WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION

# SUMMARY OFFSETS PLAN

## Mardie Project

## August 2022

Western Australian Marine Science Institution (WAMSI)

BCI Minerals Limited

# 1. OVERVIEW

Mardie Minerals Pty Ltd (Mardie Minerals, a wholly owned subsidiary of BCI Minerals Limited, BCI) is developing the Mardie Project in the Pilbara Region of Western Australia. Ministerial Statement 1175 (MS1175) provided conditional approval for the construction and operation of a solar salt and sulphate of potash production facility. Additionally, MS1175 provided for financial offsets for marine and intertidal research under Condition 14.

This Summary Offset Plan (SOP) outlines the process for planning and implementing the Mardie Project Marine and Intertidal Research Offsets Program, as required under Condition 14-5 of MS1175. Two key documents will provide the framework:

- SOP – this document– overview of the process for planning and implementing the Mardie Project Marine and Intertidal Research Offsets Program including: governance, project development strategy, project design, timeframe, completion criteria and communication.
- Science Program – detailed description of the Mardie Project Marine and Intertidal Research Offsets Program including: project objectives, participating research institutions and scientists, methodology, milestones, deliverables, schedule and budgets.

This Summary Offsets Plan has been written by the Western Australian Marine Science Institution (WAMSI) on advice of DPIRD and DBCA representatives from the Steering Committee. WAMSI and Mardie Minerals signed a contractual agreement on 29 July 2022 to develop and implement the Mardie Project Marine and Intertidal Research Offset Program.

The Plan:

- provides direction on how the Science Program will be designed and implemented to fill identified knowledge gaps through an open and transparent process.
- describes the processes and timing for the development and implementation of the Science Program and includes a draft Science Program.
- provides an overview of the governance and management structures that have been put in place to design an independent and transparent Science Program.
- outlines the role of the Steering Committee of key WA agencies (and Commonwealth if requested), which will provide the overarching project direction to ensure that the research is fit-for-purpose and fulfils the commitments outlined in Condition 14 of MS1175.
- will be delivered through WAMSI and will involve key science institutions invited to participate through a transparent process.

Although this plan includes an overview of the projects that will comprise the Science Program, it does not provide the detailed scientific methods to execute the program. The full project plans will be developed with the guidance of WAMSI and the Steering Committee once the Summary Offsets Plan has been approved. This may include amendments to site selection and finer scale details of the research program.

## 2. MARDIE PROJECT SCIENCE PROGRAM GOVERNANCE STRUCTURE

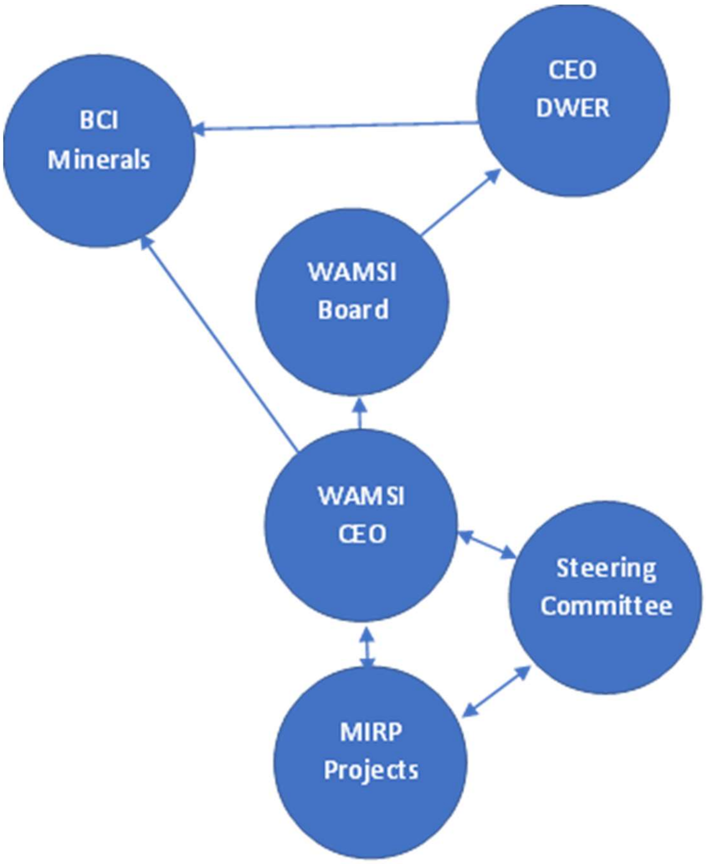



*Figure 1 Mardie Project Marine Intertidal Research Offset Program Governance Structure*

The Mardie Project Marine Intertidal Research Offset program is clearly defined in condition 14 of MS1175. The proponent was directed through MS1175 to select a third party to carry out the work. WAMSI was selected by BCI and endorsed by DWER and a contractual agreement for the Science Program to be implemented through WAMSI signed between the parties on 29 July 2022. The governance structure for oversight of the science program is in Figure 1 and highlights that WAMSI will be supported by a Steering Committee in managing the projects and will report on program development and delivery via BCI to DWER. Feedback and direction from DWER may come to WAMSI via the WAMSI Board or via BCI Minerals.

## 3. MINISTERIAL STATEMENT NO. 1175 – MARDIE PROJECT

Condition 14 of MS1175 (published on 24 November 2021) outlines the requirement to provide Marine and Intertidal Research Offsets. Specifically, Condition 14-5 outlines requirements to provide documentation to the CEO of DWER of an agreement between the proponent and the third parties (i.e. WAMSI) endorsed by the CEO of DWER. Condition 14-3 to 14-5 are reproduced below for clarity, with a status update on each obligation and where that obligation is addressed in this document (Table 1.).

*Table 1. Status of requirements under condition 14.*

| Condition number | Condition | Status |
|---|---|---|
| 14-3 | The proponent shall ensure that the financial arrangements described in schedule 2 and under condition 14-2 are maintained to achieve the outcomes of Projects A, B and C to the extent that:<br>(1) funding between projects is transferred as agreed by the CEO; and<br>(2) additional funds up to a maximum of 10 per cent are contributed to complete project outcomes. | WAMSI and BCI will seek approval from DWER CEO for funding transfers between Projects A, B and C through the development of the science program. |
| 14-4 | The proponent shall select a third party to carry out the work required to meet the outcomes of condition 14-1 to the satisfaction of the CEO, on advice of DPIRD and DBCA. In applying to the CEO for endorsement of the selected third parties, the proponent shall provide:<br>(1) demonstration of the track record, experience, qualifications and competencies of the proposed third party to carry out the work and achieve the outcomes in the intertidal and marine environment. | DWER approved BCI nomination of WAMSI on 16 February 2022. |
| 14-5 | Prior to the commencement of ground disturbance, unless otherwise agreed by the CEO, the proponent shall provide to the CEO documentation of an agreement between the proponent and the third parties endorsed by the CEO under condition 14-4. This agreement shall:<br>(1) Ensure that the funds described in schedule 2 are used to meet the outcomes of condition 14-1 | On 16 February 2022, DWER granted an extension of time to 30 April 2022 for development of the agreement with WAMSI. A further extension was granted on 13 May 2022 for research funding to be paid by 1 August 2022.<br>An agreement has been signed on 29 July 2022 between Mardie Minerals and the University of Western Australia on behalf of WAMSI, to develop a marine science program to meet the outcomes of condition 14-1. The agreement describes the contractual relationship to fund marine research to the value of $2.5M on the following three projects as described in Schedule 2 of MS1175:<br>**Project A**. Mapping of the original and current extent of Samphire and Algal mat on the west Pilbara Coast<br>**Project B**. Identify and quantify the potential effects of sea level rise on mangroves, samphire and algal mat on the west Pilbara Coast<br>**Project C**. Identify the ecological roles, values and functions of algal mat on the west Pilbara coast |

| | | |
|---|---|---|
| | (2) Provide the objectives, timing (deliver outcomes within three (3) years of issue of Ministerial Statement or as otherwise agreed with the CEO), milestones and methodology of the proposed research and management programs to meet the outcomes in Condition 14-1;<br><br>(3) Include a Summary Offset Plan, on advice of DPIRD and DBCA, that provides the design for the proposed research and management programs and completion criteria for each project to meet the outcomes of Condition 14-1; | WAMSI has drafted this Summary Offsets Plan (SOP), which outlines:<br><br>• Objectives (process for development- Section 6 and Section 7; project objectives provided in Attachments 2A, 2B and 2C)<br>• Timing, (for the program under WAMSI see Section 12; for individual project timeframes see Attachments 2A, 2B and 2C) and<br>• Process for establishing the milestones and methodology (Section 9) for the proposed research and management programs to meet the outcomes of Condition 14-1.<br><br>This SOP has been reviewed and finalised on advice by a Steering Committee, comprised of representatives from DWER, DPIRD and DBCA (Section 4). The SOP provides an overview of the governance and organisation structures that have been implemented to design the proposed research and management programs and the completion criteria for each project to meet the outcomes of Condition 14-1.<br><br>A guidance document was prepared by the Steering Committee to assist scientists in developing appropriate projects for the program. This document details the Research Design (Section 5) and Completion criteria (Section 6) (See Attachment 1, Guidance document prepared by the Mardie Project Offset Steering Committee). Finally, three project summaries have been developed and reviewed by the Steering Committee and are considered appropriate to achieve the objectives of Condition 14-1 (See Attachment 2A, 2B and 2C). It is recognised that further guidance from the Steering Committee will be used to refine these summaries as they are developed into full project plans, including confirming the indicative site selection. Once approved by DWER, these will be developed into full project plans under the oversight of the Steering Committee and become the Science Program. |
| | (4) Set out that the Summary Offset Plan will be made available publicly, within a reasonable time period in a manner agreed by the CEO; and | Section 11 of this SOP makes it clear that the document will be made available publicly, within a reasonable time period in a manner agreed by the CEO of DWER. |
| | (5) Identify how outcomes of the proposed programs will be made available publicly. | The SOP identifies how the outcomes of the proposed programs will be made available publicly (Section 11). |

## 4. MARDIE PROJECT STEERING COMMITTEE

A Steering Committee comprised of relevant government agencies has been established to provide overarching project direction. The Steering Committee is chaired by WAMSI and includes representatives from:

- Department of Water and Environmental Regulation (DWER) – Marine Ecosystems Branch: Kevin McAlpine, Fiona Webster
- Department of Water and Environmental Regulation (DWER) – North-west Region: Adrienne Sanders
- Department of Biodiversity, Conservation and Attractions (DBCA) – Marine Science Program: Dr Shaun Wilson
- Department of Primary Industries and Regional Development (DPIRD) – Aquatic Science and Assessment Branch: Dr Stephen Newman
- Australian Department of Climate Change Energy, Environment and Water (DCCEEW) – [invited, pending a nominated representative]
- Others, on recommendation of other agencies.

The agreed roles and responsibilities of the Steering Committee include:

- Provide advice to WAMSI on the scope, objectives, timing, milestones and methods of the science program. This includes advice on project funding allocation to meet outcomes of Condition 14-5 of MS1175.
- Review the Science Program for compliance against EPA Report 1704, Section 14, Marine and Intertidal Offsets, including:
    - mapping the original and current extent of Samphire and Algal mat on the west Pilbara coast
    - identifying and quantifying the potential effects of sea level rise on the values of mangroves, samphire, and algal mat on the west Pilbara coast, and identifying the significance of salt projects in preventing the adaptation of intertidal BCH to sea-level rise; and
    - identifying ecological roles, values and functions of algal mat on the west Pilbara coast.
- Advise WAMSI on project methods, deliverables and timing
- Endorse the Science Program
- Review science progress against the milestones and schedule

Meeting frequency – Over the first six months regular meetings will be required while the SOP and science program are established. Once the science program is endorsed and project agreements are in place, meetings will become biannual to monitor project progress. All meetings will be accessible via MS Teams.

Meetings in the early stages of program development have included:

- First meeting – 2 June 2022 to discuss Terms of Reference and to review the schedule (refer to Table 2).
- Several meetings from June through July for the Steering Committee to nominate interim project leaders and prepare guidance advice on the development of the research projects that will comprise the Science Program (Attachment 1).
- Additional meetings in early August to review the Expressions of Interest prepared by the project teams and endorse project summaries to include in this Plan.

## 5. RESEARCH DESIGN

The Steering Committee met several times in June to discuss the requirements of MS1175 and in particular the knowledge gaps identified by DWER that were sought to be informed by Condition 14-5. The Committee prepared a guidance document which more clearly spelled out the key objectives and information needs to guide the design and development of the 3 projects (Attachment 1). The Steering Committee also met with the interim project leaders as they developed the project plans ensure project design and delivery would meet the needs and deliver the outcomes required.

## 6. COMPLETION CRITERIA

As noted above, a guidance document was prepared by the Steering Committee with very clear knowledge gaps and deliverables expected for each project. These deliverables will be required as the completion criteria.

## 7. WAMSI SCIENCE WORKSHOP

WAMSI convened a science workshop on 1 July with partners that have the capability and capacity to undertake the Science Program as outlined in MS1175 Condition 14, and as further directed by the Steering Committee. The science workshop included invitees from: Curtin University, Edith Cowan University, Murdoch University, The University of Western Australia, Australian Institute of Marine Sciences, DPIRD, DWER, and DBCA.

The workshop was formally convened by WAMSI and addressed the following topics/items:

- Overview of offset requirements
- Overview of Steering Committee recommendations
- Discussion on present scientific understanding of the region/themes; including existing literature and data availability
- Nomination of interim project area leaders and process for Science Program development
- Timeframe for Science Program development including:
    a. Identification of project teams
    b. Expression of Interest
    c. Development of full proposals
    d. Collaboration agreement with WAMSI

## 8. EXPRESSION OF INTEREST

Interim project leaders were asked to develop, with their project teams, an Expression of Interest (EOI) that would meet the objectives outlined in the guidance document and submit this to WAMSI for review by the Steering Committee. These EOIs were endorsed by the Steering Committee and comprise the project summaries in Attachment 2A, 2B and 2C of this Plan. The EOIs include sufficient detail on project objectives, timing and methodology to be assessed by the DWER CEO as suitable to meet Condition 14-1.

The three EOIs were submitted on 29 July 2022 and reviewed by the Steering Committee with feedback provided to the project leaders. Final EOIs were submitted on 15 August 2022 and were reviewed by the Steering Committee. These are provided as detailed project summaries in Attachment 2A, 2B and 2C. The project summaries, once endorsed by DWER CEO will form the plan for the Science Program which will be fully developed by the project teams with fuller detail on project methodology, budgets, refined milestones and timeframes.

## 9. COLLABORATIVE RESEARCH AGREEMENTS

Collaborative Research Agreements (CRA) will be established between participating WAMSI partners and will be considered formal and legally binding contracts to undertake each research project. The head agreement of each contract will be based on the agreement between Mardie Minerals and WAMSI and will be negotiated with the participating research partners at the time of proposal development.

Each CRA will incorporate the details from the relevant final proposal, including the budget, research methods, timing of milestones and deliverables.

There will be a separate CRA for each project and it may include one or more WAMSI partners.

## 10. PROJECT AWARD

Projects will be awarded on execution of the CRA by each participating collaborative research institution, WAMSI, Mardie Minerals. A copy of each executed CRA will be provided to CEO of DWER.

The date of Project initiation is the date of award.

## 11. PROJECT MANAGEMENT

Projects will be managed by WAMSI. Biannual (or more regular if required) Project Reports will be developed to track project progress against the schedule, budget, milestones and deliverables. All reporting will be reviewed by the Steering Committee, who will be responsible for providing advice via the CEO WAMSI on project progress. The Steering Committee will also be responsible for issues resolution and providing endorsement for milestone payments. The CEO WAMSI will report to the CEO of DWER, BCI and the WAMSI Board.

A Final Program Report, that will encompass the three individual Project Reports will be developed on completion of the program for endorsement by the CEO of DWER. The project is completed when endorsement of the Final Report/s by the CEO of DWER is received and all milestone payments have been made to the project participants.

## 12. SCHEDULE

The table below sets out the indicative timing for development and implementation of the Science Program.

