 2A scenes of the region. Image selection primarily focussed on identifying suitable images with low cloud cover, as close as possible to the period of 2024 ground truth data acquisition.

### 5.3.3. 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 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 were derived from Sentinel2 imagery.

Established derived band ratios were calculated to reflect various surface and vegetation properties and were used as environmental predictor layers (Table 9).

Table 9: Sentinel 2- derived environmental predictor layers used in analysis

| Predictor Layer | Derivation | Comment | Reference |
|---|---|---|---|
| B02 | Sentinel 2 490 nm | Blue | |
| B03 | Sentinel 2 560 nm | Green | |
| B04 | Sentinel 2 665 nm | Red | |
| B08 | Sentinel 2 842 nm | Near Infrared | |
| CMRI (Combined Mangrove Recognition Index) | ((B8-B4)/(B8+B4))-((B3-B8)/(B3+B8)) | Vegetation | Gupta et al. (2018) |
| EVI (Enhanced Vegetation Index) | 2.5*((B8 – B4)/B8 + 6*B4 – 7.5*B2 + 1) | Vegetation | Huete et al. (1999) |
| NDVI (Normalised Difference Vegetation Index) | (B8-B4)/(B8+B4) | Vegetation | Radwin & Bowen (2021) |
| SI | SWIR 1 / SWIR 2 | Salinity | Han et al. (2021) |
| Halite | (Red - SWIR 1) / (Red + SWIR 1) | Salinity | Radwin & Bowen (2021) |
| NDMI (Normalised Difference Moisture Index) | (B8 – B9)/(B8 + B9) or (B8-B11)/(B8+B11) | Moisture | Bowen et al. (2017) |
| NDWI (Normalised Difference Wetness Index) | (B3-B8)/(B3+B8) | Moisture | Radwin & Bowen (2021) |

### 5.3.4. Training data for machine learning

Training data is an input dataset used to train a machine learning model. The dataset used for training data is the classified drone imagery transects (Figure 15).

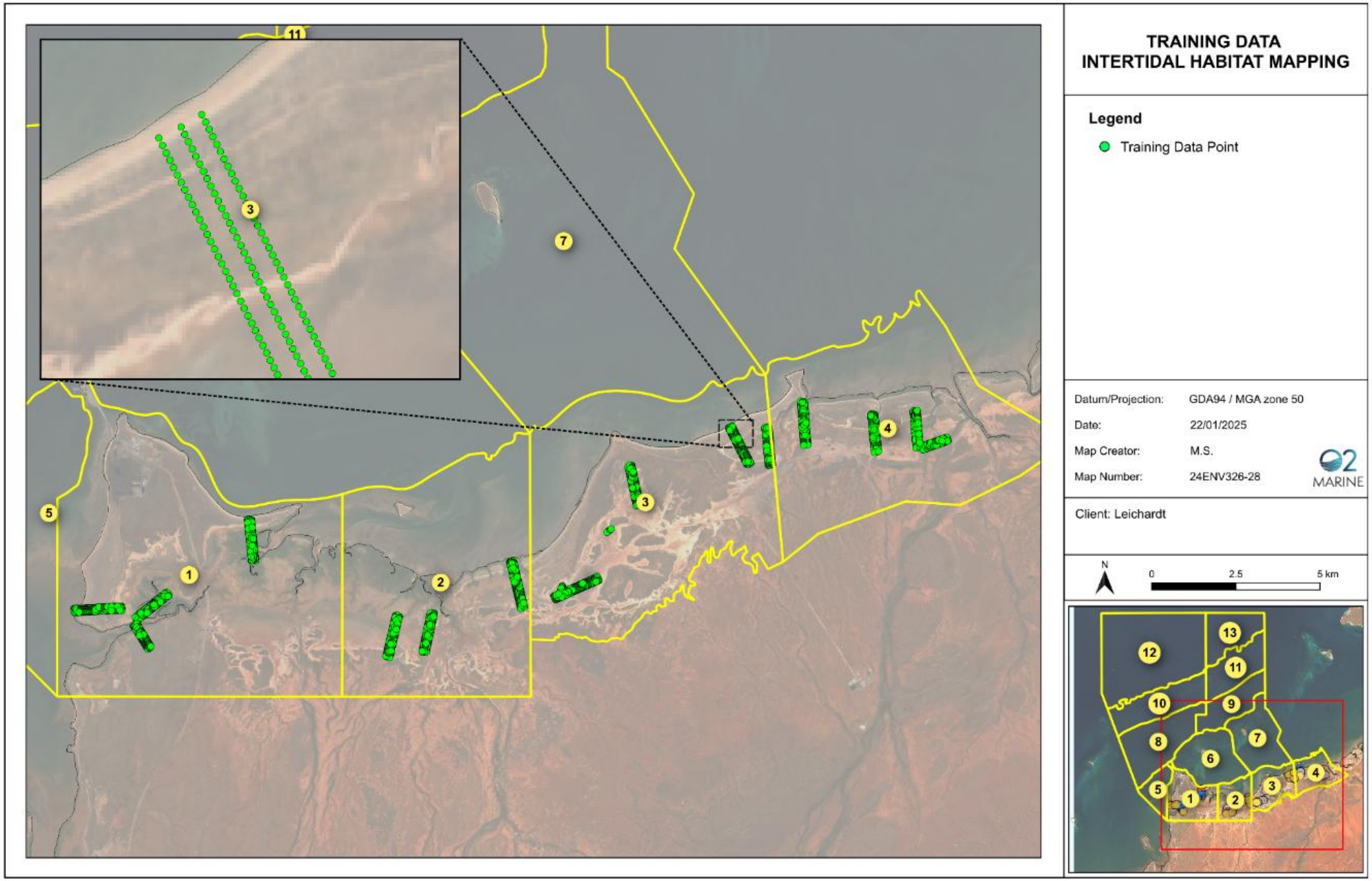



Figure 15: Training data used in intertidal habitat mapping

## 5.4. Mapping procedure

### 5.4.1. OBIA

In order to integrate different scale ground truthing point observations, 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 meanshift algorithm.

### 3.6.2. Supervised Classification

The supervised classification method used utilises Random Forest (RF), an ensemble learning method for supervised classification that operates by constructing a large number (500) 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 RF 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). A randomly selected subset (10%) of data was withheld from the training dataset for subsequent use in validation and evaluation of model performance. Using the training data (Figure 15), the known locations of identified habitats are used to query the environmental predictor 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 implementation based on WhiteBoxTools (Lindsay, 2014). Classes are outlined in Table 10. The classification was then applied to the entire dataset, allowing the algorithm to assess the band spectral values for each pixel cell. The classification was undertaken on the Sentinel 2 image (time slice) using a variation of parameters, resulting in multiple classification outputs. The resultant classified images were further integrated for analysis using a fusion of classes (majority vote) procedure to produce a single robust classification map. This procedure integrates all classification maps to obtain a majority vote to determine the final class assigned to each cell, providing the most rigorous assessment of habitat distribution. A 'Mixed Intertidal Habitat' class is assigned when no majority can be found (indicating high variability in that cell (Table 10)).°

Table 10: Mapping classifications

| BCH Classification | Description |
|---|---|
| Bare Intertidal Habitat | Intertidal areas which are unvegetated. May include high intertidal salt flats, bare sand. |
| Algal Mat | Areas dominated by algal mat. |
| Samphire | Areas hosting samphire shrublands. |
| *A. Marina* Mangrove | Areas of mangrove where the dominant species is Avicennia marina. |
| *R. stylosa* Mangrove | Areas of mangrove where the dominant species is Rhizophora stylosa. |
| Terrestrial | Terrestrial areas (above the 8 m AHD contour). May include grassland, and unvegetated habitats. |
| Mixed Intertidal Habitat | Intertidal area with no dominant habitat class. |

## 5.5. Targeted Intertidal BCH Surveys

O2 Marine completed two field surveys (May 2020 and June 2021) with the specific objectives of collecting detailed information to allow the data gaps identified through the desktop review to be sufficiently addressed. The surveys involved the following primary tasks:

- Collect information on mangrove tree health to enable an investigation into the functional ecological value and regional significance of mangrove communities throughout the Proposal area
- Collect information on mangrove fauna abundance and biodiversity to enable an investigation into the functional ecological value and regional significance of mangrove communities throughout the Proposal area
- Collect soil samples to determine any correlations between soil type and BCH associations
- Collect algal mat samples for taxonomic identification, and
- Collect low-altitude geo-referenced imagery (via helicopter) of mangrove and algal mat communities to validate satellite imagery.

### 5.5.1. Site Selection

To undertake the mangrove and algal intertidal assessment the following locations were selected:

- May 2020:
  - Five mangrove assessment locations (M1-M3, R1 and R2);
  - Seven algae sampling locations (A1-A7); and
  - Seven soil sampling locations (M2, M3, S1, S2, S6 and S10).
- June 2021
  - Four mangrove assessment locations (M4-M7); and
  - Three algae sampling locations (A8-A10).

Locations were selected based upon a review of the preliminary BCH mapping. Mangrove survey locations were selected to ensure an assessment was conducted across each of the identified mangrove assemblage types (i.e. mixed communities or specific species). Monitoring sites at each location were placed to ensure the differences in mangrove canopy cover types were represented (i.e. landward edge, seaward edge etc.). The survey also included locations within mangrove areas that have previously been identified as regionally significant (EPA, 2001a) within the mangrove Management Boundary 9 – Cape Preston (R1 and R2) to provide further context for the study locations.

Survey sites are summarised in Table 11, with the Proposal development envelope and 'Regionally Significant' mangrove area, and mangrove and algal mat sample locations identified in Figure 16.

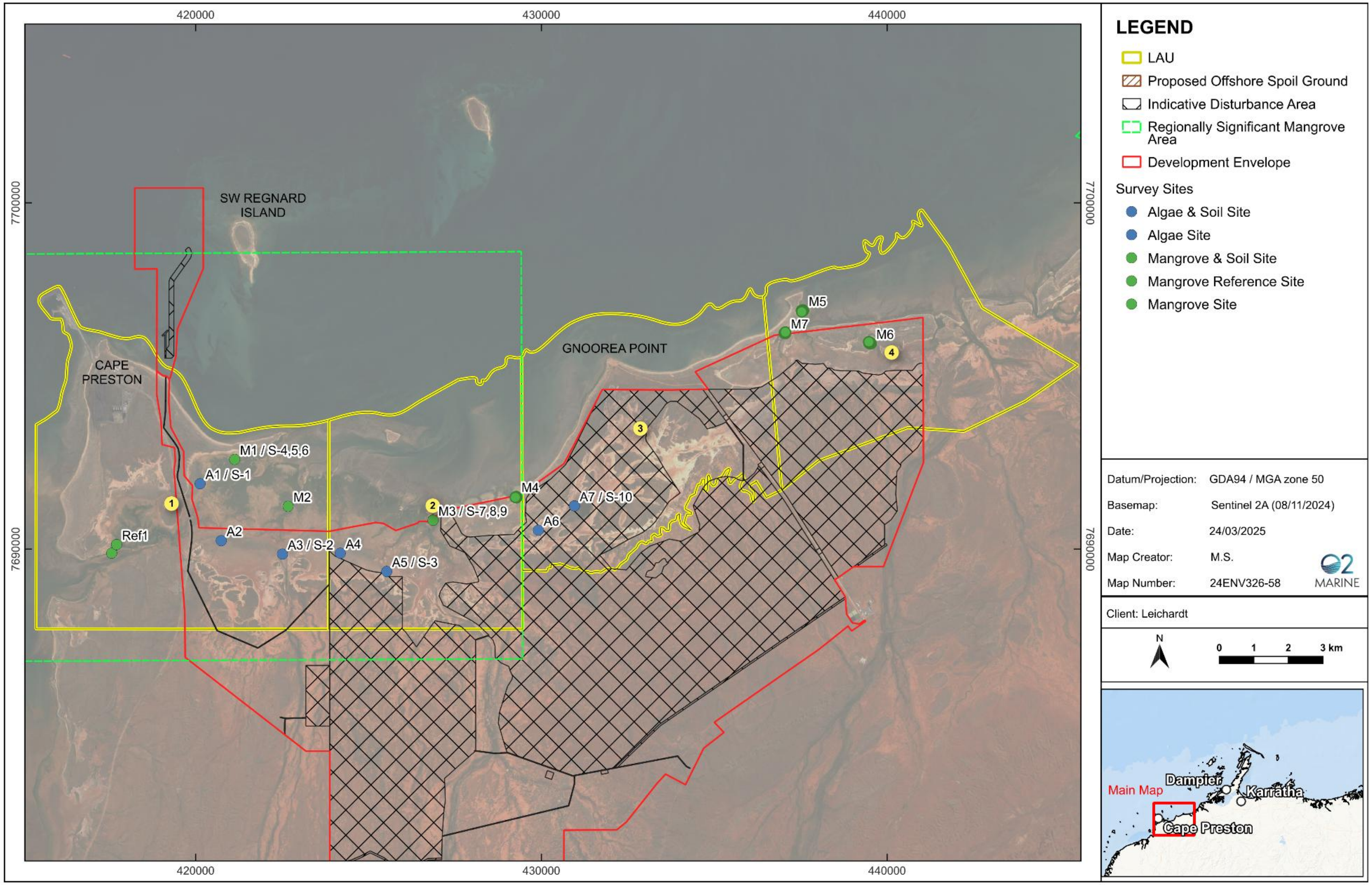



Figure 16: Mangrove, Algae and Sediment sampling locations for the Eramurra Solar Salt Project

Table 11: Mangrove, Algae and Soil Sampling locations from two Intertidal Studies (May 2020 and June 2021).

| Sample ID | Sample Type | Sample Event | Easting | Northing |
|---|---|---|---|---|
| A1 and S1 | Algae and Soil Sample | May 2020 | 420130 | 7691891 |
| A2 | Algae sample | May 2020 | 420741 | 7690247 |
| A3 and S2 | Algae and Soil Sample | May 2020 | 422510 | 7689859 |
| A4 | Algae sample | May 2020 | 424186 | 7689884 |
| A5 and S3 | Algae and Soil Sample | May 2020 | 425528 | 7689356 |
| A6 | Algae sample | May 2020 | 429915 | 7690548 |
| A7 and S10 | Algae and Soil Sample | May 2020 | 430956 | 7691249 |
| M1, S1, S4, S5 and S6 | Mangrove Survey and Soil | May 2020 | 421130 | 7692592 |
| M2 | Mangrove Survey | May 2020 | 422675 | 7691237 |
| M3 and S7, S8 and S9 | Mangrove Survey and Soil | May 2020 | 426868 | 7690836 |
| Ref1 | Mangrove Reference site | May 2020 | 417713 | 7690133 |
| Ref2 | Mangrove Reference site | May 2020 | 417570 | 7689887 |
| M4 | Mangrove Survey | June 2021 | 429272 | 7691518 |
| M5 | Mangrove Survey | June 2021 | 437583 | 7696889 |
| M6 | Mangrove Survey | June 2021 | 439537 | 7695940 |
| M7 | Mangrove Survey | June 2021 | 437064 | 7696238 |
| A8 | Algae Sample | June 2021 | 435603 | 7695190 |
| A9 | Algae Sample | June 2021 | 436557 | 7695504 |
| A10 | Algae Sample | June 2021 | 439771 | 7695278 |

### 5.5.2. Mangrove Flora

At each mangrove survey location, three sites were established along a transect with one site allocated to the landward edge, one site within the canopy centre and the remaining site at the seaward edge. Two replicate flora quadrats (25 $m^2$) were surveyed at each site during low tide. The boundary of the quadrat was measured using a 25 m tape measure and marked using fluorescent flagging tape. Quadrats were typically located within approximately 75 m of each other. Within each quadrat the following metrics were recorded:

- Coordinates
- Mangrove species
- Number of trees
- Species composition
- Canopy density (aerial estimate)
- Canopy height
- Canopy condition (including percentage of yellowing leaves)

- Diameter breast height (DBH) of 10 stems[2], and
- General observations.

Digital photographs were also captured from multiple angles at each site. Whilst the above methods were applied to most sites, tidal and access restrictions resulted in the following deviations:

- At survey locations M2, three flora quadrats were not sampled at all (CC-B, LE-A and LE-B)
- At survey location M5, two flora quadrats were not sampled (CC-A and CC-B), and
- At survey location M6 the two seaward edge flora sites were not sampled for fauna metrics.

### 5.5.3. Mangrove Fauna

Assessment of the mangrove fauna was undertaken using four 1 $m^2$ quadrats randomly deployed on the surface of the mud within each 25 $m^2$ mangrove flora quadrat to sample the epifauna present at low tide. The boundary of each quadrat was marked using fluorescent cotton string. Most crustaceans in the mangrove forests make burrows which are used for refuge and are easily startled. The following techniques were employed to avoid disturbing the fauna and ensuring repeated representative counts were achieved:

- The mangrove fauna were assessed prior to disturbing the site to undertake the flora assessment
- Each quadrat was surveyed for a minimum period of 10 minutes, and
- Commencement of the survey for each quadrat was delayed by a minimum of 5 minutes after establishing the quadrat.

A digital photo was collected, and the following information was recorded for each mangrove fauna quadrat:

- The number of burrows
- The epifauna recorded to the lowest taxonomic level possible
- The total number of each organism
- The total abundance of organisms, and
- Diversity of organisms.

Whilst the above methods were applied to most sites, tidal and access restrictions resulted in the following deviations:

- At survey location M1 no fauna quadrats from the landside edge were surveyed
- At survey locations M2, three flora quadrats were completed with fauna sampling conducted within all
- At survey location M5 only four flora quadrats were sampled with fauna collected at each site, and

[2] Limitation: Many Am3 sites characterised by low canopy heights therefore DBH measurements unable to be collected at chest height, alternatively they were measured approximately three quarters of height above ground along stems.

- At survey location M6 the two seaward edge flora sites were not sampled for fauna due to the encroaching tide.

### 5.5.4. Algal mats

At each sampling location, a sample of algal mat approximately 15 x 15 cm were collected to the depth of the underlying soil. A small trowel was used to assist with sample collection. The samples were placed into a suitably sized zip lock bag and labelled with a unique identifier.

Samples were stored during sampling in an esky on ice and frozen at earliest convenience. Samples remained frozen until delivery to laboratory.

At each site the following were observed and recorded:

- Thickness of mat (cm)
- Active/dormant
- Colour
- Wetness relevant to recent tidal inundation or rainfall, and
- Structure – contiguous, filamentous, patchy etc.

Laboratory analysis of algal mat samples was undertaken by taxonomy expert John Huisman (Department of Biodiversity, Conservation and Attractions [DBCA]), and included examination under a dissecting microscope for the presence of cyanobacteria and algae. Microscope slide preparations were made of representative portions, and examined under a compound microscope at 400x magnification, with the presence and qualitative relative abundance of each species recorded. Taxa were identified to the lowest reliable category (generally genus).

### 5.5.5. Data Analysis

#### 5.5.5.1. Mangrove flora

Mangrove characteristics (canopy density, canopy height, mangrove density) were analysed using a linear model with LAU as a predictor in R statistical software (R Core Team, 2020). Residuals were examined for normality and heterogeneity of variance. Subsequent post-hoc tests were performed on characteristics that significantly differed among LAU to determine if mangroves differed between EPA mangrove Management Area 9 (LAU1 and LAU2) and areas outside the management area (LAU4) and whether mangroves varied within the management area (LAU1 vs LAU2).

Using the DBH and number of trees in each quadrat, above-ground biomass (AGB) was calculated using the allometric relationships between DBH and AGB for the dominant mangrove species (Clough and Scott, 1989, Clough *et al*. 1997). Total AGB for mangroves occurring within the study area and within each LAU was calculated using the calculated AGB estimates and multiplying them by their mapped spatial area within the LAU as identified using ArcGIS.

Canopy condition, including yellowing leaves, or loss of leaves, are common features of mangroves under stress (Duke *et al*. 2005). Percentage of yellowing leaves was measured in the field as a way to estimate mangrove health. Duke *et al*. (2005) states that the health of individual trees can be classified into one of three categories (healthy, stressed, or dead) as per the criteria outlined in Table 12. Infield data were compared against these criteria to indicate mangrove health at the surveyed sites.

Table 12: Classification of mangrove health condition according to Duke *et al*. (2005).

| Classification | Characteristics | Quantitative Measure |
|---|---|---|
| **Healthy** | Leaves green, no visible signs of sickness | <10% dead, yellowing or wilting leaves |
| **Stressed** | Yellow, wilting leaves; low foliage cover | 10–50% dead, yellowing or wilting leaves |
| **Dead** | Plant dead | >50% dead/ yellow wilting leaves;<br>>50% dead stems<br>Plant beyond recovery/almost dead |

#### 5.5.5.2. Mangrove functional groups

For comparative purposes, the AGB results were separated into two groups: closed canopy (CC) associations that typically represent the highest mangrove AGB and are structurally complex (Paling *et al*. 2003), and scattered canopy (SC) associations that are less structurally complex and have lower canopy height. CC associations include Am1 (Seaward Edge), Am2 (Behind Am1), Rs (Behind Am1), Rs/Am (Mixed Closed Canopy). SC associations include Am3 (Landward Edge) and Ca.

#### 5.5.5.3. Mangrove fauna

The total number of organisms and the average results for the number of burrows, organisms, and phylum richness were tabulated to provide the results per square metre. Tables were prepared to present a high-level breakdown of the diversity and abundance within each LAU and mangrove association.

#### 5.5.5.4. Algal mats

Algal mats were characterised into representative communities based on the presence/absence of the six genera of cyanobacteria or algae found across all sites.

## 5.6. Nearshore Nutrient and Soil Investigation

In addition to the algal mat and mangrove site investigation, a separate investigation was undertaken to determine the relative nutrient inputs into the intertidal and nearshore system from different BCH associations in June 2021. To measure the contribution of algal mats to local nutrient cycling, the following methods were employed:

- Collect nutrient data (water samples) over ebb and flood cycles during neap tides when only mangrove communities are inundated and connected to the subtidal system
- Collect nutrient data (water samples) over the ebb and flood cycle during spring tides when the entire intertidal zone is inundated and connected to the subtidal system, in particular continuous algal mats communities
- Collect soil samples adjacent to mangrove associations and from the continuous algal mat communities, and
- Conduct an assessment to determine the contribution of algal mat communities and mangrove associations to nutrient exchange of Proposal area.

# 6. Results

## 6.1. Habitat Mapping

### 6.1.1. Intertidal BCH

A map of the intertidal BCH across the study area is presented in Figure 17. Higher resolution figures of each individual LAU are presented in Appendix A.

The total area for each intertidal habitat type per LAU is presented in Table 13 and Figure 18. Although terrestrial vegetation is not classified as an intertidal habitat, it constitutes a substantial portion of the intertidal LAUs. Consequently, this habitat has been incorporated into the mapping (Figure 17) and the overall area calculations (Table 13 and Figure 18). Overall, terrestrial vegetation was the dominant habitat type across the intertidal study area, with a total coverage of 7,055 ha (53.5%). At the landward extent of the intertidal area, a transition to terrestrial vegetation occurs. This vegetation consists of spinifex (*Triodia* spp.) grasslands, which provide ground cover and stabilise sandy soils, as well as scattered acacia shrublands (*Acacia pyrifolia*, *A. inaequilatera*). Additionally, patches of mixed shrubland communities and open woodlands are present, contributing to biodiversity and ecological function within the intertidal landscape. Detailed discussion on terrestrial vegetation habitats can be found in the Detailed flora and vegetation survey of the Eramurra Solar Salt Project (Phoenix 2025).

LAU3 exhibited the lowest proportion of mangroves (18.5 ha), with only two narrow coastal patches located west of Gnoorea Point. In contrast, mangrove communities and seaward algal mat areas were more extensive in regions with prominent inland drainage and tidal creek systems, particularly in LAU1 and LAU2. LAU1 contained the largest mangrove area at 756.7 ha, accounting for 16.6% of LAU1. Algal mats were most abundant in LAU1 (816.6 ha) and LAU2 (616.7 ha). The distribution of these BCH types appears to be strongly influenced by marine tidal drainage patterns and associated hydrological processes.

Plate 1 showcases representative images of the typical communities found within each intertidal BCH habitat captured during the surveys.

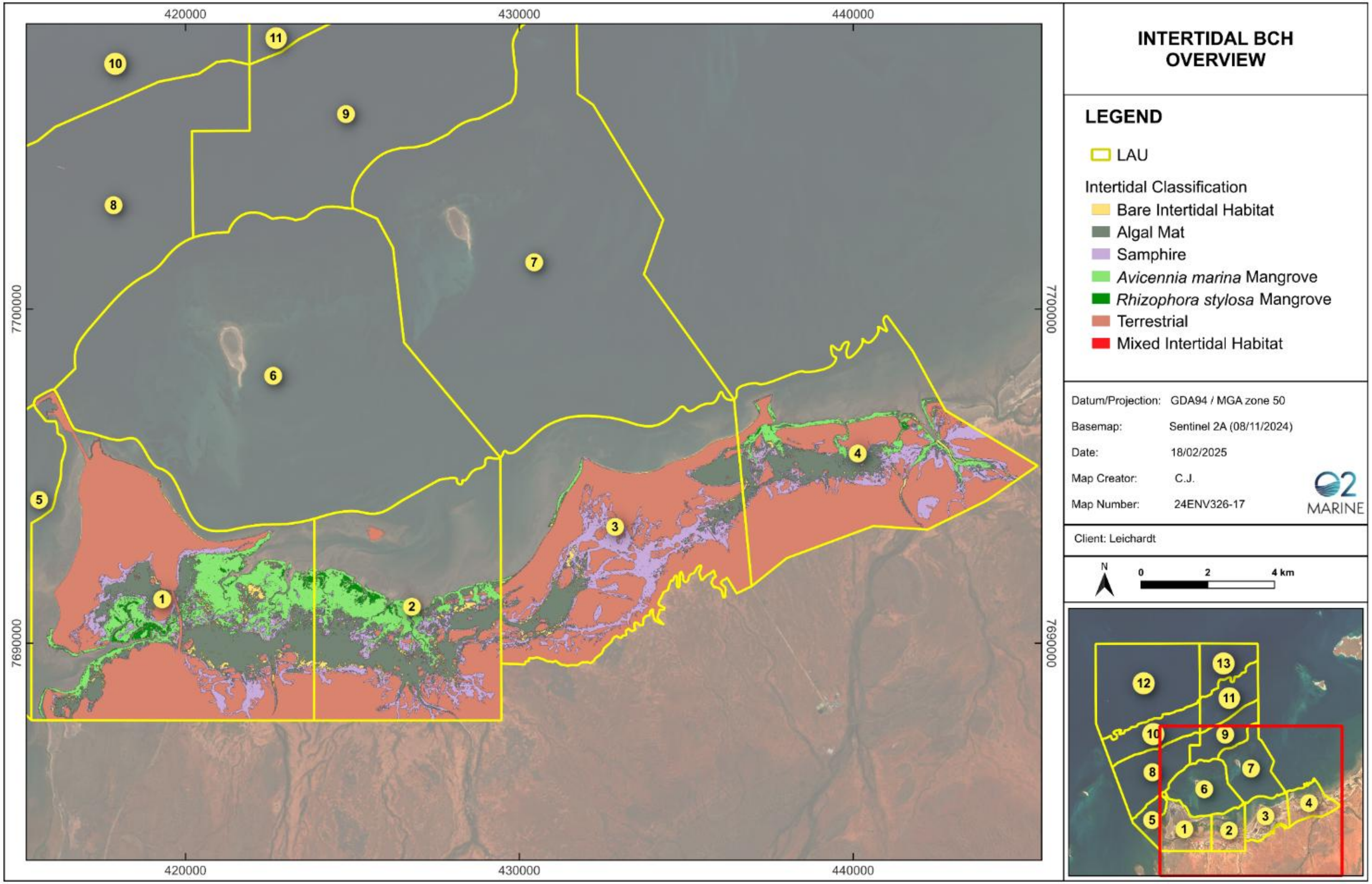



Figure 17: Intertidal BCH and Terrestrial vegetation classification within Proposed LAUs

Table 13: Total area (hectares) and relative percentage estimates for habitat type per LAU (intertidal).

| LAU | | Algal Mats | Mangroves | | Bare Intertidal Habitat | Samphire | Mixed Intertidal | Terrestrial |
|---|---|---|---|---|---|---|---|---|
| | | | A. marina | R. stylosa | | | | |
| LAU1 | ha | 816.6 | 707.4 | 49.3 | 102.2 | 436.1 | 8.6 | 2438.5 |
| | % | 17.9% | 15.5% | 1.1% | 2.2% | 9.6% | 0.2% | 53.5% |
| LAU2 | ha | 616.7 | 375.6 | 37.2 | 67.6 | 327.4 | 6 | 795.3 |
| | % | 27.7% | 16.9% | 1.7% | 3.0% | 14.7% | 0.3% | 35.7% |
| LAU3 | ha | 344.7 | 17.8 | 0.7 | 54.6 | 643.5 | 6.2 | 2061.6 |
| | % | 11.0% | 0.6% | 0.02% | 1.74% | 20.57% | 0.2% | 65.9% |
| LAU4 | ha | 379.4 | 186.1 | 7.3 | 36.9 | 408.3 | 4.9 | 1759.9 |
| | % | 13.6% | 6.7% | 0.3% | 1.3% | 14.7% | 0.2% | 63.2% |
| **Total** | **Ha** | **2157.4** | **1286.9** | **94.5** | **261.3** | **1815.3** | **25.7** | **7055.3** |

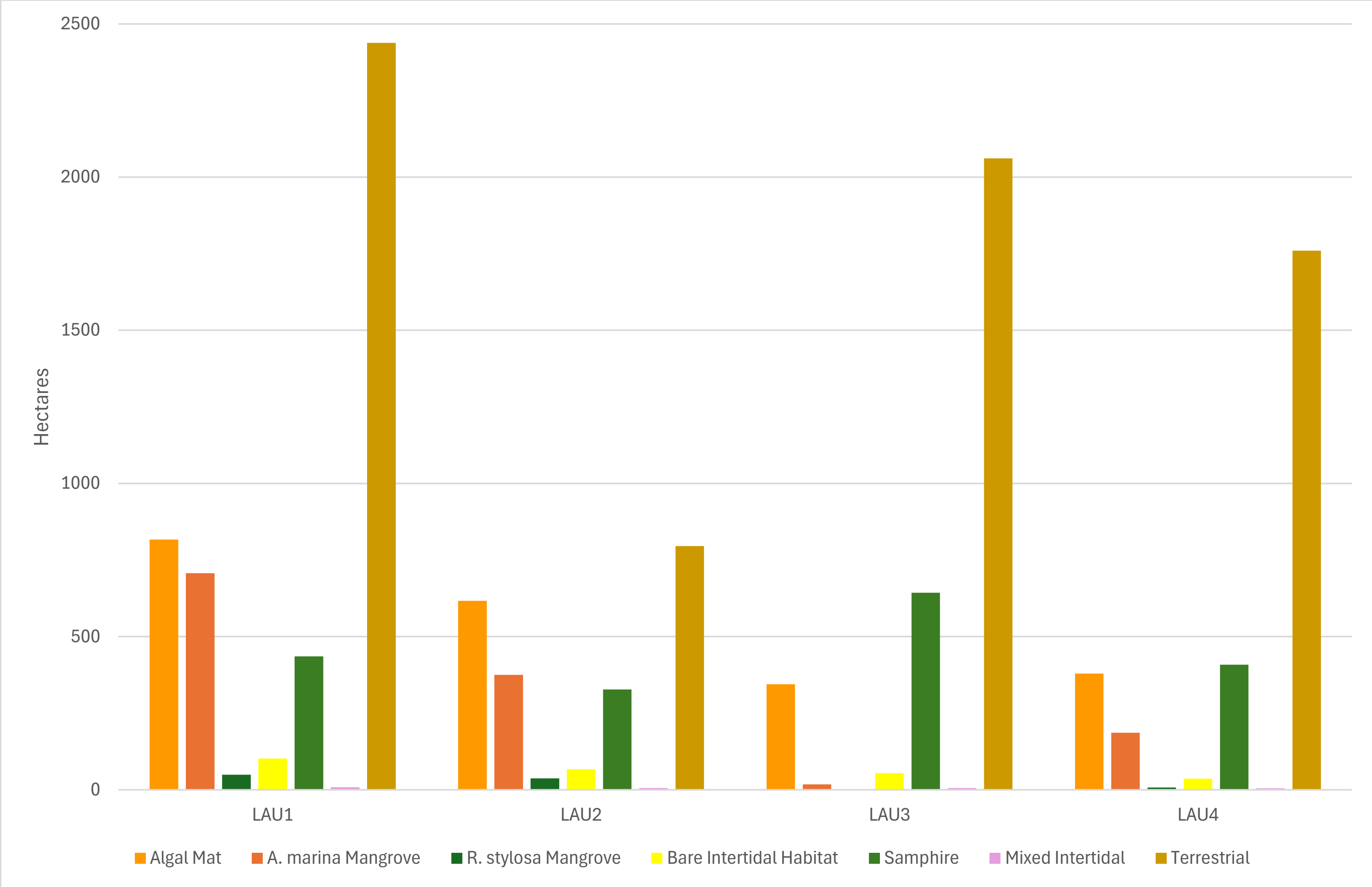
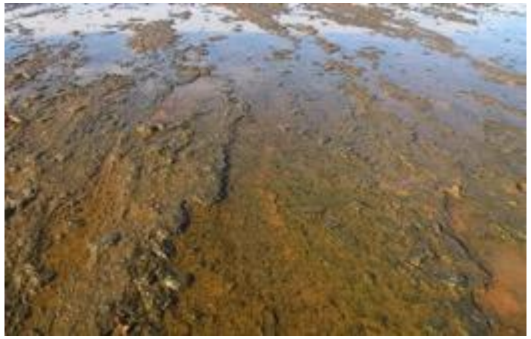



Figure 18: Total area (hectares) of each habitat type per LAU.

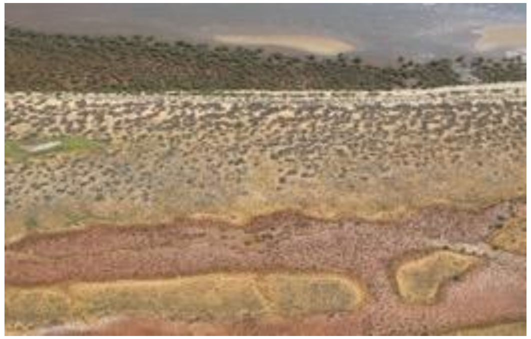
a)

b)



c)

c)



d)

f)

Plate 1: Intertidal Habitat classes identified within the study area. a) Bare Intertidal Habitat, b) Algal Mat, c) Mangroves (including Rs/Am, RS, Am1, Am2 and Am3), c) Samphire shrubland, d) Samphire shrubland including Algal mat.

### 6.1.2. Mangrove Associations

Mangrove association calculations for each of the intertidal LAUs are summarised in Table 14. Figure 19 and Figure 20 display the mapped mangrove associations across the study area, with detailed maps for individual LAUs (1-4) shown in Appendix B.

Mangrove assemblages are present within all coastal LAUs. *A. marina* communities (Am1, Am2 and Am3) are associated with the greatest spatial area across the study area covering over 1,286.9 ha or 93% of mapped mangrove BCH area. The Am3 (Scattered) association dominates the landward fringe comprising 50.1% of the total area of mangroves, followed by 25.9% for Am2 (Landward) and 17.1% for Am1 (Seaward Edge). The mixed association comprising *R. stylosa* and *A. marina* (Rs/Am) occupies 3.7% of the total area of mangroves and the mangroves dominated by *R. stylosa*. occupy 3.1% of all mangroves mapped.

Approximately 84.7% of the total mapped mangrove habitat occurs within LAU1 (54.7%) and LAU2 (29.9%) which are located within the designated EPA Regionally Significant Mangrove Area #9 (RSMA) (EPA, 2001a). Comparably, only 1.3% and 14.0% of mangrove habitats occur within LAU3 and LAU4, respectively. Not all associations are recorded in each LAU, with Am2, Rs and Rs/Am not present in LAU3.

Table 14: Total area (hectares) and relative percentages for each mapped mangrove association within proposed LAUs and the total study area.

| Mangrove Association | LAU1 | | LAU2 | | LAU3 | | LAU4 | | Total Area | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % | ha | % |
| Am1 | 105.4 | 1.78% | 72.3 | 1.91% | 8.5 | 0.19% | 50.5 | 1.34% | 236.6 | 1.32% |
| Am2 | 211.6 | 3.57% | 119.6 | 3.16% | 0.2 | 0.00% | 26.1 | 0.69% | 357.5 | 1.99% |
| Am3 | 390.5 | 6.59% | 183.7 | 4.85% | 9.1 | 0.20% | 109.5 | 2.90% | 692.7 | 3.85% |
| Rs/Am | 27.1 | 0.46% | 17.5 | 0.46% | 0.7 | 0.01% | 5.8 | 0.15% | 51.1 | 0.28% |
| Rs | 22.2 | 0.37% | 19.7 | 0.52% | 0.0 | 0.00% | 1.5 | 0.04% | 43.4 | 0.24% |
| Total | 756.8 | 12.78% | 412.8 | 10.89% | 18.4 | 0.41% | 193.4 | 5.13% | 1381.4 | 7.68% |

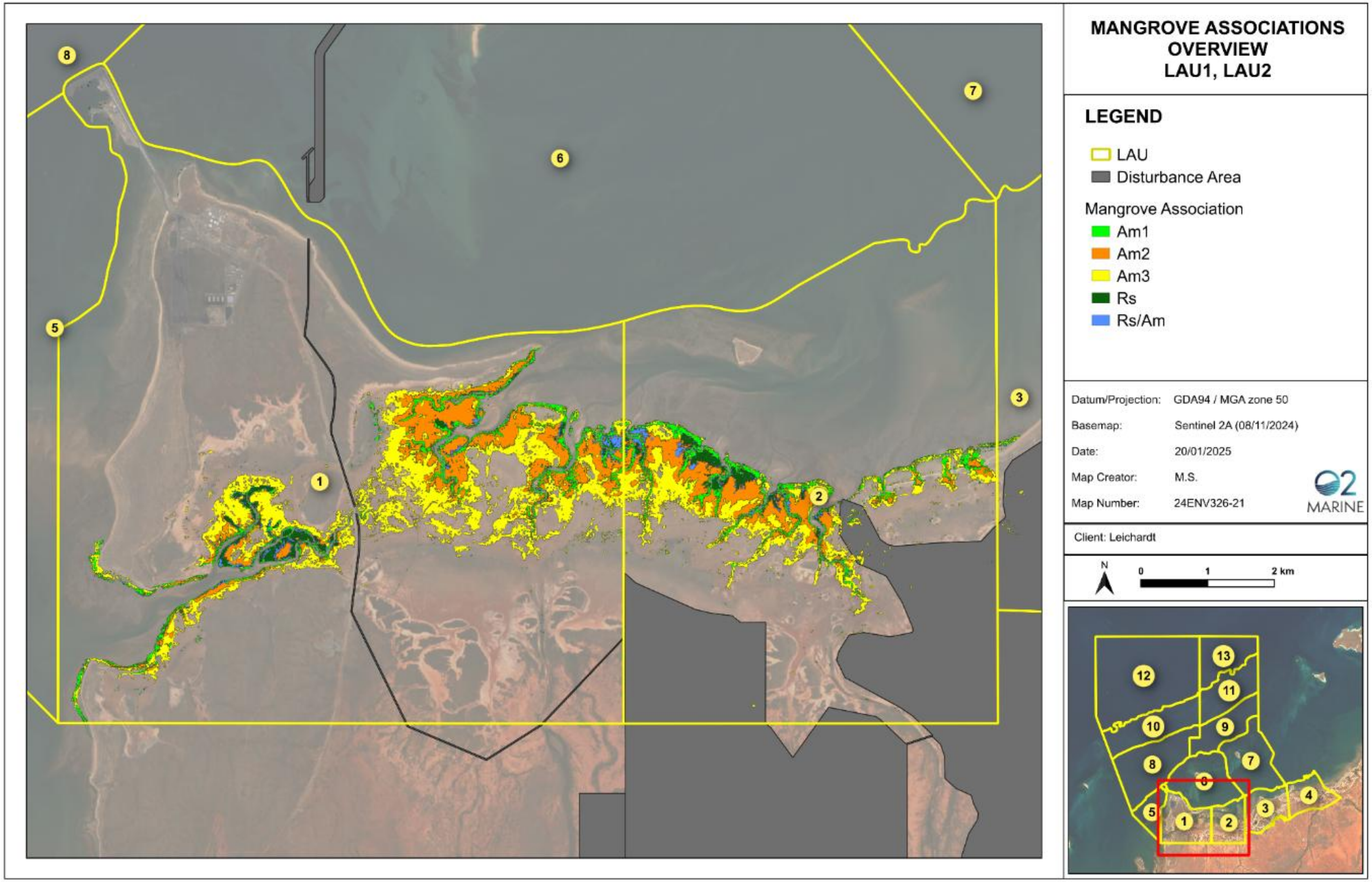



Figure 19: Mangrove Associations within the proposed development footprint area, and LAU1 / LAU2

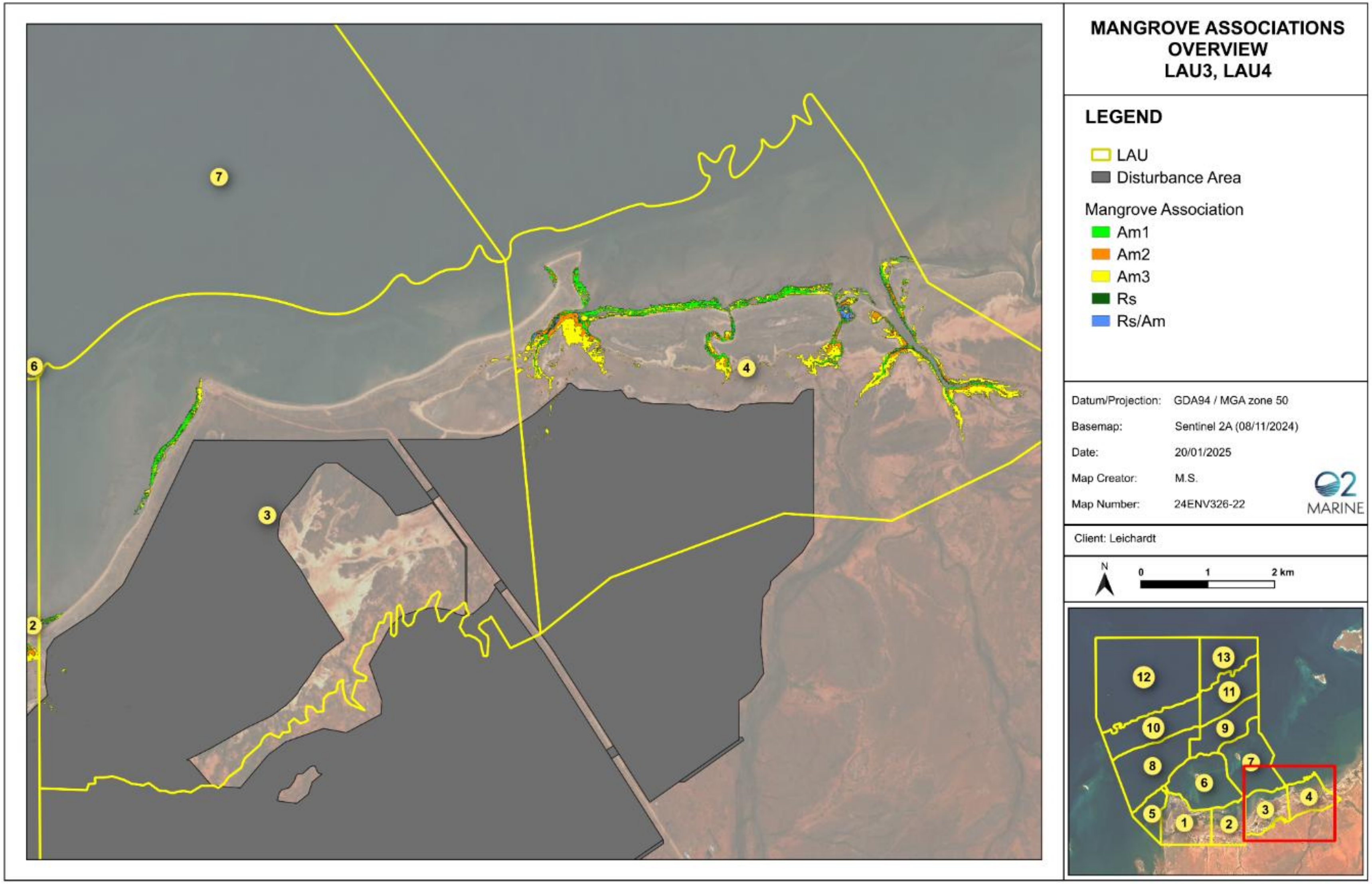



Figure 20: Mangrove Associations within the proposed development footprint area, and LAU3 / LAU4

Mangrove associations per LAU are graphically shown below in Figure 21, with example photos of each association shown in Plate 2 and Plate 3.The figure highlights the dominance of *Avicennia marina* across all LAUs, particularly in LAU1 and LAU2, where Am3 (scattered *A. marina*) comprises the largest proportion of mangrove cover. In contrast, LAU3 has minimal mangrove cover, while LAU4 contains a relatively small but notable extent of *A. marina* and *Rhizophora stylosa*.