*Table 2. Indicative schedule for Mardie Marine and Intertidal Research*

| Milestone | Description | Indicative Timing |
|---|---|---|
| Draft SOP submitted to DWER | SOP provides an overview of the governance structure and the process required to design and operationalise the science program. | 29 April 2022 |
| Steering Committee meeting 1 | Meeting 1 to set the objectives and expectations of the science program. | 2 June 2022 |
| WAMSI science workshop(s) | Workshop with science experts from the WAMSI partnership to determine the high-level methods, appropriate participating research institutions to develop the draft science program plan. | 1 & 6 July 2022 |
| WAMSI draft science program plan | EOIs submitted with project objectives, methods, deliverables, schedule and budget to form the framework for the science program. | 29 July 2022 |
| Steering Committee meeting(s) | Review of the EOIs with feedback provided to project leaders and discussed further to refine the EOIs into a plan for the science program. | 2 & 10 August 2022 |
| WAMSI draft Science Program | Revised EOIs submitted and reviewed by Steering Committee, compiled into draft Science Program. | 17 August 2022 |
| SOP submitted | SOP submitted to the CEO DWER with draft Science Program. | 22 August 2022 |

| Milestone | Description | Indicative Timing |
|---|---|---|
| WAMSI draft full project proposals | Detailed project proposals developed with detailed project objectives, methodology, resourcing, deliverables, schedule and budgets | 1 November 2022 |
| Steering Committee review | Steering committee review of project proposals. | 15 November 2022 |
| Finalise Science Program | Response to Steering Committee comments and finalisation of the Science Program | 1 December 2022 |
| Publish Science Program | Within 4 weeks of Science Program being finalised by the Steering Committee. | 29 December 2022 |
| Collaborative Project Agreements | Contractual agreement between collaborating science organisations and WAMSI to deliver each Science Project – including the Final Science Program Plan | 31 December 2022 |
| Program Start | | 1 January 2023 |
| Program Finish | Within 3 years of issue of MS1175. While the projects will endeavour to finish by 23 November 2024, at least one project will require additional time based on the breadth and complexity of objectives and on administrative timeframes. The indicative finish date reflects the completion date for the final project, noting that all projects will provide annual reports and can provide interim results in report or presentation format to DWER as required throughout the project. | 30 September 2025 |

Note: Schedule is subject to change based on advice from the Steering Committee.

## 13. PUBLIC AVAILABILITY OF THE SUMMARY OFFSETS PLAN

WAMSI intend to make this SOP publicly available within four weeks of it being endorsed by the DWER CEO as fulfilling the requirements of MS1175 Condition 14-5.

WAMSI intend to make the Science Plan publicly available within four weeks of it being finalised by the Steering Committee.

WAMSI will develop a webpage dedicated to the Mardie Project Science Program, from which it is intended to make the SOP and Science Program (and projects) publicly available within the timeframes stated above upon agreement by the DWER CEO. Further, WAMSI has a strict requirement that all research products and data are made publicly available, unless the material can be demonstrated to be Commercially Sensitive and In Confidence. WAMSI does not expect the results from the Mardie Project Science Program to be commercially sensitive, but rather there is an expectation that the results from the science program will be used to inform public decision making for the Pilbara coast for the foreseeable future.

## ATTACHMENT 1 – WAMSI GUIDANCE DOCUMENT

# Guidance for the Development of the Mardie Project Marine and Intertidal Offsets Research Program

### Provided by the Mardie Project Offset Steering Committee

**Mardie Salt Offset Program**

Mardie Minerals Pty Ltd (a wholly owned subsidiary of BCI Minerals Limited) is developing the Mardie Project, a solar salt and sulphate of pot ash production facility in the Pilbara region of Western Australia. Ministerial Statement 1175 (MS1175) provided conditional approval for the Project that includes requirement for financial offsets for marine and intertidal research. The offsets are based on the significant residual impacts and risks of the proposal to intertidal benthic communities and habitat (BCH) namely mangroves, algal mat and coastal samphire and were put in place for the purpose of guiding the strategic protection and management of the ecological values of these habitats on the west Pilbara coast. Values associated with BCH include primary productivity, ecosystem maintenance, nutrient cycling, carbon storage and habitat values such as foraging, breeding or nursery habitat.

This offset package covers three specific areas of research for a total cost of $2.5M. The research program to meet this condition will be undertaken through an independent body, the Western Australian Marine Science Institution (WAMSI), with the guidance and support of a Steering Committee comprising members from DWER, DBCA and DPIRD to ensure the research program, funding allocation and delivery meet the conditions of MS1175 and fit into the above needs highlighted for regional understanding of the Pilbara coastal environments to inform future decision-making, management and conservation.

The project areas as defined in MS1175 Condition 14 are noted below with the scope and research priorities for each. Proposed projects area summarised in the following tables:

**Project A**. ***Mapping of the original and current extent of Samphire and Algal mat on the west Pilbara Coast***

The aim of this project is to complete mapping of the extent of algal mat and samphire on the west Pilbara coast to provide an understanding of the regional extent and distribution of these habitats to complement the existing mangrove mapping. While a complete map of the current distribution of these habitats is the priority, having an understanding of how these habitats have changed over time will also inform their response to anthropogenic and natural events.

Priority research areas are:
- What is the current spatial extent of mangrove, algal mat and samphire habitat in the west Pilbara?
- What is the historic spatial extent of algal mat, mangrove and samphire habitat in the west Pilbara based on Landsat imagery (where applicable)? [Note: historical mapping of mangrove may be available]
- Has this distribution changed in the west Pilbara over the past 60 years in response to natural events (storm/cyclonic activity, heat waves) or anthropogenic pressures (coastal development)?

**Project B**. ***Identifying and quantifying the potential effects of sea-level rise on mangroves, samphire and algal mat on the west Pilbara Coast and identifying the significance of salt projects in preventing the adaptation of intertidal BCH to sea-level rise***

The aim of this project is to improve the management of intertidal BCH in the region in the event of sea-level rise given the potential for the Mardie Project (or other salt proposals) to reduce the capacity of some intertidal BCH to adapt to climate change. The priority for this project will be on understanding how BCH may respond to sea-level rise and limitations created by the presence of salt projects in terms of BCH spatial extent and capacity to function.

Priority research areas are:

- Understanding the influence of sea-level rise on BCH extent and migration including environmental and physical parameters.
- Predicting BCH response to climate change scenarios in particular to sea-level rise.
- What role will salt projects play in reducing BCH adaptation to sea-level rise and how will this affect the ecological services provided by these habitats.

The research will focus on predicted impacts to all intertidal BCH which includes mangroves, samphire and algal mats. The spatial emphasis will be on the footprint area of the Mardie Project, but will extend across the west Pilbara, particularly considering the potential for additional proposals. This project will rely on information from projects A and C to be complete.

**Project C**. ***Identifying the ecological roles, values and functions of intertidal benthic communities and habitat***

The aim of this project is to provide information on the ecological role and values of key BCH that will inform future decision making on development across the Pilbara region. The highest priority habitat is algal mat as it is the least understood of the intertidal benthic coastal habitats. In particular, very little is known about its contribution to nutrient and energy flow in the intertidal to subtidal system and how this varies spatially and temporally. The second priority will be samphire habitat, followed by mangrove. While there is an expected emphasis on the Mardie Project site footprint, research in this project area may extend to the west Pilbara coast, e.g. from the SE corner of Exmouth Gulf to Karratha.

Priority research areas are**:**

- Estimate primary productivity in space and time for algal mat and other BCH.
- Identify the pathway for transfer of nutrients and energy from BCH to other communities and habitats (e.g. from the intertidal mosaics to the subtidal).
- Describe the role of BCH as habitat, assess community composition, biodiversity constituents, trophic transfer (flow of energy), nutrient transfer to understand ecosystem function.
- Identify the key physical drivers such as the response to the wetting and drying associated tidal movement, rainfall, episodic events (storms and cyclones), evaporation etc.

The above questions will need to take into account both spatial and temporal considerations including:

- Identifying a spatial gradient of productivity and energy flow for the west Pilbara coast and extending into subtidal areas.
- Intra-annual to understand the response to the wetting and drying associated with key physical drivers such as: tidal movement, rainfall, episodic events (storms and cyclones), evaporation etc.
- Inter-annual variability, however, it is noted that this will be limited as it is likely that a maximum of two years of data would be collected in the short timeframe.

## *Mapping of coastal and intertidal habitats with a priority focus on samphire and algal mat on the wes*

**Aim:** To produce habitat maps of algal mat and samphire habitat across the west Pilbara coast comparable to those fo to historic records to better understand natural variability and the response of these habitats to natural events and ar

**Theme Leaders:** Ben Radford (AIMS), Sharyn Hickey (UWA) **Nominal funding:** $650,000

| **Project 1.1** Mapping of the original and current extent of Samphire and Algal mat on the west Pilbara Coast | |
|---|---|
| **Knowledge gap** | **Project deliverables** |
| Current extent of mangrove, samphire and algal mats in the west Pilbara | • Map of current distribution of mangrove, samphire and algal mats from SE corr Exmouth Gulf to Karratha. |
| **Project 1.2** | |
| **Knowledge gap** | **Project deliverables** |
| Historic extent of algal mats, mangrove and samphire in the west Pilbara | • Prediction of mangrove, samphire and algal mats from SE corner of Exmouth G Karratha prior to European habitation. |
| **Project 1.3** | |
| **Knowledge gap** | **Deliverables** |
| Temporal stability of mangrove, samphire and algal mats in the west Pilbara | • Investigate and identify methods for assessing changes in the temporal and spa extent of algal mat and samphire.<br>• Map and describe temporal differences in the extent of mangrove, samphire an mats in the west Pilbara, investigating the effect of season and disturbance (nat anthropogenic). This may include assessing changes in inundation patterns as so these habitats are difficult to see on Landsat imagery. |

## *Identifying and quantifying the potential effects of sea-level rise on intertidal habits of the west Pilbara coast with a focus on mangroves, samphire and algal mat:*

**Aim:** To provide a better understanding of the potential impacts of sea-level rise on intertidal habitats of the west Pilbara coast and how coastal infrastructure such as that by salt works may influence adaptation to sea-level rise.

**Theme Leaders**: Matt Hipsey (UWA) **Nominal funding:** $650,000

| **Project 2.1** | | |
|---|---|---|
| **Knowledge gap** | **Project deliverables** | **Project Leader/s** |
| To what extent do environmental and physical conditions inhibit migration of intertidal habitats with rising sea-level? | • Models projecting SLR impacts along the coast and associated redistribution of intertidal habitats (mangroves, samphire and algal mats). This will need consideration of sedimentary processes that may influence the distribution of the communities (e.g. erosion, sedimentation under existing mangrove forests, etc). | |
| **Project 2.2** | | |
| **Knowledge gaps** | **Project deliverables** | **Project Leader/s** |
| How may projected climate changes effect intertidal habitat's ability to migrate? | • Models that consider how increasing temperature (sea and land), changes to rainfall and cyclone activity influence capacity of intertidal habitats to redistribute with SLR. | |
| **Project 2.3** | | |
| **Knowledge gap** | **Project deliverables** | **Project Leader/s** |
| What is the significance of the proposed salt works in preventing adaption of BCH to sea-level rise? | • Models projecting SLR impacts along the coast, particularly at sites where there are existing or proposed salt works and how this infrastructure and sedimentary processes may influence the potential for redistribution of intertidal habitats. | |

## *Identifying the ecological roles, values and functions of intertidal benthic communities and habitats of the west Pilbara:*

**Aim:** The priority for this project will be understanding the role of algal mats including their value and function through nutrient flows and energy budgets and where this productivity goes in the system, including a spatial and temporal gradient.

**Theme Leaders**: Kath McMahon, Glenn Hyndes and Paul Lavery (ECU) **Nominal funding**: $1,000,000

| **Project 3.1** | | |
|---|---|---|
| **Knowledge gap** | **Project deliverables** | **Project Leader/s** |
| What is the primary productivity (including nitrogen fixation) in space and time for algal mat and other BCH in the west Pilbara? | • Estimation of primary productivity nitrogen fixation across a spatial gradient for algal mat, samphire and mangroves.<br>• Estimation of the relative productivity for the whole West Pilbara Coast for mangroves, samphire and algal mats.<br>• Estimation of nitrogen flux (temporal and spatial) to the marine environments from all sources (e.g., algal mats and terrestrial flows).<br>• Estimation of the relative importance of nitrogen flux from algal mat communities to the marine environment compared to other sources of nitrogen (temporal and spatial). | |
| **Project 3.2** | | |
| **Knowledge gaps** | **Project deliverables** | **Project Leader/s** |
| Identify the pathway for transfer of nutrients and primary productivity from intertidal BCH to subtidal communities and habitat | • Identification of pathways for transfer of nutrients and primary productivity from intertidal to subtidal areas.<br>• Estimation of the proportion of primary productivity and nitrogen which is exported from each intertidal habitat type to subtidal areas. | |
| **Project 3.3** | | |
| **Knowledge gaps** | **Project deliverables** | **Project Leader/s** |
| Describe the role of BCH as habitat, assess community composition, biodiversity constituents, trophic transfer (flow of energy, nutrients) etc. The primary focus is algal mat communities, but other BCH should be considered | • Identification of the role of algal mats in terms of composition, biodiversity, trophic transfer and habitat across a spatial gradient. | |

| **Project 3.4** | | |
|---|---|---|
| **Knowledge gaps** | **Project deliverables** | **Project Leader/s** |
| Identify the key physical drivers of spatial and temporal variability in primary productivity and N fixation, such as the response to wetting and drying associated tidal movement, rainfall, episodic events (storms and cyclones), evaporation etc. | • Identification of key physical drivers of spatial and temporal variability in primary productivity and nitrogen fixation.<br>• Identification of key processes which transfer the carbon and nitrogen to the subtidal environment. | |

### Linkages to other programs

There are a number of research programs currently underway or in development through research institutions and government departments in WA and nationally that will be producing deliverables relevant to this strategy. Links will be established with other organisations and programs to build upon, complement and leverage other local, regional and national initiatives and activities. Some current initiatives include:

**Department of Transport** initiative to develop topographical and habitat mapping based on lidar and digital elevation for priority coastal areas. This is part of a national project that is being led by DoT for WA. There is scope to support the Pilbara as a priority area for this project.

**CSIRO** has a project planned that will compile existing habitat mapping products to assess Australia's 'blue carbon' potential.

**DBCA** is leading research evaluating primary productivity, energy transfer and connectivity among marine habitats in the Dampier Archipelago.

**Commonwealth** required offset for research that guides conservation efforts to maintain ecological functionality of nearshore subtidal habitats of the Pilbara region that support the short-nosed sea snake.

### Governance

A governance structure has been agreed with BCI Minerals, WAMSI and DWER to manage the Mardie Salt Marine and Intertidal Offset program. This will involve a Steering Committee to provide guidance on the projects comprising the offset program and their delivery. The Steering Committee will operate under agreed Terms of Reference that set out the membership, roles and responsibilities of the Committee, membership and meeting frequency. The overall role of the Steering Committee is to provide overarching program direction and coordination, issues resolution, and oversee project delivery. The Steering Committee reports to the WAMSI CEO.

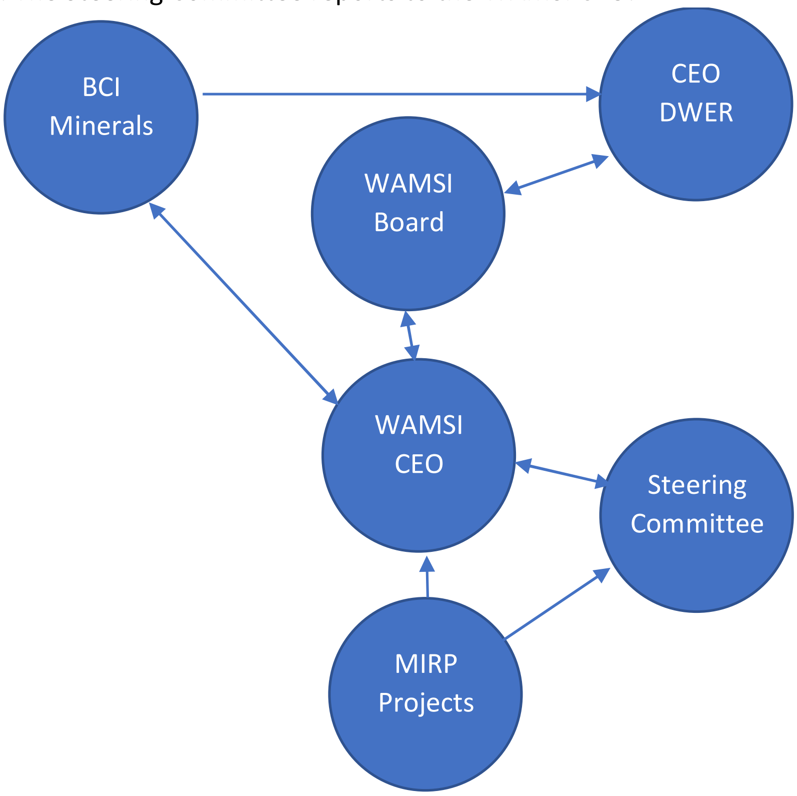



**Figure 2.** Governance Structure for delivery of the Mardie Salt Marine and Intertidal Offset program through WAMSI.

## DATA MANAGEMENT

A Data Management Plan and Technical Standard Data and Analytics Deliverables, in recognition that effective and efficient data management will underpin the Program.

ATTACHMENT 2A –PROJECT SUMMARY Mardie Project Marine and Intertidal Research Offset Program – Project A

| | |
|---|---|
| **Project Title** | **Mapping of coastal and intertidal habitats with a priority focus on samphire and algal mat on the west Pilbara coast** |
| **Project Leader/s** | Sharyn Hickey and Mick O'Leary |
| **Project Team** | Peter Fearns, Shams Islam, Catherine Lovelock, Amanda Kearny |

## *1* Project Summary

### Project Rationale

*Outline the background and need for the project including how the project will meet the conditions under the offset program described in MS1175.*

*The Mardie Minerals Pty Ltd (a wholly owned subsidiary of BCI Minerals Limited) is developing the Mardie Project, a solar salt and sulphate of potash production facility, in the Pilbara region of WA. Ministerial Statement 1175 (MS1175) provided conditional approval for the Project that includes requirement for financial offsets for marine and intertidal research. The offsets are based on the significant residual impacts and risks of the proposal to intertidal benthic communities and habitat (BCH) namely mangroves, algal mat and coastal samphire and were put in place for the purpose of guiding the strategic protection and management of the ecological values of these habitats on the west Pilbara coast. Values associated with BCH include primary productivity, ecosystem maintenance, nutrient cycling, carbon storage and habitat values such as foraging, breeding or nursery habitat.*

The Pilbara coast hosts a unique arid zone mangrove environment recognised as one of only six across the globe (Adame *et al.*, 2020). Broad flat inter/supratidal flats combined with a hot dry climate has resulted in a distinctive habitat zonation. The Pilbara coast tends to be fringed by mangrove communities that transition to samphire and salt tolerant vegetation in the lower intertidal zone. The higher intertidal zone and lower supratidal zones tend to be covered by cyanobacterial mats (referred to as 'algal mats' in the Ministerial Statement) (Figure 1). These organic mats comprise microbial cyanobacterial communities, and are considered be highly productive primary producers, fixating carbon and nitrogen (Stal, 1995; Lovelock *et al.*, 2010; Adame *et al.*, 2012) and are thought to contribute to primary and secondary productivity in the nearby coastal waters (Penrose; Lovelock *et al.*, 2010; Adame *et al.*, 2012).

However, information on these habitats, particularly in the Pilbara coastal region is limited and has largely been focussed on mangroves (Hickey and Radford, 2022), or focussed on particular sites (Lovelock *et al.*, 2010; Adame *et al.*, 2012). Similar areas, further north, which contain overlapping habitats, including mangrove, tidal flats and samphire vegetation, such as Eighty Mile Beach have been recognised as RAMSAR sites of significance under The Convention on Wetlands of International Importance, demonstrating the significance of these environments. There remains a knowledge gap in the functional role of mangrove, samphire and cyanobacterial mat habitats play in the Pilbara's dryland coastal ecosystems. The vast size, remote location, terrain and tide has possibly hindered research in this area, however advancement in remote sensing techniques alongside field observations can provide valuable insight to map these habitat communities, and explore the natural dynamics, threats and responses.

Regional climatology (e.g., El Nino Southern Oscillation), sea level, precipitation, and temperature have been demonstrated to affect these coastal habitats. For instance, a 20 cm decline in sea level at Mangrove Bay on the Ningaloo Coast in Western Australia coincided with porewater salinity increasing by 25% compared to the 16 year mean level, and ultimately resulted in areas of mangrove dieback (Lovelock *et al.*, 2017). While cyclones were shown to damage seaward mangroves, and provided an avenue for landward mangrove seedling recruitment and establishment in Exmouth Gulf (Lovelock, Reef and Masque, 2021). There is limited knowledge on the extent of mangrove, samphire and cyanobacterial mat communities in the Pilbara, however we first need to know their extent to understand their vulnerability to both climate and anthropogenic threats.

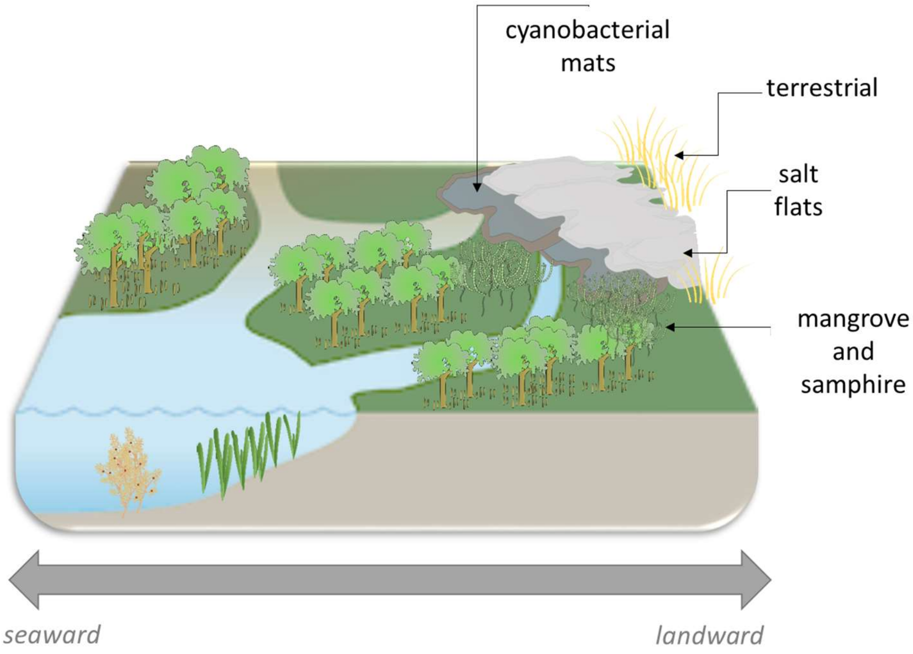



*Figure 1: Conceptual view of a representative section of the Pilbara Coast, showing tidal creeks, mangroves transitioning to samphire, then cyanobacterial mats and salt flats as the cross-section moves landward from the coastline.*

Understanding environmental change in the West Pilbara requires baseline information that predates ecological monitoring/mapping programs. This is because over time scales relevant to a changing climate and anthropogenic impacts we need to reduce the possibility of shifting baseline syndrome (SBS; Knowlton and Jackson 2008). Developed by Pauly (1995), the concept of SBS is defined in Soga and Gaston (2018) as

*"a change in the accepted norms for the condition of the natural environment due to lack of past information or lack of experience of past conditions".*

As suggested here, acceptance of an already changed coastal ecosystem's baseline as "healthy" may lead to the use of inappropriate baselines for habitat conservation (Thurstan et al. 2015; Soga and Gaston 2018;). As such, there is a need to both identify the limitations of relatively recent ecological monitoring data in capturing the full impact of anthropogenic pressures over multiple decades (Mihoub et al. 2017) and identify novel methods to capture and record environmental data that can extend our understanding beyond the observational/instrumental record.

The EOI proposes to use a unique combination of (1) satellite and aerial remote sensing techniques, (2) Indigenous knowledge to map habitat extent and track environment change across space and time (i.e., seasonal to multidecadal timescales). The Pilbara's coastal environments host a unique sedimentary and geomorphic archive that may contain palaeo-ecological records of habitat distribution and zonation during periods of high sea levels spanning the last several thousand years. Though not a focus for this investigation but flag the potential utility of these archives in predicting habitat response to future predicted changes in sea level along the Pilbara coast.

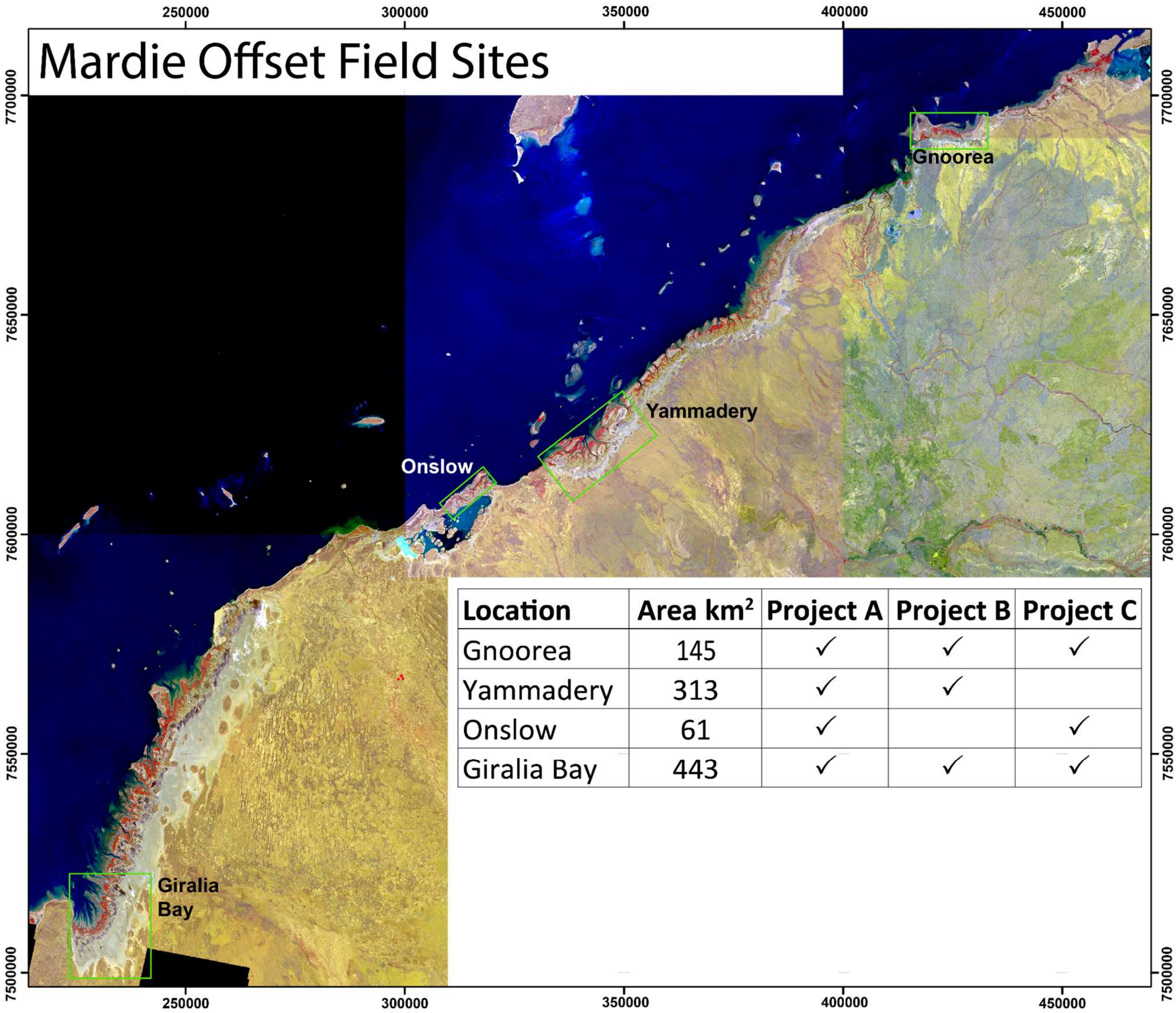
(1) The first approach uses satellite remote sensing datasets which will provide >30 years of data and represent the most recent period of coastal industrialisation and climate change along the Pilbara coast. The approach will also benefit from the recent availability in higher spatial and temporal resolution satellite, airborne and drone remote sensing datasets, and the coincident increases in cloud processing and advances in machine learning. These advances in automated mapping and processing capability have provided an avenue to link fine-scale field measurements with broader-scale remote sensing data, across spatial scales, with associated uncertainty models. Using these methods, recent history and understanding of space-time dynamics of the habitats can be made to help inform ecological drivers of change, and habitat contribution to the ecosystem values and functions. We will also use historical air photo imagery to establish the historical loss of mangrove-samphire-cyanomats that resulted from the development of the Onslow and Dampier solar ponds and crystallisers (e.g., SI1 and SI2). We will source National Archives and georectify air photos, and develop a systematic way to interpret photos of areas prior to salt pond development or in early phases and will develop an image library of this.

(2) The second approach will make use of Indigenous knowledge and living memory to identify areas, specific locations or patterns of habitat change that will both overlap and extend beyond the satellite instrumental record. With collective knowledge of the land, sea, and sky, Indigenous peoples are also excellent observers and interpreters of the natural environment and have experienced climate driven environmental change through deep time, adapting to changes in sea levels, precipitation regimes, evolving seasonal variability, and the resultant impact on their immediate environments. This knowledge can complement scientific data by providing environmental baselines (that can extend beyond the observational and instrumental timeseries) in which to measure change. Particularly we see indigenous knowledge providing reconstructions on environments that were impacted by the development of the Onslow and Dampier Salt developments.

**Project Objectives and Outcomes**

To address the priority research areas as identified by the Steering Committee to meet the Ministerial Statement we have developed two approaches (see above), related to the priority research areas identified with sub-questions and objectives within each, as outlined in Table 1.

Here we define the Pilbara coast as the coastline from Exmouth Gulf to Karratha in Figure 2. A total of four field sites (Figure 2) have been identified and selected based on the representative nature of the three key habitats (mangrove, samphire, cyanobacterial mats) and represent a gradient in tidal amplitude (1.8 m in the south to 3.7 m in the north), while incorporating highly modified (Onslow) and natural (Giralia, Yammadery, Gnoorea) areas. All projects will align their field research efforts to these **indicative** field sites.




| Location | Area km² | Project A | Project B | Project C |
|---|---|---|---|---|
| Gnoorea | 145 | ✓ | ✓ | ✓ |
| Yammadery | 313 | ✓ | ✓ | |
| Onslow | 61 | ✓ | | ✓ |
| Giralia Bay | 443 | ✓ | ✓ | ✓ |

Figure 2: Study location with proposed field study sites along the Pilbara coast.

Giralia Bay represents the southernmost Pilbara coast site. Onslow represents a solar salt pond site, and is nearby a more natural site at Yammadery. Gnoorea is used to represent the northern Pilbara coast. Imagery is a false colour representation, with red representing the mangrove vegetation, bordered by the samphire and cyanobacterial mats (purple tone).