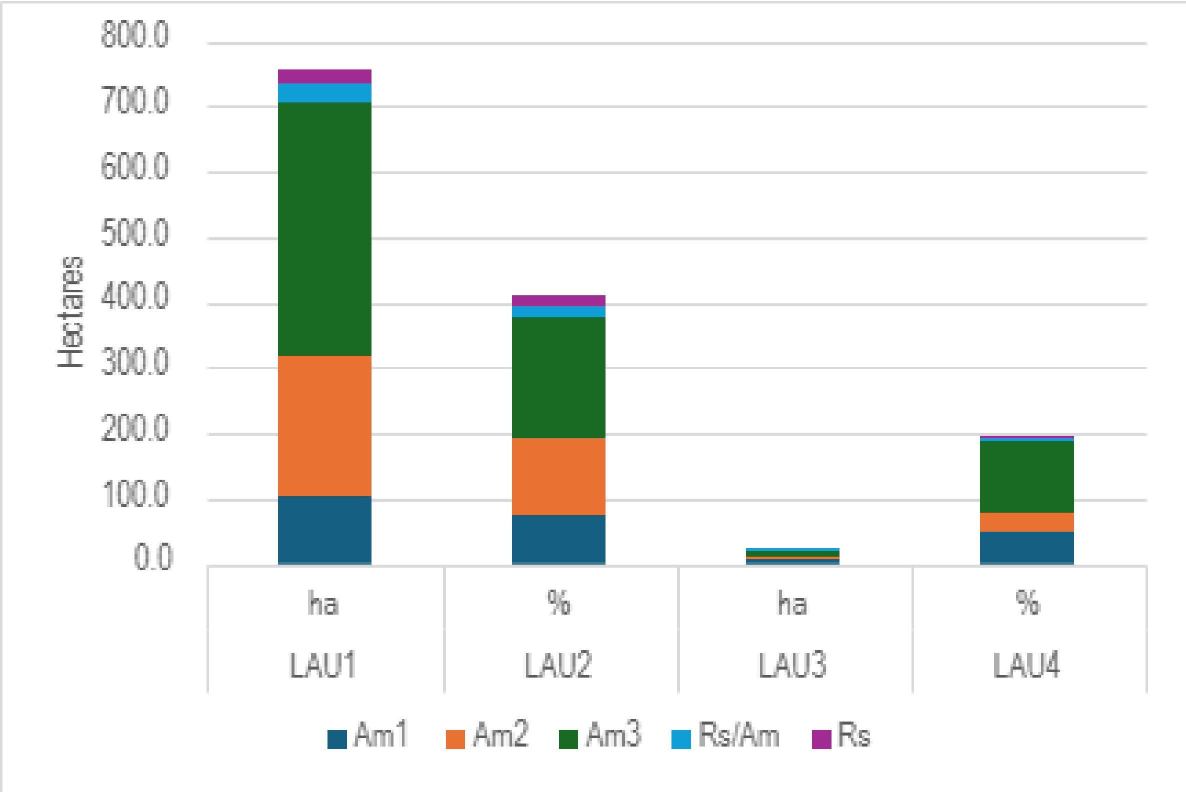



Figure 21: Graphic representation of mangrove associations within each LAU

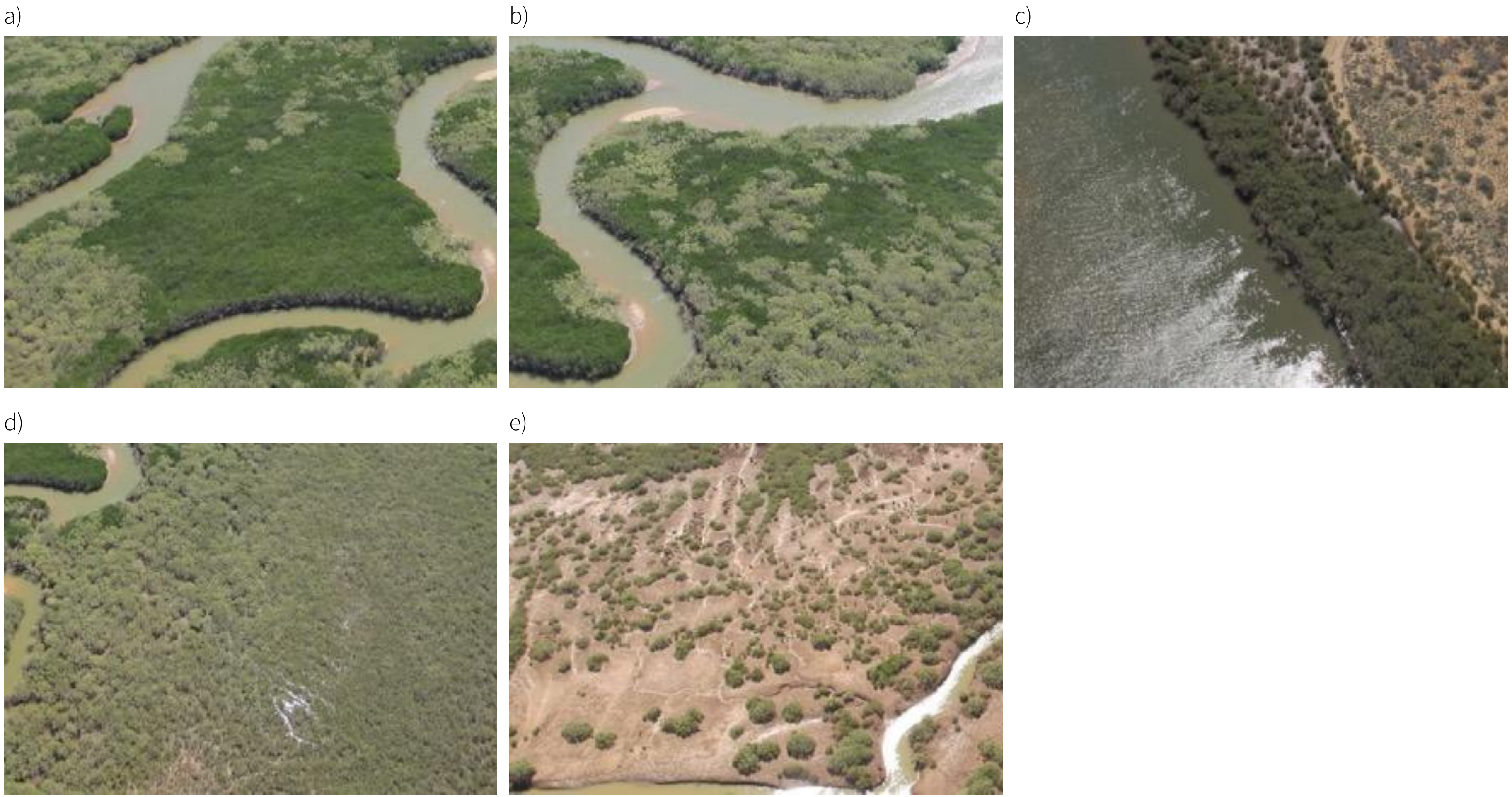



Plate 2: Photographs of the mangrove Associations surveyed within the study area. A) Rs LAU2, b) Rs/Am LAU2, c) Am1 LAU4, d) Am2 LAU2 and e) Am3 LAU1.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a)

b)

c)

d)

e)

Plate 3: Photographs of the mangrove Associations surveyed within the study area. A) Rs Site M2 LAU1, b) Rs/Am Site M2 LAU1, c) Am1 Site M1 LAU1 d) Am2 Site M3 LAU2, and e) Am3 Site M3 LAU2,

#### 6.1.2.1. Mangrove flora surveys

The mean number of trees per hectare varied among LAUs where, ranging from 2657 (LAU1) to 3933 (LAU2). Canopy density ranged from 41.6% within LAU4 to 75.8% in LAU1. Canopy height was comparable among sites, with LAU2 recording the highest mean height of 3.8 m (Table 15). Mean DBH values were comparable among LAUs, with a mean of 7.1 cm recorded for both LAU1 and LAU2, and 7.2 cm for LAU4. Both *A. marina* and *R. stylosa* were recorded within LAU1, LAU2 and LAU4, with *C. australis* only recorded in LAU1. Mangrove flora surveys were not undertaken in LAU3 as the area of mangrove stands were considered negligible.

Table 15: Mangrove characteristics of each surveyed LAU.

| | Quadrats (n) | Trees (n ha$^{-1}$) | Canopy density (%) | Canopy height (m) | DBH (cm) | Total species (n LAU$^{-1}$) |
|---|---|---|---|---|---|---|
| LAU1 | 14 | 2657 (2835) | 75.8 (22.9) | 3.0 (0.7) | 7.1 (4.4) | 3 |
| LAU2 | 12 | 3933 (2529) | 73.4 (12.1) | 3.8 (0.8) | 7.1 (2.8) | 2 |
| LAU4 | 16 | 3800 (2267) | 41.6 (22.4) | 3.2 (0.9) | 7.2 (2.1) | 2 |

#### 6.1.2.2. Above Ground Biomass

Each LAU recorded maximum Above Ground Biomass (AGB) per hectare from the closed canopy functional group, with values of 50.2 t ha$^{1}$ (LAU4), 38.6 t ha$^{1}$ (LAU2) and 33 t ha$^{1}$ (LAU1). The proportions of closed canopy (CC) and scattered canopy (SC) within LAU2 and LAU4 were comparable with a previous study that suggests SC comprised only 10-20% of the total above ground biomass within the area (Alongi *et al.* 2005). The proportions of CC and SC were more similar within LAU1, with the closed canopy functional group recording 61% of the AGB and scattered canopy 39%.

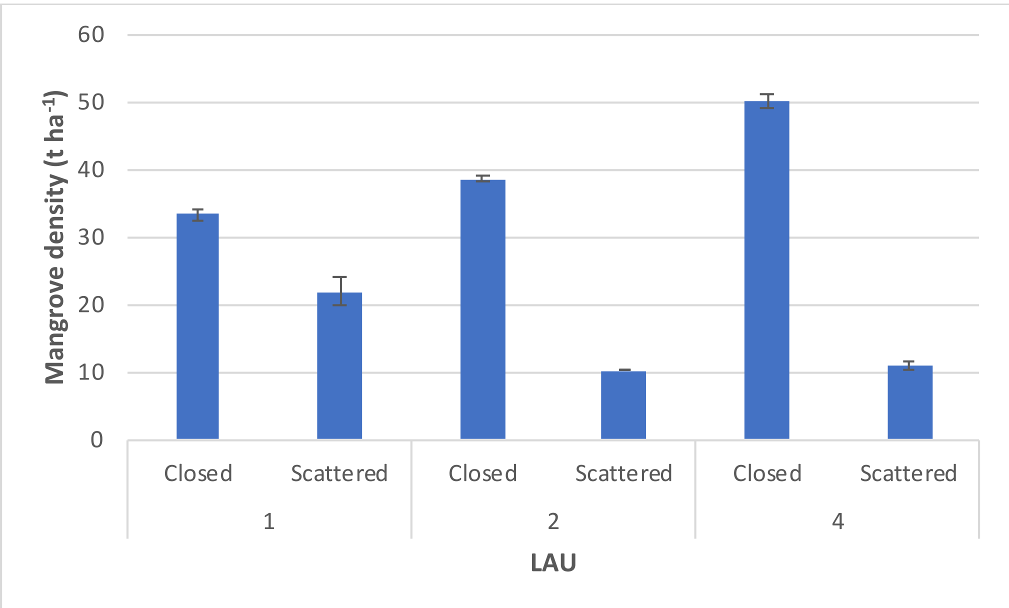



Figure 22: Mangrove Density (tonnes per hectare) calculated for the closed canopy (CC) and scattered canopy (SC) mangrove functional groups per LAU.

Table 16 and Figure 23 show the total above ground biomass (tonnes and percent) per LAU and functional group. Calculations for LAU1, LAU2 and LAU4 were derived from the abovementioned biomass values, multiplied by functional group area. No infield measurements were recorded within LAU3, as such, the calculations for LAU3 are an estimate, and use the mean biomass values per functional group derived from the other LAUs, then multiplied by the mapped area. Overall, LAU1 contains the highest mean AGB (23,731 tonnes), making up 58% of the total AGB across the study area (Table 16). The CC functional group accounted for the majority of total mangrove AGB for LAU1 (67%), LAU2 (84%), and LAU4 (73%). LAU3 was estimated at having a higher proportion of the SC functional group (57%), and only 1% of mangroves across the study area.

Table 16: Mean above ground biomass (tonnes and percentage) for CC and SC mangrove functional groups per LAU.

| Mangrove Functional Group | LAU1 | | LAU2 | | LAU3 | | LAU4 | | Total Biomass | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T | % | T | % | T | % | T | % | T | % |
| Closed canopy | 15,964 | 67% | 10,423 | 84% | 205 | 43% | 3,828 | 73% | 30,215 | 73% |
| Scattered canopy | 7,767 | 33% | 1,910 | 16% | 269 | 57% | 1,415 | 27% | 11,092 | 27% |
| Total | 23,731 | 58% | 12,333 | 29% | 474 | 1% | 5,243 | 12% | 41,307 | 100% |

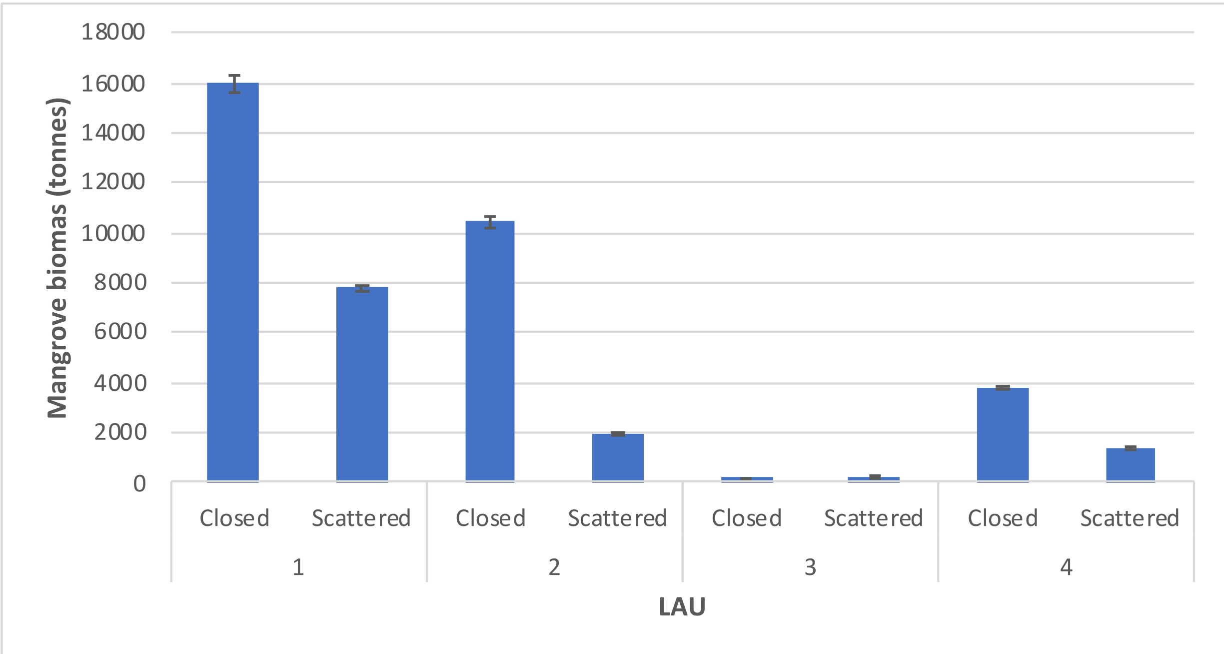



Figure 23: Total biomass estimates (tonnes) for closed canopy and scattered functional groups.

### 6.1.2.3. Canopy Condition

Nine mangrove locations were surveyed across three LAUs, two of these sites were reference sites (Ref 1 and Ref 2) located in LAU1. At each mangrove survey location, three sites were established along a transect, with one site allocated to the landward edge, one site within the canopy centre and the remaining site at the seaward edge. Percent of yellowing leaves were recorded within each of the replicate quadrats (A and B) at each site. Results were comparable among all surveyed sites, with all vegetation classified as 'healthy' in accordance with the Duke *et al.* (2005) mangrove health condition criteria. Table 17 shows a maximum reading of <10% yellowing leaves was recorded at M4, LE, quadrat A. All remaining results were 5% or less yellowing leaves. Six quadrats were not sampled in the field due to access restriction and tide encroachment.

Table 17: Mangrove health assessment derived from percentage of yellow leaves using Duke *et al*. (2005) criteria.

| LAU | Site ID | Quadrat location | Quadrat ID | % Yellow leaves | Health criteria |
|---|---|---|---|---|---|
| 1 | M1 | LE | A | <1 | Healthy |
| | M1 | LE | B | <1 | Healthy |
| | M1 | CC | A | <1 | Healthy |
| | M1 | CC | B | DNS | Healthy |
| | M1 | SE | A | <1 | Healthy |
| | M1 | SE | B | <5 | Healthy |
| | M2 | CC | A | <5 | Healthy |
| | M2 | CC | B | DNS | DNS |
| | M2 | LE | A | DNS | DNS |
| | M2 | LE | B | DNS | DNS |
| | M2 | SE | A | <1 | Healthy |
| | M2 | SE | B | 5 | Healthy |
| | Ref 1 | | A | 1 | Healthy |
| | Ref 1 | | B | <5 | Healthy |
| | Ref 2 | | A | <1 | Healthy |
| | Ref 2 | | B | <1 | Healthy |
| 2 | M3 | LE | A | DNS | DNS |
| | M3 | LE | B | 1 | Healthy |
| | M3 | CC | A | 5 | Healthy |
| | M3 | CC | B | 1 | Healthy |
| | M3 | SE | A | <5 | Healthy |
| | M3 | SE | B | <1 | Healthy |
| | M4 | CC | A | 0 | Healthy |
| | M4 | CC | B | 0 | Healthy |
| | M4 | LE | A | <10 | Healthy |
| | M4 | LE | B | 0 | Healthy |
| | M4 | SE | A | 5 | Healthy |
| | M4 | SE | B | 0 | Healthy |
| 4 | M5 | LE | A | <5 | Healthy |
| | M5 | LE | B | 5 | Healthy |
| | M5 | CC | A | DNS | DNS |
| | M5 | CC | B | DNS | DNS |
| | M5 | SE | A | <5 | Healthy |

| LAU | Site ID | Quadrat location | Quadrat ID | % Yellow leaves | Health criteria |
|---|---|---|---|---|---|
| | M5 | SE | B | <5 | Healthy |
| | M6 | CC | A | 0 | Healthy |
| | M6 | CC | B | 5 | Healthy |
| | M6 | LE | A | 0 | Healthy |
| | M6 | LE | B | 5 | Healthy |
| | M6 | SE | A | 5 | Healthy |
| | M6 | SE | B | <5 | Healthy |
| | M7 | CC | A | <5 | Healthy |
| | M7 | CC | B | <5 | Healthy |
| | M7 | LE | A | 5 | Healthy |
| | M7 | LE | B | <5 | Healthy |
| | M7 | SW | A | 0 | Healthy |
| | M7 | SW | B | 5 | Healthy |

LE – landward edge, CC – canopy centre, SE – seaward edge, DNS – Did not survey

### 6.1.3. Algal mats

Algal mats area calculations for each of the intertidal LAUs are summarised in Table 18 , while Figure 24 and Figure 25 display the mapped algal mats across the study area, with detailed maps for individual LAUs (1-4) shown in Appendix BC.

Algal mats are present within all coastal LAUs. Low Density Algal Mats (LDAM) occupy the largest spatial extent, covering approximately 1,460.4 ha, which represents 67.7% of the mapped algal mat area. In October 2024, High Density Algal Mats (HDAM) accounted for 32.3% of the total algal mat area.

Approximately 66.4% of the total mapped algal mat habitat is located within LAU1 (37.8%) and LAU2 (28.5%). In comparison, LAU3 and LAU4 contain 15.9% and 17.5% of the total algal mat coverage, respectively. Additionally, an extra 1,197.3 ha of Samphire inclusive of algal mats (Sam1 and Sam2) has been categorised across the Proposal area (see Section 6.1.4). The exact area (ha) of algal mats within this category is unknown, however, it is likely at least 80% of the area supports algal mat habitat. The cumulative loss assessment for the Proposal (02 Marine, 2025b) takes a conservative approach, and includes 100% of this category when assessing the total impacts to algal mats.

Table 18: Total area (hectares) and relative percentages for each mapped algal mats within proposed LAUs and the total study area.

| Algal mats | LAU1 | | LAU2 | | LAU3 | | LAU4 | | Total Area | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % | ha | % |
| HDAM | 275.2 | 4.6% | 167.0 | 4.4% | 127.6 | 2.8% | 127.4 | 3.4% | 697.3 | 3.9% |
| LDAM | 541.4 | 9.1% | 449.9 | 11.9% | 217.1 | 4.8% | 252.0 | 6.7% | 1460.4 | 8.1% |
| Total | 816.6 | 13.8% | 616.9 | 16.3% | 344.7 | 7.7% | 379.4 | 10.1% | 2157.7 | 12.0% |

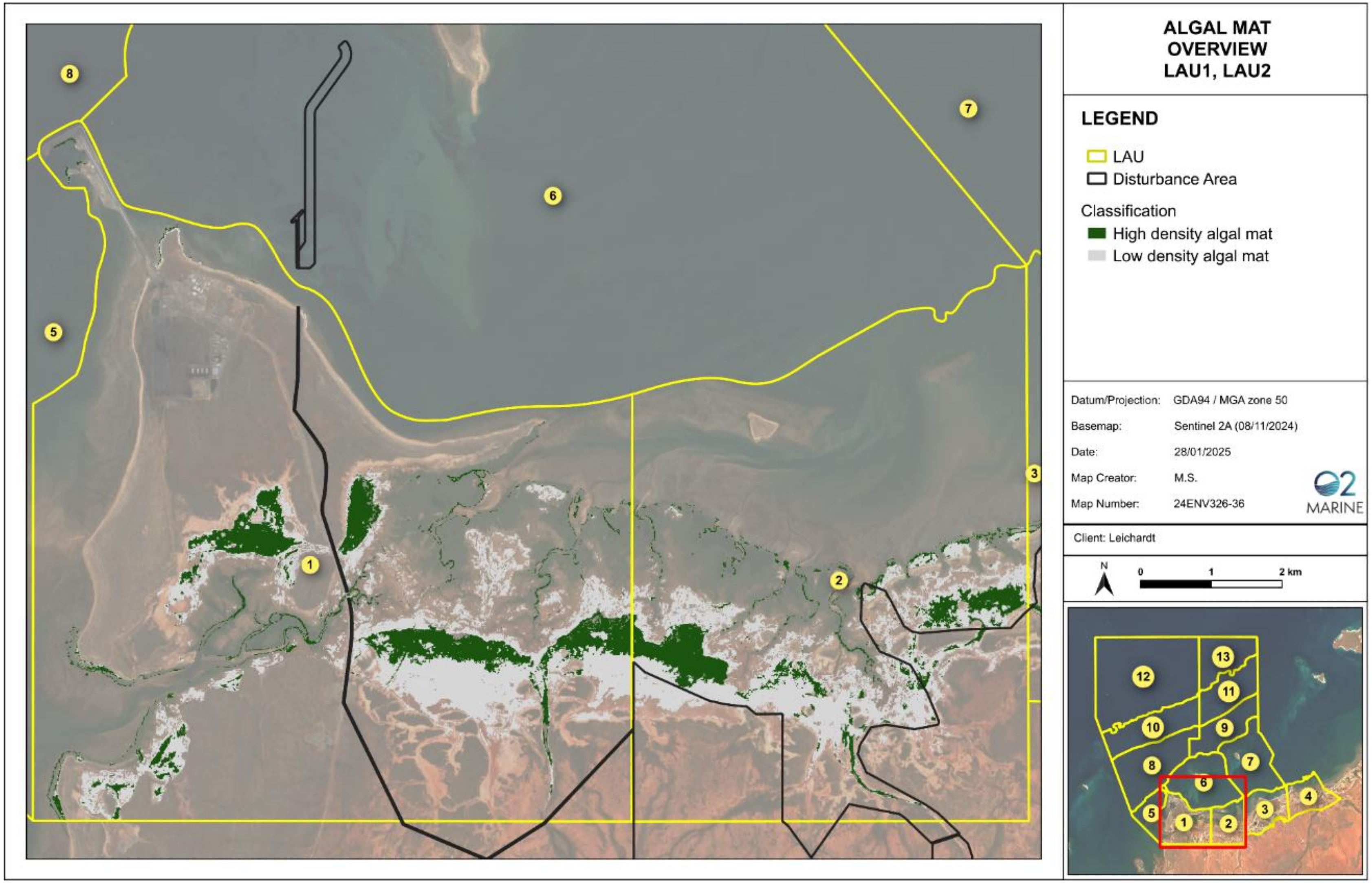



Figure 24: Algal mats within the proposed development footprint area, and LAU1 / LAU2

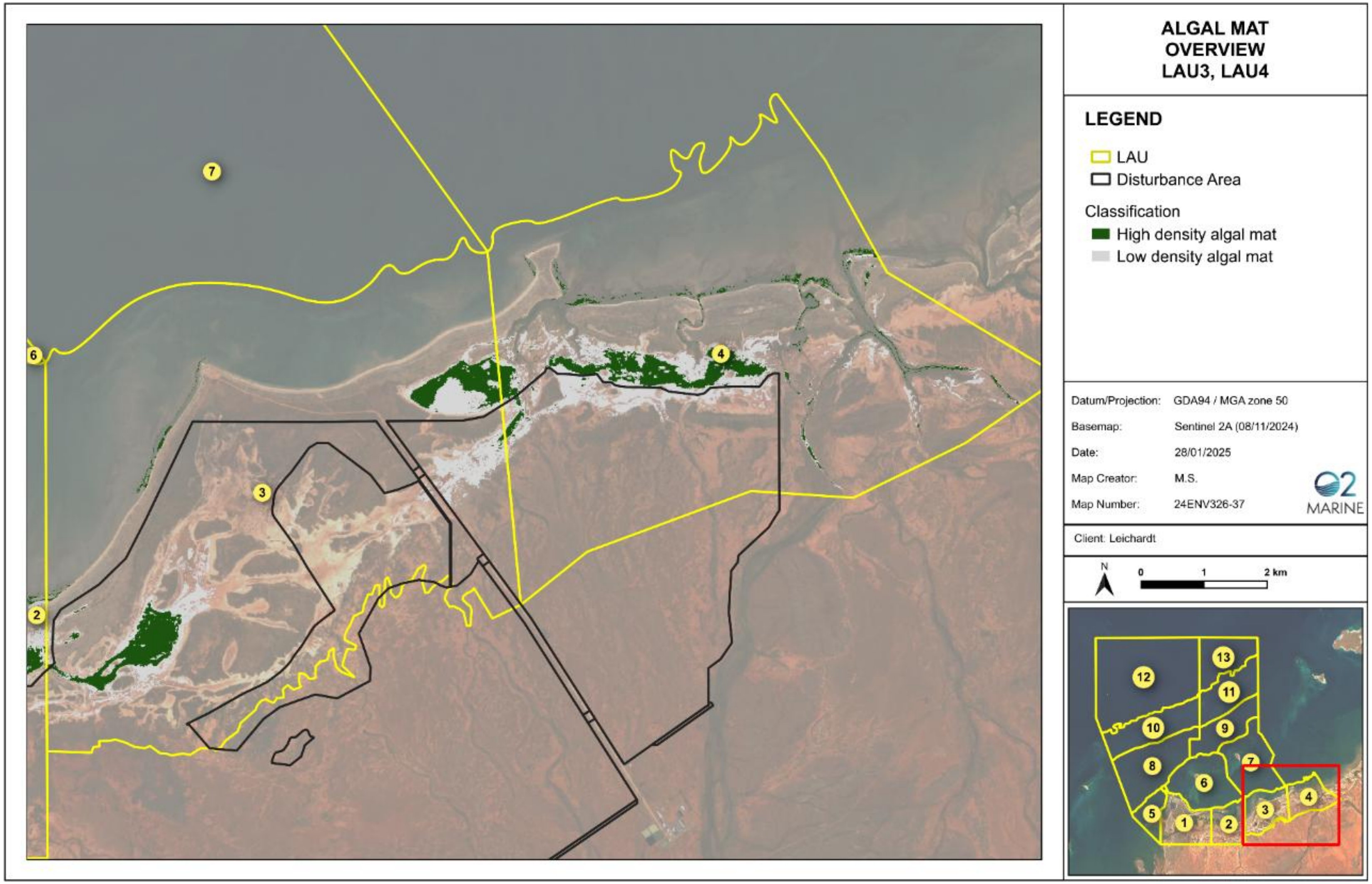



Figure 25: Algal mats within the proposed development footprint area, and LAU3 / LAU4

Algal mats (HDAM and LDAM) per LAU are graphically shown below in Figure 26, with example photos of each association shown in Plate 4.

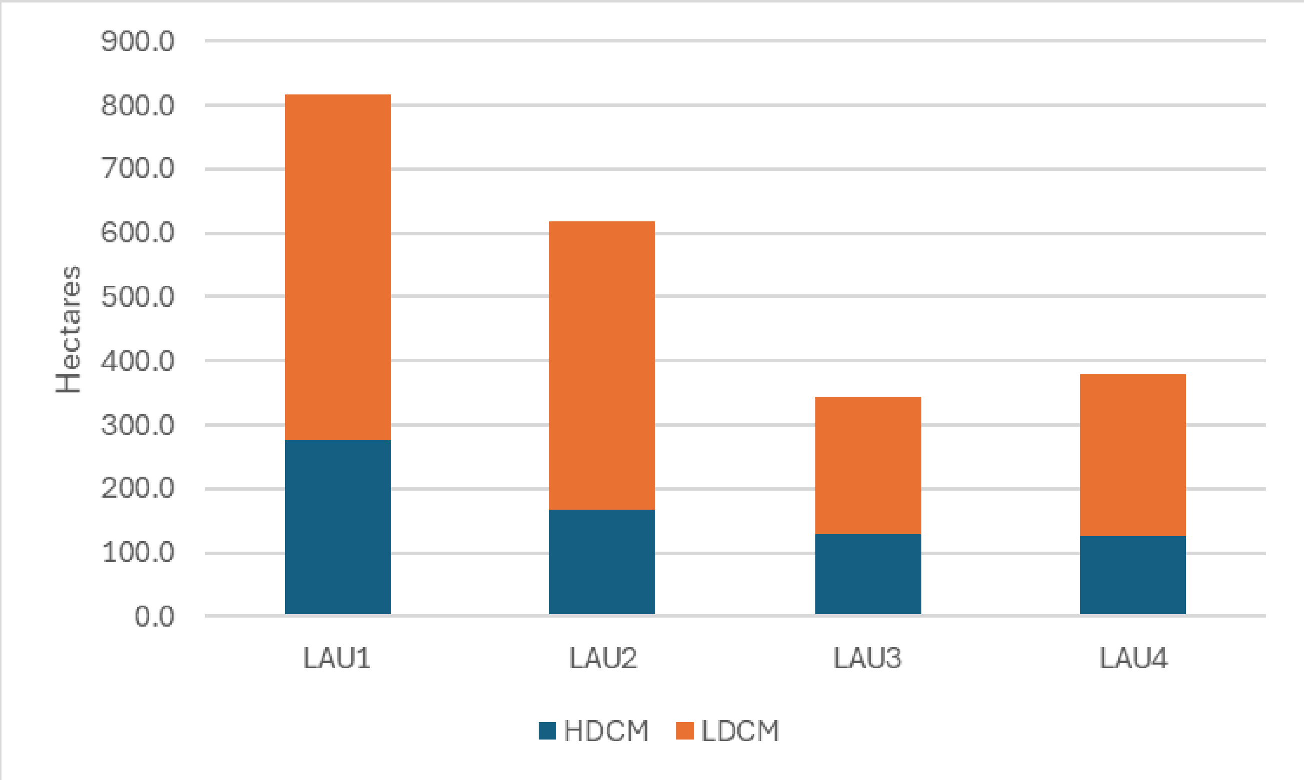



Figure 26: Graphic representation of algal mats distributions within each LAU

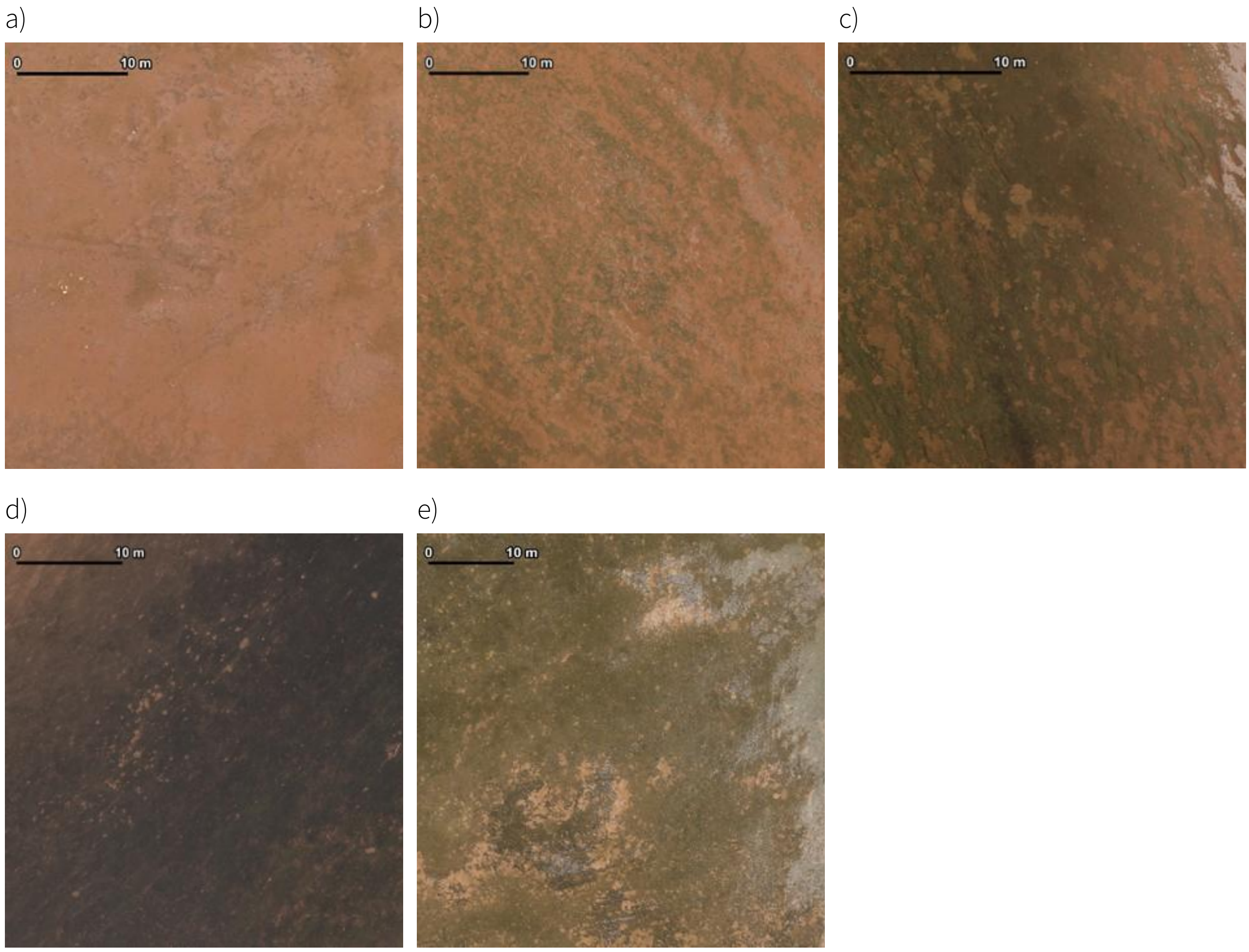



Plate 4: Drone photographs of the algal mat classes within the study area. a - b) LDAM, c – e) HDAM

### 6.1.4. Samphire

The samphire communities within the study area are primarily composed of *Tecticornia* species. The vegetation cover varies significantly across sampling sites, ranging from 1% to 70%. Heights of the samphire species generally range from 0.1 m to 0.5 m, with some individuals occasionally reaching 1 m.

Samphire calculations for each of the intertidal LAUs are summarised in Table 19. Figure 27 and Figure 28 displays the mapped samphire across the study area, with detailed maps for individual LAUs (1-4) shown in Appendix C.

Samphire's are present within all coastal LAUs. Samphire including algal mat are associated with the greatest spatial area across the study area covering over 1,197.3 ha or 66.0% of mapped samphire area. Total area (hectares) and relative percentages for each mapped samphire within proposed LAUs and the total study area. Samphire shrublands occupies 34.0% of the total area of all samphire mapped.

Table 19 Total area (hectares) and relative percentages for each mapped Samphire category within proposed LAUs and the total study area.

| Samphire | LAU1 | | LAU2 | | LAU3 | | LAU4 | | Total Area | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % | ha | % |
| Sam1 - Samphire incl algal mat (sparse) | 240.1 | 4.1% | 194.2 | 5.1% | 372.4 | 8.3% | 208.6 | 5.5% | **1015.3** | **5.6%** |
| Sam2 - Samphire incl algal mat (dense) | 71.0 | 1.2% | 33.0 | 0.9% | 14.7 | 0.3% | 63.4 | 1.7% | **182.0** | **1.0%** |
| Sam3 - Samphire shrublands (sparse) | 70.3 | 1.2% | 68.5 | 1.8% | 176.8 | 3.9% | 98.6 | 2.6% | **414.3** | **2.3%** |
| Sam4 - Samphire shrublands (dense) | 54.6 | 0.9% | 31.8 | 0.8% | 79.7 | 1.8% | 37.7 | 1.0% | **203.7** | **1.1%** |
| **Total** | **436.1** | **7.4%** | **327.4** | **8.6%** | **643.5** | **14.3%** | **408.3** | **10.8%** | **1815.3** | **10.1%** |

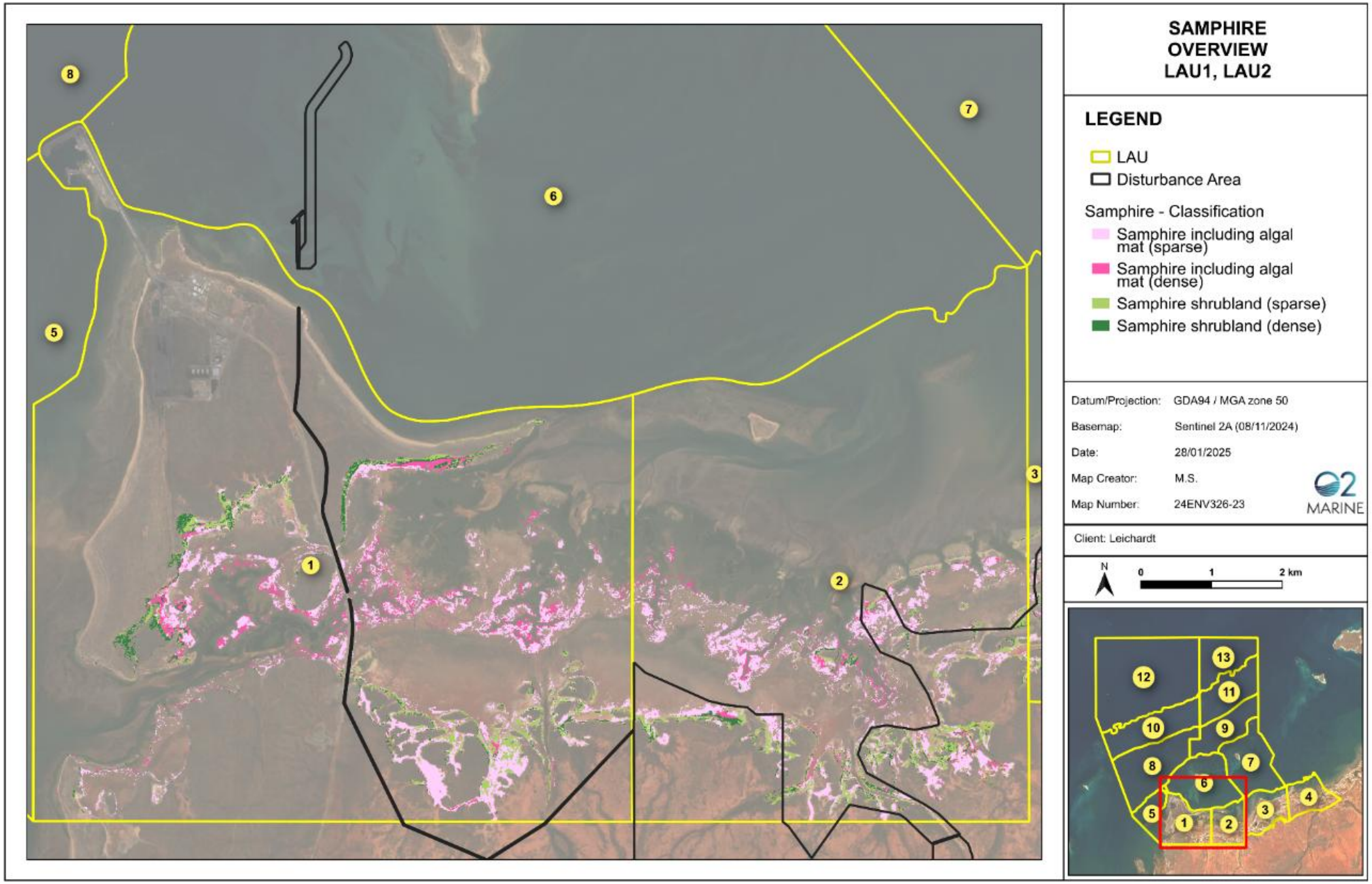



Figure 27: Samphires within the proposed development footprint area, and LAU1 / LAU2

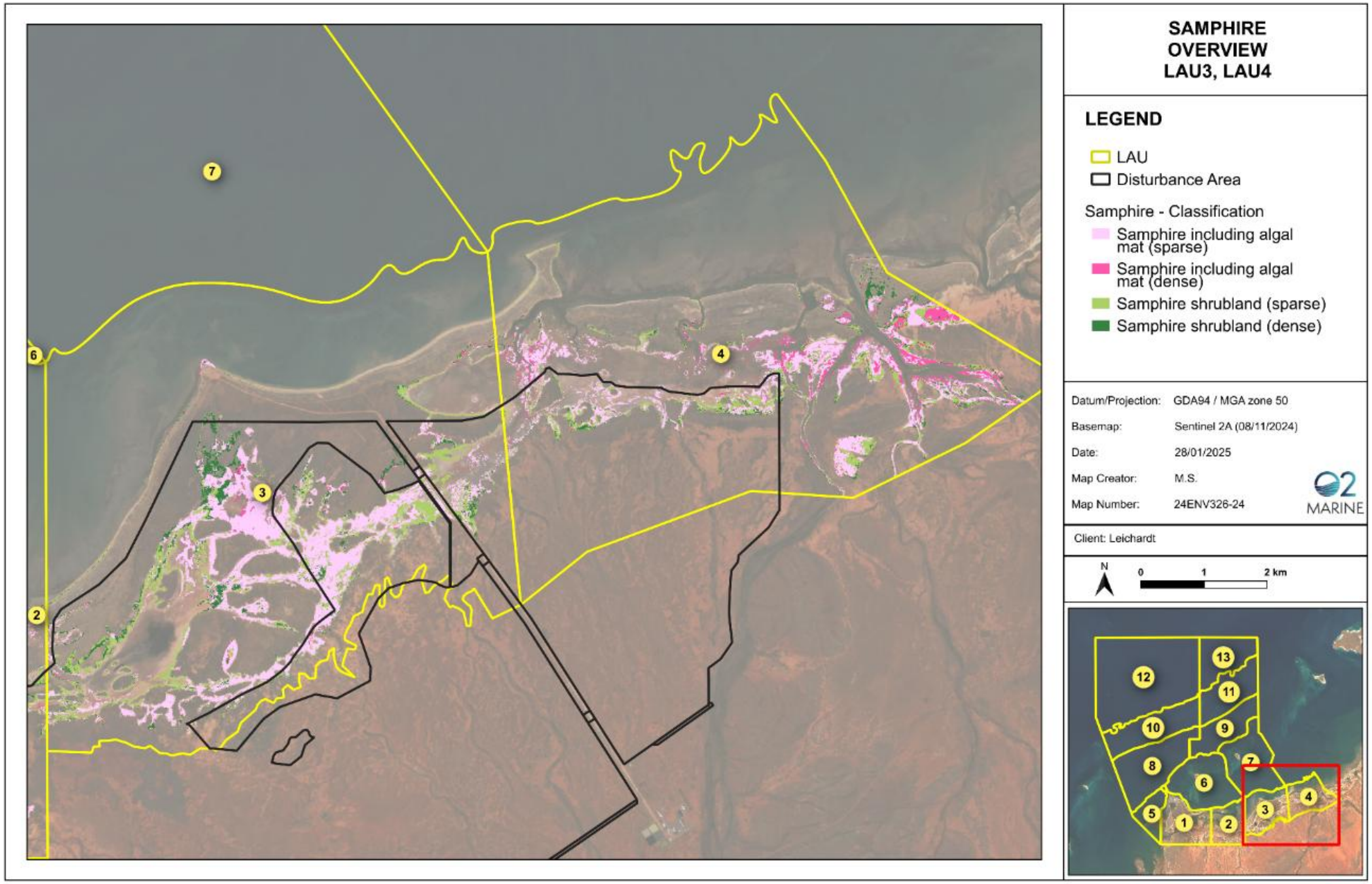



Figure 28: Samphires within the proposed development footprint area, and LAU3 / LAU4

Samphire categories per LAU are graphically shown below in Figure 29, with example photos of each association shown in Plate 5.