Table 1: Project Outputs and sub-objectives within the 3 approaches

| WAMSI and Steering Provided Deliverables | Knowledge Gap Identified | 1.1 Current extent of mangrove, samphire and algal mats in the west Pilbara | 1.2 Historic extent of algal mats, mangrove and samphire in the west Pilbara | 1.3 Temporal stability of mangrove, samphire and algal mats in the west Pilbara | |
|---|---|---|---|---|---|
| | **Deliverable Requested** | **1.1 Map of current distribution of mangrove, samphire and algal mats from SE corner of Exmouth Gulf to Karratha** | **1.2 Prediction of mangrove, samphire and algal mats from SE corner of Exmouth Gulf to Karratha prior to European habitation** | **1.3.1 Investigate and identify methods for assessing changes in the temporal and spatial extent of algal mat and samphire** | **1.3.2 Map and describe temporal differences in the extent of mangrove, samphire and algal mats in the west Pilbara, investigating the effect of season and disturbance** |
| Approach A | **A1 Broadscale habitat models for Pilbara coastas** | | | | |
| | A1.1 Utilise remote sensing and available validation data to provide a habitat extent model for mangrove vegetation, samphire zone, and cyanobacterial mat area on the Pilbara coast at annual timescales for satellite temporal scale (e.g., Landsat 30 years) | ☑ | | ☑ | ☑ |
| | A1.2 Provide validation data around habitat models. | ☑ | | ☑ | ☑ |
| | **A2 Investigate space-time dynamics of habitat for Pilbara coast** | | | | |
| | A2.1 Compare habitat extent models at temporal scales and investigate both spatial and temporal changes in mangrove, samphire zone area and cyanobacterial mat areas | ☑ | | ☑ | ☑ |
| | **A3 For selected field sites provide finescale models of current habitat extent** | | | | |
| | A3.1 Utilise remote sensing and field data to provide current habitat extent model for mangrove canopy, samphire, and cyanobacterial mat extents | ☑ | | | |
| | A3.2 Provide validation data around habitat models. | ☑ | | | |
| Approach B | **B1 Indigenous observations of environmental change** | | | | |
| | B1.1 Provide a record of living memories that capture environmental changes on Sea Country | | ☑ | | |
| | B1.2 Creation of ESRI Story Map for digital story telling of Indigenous narratives of Environmental change | | ☑ | | |
| | B1.3 Delivery of digitised participatory mapping datasets to Aboriginal Corporation cultural heritage managers | | ☑ | | |
| Approach C | **C1 Palaeo-eco-geomorphic investigation of West Pilbara coastal environments – NOT INCLUDED IN CURRENT BUDGET AND SCOPE** | | | | |
| | C1.1 Identification and characterisation of active and relic coastal landforms, establish their formation age | | ☐ | ☐ | ☐ |
| | C1.2 Creation of spatially-temporally contiguous sediment facies maps and assign an depositional environment | | ☐ | ☐ | ☐ |
| | C1.3 Reconstruction of high resolution palaeosea level curve spanning the late Holocene | | ☐ | ☐ | ☐ |

## Brief Summary of Methods including Proposed Timing and Data Analysis

The proposed methods are detailed below. The Project will provide 6 monthly summary briefs of completed tasks, as per the milestone data in Section 4. At the completion of the project a final report will be provided summarising all outputs.

### *Approach A > Remote Sensing*

This approach will utilise a combination of broadscale (satellite multispectral) and fine scale (airborne LiDAR-hyperspectral) remote sensing data to develop both predictive and actual habitat maps for the Pilbara coast respectively (Figure 3). Although not ideal the use of broadscale (satellite multispectral)  imagery is justified on the basis of limited budget and the requirement to produce a contiguous coastal habitat map (mangrove, samphire [habitat zone], cyanobacterial mats) for the entire Pilbara coast.

We will also develop a series of  temporal change maps at set time points using a composite image technique. This technique will provide an 'best pixel' across a time period to produce a more spectrally similar image for temporal change comparisons.

Higher resolution airborne topo-LiDAR and hyperspectral imagery will be collected across the defined study sites in Figure 3, with the aim to provide information on species level distribution across the various coastal habitats.  Higher spatial resolution satellite imagery will be purchased in order to expand the coverage beyond the study sites and improve the uncertainty in the regional scale predictive habitat map.

At a smaller number of locations we will purchase higher resolution satellite imagery (aerial footprint to be determined) to cover timepoints (seasonal/interannual) in order to provide information on the dynamic response of habitats to events like ENSO and past extent of coastal communities.

On ground mapping of habitat will be essential to validate both the airborne hyperspectral remote sensing data within the field study areas, and broadscale remote sensing satellite data outside the field study areas. This will require extensive field mapping across the entire Pilbara coastal study area with traverses covering as many habitat and community types as possible. Ground based fieldwork will also provide the ground control points which are required to validate the Topo LiDAR datasets.

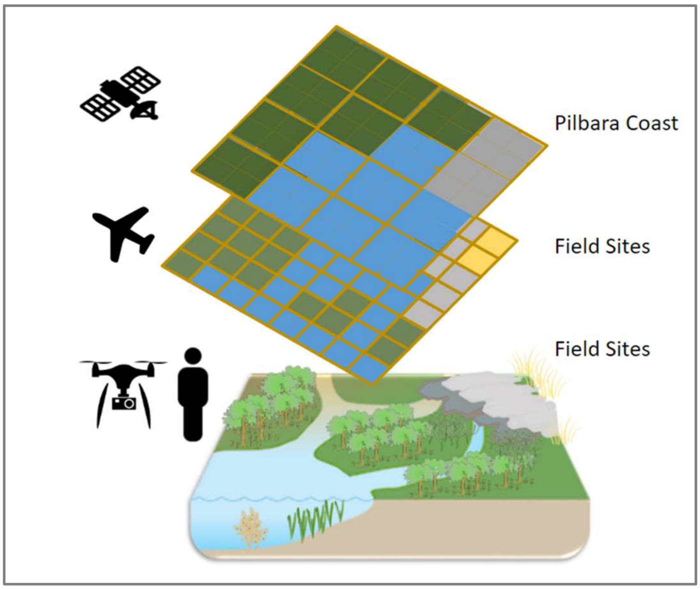



Figure 3: Conceptual overview of Approaches A1 and A3 illustrating the different scales and indicative methods data will be collected and habitat modelled at. See Supplementary Information for imagery examples.

**A1. Broadscale habitat models for Pilbara coast**

Landsat and/or Sentinel satellite imagery will provide the multi-decadal scale time series of environmental change along the Pilbara coast, as well as provide information on the regional scale spatial extent of key habitats in order to define areas for more focused (higher resolution) investigations. Modelling will follow the techniques of Hickey et al. (2021), Hickey and Radford (2022), and Chamberlain et al. (2021). Samphire has traditionally been difficult to map with multispectral imagery due to its similar spectral scale with the surrounding environment and low height, however it may be possible to map out the representative extent of samphire based on the landward and seaward boundaries of mangrove and cyanobacterial mats respectively, this is similar to techniques by Murray *et al.*, 2019. Cyanobacterial mat detection via broadscale remote sensing will be attempted following techniques by Murray *et al.*, 2019 and Hickey and Radford, 2022. A range of remotely sensed indices will also be established including greenness (e.g., NDVI for mangroves), and water (e.g., NDWI). Model validation will be undertaken where validation data is available (e.g., high resolution imagery, previous available field data).

*Deliverable A1.2 is to provide validation data for habitat models. Validation data refers to uncertainty mapping. We are mapping 4 focus sites with high resolution LiDAR and hyperspectral imagery as well as field data (A3). We have allocated a budget to purchase available historical high resolution satellite data to supplement current information for these sites, listed in the budget as Remote Sensing Data. All maps will have uncertainty information. Also, we are mapping the entire Pilbara coast study region from Giralia to Karratha as identified in Figure 1 at a broader scale due to project budget limitations in collecting high resolution data over wider areas. We will use the overlap of the focus sites to help develop and validate models to inform the uncertainty of the mapping. However it is important to note that if there is no high resolution data or field data at sites there is no way to validate the model with certainty at these sites, a global (e.g., regional) validation will be provided.*

*NDVI and water indices are provided as examples of common spectral indices. Everything on the Earth's surface reflects and absorbs wavelengths (spectra) uniquely. We will be utilising this with other ecological information to develop a model to predict these habitats. For instance, Lovelock et al. 2009 has shown that at least for Giralia, cyanobacterial mats, samphire and mangrove exist in specific tidal envelopes, characterised by the location relative to lowest astronomical tide and sea level. Field data and hyperspectral information, along with LiDAR will be collected at the 4 field focus sites, with this information we will be able to explore what specific spectral indices, along with what other information (e.g., water inundation) are useful for predicting samphire and cyanobacterial mat presence or absence.*

**A2. Investigate space-time dynamics of habitat for Pilbara coast**

Spatial-temporal analysis will be used to investigate changes in key habitats (yearly through to multidecadal) following the methods of Hickey et al. (2018); Hickey and Radford (2022). This will be key in establishing the response of these habitats to climate driven changes in sea surface height, precipitation and atmospheric temperatures. It will also establish those habitat areas which 1) experience a more ephemeral existence, 2) have experienced a transition in habitat type, or (3) those areas where indicative habitat is more stable or persistent though time. It is these areas of more stable habitat that could become the focus of long-term monitoring (e.g., TERN). We will also use historical air photo imagery to establish the historical loss of mangrove-samphire-cyanomats that resulted from the development of the Onslow and Dampier solar ponds and crystallisers (e.g., SI1 and SI2).

**A3. For field sites provide finescale models of current habitat extent**

Due to the limitations in spatial/spectral resolution when mapping at the regional scale, four locations within the border study area are selected for higher (spectral and spatial) resolution investigation. Following the techniques of Hickey et al. (2018), we use airborne LiDAR and hyperspectral scanners to map geomorphology and vegetation at the decimetre scale. At this level of resolution it will be possible to quantify mangrove canopy height and cover, map the distribution of samphire, examine the spectral traits of cyanobacterial mats, and detail the transition of habitat as it relates to surface elevation or tidal dynamics. Spatial modelling at this final scale will use similar techniques to the broadscale mapping approach discussed above.

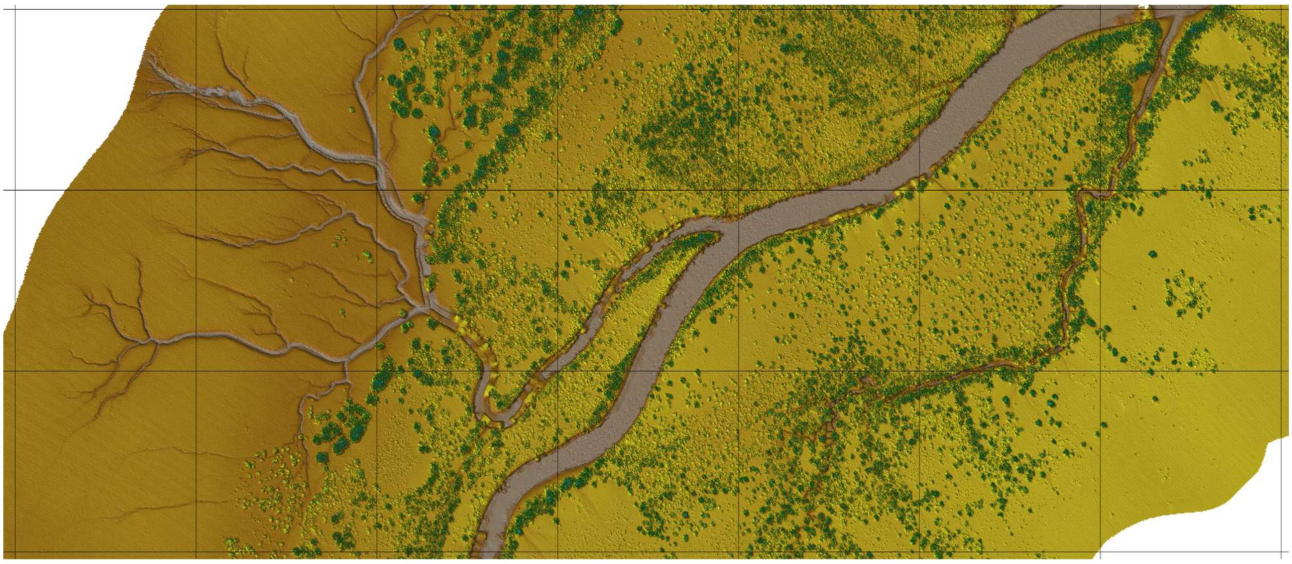


*Figure 4: Exemplar LiDAR data showing Urala Creek (NE Exmouth Gulf). Grid cells = 100 m and pixel resolution is 25 cm. Green is representative of mangrove canopy.*

***Approach B***

**B1 Provide a record of living memories that capture environmental changes on sea country**

We will document cross-cultural perceptions and configurations of threat as it relates to the West Pilbara coastal environments. The cross-cultural emphasis will be on establishing the parameters and nature of Indigenous and mainstream non-Indigenous understandings of threat/risk/harm as it relates to these coastal environments (See Kearny et al., 2022). This is a crucial step in establishing the cross-cultural parameters of this project and will inform the project's 'bridging discussions' aimed at centralising Indigenous perspectives in a discussion of risk/threat/future security, and of generating intercultural approaches to addressing the impact of change in sea country settings over the short and long term.

Key activity will be the presentation at a workshop of very large printed airphoto maps of the Pilbara coast, to Indigenous Elders, Rangers, and community participants. The maps are then annotated by the traditional custodians with their personal observations as well as contextualising change across longer timescales using intragenerational intergenerational ancestral narratives. These annotated maps can be then used to extend the deeper time understanding of environmental change along the Pilbara Coast. This will be communicated back to the community via ESRI storymap as a form of digital storytelling of Indigenous narratives of environmental change. We will also digitistise participatory mapping outputs as spatial layers and provide these to the appropriate Aboriginal corporation and their cultural custodians/managers.

Key Indigenous stakeholders within the study area are the Buurabalayji Thalanyji Aboriginal Corporation (BTAC) based in Onslow and the Murujuga Aboriginal Corporation (MAC) Based in Dampier. O'Leary has had strong engagement with MAC over the last 6 years and has engaged with BTAC on a number of project proposals. Amanda Kearny (Melb Uni) is an internationally recognised Australian anthropologist and will lead the Indigenous engagement component of this project.

## 2 Linkages to other Projects

Project A will provide initial assessment of the spatial extent of the habitats for Project B and C to inform sampling design. Project A will provide updated habitat models to Projects B and C to scale data to Pilbara coast and regions of interest. Project A will work closely with Projects B and C on ecological data and application of spatial data and temporal scales for prediction modelling. Project A will work with Project B if change analysis is shown to link to sea level, or cyclone events to explore impact on habitat here from the remotely sensed habitat data.

All projects will share data, and will aim to coordinate field trips. A data management plan following WAMSI protocols will be implemented for access during and post project duration. We will liaise with DBCA, DPIRD and other relevant stakeholders.

**Other Work Declaration**

Hickey and Lovelock are currently engaged by Minderoo Foundation to write a review of the Exmouth Gulf Salt Flats, and develop a cyanobacterial habitat envelope spatial layer for the Exmouth Gulf (Giralia to south of Onslow). The review is due to be completed August 2022, and the spatial layer December 2022 (desktop study, and not representative of a single time-point - envelope of likely area). There is a further review of carbon and productivity modelling using current literature (desktop study), and potential changes (desktop study) due June 2023 and December 2023. The initial review and spatial layer will be completed prior to this project commencement, and the further reviews are based on published data or methods so will not use data or methods from this proposal and projects. The published methods of this engagement may aid in the method development for this proposal/project but due to scale and validation of outputs (spatial and temporal) does not overlap deliverables. All outputs are to be open access.

## 3 Project Funds Requested

*Estimated cost of the project with supporting rationale including:*

- Resource contributions from other parties (including in-kind contributions);
- Potential synergies and co-dependence on other projects.
- Possible opportunities to leverage funds;

The budget is based on salary and operational costs starting January 2023. Total funds requested $690,000.00 and in-kind contribution $430,205.

Salaries: Appointed positions will be required to undertake extensive remote sensing analysis, assist in field, and Indigenous engagement activities.

Operating Costs: The field work budget is based on the hire of a vessel, accommodation, vehicle travel. transport of equipment, flights for 4 field campaigns.

Data: We have attempted to budget $300k across the 3 projects ($120k(A), ~$70k(B), $75k(C) to do this. This equates to a coverage of approximately 12% of the Pilbara coast region as identified from the Steering Committee. Any gap in amount we ask the Steering Committee to help with allocating resources for this.

This cost covers transfers of aircraft from Adelaide-Karratha-Adelaide, all ground logistics, plus 10 days of survey. It is possible to map approx. 50 square km per day (LiDAR/Hyperspectral/Airphoto). The Aircraft can carry the hyperspectral scanner (SPECIM EAGLE II VNIR 400-1000nm, up to 488 bands) or either a Topo-Bathy Lidar (RIEGL VQ820G) or topographic lidar (RIEGL Q680i-S) (there are only 2 underwing pods to house these instruments). The Topo-Bathy Lidar will capture tidal creeks, nearshore bathymetry and landforms now submerged within the solar ponds, however this is not the best instrument for capturing terrestrial vegetation and landforms, so for terrestrial mapping we would recommend the Q680i-S topo-Lidar system. To operate both LiDAR systems simultaneously. To extend LiDAR and hyperspectral imagery to the entire coastal region would equate to $1.5 million, and a minimum of 50 days of flight time.

Due to the limited area (12%) covered by the airborne survey we intend to augment this with high resolution satellite imagery, however, to cover the entire region this was quoted at $1.25 million - $4.5 million depending on satellite data available. This would be for 1 time point, which may not be the same along the entire coast as it is based on satellite capture date and it is an extensive area, so is not captured in a single scene. This is based on an academic price from Apollo Mapping at $156-.25-$568.75 for 25km2.

Instead, to scale the data within the budget constraints we have augmented high resolution data at focus sites that overlap field data, and will use broadscale lower spectral/spatial satellite data to scale. This has limitations around sites being representative of the Pilbara coast, of being able to detect samphire or cyanobacterial mats, utilising habitat ecology with remote sensing data to build habitat prediction models. We will be required to validate these additional areas with in situ field observations and provide uncertainty models. We are also utilising in-kind high spatial resolution satellite data PlanetLabs (low spectral data) under the UWA academic licence (10,000 sqkm per month costed at $15, 0000 annual licence) to augment Landsat and Sentinel imagery for the Pilbara coast scale maps. Where there is no field data or high resolution imagery validation of habitat models is based on global values and there will be uncertainty here.

In-kind: Is based on a contribution of team members employed at UWA, ECU, CURTIN and UQ. It is anticipated that Universities will waive their University Service Charge (USC) on research grant income. Other in-kind contributions relate to use of infrastructure such as computing, imagery and LiDAR, field equipment, and lab infrastructure.

**Table 2. Funds requested from WAMSI**

| | | | |
|---|---|---|---|
| **Item** | **Year 1** | **Year 2** | **Total** |
| Salaries Post-doctoral fellow -Remote Sensing (2 years *1.0fte) | $147,055.00 | $149,996.00 | **$297,051.00** |
| Salaries Post-doctoral fellow - Indigenous Engagement and Field (2 years *0.5fte) | $73,528.00 | | **$73,528.00** |
| Salaries Research Assistant (Level 4.4) (3 months) | $35,000.00 | | **$35,000.00** |
| Remote Sensing Data | $97,421.00 | | **$97,421.00** |
| Field Costs (boat, vehicle, accommodation, logistics) | $40,000.00 | | **$40,000.00** |
| LiDAR (across 3 projects) | $120,000.00 | | **$120,000.00** |
| Indigenous narrative workshop | $15,000.00 | | **$15,000.00** |
| Hardware/Computing | $6,000.00 | $6,000.00 | **$12,000.00** |
| | | | |
| **Total** | **$534,004.00** | **$155,996.00** | **$690,000.00** |

Table 3. Co-investment (staffing)

| Organisation | Year 1 | | Year 2 | | Total |
|---|---|---|---|---|---|
| | *FTE* | *($'000)* | *FTE* | *($'000)* | |
| **Sharyn Hickey (UWA)** | 0.2 | $30,174.00 | 0.2 | $31,829.00 | $62,003.00 |
| **Mick O'Leary (UWA)** | 0.2 | $39,452.00 | 0.2 | $40,241.00 | $79,693.00 |
| **Peter Fearns (Curtin)** | 0.1 | $17,000.00 | 0.1 | $17,000.00 | $34,000.00 |
| **Shams Islam (ECU)** | 0.2 | $36,283.00 | 0.2 | $38,226.00 | $74,509.00 |
| **Catherine Lovelock (UQ)** | 0.02 | $12,000.00 | 0.02 | $12,000.00 | $50,000.00 |
| **Total** | | **$134,909.00** | | **$139,296.00** | $274,205.00 |

**Table 4. Co-investment (cash and in-kind)**

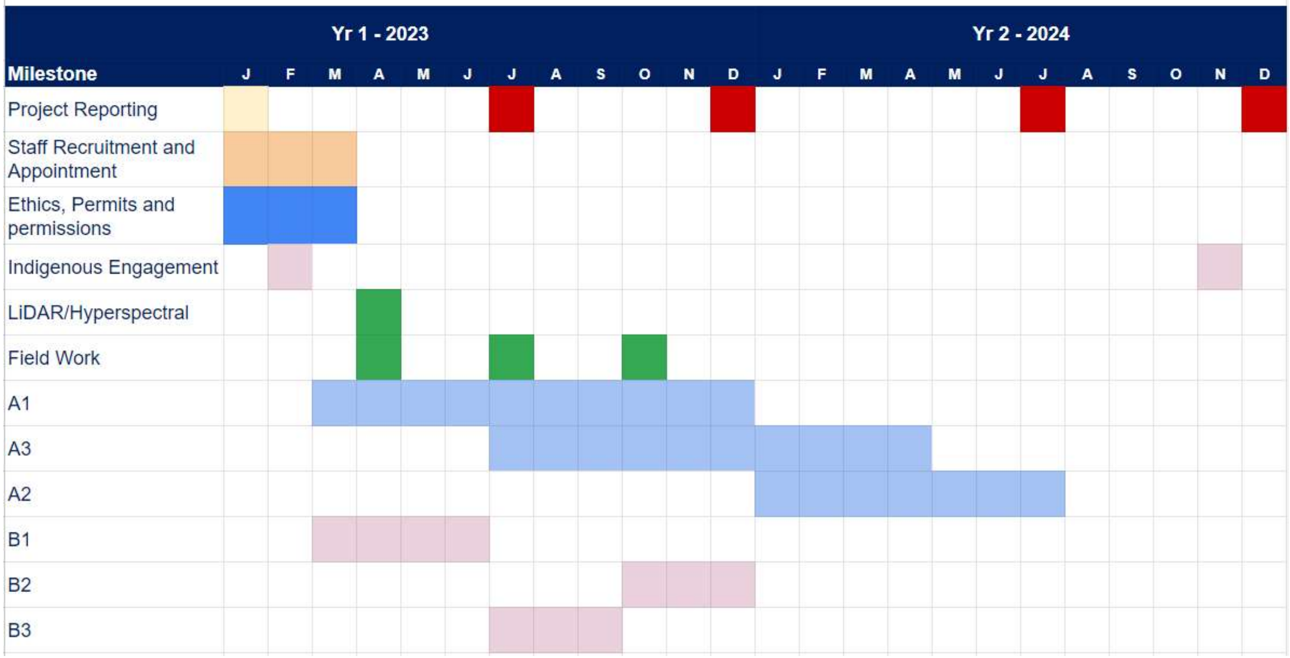
| Organisation | Year 1 | | Year 2 | | Total | |
|---|---|---|---|---|---|---|
| | *Cash ($'000)* | *In-kind ($'000)* | *Cash ($'000)* | *In-kind ($'000)* | *Cash ($'000)* | *In-kind ($'000)* |
| UWA | | $57,000.00 | | $53,000.00 | | $110,000.00 |
| ECU | | $23,000.00 | | $23,000.00 | | $46,000.00 |
| Curtin (TBC) | | | | | | |
| UQ (TBC) | | | | | | |
| **Total** | | **$80,000.00** | | **$76,000.00** | | **$156,000.00** |

## 4 Timing and Deliverables

*Proposed timing (start data and duration) and the deliverables of each Project.*

The project has been planned to be completed within the 2 year timeframe.

Table 5: Overview of Milestones and pproject timeline. A1 -B3 refer to Appraoches and objectives within each, refer to Table 1.



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**Supplementary Information**

SI1 and SI2: Example of historical imagery available - noting resolution, black and white and not georeferenced.

Figure SI1: Solar salt fields near Dampier, Western Australia taken by Wolfgang Sievers 1971, available on Trove (https://nla.gov.au/nla.obj-145889266/view )

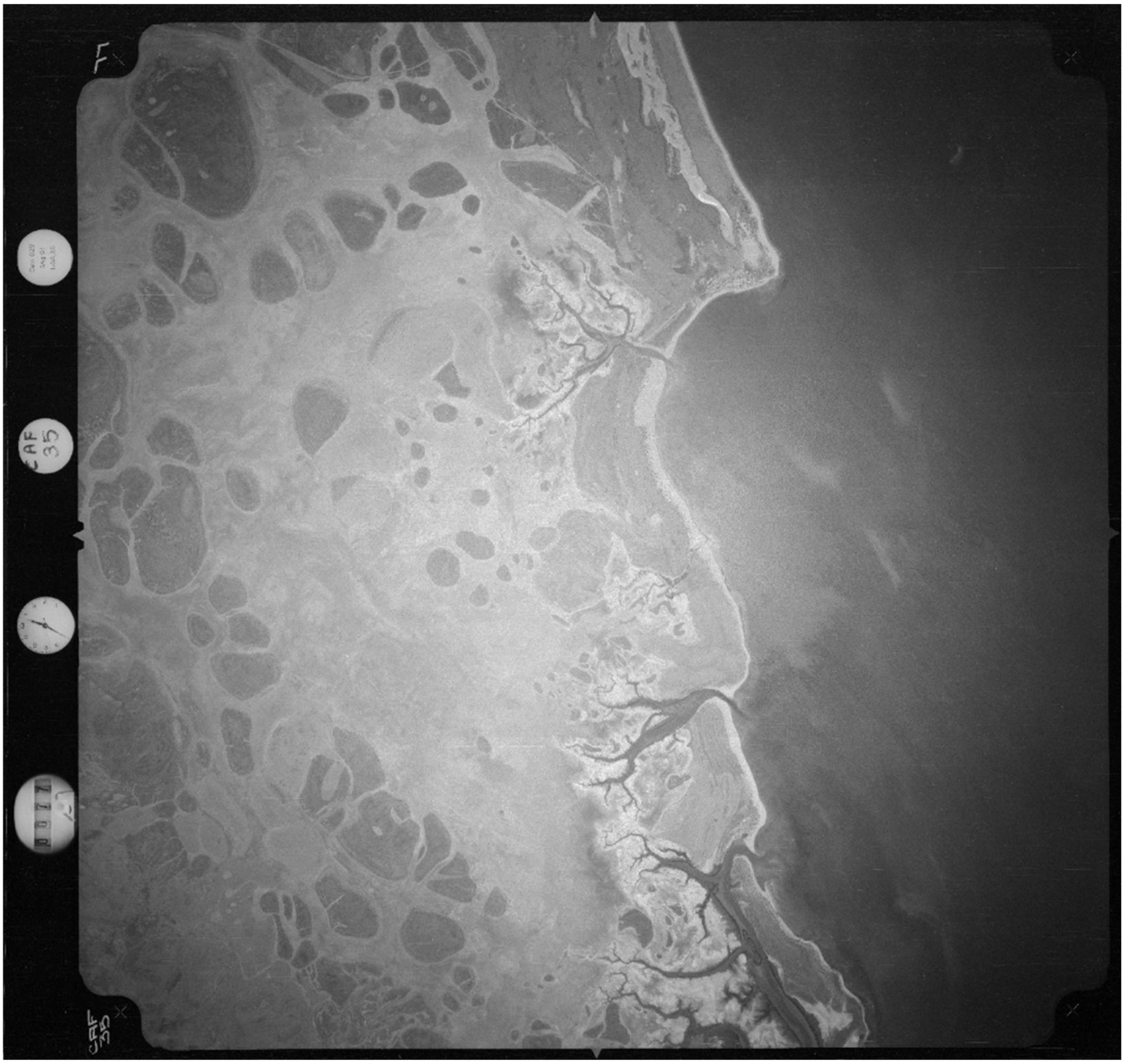


Figure SI2: Black and white non georeferenced image of Onslow solar salt ponds area, flown 1967, source: Geoscience Australia (Historical Aerial Photogrpahy).

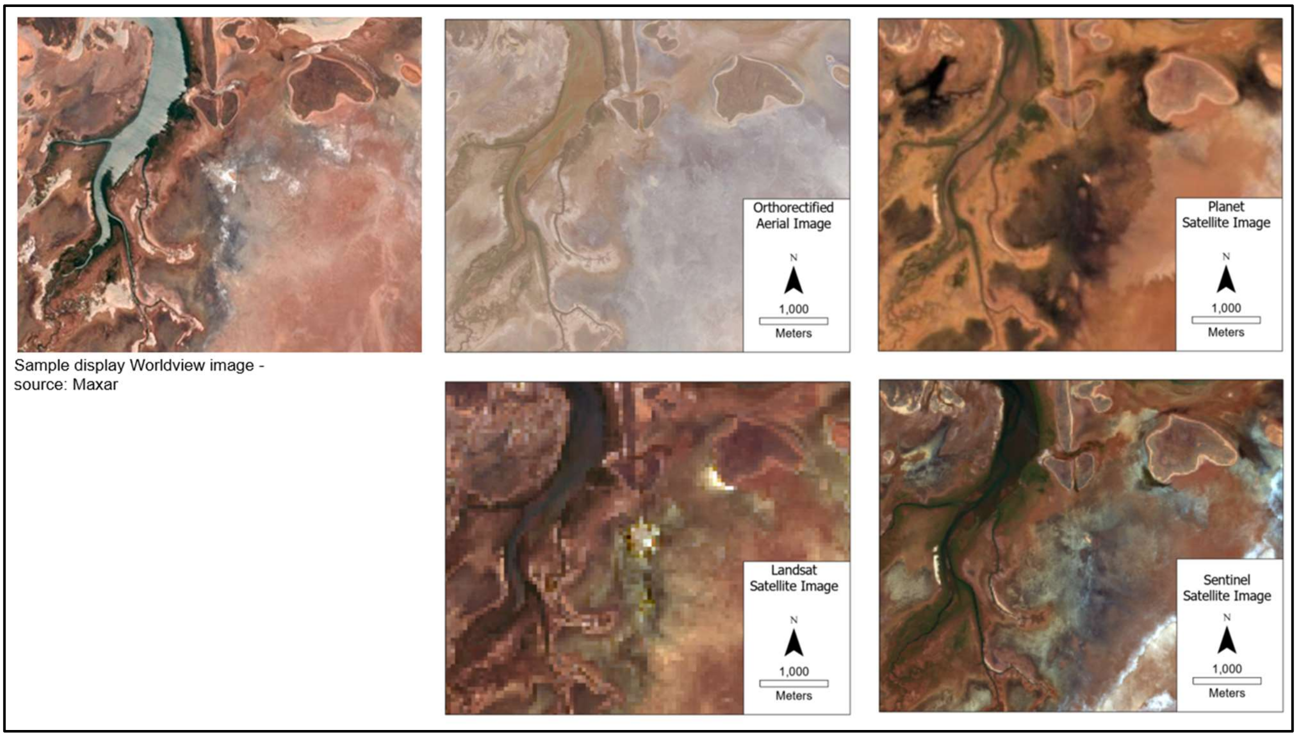



Figure SI3: Samples of different images available to do the mapping for more recent extents. Samples show differences in resolution, that is, pixel size, which reflects what can be detected on the ground. Pixel size ranges from cm for orthorectified aerial image and WorldView to 30m with Landsat. The temporal resolution also changes, with some options daily like Planet, or weekly/fortnightly like Sentinel and Landsat. Landsat also provides a longer time series at approximately 30years of regular available data.