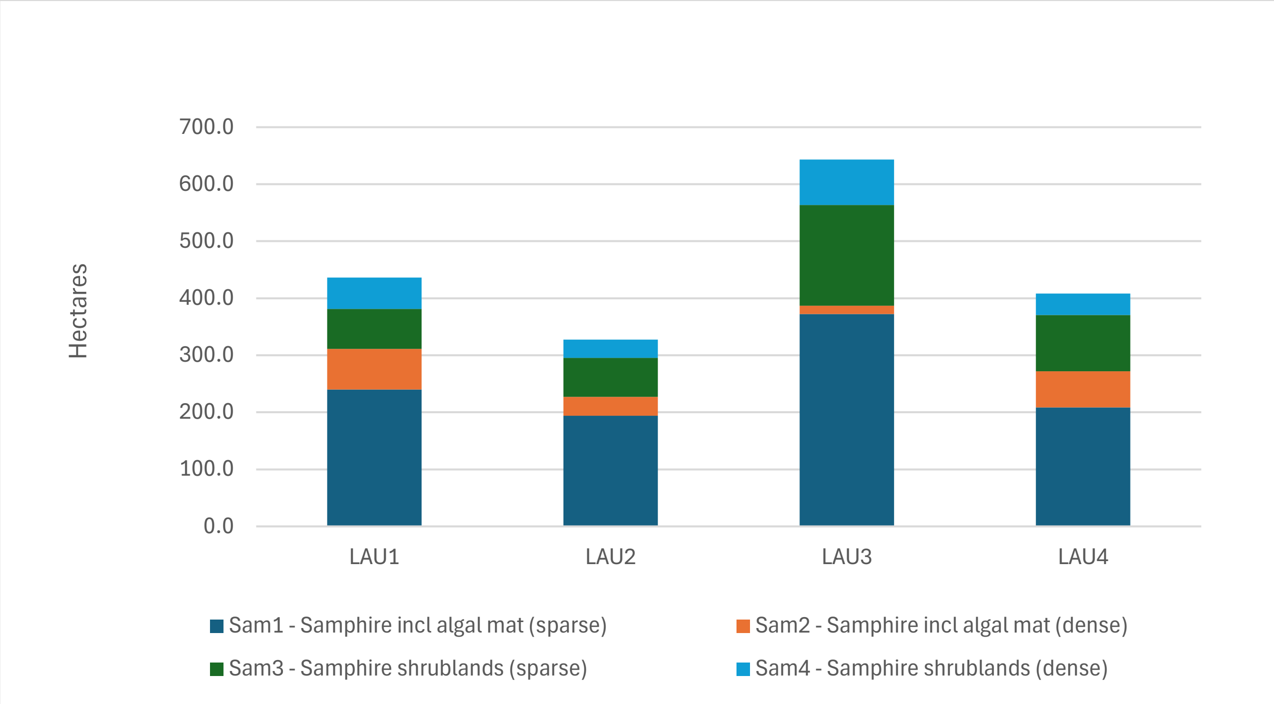



Figure 29: Graphic representation of mangrove association within each LAU

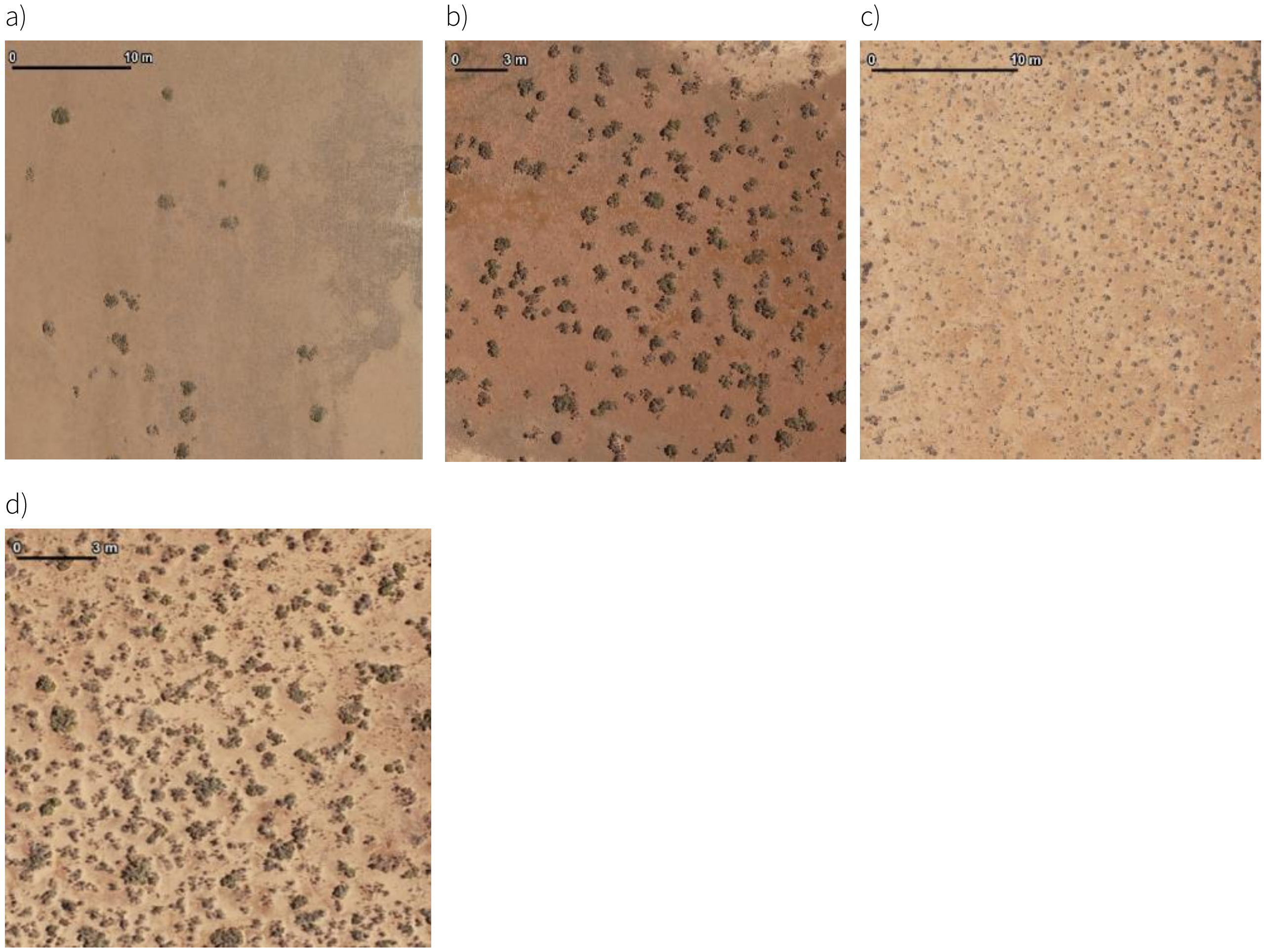



Plate 5: Photographs of the samphire classifications within the study area. a) Sam1 (Open Samphire flats (sparse cover)including algal mat), b) Sam2 (Open Samphire flats (low cover) including algal mat), c) Sam3 (Samphire shrubland (sparse)), d) Sam4 (Samphire shrubland (dense)).

## 6.2. Mangrove Fauna Surveys

### 6.2.1. Fauna by LAU

The survey recorded 1096 organisms within 39 quadrats across the study site. The total number of organisms and density of organisms were substantially higher in LAU4 compared to LAU1 or LAU2 (Table 20). Within LAU4, sites LWE5 and LWE7 accounted for 73% of the number of organisms observed across the study site. The number of surveyed quadrats and identified burrows were comparable among LAUs.

Most of the fauna were molluscs, the majority of which (97%) were concentrated in LAU4 (Table 21). In addition, more fish and more crustaceans were observed in LAU4 than LAU1 or LAU2. Within LAU1 and LAU2, crustaceans were the most abundant organism. Photos of example fauna quadrats are shown in Plate 4, with tabulated fauna results included in Appendix G.

Table 20 Fauna and burrow observations per LA

| LAU | Quadrats (n) | Burrows ($m^{-2}$) | Organisms (n) | Organisms ($m^{-2}$) | Richness ($m^{-2}$) |
|---|---|---|---|---|---|
| 1 | 13 | 9.1 (1.9) | 64 | 1.2 (0.3) | 0.9 (0.2) |
| 2 | 12 | 12.8 (4.2) | 82 | 1.7 (0.4) | 1.1 (0.2) |
| 4 | 14 | 8.4 (1.7) | 949 | 17.0 (7.9) | 1.9 (0.2) |

Table 21 The count of crustaceans (Sesarmidae, Diogenidae etc), fish (Periophthalmus spp.), and molluscs (Batillariidae, Neritidae etc) recorded within LAU.

| LAU | Crustaceans | Fish | Molluscs |
|---|---|---|---|
| 1 | 58 (16%) | 4 (19%) | 3 (1%) |
| 2 | 63 (17%) | 4 (19%) | 15 (2%) |
| 4 | 243 (67%) | 8 (62%) | 698 (97%) |

### 6.2.2. Fauna by mangrove association

Fauna were observed to differ among mangrove associations (Table 22). The density of burrows was four-fold higher in Rs1 mangroves compared to other mangrove associations, but almost all organisms were observed in Am2 and Am3 mangroves. Table 22 includes the number of quadrats, burrow density, number of organisms, density of organisms, and taxonomic richness (i.e., crustaceans, fish, mollusc). Values represent counts (n) or means per quadrat, value in brackets indicate standard error.

There were notable differences in the composition of fauna observed in different mangrove associations: 73% of crustaceans were observed in Am2 mangroves while 94% of molluscs were observed in Am3 mangroves (Table 23). In contrast, similar counts of crustaceans and molluscs were observed in Am1 and Rs1. Table 23 shows total counts for crustaceans (*Sesarmidae, Diogenidae* etc), fish (*Periophthalmus* spp.), and molluscs (*Batillariidae, Neritidae* etc). Percentages indicate the proportion of organism per association. Plate 4 shows examples of fauna quadrats set up in the field.

Table 22 Total fauna observed within each mangrove association.

| Mangrove. assoc. | Quadrats (n) | Burrows ($m^{-2}$) | Organisms (n) | Organisms ($m^{-2}$) | Richness ($m^{-2}$) |
|---|---|---|---|---|---|
| Am1 | 6 | 10.0 (4.1) | 52 | 2.2 (1.0) | 1.3 (0.3) |
| Am2 | 17 | 6.9 (0.7) | 283 | 4.2 (1.2) | 1.6 (0.2) |
| Am3 | 7 | 9.3 (3.1) | 698 | 24.9 (15.7) | 1.0 (0.4) |
| Rs/Am | 7 | 9.0 (2.0) | 55 | 2.0 (2.4) | 1.2 (0.3) |
| Rs1 | 2 | 42.8 (1.0) | 12 | 1.5 (-) | 0.8 (0.3) |

Table 23 Total fauna type per mangrove association.

| Mang. Assoc. | Crustaceans (n) | Fish (n) | Molluscs (n) |
|---|---|---|---|
| Am1 | 27 (7.4%) | 2 (5.3%) | 23 (3.2%) |
| Am2 | 266 (73.3%) | 2 (15.8%) | 15 (2.1%) |
| Am3 | 15 (4.1%) | 12 (52.6%) | 671 (93.7%) |
| Rs/Am | 47 (13.0%) | 5 (26.3%) | 3 (0.4%) |
| Rs1 | 8 (2.2%) | 0 | 4 (0.7%) |


Plate 6: Photographs of typical fauna quadrats surveyed within the study area. A) Am2 Site M2 LAU1, b) Rs Site M2 LAU1, c) Am1 Site M2 LAU1, d) Am3 Site M3 LAU2.

## 6.3. Algal mat composition

Ten algal mat samples were collected across the four intertidal LAUs (Figure 16 and Table 11). From the ten samples, six types of bacteria and algae were identified, including diatoms, dinoflagellates, and cyanobacteria. All sites (except A7) recorded an abundant layer of the filamentous cyanobacteruium *Lyngbya. Coleofasciculus* and *Schizothrix* were regularly recorded at most sites. Infrequent recordings of the diatom *Navicula* (Site A1 and A9), the dinoflagellate *Ceratium* (A1) and the cyanobacterium *Synechococcus* (A5) were recorded in low ('rare') abundance. From these results three communities (A, B and C) were identified. Community A were the only sites to record *Navicula* (rare), Community B all had records of *Lyngbya, Coleofasciculus* and *Schizothrix*, while Community C had no record of *Lyngbya.* Examples of the key algal taxa identified are presented in Table 24 , with a summary of sample results included in Table 25. Algal mat samples were analysed by marine benthic algae taxonomy expert John Huisman (DBCA), with results and a summary report included as Appendix E.

Table 24 Six micro algae identified during the May 2020 survey.

| Common name | Phylum | Species | Representative image from samples |
|---|---|---|---|
| Diatom | Ochrophyta | *Navicula* sp. | NA |
| Dinoflagellate | Myzozoa | *Ceratium* | NA |
| Cyanobacteria | Cyanobacteria | *Lyngbya* |   |
| Cyanobacteria | Cyanobacteria | *Coleofasciculus chthonoplastes* |  |

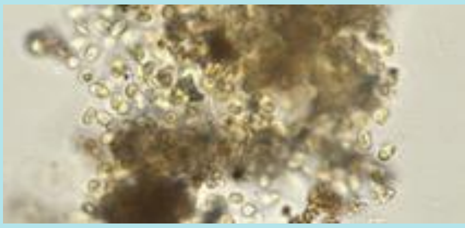
| | | | |
|---|---|---|---|
| Cyanobacteria | Cyanobacteria | *Scizothrix* spp. |  |
| Cyanobacteria | Cyanobacteria | *Synechococcus* sp. |  |

Table 25 Algae community types recorded during the May 2020 survey

| Sample ID | LAU | Sample Description. | Community | *Navicula* | *Ceratium* | *Lyngbya* | *Coleofasciculus* | *Schizothrix* | *Synechococcus* |
|---|---|---|---|---|---|---|---|---|---|
| **A1** | LAU1 | Mostly contiguous, ~3-5mm thick, recently inundated/surface moisture present | A | Rare | Rare | Abundant | Common | Common | NA |
| **A2** | LAU1 | Inundated, contiguous, slightly filamentous, ~3-5mm thick, surface water present | B | NA | NA | Abundant | Common | Common | NA |
| **A3** | LAU1 | Fragmented, 2-3 mm thick, filamentous, recently inundated, surface water present | B | NA | NA | Abundant | Common | Common | NA |
| **A4** | Lau2 | Br/Gr ~2-3mm thick, contiguous, filamentous, recent inundation, surface water present | B | NA | NA | Abundant | Common | Common | NA |
| **A5** | LAU2 | Contiguous ~2-3mm thick, recently inundated, low surface water, slightly filamentous | B | NA | NA | Abundant | Common | Common | Rare |
| **A6** | LAU3 | 2-3mm thick, contiguous, slightly filamentous, slightly inundated from recent spring tides, green | B | NA | NA | Abundant | Common | Common | NA |
| **A7** | LAU3 | Brown mudflat but thin algal mat layer ~1-2mm, contiguous, non-filamentous, inundated approx. 5-7mm | C | NA | NA | NA | Common | Rare | NA |
| **A8** | LAU3 | Dark green/brown, contiguous. Sample wet but not inundated. ~2-3mm thick | B | NA | NA | Abundant | Abundant | Rare | NA |
| **A9** | LAU4 | Dark green/brown, contiguous, filamentous. Sample moist, but not wet - no inundation. ~2-3mm thick | A | Rare | NA | Abundant | Rare | Rare | NA |
| **A10** | LAU4 | Green/dark green, mostly contiguous, filamentous, moist but not wet. ~1-2mm thick | B | NA | NA | Abundant | Common | Common | NA |

# 7. Intertidal Habitats of the Eramurra Coastline

In accordance with technical guidance for the protection of BCH from the EPA (EPA, 2016), full coverage accurate maps of the intertidal BCH within the study area have been prepared using a combination of remote sensing technologies coupled with targeted field work to ground truth the interpretation of remote sensing. The maps produced enable the calculation of the area coverage for each intertidal BCH type across the entire study area and within each of the proposed LAUs. Detailed maps displaying intertidal BCH habitats within each of the proposed intertidal LAUs are presented in Appendix A. These maps will be used to inform the spatial context for the calculation and assessment of recoverable impacts and cumulative losses to assist with the Environmental Impact Assessment for the Proposal. These findings will be detailed in the Eramurra Solar Salt Project – Cumulative Loss Assessment Report (O2 Marine 2025).

The intertidal study area is predominantly comprised of algal mats (16.99%), samphire (14.30%), and *A. marina* mangroves (10.14%). The 'other' habitat types include terrestrial vegetation and infrastructure / cleared areas (55.57%). Detailed discussion on terrestrial vegetation is included in Phoenix (2025).

Broadscale regional characteristics within the study area (excluding west of the Cape Preston causeway) identifies decreasing spatial area of the intertidal zone with an increase in terrestrial habitats from west to east (LAU1 to LAU4). East of the causeway is typically dominated by a north to south oriented ridgeline, which terminates at Cape Preston in the north. This ridgeline is dissected in two in the centre of LAU1 by a medium sized intertidal creek and associated mangrove and algal mats/mudflats. Algal mats are consistent across the study area, however, are lowest by proportion in the east (LAU4) and tend to become more fragmented by terrestrial islands through LAU2 and LAU3 and reduce in size considerably within LAU4. A sheltered bay has formed behind the sand spit running east from Cape Preston towards Great Sandy Island within which extended intertidal mudflats and a series of intertidal creeks occur. This system has provided a suitable habitat which supports an almost continuous mangrove community from the causeway in LAU1 to the eastern boundary of LAU2. As the coastal aspect and level of shelter alters through LAU3 the coastal landforms convert to a long sandy beach, interspersed with several rocky sections, and sand dune system right up to Gnoorea Point and then continues slightly into LAU4 where the coastal landforms alter once more. Here an anvil shaped headland provides a semi sheltered bay where foreshore mudflats replace sandy beaches and a series of smaller intertidal creeks cut through the coastal sand dune formations. Mangroves have become established as thin ribbons along the tidal creeks. However, the riverbanks are quite steep and the supporting vegetation behind the mangroves is typically terrestrial. Mangroves have also established thin communities along the north facing shoreline in LAU4 and west-north-west facing shoreline east of Gnoorea Point in LAU3.

Regional characteristics from the seaward to landward zones of the intertidal area are quite variable between LAUs. East of the causeway within LAU1 and LAU2, and to a lesser extent LAU4, the intertidal BCH is typified by foreshore mudflats/tidal creeks extending to the high-water mark whereby mangrove communities have become established as the dominant intertidal BCH type. Mangroves occur in bands of varying width along the coastline and banks of tidal creeks, with more structurally complex, taller, and denser CC communities occurring on the seaward extent and making way for the sparser, lower and less structurally complex SC communities on the landward extent. CC communities are particularly dominant throughout these LAUs, occurring over a wider range of habitats and forming larger forests extending out over tidal flats. Thin bands of samphire communities occur on the landward extent of mangrove communities, typically Am2, where they often form overlapping boundaries with SC mangroves (these shared habitats are classified to the dominant BCH type and mapped as mangroves). Behind samphires, mudflats/saltflats or algal mats typically occur up to the supratidal zone where terrestrial communities commence. The exception is the zonation observed in LAU3, and to a lesser extent LAU4, where the intertidal zone is typically restricted to algal mats and mudflats/saltflats occurring behind coastal sand dunes and interspersed by terrestrial islands. A series of intermittent freshwater creeks can be observed in LAUs 1 and 2 and LAU4 which would sporadically feed freshwater into the mudflats/algal mats and link to the intertidal zone through the creeks.

Identifying fauna species and abundance that utilise the different intertidal BCH is important in understanding the significance of these habitats. For more detailed assessment of the faunal assemblages, please refer to Phoenix (2023).

## 7.1. Mudflats

Mudflats across the study area ranged from the spring low tide mark, landward to the spring high tide mark. mudflats were typically located immediately adjacent (both seaward and landward) of mangal communities and generally have 'Terrestrial Vegetation' as the landward limit. Mudflats were the most dominant intertidal BCH across the four LAUs, and are calculated over two BCH categories; Bare Intertidal Habitat including High Intertidal Salt Flats (HISF), and Algal mat (transitional). A total of 2,419 ha of mudflat was identified, making up 19.1% of the intertidal study area.

The most continuous and extensive mudflat areas within the study area exist seaward of mangrove or beach/foredunes, extending out towards the intertidal macroalgae/seagrass/rock platform communities (Figure 17). LAU1 comprised the largest area of Mudflat, with 919 ha. Mudflat areas were notably lower within LAU3 and LAU4 with areas of 399 ha and 416 ha respectively. Large sections of the seaward Mudflat areas have a regular exposed/inundated cycle as a result of daily tidal movement. These areas were generally classified as flat, fine sand with shells, and were predominantly devoid of biotic cover except for the occasional macroalgae and crab burrows.

Mudflats on the landward side of the mangal were found to contain less sand and have more clay properties, shells and organic debris were commonly interspersed on the surface. These areas (particularly towards the Terrestrial Vegetation edge) have longer atmospheric exposure periods, with inundation only occurring at spring high tides.

### 7.1.1. Associated Faunal Diversity

Details on associated faunal diversity are discussed in Phoenix (2023).

## 7.2. Mudflats / Algal mats

Algal mats occurring within the Pilbara coastal region have been subject to numerous studies, particularly related to a variety of project impact assessments, as well as pure research projects. Relevant references include Paling (1990), Biota (2005), URS (2010) and O2 Marine (2020a, and 2020b).

### 7.2.1. Species diversity

Field surveys for the Proposal identified algal communities as either continuous or fragmented and varying in colour between green, to brown or grey depending upon hydration states. Algal mats were noted as being inundated, or recently inundated, during sample collection. Continuous algal mats were described as extensive, thicker (2-5 mm) and more cohesive, characterised by a smooth appearance. Several sites were observed where algal mats have a slightly filamentous appearance. Fragmented algal mats were thinner (1–3 mm) and patchier, often appearing pustular. Laboratory analysis identified six taxa recorded within algal mat samples collected from the study area, dominated by filamentous cyanobacteria *Lyngbya sp*. with *Coleofasciculus chthonoplastes* and *Schizothrix spp*. typically recorded as common. Comparable composition of taxa was identified between contiguous and fragmented communities, and little variation among assemblages was evident across the entire study area. Algal mats were typically associated with a fine clay material overlaying a dark anoxic layer. Table 25 displays a summary of the taxa recorded during field surveys.

Algal mats surveyed for this Proposal were considered representative of algal mat habitats assessed through studies occurring in similar sites within the Pilbara region, including the Mardie coastline (O2 Marine, 2020a), Exmouth Gulf (Biota, 2005) and south of Onslow (Paling, 1990, URS, 2010). Algal mat colour, form and composition are consistent with similar regional Pilbara studies (Paling, 1990, Biota, 2005, URS, 2010 and O2 Marine, 2020a). Similar smooth or folded thicker contiguous layers were characteristic within Algal mat communities studied within the Mardie Project where recent inundation was observed (O2 Marine 2020a).

Algal mat diversity and composition of species identified across the Proposal site are also comparable with these similar studies undertaken locally within the Pilbara region. Table 26 provides a comparison between Algal mat characteristics from the Eramurra study area, with information presented from similar regional studies occurring within the Pilbara region.

Table 26 Summary of Algal Mat characteristics from the Eramurra Proposal and similar regional studies

| Project | Dominant Genera | Colour | Form | Thickness (mm) | Elevation (m AHD) | Tidal Regime (m) |
|---|---|---|---|---|---|---|
| Onslow Solar Salt[1] | *Microcoleus* | Dark green | Smooth to pustular | 8-10 | N/A | 2.6 |
| Yannarie Salt[2] | *Lyngbya Microcoleus Oscillatoria Schizothrix* | Grey to black | Smooth to pustular | 5-10 | 1.3-1.4 | 2.0 |
| Wheatstone LNG[3] | *Oscillatoria* | Grey to black | Smooth to pustular | 5-10 | N/A | 2.6 |
| Mardie[4] | *Lyngbya Microcoleus Calothrix Oscillatoria Schizothrix* | Green, grey to black | Smooth to pustular | 1-5 | 1.1-1.3 | 2.7 |
| Eramurra | *Lyngbya Schizothrix C. chthonoplastes* | Green, brown to grey | Smooth to pustular | 2-5 | 1.2 – 1.3 | 2.7 |

References: 1 – Paling, 1990, 2 – Biota, 2005, 3 – URS, 2010, 4- O2 Marine, 2020a and b.

### 7.2.2. Mudflat / Algal mat distribution

Mudflat / algal mat BCH occurs in 2,157 ha and comprises ~17.0% of the total coverage of BCH within the intertidal study area. Algal mats are also included in the category open samphire flats inclusive of algal mats, which comprise 1,197 ha (9.4%) of the intertidal study area. Algal mat areas were identified to occur within a relatively nominal elevation of 1.47 – 1.87 m AHD. Algal mats were observed to typically occur adjacent to samphire shrublands (or within low density samphire areas in transition zones) and be centralised between mudflat areas on both the seaward and landward side. mudflats/samphire mudflats on the seaward edge and mudflats/saltflats on the landward edge. There are two primary communities of algal mats identified across the four intertidal LAUs:

1. Centralised across LAU1 and LAU2, and stretching to the east boundary of LAU2, into the lower western area of LAU3.
2. Begins at the north eastern boundary of LAU3 and extends into the central area of LAU4.

Across two BCH categories (Algal mats and Samphires), algal mats were most abundant by area within LAU1 (1128 ha), making up 8.9% of the total intertidal study area. LAU2 and LAU3 recorded comparable algal mat areas with 844 ha and 738 ha respectively. LAU4 recorded less area of algal mat with 651 ha.

All but one sample (A3 in LAU1) were reported as contiguous (thick and extensive), with most samples classified as filamentous or slightly filamentous. A3 was reported as fragmented (2-3mm thick) and filamentous. Three community classifications were assigned to the ten Algal Mat samples. Samples A1 and A9 (Community A) were the only two samples to record *Navicula*, with an abundance rating of 'rare', and also recorded an 'abundant' layer of *Lyngbya*. Samples A2-A6, A8 and A10 (Community B) all recorded an abundant layer of *Lyngbya*, and *Coleofasciculus* and *Schizothrix* in either 'common' or 'rare' abundance. A7 was the only sample where *Lyngbya* was not reported, and the only site where inundation at the time of sampling was reported (5-7mm), this sample was assigned its own Community (Community C).

### 7.2.3. Factors affecting the distribution of algal mat BCH

Microbial mats proliferate in shallow aquatic ecosystems, including tidal flats and coastal and hypersaline lagoons because of their ability to tolerate extremes in salinity, desiccation, temperature and ultraviolet radiation (Lee and Joye 2006). Biota (2005), URS (2010) and Stantec Australia (2018) observed high salinity and dehydration as the controlling factors at the higher elevations of Algal Mat communities in studies along the Pilbara Coast. These observations are commensurate with the Eramurra Proposal study area. Mudflats (often with areas of crystallised salt crust) typically occur on the landward edge of Algal Mat communities throughout the study area, likely indicating the point at which either the maximum salinity or dehydration levels are reached or exceeded. Mudflats/Saltflats are characterised by very high salinity, little to no tidal inundation and are extremely dry, which is consistent with observations from both the Yannarie and Wheatstone project assessments (Biota, 2005 and URS, 2010). Mapping by URS (2010) identified the same relationship at the Wheatstone Project between elevation and the distribution of algal mats and mudflats/saltflats, noting the upper limits are controlled by desiccation and salinity, and the lower limits likely controlled by grazing of invertebrates (associated with adjacent habitat class) and greater levels of inundation. Grazing by invertebrates, molluscs and fish at high tides was also noted by Paling (1990) as a controlling factor in the distribution of algal mats at the lower gradient. This should be considered a factor at Eramurra (particularly within LAU3 and LAU4) with grazing invertebrates associated with samphire shrubland typically occurring on the seaward edge, confining the extent of Algal Mat by grazing.

Whilst the above salinity, inundation and predation mechanisms are reported to impact distributions, similar to the Algal Mat boundaries for the Mardie Project, the Eramurra communities occur in areas of slight depression within the wider mudflat zones. The majority of the spring tide water retreats back to the ocean via creek systems, however some water temporarily resides in low lying areas, leaving behind small pools of water that either evaporate or filtrate into the ground water. This is followed by period of around 7-10 days whereby no tidal inundation occurs (during neap tides). This cycle results in a continuous source of saline water entering the Algal Mat communities, whereby exposure to intense insolation results in evaporation-concentration and ultimately very high salinities. Hence, algal mats are the only BCH type able to thrive under these conditions.

Modelled impacts on water levels post development are discussed in the Tidal Inundation Modelling Report (O2 Marine, 2022c). The implications of these modelled results to algal mat communities are discussed in the Cumulative Loss Assessment Report (O2 Marine 2025).

### 7.2.4. Associated Faunal Diversity

Other studies from the Pilbara region have also concluded that, other than to support algal and bacterial communities, algal mats do not tend to support any particular species solely reliant upon them, apart from opportunistic grazing on the seaward boundary by crabs and some fish species during high tides as described in the section above (Paling, 1990, Biota, 2005, URS, 2010). Live Algal mat communities were observed by SKM (2011) within Port Hedland mudflats to have no evidence of grazing and live samples analysed under microscope identified no evidence of micro-invertebrates. Cyanobacterial communities found in CC mangrove areas (discussed below) support a far greater diversity and level of secondary productivity compared cyanobacterial communities found in mudflats with higher salinities.

## 7.3. Mangroves

Mangroves occurring within the study area extend over 1,381 ha, or 7.7% of mapped intertidal BCH. Being typically associated with tidal creeks, distribution patterns for mangroves are consistent with mapped extents of Tidal Creeks. The densest and most extensive communities are present within LAU1 and LAU2 where the creeks are more frequent and typically larger in extent, while the more sparse and fragmented mangrove communities occur in LAU3 and AU4 where creeks are less frequent and generally smaller (with the only exception of Devil's creek). 85% of the total area of mapped mangrove BCH is found within LAUs 1 and LAU2. Mangrove BCH within these two LAUs almost form continuous forests extending out across the tidal flats between creeks interspersed by Samphire and Mudflat communities. These mangrove BCH are typically found occurring in narrow ribbons associated with Tidal Creek banks or at the high-water mark along shorelines until they reduce in size at the eastern border of LAU2 and marginally into the western edge of LAU3. The coastline of LAU3 has very little mangrove BCH (18 ha or 0.4%) and instead is dominated by a coastal dune system and sandy beach. Within LAU3, there are no mapped tidal creeks and therefore there are no associated mangrove communities occurring alongside these. However, running for approximately 1,500 m along the north-west facing coastline from Gnoorea Point is a small ribbon of mangroves which have established in the intertidal zone adjacent to the sandy beach which extends right down to LAU2. LAU4 presents mangrove community characteristics similar to LAU1 and LAU2, albeit smaller and less frequent (193 ha or 5%). There are some smaller areas where the canopy extends over tidal flats to form forests. Rather than extending across tidal flats between creeks, as observed in LAU1 and LAU2, the creeks in LAU4 have established between coastal sand dune communities which occur above the supratidal zone, therefore comprising terrestrial vegetation complexes. Similarly to LAU3, mangroves have established in the lower intertidal zone stretching along the coastline adjacent to sandy beaches which are distributed between the creek mouths. This community is slightly more established, typically being wider and longer in size than the LAU3 community. The distribution of mangrove BCH within the study area is considered typical of the Pilbara coastline (Johnstone, 1990; Kenneally, 1982; Semeniuk, 1994).

### 7.3.1. Species Diversity

Seven species of mangroves are known to occur within the Pilbara region (EPA, 2001a). Of these, three species representing two families were identified during surveys undertaken by O2 Marine (Plate 7). These included:

1. *A. marina* (Acanthaceae)
2. *C. australis* (Rhizophoraceae), and
3. *R. stylosa* (Rhizophoraceae).

Investigations within the study area undertaken by HGM (2000) as part of an assessment for a separate project identified the following additional species occurring within LAU1:

- *Aegialitis annulate*
- *Aegiceras corniculatum (Primulaceae)*
- *Ceriops tagal,* and
- *Bruguiera exaristata.*

The aim of this present study was to map the major mangrove associations and their distributions and to assess community health. There may be additional uncommon species present that were not identified during this survey. The species identified during this study and the associations they form are typically the most common in this region.

All seven mangrove species listed by EPA (2001b) including the three species recorded in this survey have broad distributions across northern Australia (Duke, 2006). The two most common species (*A. marina* and *R. stylosa*) are broadly distributed throughout the Asia-Pacific region (*R. stylosa*) and the wider Indo-Pacific region (*A. marina*) (Duke, 2006; IUCN, 2017a, b). These two species are characteristic of the regional area (Johnstone, 1990; Kenneally, 1982; Semeniuk, 1994) and are not listed as species of conservation significance (Florabase 2021). Figure: 30 presents the distribution of these three mangrove species as they have been recorded for WA in https://florabase.dpaw.wa.gov.au. *A. marina* occurs from Bunbury in the south to the border with Northern Territory in the north, with a vast distribution within intertidal zones. They also occur in various types of associations as described in more detail below. *R. stylosa* and *C. australis* are both found from Exmouth Gulf in the south to the border with Northern Territory in the north. *R. stylosa* occurs in monospecific stands or mixed with other species, typically on tidal flats or toward the landward edge of mangrove communities, whilst *C. australis* occurs near the supratidal margin in well drained consolidated clays (Clarke *et al*. 2001, Duke, 2006, Florabase, 2021, Wells, 1982).

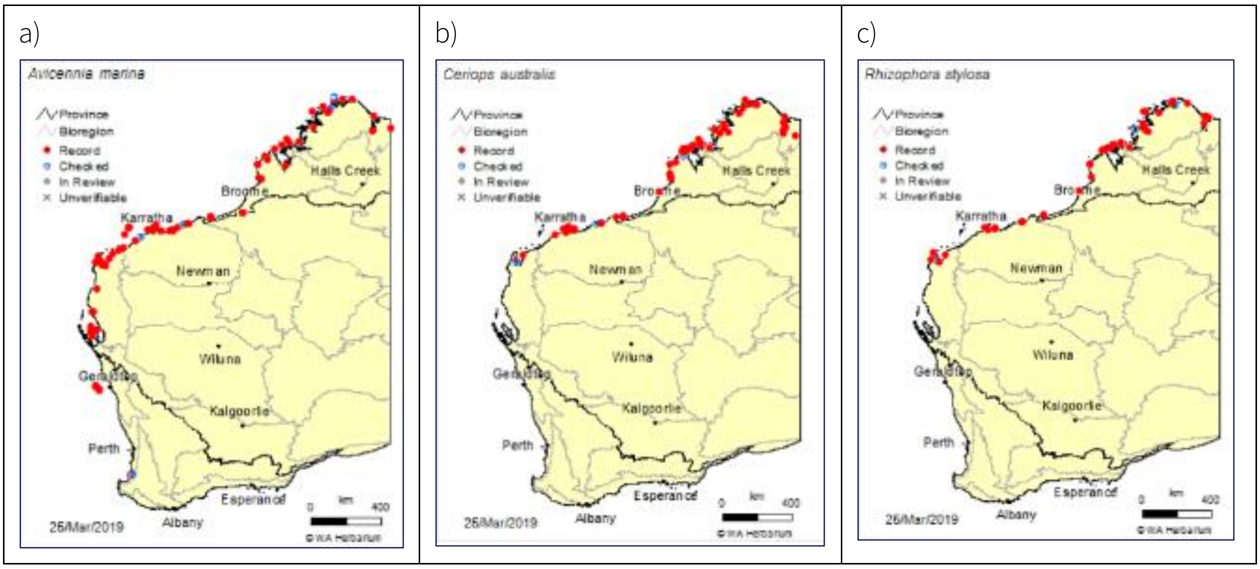



Figure: 30 Western Australian distribution of mangrove species identified within the Study area.

a) b) c)

Plate 7: Photographs of mangrove species observed during Eramurra Proposal surveys: a) *A. marina*, b) *R. stylosa,* and c) *C. australis*

Table 27 presents a summary of mangrove assessments undertaken in the local Pilbara region. The species richness recorded from the Eramurra study area is low when compared with other regional project assessments where species richness recorded a maximum of six of the seven species known to occur within the Pilbara. *A. marina* communities are the dominant mangrove associations within the Proposal study area, representing over 84% of the total mapped area. This dominance by *A. marina* is typical of mangrove communities within this local region of the Pilbara and the wider Pilbara and Canning coasts of north-western Australia (LeProvost Environmental Consulting, 1991; Semeniuk, 1993).

Table 27 Mangrove species recorded from the Eramurra Proposal study site compared with regional project assessments from the Pilbara region.

| Project | Recorded Species | Dominant Species | Species Richness | Number of Associations |
|---|---|---|---|---|
| Onslow Solar Salt[1] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Ceriops tagal**  | *Avicennia marina* | 3 | N/A |
| Roller Oilfield[2] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Bruguiera exaristata*<br>*Ceriops tagal**<br>*Aegialitis annulate*<br>*Aegiceras corniculatum* | *Avicennia marina* | 6 | N/A |
| Yannarie Salt[3] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Bruguiera exaristata*<br>*Ceriops tagal**<br>*Aegialitis annulate*<br>*Aegiceras corniculatum* | *Avicennia marina* | 6 | 5 |
| Domgas LNG – Mardie[4] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Ceriops australis*<br>*Aegialitis annulate Aegiceras corniculatum* | *Avicennia marina* | 6 | N/A |
| Wheatstone LNG[5] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Bruguiera exaristata*<br>*Ceriops australis*<br>*Aegialitis annulate*<br>*Aegiceras corniculatum* | *Avicennia marina* | 6 | 7 |
| Mardie[6] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Ceriops australis* | *Avicennia marina* | 3 | 5 |
| Cape Preston[7] | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Bruguiera exaristata*<br>*Ceriops tagal**<br>*Aegialitis annulate*<br>*Aegiceras corniculatum* | *Avicennia marina* | 6 | 12 |
| Eramurra | *Avicennia marina*<br>*Rhizophora stylosa*<br>*Ceriops australis* | *Avicennia marina* | 3 | 8 |

References: 1 – Paling, 1990, 2 – LeProvost Environmental Consulting, 1991, 3 – Biota, 2005, 4 – Chevron, 2015, 5 – URS 2010, 6 – O2 Marine, 2020a,b and c, and 7 – HGM, 2000.

* *Ceriops tagal* and *Ceriops australis* were previously thought to be the same species prior to 2005, although it has now been shown to be genetically distinct.

### 7.3.2. Mangrove associations and distribution

Mangrove associations and distribution within LAU1 and LAU2 indicate high diversity, greater structural complexity and more expansive CC communities in comparison to the other two LAUs. LAU 1 and LAU2 contain approximately 84% of all mapped mangrove BCH in the study area and include all eight of the mapped associations. These mangroves occur in a unique ria shore habitat formed behind a supratidal sand spit and offshore island and are further protected by an intertidal platform extending between the two, along with a series of intertidal mudflats extending out between intertidal creek systems. These coastal structures provide both habitat and protection for the mangroves, whilst a series of winding tidal creeks have breached narrow channels providing additional habitat characteristic of mangrove forest along this coastline. Located within the EPA RSMA #9 there is a far greater area and diverse habitat suitable for mangrove colonisation and the mangrove BCH in these two LAUs represent the most ecologically valuable within the mapped study area. In contrast, LAU3 where there are no tidal creeks and mangrove communities are restricted to Am1 and Am3 associations, mangroves have only been able to establish a small community (20.2 ha) extending along the shoreline adjacent to the sandy beach shoreline and sand dune complex. Further east within LAU4, the coast again becomes somewhat protected by a headland and a series of small sparsely placed tidal creeks once again are present, providing some habitat for mangroves to establish. *A. marina* dominates, accounting for 92.5% of mapped mangroves, although seven associations occur within the mapped area.

Of the mapped mangrove association types within the study area, Am3 (scattered) is by far the most abundant representing greater than 48.4% of the total mapped area, followed by Am2 (landward edge) with 30.3%. Communities Rs2 *(R. stylosa* scattered) and Ca (*C. australias* scattered) recorded the lowest association area with 2 ha (0.1%) and 7.4 ha (0.5%) respectively.

Comparable regional studies which also mapped and calculated the total areas of each assemblage type after Paling *et al*. (1990) are presented in Table 28. This comparison shows Am2 and Am3 consistently make up the largest proportion of the mapped associations for each of the Pilbara studies. Yannarie Salt and Wheatstone Project studies recorded Am2 as the dominant association, while Cape Preston, Mardie and Eramurra studies recorded Am3 with the largest area. This difference is potentially an artefact of how the boundaries between the two types of associations were delineated during investigations, as the boundaries between the two commonly overlap.

Table 28 Mapped areas for comparable mangrove association types from regional project studies

| Mangrove Association | Yannarie Salt[1] | Wheatstone LNG[2] | Cape Preston[3] | Mardie Proposal[4] | Eramurra Study Area |
|---|---|---|---|---|---|
| | Total Area [ha (%)] | | | | |
| Am1 (Seaward edge) | 195 (2%) | 70 (11%) | 1.24 (3%) | 392 (11%) | 236.6 (17.1%) |
| Am2 (Landward edge) | 8,485 (76%) | 292 (48%) | 5.85 (14%) | 438 (12%) | 357.5 (25.9%) |
| Am3 (Scattered) | 2,058 (18%) | 193 (32%) | 22.53 (53%) | 2,330 (64%) | 636.1 (50.2%) |
| Rs/Am (Mixed closed canopy) | 290 (3%) | 39 (6%) | 4.44 (10%) | 291 (8%) | 94.3 (3.7%) |
| Rs (Behind Am) | 126 (1%) | 15 (2%) | 3.68 (9%) | 164 (5%) | 60.3 (3.1%) |

References: 1 – Biota 2005, 2 – URS 2010, 3 – HGM 2000, 4 – O2 Marine 2020

The distribution of each mangrove association present in the Eramurra study area is described in more detail in the following sections.

#### 7.3.2.1. Am1 (Seaward Edge) distribution

Am1 mangrove associations occurred throughout all four LAUs, comprising 17.13% of the total mapped mangrove area. Am1's relative composition differed among LAUs, with the largest proportion recorded in LAU3 (45.92%). The remaining compositions ranged from 13.93% (LAU1) to 26.10% (LAU4). The distribution of Am1 within the study area was typically associated with thin ribbons along the front (seaward) edge of mangrove communities, including running up many of the creek systems. Generally, Am1 was immediately backed by Am3 (particularly in LAU1, LAU3, and LAU4) or, on occasion, by Rs/Am (LAU2).

#### 7.3.2.2. Am2 Closed Canopy (Landward Edge) distribution

Am2 mangrove associations were most widely distributed in the two western LAUs (LAU1 and LAU2), where they made up 27.96% and 28.97% of their respective LAUs. A smaller representation was identified in LAU4 (13.52%), and almost no Am2 was recorded in LAU3 (0.92%). Am2 communities varied between laying behind Rs/Am, Am3, and at times Am1, often forming widespread forests, particularly within the north-east section of LAU1 and the western side of LAU2. Am2 associations also occurred in smaller, scattered pockets, fringing the mid to upper reaches of tidal creeks. On the landward edge, Am2 associations were strongly associated with Am3 communities, often becoming integrated where they meet.

#### 7.3.2.3. Am3 (Scattered) distribution

Am3 was the dominant mangrove community type occurring within each LAU and over the study area. Am3 comprised 50.15% of the total mangrove area, with the highest area in LAU1 (390.5 ha or 51.59%), and LAU4 recorded the highest relative composition of Am3, with 56.60%. LAU3 had the smallest amount of mangrove (9.1 ha or 49.58%) across all LAUs. This mangrove association generally occurred in widespread areas associated with the higher reaches of drainage systems and the landward edge of the mapped mangrove extent. They were often integrated with Am2 (or to a lesser extent Am1) communities on the seaward edge and samphire communities towards the landward edge, where they often shared an overlap between distinctly defined habitats. The qualitative canopy condition analysis was observed as 'healthy' among all sites, with a general condition of 'juvenile trees' noted at many sites. Being located at the landward edge of mapped mangrove habitat, Am3 was exposed to reduced tidal inundation frequencies, which regulate soil salinities, and these communities existed at the extreme end of their salinity range (Paling et al. 2003).

#### 7.3.2.4. Rs/Am distribution

Mixed Rs/Am associations were found in LAU1 (27.1 ha, 3.59%) and LAU2 (17.5 ha, 4.23%), with a smaller distribution in LAU3 (0.7 ha, 3.57%) and LAU4 (5.8 ha, 3.01%). The greatest proportion of Rs/Am was recorded in LAU2 (4.23%), followed by LAU1 (3.59%) and LAU4 (3.01%).

Mixed Rs/Am was typically observed to have a seaward/creek edge, and then extend back inland into reasonably sized stands. This association was often observed to be adjacent to Rs (particularly in central LAU1 and western areas of LAU2) and commonly associated with Am2 on its landward edge.

#### 7.3.2.5. Rs1 and Rs2 distribution

Rs (*R. stylosa*) continuous cover was found to be of comparatively low extent, with maximum proportions recorded in LAU2 (4.78%), followed by LAU1 (2.93%), and LAU4 (0.77%). No Rs were recorded in LAU3 (0.00%). As above, Rs was typically found on the landward edge of Rs/Am (LAU2), however, some areas where Rs was identified along the creek edges in LAU1.

By area, Rs was one of the lowest recorded associations, with an overall coverage of 3.14% (43.4 ha) across the study area, the vast majority of which was recorded in LAU1 (22.2 ha), LAU2 (19.7 ha), and LAU4 (1.5 ha), with no Rs in LAU3.

### 7.3.3. Mangrove Biomass

The positioning of the LAU2 eastern boundary, was purposely aligned with the eastern edge of the RSMA #9 boundary. This allowed accurate and representative assessment of impacts to BCH within this specialised zone. LAU1 also sits wholly within the bounds of the RSMA #9. Therefore, as expected, much of the mangrove biomass across the study area existed within LAU1 (54%) and LAU2 (30%), most of which was classified as CC (Table 16). The Am3 (*A. marina*) dominated the study area, recording the most area within each of the four LAUs. During the field study, *A. marina* trees typically recorded thicker DBH readings compared to *R. stylosa*. Less variation was associated with the above-ground biomass recorded for *R. stylosa* trees throughout sites and the highest above-ground biomass was calculated for quadrats containing tall/thick diameter *A. marina* trees, of which LAU1 and LAU2 had the most abundance. *A. marina* trees within LAU4 were seen to be thicker than the majority of those measured in LAU1 and LAU2 and recorded a higher biomass per hectare (5.3 t-$ha^{-1}$). However, due to the notably reduced number of trees, the overall biomass remained well below that recorded in the western LAUs.

Comparison of the functional groups identified within Section 6.1.2 shows LAU1, LAU2 and LAU4 each recorded a higher proportion of CC mangrove compared to SC mangrove, with 67%, 84% and 73% respectively within each LAU. Within LAU3, results indicated functional groups were reversed in comparison to the three other LAUs, whereby SC (57%) was higher than CC (43%). It is noted that these results may have a level of uncertainty due to the low number of mangroves identified in the LAU3.

A comparison of the mean tree density, DBH and AGB recorded within the Eramurra study area with results from other arid-zone mangrove areas in north-western Australia from Alongi *et al*. (2005) is shown in Table 29. The results demonstrate that the closed canopy mangrove areas within the study area, recorded slightly less tree density and AGB compared to mangroves at the Mardie study area, but higher than the Ningaloo and Exmouth Gulf study areas.