# ATTACHMENT 2B –PROJECT SUMMARY Mardie Project Marine and Intertidal Research Offset Program – Project B

| | |
|---|---|
| **Project Title** | ***Quantifying the effects of climate change on intertidal habitats of the west Pilbara coast*** |
| **Project Leader/s** | Matthew Hipsey and Ryan Lowe |
| **Project Team** | Arnold van Rooijen, Jeff Hansen, Mike Cuttler, Marco Ghisalberti, Catherine Lovelock |

## *1* Project Summary

*Mardie Minerals Pty Ltd (a wholly owned subsidiary of BCI Minerals Limited) is developing the Mardie Project, a solar salt and sulphate of pot ash production facility, in the Pilbara region of WA. Ministerial Statement 1175 (MS1175) provided conditional approval for the Project that includes requirement for financial offsets for marine and intertidal research. The research is to focus on risks to the intertidal benthic communities and habitat (BCH) along the West Pilbara Coast, namely the areas of mangroves, algal mat and coastal samphire. Values associated with BCH include primary productivity, ecosystem maintenance, nutrient cycling, carbon storage and habitat values such as foraging, breeding or nursery habitat. The proposed research project (Project B in MS1175) aims to quantify the nature of future risks faced by BCH, with the outcomes to be used to guide the strategic protection and management of the ecological values of these habitats into the future.*

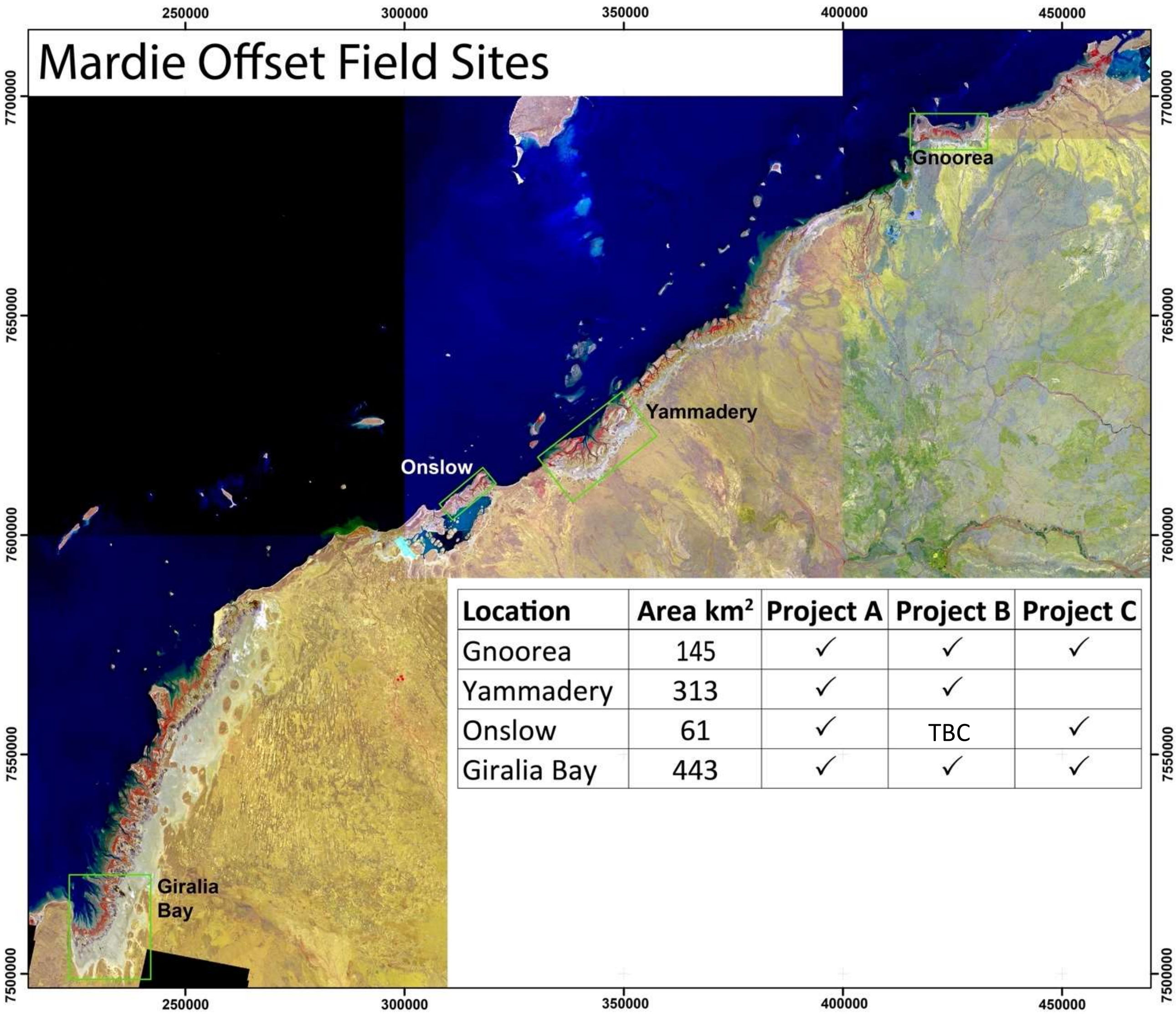
**Project Rationale**

The intertidal communities and habitats across the West Pilbara Coast, where salt projects are being developed, create a unique eco-geomorphic setting with extensive tidal creeks, tidal flats and other low-lying coastal landforms (Brocx and Semeniuk 2015). Such arid zone coastal wetlands are rare globally compared to analogous temperate or tropic zone systems (Adame et al. 2020), due to how they are established by the complex zonation of salinity, sediments and habitat that are collectively shaped by tidal cycles. Episodic inputs and flooding from the terrestrial edge interact with sea level variability to create a complex inundation regime and pattern of salt, nutrient and sediment redistribution within the intertidal landscape. However, there remains limited data and gaps in our understanding how different coastal units in this region behave, making it difficult for regulators and managers to assess the risks of coastal developments and environmental change, and to support conservation efforts.

The large intertidal areas along the West Pilbara Coast display a notable zonation of mangrove, samphire and algal (cyanobacterial) mat communities that span from the sub-tidal areas within the coastal embayments to the terrestrial edge (Figure 1). The broad salt-flat areas where the algal mat exists, experience a complex ecohydrological regime based on the interaction between rainfall, evaporation, surface-groundwater interaction, and flooding and inundation frequency (controlled by periodic tidal cycles and episodic extreme events such as tropical cyclones). These coastal habitats likely provide a substantial subsidy to both sub-tidal marine ecosystems and surrounding terrestrial ecosystems; however, to what extent remains unknown. In addition, given the sensitivity of many of these BCH to altered inundation and salinity regimes, any abrupt changes to conditions may trigger mortality of different species or communities and eventually alter their present distributions. For example, relatively small sea level anomalies (order 10 cm) during the 2015/16 El Nino, led to well-documented Mangrove dieback events at a number of locations across northern Australia (Lovelock et al. 2017). Furthermore, recent examples have shown that mangroves experiencing hyper-salinity may have little room to adapt when conditions become stressed, which can lead to tree mortality (Dittmann et al. 2022).

Complex feedbacks between physical and ecological processes mediate how vegetation and habitat areas adapt to sea level variability and salinity regimes (Sandi et al. 2018, Wimmler et al. 2021). Different vegetation biomass and form has a different ability to attenuate flows (Rodriquez et al. 2017, Gelderland

2020), and flows and inundation patterns also mediate soil salinity in the root zone which can affect growth and persistence of vegetation (Wimmler et al. 2021, Dittmann et al. 2022). By modifying near-bed flows, the physical properties of coastal vegetation often have a profound influence on local sediment transport processes (including those responsible for coastal erosion and accretion), which over periods of time (e.g. years to decades) can play a major role in shaping evolution of coastal landforms (Lowe and Ghisalberti 2016). Changes to coastal vegetation can thus determine the capacity of a coastal system to mitigate and adapt to different coastal hazards (e.g., extreme storms and sea level rise) (Willemsen et al. 2021). For example, historical losses of mangroves in southern Asia have been directly attributed to large-scale erosion of deforested sections of coastlines (e.g., Mazda et al. 2002).




| Location | Area km² | Project A | Project B | Project C |
|---|---|---|---|---|
| Gnoorea | 145 | ✓ | ✓ | ✓ |
| Yammadery | 313 | ✓ | ✓ | |
| Onslow | 61 | ✓ | TBC | ✓ |
| Giralia Bay | 443 | ✓ | ✓ | ✓ |

Figure 1. Study location showing the proposed focus sites along the Pilbara coast. Imagery is a false colour representation, with red representing the mangrove vegetation, bordered by the samphire and cyanobacterial mats (purple tone).

The potential for disruption of intertidal habitats is primarily in response to developments and operations within the intertidal zone, which are superimposed onto projected changes associated with climate change (Gordon 1998; Guo et al. 2022). Climate change effects include sea level rise (SLR), as well as changes in rainfall, cyclone frequency and temperature. Whilst there are various conceptual depictions of these environments (e.g., Semeniuk, 1994; Eliot 2013) and site-specific studies (e.g., as undertaken as part of regulatory requirements or commercial activities), their remains a fundamental lack of knowledge of how sensitive these habitats, and the ecosystem services they provide, are to proposed future developments and anticipated climate changes. It also remains unclear how sensitive habitats may be across the variety of different coastal landforms that exist within the Pilbara Coast.

As a result, there is a need to identify and quantify the potential effects of climate change (including sea level rise) on mangroves, samphire and algal mat along the West Pilbara Coast, and to be able to assess the significance of salt projects in potentially altering the capacity of intertidal BCH to move and adapt to changing future conditions. The development of conceptual and numerical models is therefore needed to provide a holistic assessment of how these ecosystems are likely to respond; however, to date there are not well accepted conceptual or numerical models able to fully resolve the interactions that are known to be important in shaping the coupled evolution of both habitats and coastal morphology under changing environmental conditions.

**Project Objectives and Outcomes**

The overall aim of the project is to develop a predictive understanding of how West Pilbara coastal wetlands are likely to change in the future due to climate change and salt project developments.

Specific project objectives include:

1. Undertake synthesis of our current understanding and knowledge gaps through data review, and conceptual model development
2. Develop a modelling capability that will be applied to assess how intertidal BCH will respond changes in sea level, flooding and extreme events, and coastal development
3. Assess how different coastal processes determine the function and migration capacity of intertidal habitats
4. Assess how future changes in sea level, extreme events and salt works may impact upon the intertidal habitat distributions and function

Specific outcomes from the research project include:

- Collation and analysis of available environmental data and revised conceptual models relevant for the region
- High-resolution and sub-regional coastal models for the complex West Pilbara Coast, including intertidal areas.
- Understanding of environmental controls on intertidal BCH, and projections of future habitat areas in response to climate change
- Understanding of the sensitivity of intertidal BCH to developments within the intertidal zone
- New fit-for-purpose coastal modelling capability for the region that will be available for future environmental assessments

**Brief Summary of Methods including Proposed Timing and Data Analysis**

The project proposes to include an initial data collation and conceptual modelling phase (Task 1), followed by the sequential development of a fit-for-purpose modelling capability (Task 2-4), and finally application of the models to answer the key questions related to future responses and risks faced by the intertidal BCH (Task 5). The relationship and dependencies between the major work components is shown as a summary in Figure 2, the proposed approach is expanded upon further below.

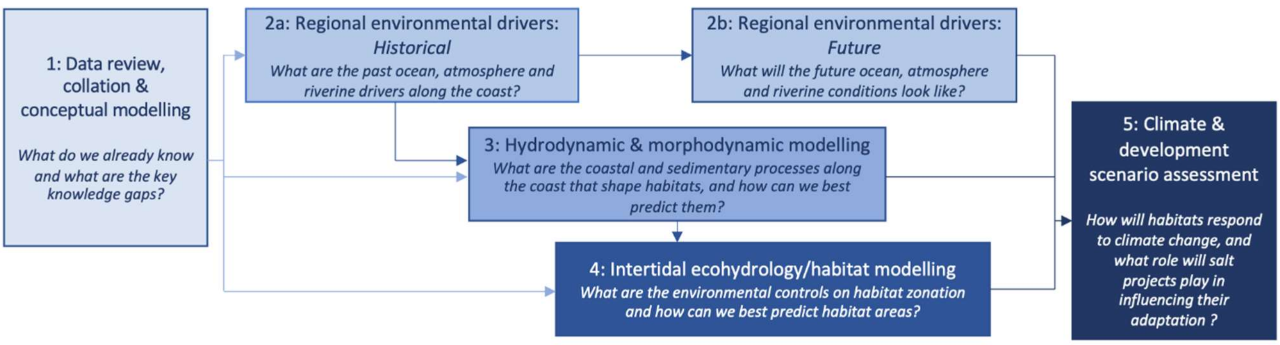


Figure 2. Overview of the five key work components proposed for the assessment and the key question(s) they seek to focus on.

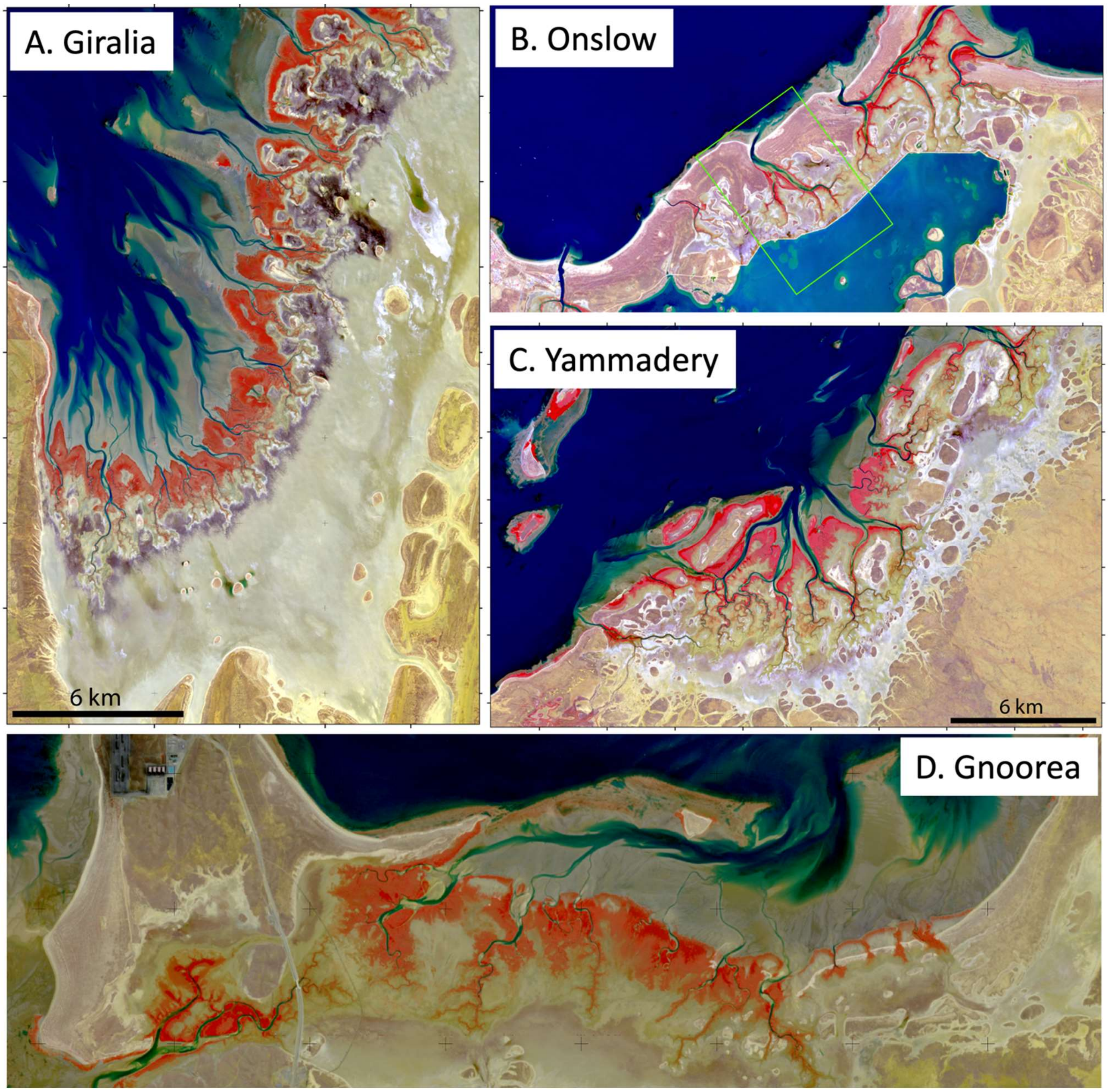



Figure 3. Focus sites chosen for model development, validation and testing.

The project will focus on understanding and predicting the physical, environmental and biological processes at up to four focus sites (Figure 3). These sites have been chosen to represent a range of tidal regimes, coastal morphologies and habitat landscape characteristics and also coincide with focus field study sites for Projects A and C. The development of models for each site (detailed below) will require critical field data for model input (e.g., high resolution bathymetry/topography, sediment properties, habitat properties, hydrodynamic observations, etc.) and for model calibration/validation. The exact scope of the model applications will thus likely vary among sites depending on available field data at each site (i.e., from data collected in Projects A and C and any available historical industry datasets). For example, Project C will likely collect in situ field data at 2-3 of the sites, allowing for a more detailed validation of the processes at these sites. Final site selection will be reviewed in the next phase of the Mardie Offset Program application process following the EOI phase.

***Task 1. Data review collation and conceptual modelling***

The West Pilbara Coast is remote with patchy availability of prior environmental data. There is a range of potentially valuable data available held in unpublished studies, or undertaken by consultants and industry. Similarly, there are a range of past coastal management relevant impact and assessment studies that have been undertaken.