Table 29 Comparison of the mean tree density, diameter breast height and above-ground biomass from this study with other arid-zone mangrove areas in North Western Australia presented in Alongi et al. (2005)

| Study Area | Tree Density (stems $ha^{-1}$) | Diameter Breast Height (cm) | Above-Ground Biomass (t DW $ha^{-1}$) |
|---|---|---|---|
| Eramurra (Scattered) | 261-7,852 | 3.9-11 | 1.2-38 |
| Eramurra (Closed canopy) | 3,269-28,600 | 2.7-19.9 | 3.7-216 |
| Mardie (Scattered) | 400-8400 | 1.1-14 | 0.9-164 |
| Mardie (Closed canopy) | 7,287-30,400 | 2.2-13.3 | 19-369 |
| Dampier | 8,933-12,000 | 4.9-6.9 | 46-247 |
| Port Hedland | 5,600-10,600 | 6.8-8.9 | 148-283 |
| Ningaloo | 10,600 | 3.6 | 90.5 |
| Exmouth Gulf | 18,000 | 3.9 | 208 |

### 7.3.4. Factors Affecting mangrove distribution

#### 7.3.4.1. Salinity gradient

The major contributing factor for mangrove distribution is the salinity gradient (URS, 2010). Salinity gradients are established through the regularity of tidal inundation of seawater which alters depending upon tidal elevation of the land, typically resulting in lower soil and groundwater salinities at the lower tidal elevations due to increased levels of inundation. In the higher tidal elevation areas, (i.e., tidal flats and upper reaches of tidal systems) reduced tidal regulation occurs resulting in greatly increased soil salinity levels. Several factors contribute to increasing landward salinities such as reduced tidal inundation (only the spring tides or tidal surges reach these areas), seasonal variation (hot days increase salinity through evaporation-concentration), or rainfall (reduces salinity by flushing with fresh water) (Paling and McComb, 1994). These salinity gradients are responsible for the variability in mangrove species distribution (a result of differing salt tolerances among species) and mangrove community structure (URS, 2010). Of all the mangrove species within the Pilbara *A. marina* has the widest salt tolerance range and can occur anywhere in the salinity gradient from normal seawater (~53 mS/m) to around 120 mS/m (Gordon, 1988). However, for *A. marina* to thrive and develop into Am1 or Am2 or mixed associations (like *R. stylosa*) they require salinities at the lower end of their range. *R. Stylosa* typically requires salinities around 60-80 mS/m, hence they are commonly located within the study area at the seaward margins where regular tidal inundation occurs (often as thin bands along small drainage channels) or occurring with the larger structural forms of *A. marina (*as seen in LAU1).

#### 7.3.4.2. Surface and groundwater hydrology

Freshwater flows, whether subterranean (groundwater) or extra-terranean (surface water), can be important pathways for the removal of salt extruded through mangrove roots and the removal of wastes, such as sulphides, methane etc. (Alongi, 2009). During extended drought periods, freshwater flows drastically subside resulting in increased salinities, particularly at the higher tidal elevations due to reduced tidal salinity regulation and increased evaporation-concentration (Alongi, 2009). The importance of freshwater input in maintaining mangrove systems typically decreases with increasing aridity (Semeniuk, 1983; Gordon, 1988). As discussed in Section 2 this is particularly relevant within the Pilbara region as rainfall is highly sporadic and often extended periods of drought are experienced. The Pilbara region is known to support the most arid mangrove assemblages within Australia (EPA, 2001a). Freshwater flows may also provide nutrient inputs, however this is highly dependent upon local climatology and season (Alongi, 2009). A previous study within Exmouth Gulf concluded freshwater inputs to regulation of salinity, nutrient flows and removal of wastes was negligible due to the high evaporation rate, limited catchment area, low rainfall, and lack of perennial rainfall (Biota, 2005). The similarities between the Eramurra study area and Exmouth Gulf in terms of mangrove associations, climate and catchment characteristics suggest the maintenance of mangrove associations is not reliant on substantial freshwater inputs unlike mangrove associations on coastlines further north in Australia where seasonal rainfall is both higher and more reliable. The densest aggregation of drainage channels and associated tidal creeks are found in LAU1 and LAU2 (and to a lesser extent in LAU4) where episodic freshwater flows have carved a series of winding draining channels through which frequent tidal inundation now occurs, ultimately providing a variety of habitats supporting the most ecologically significant mangroves within the study area.

## 7.3.5. Associated Faunal Diversity

### 7.3.5.1. Mangrove Invertebrate Fauna

The two field surveys recorded a total of 1096 organisms from seven taxa within 39 fauna quadrats at 21 individual sites. The measured parameters included the number of burrows, the number of organisms of each taxa and the species richness. Recorded fauna abundance was significantly higher within LAU4 (n – 949) when compared to LAU1 (n – 65) and LAU2 (n – 82) (Table 30). It should be noted that LAU4 was surveyed in June 2021, whereas sites within LAU1 and LAU2 were surveyed in May 2020.

Table 30 Total fauna organisms recorded per LAU during mangrove surveys (May 2020 and June 2021)

| LAU | Crustacean | Mollusc | Periophthalmus |
|---|---|---|---|
| 1 | 58 | 3 | 4 |
| 2 | 63 | 15 | 4 |
| 4 | 243 | 698 | 8 |
| **Total** | 364 | 716 | 16 |

The highest mean burrow density was recorded within the closed canopy seaward mangrove assemblage Rs1 (42 burrows per quadrat). Surprisingly, this association recorded the lowest overall organism counts (12). It should be noted that only one site was surveyed in the Rs1 association.

Mangrove associations Am3 and Am2 (the two largest associations across the study area) recorded the highest fauna counts with 698 (63%) and 283 (26%) respectively. The vast majority of these counts were mollusc numbers (671) recorded in the Am3 association at one site within LAU4. The highest number of crustaceans were recorded within the Am2 association (266), the majority of which were identified within LAU4 monitoring sites. A low number of *Periophthalmus* (mudskippers) were recorded across the survey sites. A total of four each in LAU1 and LAU2, and a total of eight in LAU4, the majority were recorded in the Am3 association.

Crustacean records were dominated by *sesarmid* crabs, with rare sighting of other crab families such as *Grapsidae* and *Ocypodidae*. Most mollusc recordings were either *Terabralia sp*. or *Nerita balteata*. The taxa recorded and the findings of dense fauna of limited diversity are typical of the tropical arid zone mangroves of the Pilbara coastline (SKM 2001). SKM (2001) also identified the abundances and diversity of invertebrate species to be higher in the structurally complex association, such as CC mangroves, as compared with SC mangroves and samphire communities. Certain species of crab were also identified as requiring a certain shading requirement and are therefore likely only associated with CC mangrove communities.

There was a notable difference in fauna numbers between the two survey efforts (both undertaken in the dry season May 2020 and June 2021). Despite the different survey areas, it would be expected that fauna within similar mangrove associations may be more comparable. Nobbs and Blamires (2015) found factors such as wind, humidity, temperature and sunshine are influential over crab distribution and abundance during spring tides, rather than being associated with seasonal or yearly trends in abundance. This suggests that the presence of some organisms (in this instance crabs) is strongly dependant and sensitive to local conditions at the time of sampling.

#### 7.3.5.2. Marine Turtles

O2 Marine undertook aerial surveys to assess turtle nesting activity across the study area during December 2020, January, February and March 2021, and January 2022 (O2 Marine, 2022a). Flatback and green turtles were found to nest infrequently and in low densities on the mainland across the study area, including at the beach nearest to the proposed trestle jetty at the Cape Preston East Port. No turtle activity was recorded on the North East or South West Regnard Islands.

Additionally, Pendoley Environmental undertook marine turtle benchmark nesting surveys in the vicinity of the Proposal. The aim was to determine the species and abundance of marine turtles nesting and hatching on nearby (within 20 km of the Proposal) beaches, including mainland and islands offshore. Turtle surveys were completed during the 2022/23 and 2023/24 nesting periods (Pendoley Environmental 2023; 2024). Surveys were conducted by personnel walking the survey beaches and recorded turtle tracks in-situ. Results from the benchmark turtle surveys determined that the beaches around the Proposal have low nesting abundance, and the cumulative contribution of nesting females to the genetic stock for each species is <1% and is not thought to represent an important nesting population (Pendoley Environmental 2024). The surveys found low nesting success for hawksbill and flatback turtles, indicating that it is unlikely that the area provides an important contribution to the genetic stock (Pendoley Environmental 2024).

## 7.4. Samphire Habitats

Samphire shrubland was distributed over two categories (samphire shrubland and samphire shrubland / algal mat), with a total area of 1,815.3 ha (10.1%) across the intertidal study area. Samphire shrublands were generally found to be the most landward intertidal BCH, often situated between inland mudflats and Terrestrial Vegetation. A small section within LAU1 had samphire shrubland backing directly onto mangrove BCH.

The total area of samphire shrublands was highest in LAU3 (643.5 ha), followed by LAU4 (408.3 ha), LAU1 (436.1 ha), and LAU2 (327.4 ha). Notably, samphire shrubland was observed in close proximity to the upper creek branches in LAU4. Similar distributions were not observed in creeks located in LAU1 and LAU2. The refined mapping and classification (which included review and verification of historic data [Phoenix, 2025]) provides a higher detail improved spatial accuracy.

Samphire shrublands provide essential ecosystem services, including coastal protection by stabilizing intertidal zones and reducing erosion, habitat for migratory shorebirds and small invertebrates, and contributions to blue carbon storage, particularly in dense samphire-algal mat complexes. These communities exhibit natural zonation, where salt-tolerant species such as Tecticornia halocnemoides dominate lower intertidal zones, while Tecticornia indica and Tecticornia pergranulata are more common in higher, less frequently inundated areas (Phoenix, 2025). The updated assessment ensures a more comprehensive evaluation of these habitats, addressing the need for improved descriptions and better quantification of their ecological role within the intertidal system.

Compared to previous assessments, the updated mapping has refined habitat classifications by incorporating ground-truthed survey data, corrected previous underestimations of samphire-algal mat complexes, increasing the mapped samphire area by 67.5% (adding 731.6 ha)

# 8. Temporal Variability of Intertidal BCH

Parts of the intertidal study area have been slightly to moderately impacted by human interaction. The industrial development and associated assess routes at Cape Preston have interrupted the natural state of Intertidal BCH within LAU1. While the seemingly less impactful 'recreational activity' is common (particularly in the winter months) along the coastal strips of LAU3 and parts of LAU4. Currently LAU2 would be considered the least impacted, mainly due to restricted access to the general public.

## 8.1. Historical Land-use and Recreational Activities

The Cape Preston East land area is largely undeveloped, however grazing from cattle and clearing for tracks and pastoral activity has occurred across some areas. A road, causeway and bridge were constructed in the north-western portion of the Cape Preston East land area in 2010 by CITIC-Pacific as part of the Sino Iron Project. These will become common user infrastructure facilitating access to both the Sino Iron Project export facilities and the Cape Preston East facilities. The port waters for the proposed Port of Cape Preston East will be created to facilitate transhipping routes, anchorages and the construction of marine infrastructure; and will be vested with Pilbara Ports (PP).

Gnoorea Point, also known as 40-Mile Beach, is a natural, coastal camping area managed by the City of Karratha that is situated 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. Four-wheel-drive access tracks run along the coastal dune areas both west and east of Gnoorea Point. 40-Mile Beach Road runs from the North West Coastal Hwy to Gnoorea Point, creating a division across the mapped mudflat within LAU3.

Native Title Determination of the Proposal area identifies the Mardudhunera people as Traditional Owners. 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.

## 8.2. Historical Construction Activities

The MDE area currently resides within the Port of Cape Preston (CP) boundaries (see Figure 2). 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 2). 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.

## 8.3. Current Status of Intertidal BCH

As detailed in Section 6.1.2.3, all mangroves surveyed across the study area were classified as 'healthy' in accordance with the mangrove health index criteria provided by Duke *et al*. (2005). This was largely based on the low level of yellowing leaves (<10%), and general observations including: insect damage, number of dead or dying limbs , and a lack of direct anthropogenic impacts. Recreational vessel fishing is known to occur within the associated creek systems (largely from campers at Gnoorea Point), however this activity is of low intensity and the impacts would be likely be minimal. The intertidal BCH seaward of the coastline (mudflats, Macroalgae, Filter Feeders and Corals) are also relatively untouched, with restricted access the main driver for minimal human disturbance.

Development at the Cape Preston port area (including access roads and infrastructure) has had the most direct impact on BCH within the ESSP study area, these impacts are largely related to Terrestrial Vegetation, with reduced spatial impacts to mudflats, mangroves, and intertidal rock platforms. Dune vegetation has been slightly/moderately impacted at Gnoorea Point and surrounding areas due to recreational camping and four-wheel-driving.

The major factors influencing the temporal distribution of intertidal BCH within the study area are natural. Over time this may have included acute effects such as wind, floods and storm surges associated with cyclones or large tropical lows which can alter intertidal BCH distribution through physical (direct force, erosion etc.) or physicochemical (altered salinity gradients, nutrient cycles etc.) changes, or chronic effects such as historical sea level rise, or local climatic cycles such as rainfall and temperature changes. Chronic and acute natural processes will continue to impact upon the distribution of intertidal BCH within the ESSP study area

Large tropical storms or cyclones are capable of significantly altering communities during a short period of time due to their associated strong winds (>200 km/hr), storm surges (>3 m) and torrential rain (>200 mm/48hr). Biota (2005) identified acute cyclonic impacts upon mangrove BCH to occur through two typical mechanisms which are considered applicable to any structural BCH:

1. Defoliation / direct storm damage - Cyclones and other tropical storm events are known to defoliate, delimb or simply uproot intertidal BCH due to intense winds and physical damage during surge and

wave action. Intertidal BCH species display different resistances and recovery to direct impacts, with the associated intensity of the natural event responsible for varying degrees of impacts.

2. Storm driven sedimentation/deposition - Cyclones and other tropical storm events are able to mobilise considerable volumes of sediment during a short period. This mechanism can remove or create habitat (through erosion and deposition) and alter localised hydrogeological systems (i.e. alter tidal creeks). Habitat removal can occur directly through erosion, or indirectly due to smothering caused by sedimentation which can ultimately lead to a reduction of BCH. Longer term impacts of altered hydrogeological systems is also responsible for both loss or recolonisation of habitat or altering the type of BCH within impacted areas.

# 9. Functional Ecological Significance

Intertidal habitats assessed within the ESSP study were found to be commonly distributed throughout the wider Pilbara region, with many having distributions either within the Australian tropics or internationally. Many species identified during the assessment are also typically found within a broader geographical distribution. Of particular significance within the study area are the regionally significant mangroves within LAU1 and LAU2 and as defined by RSMA #9 (EPA, 2001b), and algal mats (identified in this report as mudflats including algal mats)

All mangroves are known to provide key ecological value due to their high primary productivity, coastal stabilisation, carbon storage, variety of habitats and regulation of water quality (Almahasheer *et al*. 2017). However, Semeniuk (1997) recognises these particular mangroves as internationally, nationally and regionally significant due to their extensive formations, and unique position as "the most southern development ria shore type of mangrove habitats that are more fully represented in the Dampier Archipelago". Significance was also placed on the ecological role they play in terms of fisheries and avifauna they support. Large, well-developed mangrove stands, with broad seaward tidal flats, tend to be ecologically significant, either locally or regionally (Semeniuk, 1997).

Algal mats (in particular blue green algae) have been proven to play an important role in the carbon and nitrogen cycle in the intertidal zone (Paling and McComb, 1994), and provide habitat for many invertebrates and juvenile fish (Penrose, 2011). Despite these findings, the overall ecological role (and the potential impact if removed from the system) is not well documented. Following completion of the WAMSI Mardie Salt Marine Research program (proposed for mid 2025), contemporary information around the ecological role, value and function of algal mats will be incorporated into the Proposals EIA and management accordingly.

## 9.1. Geographic distribution patterns

Mangrove communities identified within the study area were dominated by *A. Marina*. *R. stylosa* were also commonly recorded as seaward communities with several observations of *C. australis* occurring in landward associations. The algal mats were dominated by cyanobacteria *Lyngbya sp* and *Coleofasciculus*. Algae results indicate that algal composition was relatively uniform across the study area.

### 9.1.1. Mangroves

About 60 species of mangrove trees belong to several botanical families; eight in the Americas, 40 species in Asia, and 13 in Africa (Holguin et. al. 2001). Of the 40 recorded Asian species nine have been identified within the Pilbara region, 19 within the Kimberley region, 32 in the Darwin region and 39 in northern Queensland (Duke, 2006). Internationally Brazil, Indonesia, and Australia have the largest representative areas of mangrove communities (Holguin et. al. 2001). Within WA, mangrove habitats and assemblages have been widely assessed and seven recognised sets of mangrove biogeographic regions or coastal sectors have been identified (Johnstone, 1990 and Semeniuk, 1993). These are characterised by distinctive climatic and geomorphic settings and follow the decrease in species richness evident from north to south (URS, 2010).

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

Of the nine known species of mangroves from the Pilbara region, this survey identified three of the well-known species distributed across the Pilbara region (*A. marina, R. stylosa* and *C. australis).* The dominant mangrove species, *A. marina* is extremely common along the WA coast occurring across the greatest range. Internationally *A. marina* is widely distributed with populations occurring across New Zealand, South-East Asia, Japan, Southern China, Pacific, India and East Africa (WoRMS, 2019). *R. stylosa* is also widely distributed with populations occurring throughout South-East Asia, southern China, Japan and the Pacific (WoRMS, 2019). *C. australis* is more limited in its geographic distribution with communities recorded from Papua New Guinea and tropical northern Australia (WoRMS, 2019). Despite these being commonly distributed regionally and internationally, the mangroves recorded with LAU1 and LAU2 are classified as regionally significant (EPA 2001a). This classification comes largely because of the geographical location of where the mangroves are located (Semeniuk, 1997), refer Section 9.3.2.

### 9.1.2. Algal mats

Microbial or cyanobacterial mats, commonly referred to as algal mats, are a geographically widespread and ubiquitous intertidal BCH type common to estuarine and inter – and subtidal marine environments (Joye and Paerl, 1993). They are typically found existing asynchronously of other organisms, occupying mudflats and saltflats, and are exposed to extreme variations in salinity, temperature and moisture (Sørensen *et al*. 2005, SKM, 2001). Algal mats vary widely in appearance, ranging from barely perceptible mucilagenous coatings on sand, mud and organic debris to well-developed, accreted, multilayered 'leathery' carpets dominating lagoonal, reef, mud and sandflat as well as saltmarsh systems (Joye and Paerl, 1993). Algal mats are generally dominated by cyanobacteria, have many nitrogen fixing taxa and possess a range of unique physiological traits enabling them to occupy these extreme environments (Sørensen *et al*. 2004, Sørensen *et al*. 2005). Local studies within the Pilbara have identified algal mats dominated by cyanobacteria, generally comprised of a combination of several genera. The genera identified within the ESSP study area are not unique to the local area, or Pilbara region.

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## 9.2. Productivity and Nutrient Recycling

The structural complexity, productivity and associated AGB characteristics of BCH relate to different functions and ecological services. High-level ecological elements include relative primary productivity, the associated heterotrophic relationships (secondary productivity of grazers and predators) this supports, which depending upon the structural complexity, primary productivity rates and AGB may in turn support a large and intricate food web.

The seaward to landward characteristics within intertidal BCH typically correlate with an initial sharp decline in ecological functionality, structural complexity and AGB, and then a gradual decline therein through to the terrestrial communities. For example, the CC mangrove communities, which represent the most productive, structurally complex and ecologically diverse BCH within the study area. SC mangroves, due to their lower structural complexity and typically scattered nature, are less ecologically valuable in terms of both primary and secondary productivity. Functional ecological diversity, structural complexity and AGB continue to decline further landward, now represented by the low and scattered Samphire BCH, then mudflats, algal mats and finally the Saltflats, which in turn support lower and lower ecological value, with the exception of Algal Mat primary productivity, although as presented below, this is likely to be supplementary rather than essential. Whilst less important in terms of net primary productivity, foreshore mudflats have been identified to support BCH habitats such as macroalgae and seagrasses in varied abundances. These ecosystems are likely to have a lower primary productivity in comparison to subtidal BCH, due to the more extreme environments (exposure to terrestrial climate during times of exposure (i.e. spring tides) in which they are located, however support a wide array of secondary productivity and have been identified as important foraging areas for migratory birds (Phoenix, 2023).

Intertidal BCH, primarily CC mangroves, are well understood to play key roles in primary and secondary productivity, and nutrient and carbon cycling in coastal environments. Intertidal BCH provide varying levels of organic matter in the form of vegetative litter and are active sinks for dissolved nitrogen, phosphorous, carbon and silicon (Adame *et al.* 2012). Detritus serves as an important nutrient source and forms the basis of an extensive coastal food web. In addition, intertidal BCH ecosystems serve as shelter, feeding, nursery and breeding zones for crustaceans, molluscs, fish, and resident and migratory birds. The importance of these ecological functions delivered by intertidal BCH are directly proportional to the structural complexity, AGB and their spatial distributions. As described above this therefore presents the case that the seaward BCH communities (i.e. CC and SC mangroves and seaward mudflats) present, by far, the most ecologically valuable communities within the study area, particularly the CC mangroves within LAU1 and LAU2 which represent the most valuable BCH within the study area.

### 9.2.1. Carbon and Nutrient Cycles

Although mangrove systems are generally highly productive and rich in organic matter, they are generally nutrient poor, especially nitrogen and phosphorous which are often limiting in estuarine and marine ecosystems (Holguin *et. al*. 2001; Alongi, 2009). There is evidence of a close microbe-nutrient-plant relationship that functions as a mechanism to recycle and conserve nutrients in the mangrove ecosystem (Alongi, 2009). The highly productive and diverse microbial community living in tropical and subtropical mangrove ecosystems continuously transforms nutrients from dead mangrove vegetation into sources of nitrogen, phosphorus, and other nutrients that can be used by the plants. In turn, mangrove pneumatophores exudates serve as a food source for the microorganisms living in the ecosystem with other plant material serving similarly for larger organisms like crabs (Holguin et. al. 2001). Various studies have shown that detritivores, particularly crabs, consume or hide below-ground large proportions of mangrove leaf litter, bark and seeds thus acting as a retention mechanism through reducing tidal export of nutrients, carbon and minerals (Alongi 2009). Microbial decomposition is responsible for decomposition of remaining litter and bacteria are responsible for much of the carbon flux, flow of energy and nutrients and act as a carbon sink (Holguin et. al. 2001).

Carbon and nitrogen cycles within mangrove systems, whilst variable from region to region, have been widely studied and extensively documented. Fundamentally the processes are the same, however the associated fauna, algal and bacterial species vary between the different cycles, along with the levels each of the biota play in the cycle. Biota (2005) undertook an extensive review of data collected from regional studies and compiled them within their assessment of mangrove systems within their study area located in southern and eastern intertidal habitats of Exmouth Gulf. Whilst located approximately 270km away from the ESSP study area, the high level ecological processes within the arid mangrove systems likely have comparable characteristics.

### 9.2.2. Carbon Cycling in mangrove Communities

Energy is transported between trophic levels within ecosystems through the transfer of organic and inorganic carbon compounds and is referred to as the carbon cycle. Carbon cycling within mangrove and associated intertidal ecosystems has been widely studied and the key processes summarised below. A high-level conceptual model is presented in Figure 31 which provides an overview of these key processes as they relate to the ESSP intertidal BCH habitats.

- Photosynthesis

  This involves the conversion of atmospheric carbon dioxide to organic carbon by autotrophs (intertidal BCH plants such as mangroves, samphires and algae). Carbon is fixed into this system through direct biomass, retention of litter, immobilisation in soils and incorporation into sediments

- Consumption

  This involves the passing of organic carbon from plant matter to secondary producers (primary heterotrophs), such as crabs and molluscs, through grazing both directly (live plant material) or indirectly (detritus or litter).

- Export and Import

  This process involves plant derived matter from intertidal BCH migrating to coastal environments through tidal cycles or rainfall events. Additionally, carbon sources are also brought into the intertidal zone during incoming tides (sea wrack, animal remains).

- Predation

  This involves the direct consumption of primary heterotrophs by higher trophic level organisms (secondary heterotrophs) which often establish quite complex food webs.

- Microbial decay

  The majority of organic matter from animal remains or excretory products along with remaining detritus not exported are decomposed through bacterial processes. Carbon compounds then enter the intertidal sediment bacterial / geochemical cycle. This process is primarily the largest carbon sink within intertidal BCH systems (Alongi 1994).

- Respiration

  This process releases carbon in the form of carbon dioxide through the process of cellular respiration in associated plants and animals.

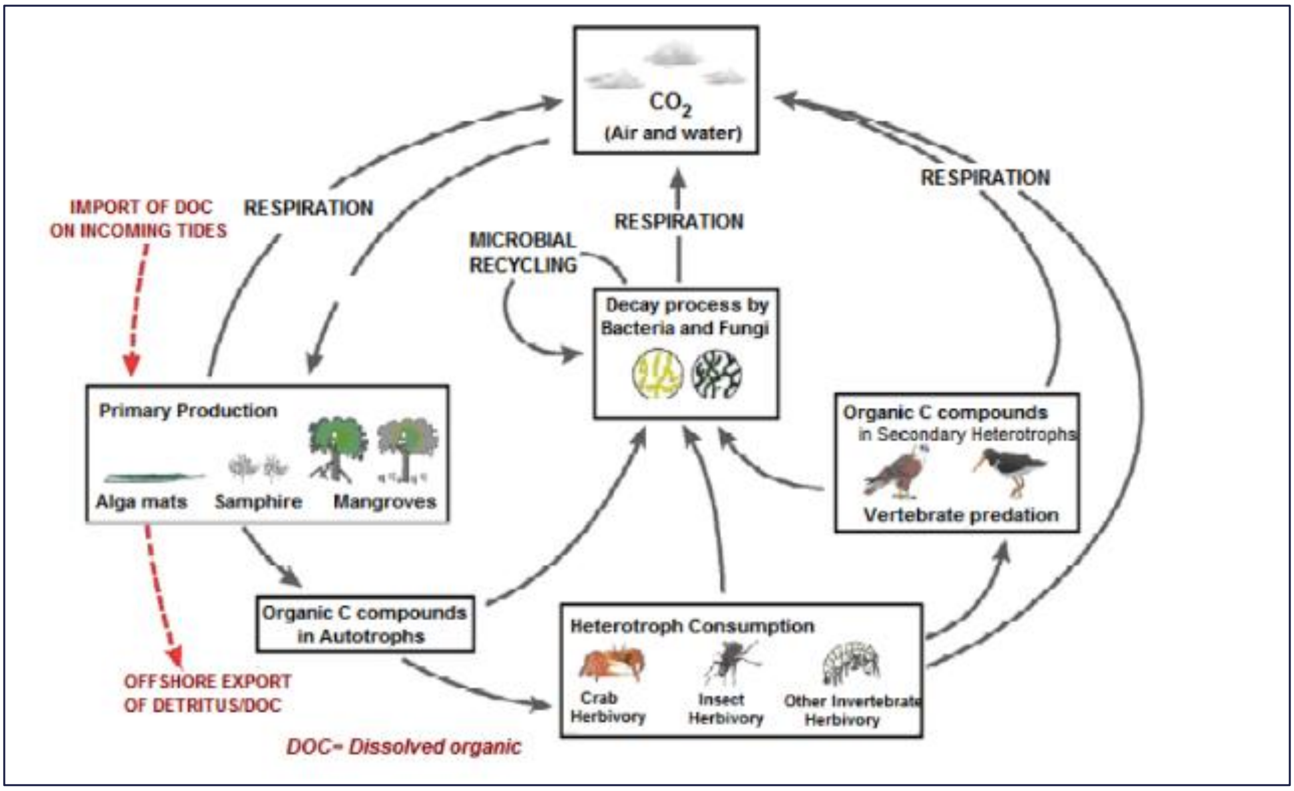


Figure 31: Simplified mangrove and intertidal system carbon cycle conceptual model (Biota 2005 page 44)

### 9.2.3. Nitrogen Cycling in algal mats/mangrove Communities.

The cycling of nitrogen through intertidal BCH habitats is quite similar to the carbon cycle although there are quite a number of different nitrogen compounds, and the nitrogen cycle explains the alteration of these compounds by various physical, biological and chemical processes. As with the carbon cycle, nitrogen processes within intertidal BCH has been extensively studied and documented. A simplified conceptual model of the nitrogen cycle is presented in Figure 32 and a summary of the key processes outlined below.

- Fixation
  - The process through which inorganic nitrogen is removed from the atmosphere and converted to ammonia by cyanobacteria within algal mats and bacteria within soil and detritus associated with mangrove, mudflat/saltflat and samphires/samphire mudflats. Lightning is also able to convert inorganic nitrogen to nitrates, though this is considered a far lesser source.
- Export
  - Nitrogen fixed within algal mats or by bacteria associated with mudflats/saltflats, samphires and mangrove soils is exported, or relocated between habitats types, during runoff from significant rainfall events and tidal cycles. Organic nitrogen, nitrates and ammonium may be mobilised between habitat types during this process.
- Uptake
  - Autotrophs utilise dissolved nitrogen in the form of nitrates and ammonium for growth made available through fixing or from recycling through the bacterial decomposition or excretion from detritovores.
- Consumption
  - Heterotrophs grazing on plant matter or detritus obtain their sources of nitrogen in this way. Nitrogen is then passed through trophic levels through predation by secondary heterotrophs. Excretion from heterotrophs then enters the cycle as ammonia whereby bacterial processes convert this into ammonium which becomes available for autotroph uptake.
- Nitrification and Denitrification
  - Nitrification process involves conversion of ammonium into nitrite and then to nitrate by anaerobic bacteria whereby it becomes re-available for autotroph uptake. Denitrification is the loss of nitrogen during this process as gaseous atmospheric nitrogen, although denitrification rates tend to be low in mangroves (Alongi 2001).

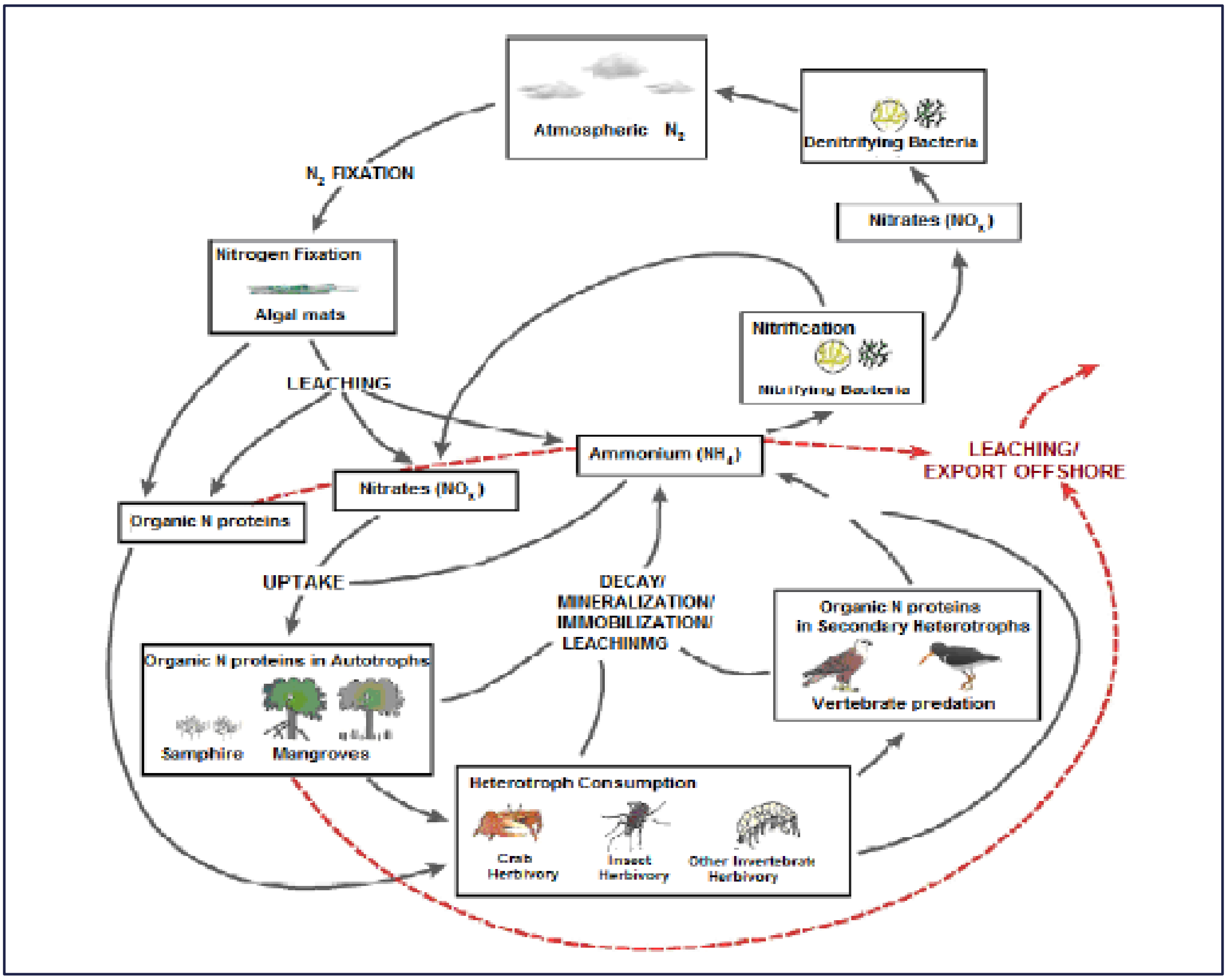


Figure 32: Simplified mangrove and Algal Mat nitrogen cycle conceptual model (Biota 2005, page 47).

## 9.2.4. Primary and Secondary Production

### 9.2.4.1. Mangrove communities

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

Primary productivity within mangrove habitats is not just limited to the mangrove trees themselves, many studies have also investigated the microbial activity of associated soils. Soils in which mangroves grow are typically composed of thick organic matter mixed with sediment, are anaerobic except for the sediment surface, and supports highly productive microphytobenthos which fix significant amounts of nitrogen. The higher the AGB associated with the mangrove community, the higher the associated microbial activity is (Wang *et al.*, 2022). Therefore, with AGB related to nutrient export, the CC mangroves also support a far greater net primary productivity through associated microbial activity.

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

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

#### 9.2.4.2. Algal Mat BCH and nitrogen fixing cyanobacteria

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

Primary productivity that occurs within algal mats is directly related to the nitrogen fixing characteristics of the cyanobacteria that dominate the species composition within this BCH type. Whilst there are specific areas located within the study area assigned to the BCH classification Algal Mat, it is widely understood that nitrogen fixing cyanobacteria are present within most intertidal BCH, particularly mangroves (Alongi, 1994, Holguin *et al*. 2001 and Alongi, 2009), though there is little in the literature through which a direct comparison can be determined with respect to distinct BCH types and their respective nitrogen fixing or export loads. Whilst the predominately cyanobacterial Algal Mat communities form a higher standing biomass, the cyanobacterial communities associated with CC mangroves are likely to be higher in primary productivity (non-seasonal) and due to lower associated soil salinities also support significant secondary productivity (grazing by primary heterotrophs) and therefore play a more valuable ecological function within the system.

Burford *et al.* (2012) investigated the production of nitrates and ammonia to the overlying water column from freshwater flow over algal mats on the Norman River in the Gulf of Carpentaria. Flooding of mats was found to lead to increased levels of nitrates and ammonia for several days after inundation. Burford *et al*. (2012) noted that while some proportion of the nitrogen fixed by the mats investigated in their study may be exported to the wider coastal ecosystem, the nitrogen requirements of benthic algal on the supratidal flats may mean that the mudflats are a nitrogen sink.

O2 Marine undertook a similar 'Nutrient Flux' study in 2021, with the purpose to obtain quantitative data to determine the ecological significance and regional importance of algal mats with respect to nutrient export into the intertidal and nearshore subtidal system at the ESSP. The difference was the assessment of change in relation to regular tidal inundation, rather than freshwater flow events as per Burford *et al.* (2012). Overall, the results were inconclusive, with no significant change in nutrient levels able to be associated solely to spring tidal exchange. The small changes that were recorded in nutrient levels, were on a tide to tide, and site to site basis, suggesting that the intra site variability in nutrients (temporal and spatial) may be greater than nutrient changes due to spring tides flowing over algal mats. Further information on the role that algal mats play will be assessed following the outcomes of the WAMSI Mardie Salt Marine Research program (findings proposed to be available mid 2025). The Nutrient Flux study is included in Appendix F.

Algal mats support a limited number of grazing heterotrophs that are associated with adjacent BCH along seaward edges. During certain tides or seasons these heterotrophs migrate from their associated BCH to the edges of algal mats whereby they graze directly on the 'crust'. In terms of supported heterotroph biomass, algal mats provide these opportunistic grazers with supplementary primary productivity sources and do not solely support them, unlike mangroves and samphire BCH. Penrose (2011) undertook a study in Exmouth Gulf to investigate the potential role of nekton as transport pathways for the export of cyanobacterial mat primary production and nutrients from supratidal flats to adjacent habitats and thereby into coastal food webs. The results show a clear link between several fish species and cyanobacterial primary productivity using carbon and nitrogen isotope tracing. Evidence is presented that several species are dependent on cyanobacterial sources of carbon (Penrose, 2011). Attribution of the cyanobacterial 'mats' as the likely source of the cyanobacterial carbon (Penrose, 2011) is however, problematic because there is substantial cyanobacterial primary productivity in the adjacent habitats, where grazing prevents the formation of mats. The majority of the mats form at levels on the shore where soil salinities exclude virtually all of the grazers such as molluscs, crustaceans and especially polychaetes (osmoconformers) which have limited tolerances of high salinities. It appears that Penrose (2011) employs a much broader definition of cyanobacterial mats and includes areas much lower in the tidal zone which are classified in this report as other habitat types.

#### 9.2.4.3. Nutrient pathways

Whilst primary productivity within mangroves is widely understood and investigated, there is limited understanding of the direct pathways between BCH and the primary productivity associated with algal mats. The mudflat/algal mat setting of the ESSP study area has similar characteristics to that identified within the Mardie Project study area, located approximately 50 km to the south-west. Both areas have extensive mudflat/algal mat areas located in flat, low-lying depression areas behind the mangrove communities. During incoming tides (>1.2m) oceanic water flows up through tidal creeks flooding the flat areas, with some water being retained for a period after the flooding. This remaining water either evaporates, resulting in the high salinities which characterise this BCH, or migrates down into groundwater.

During heavy rainfall, associated with low-pressure systems, the surrounding catchments may fill and begin to flow through drainage channels into the study area. Depending upon which catchment, these flows are either directed straight through natural drainage channels and tidal creeks into coastal waters (Cooglegong Creek in LAU4), however small, localised catchments discharge across the flats and may be retained minor depressions where algal mats occur.

The portion of water that is trapped within the depressions (whether oceanic or fresh) is only able to exit via groundwater or evaporation, and any dissolved nutrients remaining in the system unless stormwater or storm surges are significant enough to promote mobilisation.

Burford *et al*. (2012) concluded that supratidal algal mat production on the Norman River system potentially contributed to higher trophic levels in years when the period of inundation was sufficiently long. Periods of inundation were related to episodic floods and there were many years where there was no flooding of the supratidal flats with freshwater and consequently negligible export of carbon or fixed nitrogen to coastal waters.

As there are limited pathways available for the export of nitrogen accumulated through cyanobacterial activity within Algal Mat systems, export loads are therefore considered to be low, particularly when compared with the combined nutrient exports associated with the seaward BCH. Not only are these BCH more structurally complex with higher associated AGB and their own cyanobacterial communities, they are frequently inundated therefore providing connectivity and a mechanism for nutrient export to adjacent coastal waters.

### 9.2.5. Biomass and productivity

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

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

As the seaward communities become more scattered, less structurally complex and support lower AGB, the range of ecological functions they provide also reduces. The ecological functionality decreases from CC to SC mangroves; samphire shrubland represent a further reduction in functional ecology which continues through mudflats, algal mats and finally the saltflats which support few or no organisms and/or provide negligible productivity to surrounding BCH.

Whilst algal mats are identified to contribute some nutrients to support primary productivity of adjacent BCH, they do not support, nor provide any additional associated ecological functionality.

Targeted faunal surveys undertaken by Phoenix (2023, 2025) provide a strong argument to support the above statements through clearly identifying faunal diversity being higher within the seaward BCH and declining with distance from the coast. Figure 33 indicates a strong relationship between identified terrestrial fauna (Amphibia, Aves, Magnoliopsida, Mammalia and Reptilia) and their location within the more structurally complex seaward intertidal BCH classes which are used for shelter and foraging during their visiting periods. Further information on the importance of these habitats for faunal assemblages is detailed in Phoenix (2023, 2025).

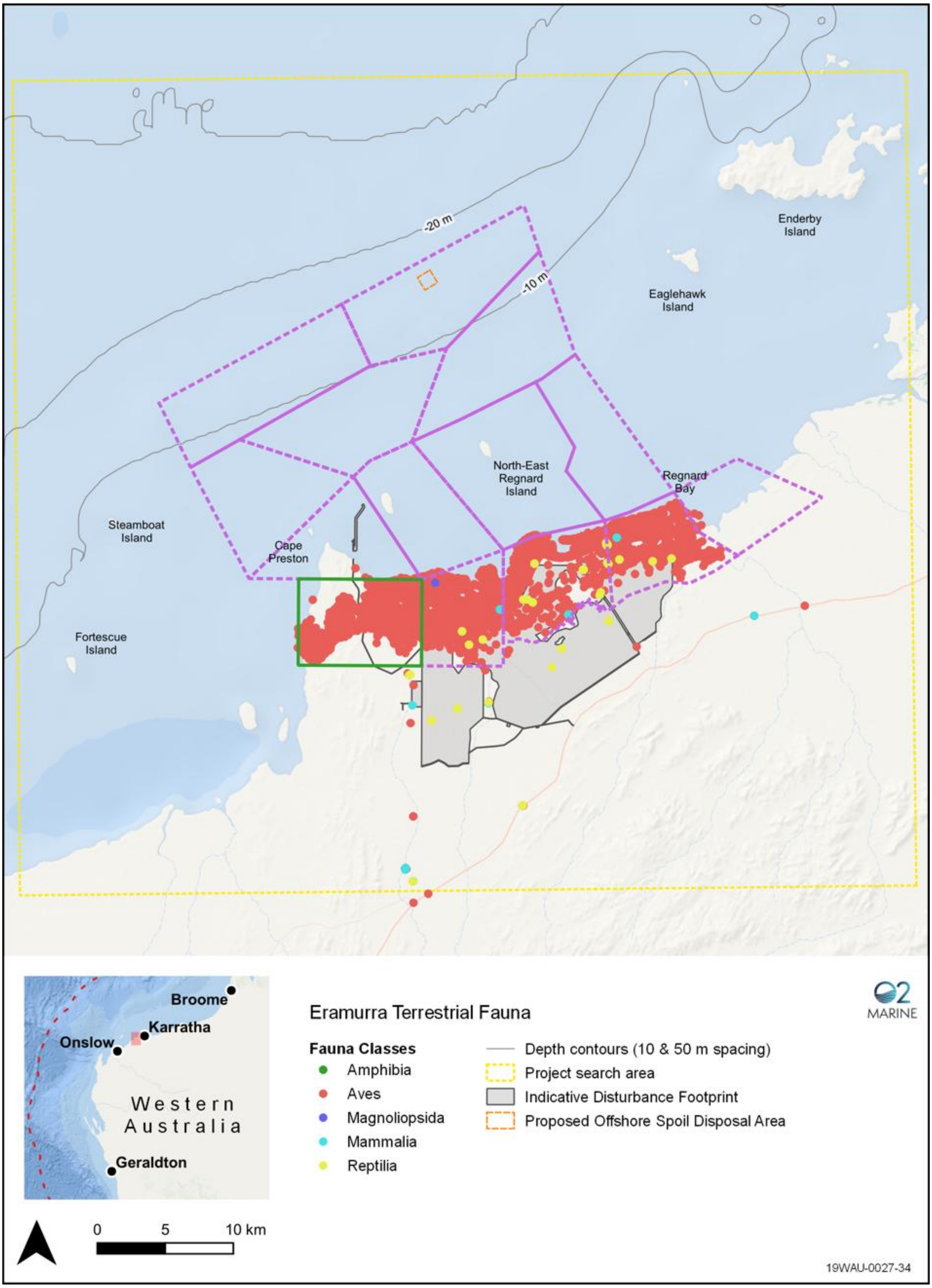


Figure 33: Terrestrial fauna survey results for the ESSP (Source data Phoenix 2023)

## 10. Conclusion

The Intertidal BCH mapping and assessment study made the following findings:

- The ESSP intertidal study area extends along approximately 40 km of complex coastline, made up of several headlands, shallow embayment's, mangrove stands, tidal creeks, dune complexes and expansive mudflat areas.
- A total of 12,696 ha were mapped over four established LAUs (LAU1, LAU2, LA3 and LAU4). These areas were verified via two field surveys in May 2020 and June 2021. Terrestrial Vegetation dominated the LAU areas (55.57%), however this in not considered an intertidal BCH, and is discussed further in Phoenix (2025).
- Algal mats (17.0%) were the dominant intertidal BCH then, samphires (14.3%).and mangroves (10.8%).
- Mangroves (in particular the CC functional group) are deemed the most ecological significant intertidal BCH within the ESSP study area. These CC groups, dominated by *A. marina* make up 93.2% of the total mangroves mapped, and are considered in good health with relatively no anthropogenic impacts observed.
- All mangroves with LAU1 and LAU2 (1170 ha) lie within the RSMA #9 (EPA 2001a), and are classified by Semeniuk (1997) as internationally, nationally and regionally significant.
- Algal Mat sampling recorded six taxa across the study area, dominated by filamentous cyanobacteria *Lyngbya sp.* then *Coleofasciculus chthonoplastes* and *Schizothrix spp*. These taxa are well documented along the Pilbara coastline.
- Intertidal invertebrate sampling recorded a total of 1095 organisms from 7 taxa within 42 fauna quadrats at 21 individual sites. Fauna counts were significantly higher within LAU4 (n–949) when compared to LAU1 (n–64) and LAU2 (n–82). Overall, these results support the conclusion that the dominant taxa were Mollusc (n-716) followed by Crustaceans (n-363) and Fish (n-16).