In collaboration with Project A and C, this first task will therefore seek to:

- Catalogue and collate prior environmental data-sets relevant to the region, including seeking permission for access to datasets held in the private domain;
- Undertake a workshop including selected research and industry experts on coastal management to develop refined conceptual models of the physical and ecological processes shaping BCH distribution and adaptation pathways;
- Identify key knowledge gaps, including priority areas of model development to resolve BCH (e.g., physical controls on sediment movement, processes controlling mangrove seedling recruitment, environmental controls on algal mat productivity, surface-groundwater interaction and salt redistribution, etc.).

***Task 2. Regional environmental drivers***

Available oceanic and atmospheric data for the Pilbara coastal region will be compiled for a period spanning several decades (up to 60 years) to identify how historical changes to intertidal BCH and coastal morphology (quantified in Project A) are related to key environmental drivers over a range of timescales, i.e., from long term (decadal) to extreme events (e.g., from tropical cyclones).

Data for this task will be sourced from a combination of existing hindcast regional ocean model outputs, regional weather/climate model datasets, remote sensing data and available historical *in situ* coastal observations available in the region, noting that individual datasets are available over different timeframes. Regional model output of historical ocean conditions (e.g., waves, sea level, ocean currents, temperature, salinity, etc.) will be sourced from a combination of existing high-resolution model simulations of the North West Shelf using ROMS-SWAN (Dufois et al. 2019) and using Delft3D-SWAN (Sun and Branson 2018), both of which have been extensively validated using data collected as part of the Wheatstone monitoring program. Additional ocean data will be sourced from satellite remote sensing products (e.g., for SST, turbidity, etc.), long term sea level (tide gauge) and wave records (e.g., from DoT). For atmospheric data, output from the ERA5 Reanalysis (Hersbach et al. 2020) and regional BOM weather stations will provide atmospheric forcing information (e.g., rainfall, wind, atmospheric heat fluxes, etc.).

Project A will develop maps of historical changes of key BCH in the West Pilbara (i.e., algal mat, mangrove and samphire habitat) and changes to coastal landforms. Analysis of data from Task 2 will be used to develop long term timeseries of the key environmental drivers in the region to quantify the influence of environmental drivers on historical changes to BCH and coastal landforms, in collaboration with Project A. Data from Task 2 will also be used as boundary conditions for the much-finer scale coastal models developed in Tasks 3-5.

Finally, Task 2 will develop a set of environmental conditions under future climate change scenarios (e.g., up to 2100) using data from CMIP6 (O'Neill et al. 2016), which will include projected changes from sea level, ocean and atmospheric warming, and wind and wave conditions. These future climate forcing scenarios will be used to force the coastal-scale model applied in Task 5, providing the necessary inputs for future habitat predictions.

***Task 3. Coastal hydrodynamic and morphodynamic assessment***

A coupled high-resolution hydro-morphodynamic model will be developed using the Delft3D Flexible Mesh software suite (Delft3D-FM). Delft3D-FM is a state-of-the-art numerical modelling suite developed by Deltares and that is capable of simulation complex interactions in coastal and estuarine environments. The hydrodynamics will be simulated on unstructured 2D or 3D (or a combination thereof) domains, with high mesh resolutions designed to resolve complex intertidal zones that typify the study region, e.g., tidal creeks and other heterogeneous geomorphological features. The model will include a range of processes including resolving the effects of currents and waves, on cohesive and non-cohesive sediment transport, and the influence of different vegetation types such as mangroves, samphire, algae mats and other aquatic vegetation on hydrodynamics and sediment transport. Models will be developed for the sites shown in Figure 1, with domains focused around the areas where field work and validation measurements are planned for collection (Figure 3). Note, the final simulated sites may be subject to change depending on the final bathymetric and data collection campaigns agreed within Project A and C.

Bathymetry for the model domains will be based on the higher-resolution data that is to be obtained in collaboration with Project A using aerial LiDAR and/or photogrammetry, and supplemented by merging with the existing 30-m-resolution North-West Australia Digital Elevation Model (available from Geoscience Australia) or TanDEM-X products where necessary.

Sediment model inputs will be based on analysis of sediment samples (both grab samples and sediment cores) collected at the site as part of the Project A field campaigns (i.e., grain size distributions and composition), and mapped over the simulated regions. In addition, sediment cores will be analysed in the UWA Coastal & Offshore Engineering Laboratory O-tube facility to obtain critical shear stress values and sediment resuspension rates that are required for the different sediment types within the model.

Vegetation model input will be derived from the validated BCH distribution maps from Project A and will impact upon water flows through water drag and altering resuspension. The model also enables coupling with a dynamic vegetation module, allowing for inclusion of the parameterization of vegetation colonization, development and mortality (Willemsen et al. 2022), which will be tailored for the application based on review work undertaken in Task 1.

Once the domains are setup, a range of hindcast model simulations will be undertaken, as forced by the regional ocean and atmospheric condition data from Task 2. A range of different conditions will be resolved including for key cyclone and flood events for where data is available for model comparison and validation (e.g., studies undertaken in Giralia Bay such as May et al. (2018) and Lovelock et al. (2021) showing post-cyclone shifts in sediment, mangrove dieback and recruitment). For the present study period (2023-2024), the models will additionally be assessed by comparing to available in-situ hydrodynamic and sediment data collected at a range of strategically chosen sites (collected in collaboration with Project A and C), and data from remote imagery (e.g., ponded areas, water turbidity).

The validated model will be used to improve understanding of local and larger scale flows (transport pathways) and resulting sediment dynamics both at the scale of the focus sites. Analyses of the model results will be undertaken to develop insights into the role of the present BCH on hydro- and morphodynamic processes, as well as how current typical conditions influence the present BCH distributions. The results will be explored in terms of the relative contribution of long-term changes (e.g., sea level variability) and past extreme events (e.g. cyclones) to the distributions of BCH.

***Task 4. Intertidal ecohydrology assessment***

Beyond physical controls (e.g., water inundation patterns, and sediment supply or erosion), habitats in the broad intertidal flats are also sensitive to water and soil salinities, nutrient availability, and weather drivers such as light and temperature. In this task the hydro-morphodynamic model developed in Task 3 will be extended to include simulation of the intertidal ecohydrology, with new modules for capturing the salt dynamics, and algal mat and samphire habitat.

Salinity within the intertidal regions of arid coastal wetlands can be complex and excessive salinities may become a barrier to the movement of habitats inland into the future. The accumulation of salt occurs as saline ocean and ground water is subject to evapo-concentration, forming areas of hyper-salinity in the root-zone and salt crusts. Salt becomes redistributed following periods of inundation, flooding and rainfall. Seeps of saline groundwater in local depressions and tidal channels can also influence local salinity regimes. Various models such as SUTRASET and OGS have recently been used resolve the tidally driven changes in groundwater levels and salinity in tidal marshes (Liu et al. 2022, Bathmann et al. 2021); however, to date coastal hydrodynamic models do not account for these dynamics, making it difficult to connect hydrodynamics, sediment transport, vegetation and habitat. Therefore, whilst coastal models like Delft3D-FM provide a base platform able to resolve evapo-concentration and hyper-salinity, further development is required to model processes necessary to resolve intertidal salinity dynamics before the controls on intertidal habitats can be fully captured.

Model tools for simulation of vegetation communities in salt-marsh and mangrove ecosystems include MANTRA (Luo and Chui 2022) and MANGA (Bathmann et al. 2021). These models resolve the groundwater flow and salinity dynamics, and by capturing the persistence of vegetation based on the underlying salinity and water constraints on growth and establishment, they have been used to show how vegetation will adapt to changes in hydrologic conditions over long time periods. Whilst some examples have been published, they have not been used as part of an integrated assessment accounting for variability in hydrodynamic and sediment transport processes which may alter the landform shape. Furthermore, models for capturing responses of cyanobacterial mats and samphire to environmental conditions also currently do not yet exist.

In this Task 4, we will therefore develop an integrated platform for resolving coastal salinity and habitat models suited for the Pilbara Coast. Model development will be undertaken with the AED aquatic ecology library (Hipsey, 2022) or through linkages with existing open-source codes where possible. These will be used linked with the hydrodynamic-sediment transport model as developed in Task 3. Samphire and algal mat model parameterization will be undertaken based on literature review (e.g., Stal 1995, Adame et al. 2012), and process data collected within Project C, assessing environmental controls on algal mat biomass and productivity.

The salinity predictions will be first validated using data from in situ soil and water salinity measurements collected within the 'natural' focus sites, and in addition we will explore salt crust quantification via remote sensing tools in collaboration with Project A. Validation of the vegetation/habitat models will be based on spatial data on vegetation extent from Project A, and local data from the focus sites collected during surveys with (or in collaboration with) Project C.

The integrated model simulations will be analysed to undertake an assessment of the water, salt and sediment budgets, habitat areas and net productivity. Model tracers of different nutrient/carbon loading sources (e.g., ocean, river, mangrove and algal mat derived) will be undertaken to elucidate the relative contribution of intertidal productivity to broader ecosystem processes.

A final application to the 'impacted' site will be undertaken to assess the ability of the approach to resolve the habitat distribution in a site with existing salt-works (e.g., Figure 4).

Figure 4. Proposed impacted study site in Onslow, allowing assessment of the habitat model to capture the distribution near to a salt pond.

### *Task 5. Climate change and development trajectories*

The model will be used to investigate the sensitivity of intertidal habitats to climate change and salt works developments. Priority focus areas for future scenario simulations include:

- Understanding the influence of sea level rise on BCH extent and migration including environmental and physical parameters.
- Predicting BCH response to climate change scenarios in particular to sea level rise.
- What role will salt projects play in reducing BCH adaptation to sea level rise and how will this affect the ecological services provided by these habitats.

The integrated model developed in Tasks 3 and 4 will be used to simulate a range of future scenarios at the focus sites shown above which represent different coastal landforms and experience different environmental drivers (tide, waves, and riverine inputs). A scenario matrix will be assessed considering SLR, extreme event severity (including associated effects on storm surge, waves and flooding) as identified in Task 2, and vegetation and landform properties. These scenarios will be used to create an envelope of possible future trajectories for inundation, salinity, landform stability and habitat area and function.

Separate scenarios will be undertaken to show the nature of changes that hypothetical salt works developments will have on water and sediment movement, and habitat areas. Simulations will explore the structures associated with the salt works including features such as bund walls, high saline water heads, and high salinity surface water discharges. Selected scenarios will be run with and without climate change effects included to ascertain if the presence of salt-works may reduce the future adaptation ability of intertidal BCH.

Within this Task, it may also be possible to use historical salt pond developments at the Onslow site to hindcast validate the ability of the model to simulate historical changes that have occurred post-development. The ability to do this hindcast modelling would require access to historical field data for conditions pre-development (e.g., bathymetry/topography data) that may be available (e.g., within industry datasets) but is presently unknown. The feasibility of this modelling and available data will be confirmed prior to the project commencement.

## 2 Linkages to other Projects

**Linkage to Project A**

Project A will provide a range of essential datasets, required for model setup and validation, both at local and regional scales. These include:

- Bathymetric data (e.g. from LIDAR)
- Habitat/cover/biomass mapping data for present and past periods
- Survey/mapping data on sediment/soil particle size distributions and composition
- Ad hoc environmental data collected during surveys (e.g. soil salinity etc)

**Linkage to Project C**

Project C will provide a range of essential datasets, required for model setup and validation, both at local and regional scales. These include:

- In situ sensor deployments at focus sites – water level, salinity, current velocities, turbidity
- Algal mat density/biomass and productivity surveys a different stages of wetting
- Samphire density/biomass surveys linking cover, height and stem density
- Experimental (mesocosm) data on environmental tolerances (salinity, temperature, desiccation, etc.)
- Soil nutrient and salt fluxes, following inundation.

**Linkage to other projects**

The project extends or will be informed by several past and present projects:

- WAMSI Dredging Science Node (output from regional ocean models of the North West Shelf region)
- The project will seek to use field data and conceptual models from PI Lovelock's recent ARC projects being undertaken at the Giralia focus site.

## 3 Project Funds Requested

The budget is based on salary and operational costs starting January 2023 for 2 years. Total funds requested are $682,869, and in-kind contribution $408,900.

*In-kind*: The project team includes time allocation from existing staff members employed at UWA and UQ, which totals an approximate load of 0.8FTE/yr. Based on direct salary costs only this is estimated as $363,000 for the two-year project span. We also note that as a WAMSI member, UWA will waive their University Infrastructure Charge on research grant income, which is not costed here. Other in-kind contributions relate to use of infrastructure such as computing, field equipment, and laboratory infrastructure. Total co-investment = $408,900.

*Salaries*: Appointed positions will be required to undertake extensive model development, data analysis, scenario simulation and co-ordination activities. A 2yr 1.0FTE position is allocated to lead the modelling, and this will be supported by fractional appointments related to specific requirements for conceptual modelling and habitat model development and validation. As the project requires model software development, funding allocation is also made for software development activities.

*Operating Costs*: Allocation for assisting Project A and C field work is costed, plus co-contribution to LIDAR data collection. An allocation for consulting services is made for industry experts to facilitate their substantive inputs to the conceptual modelling and data collation process outlined in Task 1. An allocation for support services associated software technical support and customisation is also made.

**Table 1. Funds requested from WAMSI**

| **Item** | **Year 1** | **Year 2** |
|---|---|---|
| ***Salaries*** | | |
| Post-doctoral fellow (Coastal processes) 1.0FTE | 131 | 131 |
| Post-doctoral fellow (Habitat modelling) 0.7FTE | 84 | 160 |
| Software engineer/support | 5 | 5 |
| ***Other*** | | |
| LIDAR data collection | 70 | |
| Software technical support (Deltares) | 25 | 25 |
| Industry expert fees (Professional services fees) | 20 | |
| Field and travel related costs | 15 | 10 |
| Publication fees | | 2 |
| **Total** | **350** | **333** |

**Table 2. Co-investment (staffing)**

| **Organisation** | **Year 1** | | **Year 2** | |
|---|---|---|---|---|
| | ***FTE*** | ***($'000)*** | ***FTE*** | ***($'000)*** |
| **UWA** | | | | |
| Hipsey | 0.2 | 44.3 | 0.2 | 44.3 |
| Lowe | 0.2 | 51.7 | 0.2 | 51.7 |
| van Rooijen | 0.1 | 17.0 | 0.1 | 17.0 |
| Hansen | 0.1 | 21.0 | 0.1 | 21.0 |
| Ghisalberti | 0.1 | 21.0 | 0.1 | 21.0 |
| Cuttler | 0.1 | 14.4 | 0.1 | 14.4 |
| **UQ** | | | | |
| Lovelock | 0.02 | 12 | 0.02 | 12 |
| **Total** | | 181.4 | | 181.4 |

**Table 3. Co-investment (cash and in-kind)**

| **Organisation** | **Year 1** | | **Year 2** | |
|---|---|---|---|---|
| | ***Cash ($'000)*** | ***In-kind ($'000)*** | ***Cash ($'000)*** | ***In-kind ($'000)*** |

| | | | | |
|---|---|---|---|---|
| **UWA** | | | | |
| Equipment (sensors etc) | | *20* | | *20* |
| Computing | | *3* | | *3* |

## 4 Timing and Deliverables

### Timing

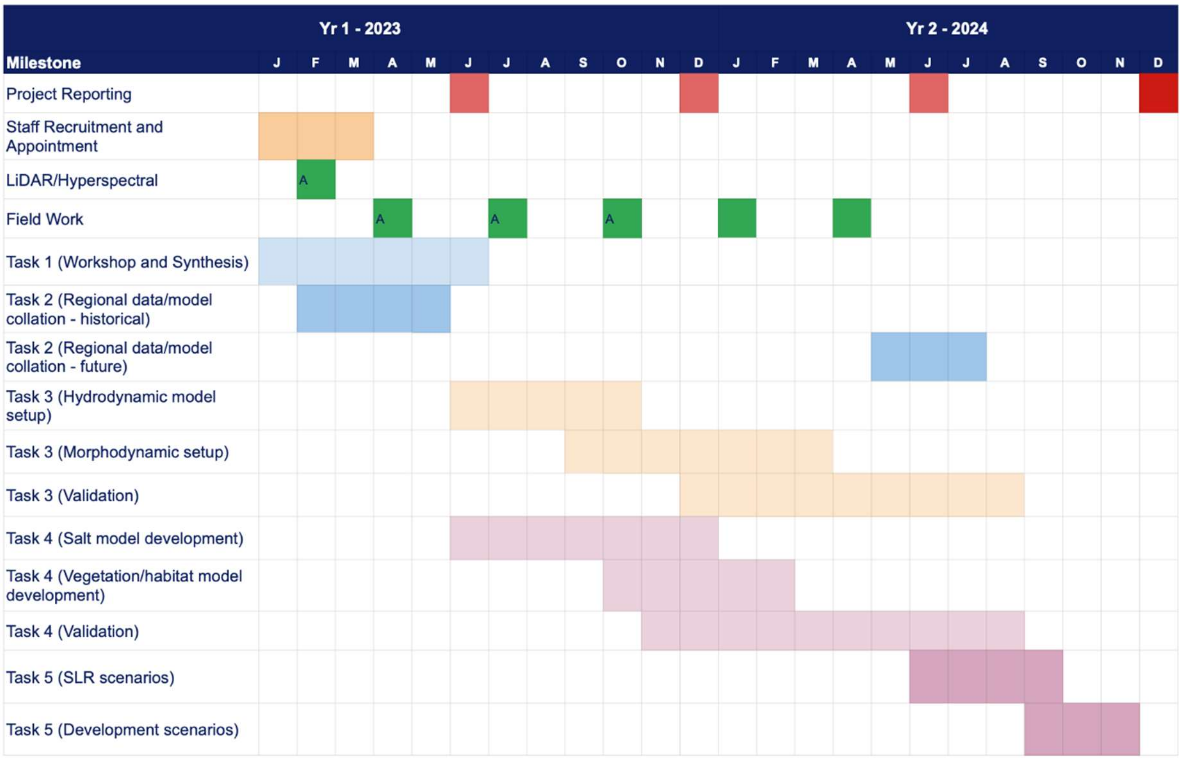
The project tasks are planned to span 2 years over the period Jan 2023 to December 2024, inclusive. Several dependencies exist related to data requirements for model setup and validation, that are anticipated here, but will need refinement as project plans are finalised. An overview of the timing of the project tasks and reporting activities are shown in Table 4.