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## Appendix A. Mapped BCH per LAU

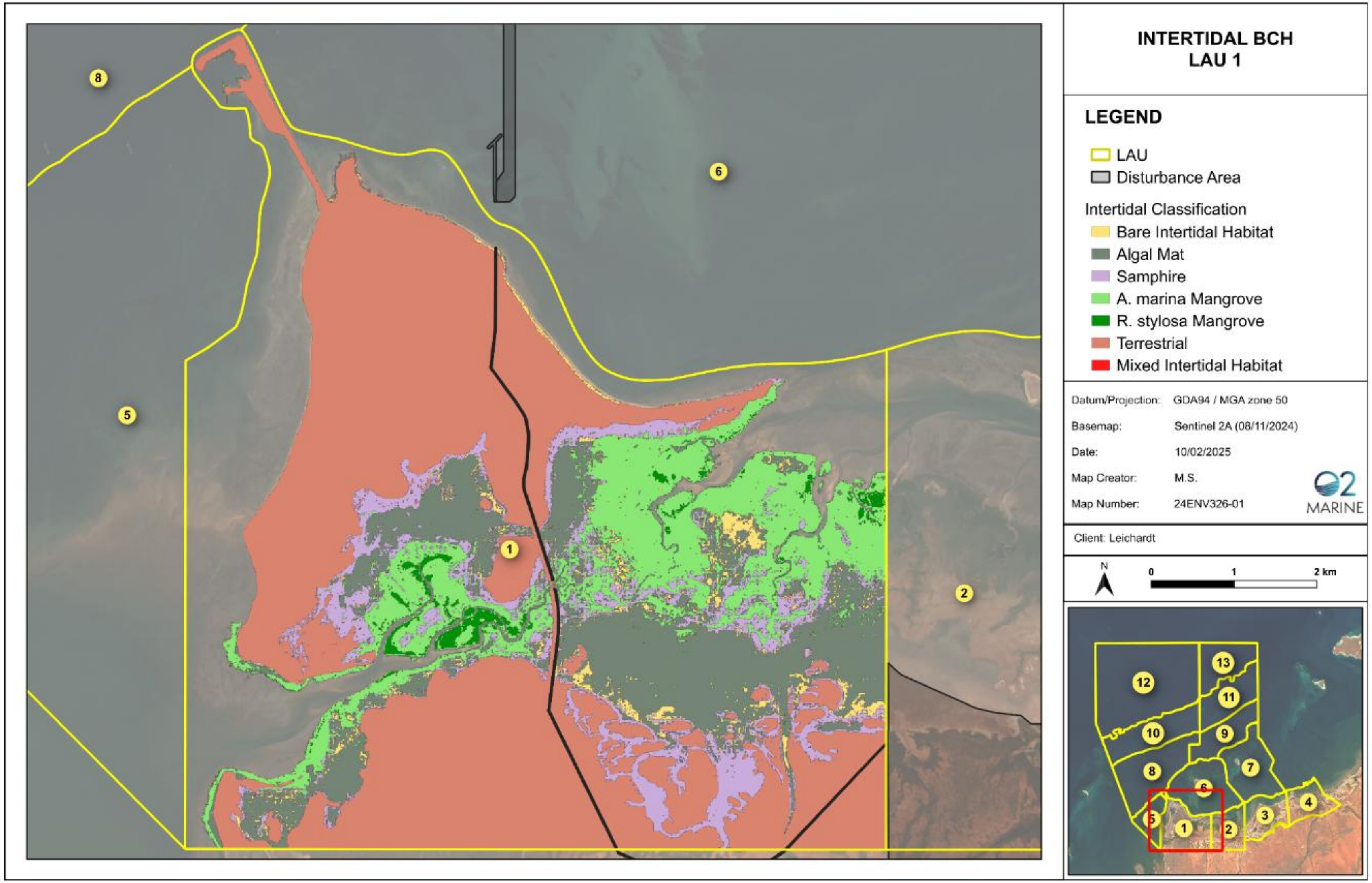



Figure 34: BCH and Terrestrial Vegetation identified in LAU1

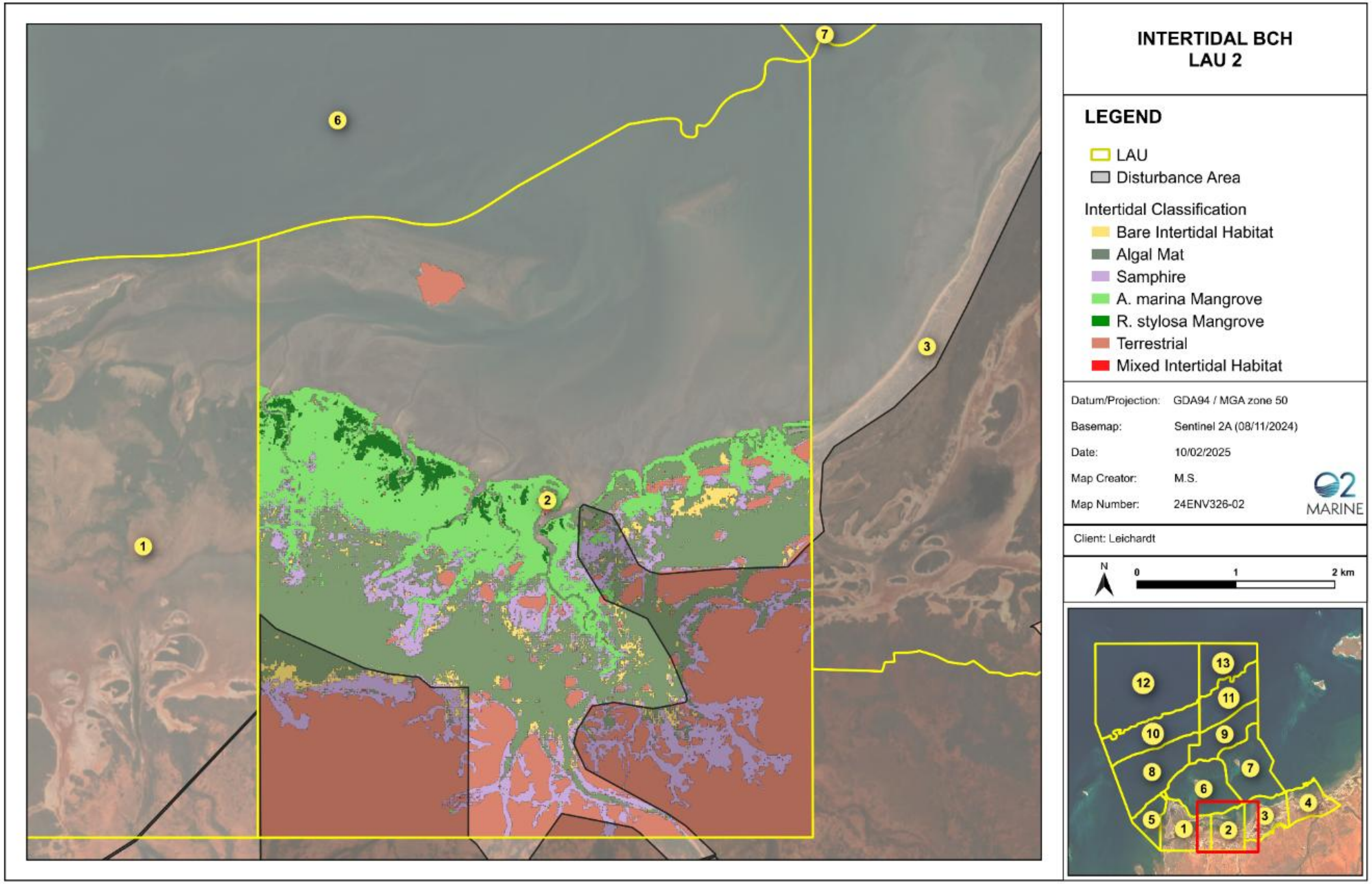



Figure 35: BCH and Terrestrial Vegetation identified in LAU2

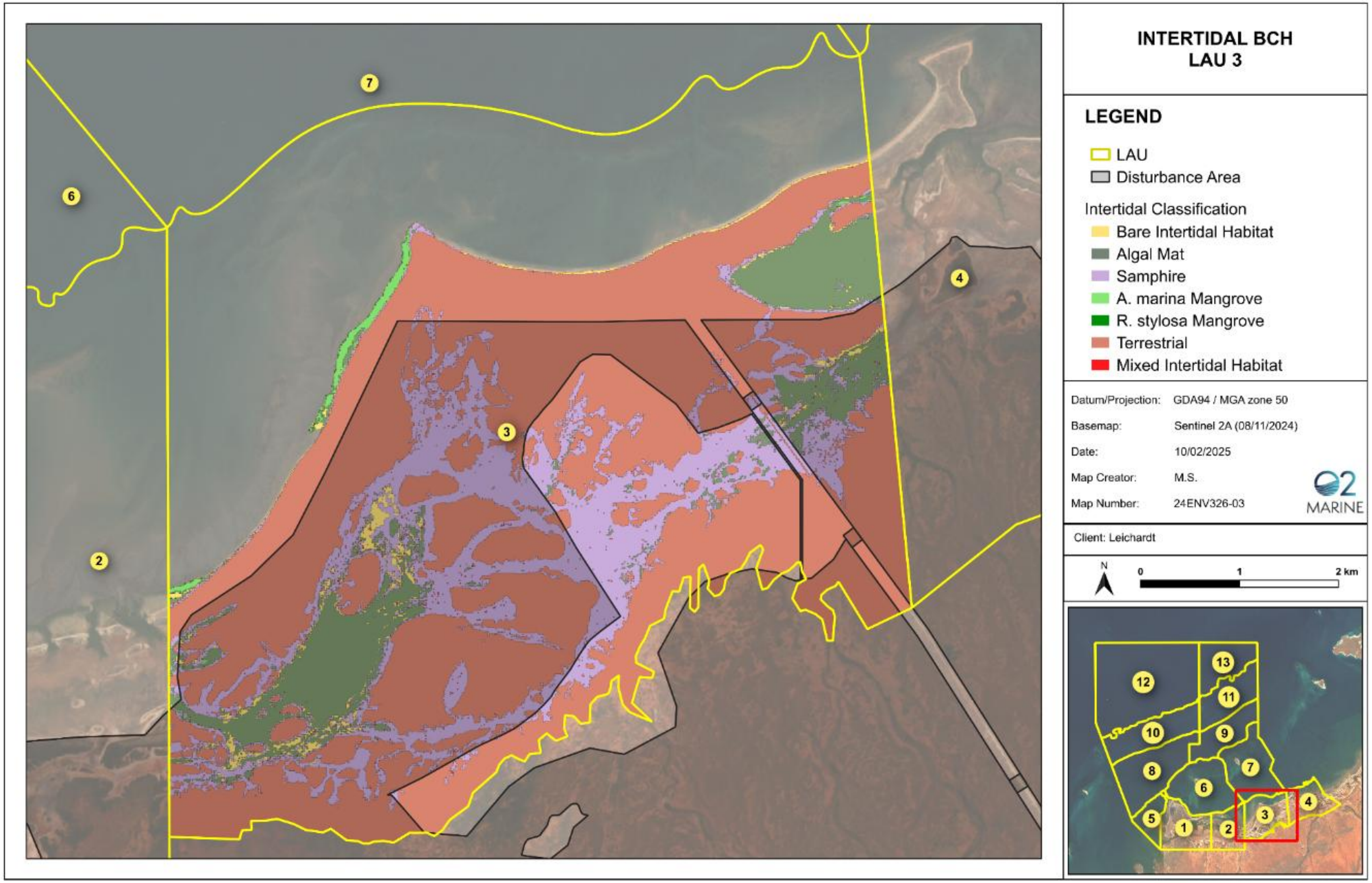



Figure 36: BCH and Terrestrial Vegetation identified in LAU3

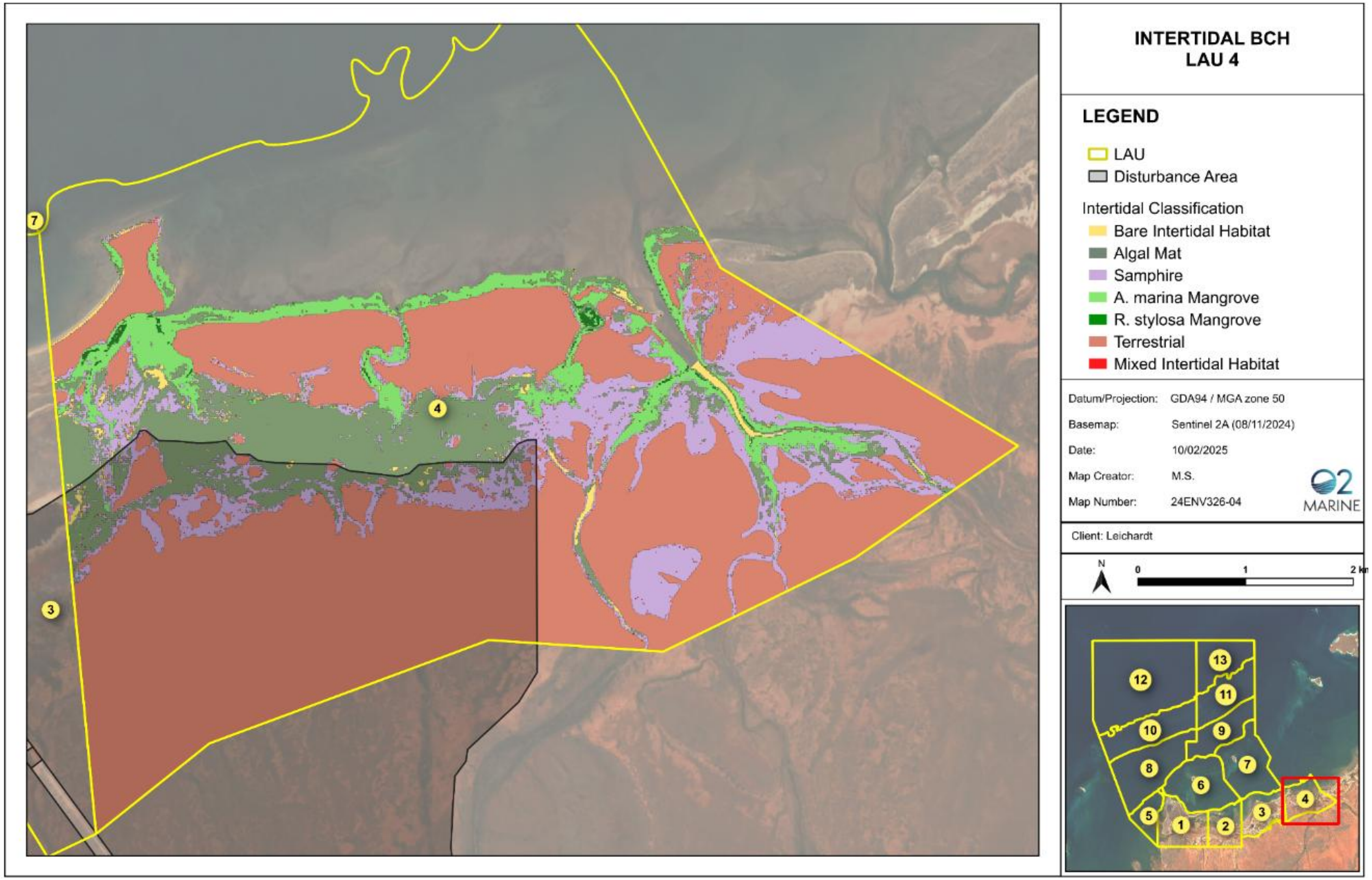



Figure 37: BCH and Terrestrial Vegetation identified in LAU4

## Appendix B. Mangrove Associations per LAU

MARINE

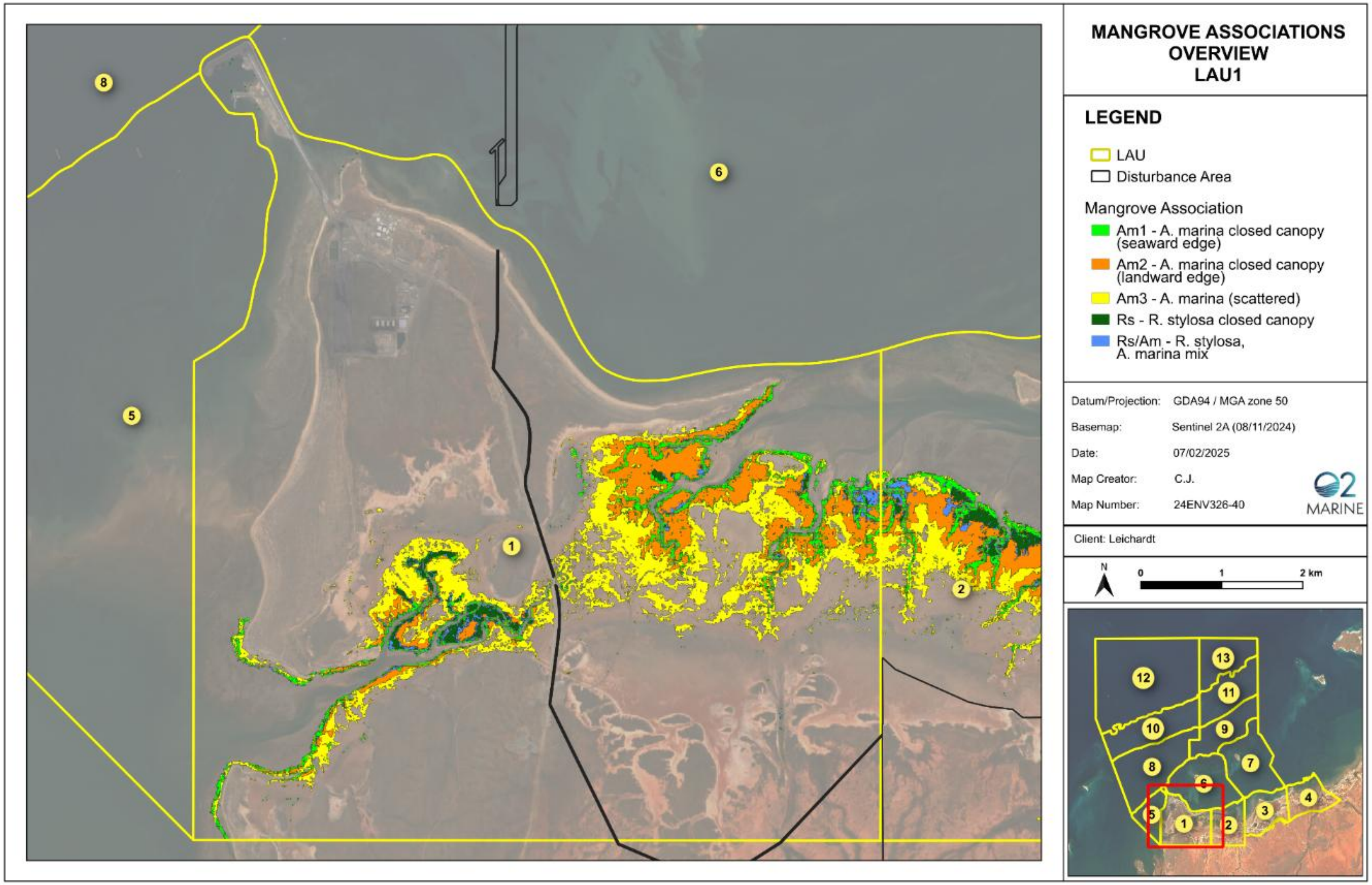



Figure 38: Mangrove Associations for LAU1

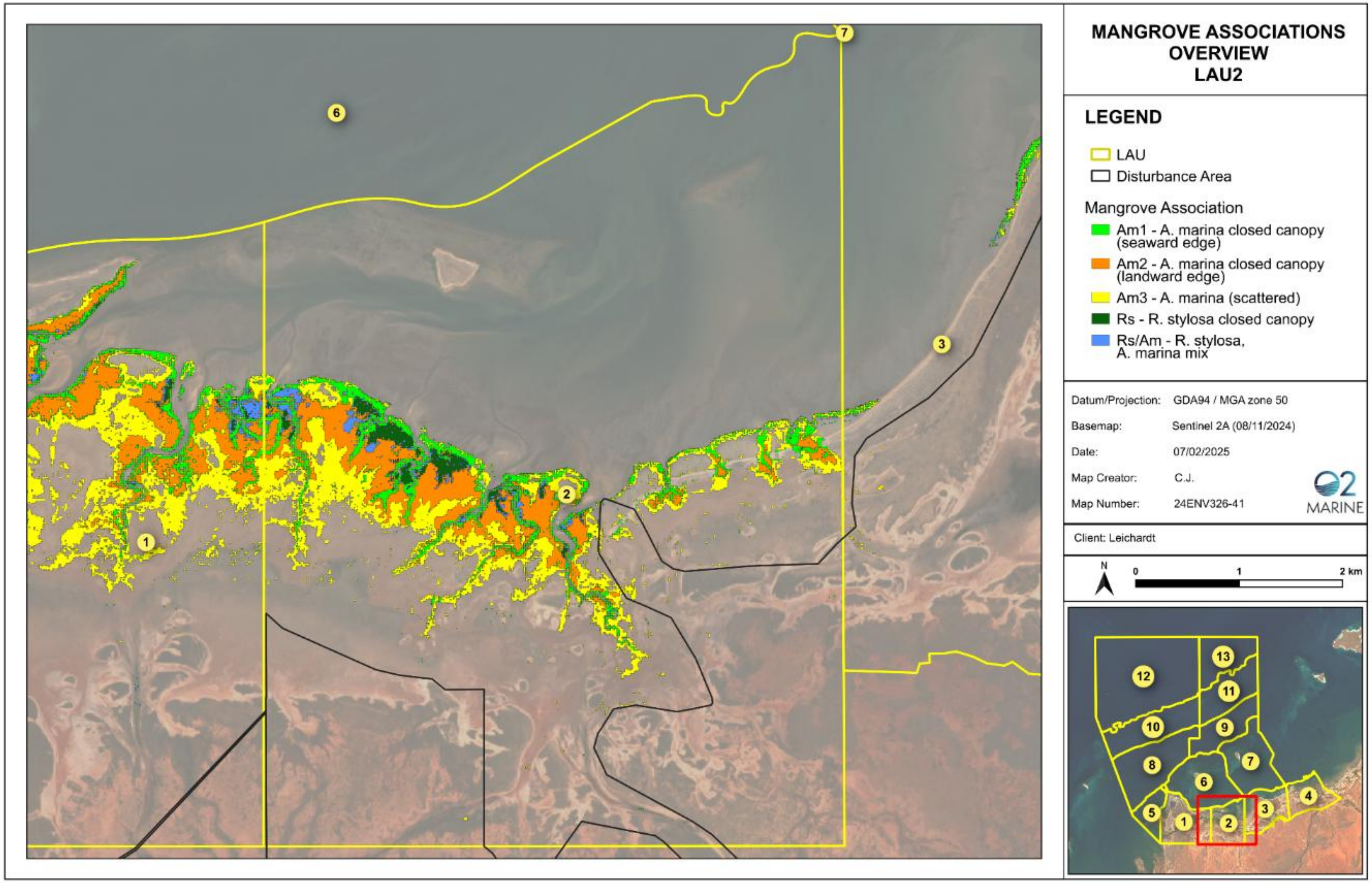



Figure 39: Mangrove Associations for LAU2

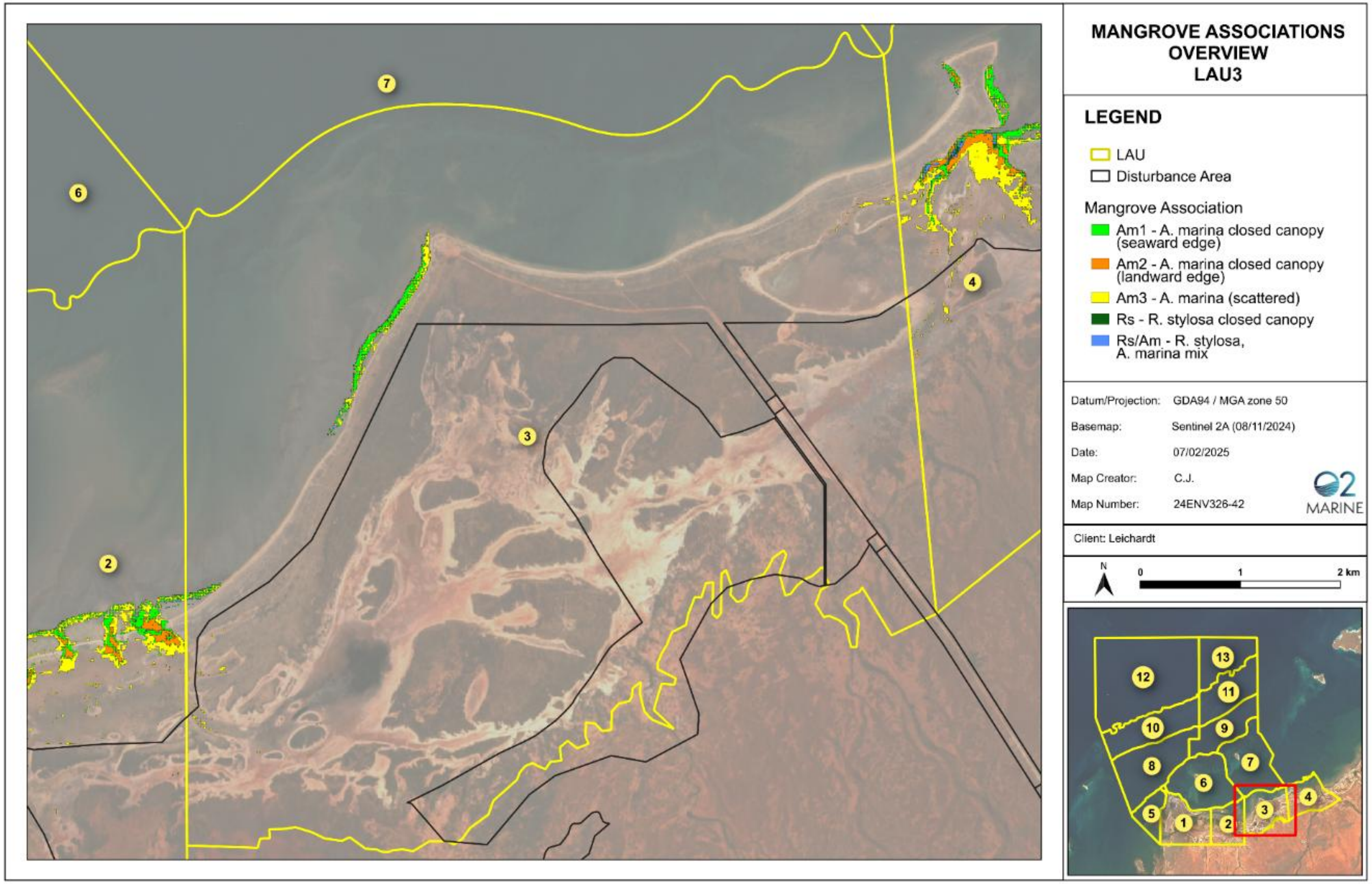



Figure 40: Mangrove Associations for LAU3

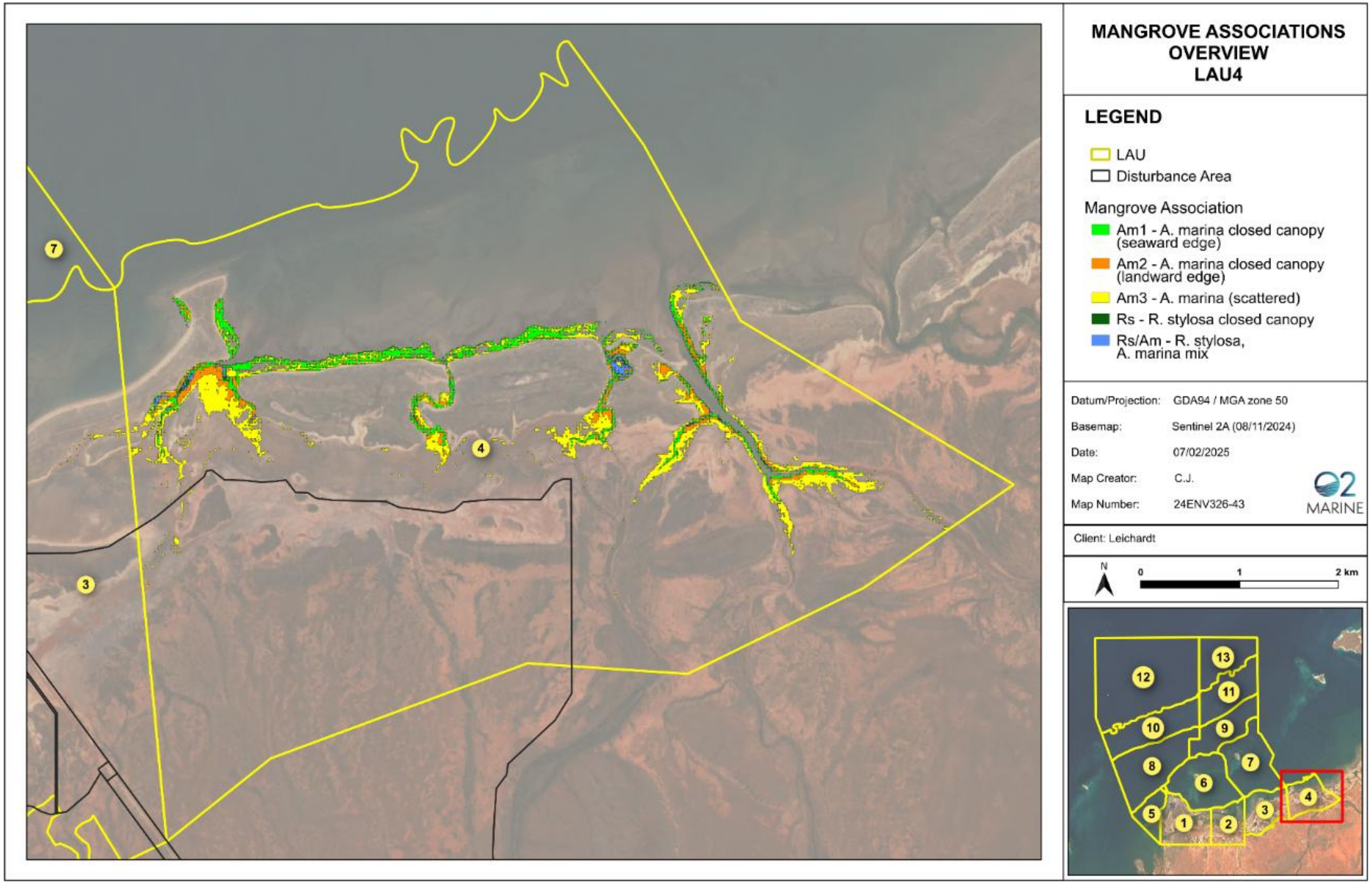



Figure 41: Mangrove Associations for LAU4

# Appendix C. Algal Mats per LAU

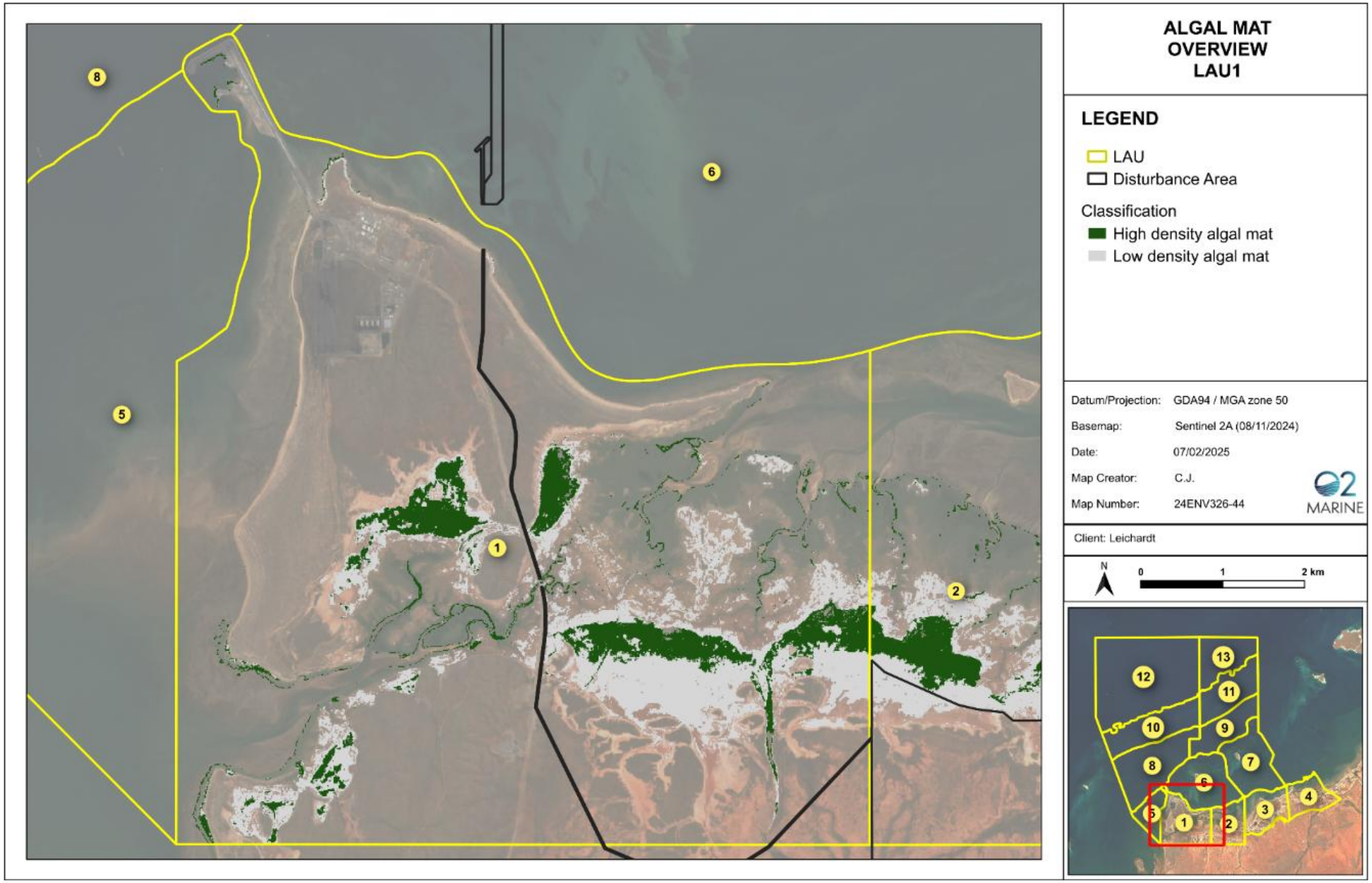



Figure 42: Algal Mats for Lau 1

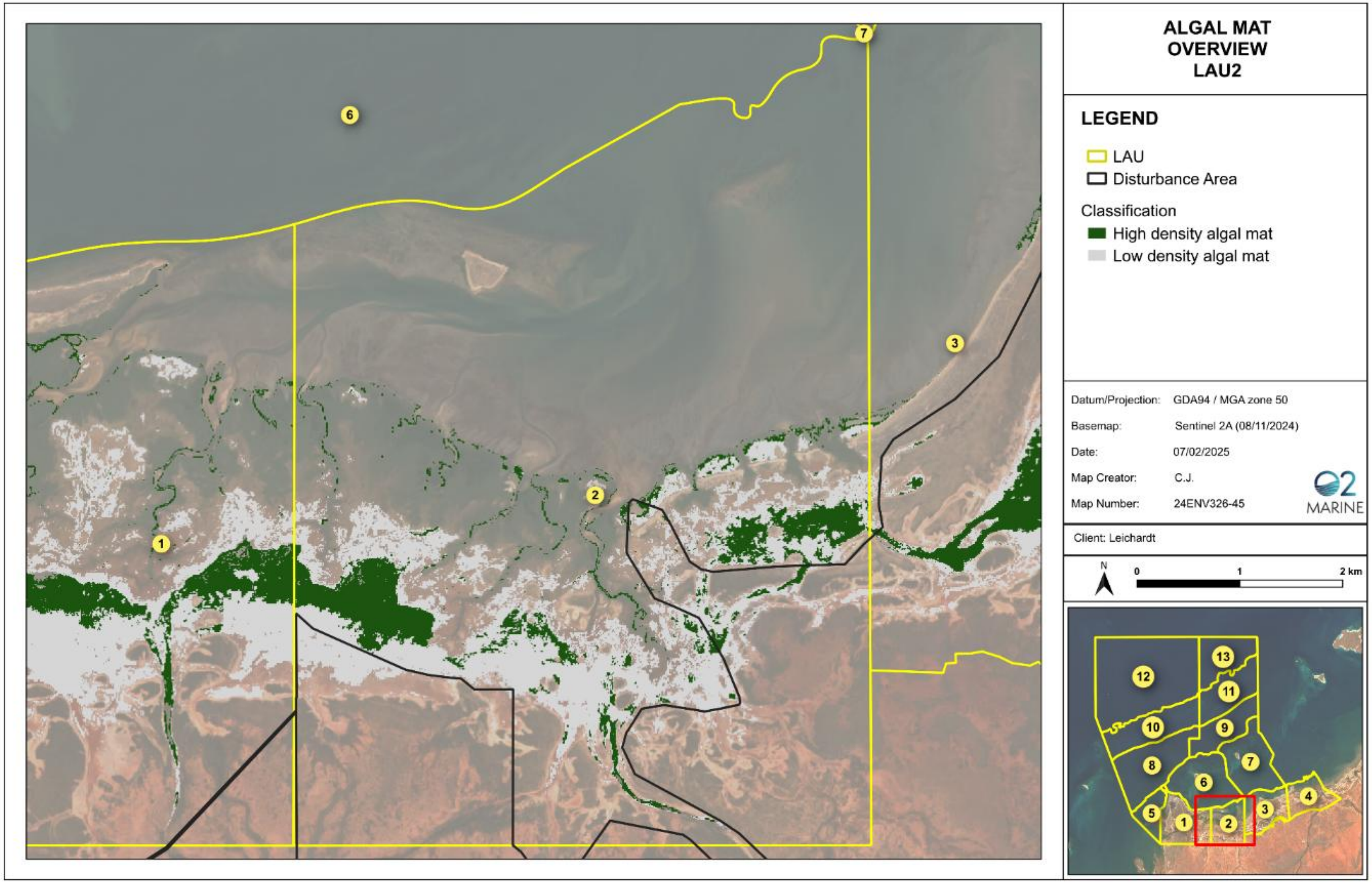



Figure 43: Algal Mats for LAU 2

O2 MARINE

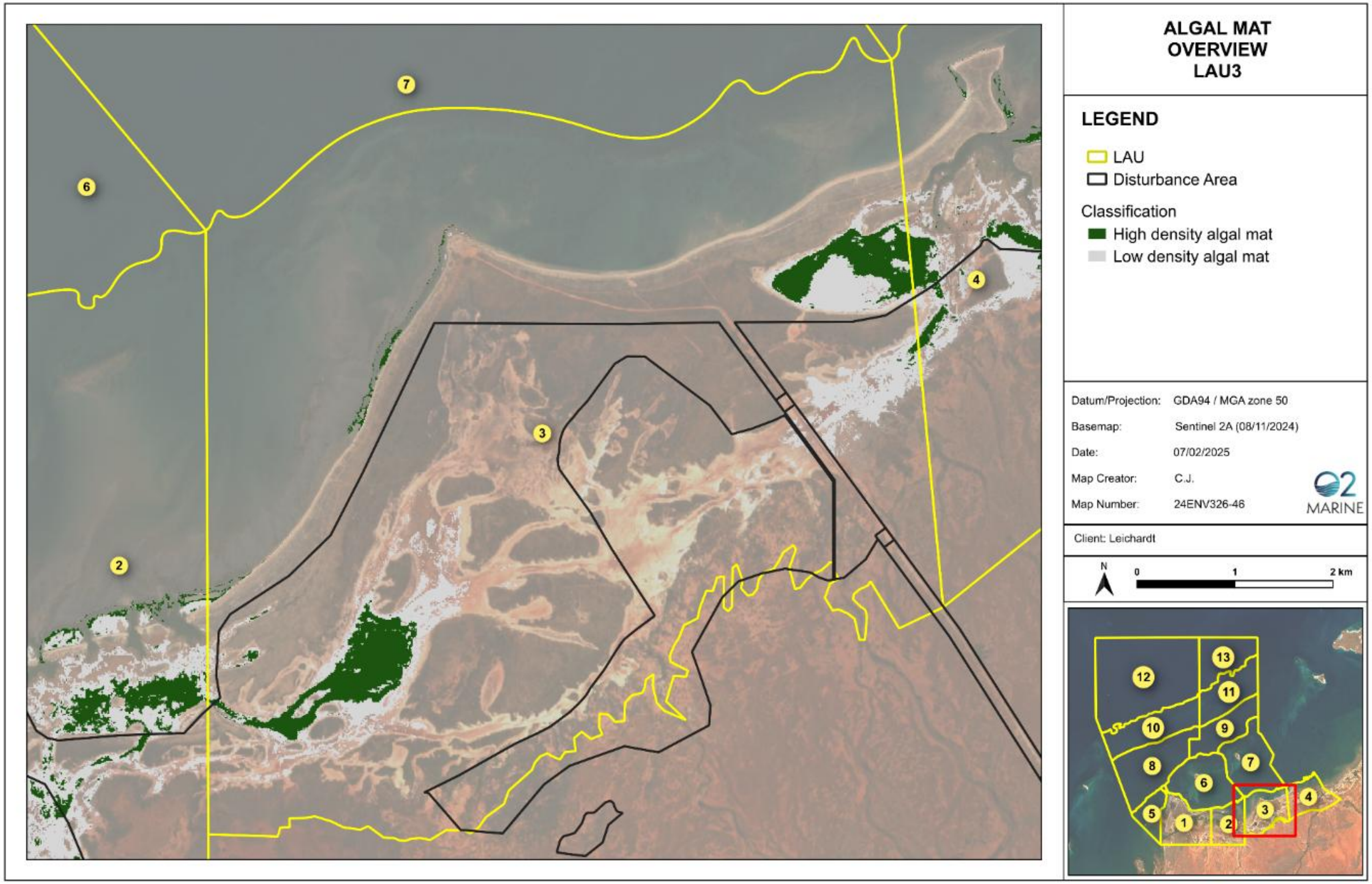



Figure 44: Algal Mats for LAU 3

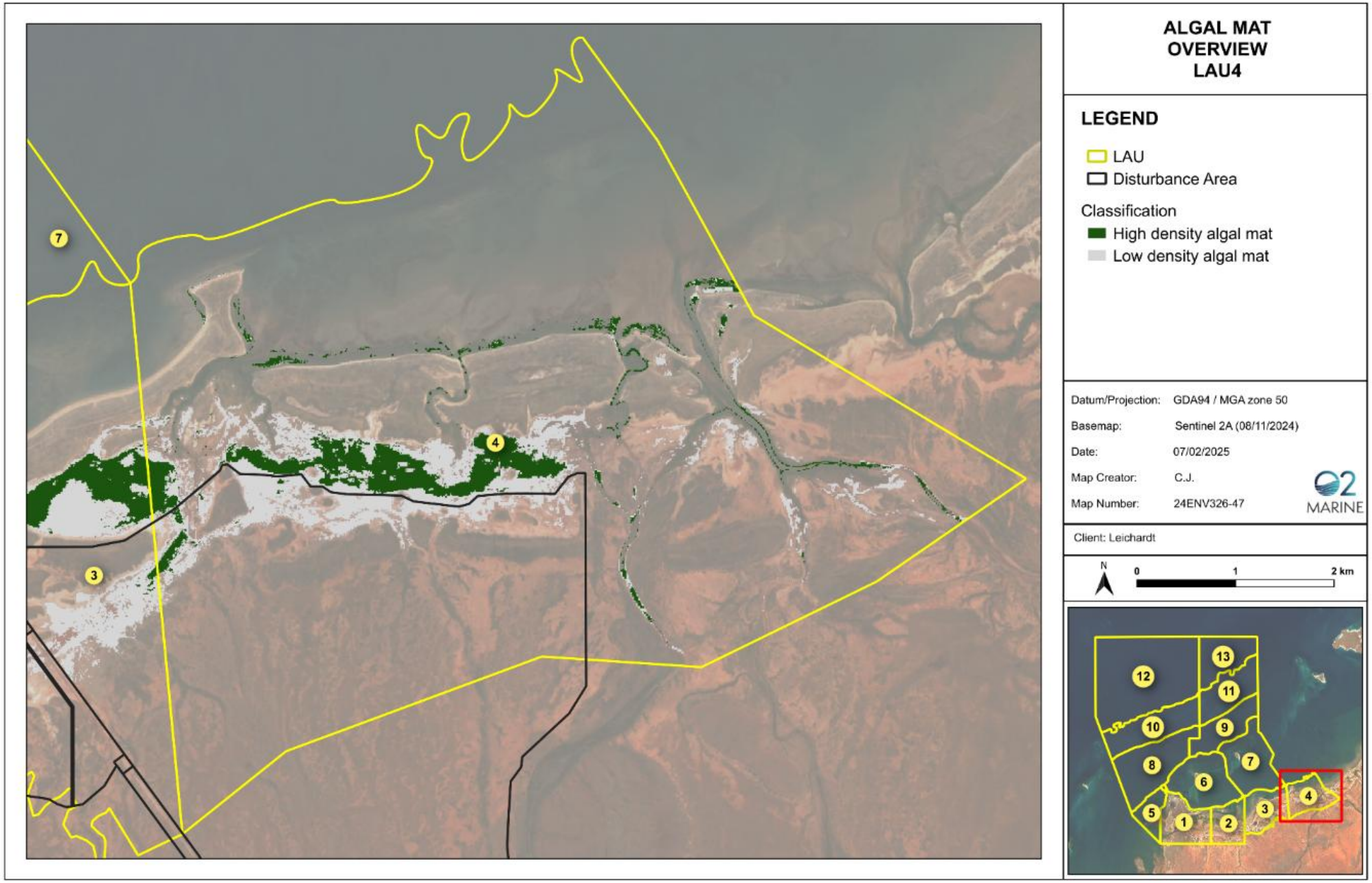



Figure 45: Algal Mats for LAU 4

# Appendix D. Samphire Habitats per LAU

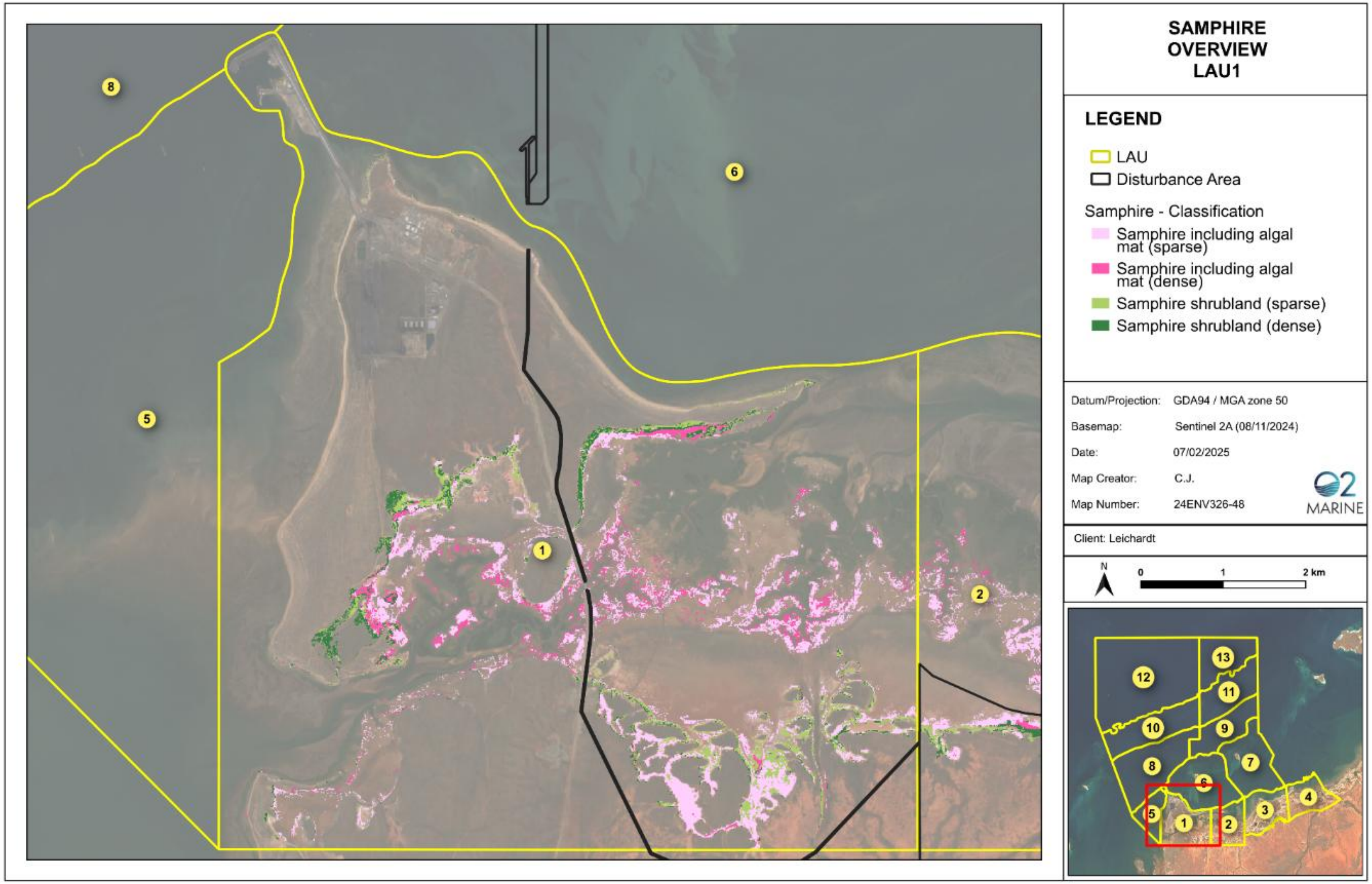



Figure 46: Samphires for LAU 1

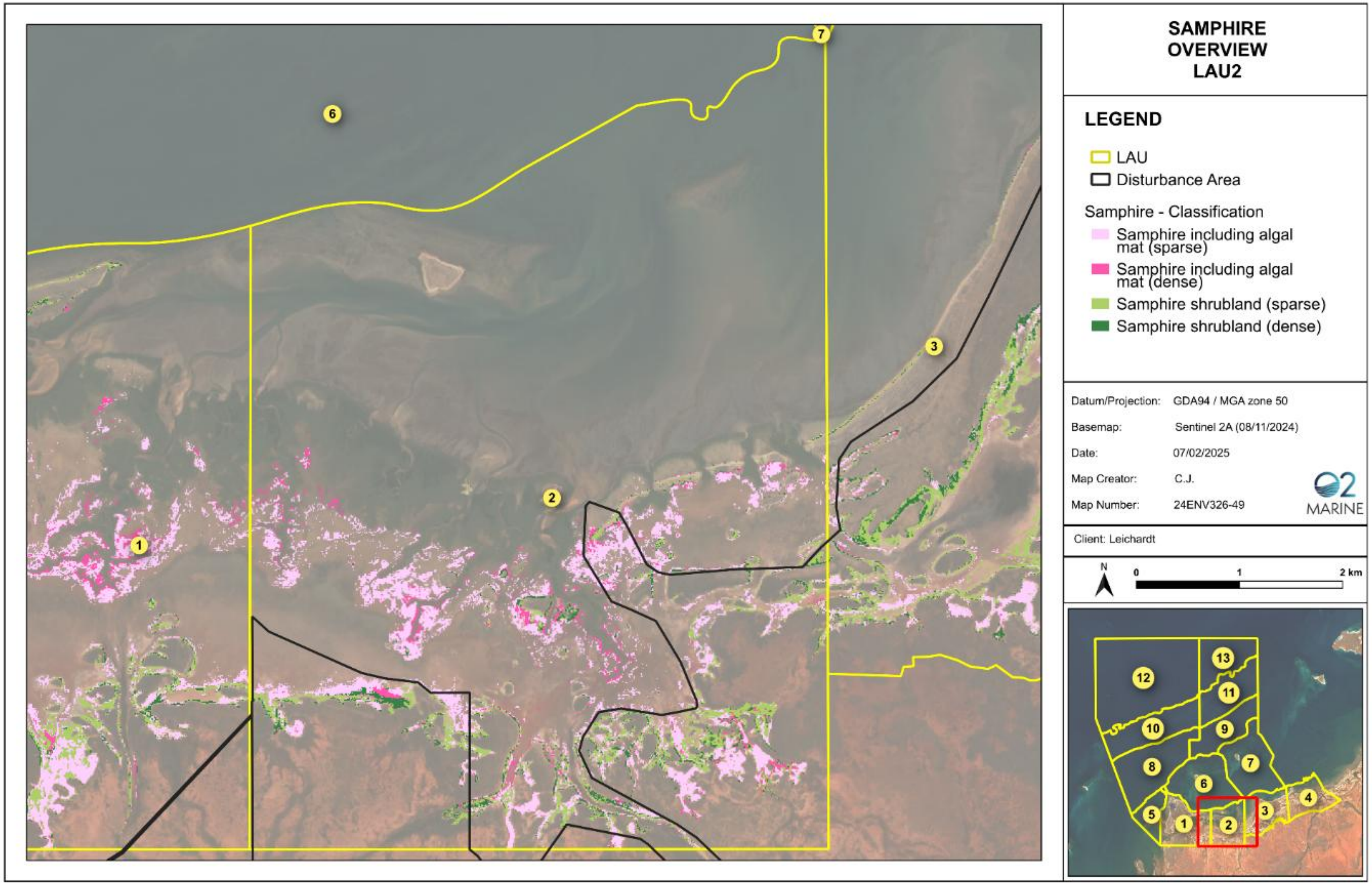



Figure 47: Samphires for LAU 2

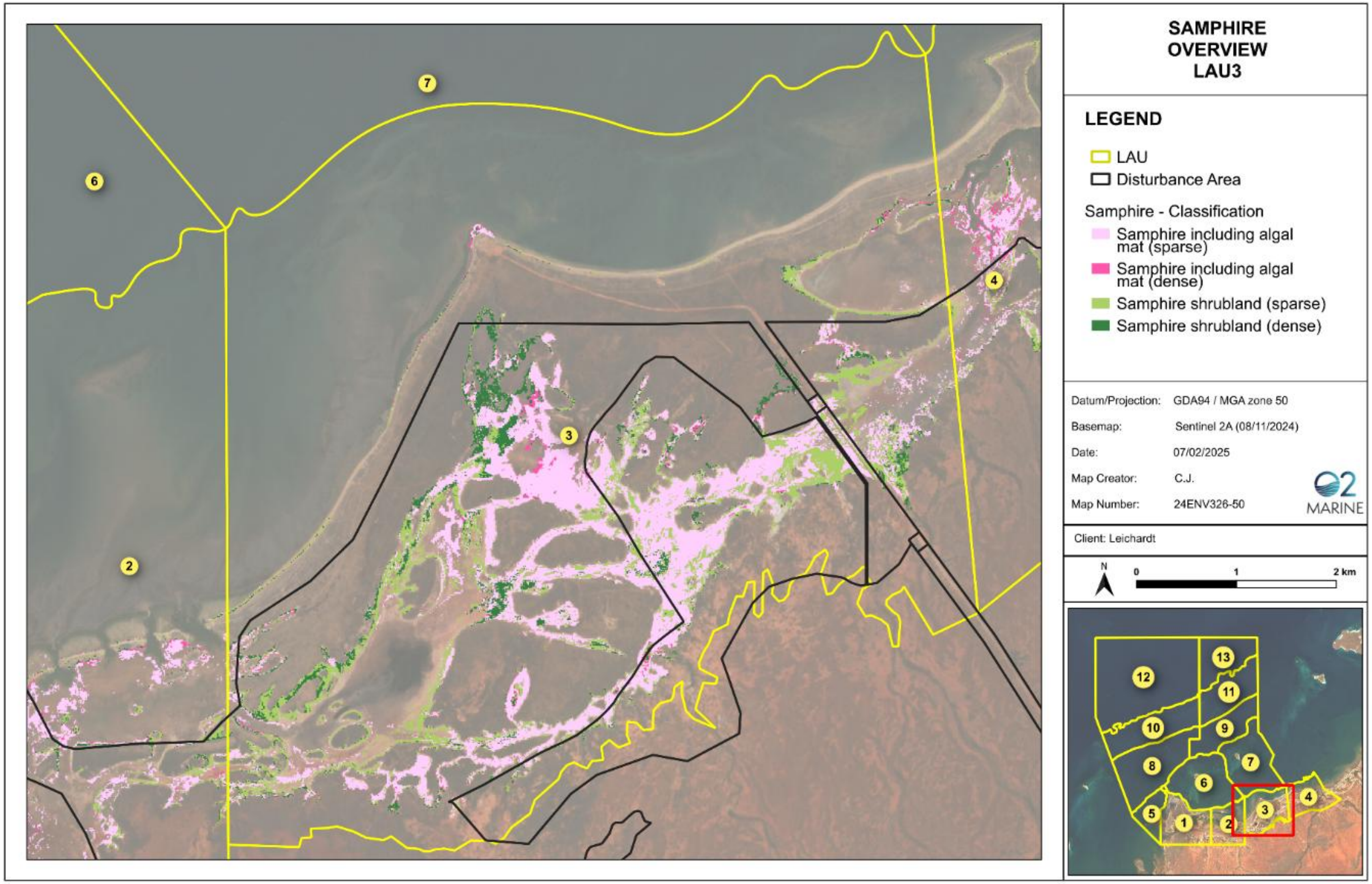



Figure 48: Samphires for LAU 3

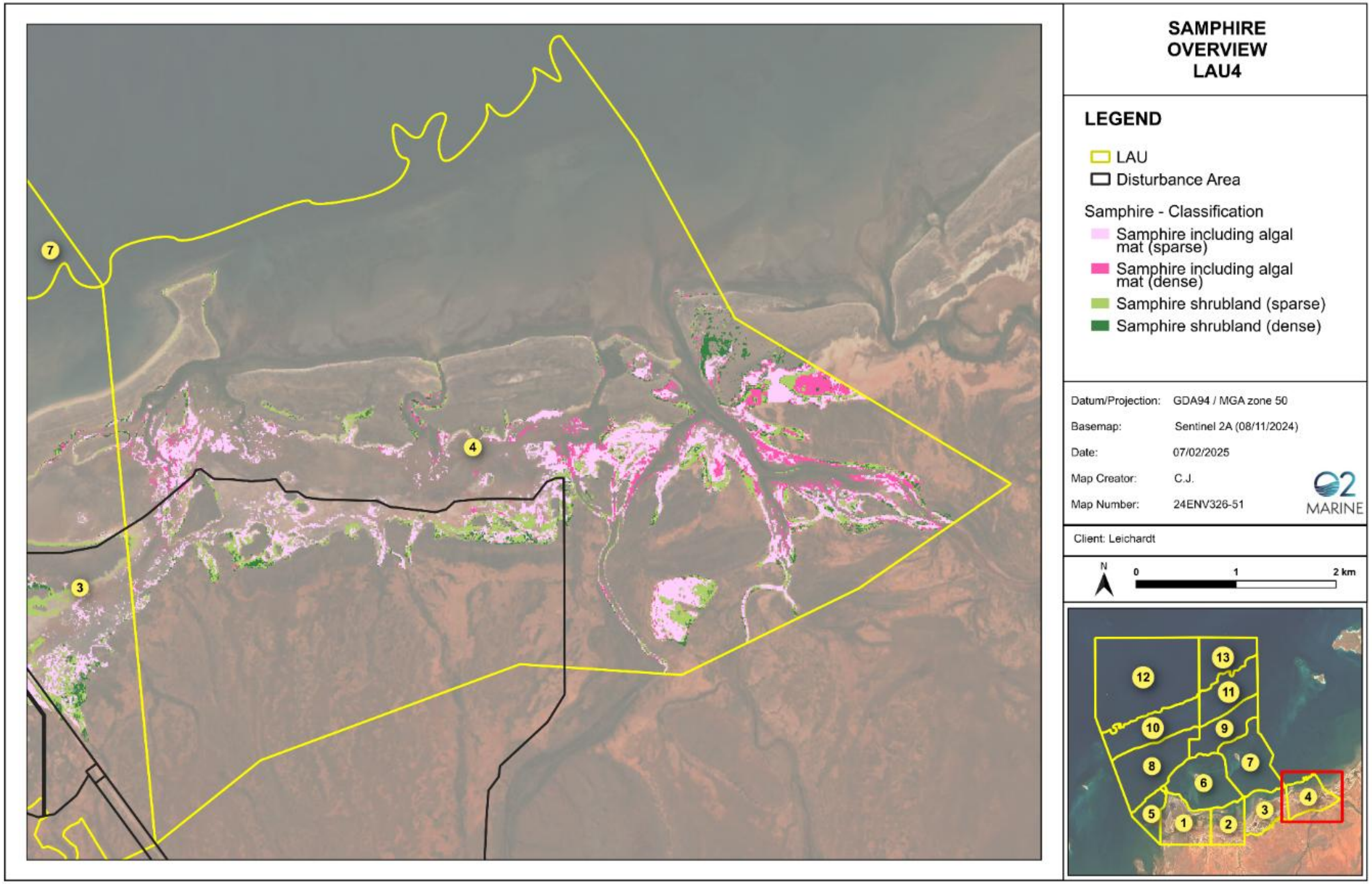



Figure 49: Samphires for LAU 4

# Appendix E. Algal mats results

## Cyanobacterial ('Blue-green algal') Mats

John M. Huisman

Methods: Ten samples (some with additional subsamples) of cyanobacterial mats, each approximately 12 x 12 cm in size, were examined. Subsamples of 5 x 1 $cm^2$ were excised from each sample and examined under a dissecting microscope for the presence of cyanobacteria and algae, then microscope slide preparations were made of representative portions. Slides were examined under a compound microscope at 400x magnification and the presence and qualitative relative abundance of each species recorded. Taxa were identified to the lowest reliable category (generally genus), using various guides and online resources (Hoffmann, 1994; Huisman, 2019; Huisman *et al.*, 2015; Guiry & Guiry, 2020; Siegesmund *et al.*, 2008). Samples 1 to 6 and 8 were relatively uniform in having a coherent layer of *Lyngbya* mixed with *Coleofasciculus* as the dominant taxa. *Lyngbya* was absent from sample 7. Samples 9 and 10 were both dominated by *Lyngbya*, with *Coleofasciculus* present in small amounts.

Samples 8, 9, and 10 presented superficial differences in macroscopic appearance, with sample 8 somewhat patchy and rugose, sample 9 tufted, and sample 10 with a smooth surface with no obvious emergent filaments (see figures).

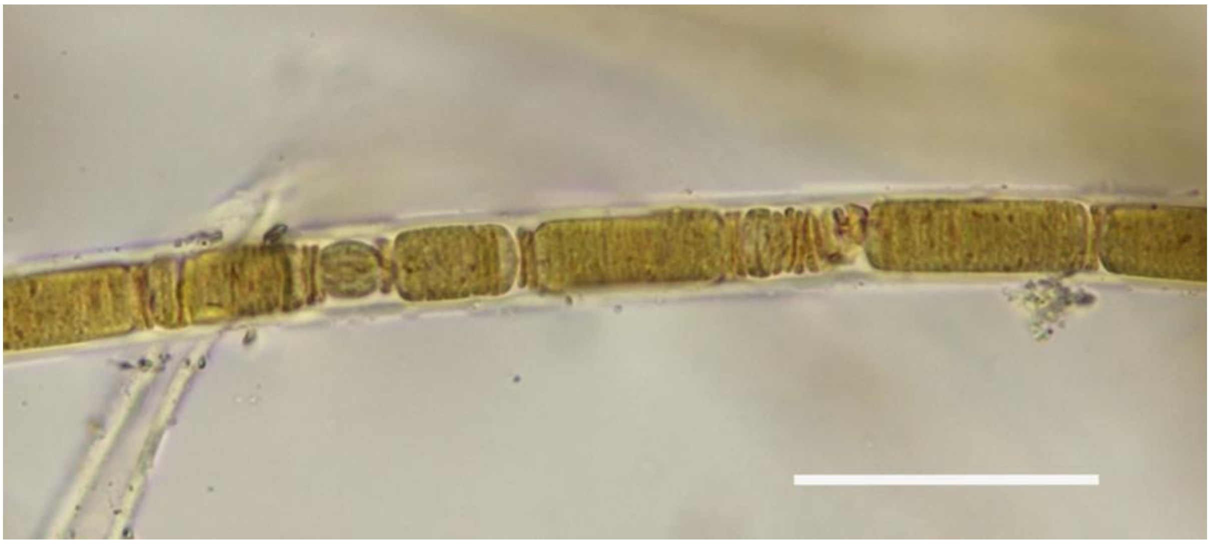
Notes on species:

*Lyngbya* sp. has disc shaped cells, considerably shorter than wide; these occasionally rotating and appearing as circular objects. The species has a prominent sheath that is mostly unpigmented but can become a dark yellow/brown in older portions and when the sheaths are empty. This is most likely the same Lyngbya species recorded and illustrated in earlier reports.

*Coleofasciculus* has green cells that are longer than broad, within an unpigmented sheath. There is considerable variation in the number of trichomes per sheath, ranging from one to many (as in the photograph). *Coleofasciculus* is the genus name now used for marine species formally included in *Microcoleus*, and this is most likely the species recorded under that name in earlier reports. There is currently only a single species included in the genus, but this is likely to change with further study.

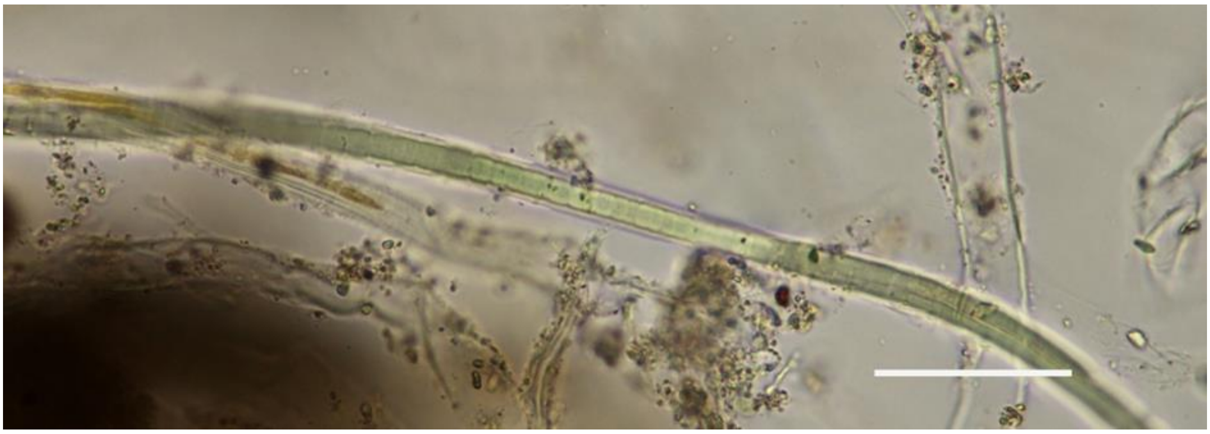
Images: (1) *Coleofasciculus*; (2) *Lyngbya* sp.; (3) *Lyngbya* sp. with dark sheath; (4) *Schizothrix* sp.; (5) *Synechococcus* sp. Scale bars = 50 µm.

(1)

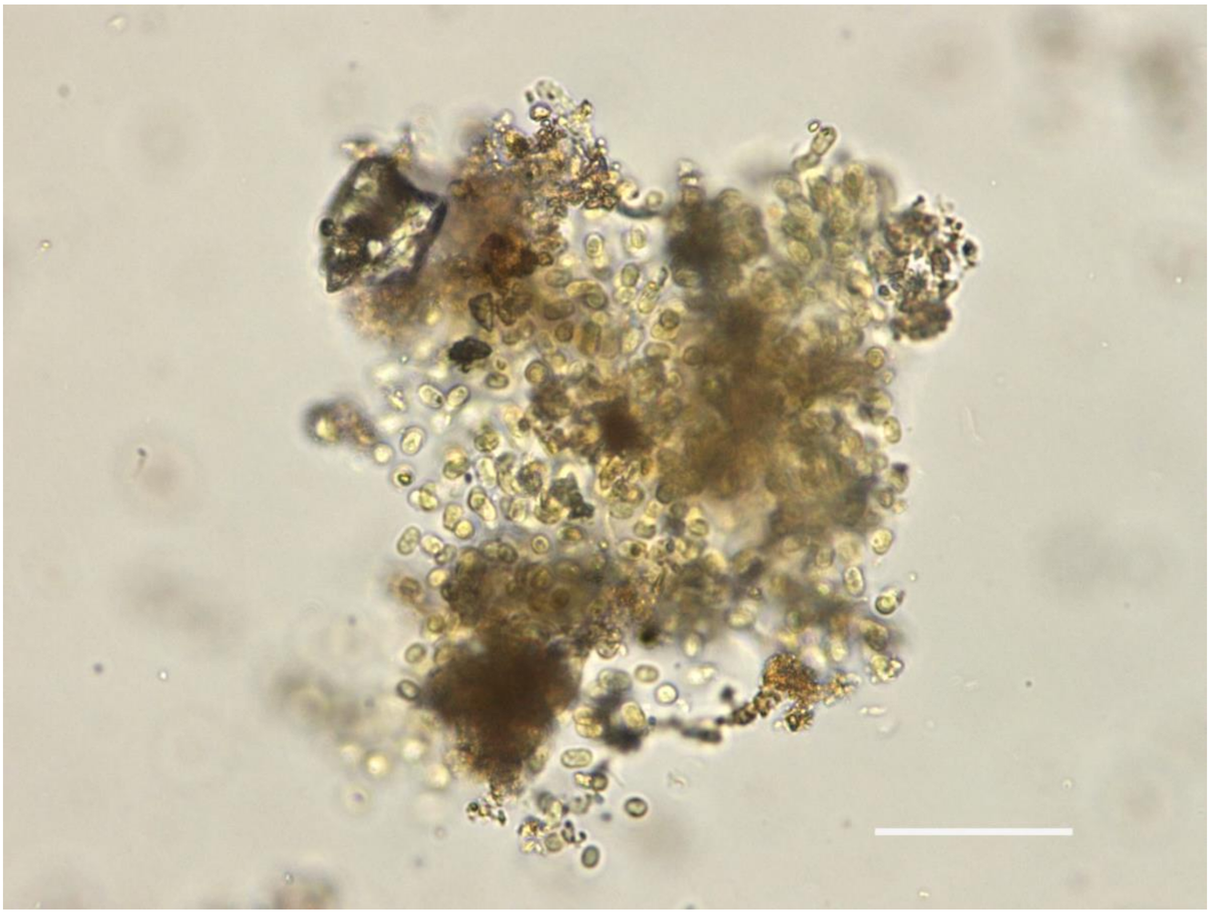


(2)

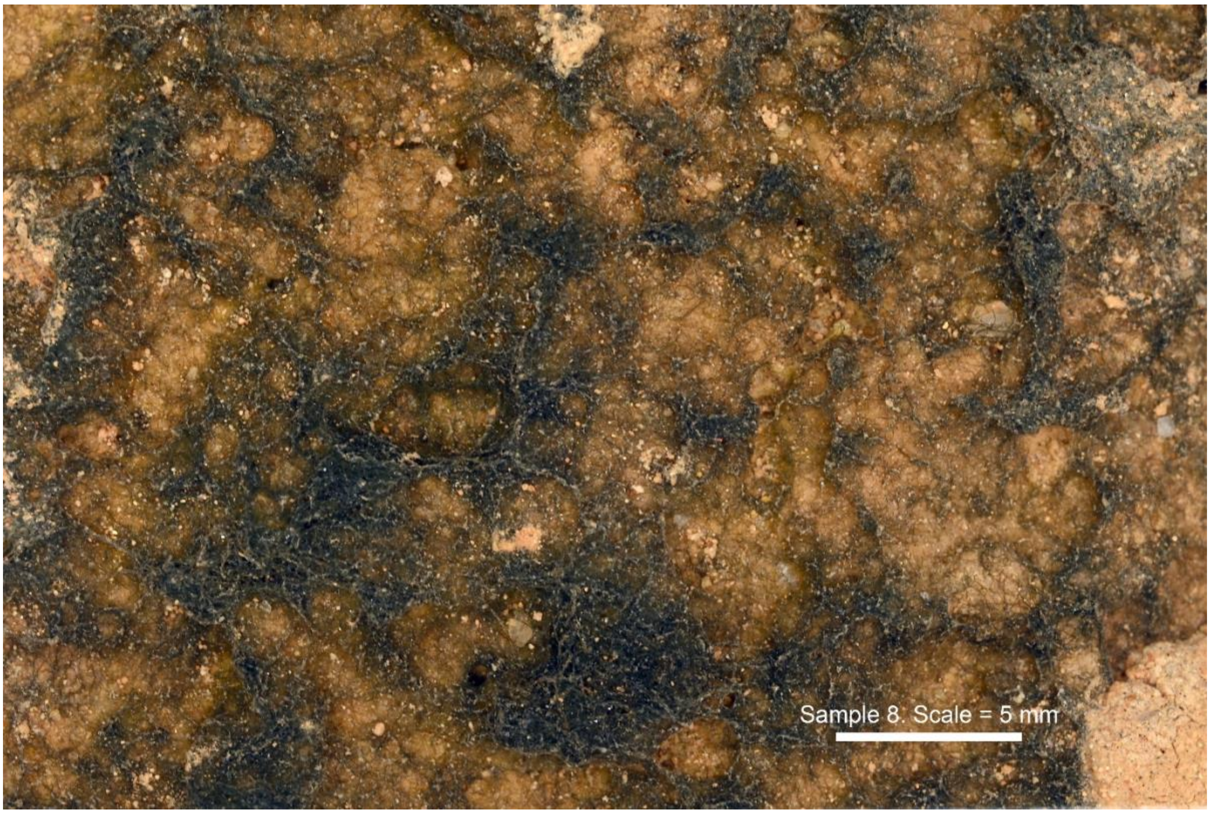
(2)



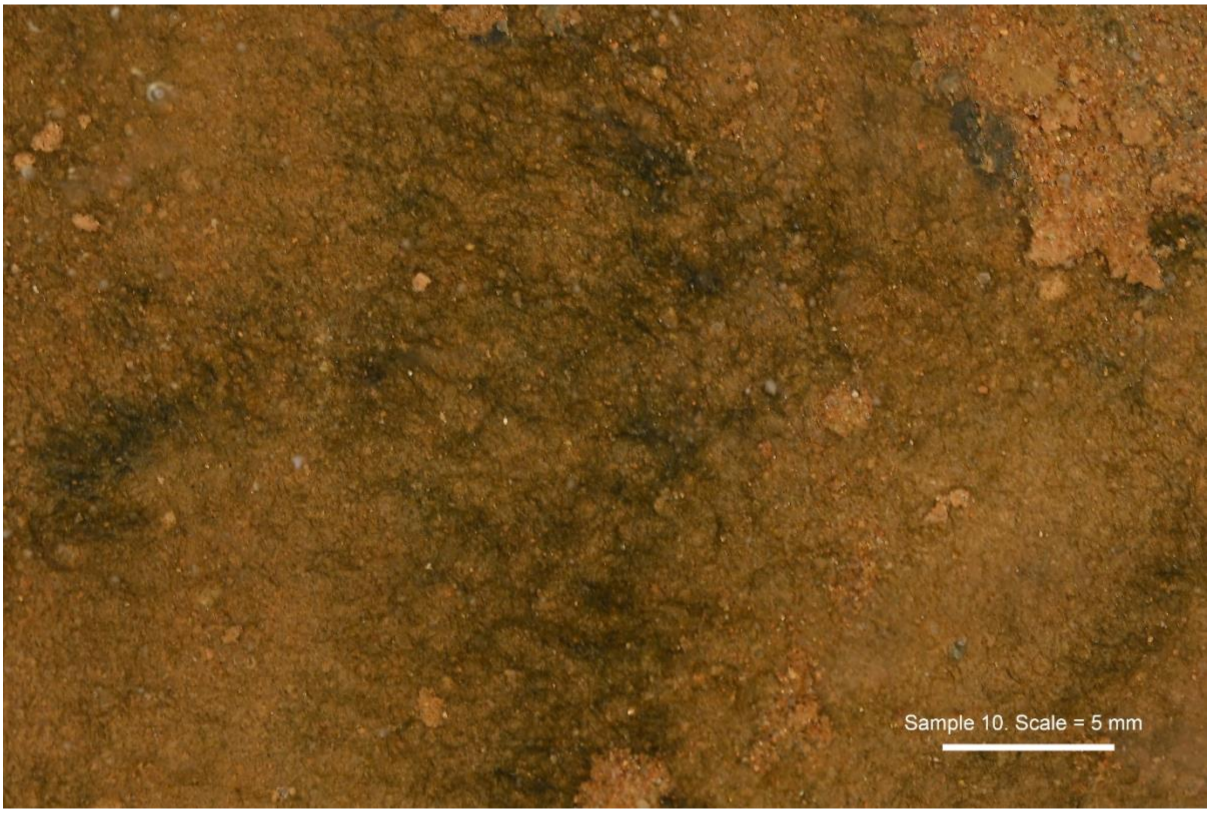
(3)



(4)


Sample 8. Scale = 5 mm


Sample 9. Scale = 5 mm


Sample 10. Scale = 5 mm

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| Phylum | Genus | Species | Algae 1 | Algae 2 | Algae 3 | Algae 4 | Algae 5 | Algae 6 | Algae 7 | Algae 8 | Algae 9 | Algae 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bacillariophyta | *Navicula* | sp. | R | | | | | | | | R | |
| Miozoa | *Ceratium* | *furca* | R | | | | | | | | | |
| Cyanobacteria | *Lyngbya* | sp. | A | A | A | A | A | A | | A | A | A |
| Cyanobacteria | *Coleofasciculus* | *chthonoplastes* | C | C | C | C | C | C | C | A | R | C |
| Cyanobacteria | *Schizothrix* | spp. | C | C | C | C | C | C | R | R | R | C |
| Cyanobacteria | *Synechococcus* | *sp.* | | | | | R | | | | | |

A - Abundant, C - Common, R - Rare

# Appendix F. Nutrient Flux Study

| | | | |
|---|---|---|---|
| Date | 24 September 2021 | | |
| To | Regina Flugge | Email | regina.flugge@leic.com.au |
| From | Blake Ramsby<br>Russell Stevens | Email | Blake.ramsby@o2marine.com.au<br>Russell.stevens@o2marine.com.au |
| Subject | Eramurra Intertidal Nutriflux Investigation | | |
| Reference | T210135 | | |

# 1. Introduction

## 1.1. Project Description

Leichhardt Salt Pty Ltd (LS) propose to develop the Eramurra Solar Salt Project (ESSP) in the Cape Preston East area, Western Australia (Figure 1). The Proposal will produce high purity industrial grade sodium chloride salt from seawater via a solar evaporation, using crystalliser ponds and processing plant. Salt will be shipped from a marine loading terminal to overseas markets. Key development areas associated with the ESSP are identified in Figure 1. A short summary of the Proposal is presented in Table 1.

O2 Marine was engaged by the proponent to undertake marine environmental investigations to help identify environmental risks of the ESSP, 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.

Table 1 Short Summary of the Proposal

| | |
|---|---|
| **Project Title** | **Eramurra Solar Salt Project** |
| **Proponent Name** | **Leichhardt Salt Pty Ltd** |
| **Short Description** | Leichhardt Salt Pty Ltd is seeking to develop a solar salt project in the Cape Preston East Area, approximately 55 kilometres (km) west-south-west of Karratha in Western Australia (WA) (the Proposal). The Proposal will utilise evaporated seawater to produce a concentrated salt product for export.<br><br>The Proposal includes the development of a series of concentrator and crystalliser ponds, and a processing plant. Supporting infrastructure includes a bitterns outfall, drainage channels, product dewatering facilities, a desalination plant and/or groundwater bores, pumps, pipelines, power supplies, access roads, administration buildings, workshops, laydown areas, landfill facilities, communication facilities and other associated infrastructure. The Proposal also includes an approximated 314,000 $m^3$ capital dredging program of the Cape Preston East Port with offshore spoil disposal. |

## 1.2. Purpose and objective

The purpose of this investigation is to collect quantitative data to determine the ecological significance and regional importance of key intertidal communities with respect to nutrient export into the intertidal and nearshore subtidal system at the Eramurra project site. This will inform the intertidal assessment for the Project and assist with wholistic project impact assessment process.

The general objective of this investigation is to determine whether inundation of algal mats on a spring tide alters nutrient concentrations relative to a neap tide where algal mats are not flooded, thereby quantifying the contribution of algal mats to local nutrient cycling. The specific objectives of this investigation are to:

- Collect nutrient data over the ebb and flood cycle during neap tides when only mangrove communities are inundated and connected to the subtidal system
- Collect nutrient data over the ebb and flood cycle during spring tides when the entire intertidal zone is inundated and connected to the subtidal system, in particular continuous algal mats communities
- Collect soil samples adjacent to mangrove associations and from the continuous algal mat communities, and
- Conduct an assessment to determine the contribution of algal mat communities and mangrove associations to nutrient exchange of project area.

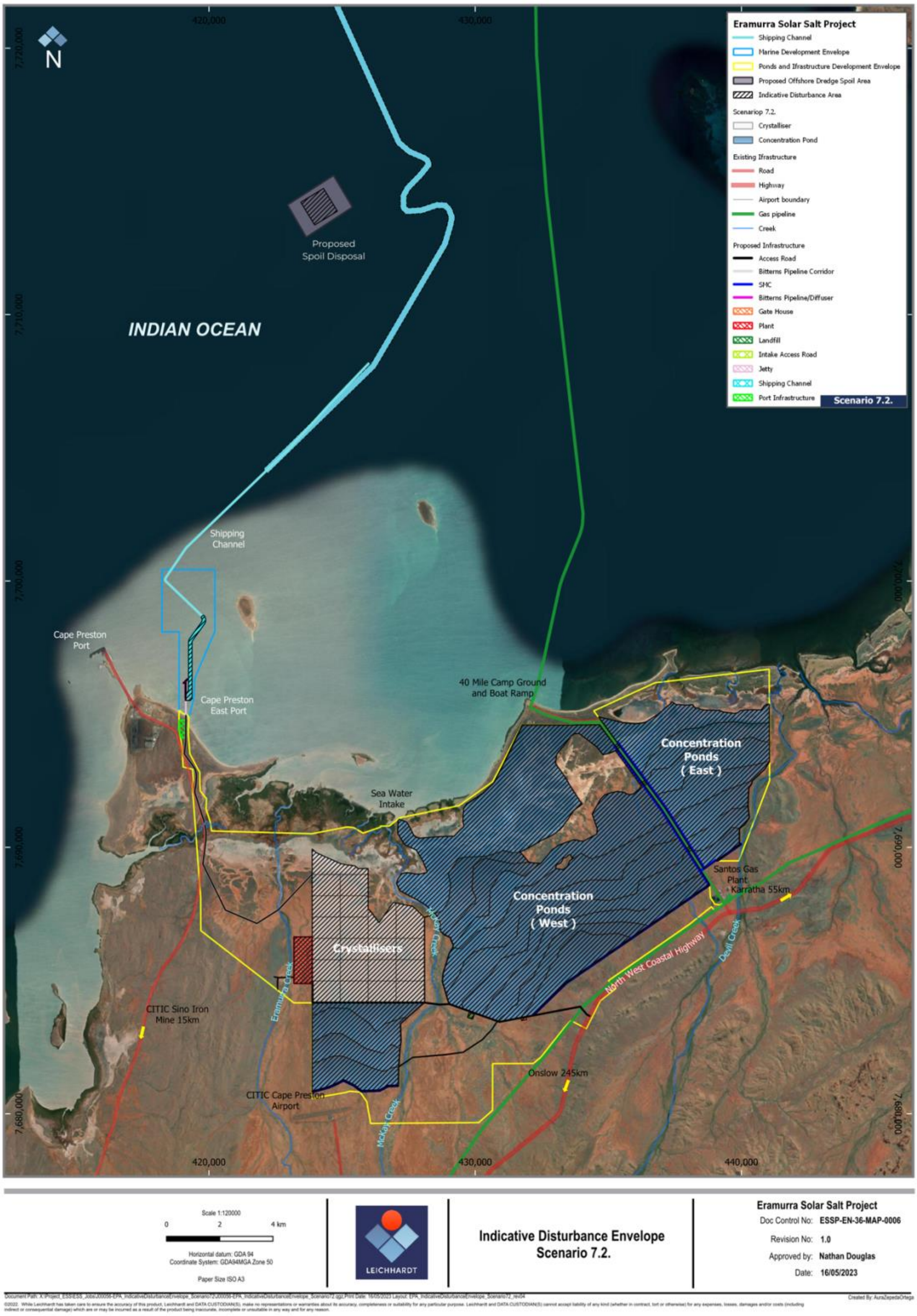


Figure 1 Regional location of the proposal

# 2. Methods

## 2.1. Tidal nutrient investigation

### 2.1.1. Sampling locations

Water sampling for nutrients was completed at the three locations in LAU1 and LAU2: one east (CC) of the Great Sand Island Nature Reserve and two locations further inshore to the west (CB) and southeast (CA) of the Reserve (Figure 2 and Table 2). Each location was sampled in triplicate, e.g. CC-1,2,3, with triplicate 1 furthest inshore and triplicate 3 furthest seaward and each sampling site separated by ~30 m.

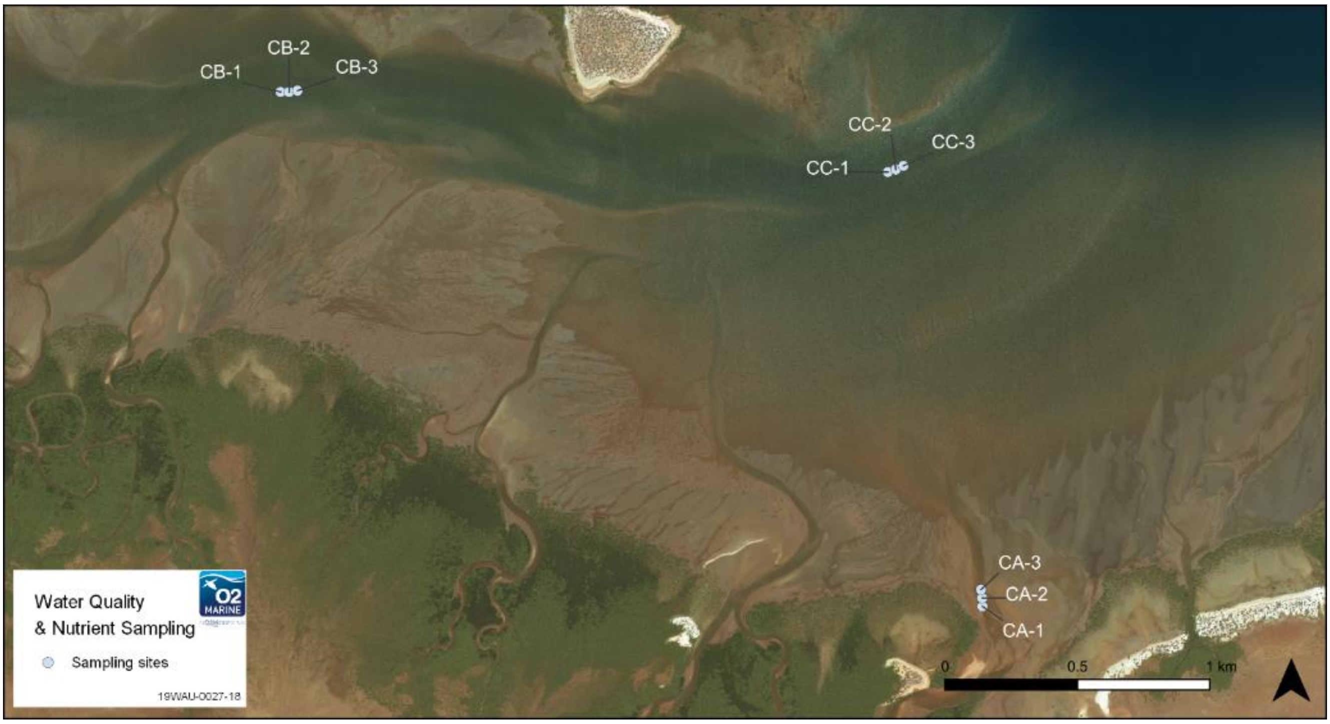


Figure 2 Tidal nutrient concentration sampling locations

Table 2 Latitude and longitude of tidal nutrient concentration sampling locations (WGS 84)

| Site | Latitude | Longitude |
|---|---|---|
| CA-1 | 20°52'38.35"S | 116°17'53.32"E |
| CB-1 | 20°51'39.49"S | 116°16'27.48"E |
| CC-1 | 20°51'48.66"S | 116°17'41.75"E |

#### 2.1.2. Sampling design

To measure the contribution of algal mats to local nutrient cycling, nutrient levels were measured during flood and ebb cycles of two spring tides that were high enough to inundate the algal mats and during two neap tides that did not inundate algal mats. Neap tides were sampled on 8 and 9 June 2021 while spring tides were sampled on 27 and 28 June 2021.

Nutrients sampled in triplicate in each location in front of the mangroves 20 cm below the surface of the water in a prewashed sample bottle. Four samples were collected into laboratory supplied sample containers as follows:

- 250 mL was collected for total inorganic carbon and total carbon;
- 40 mL was collected for total organic carbon and laboratory included sulfuric acid to preserve sample;
- 60 mL was collected for total nitrogen and total phosphorus; and
- 60 mL was collected and filtered through a 0.4 µm filter for nitrate/nitrite, ammonia/ammonium, and reactive phosphorus determination.

Samples were stored on ice, frozen if required (total N, total P, and nitrate/nitrite, ammonia/ammonium, and reactive phosphorus), and transported to the analytical laboratory as soon as practicable considering transportation restrictions due to the remote sampling location.

At the time of water sampling, water quality was measured in situ, including pH, salinity, temperature, dissolved oxygen, turbidity, current speed, and water depth (YSI Pro DS).

#### 2.1.3. Data Analysis

Nutrient concentrations (nitrite and nitrate, total N, total P, reactive Phosphorus, total organic C, total inorganic C, and total C) were analysed using a linear model to test for differences across the tidal cycle (flood, ebb), tidal height (<4 m, >4 m), time (each tide/day) as well as whether the differences across the tidal cycle varied between tidal heights or locations. Data were log transformed as necessary to meet the assumptions of normality and homogeneity of variance.

### 2.2. Soil Nutrients

#### 2.2.1. Sampling locations

Soil sampling for nutrients was completed at six locations in LAU1, LAU2 and LAU3. Sample locations are presented in Figure 3with sample coordinates provided in Table 3.


Figure 3 Soil nutrient sampling locations

Table 3 Latitude and longitude and number of samples for each soil sampling site (WGS 84).

| LAU | Site | Sample names | Latitude | Longitude | Samples (n) |
|---|---|---|---|---|---|
| 1 | Algae1 | ES1 | 20° 52' 17.147" S | 116° 13' 55.787" E | 1 |
| 1 | Algae3 | ES2 | 20° 53' 23.611" S | 116° 15' 17.851" E | 1 |
| 2 | Algae5 | ES3 | 20° 53' 40.415" S | 116° 17' 2.203" E | 1 |
| 3 | Mangrove1 | ES4, ES5, ES6 | 20° 51' 54.483" S | 116° 14' 30.527" E | 3 |
| 1 | Mangrove3 | ES7, ES8, ES9 | 20° 52' 52.457" S | 116° 17' 48.815" E | 3 |
| 2 | Algae7 | ES10 | 20° 52' 39.594" S | 116° 20' 10.375" E | 1 |

## 2.2.2. Sampling design

Soils were collected beneath algal mats and around mangrove roots using a hand trowel from two mangrove sites (n=3 each) and four algal mat sites (n=1 each) in May 2020 (Figure 3 and Table 3). Mangrove sites were sampled in triplicate with one sample collected from the landside edge, centre, and seaward edge of the mangrove canopy.

Soil samples were stored in a car refrigerator set to -10°C and then placed into the freezer upon return from the field survey. Samples were then transported in an eski containing frozen ice bricks via courier to the laboratory for analysis. Nutrient concentrations and chemical characteristics were measured using standard protocols by the Analytical Reference Laboratory (Welshpool, WA).

### 2.2.3. Data Analysis

Nutrient concentrations (ammonia, nitrite and nitrate, total N, total P, total organic C) and chemical characteristics (temperature and salinity) were analysed using a linear model to test for differences between algal mat and mangrove sites and accounting for subsampling within mangrove sites. Data were log transformed as necessary to meet the assumptions of normality and homogeneity of variance.

# 3. Results

## 3.1. Tidal nutrient investigation

Raw data for the two sampling rounds are presented in Attachment 3 and Attachment 4, respectively. The following sections provide an analysis of the results.

### 3.1.1. Location characteristics

Most physiochemical characteristics were similar among locations. However, location CA was shallower, had higher turbidity, and lower TDS than CB and CC (Table 4)[1].

Table 4 Physiochemical characteristics of water sampling sites on 27-28 June 2021 (4.3 m tide) during flood and ebb tides.

| Site ID | Count | Depth (m) | Temp (°C) | DO (mg/L) | pH | Salinity (ppt) | NTU | TDS (mg/L) |
|---|---|---|---|---|---|---|---|---|
| CA | 201 | 2.2 | 17.9 (0.8) | 7.6 (0.5) | 8.2 (0.03) | 37.3 (3.8) | 1.1 (1.0) | 34470.8 (8864.4) |
| CB | 281 | 4.1 | 18.1 (0.6) | 7.5 (0.2) | 8.3 (0.02) | 37.0 (2.6) | 0.2 (0.3) | 36191.0 (2509.0) |
| CC | 247 | 4.8 | 18.1 (0.5) | 7.5 (0.2) | 8.2 (0.08) | 36.8 (3.3) | 0.1 (0.4) | 36017.6 (3167.7) |

The difference in temperature, but not salinity, between flood and ebb cycles varied across tidal heights (Figure 3, Table 4). On small tides, ebb cycles had similar temperature to the flood cycle, but on larger tides, ebb cycles were significantly warmer than the preceding flood cycle (Table 5).

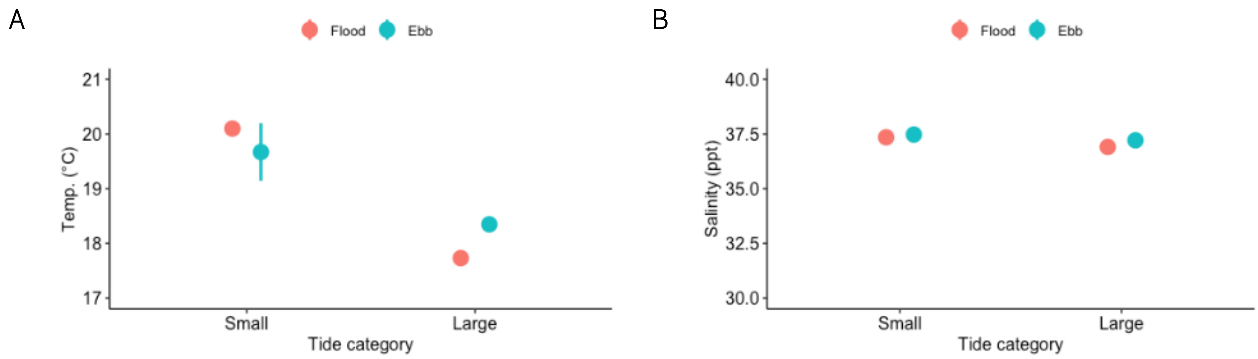


Figure 4 Temperature and conductivity across flood and ebb tidal cycles following small or large tidal heights

[1] Data are pooled to each location (CA, CB, CC) across sites and sampling days. The table includes the number of measurements at each location, maximum depth, and the average (±SD) of temperature, dissolved oxygen (DO), pH, salinity, nephelometric turbidity unit (NTU), total dissolved solids (TDS).

Table 5 Statistical results for linear models comparing tidal physiochemical characteristics across tidal cycles.[2]

| | Num. df | | Temperature | Salinity |
|---|---|---|---|---|
| T cycle | 1 | den. df | 175 | 174 |
| | | $R^2$ | 0 | 0.07 |
| | | p | 0.51 | **<0.01** |
| Location | 2 | den df | 173 | 172 |
| | | $R^2$ | 0.01 | 0 |
| | | p | 0.29 | 0.68 |
| T height | 1 | den df | 172 | 171 |
| | | $R^2$ | 0.01 | 0.18 |
| | | p | 0.1 | **<0.01** |
| Day | 2 | den df | 170 | 169 |
| | | $R^2$ | 0.04 | 0.2 |
| | | p | **0.02** | **<0.01** |
| T cycle : Location | 2 | den df | 168 | 167 |
| | | $R^2$ | 0.02 | 0 |
| | | p | 0.14 | 0.8 |
| T cycle : T height | 1 | den df | 167 | 166 |
| | | $R^2$ | 0.04 | 0.12 |
| | | p | **<0.01** | **<0.01** |
| T height : Location | 2 | den df | 165 | 164 |
| | | $R^2$ | 0 | 0 |
| | | p | 0.76 | 0.46 |

[2] T cycle: flood/ebb, locations (CA, CB, CC), tidal height (T height: <4 m, >4 m), and individual day/tide (4 sampling tides/days). Parameters tested include temperature (°C) and salinity (ppt). Results include the numerator degrees of freedom, denominator degrees of freedom, R2 (as % deviance explained), and P-value for a linear model with the following predictors: tidal cycle, sampling location (i.e., spatial variation), tidal height (<4 m, >4 m), day (i.e., temporal variation and tide), tidal cycle : location interaction, tidal cycle : tidal height interaction, tidal height : location interaction, and tidal cycle : location : tidal height. Values in bold indicate statistically significant parameters (p≤0.05). Significant T cycle: T height interactions are taken as potential effects of algal mat inundation on physiochemical characteristics.

Table 6 Statistical results for posthoc comparison of temperature across the tidal cycle for different tidal heights.[3]

| Parameter | Tidal height | Comparison | Estimate (°C) | SE | z | P |
|---|---|---|---|---|---|---|
| Temperature | Small | Flood vs. ebb | 0.1 | 0.1 | 0.6 | 0.57 |
| | Large | Flood vs. ebb | 0.3 | 0.1 | 43.5 | **<0.01** |

### 3.1.2. Nutrient Concentration

To test whether nutrient concentrations were affected by the inundation of algal mats, nutrient concentrations were measured on flood and ebb tides at two tidal heights: <4 m where algal mats are not expected to be inundated, and >4 m where algal mats are expected to be inundated. However, there was little evidence that the difference in nutrients between flood and ebb tidal cycles was altered by tidal height, suggesting no measurable effect of algal mat inundation on nutrient concentrations (Figure 5 and Table 7).

Nitrate+nitrite (NOx) and ammonia (NH3) were the only parameters where the change in concentration over tidal cycle differed between small and large tides. NOx significantly varied between flood and ebb tides after small tides but not after large tides. However, the difference after small tides was inconsistent and only occurred on one of the two measured smaller tidal cycles and appears to be not related to inundation of algal mats. Ammonia concentration was significantly higher on flood versus ebb cycles after small tides, but not significantly different between flood and ebb cycles after large tides (Table 7). When considering overall differences between flood and ebb tides regardless of tidal height, only NOx (pattern described above) and total C (lower on ebb) were significantly different between tidal cycles.

Nutrient concentrations on large and small tides differed for all parameters except ammonia and reactive P. NOx (due to pattern described above), total N, and all carbon parameters (organic, inorganic, and total) were significantly lower on large tides. In contrast, Total P was significantly higher on large tides.

There was some evidence of spatial variation in nutrient concentrations among sampling locations, although these effects were small. For reactive P, total IC, and total C. This difference among locations varied between tidal cycles for total IC and between tidal heights for total IC and total C.

[3] (T cycle: T height interaction). The table includes the parameter tested, tidal height, means compared, estimate of the difference, standard error of the differences (SE), z statistic, and P value. P Values in bold indicate statistically significant parameters (p≤0.05).

Table 7 Statistical results for linear models comparing tidal nutrient concentrations across tidal cycles.[4]

| | Num. df | | $NH_3$ | $NO_x$ | Total N | Total P | React. P | Total org. C | Total inorg. C | Total C |
|---|---|---|---|---|---|---|---|---|---|---|
| T cycle | 1 | den. df | 175 | 174 | 175 | 175 | 175 | 175 | 172 | 172 |
| | | $R^2$ | 0 | 0.07 | 0 | 0 | 0 | 0.01 | 0 | 0.02 |
| | | p | 0.51 | **<0.01** | 0.26 | 0.85 | 0.76 | 0.07 | 0.89 | **<0.01** |
| Location | 2 | den df | 173 | 172 | 173 | 173 | 173 | 173 | 170 | 170 |
| | | $R^2$ | 0.01 | 0 | 0.01 | 0 | 0.11 | 0 | 0.05 | 0.17 |
| | | p | 0.29 | 0.68 | 0.25 | 0.45 | **<0.01** | 0.6 | **<0.01** | **<0.01** |
| T height | 1 | den df | 172 | 171 | 172 | 172 | 172 | 172 | 169 | 169 |
| | | $R^2$ | 0.01 | 0.18 | 0.27 | 0.3 | 0 | 0.28 | 0.44 | 0.33 |
| | | p | 0.1 | **<0.01** | **<0.01** | **<0.01** | 0.8 | **<0.01** | **<0.01** | **<0.01** |
| Day | 2 | den df | 170 | 169 | 170 | 170 | 170 | 170 | 167 | 167 |
| | | $R^2$ | 0.04 | 0.2 | 0.03 | 0.23 | 0.31 | 0.07 | 0.33 | 0.12 |
| | | p | **0.02** | **<0.01** | **0.02** | **<0.01** | **<0.01** | **<0.01** | **<0.01** | **<0.01** |
| T cycle : Location | 2 | den df | 168 | 167 | 168 | 168 | 168 | 168 | 165 | 165 |
| | | $R^2$ | 0.02 | 0 | 0.02 | 0 | 0.02 | 0 | 0.01 | 0.02 |
| | | p | 0.14 | 0.8 | 0.1 | 0.81 | 0.09 | 0.7 | **<0.01** | **<0.01** |
| T cycle : T height | 1 | den df | 167 | 166 | 167 | 167 | 167 | 167 | 164 | 164 |
| | | $R^2$ | 0.04 | 0.12 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | p | **<0.01** | **<0.01** | 0.91 | 0.44 | 0.32 | 0.28 | 0.95 | 0.84 |
| T height : Location | 2 | den df | 165 | 164 | 165 | 165 | 165 | 165 | 162 | 162 |
| | | $R^2$ | 0 | 0 | 0.04 | 0.01 | 0 | 0.05 | 0.01 | 0.01 |
| | | p | 0.76 | 0.46 | **<0.01** | 0.2 | 0.62 | **<0.01** | **0.02** | 0.07 |
| T cycle : Location : T height | 2 | den df | 163 | 162 | 163 | 163 | 163 | 163 | 160 | 160 |
| | | $R^2$ | 0.01 | 0 | 0 | 0.03 | 0.01 | 0.01 | 0 | 0.01 |
| | | p | 0.34 | 0.26 | 0.82 | **<0.01** | 0.11 | 0.17 | 0.33 | 0.18 |

[4] (T cycle: flood/ebb), locations (CA, CB, CC), tidal height (T height: <4 m, >4 m), and individual day/tide (4 sampling tides/days). Parameters tested include ammonia (NH3), nitrate+nitrite (NOx), total nitrogen, total phosphorus, reactive phosphorus, total organic carbon, total inorganic carbon, total carbon. Results include the numerator degrees of freedom, denominator degrees of freedom, R2 (as % deviance explained), and P-value for a linear model with the following predictors: tidal cycle, sampling location (i.e., spatial variation), tidal height (<4 m, >4 m), day (i.e., temporal variation and tide), tidal cycle : location interaction, tidal cycle : tidal height interaction, tidal height : location interaction, and tidal cycle : location : tidal height. Values in bold indicate statistically significant parameters (p≤0.05).

Table 8 Statistical results for posthoc comparison of nutrient concentrations across the tidal cycle for different tidal heights.[5]

| Parameter | Tidal height | Comparison | Estimate (µg $L^{-1}$) | SE | z | P |
|---|---|---|---|---|---|---|
| $NO_x$ | Small | Flood vs. ebb | 589.6 | 6.4 | 9.2 | **<0.01** |
| | Large | Flood vs. ebb | 2.7 | 5.0 | 0.1 | 0.96 |
| $NH_3$ | Small | Flood vs. ebb | 2.1 | 0.9 | 2.3 | **0.02** |
| | Large | Flood vs. ebb | 2.2 | 1.2 | -1.8 | 0.07 |

[5] (T cycle: T height interaction). The table includes the parameter tested, tidal height, means compared, estimate of the difference, standard error of the differences (SE), z statistic, and P value. P Values in bold indicate statistically significant parameters (p≤0.05).

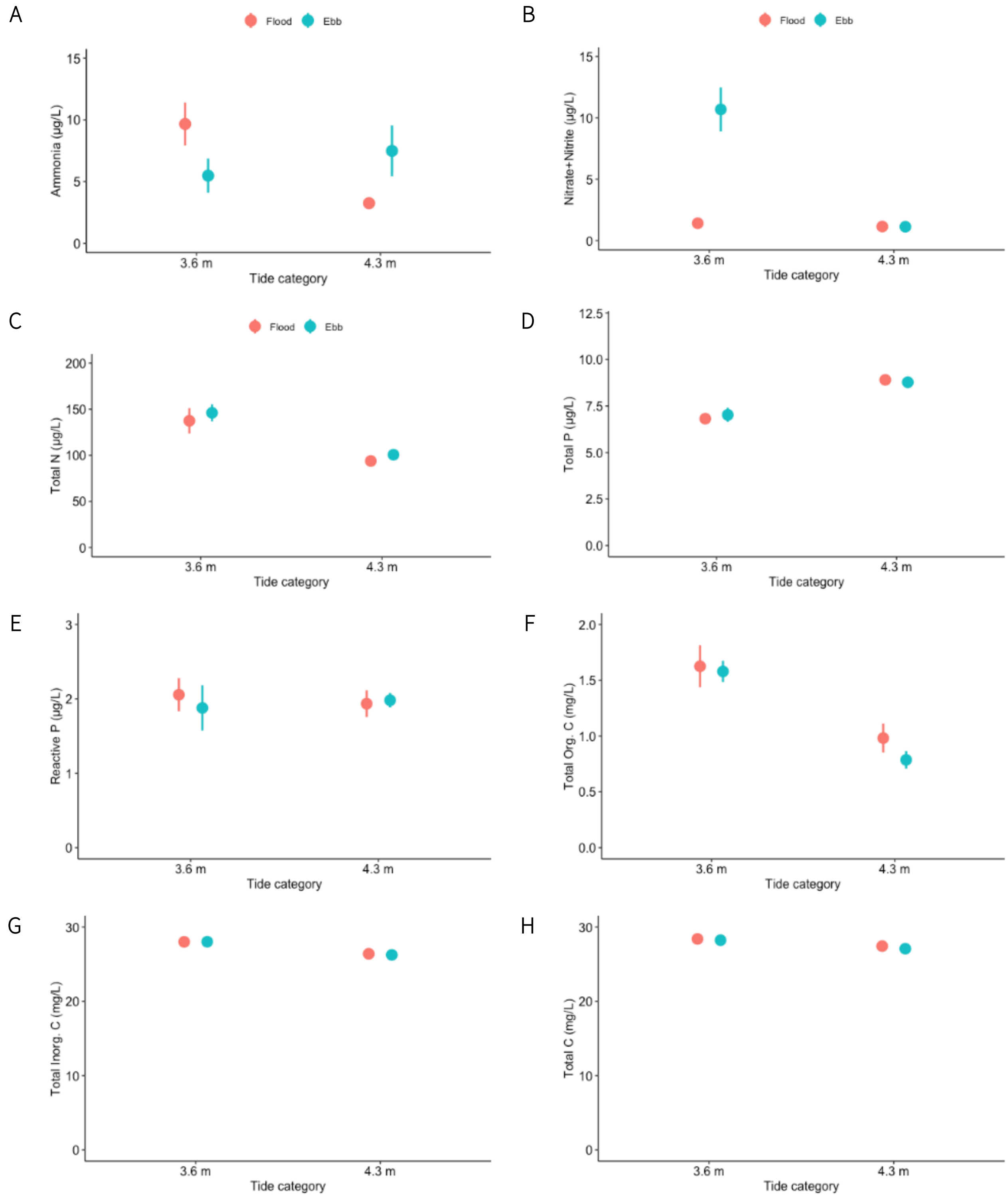


Figure 5 Nutrient concentrations during flood and ebb cycles at two tidal heights (3.6 or 4.3 m).[6]

[6] Points represent the mean concentration among the three sampling locations and error bars represent SE among sampling locations (in many cases, SE is smaller than the size of the point) for A) ammonia B) nitrate+nitrite, C) total nitrogen, D) total phosphorus, E) reactive phosphorus, F) total organic carbon, G) total inorganic carbon, H) and total carbon.

### 3.1.3. Soil nutrients

Raw data are presented in Attachment 5. The following sections provide an analysis of the results.

Soil nutrients significantly differed between mangrove and algal mat areas (Table 9). Soils beneath algal mats had significantly less ammonia, less organic C, and higher conductivity than soils in mangrove areas (Figure 6, Table 9).

Soils were below default guideline values for copper and zinc (Attachment 2).

Table 9 Statistical results for linear models comparing nutrient concentrations, pH, and conductivity between soils collected beneath algal mats and around mangroves.[7]

| | Num. df | | $NH_3$ | $NO_x$ | Total N | Total P | pH | Conduct. | TOC | Total S |
|---|---|---|---|---|---|---|---|---|---|---|
| Soil type | 1 | df | 8 | 3.5 | 3.8 | 3 | 4.5 | 3.4 | 5.2 | 4.3 |
| | | $R^2$ | 0.38 | 0.21 | 0.30 | 0.03 | 0.19 | 0.80 | 0.41 | 0.04 |
| | | P | **0.05** | 0.31 | 0.09 | 0.65 | 0.27 | **0.01** | **0.05** | 0.63 |

[7] The table includes the p value and proportion of variance explained (R2) for each parameter (ammonia (NH3), nitrate and nitrite (NOx), total nitrogen, total phosphorus, pH, conductivity, total organic carbon (TOC), and total sulphur). P Values in bold indicate statistically significant differences between soil types (p≤0.05)

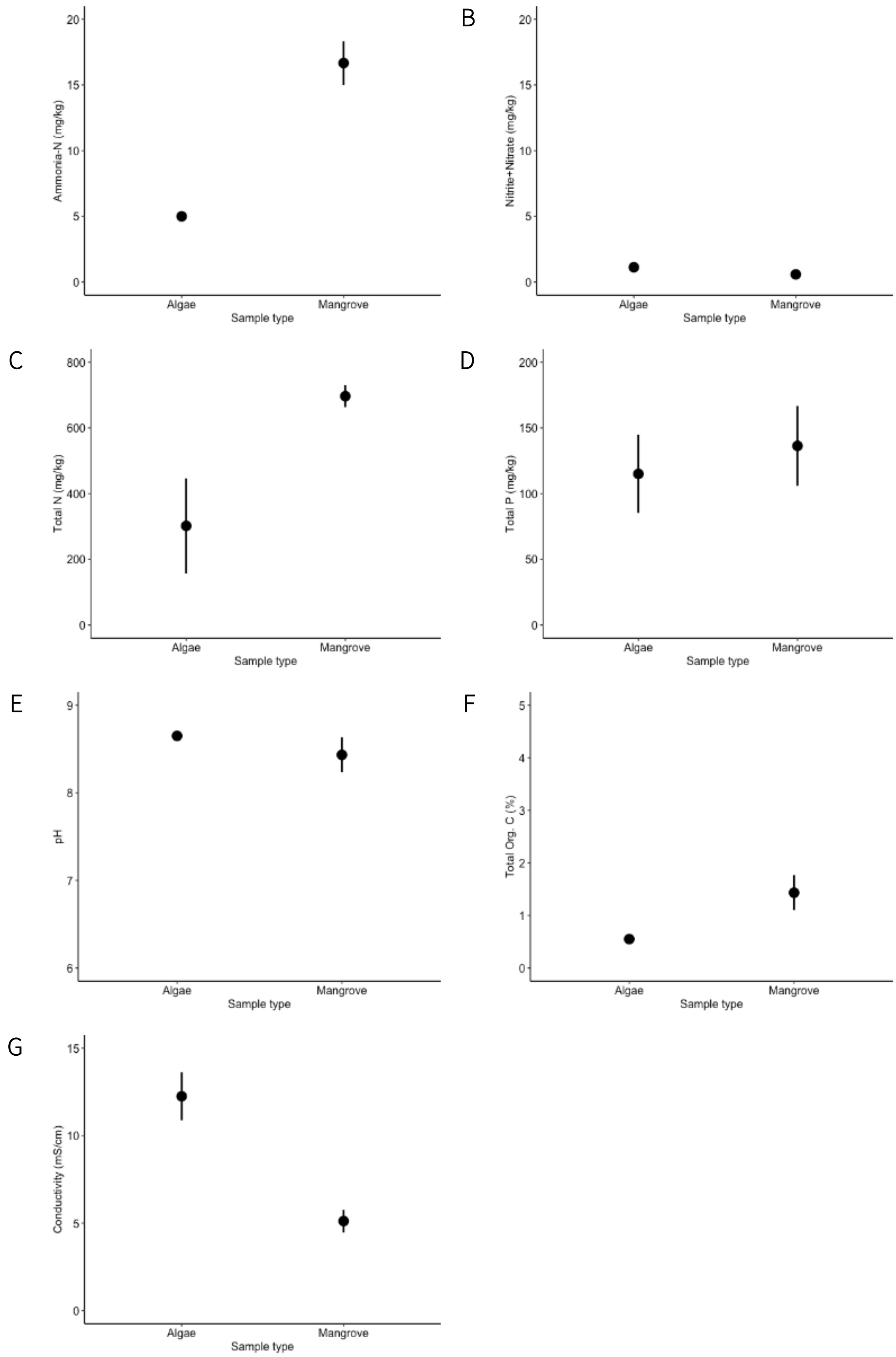


Figure 6 Nutrient, pH, and conductivity in mangrove and algal mat soils. Points represent means and error bars represent standard error.

# 4. Discussion and conclusion

The field study aimed to determine ecological contribution of algal mats in soils and nearshore marine waters following large tides (>4 m), which results in inundation and flushing algal mat area. Inundation of algal mats does not occur during smaller tides (<4 m). Results indicated that the physiochemical and nutrient concentrations in the nearshore areas were not significantly impacted following algal mat inundation, and thus do not contribute to nutrient cycling in nearshore waters and only small differences over tidal cycles.

Soils under algal mats had nutrient concentrations that were less than or similar to soils under mangroves, making it difficult to measure the effect of algal mat inundation. Soils under algal mats had higher conductivity (i.e., salinity) than soils in mangroves, likely due to salt deposition from evaporation, an observation consistent with other regional intertidal investigations. However, there was little evidence that algal mats influenced the salinity of nearshore waters, as the change in salinity over the tidal cycle was not affected by tidal height. The temperature of ebb tides was warmer than flood tides after a large tide but not after small tides, suggesting that flooding areas like algal mats were warming water before it receded on ebb tide.

Few nutrients exhibited differences across tidal cycles depending on whether algal mats were inundated. Ammonia was lower on ebb compared to flood on small tides, but larger on ebb compared to flood on large tides. This would suggest that algal mats are contributing to ammonia through fixation of inorganic nitrogen from the atmosphere after inundation, however algal mat soils only contained one-third the ammonia of mangrove soils, suggesting that algal mat inundation may have less of an effect on ammonia levels than flooding additional mangrove habitat. The change in nitrites and nitrates also differed across tidal heights, however the difference was inconsistent between sampling days and did not appear to be related to algal mat inundation. The other measured nutrients exhibited consistent differences across tidal cycles regardless of tidal height, suggesting no effect of algal mat inundation.

This investigation revealed difficulties in measuring the contribution of algal mats to nearshore nutrient cycles. Soil samples suggested that nutrient concentrations in algal mat soils were generally lower than mangrove soils, making it difficult to measure effects of algal mat inundation. In addition, nutrients in mangrove soils varied among samples taken from the seaward edge, central canopy, and landward edge of the mangrove canopy and increased sampling would be required to distinguish changes along this gradient (Attachment 1). Nutrient concentrations in water samples were at the limit of detection, making inference difficult. Furthermore, nearly every nutrient measured in water samples exhibited tide-to-tide differences (i.e., sampling day), suggesting that measurement of additional tides would be required to account for temporal variation.

# Attachment 1. Soil Nutrients across mangrove canopy

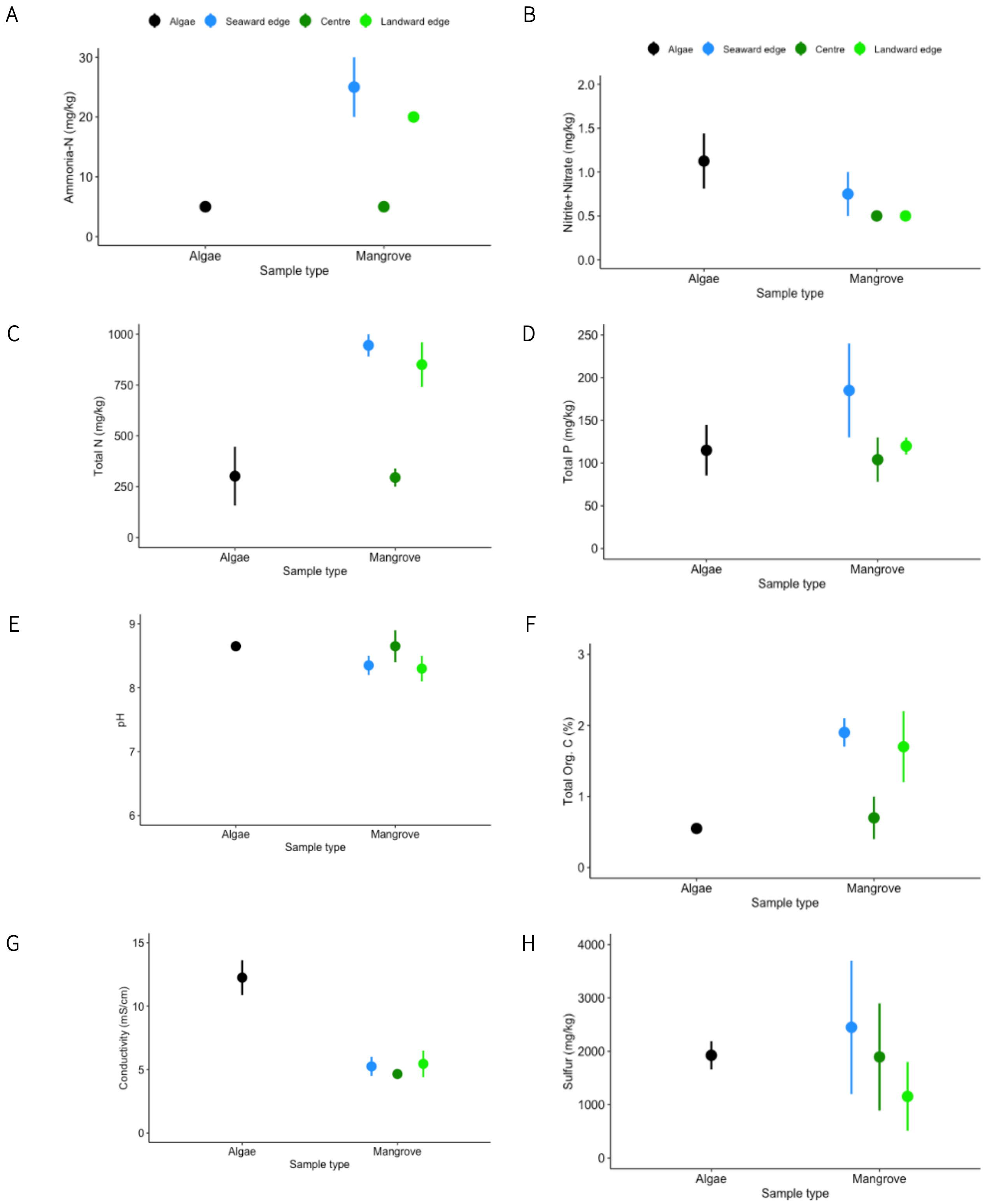


Figure 7 Nutrient, pH, and conductivity in mangrove and algal mat soils. Points represent means and error bars represent standard error. Mangrove samples are coloured according to their position within the mangrove zone as indicated in panels A and B. There appear to be several differences in soil characteristic across the mangrove zone, including higher N and organic C at the edges of the mangroves

# Attachment 2. Soil toxicants

Two toxicants were measured with ANZECC & ARMCANZ default guideline values (DGV). The values for copper and zinc were averaged across all samples and are an order of magnitude below default guideline values.

| Metal | Samples (n) | Sample mean (SD) | DGV (mg/kg) |
|---|---|---|---|
| Copper | 10 | 1.5 (0.4) | 65 |
| Zinc | 10 | 1.2 (0.1) | 200 |

# Attachment 3. Water laboratory results-Sampling Round 1

# CERTIFICATE OF ANALYSIS



| | | | |
|---|---|---|---|
| **Work Order** | : **EP2106524** | Laboratory | : Environmental Division Perth |
| Client | : **WA MARINE PTY LTD** | Contact | : Nick Courts |
| Contact | : JOSH ABBOTT | Address | : 26 Rigali Way Wangara WA Australia 6065 |
| Address | : SUITE 5, 5/18 GRIFFON DRIVE PO BOX 1370 DUNSBOROUGH, PERTH WA, AUSTRALIA 6281 | | |
| Telephone | : ---- | Telephone | : +61-8-9406 1301 |
| Project | : 21WAU-0016 Eramurra Solar Salt | Date Samples Received | : 09-Jun-2021 17:50 |
| Order number | : ---- | Date Analysis Commenced | : 10-Jun-2021 |
| C-O-C number | : ---- | Issue Date | : 17-Jun-2021 17:21 |
| Sampler | : ES + JS | | |
| Site | : ---- | | |
| Quote number | : EP/348/21_V2 | | |
| No. of samples received | : 33 | | |
| No. of samples analysed | : 33 | | |

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

**Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.**

## *Signatories*

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

| *Signatories* | *Position* | *Accreditation Category* |
|---|---|---|
| Canhuang Ke | Inorganics Supervisor | Perth Inorganics, Wangara, WA |
| Chris Lemaitre | Laboratory Manager (Perth) | Perth Inorganics, Wangara, WA |

## *General Comments*

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- It has been noted that the sum of Total Inorganic Carbon (EP006) & Total Organic Carbon (EP005) exceeds that of Total Carbon (EP007) for various samples, however the difference is within the limits of experimental variation.

## *Analytical Results*

Sub-Matrix: **WATER**
(Matrix: **WATER**)

| Compound | CAS Number | LOR | Unit | D1. CA 1 F | D1. CA 1 F | D1. CA 2 F | D1. CA 2 F | D1. CA 3 F |
|---|---|---|---|---|---|---|---|---|
| | | | *Sampling date / time* | 08-Jun-2021 07:55 | 08-Jun-2021 09:02 | 08-Jun-2021 08:02 | 08-Jun-2021 09:05 | 08-Jun-2021 08:08 |
| | | | | EP2106524-001 | EP2106524-002 | EP2106524-003 | EP2106524-004 | EP2106524-005 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | **0.009** | **0.005** | <0.005 | <0.005 | **0.012** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | **0.009** | <0.005 | <0.005 | <0.005 | **0.011** |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | **0.004** | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.148** | **0.158** | **0.314** | **0.158** | **0.202** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.008** | **0.006** | **0.008** | **0.007** | **0.006** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.006** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | **2** | **1** | **1** | **2** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **28** | **28** | **28** | **28** | **28** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **29** | **28** | **29** | **29** | **29** |

## Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

| | | | Sample ID | D1. CA 3 F | D1. CA 1 E | D1. CA 2 E | D1. CA 3 E | D1. CB 1 F |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 08-Jun-2021 09:09 | 08-Jun-2021 12:15 | 08-Jun-2021 12:18 | 08-Jun-2021 12:23 | 08-Jun-2021 08:21 |
| Compound | CAS Number | LOR | Unit | EP2106524-006 | EP2106524-007 | EP2106524-008 | EP2106524-009 | EP2106524-010 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | **0.004** | **0.003** |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.137** | **0.149** | **0.166** | **0.166** | **0.172** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.006** | **0.009** | **0.008** | **0.009** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.003** | **0.003** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **1** | **1** | **1** | **2** | **2** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **28** | **29** | **28** | **29** | **28** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **29** | **30** | **29** | **29** | **28** |

## Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

| | | | Sample ID | D1. CB 1 F | D1. CB 2 F | D1. CB 2 F | D1. CB 3 F | D1. CB 3 F |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 08-Jun-2021 09:19 | 08-Jun-2021 08:29 | 08-Jun-2021 09:26 | 08-Jun-2021 08:34 | 08-Jun-2021 09:29 |
| Compound | CAS Number | LOR | Unit | EP2106524-011 | EP2106524-012 | EP2106524-013 | EP2106524-014 | EP2106524-015 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | **0.013** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | **0.012** |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.163** | **0.143** | **0.133** | **0.150** | **0.138** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.006** | **0.007** | **0.007** | **0.006** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.003** | **0.002** | **0.003** | **0.003** | **0.003** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | **1** | **2** | **1** | **1** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **28** | **28** | **28** | ---- | **28** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **28** | **28** | **28** | ---- | **28** |

## Analytical Results

Sub-Matrix: WATER
(Matrix: WATER)

| Compound | CAS Number | LOR | Unit | D1. CB 1 E | D1. CB 1 E | D1. CB 2 E | D1. CB 2 E | D1. CB 3 E |
|---|---|---|---|---|---|---|---|---|
| Sampling date / time | | | | 08-Jun-2021 11:22 | 08-Jun-2021 12:40 | 08-Jun-2021 11:28 | 08-Jun-2021 12:44 | 08-Jun-2021 11:32 |
| | | | | EP2106524-016 | EP2106524-017 | EP2106524-018 | EP2106524-019 | EP2106524-020 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | **0.006** | **0.012** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | **0.006** | **0.011** |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.223** | **0.139** | **0.182** | **0.119** | **0.162** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.009** | **0.008** | **0.008** | **0.007** | <0.005 |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.003** | **0.002** | **0.002** | **0.002** | **0.003** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | **2** | **1** | **2** | **2** | **2** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **28** | **28** | **28** | **28** | **28** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **28** | **28** | **28** | **28** | **28** |

## Analytical Results

| Sub-Matrix: **WATER** (Matrix: **WATER**) | | | Sample ID | **D1. CB 3 E** | **D1. CC 1 F** | **D1. CC 1 F** | **D1. CC 2 F** | **D1. CC 2 F** |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 08-Jun-2021 12:48 | 08-Jun-2021 08:42 | 08-Jun-2021 09:41 | 08-Jun-2021 08:48 | 08-Jun-2021 09:45 |
| Compound | CAS Number | LOR | Unit | **EP2106524-021** | **EP2106524-022** | **EP2106524-023** | **EP2106524-024** | **EP2106524-025** |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | **0.013** | **0.014** | **0.006** | **0.006** | **0.012** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | **0.012** | **0.013** | **0.006** | **0.006** | **0.011** |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.141** | **0.118** | **0.115** | **0.098** | **0.086** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.008** | **0.007** | **0.007** | **0.006** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.003** | **0.003** | **0.003** | **0.003** | **0.004** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **2** | **1** | **4** | **1** | **2** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **27** | **28** | **27** | **27** | **28** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **28** | **28** | **28** | **28** | **28** |

[redacted]

## Analytical Results

| Sub-Matrix: **WATER** (Matrix: **WATER**) | | | Sample ID | **D1. CC 3 F** | **D1. CC 3 F** | **D1. CC 1 E** | **D1. CC 1 E** | **D1. CC 2 E** |
|---|---|---|---|---|---|---|---|---|
| | | | *Sampling date / time* | 08-Jun-2021 08:52 | 08-Jun-2021 09:52 | 08-Jun-2021 11:44 | 08-Jun-2021 13:02 | 08-Jun-2021 11:48 |
| *Compound* | *CAS Number* | *LOR* | *Unit* | **EP2106524-026** | **EP2106524-027** | **EP2106524-028** | **EP2106524-029** | **EP2106524-030** |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | **0.006** | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | **0.006** | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | **0.019** | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.098** | **0.148** | **0.135** | **0.138** | **0.168** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.008** | **0.008** | **0.007** | **0.008** | <0.005 |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.003** | **0.003** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **----** | **2** | **2** | **2** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **27** | **28** | **27** | **28** | **28** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **28** | **28** | **28** | **28** | **28** |

## Analytical Results

| Sub-Matrix: **WATER** (Matrix: **WATER**) | | | Sample ID | D1. CC 2 E | D1. CC 3 E | D1. CC 3 E | ---- | ---- |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 08-Jun-2021 13:07 | 08-Jun-2021 11:52 | 08-Jun-2021 13:09 | ---- | ---- |
| Compound | CAS Number | LOR | Unit | EP2106524-031 | EP2106524-032 | EP2106524-033 | -------- | -------- |
| | | | | Result | Result | Result | ---- | ---- |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | ---- | ---- |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | ---- | ---- |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | ---- | ---- |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.152** | **0.164** | ---- | ---- | ---- |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.008** | **0.008** | ---- | ---- | ---- |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.003** | **0.002** | **0.002** | ---- | ---- |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **2** | **2** | **1** | ---- | ---- |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **28** | **28** | **28** | ---- | ---- |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **28** | **28** | **29** | ---- | ---- |

# Attachment 4. Water Laboratory Results-Sampling Round 2

# CERTIFICATE OF ANALYSIS

| | | | |
|---|---|---|---|
| **Work Order** | : **EP2107453** | Page | : 1 of 13 |
| Client | : **WA MARINE PTY LTD** | Laboratory | : Environmental Division Perth |
| Contact | : JOSH ABBOTT | Contact | : Nick Courts |
| Address | : SUITE 5, 5/18 GRIFFON DRIVE PO BOX 1370 DUNSBOROUGH, PERTH WA, AUSTRALIA 6281 | Address | : 26 Rigali Way Wangara WA Australia 6065 |
| Telephone | : ---- | Telephone | : +61-8-9406 1301 |
| Project | : 21WAU-0016 North Coogee Dredge Sampling | Date Samples Received | : 29-Jun-2021 17:50 |
| Order number | : ---- | Date Analysis Commenced | : 30-Jun-2021 |
| C-O-C number | : ---- | Issue Date | : 08-Jul-2021 16:10 |
| Sampler | : ---- | | |
| Site | : ---- | | |
| Quote number | : EP/348/21_V2 | | |
| No. of samples received | : 54 | | |
| No. of samples analysed | : 54 | | |

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

**Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.**

## *Signatories*

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

| *Signatories* | *Position* | *Accreditation Category* |
|---|---|---|
| Chris Lemaitre | Laboratory Manager (Perth) | Perth Inorganics, Wangara, WA |
| Mark Kinnin | Laboratory Technician | Perth Inorganics, Wangara, WA |

## General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.

LOR = Limit of reporting

^ = This result is computed from individual analyte detections at or above the level of reporting

ø = ALS is not NATA accredited for these tests.

~ = Indicates an estimated value.

## Analytical Results

| Sub-Matrix: **MARINE WATER** (Matrix: **WATER**) | | | Sample ID | D1. CA 1 F 1037 | D1. CA 1 F 1105 | D1. CA 1 F 1007 | D1. CA 2 F 1039 | D1. CA 2 F 1009 |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 10:37 | 27-Jun-2021 11:05 | 27-Jun-2021 10:07 | 27-Jun-2021 10:39 | 27-Jun-2021 10:09 |
| Compound | CAS Number | LOR | Unit | EP2107453-001 | EP2107453-002 | EP2107453-003 | EP2107453-004 | EP2107453-005 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | **0.005** | <0.005 | <0.005 | **0.009** | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | **0.008** | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | **0.004** | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.071** | **0.082** | **0.118** | **0.118** | <0.050 |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.008** | **0.009** | **0.006** | **0.007** | **0.008** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.001** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **2** | **2** | **1** | **1** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **26** | **26** | **26** | **26** | **26** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **28** | **28** | **28** | **28** | **28** |

## Analytical Results

| Sub-Matrix: MARINE WATER (Matrix: WATER) | | | Sample ID | D1. CA 2 F 1107 | D1. CA 3 F 1041 | D1. CA 3 F 1109 | D1. CA 3 F 1011 | D1. CA 1 E 1345 |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 11:07 | 27-Jun-2021 10:41 | 27-Jun-2021 11:09 | 27-Jun-2021 10:11 | 27-Jun-2021 13:45 |
| Compound | CAS Number | LOR | Unit | EP2107453-006 | EP2107453-007 | EP2107453-008 | EP2107453-009 | EP2107453-010 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | **0.007** | <0.005 | <0.005 | **0.009** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | **0.007** | <0.005 | <0.005 | **0.008** |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.124** | **0.078** | **0.066** | **0.075** | **0.075** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.006** | **0.008** | **0.007** | **0.008** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **2** | **2** | **2** | **1** | **2** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **26** | **26** | **26** | **26** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **27** | **27** | **27** | **27** | **27** |

## Analytical Results

| Sub-Matrix: **MARINE WATER** (Matrix: **WATER**) | | | Sample ID | D1. CA 1 E 1320 | D1. CA 1 E 1408 | D1. CA 2 E 1410 | D1. CA 2 E 1322 | D1. CA 2 E 1347 |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 13:20 | 27-Jun-2021 14:08 | 27-Jun-2021 14:10 | 27-Jun-2021 13:22 | 27-Jun-2021 13:47 |
| Compound | CAS Number | LOR | Unit | EP2107453-011 | EP2107453-012 | EP2107453-013 | EP2107453-014 | EP2107453-015 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | **0.022** | <0.005 | <0.005 | <0.005 | **0.016** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | **0.021** | <0.005 | <0.005 | <0.005 | **0.015** |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.080** | **0.056** | **0.145** | **0.120** | **0.113** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.007** | **0.008** | **0.006** | **0.006** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.003** | **0.002** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | **2** | **1** | **1** | **1** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **26** | **26** | **26** | **26** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **27** | **27** | **27** | **27** | **27** |

## Analytical Results

Sub-Matrix: MARINE WATER
(Matrix: WATER)

| Compound | CAS Number | LOR | Unit | D1. CA 3 E 1324 | D1. CA 3 E 1349 | D1. CA 3 E 1412 | D1. CB 1 F 956 | D1. CB 1 F 1026 |
|---|---|---|---|---|---|---|---|---|
| Sampling date / time | | | | 27-Jun-2021 13:24 | 27-Jun-2021 13:49 | 27-Jun-2021 14:12 | 27-Jun-2021 09:56 | 27-Jun-2021 10:26 |
| | | | | EP2107453-016 | EP2107453-017 | EP2107453-018 | EP2107453-019 | EP2107453-020 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | **0.003** | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.073** | **0.071** | **0.074** | **0.145** | **0.099** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.008** | **0.008** | **0.008** | **0.006** | **0.009** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.001** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | **2** | **1** | <1 | **1** | **2** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **26** | **25** | **26** | **26** | **26** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **27** | **27** | **27** | **27** | **27** |

## Analytical Results

| Sub-Matrix: **MARINE WATER** (Matrix: **WATER**) | | | Sample ID | **D1. CB 1 F 1055** | **D1. CB 2 F 958** | **D1. CB 2 F 1028** | **D1. CB 2 F 1057** | **D1. CB 3 F 1000** |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 10:55 | 27-Jun-2021 09:58 | 27-Jun-2021 10:28 | 27-Jun-2021 10:57 | 27-Jun-2021 10:00 |
| Compound | CAS Number | LOR | Unit | **EP2107453-021** | **EP2107453-022** | **EP2107453-023** | **EP2107453-024** | **EP2107453-025** |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | **0.007** | <0.005 | <0.005 | **0.005** |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | **0.007** | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | <0.050 | **0.066** | **0.066** | **0.142** | **0.068** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.008** | **0.009** | **0.008** | **0.006** | **0.008** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **1** | **1** | **1** | **2** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **25** | **26** | **26** | **25** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **27** | **27** | **27** | **27** | **27** |

[redacted]

## Analytical Results

| Sub-Matrix: **MARINE WATER** (Matrix: **WATER**) | | | *Sample ID* | **D1. CB 3 F 1030** | **D1. CB 3 F 1059** | **D1. CB 1 E 1416** | **D1. CB 1 E 1354** | **D1. CB 1 E 1330** |
|---|---|---|---|---|---|---|---|---|
| | | | *Sampling date / time* | 27-Jun-2021 10:30 | 27-Jun-2021 10:59 | 27-Jun-2021 14:16 | 27-Jun-2021 13:54 | 27-Jun-2021 13:30 |
| *Compound* | *CAS Number* | *LOR* | *Unit* | **EP2107453-026** | **EP2107453-027** | **EP2107453-028** | **EP2107453-029** | **EP2107453-030** |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | **0.002** |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.124** | **0.115** | **0.131** | **0.062** | **0.104** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.007** | **0.006** | **0.009** | **0.008** | **0.008** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **1** | **1** | **1** | **2** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **25** | **26** | **26** | **26** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **26** | **27** | **27** | **27** | **27** |

## Analytical Results

| Sub-Matrix: MARINE WATER (Matrix: WATER) | | | Sample ID | D1. CB 2 E 1418 | D1. CB 2 E 1356 | D1. CB 2 E 1332 | D1. CB 3 E 1420 | D1. CB 3 E 1358 |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 14:18 | 27-Jun-2021 13:56 | 27-Jun-2021 13:32 | 27-Jun-2021 14:20 | 27-Jun-2021 13:58 |
| Compound | CAS Number | LOR | Unit | EP2107453-031 | EP2107453-032 | EP2107453-033 | EP2107453-034 | EP2107453-035 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | **0.002** | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.078** | **0.094** | **0.143** | **0.131** | **0.142** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.007** | **0.006** | **0.007** | **0.007** | **0.008** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | **1** | <1 | <1 | **1** | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **26** | **25** | **25** | **25** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **27** | **27** | **27** | **27** | **26** |

## Analytical Results

Sub-Matrix: MARINE WATER
(Matrix: WATER)

| Compound | CAS Number | LOR | Unit | D1. CB 3 E 1334 | D1. CC 1 F 945 | D1. CC 1 F 1015 | D1. CC 1 F 1045 | D1. CC 2 F 1017 |
|---|---|---|---|---|---|---|---|---|
| Sampling date / time | | | | 27-Jun-2021 13:34 | 27-Jun-2021 09:45 | 27-Jun-2021 10:15 | 27-Jun-2021 10:45 | 27-Jun-2021 10:17 |
| | | | | EP2107453-036 | EP2107453-037 | EP2107453-038 | EP2107453-039 | EP2107453-040 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | <0.005 | **0.005** | <0.005 | **0.010** | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | **0.010** | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | <0.002 | **0.003** | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.163** | **0.072** | **0.114** | **0.101** | **0.102** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.008** | **0.009** | **0.007** | **0.007** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.003** | **0.003** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | <1 | <1 | **2** | <1 | **1** |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **17** | **26** | **25** | **25** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **19** | **27** | **27** | **27** | **27** |

## Analytical Results

| Sub-Matrix: MARINE WATER (Matrix: WATER) | | | Sample ID | D1. CC 2 F 947 | D1. CC 2 F 1047 | D1. CC 3 F 949 | D1. CC 3 F 1019 | D1. CC 3 F 1049 |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 09:47 | 27-Jun-2021 13:38 | 27-Jun-2021 00:00 | 27-Jun-2021 00:00 | 27-Jun-2021 00:00 |
| Compound | CAS Number | LOR | Unit | EP2107453-041 | EP2107453-042 | EP2107453-043 | EP2107453-044 | EP2107453-045 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | **0.002** | <0.002 | <0.002 | <0.002 | <0.002 |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.066** | <0.050 | <0.050 | **0.060** | **0.051** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.008** | **0.009** | **0.009** | **0.009** | **0.009** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.003** | **0.003** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | <1 | **2** | <1 | <1 | <1 |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **25** | **25** | **25** | **25** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **27** | **26** | **26** | **26** | **26** |

## Analytical Results

Sub-Matrix: **MARINE WATER**
(Matrix: **WATER**)

| Compound | CAS Number | LOR | Unit | D1. CC 1 E 1338 | D1. CC 1 E 1400 | D1. CC 1 E 1424 | D1. CC 2 E 1340 | D1. CC 2 E 1402 |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling date / time | 27-Jun-2021 00:00 | 27-Jun-2021 14:00 | 27-Jun-2021 14:24 | 27-Jun-2021 13:40 | 27-Jun-2021 14:02 |
| | | | | EP2107453-046 | EP2107453-047 | EP2107453-048 | EP2107453-049 | EP2107453-050 |
| | | | | Result | Result | Result | Result | Result |
| **EK255A: Ammonia** | | | | | | | | |
| Ammonia as N | 7664-41-7 | 0.005 | mg/L | **0.006** | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| Ammonium as N | 14798-03-9_N | 0.005 | mg/L | **0.006** | <0.005 | <0.005 | <0.005 | <0.005 |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| Nitrite + Nitrate as N | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | **0.003** |
| **EK262A: Total Nitrogen** | | | | | | | | |
| Total Nitrogen as N | ---- | 0.050 | mg/L | **0.097** | **0.172** | **0.079** | **0.070** | **0.135** |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| Total Phosphorus as P | ---- | 0.005 | mg/L | **0.010** | **0.011** | **0.009** | **0.009** | **0.007** |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| Reactive Phosphorus as P | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| Total Organic Carbon | ---- | 1 | mg/L | <1 | <1 | <1 | **1** | <1 |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| Total Inorganic Carbon | ---- | 1 | mg/L | **25** | **25** | **26** | **26** | **25** |
| **EP007 Total Carbon** | | | | | | | | |
| Total Carbon | TC | 1 | mg/L | **27** | **27** | **27** | **27** | **27** |

## Analytical Results

| Sub-Matrix: **MARINE WATER** (Matrix: **WATER**) | | | *Sample ID* | **D1. CC 2 E 1426** | **D1. CC 3 E 1342** | **D1. CC 3 E 1428** | **D1. CC 3 E 1404** | **----** |
|---|---|---|---|---|---|---|---|---|
| | | | *Sampling date / time* | 27-Jun-2021 14:26 | 27-Jun-2021 13:42 | 27-Jun-2021 14:28 | 27-Jun-2021 14:04 | ---- |
| *Compound* | *CAS Number* | *LOR* | *Unit* | **EP2107453-051** | **EP2107453-052** | **EP2107453-053** | **EP2107453-054** | **--------** |
| | | | | Result | Result | Result | Result | ---- |
| **EK255A: Ammonia** | | | | | | | | |
| **Ammonia as N** | 7664-41-7 | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | ---- |
| **EK255A-NH4: Ammonium** | | | | | | | | |
| **Ammonium as N** | 14798-03-9_N | 0.005 | mg/L | <0.005 | <0.005 | <0.005 | <0.005 | ---- |
| **EK259A: Nitrite and Nitrate (NOx)** | | | | | | | | |
| **Nitrite + Nitrate as N** | ---- | 0.002 | mg/L | <0.002 | <0.002 | <0.002 | <0.002 | ---- |
| **EK262A: Total Nitrogen** | | | | | | | | |
| **Total Nitrogen as N** | ---- | 0.050 | mg/L | **0.065** | **0.057** | **0.111** | **0.062** | ---- |
| **EK267A: Total Phosphorus (Persulfate Digestion)** | | | | | | | | |
| **Total Phosphorus as P** | ---- | 0.005 | mg/L | **0.008** | **0.010** | **0.007** | **0.008** | ---- |
| **EK271A: Reactive Phosphorus** | | | | | | | | |
| **Reactive Phosphorus as P** | 14265-44-2 | 0.001 | mg/L | **0.002** | **0.002** | **0.002** | **0.002** | ---- |
| **EP005: Total Organic Carbon (TOC)** | | | | | | | | |
| **Total Organic Carbon** | ---- | 1 | mg/L | **1** | **1** | **1** | <1 | ---- |
| **EP006 Total Inorganic Carbon** | | | | | | | | |
| **Total Inorganic Carbon** | ---- | 1 | mg/L | **24** | **26** | **26** | **26** | ---- |
| **EP007 Total Carbon** | | | | | | | | |
| **Total Carbon** | TC | 1 | mg/L | **26** | **27** | **27** | **27** | ---- |

# Attachment 5. Soil Laboratory Results

ARL Group
Proudly Western Australian

ARL ProMicro EcoDiagnostics

# LABORATORY REPORT

| | |
|---|---|
| **Job Number:** | 20-08951 |
| **Revision:** | 00 |
| **Date:** | 5 June 2020 |

**ADDRESS:** **O2 Marine**
Suite 2, 4B Mews Rd
Fremantle WA 6160

**ATTENTION:** Russell Stevens

**DATE RECEIVED:** 21/05/2020

**YOUR REFERENCE:** 20WAU-0027 - Eramurra Soil Sampling

**PURCHASE ORDER:**

**APPROVALS:**

Sean Sangster, Inorganics Supervisor
Kim Rodgers, General Manager
Sam Becker, Inorganics Manager

**REPORT COMMENTS:**

This report is issued by Analytical Reference Laboratory (WA) Pty Ltd. The report shall not be reproduced except in full without written approval from the laboratory.

Samples are analysed on an as received basis unless otherwise noted.

Metals, Nutrients and TOCs in soil analysis was conducted on a dry weight basis.

Various testing subcontracted to CSBP, Report Number VMS20125-131 and VMS20133-135

## METHOD REFERENCES:

Methods prefixed with "ARL" are covered under NATA Accreditation Number: 2377
Methods prefixed with "PM" are covered under NATA Accreditation Number: 2561
Methods prefixed with "EDP" are covered under NATA Accreditation Number: 19290

| Method ID | Method Description |
|---|---|
| ARL No. 304 | Ammonia in Soil and Sediment by Discrete Analyser |
| ARL No. 314 | NOx in Soil and Sediment by Discrete Analyser |
| ARL No. 312 | Nitrite in Soil and Sediment by Discrete Analyser |
| ARL No. 118 | Total Phosphorus and TKN in Soil and Biosolids |
| ARL No. 138 | pH in Soil and Biosolid |
| Subcontracting | See Report Comments section for more information. |
| ARL No. 140 | Conductivity in Soil and Biosolid |
| ARL No. 064 | Total Organic Carbon in Sediment |
| ARL No. 213 | Exchangeable Bases |
| ARL No. 212 | Exchangeable Acidity |
| ARL No. 401/403 | Metals in Soil and Sediment by ICPOES/MS |

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Accredited for compliance with ISO/IEC 17025 - Testing

*O2 Marine*
*Job No: 20-08951*

*LABORATORY REPORT*
*Revision: 00*

*Date: 5/06/20*

| Nutrients in Soil | | Sample No | 20-08951-1 | 20-08951-2 | 20-08951-3 | 20-08951-4 | 20-08951-5 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-1 | ES-2 | ES-3 | ES-4 | ES-5 |
| | | Sample Date | 10/05/2020 10:00 | 10/05/2020 11:00 | 10/05/2020 12:00 | 11/05/2020 09:00 | 11/05/2020 09:30 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Ammonia-N | 10 | mg/kg | <10 | <10 | <10 | 30 | 20 |
| Nitrate-N | 1 | mg/kg | 2 | 1 | 1 | 1 | <1 |
| NOx-N | 1 | mg/kg | 2 | 1 | 1 | 1 | <1 |
| Nitrite-N | 1 | mg/kg | <1 | <1 | <1 | <1 | <1 |
| Total Kjeldahl Nitrogen | 10 | mg/kg | 720 | 270 | 120 | 1,000 | 740 |
| Total Nitrogen | 10 | mg/kg | 720 | 270 | 120 | 1,000 | 740 |
| Total Phosphorus | 1 | mg/kg | 200 | 110 | 67 | 240 | 130 |

| Nutrients in Soil | | Sample No | 20-08951-6 | 20-08951-7 | 20-08951-8 | 20-08951-9 | 20-08951-10 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-6 | ES-7 | ES-8 | ES-9 | ES-10 |
| | | Sample Date | 11/05/2020 10:00 | 13/05/2020 09:00 | 13/05/2020 09:30 | 13/05/2020 10:00 | 15/05/2020 09:00 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Ammonia-N | 10 | mg/kg | <10 | 20 | 20 | <10 | <10 |
| Nitrate-N | 1 | mg/kg | <1 | <1 | <1 | <1 | <1 |
| NOx-N | 1 | mg/kg | <1 | <1 | <1 | <1 | <1 |
| Nitrite-N | 1 | mg/kg | <1 | <1 | <1 | <1 | <1 |
| Total Kjeldahl Nitrogen | 10 | mg/kg | 250 | 890 | 960 | 340 | 97 |
| Total Nitrogen | 10 | mg/kg | 250 | 890 | 960 | 340 | 97 |
| Total Phosphorus | 1 | mg/kg | 130 | 130 | 110 | 78 | 83 |

| Misc. Inorganics in Soil | | Sample No | 20-08951-1 | 20-08951-2 | 20-08951-3 | 20-08951-4 | 20-08951-5 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-1 | ES-2 | ES-3 | ES-4 | ES-5 |
| | | Sample Date | 10/05/2020 10:00 | 10/05/2020 11:00 | 10/05/2020 12:00 | 11/05/2020 09:00 | 11/05/2020 09:30 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| pH | 0.1 | pH units | 8.7 | 8.7 | 8.7 | 8.5 | 8.5 |
| pH ($CaCl_2$) 1:5 | 0.1 | pH units | 8.5 | 8.5 | 8.5 | 8.2 | 8.1 |
| Conductivity | 0.01 | mS/cm | 11 | 9.0 | 14 | 4.5 | 4.4 |
| TOC | 0.1 | % | 0.7 | 0.5 | 0.4 | 1.7 | 1.2 |

| Misc. Inorganics in Soil | | Sample No | 20-08951-6 | 20-08951-7 | 20-08951-8 | 20-08951-9 | 20-08951-10 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-6 | ES-7 | ES-8 | ES-9 | ES-10 |
| | | Sample Date | 11/05/2020 10:00 | 13/05/2020 09:00 | 13/05/2020 09:30 | 13/05/2020 10:00 | 15/05/2020 09:00 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| pH | 0.1 | pH units | 8.9 | 8.2 | 8.1 | 8.4 | 8.5 |
| pH ($CaCl_2$) 1:5 | 0.1 | pH units | 8.6 | 8.0 | 7.9 | 8.1 | 8.3 |
| Conductivity | 0.01 | mS/cm | 4.5 | 6.0 | 6.5 | 4.8 | 15 |
| TOC | 0.1 | % | 0.4 | 2.1 | 2.2 | 1.0 | 0.6 |

| Cation Exchange Capacity | | Sample No | 20-08951-1 | 20-08951-2 | 20-08951-3 | 20-08951-4 | 20-08951-5 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-1 | ES-2 | ES-3 | ES-4 | ES-5 |
| | | Sample Date | 10/05/2020 10:00 | 10/05/2020 11:00 | 10/05/2020 12:00 | 11/05/2020 09:00 | 11/05/2020 09:30 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Exchangeable Calcium | 0.2 | $cmol_c/kg$ | 31 | 20 | 17 | 25 | 4.5 |
| Exchangeable Acidity | 0.1 | $cmol_c/kg$ | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Exchangeable Potassium | 0.05 | $cmol_c/kg$ | 2.6 | 2.2 | 2.2 | 2.0 | 0.57 |
| Exchangeable Magnesium | 0.2 | $cmol_c/kg$ | 14 | 12 | 16 | 8.2 | 4.7 |
| Exchangeable Sodium | 0.2 | $cmol_c/kg$ | 60 | 49 | 62 | 24 | 18 |

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| Cation Exchange Capacity | | Sample No | 20-08951-1 | 20-08951-2 | 20-08951-3 | 20-08951-4 | 20-08951-5 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-1 | ES-2 | ES-3 | ES-4 | ES-5 |
| | | Sample Date | 10/05/2020 10:00 | 10/05/2020 11:00 | 10/05/2020 12:00 | 11/05/2020 09:00 | 11/05/2020 09:30 |
| Cation Exchange Capacity | 1 | cmol$_c$/kg | 108 | 83.2 | 97.2 | 59.2 | 27.8 |

| Cation Exchange Capacity | | Sample No | 20-08951-6 | 20-08951-7 | 20-08951-8 | 20-08951-9 | 20-08951-10 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-6 | ES-7 | ES-8 | ES-9 | ES-10 |
| | | Sample Date | 11/05/2020 10:00 | 13/05/2020 09:00 | 13/05/2020 09:30 | 13/05/2020 10:00 | 15/05/2020 09:00 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Exchangeable Calcium | 0.2 | cmol$_c$/kg | 24 | 24 | 7.1 | 26 | 25 |
| Exchangeable Acidity | 0.1 | cmol$_c$/kg | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Exchangeable Potassium | 0.05 | cmol$_c$/kg | 2.2 | 2.9 | 0.94 | 0.67 | 2.8 |
| Exchangeable Magnesium | 0.2 | cmol$_c$/kg | 11 | 10 | 8.3 | 6.5 | 17 |
| Exchangeable Sodium | 0.2 | cmol$_c$/kg | 23 | 31 | 28 | 21 | 76 |
| Cation Exchange Capacity | 1 | cmol$_c$/kg | 60.2 | 67.9 | 44.3 | 54.2 | 121 |

| Metals in Soil and Sediment | | Sample No | 20-08951-1 | 20-08951-2 | 20-08951-3 | 20-08951-4 | 20-08951-5 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-1 | ES-2 | ES-3 | ES-4 | ES-5 |
| | | Sample Date | 10/05/2020 10:00 | 10/05/2020 11:00 | 10/05/2020 12:00 | 11/05/2020 09:00 | 11/05/2020 09:30 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Sulfur | 10 | mg/kg | 2,700 | 1,700 | 1,800 | 1,200 | 510 |

| Metals in Soil and Sediment | | Sample No | 20-08951-6 | 20-08951-7 | 20-08951-8 | 20-08951-9 | 20-08951-10 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-6 | ES-7 | ES-8 | ES-9 | ES-10 |
| | | Sample Date | 11/05/2020 10:00 | 13/05/2020 09:00 | 13/05/2020 09:30 | 13/05/2020 10:00 | 15/05/2020 09:00 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Sulfur | 10 | mg/kg | 890 | 3,700 | 1,800 | 2,900 | 1,500 |

| Subcontracting | | Sample No | 20-08951-1 | 20-08951-2 | 20-08951-3 | 20-08951-4 | 20-08951-5 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-1 | ES-2 | ES-3 | ES-4 | ES-5 |
| | | Sample Date | 10/05/2020 10:00 | 10/05/2020 11:00 | 10/05/2020 12:00 | 11/05/2020 09:00 | 11/05/2020 09:30 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Phosphorus Colwell | 1 | mg/kg | 10 | 9 | 6 | 16 | 14 |
| Potassium Colwell | 1 | mg/kg | 690 | 690 | 580 | 530 | 520 |
| DTPA Copper | 0.1 | mg/kg | 0.6 | 0.5 | 0.3 | 0.6 | 0.6 |
| DTPA Iron | 0.1 | mg/kg | 14 | 23 | 15 | 89 | 69 |
| DTPA Manganese | 0.1 | mg/kg | 2.7 | 4.2 | 3.6 | 4.7 | 1.6 |
| DTPA Zinc | 0.1 | mg/kg | 0.4 | 0.3 | 0.2 | 0.5 | 0.4 |

| Subcontracting | | Sample No | 20-08951-6 | 20-08951-7 | 20-08951-8 | 20-08951-9 | 20-08951-10 |
|---|---|---|---|---|---|---|---|
| | | Sample Description | ES-6 | ES-7 | ES-8 | ES-9 | ES-10 |
| | | Sample Date | 11/05/2020 10:00 | 13/05/2020 09:00 | 13/05/2020 09:30 | 13/05/2020 10:00 | 15/05/2020 09:00 |
| ANALYTE | LOR | Units | Result | Result | Result | Result | Result |
| Phosphorus Colwell | 1 | mg/kg | 13 | 13 | 8 | 6 | 14 |
| Potassium Colwell | 1 | mg/kg | 660 | 750 | 630 | 340 | 710 |
| DTPA Copper | 0.1 | mg/kg | 0.7 | 1.7 | 0.8 | 0.3 | 0.4 |
| DTPA Iron | 0.1 | mg/kg | 39 | 110 | 87 | 37 | 20 |
| DTPA Manganese | 0.1 | mg/kg | 2.0 | 14 | 4.3 | 3.1 | 2.4 |
| DTPA Zinc | 0.1 | mg/kg | 0.2 | 0.6 | 0.5 | 0.2 | 0.4 |

**Result Definitions**

LOR Limit of Reporting [NT] Not Tested [ND] Not Detected at indicated Limit of Reporting

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* Denotes test not covered by NATA Accreditation

FOR MICROBIOLOGICAL TESTING - The data in this report may not be representative of a lot, batch or other samples and may not necessarily justify the acceptance or rejection of a lot or batch, a product recall or support legal proceedings. Tests are not routinely performed as duplicates unless specifically requested. Changes occur in the bacterial content of biological samples. Samples should be examined as soon as possible after collection, preferably within 6 hrs and must be stored at 4 degrees Celsius or below. Samples tested after 24 hrs cannot be regarded as satisfactory because of temperature abuse and variations.

| | | | |
|---|---|---|---|
| Date | 07/03/2025 | Reference | T250090 |
| To | Regina Flugge | Email | regina.flugge@leic.com.au |
| From | Josh Abbott | Email | josh.abbott@o2marine.com.au |
| Subject | Revised Assessment of the Nutrient Flux Study - Eramurra Solar Salt Project | | |

# 1. Introduction

This technical memorandum has been developed to provide additional information/analysis of water quality data collected in 2021 for the Eramurra Solar Salt Project. The additional analysis is at the request of the Environmental Protection Authority (EPA) who reviewed the original technical report above (T210135).

The purpose of the original nutrient flux study was to collect quantitative data to determine the ecological significance and regional importance of key intertidal communities with respect to nutrient export into the intertidal and nearshore subtidal system at the Eramurra project site. The specific study objective was to determine whether the inundation of algal mats on a spring tide alters nutrient concentrations within the creeks and near coastal environments relative to a neap tide where algal mats are not inundated.

O2 Marine (O2M) conducted the study over two separate surveys to capture both neap and spring tide cycles (8/9 June 2021, and 27/28 June 2021 respectively), with the results presented in the original report (T210135). The EPA provided feedback and requested additional analysis of the results, specifically for data collected from one site (CA) (refer Figure 2 in report T210135). The comments and requested action from the EPA are provided below in Table 1.

Table 1: EPA comments and requested action related to O2 Marine report T210135.

| Comment | Action |
|---|---|
| It is noted ESD requirement 20a – 20c has been met. However there is insufficient information to support the conclusion that algal mats do not contribute to nutrient cycling. The study involved sampling marine waters to test for nutrient exports from intertidal areas to subtidal areas. Two of the sampling sites (sites CB and CC) are located in a marine channel and around 1.5 and 2 km from the coastal edge. It is likely that these sites are highly influenced by tidal movement through the marine channel and that they are too far from the coast to detect nutrient exports.<br>Whilst some interpretations of nutrient flux can be made from the tidal creek site, the assessment would greatly benefit from additional data and a better | Please provide updated information by segregating the data by site, and use the samples taken at site CA, which is located in a tidal creek, to assess nutrient flows from the intertidal zone to nearshore waters. |

| Comment | Action |
|---|---|
| design. An assessment of nutrient flux would best be done along a gradient across the tidal interface, on both incoming and outgoing spring tides, capturing data on water nutrients in each of the following locations: algal mats mangroves, upper tidal creek, lower tidal creek and nearshore marine areas. | |

# 2. Revised Data Assessment

As per the abovementioned request from the EPA, O2M have segregated the water quality data by site, only presenting the results and statistical analysis for replicate samples at locations CA1, CA2 and CA3, from Site CA. Details of the site location and sample design remain the same as those outlined in Section 2.1.1 and 2.1.2 of report T210135. The revised data analysis methods and results are presented below in Sections 2.1. and 2.2 respectively. All water quality (nutrient) parameters tested in the original analysis have been included in the revised analysis.

## 2.1. Statistical Analysis Methods

For each parameter at Site CA, a linear model was fitted to test the parameter values against the interaction of the predictors tide direction (ebb or flood) and maximum tide height (as a categorical variable, i.e. neap or spring tide cycle). Parameter values that were under the laboratory limit of reporting (LoR) were considered to be half of the detection threshold. The normality of data distribution was checked visually prior to fitting the models. A gaussian linear model was deemed adequate given the data distributions. Fitted models were validated using standard model validation tools (QQ-plot of residuals, residuals vs fitted values, Cook's distance, Leverage, Kolmogorov-Smirnov test, dispersion test, outlier test) and summarised. Three different post-hoc tests were run on model results:

1. a full pairwise Tukey's test,
2. a pairwise comparisons between spring and neap tides for ebb and flood tides, separately; and
3. a pairwise comparisons between ebb and flood tides for spring and neap tides, separately.

In these post-hoc tests, we tested the hypothesis that samples collected on ebb tides during the spring cycle had a higher nutrient concentration than samples collected on the ebb tide during the neap cycle. This was done through a directional (one-tailed) approach, where the two-tailed p-value was divided by two when model estimates were negative (i.e, higher spring tide concentrations compared to neap tide concentrations).

## 2.2. Results

For the ease of interpretation, the results for the three sampling locations within site CA have been separated into the following nutrient subcategories:

- Nitrogen: Ammonia, Nitrate + Nitrite, and Total Nitrogen
- Phosphorus: Total Phosphorus and Reactive Phosphorus
- Carbon: Total Carbon, Total Organic Carbon, and Total Inorganic Carbon.

### 2.2.1. Nitrogen

Four nitrogen components (ammonium, ammonia, nitrate + nitrite, and total nitrogen) were sampled during the ebb and flood tides, for both the neap and spring cycles. Table 2 outlines the results from the linear models for the difference between spring ebb tide (outgoing tide following algal mat inundation), and a neap ebb tide (outgoing tide following no algal mat inundation). These results indicate significant difference ($p<0.05$) was recorded, however in each case, the higher value was recorded during the neap ebb tide cycle (i.e. when the algal mats were not inundated) (Figure 1). Overall, nitrogen results were observed to vary between sites, and showed no obvious trends across tide direction or cycle. Approximately half of the samples recorded values below the laboratory LoR, in these circumstances, values half of the LoR were used in the statistical analysis.

Table 2: Significance tests ($p < 0.05$) for nitrogen concentrations during ebb tides for both neap and spring cycles.

| site | Tide Cycle Comparison | | Ammonium | Ammonia | Nitrate + Nitrite | Total Nitrogen |
|---|---|---|---|---|---|---|
| | | | *ug/L* | *ug/L* | *ug/L* | *ug/L* |
| CA 1 | Ebb neap | Ebb spring | NS | NS | <0.01 | <0.001 |
| CA 2 | Ebb neap | Ebb spring | NS | NS | <0.01 | NS |
| CA 3 | Ebb neap | Ebb spring | NS | NS | <0.001 | <0.001 |

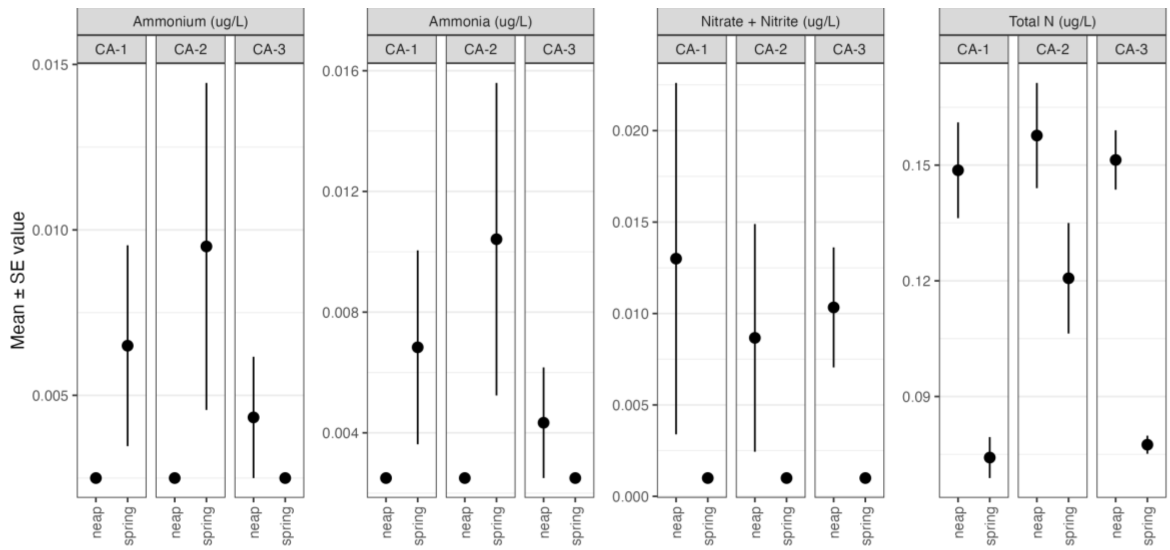


Figure 1: Mean nitrogen concentrations for ebb tides across spring and neap cycles.

### 2.2.2. Phosphorus

Total phosphorus and reactive phosphorus concentrations varied between replicate sites and tide cycles. Total phosphorus concentrations indicate high levels during spring ebb tides when compared to neap ebb tides, however, the linear models concluded that this trend was not significant. Statistical results presented in Table 3 show only one occasion where there was a significant difference ($p<0.05$) between the spring and neap ebb tides, with comparatively higher reactive phosphorus concentrations at CA-1 recorded during the spring ebb tide compared to the neap ebb tide (Figure 2). All remaining comparisons were observed to be non-significant ($p>0.05$).

Table 3: Significance tests ($p<0.05$) for phosphorus concentrations during ebb tides for both neap and spring cycles.

| site | Tide Cycle Comparison | | Total Phosphorus | Reactive Phosphorus |
|---|---|---|---|---|
| | | | ug/L | ug/L |
| CA 1 | Ebb neap | Ebb spring | NS | <0.05 |
| CA 2 | Ebb neap | Ebb spring | NS | NS |
| CA 3 | Ebb neap | Ebb spring | NS | NS |

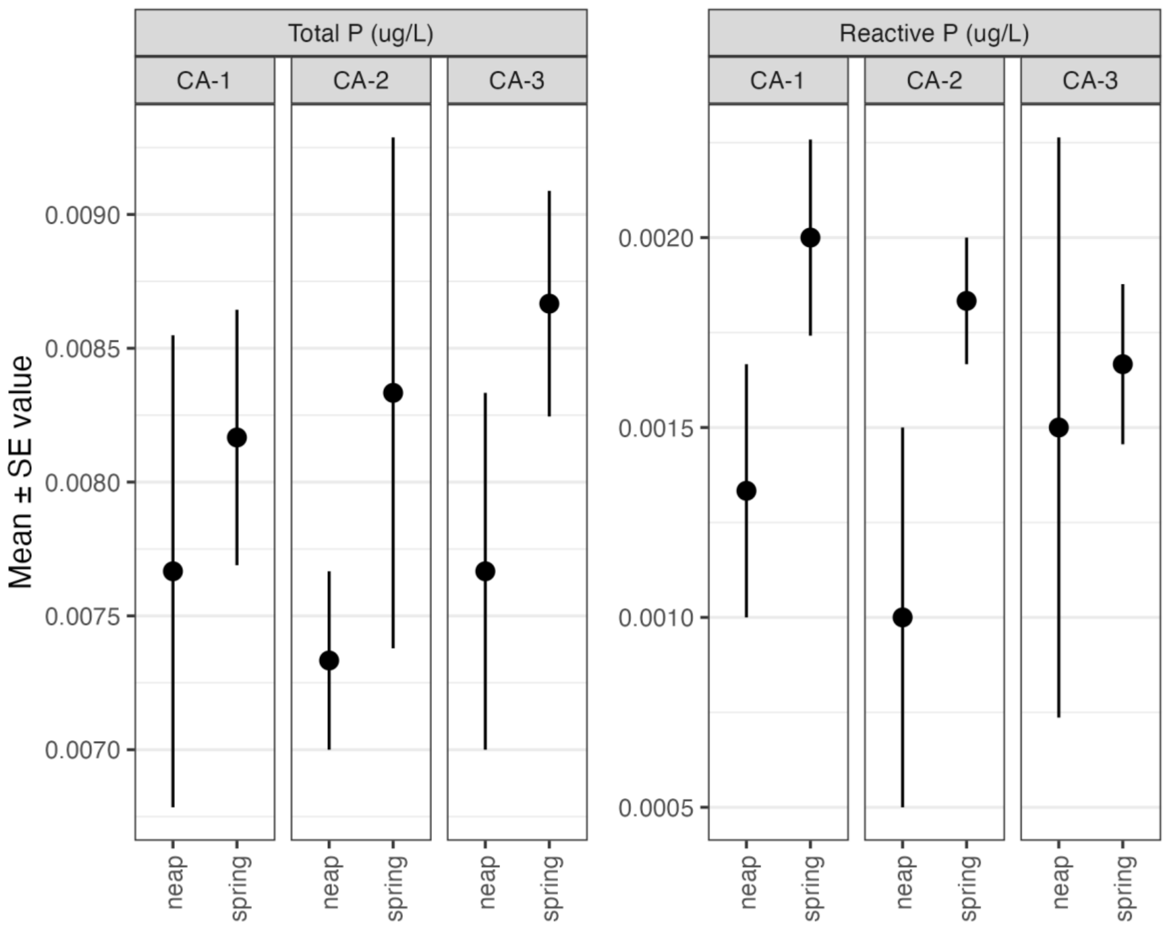


Figure 2: Mean phosphorus concentrations for ebb tides across spring and neap cycles.

### 2.2.3. Carbon

The majority of the carbon concentrations presented below, show higher levels during flood tidal flows compared to ebb flows (Figure 3). The exception was at site CA-3 during the neap cycle, where mean concentrations across all three carbon constitutes were higher during the ebb flow on the neap tide. Statistical analysis presented in Table 4 identifies significant difference ($p<0.05$) in carbon concentrations between neap and spring ebb tides, where each significant result recorded higher concentrations during the flood tidal flow.

Table 4: Significance tests ($p < 0.05$) for Carbon concentrations during ebb tides for both neap and spring cycles.

| site | Tide Cycle Comparison | | Total Organic Carbon | Total Inorganic Carbon | Total Carbon |
|---|---|---|---|---|---|
| | | | *mg/L* | *mg/L* | *mg/L* |
| CA 1 | Ebb neap | Ebb spring | NS | <0.05 | <0.05 |
| CA 2 | Ebb neap | Ebb spring | NS | <0.05 | <0.01 |
| CA 3 | Ebb neap | Ebb spring | < 0.05 | <0.05 | <0.05 |

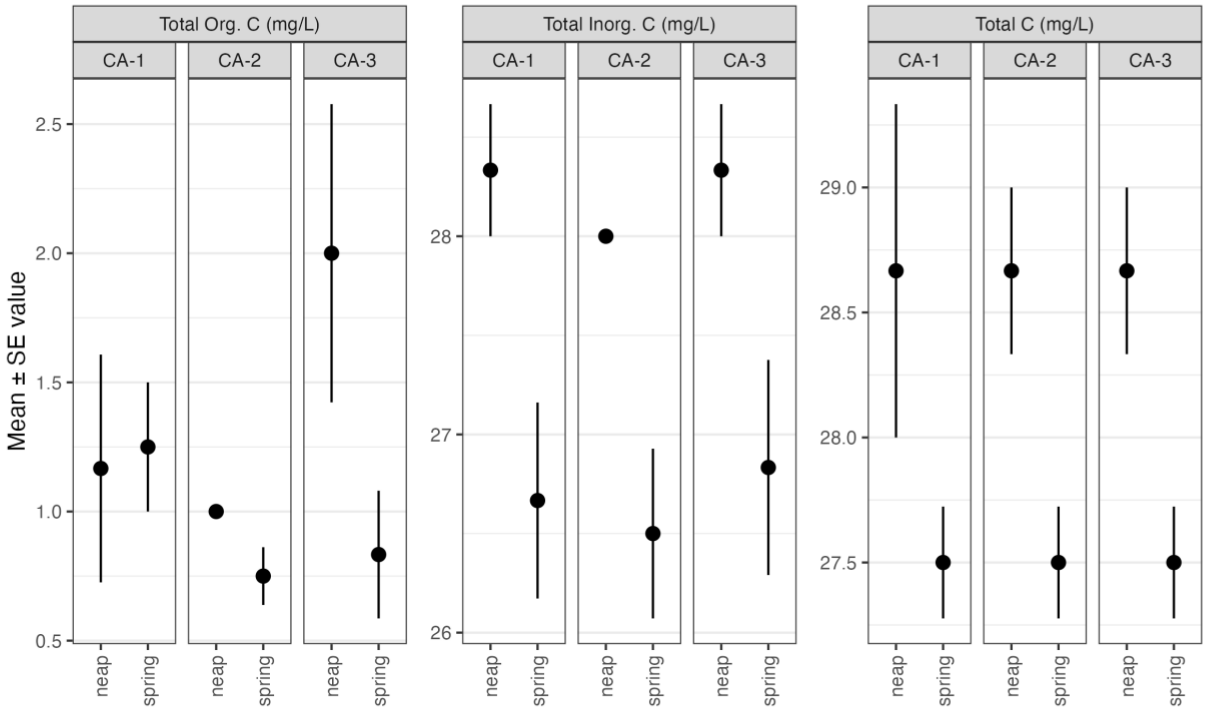


Figure 3: Mean phosphorus concentrations for ebb tides across spring and neap cycles.

# 3. Conclusion

O2M acknowledges EPAs request to focus solely on data collected from Site CA, which spatially is most likely to record differences in nutrient concentrations as a result of tidal algal mat inundation (compared to Sites CB and CC). In re-assessing the data as per the EPAs request, and as presented above, the revised analysis confirms that overall, there was no significant increase in nutrient concentration resulting from tidal algal mat inundation. Of the 27 significance tests, only one (1) result indicated a significantly ($p<0.05$) higher concentration during the spring ebb tide when compared to a neap ebb tide: Reactive P at location CA1. Results were variable among locations, tide direction and tide cycles, with no consistent patterns identified overall. Further to this, a large proportion of the results were below the laboratory LoR, limiting the power of comparison and statistical analysis.

This revised assessment, whilst providing more detailed spatial analysis, agrees with the original conclusion that: the nutrient concentrations in the nearshore areas were not significantly higher following algal mat inundation, and thus did not contribute to nutrient cycling in nearshore waters and only small differences over tidal cycles.

## Appendix G. Tabulated Fauna Results

| Site | Quadrat | Sub Quadrat | Crustacean | | | | Mollusc | | | | Fish | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Sesarmidae* | *Metapograpsus frontalis* | *Clibanarius longitarsus* | Other | *Terabralia sp.* | *Nerita balteata* | *Onchidium sp.* | Other | *Periophthalmus* | |
| M1LE | A | 1 | | | | | | | | | | |
| M1LE | A | 2 | | | | | | | | | | |
| M1LE | A | 3 | 1 | | | | | | | | | |
| M1LE | A | 4 | 1 | | | | | | | | | |
| M1LE | B | 1 | 1 | | | | | | | | | |
| M1LE | B | 2 | 8 | | | | | | | | | |
| M1LE | B | 3 | 3 | | | | | | | | | |
| M1LE | B | 4 | 1 | | | | | | | | | |
| M1SE | A | 1 | | | | | | | 1 | | | |
| M1SE | A | 2 | 1 | | | 3 | | | | | | |
| M1SE | A | 3 | | | | | 1 | | | | | |
| M1SE | A | 4 | 1 | | | 1 | | | | | | |
| M1SE | B | 1 | 1 | | | 2 | | | | | | |
| M1SE | B | 2 | 1 | | | | | | | | | |
| M1SE | B | 3 | | | | 1 | | | | | | |
| M1SE | B | 4 | | | | 1 | | | | | | |
| M2LE | A | 1 | | | | 4 | | | | | | |
| M2LE | A | 2 | | | | 8 | | | | | | |
| M2LE | A | 3 | | | | 4 | | | | | | |
| M2LE | A | 4 | | | | 4 | | | | | | |
| M2LE | B | 1 | | | | 3 | | | | 1 | | |
| M2LE | B | 2 | | | | 1 | | | | | | |
| M2LE | B | 3 | | | | 7 | | | | | | |
| M2LE | B | 4 | 4 | | | 1 | | | | | | |
| M2CC | A | 1 | | | | | | | | | | |
| M2CC | A | 2 | | | | | | | | | | |
| M2CC | A | 3 | | | | | | | | | | |
| M2CC | A | 4 | | | | | | | | | | |
| M2SE | A | 3 | 1 | | | | | 1 | | | | |
| M2SE | A | 4 | | | 1 | | | | | | | |
| M2SE | A | 1 | | | | | | | | | | |
| M2SE | A | 2 | | | | | | | | | | |

| Site | Quadrat | Sub Quadrat | Crustacean | | | | Mollusc | | | | Fish | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Sesarmidae* | *Metapograpsus frontalis* | *Clibanarius longitarsus* | Other | *Terabralia sp.* | *Nerita balteata* | *Onchidium sp.* | Other | *Periophthalmus* | |
| M2SE | B | 1 | 3 | | | | | | | | | |
| M2SE | B | 2 | 2 | | | | | 1 | | | | |
| M2SE | B | 3 | | | | | | | 2 | | | |
| M2SE | B | 4 | 1 | | | 1 | | | | | | |
| M3LE | A | 1 | 0 | | | | | | | | 1 | |
| M3LE | A | 2 | 1 | | | | | | | | 1 | |
| M3LE | A | 3 | 1 | | | | | | | | | |
| M3LE | A | 4 | 2 | | | | | | | 1 | | |
| M3LE | B | 1 | 5 | | | | | | 1 | 3 | | |
| M3LE | B | 2 | 4 | | | | | | | 1 | | |
| M3LE | B | 3 | 3 | | | | 3 | | | 2 | | |
| M3LE | B | 4 | 1 | | | | | | | 2 | 1 | |
| M3CC | A | 1 | | | | | | | | | | |
| M3CC | A | 2 | 1 | | | | | | | | | |
| M3CC | A | 3 | | | | | | | | | | |
| M3CC | A | 4 | | | | | | | | | 1 | |
| M3CC | B | 1 | | | | | | | | | | |
| M3CC | B | 2 | | | | | | | | | | |
| M3CC | B | 3 | | | | | | | | | | |
| M3CC | B | 4 | | | | | | | | | | |
| M3SE | A | 1 | 1 | | | 2 | | | | | | |
| M3SE | A | 2 | 1 | | | | | | | | | |
| M3SE | A | 3 | | | | | | | | | | |
| M3SE | A | 4 | 3 | | | | | | | | | |
| M3SE | B | 1 | 2 | | | | | | | | | |
| M3SE | B | 2 | | | | | | | | | | |
| M3SE | B | 3 | | | | | | 3 | 1 | | | |
| M3SE | B | 4 | | | | | | | | | | |
| REF1 | A | 1 | | | | | | | | | | |
| REF1 | A | 2 | | | | | | | | | | |
| REF1 | A | 3 | 1 | | | | | | | | | |
| REF1 | A | 4 | 2 | | | | | | | | | |
| REF1 | B | 1 | | | | | | | | | | |
| REF1 | B | 2 | 2 | | | | | | | | 2 | |
| REF1 | B | 3 | | | | | | | | | | |
| REF1 | B | 4 | | | | | | | | | | |

| Site | Quadrat | Sub Quadrat | Crustacean | | | | Mollusc | | | | Fish | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Sesarmidae* | *Metapograpsus frontalis* | *Clibanarius longitarsus* | Other | *Terabralia sp.* | *Nerita balteata* | *Onchidium sp.* | Other | *Periophthalmus* | |
| REF2 | A | 1 | 1 | | | | | | | | | |
| REF2 | A | 2 | | | | | | | | | 1 | |
| REF2 | A | 3 | | | | | | | | | 1 | |
| REF2 | A | 4 | | | | | | | | | | |
| REF2 | B | 1 | 2 | | | 2 | | | | | | |
| REF2 | B | 2 | | | | | | | | | | |
| REF2 | B | 3 | | | | | | | | | | |
| REF2 | B | 4 | | | | | | | | | | |
| M4LE | A | 1 | | | | | | | | | | |
| M4LE | A | 2 | | | | | | | | | | |
| M4LE | A | 3 | | | | 4 | | | | | | |
| M4LE | A | 4 | | | | 4 | | | | | | |
| M4LE | B | 1 | | | | 2 | | | | | | |
| M4LE | B | 2 | | | | 2 | | | | | | |
| M4LE | B | 3 | | | | 2 | | | | | | |
| M4LE | B | 4 | | | | | 4 | | | | | |
| M5LE | A | 1 | | | | | | | | 62 | 1 | |
| M5LE | A | 2 | | | | | | | | 206 | 0 | |
| M5LE | A | 3 | | | | 5 | | | | 50 | 0 | |
| M5LE | A | 4 | | 1 | | | | | | 35 | 0 | |
| M5LE | B | 1 | | | | 1 | | | | 30 | 0 | |
| M5LE | B | 2 | | | | | | | | 212 | 1 | |
| M5LE | B | 3 | | | | 3 | | | | 57 | 2 | |
| M5LE | B | 4 | | | | | | | | 10 | 1 | |
| M6LE | A | 1 | | | | 3 | | | | | | |
| M6LE | A | 2 | | | | 1 | | | | | | |
| M6LE | A | 3 | | | | | | | | | 1 | |
| M6LE | A | 4 | | | | 2 | | | | | | |
| M6LE | B | 1 | | | | | | | | | | |
| M6LE | B | 2 | | | | | | | | | | |
| M6LE | B | 3 | | | | | | | | | | |
| M6LE | B | 4 | | | | | | | | | | |
| M7LE | A | 1 | | | | 8 | | | | | | |
| M7LE | A | 2 | | | | | | | | | | |
| M7LE | A | 3 | | | | 9 | | | | | 1 | |
| M7LE | A | 4 | | | | 6 | | | | | | |

| Site | Quadrat | Sub Quadrat | Crustacean | | | | Mollusc | | | | Fish | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Sesarmidae* | *Metapograpsus frontalis* | *Clibanarius longitarsus* | Other | *Terabralia sp.* | *Nerita balteata* | *Onchidium sp.* | Other | *Periophthalmus* | |
| M7LE | B | 1 | | | | 12 | | | | 1 | | |
| M7LE | B | 2 | | | | 20 | | | | | | |
| M7LE | B | 3 | | | | 22 | | | | 1 | | |
| M7LE | B | 4 | | | | 15 | | | | 2 | | |
| M4SE | A | 1 | | | | | | | | | | |
| M4SE | A | 2 | | | | | | | | | | |
| M4SE | A | 3 | | | | | | | | | | |
| M4SE | A | 4 | | | | 2 | | | | | | |
| M4SE | B | 1 | | | | | | | | | | |
| M4SE | B | 2 | | | | 3 | | | | | | |
| M4SE | B | 3 | | | | | | | | | | |
| M4SE | B | 4 | | | | 2 | | | | | | |
| M5SE | A | 1 | | | | 1 | | | | | | |
| M5SE | A | 2 | | | | 2 | | | | | | |
| M5SE | A | 3 | | | | 2 | | | | | | |
| M5SE | A | 4 | | | | 4 | | | | | | |
| M5SE | B | 1 | | | | | | | | | | |
| M5SE | B | 2 | | | | 4 | | 4 | | 1 | | |
| M5SE | B | 3 | | | | | | | | 10 | | |
| M5SE | B | 4 | | | | 1 | | 1 | | 1 | | |
| M6SE | A | **1** | | | | | | | | | | |
| M6SE | A | **2** | | | | | | | | | | |
| M6SE | A | **3** | | | | | | | | | | |
| M6SE | A | **4** | | | | | | | | | | |
| M6SE | B | **1** | | | | | | | | | | |
| M6SE | B | **2** | | | | | | | | | | |
| M6SE | B | **3** | | | | 1 | | | | | | |
| M6SE | B | **4** | | | | 2 | | | | | | |
| M7SE | A | **1** | | | | 3 | | | | | | |
| M7SE | A | **2** | | | | 1 | | | | | | |
| M7SE | A | **3** | | | | 1 | | | | | | |
| M7SE | A | **4** | | | | 1 | | | | | | |
| M7SE | B | **1** | | | | 1 | | | | | | |
| M7SE | B | **2** | | | | 7 | | | | | 1 | |
| M7SE | B | **3** | | | | 5 | | | | | | |
| M7SE | B | **4** | | | | | | | | | | |

| Site | Quadrat | Sub Quadrat | Crustacean | | | | Mollusc | | | | Fish | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Sesarmidae* | *Metapograpsus frontalis* | *Clibanarius longitarsus* | Other | *Terabralia sp.* | *Nerita balteata* | *Onchidium sp.* | Other | *Periophthalmus* | |
| M4CC | A | **1** | | | | 3 | | | | | | |
| M4CC | A | **2** | | | | | | | | | | |
| M4CC | A | **3** | | | | 6 | | | 2 | | | |
| M4CC | A | **4** | | | | 2 | | | | 2 | | |
| M4CC | B | **1** | | | | 2 | | | | 1 | | |
| M4CC | B | **2** | | 1 | | 3 | | | | | | |
| M4CC | B | **3** | | 3 | | 3 | | | | | | |
| M4CC | B | **4** | | | | 3 | | | | | | |
| M6CC | A | **1** | | | | | | | | | | |
| M6CC | A | **2** | | | | | | | | | | |
| M6CC | A | **3** | | | | | | | | | | |
| M6CC | A | **4** | | | | | | | | | | |
| M6CC | B | **1** | | | | 1 | | | | | | |
| M6CC | B | **2** | | | | 2 | | | | | | |
| M6CC | B | **3** | | | | 2 | | | | | | |
| M6CC | B | **4** | | | | | | | | | | |
| M7CC | A | **1** | | | | | | | | | | |
| M7CC | A | **2** | | | | 2 | | | | | | |
| M7CC | A | **3** | | | | 8 | | | | | | |
| M7CC | A | **4** | | | | 8 | | | | | | |
| M7CC | B | **1** | | | | 15 | | | | | | |
| M7CC | B | **2** | | | | 15 | | | | | | |
| M7CC | B | **3** | | | | 4 | | | | | | |
| M7CC | B | **4** | | | | 7 | | | | | | |
| | | **Total** | 63 | 5 | 1 | 295 | 8 | 10 | 7 | 691 | 16 | 1096 |

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