### Deliverables

Project deliverables will include:

- 6-monthly reporting, including a project final report.
- Scientific publications on the model development and scenario assessment
- Model setup files and data, archived on Github
- Presentations, as agreed.

**Table 4. Project B schedule.**

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**ATTACHMENT 2C –PROJECT SUMMARY Mardie Project Marine and Intertidal Research Offset Program – Project C.**

| | |
|---|---|
| **Project Title** | **Identifying the ecological roles, values and functions of intertidal benthic communities and habitat** |
| **Project Leader/s** | Glenn Hyndes and Kathryn McMahon |
| **Project Team** | Elizabeth Watkin, Sora Marin-Estrella, James Tweedley, Catherine Lovelock |

## *1* Project Summary

### Project Rationale

This project fits into the offset research program for the conditionally approved Mardie Project (Mardie Minerals Pty Ltd), a solar salt and sulphate of pot ash production facility in the Pilbara region of Western Australia. Conditional approval under the Ministerial Statement 1175 (MS1175) requires research on the marine and intertidal environment in the region, based “on the significant residual impacts and risks of the proposal to intertidal benthic communities and habitat (BCH) namely mangroves, algal mat and coastal samphire”. This will inform future decision-making, management and conservation of the ecological values of BCH on the Pilbara coast.

A preliminary assessment of the Pilbara region indicates that mangroves, cyanobacterial mat and saltmarshes form major coastal intertidal habitats along the shores in the region. Globally, these habitats provide significant ecological functions, including primary production, nutrient cycling, carbon storage as well as foraging, breeding and/or nursery areas for a range of invertebrates, fish and birds (Adame et al. 2021). Furthermore, the immigration and emigration of fauna, as well as the outflow of dissolved nutrients and particulate material from these systems can strongly influence production and diversity in neighbouring ecosystems in the coastal seascape (Hyndes et al. 2014). Despite the recognition of the ecological values of mangroves and saltmarshes globally (Barbier et al. 2011), little is known about the relative value of these systems in arid environments like the Pilbara coast. Also, while cyanobacterial or microbial mats can be extensive and highly productive and diverse (Prieto-Barajas et al. 2018), little is known about their functional role (Penrose 2011, Adame et al. 2012). In Exmouth Gulf where some research has been carried out, cyanobacterial mats are highly productive and form an important source of carbon and nitrogen to nearshore food webs (Lovelock et al. 2010, Penrose 2011, Adame et al. 2012), suggesting that these mats play an important function to the coastal seascape more broadly across the Pilbara region.

Mangroves, cyanobacterial mat and saltmarshes are influenced by coastal processes such as tides, waves and wind (Lovelock et al. 2011). For example, mangroves occur in wet and arid tropical regions, where they are influenced by the hydrological regime (e.g. tidal range) and evapotranspiration and rainfall that affects salinity and moisture (e.g. Santini et al. 2013, Asbridge et al. 2015). Cyanobacterial mats occur in a range of extreme environments, with coastal mats in intertidal zones subjected to large changes in salinity, temperature and moisture (Prieto-Barajas et al. 2018). The diversity and function of these systems is therefore likely to alter over daily and seasonal scales, and be impacted by climatic events such as cyclones, changes in hydrological cycles associated with coastal developments, and hydrological and atmospheric conditions associated with climate change.

Understanding the environmental drivers that influence productivity and ecosystem function of these coastal systems is therefore key to future guidance on proposed coastal developments in the region.

This project will meet the conditions of MS1175 under Condition 14-1(3) by directly aiming to identify the ecological roles, values and functions of intertidal benthic communities and habitat, and will be either informed by or feed into projects addressing Conditions 14-1(1) Project A and 14-1(2) Project B.

## Project Objectives and Outcomes

The project will address the following priority objectives outlined in the Mardie Salt Offset Program guidelines:

- Estimate primary productivity in space and time for algal (cyanobacterial) mat and other BCH;
- Identify the pathway for transfer of nutrients and energy from BCH to other communities and habitats (e.g. from the intertidal mosaics to the subtidal), which includes trophic transfer (flow of energy) and nutrient transfer to understand ecosystem function; and
- Identify the key physical drivers such as the response to the wetting and drying associated tidal movement, rainfall, episodic events (storms and cyclones), evaporation etc.

## Brief Summary of Methods including Proposed Timing and Data Analysis

The current scope of the project and methodology outlined in this EOI is indicative, recognising the need to form a research team with appropriate skills and develop a research outline in a short period of time. Due to the remote field locations, staff requirements and sample analyses, the project is costly, and the allocated funds to Project C will not cover the complete design proposed here, but we anticipate contributions from our institutions. The short timeline for the development of the EOI has limited the capacity of the Project Leads to confirm cash contributions and PhD stipends by partner institutes. We also have the potential to modify the project and reduce the budget by reducing for example the number of sites we sample or some of the more detailed analysis. The final scope of the project will, therefore, depend on outcomes from a workshop and negotiations with ECU and MU regarding partner contributions. These will occur in the next phase of the application process.

The above objectives will be addressed through a combination of field surveys or field and/or mesocosm experiments across appropriate spatial and temporal scales to account for spatial and temporal variability and influences of hydrodynamic and atmospheric drivers. Our approach is to link field measurements with remote sensing from Project A and models from Project B to enable upscaling to the region through modelling. It is anticipated that field activities for Objectives 1-2 will occur at a maximum of three locations along the Pilbara coast. Indicative locations are Giralia in southern Exmouth Gulf, Gnoorea and Onslow (Figure 1). These sites have been chosen to represent a range of tidal regimes, coastal morphologies and habitat landscape characteristics, while Giralia has also been the focus of a number of studies led by Prof. Catherine Lovelock. The intent is to focus on the same sites as Projects A and B. The inclusion of Yammadery as a site in Project A can be considered but this will have implications for the total number of sites sampled in the project and flow-on effects to Project A and B in this Offset package. Sites will be reviewed in the next phase of the Mardie Offset Program application process following the EOI phase. Temporal sampling will vary depending on the research question (see below), but will be limited due to budgetary constraints associated with the cost of field work to two years with field trips planned twice a year. One of these trips, is planned to be opportunistic following a significant rainfall event, if it occurs over the life of the project and it is safe to access. See Figure 2 which outlines the timing of each objective and the team members of that part of the project.

### *Objective 1 – Primary productivity*

Net primary production (NPP) will be estimated for three habitat types: cyanobacterial mats; mangroves; and saltmarshes. For each of the three BCHs, measurements of NPP will be stratified over a gradient from the coastal to landward edge to capture different tidal inundation conditions and species composition of each BCH. The locations of sampling will depend on the landscape configuration at each site. Estimates will be made in two contrasting seasons (e.g. late wet and late dry). Due to the different growth forms and rates of productivity in these different habitat types, different methods will be used to estimate NPP. However, it will be designed in a way so that NPP (g/area/time) can be scaled up to site and regional estimates by area and with the habitat mapping outputs from Project A. This objective will be assessed in Year 1, but as some methods require tagging of plants and measurements after a period of time, the final data collection will occur in Year 2. Sampling at two times will enable an understanding of intra-annual variation, but not inter-annual variation. We acknowledge that inter-annual variation in NPP is likely to be large due to the episodic nature of rainfall events in this region, but due to the limited timeframe of this project and the cost of field campaigns in the region this is not feasible. Environmental variables such as soil salinity, surface salinity, temperature and elevation will also be collected where the NPP estimates are made. Location specific data such as rainfall and evaporation will also be extracted from data repositories for the duration of the study. This information will be used to examine the associations between NPP and these potential environmental drivers.

Cyanobacterial mats

The NPP of cyanobacterial mats will be assessed along a gradient such as distance from tidal influence or elevation to account for the potential variability in NPP due to differential wetting and drying. An "in-growth" technique will be used, where small sections of cyanobacterial mat will be removed and the amount of material that grows into the vacant space assessed over a set time period to enable an estimate of g dry weight per time. The Project Team has experience with performing these experiments and has preliminary data that can help inform the design.

In addition to measuring the photosynthetic activity of the cyanobacterial mat (active or dormant) across the spatial extent of the mat in relation to elevation and inundation gradients, a pulse amplitude modulated (PAM) fluorometer will be used to understand how the photosynthetic activity of the mat varies spatially and under different inundation frequencies. This information will assist with validating the regional estimates of cyanobacterial extent and productivity.

Saltmarsh and mangroves

The NPP of saltmarsh will be assessed by two methods, tagging of above-ground structures (e.g. leaves/stems on plants) and spatial extension of plants through markers that outline the perimeter of the plant and the extension beyond these markers is measured. This will give an estimate of new biomass produced over a set period of time (g dry weight per time). In addition, litterfall (detritus) will be estimated to contribute to the NPP estimates. To enable upscaling to site and regional estimates, plot-based measurements such as cover, height and stem density of plants will be recorded so that NPP can be scaled to area based on the cover/density of plants (Howard et al. 2014). The measurements for saltmarsh will be stratified to coastal and landward habitats.

For mangroves, NPP will be estimated through assessment of litterfall (detritus) and tree growth (leaf growth, wood growth using dendrometer bands) and scaled up using plot-based assessments of tree size (stem diameter and tree height) and density as well as existing allometric relationships. These measurements will be stratified to two mangrove habitat types, lower intertidal fringing mangroves and higher intertidal scrub mangroves).

### *Objective 2 – Pathway for transfer of nutrients and energy*

This objective will be split into two core research questions:

a. Do the pools and outflow of dissolved and particulate nutrients differ between algal (cyanobacterial) mats and other main BCHs?
b. What is the relative contribution of algal (cyanobacterial) mats and other main BCHs to the food web in the coastal seascape?

This objective will be addressed in two contrasting seasons (e.g. late wet and late dry) in Year 1 across the landscape of the intertidal zone and capturing the catchment inflows and outflows, and if possible over an event after the sites have been selected and sampled on at least one occasion. This vent sampling will be restricted to dissolved and particulate nutrients as outlined for Objective 2a.

For Objective 2a, both dissolved and particulate nutrients will be sampled across the different habitat community types (e.g. cyanobacterial mats, saltmarsh and mangroves) over a tidal cycle, and freshwater (if present) in the creeks and rivers that form the downstream end of the catchments. The locations and number of samples will depend on the landscape configuration at each site. Water samples will be collected from the water column and sediment porewater and filtered where appropriate. Replicate samples will be collected within each of the key BCHs over the tidal cycle, and from key locations from the catchments. Samples will be collected and processed for concentrations of total dissolved organic and inorganic carbon, total dissolved nitrogen and inorganic nitrogen ($NO_x$ & $NH_4^+$), and total dissolved phosphorus and $PO_3$. Suspended particulate organic matter filtered from the water column samples, as well as sedimentary particulate organic matter collected by cores, will be analysed for total organic C, N and P.

Rates of nitrogen fixation of cyanobacteria mats will be determined across three zones along a gradient of tidal influence or elevation to account for the potential variability in N fixation due to different levels of wetting and drying. Replicate samples (1 $cm^2$) of cyanobacteria mat will be stamped out of the mat at each tidal position and assessed for nitrogen fixation using the acetylene reduction assay (ARA, Brocke et al. 2018). The sections of mat will be taken back to the laboratory, placed in bottles and incubated in flow-through aquaria under controlled day/night and temperature conditions for 24 hours following the procedures of Brocke et al. (2018). Dry weight of the cyanobacteria samples will be determined at the end of the experiment. These data will be used to upscale rates of N fixation at the three sites, where replicate samples of cyanobacteria mat will be collected across the gradient of tidal influence or elevation, dried and weighed. Upscaling at broader spatial scale will be linked to habitat mapping in Project A.

To determine the role of cyanobacteria mats in the cycling of nutrients, these mats will be assessed to determine the dominant taxa, followed by metagenomics to determine their functional roles. Replicate samples will be aseptically collected within the mats and stored on ice in sterile bags for DNA extraction, avoiding contamination across samples. Samples will be collected over environmental gradients (e.g. locations exposed to desiccation for different periods over the tidal cycle). DNA extractions will be performed on samples using modified protocols for FastDNA® Spin Kit for Soil (MP Biomedicals). All DNA samples will be quantified, quality checked and sent for 16S rDNA (bacteria) 18S rDNA (eucaryotes) and ITS (fungi) diversity sequencing at Australian Genomics Research Facility (AGRF). Metagenome sequencing will be performed on samples selected based on the diversity analysis results.

The transport of particulate material can also occur through the detachment of cyanobacterial mats. As cyanobacterial mats occur over a narrow range of elevation, reflecting their inundation niche, they can be highly dynamic (Lovelock et al. 2021). When they are desiccated, they can become detached from the sediment and then transported with water flow generated from tides or surface flows. These mats can also become detached during fast surface flows associated with flooding events and transported to the coastal zone. Observations at Giralia, Exmouth Gulf, suggest that detached cyanobacterial mats are transported seaward into adjacent mangroves during ebbing tides, or with southerly winds. How often this occurs (event driven) and how much material is transported is unknown. We will qualitatively measure transport of detached mats using a combination of approaches such as digital imagery from fixed cameras or with a live feed if possible and traps to assess this transport.

For Objective 2b, the food web structure will be determined through a combination of gut content analyses (GCA) and stable isotope analyses (SIA) for the two time periods (e.g. late wet and late dry) and across the different community types (e.g. cyanobacterial mats, saltmarsh and mangroves). For SIA, replicate samples of potential sources of production, including cyanobacterial mat, mangroves, saltmarsh, phytoplankton, benthic microalgae and detritus, will be collected from the key BCHs, while detrital samples and terrestrial vegetation will be collected from the catchments. SIA for these sources and sinks (detritus) will allow the source of material contributing to the detritus across the landscape. In addition, replicate samples of key consumers in each BCH, including benthic meiofauna and macroinvertebrates, zooplankton, insects, and fish. Benthic invertebrates will be collected using a range of methods including cores and dip nets, while fish will be collected using seine, fyke, gill, scoop and/or throw nets. Species targeted will depend on the relative abundances of species during sampling. Where possible, droppings will be collected for shorebirds (Kuwae et al. 2012). Samples will be processed for the determination of $\delta^{15}N$, $\delta^{13}C$ and $\delta^{34}S$ (and possibly $\delta^{2}H$, which has been shown to be a useful tool in mangrove systems; Then et al. 2021). The main potential sources being assimilated by different consumers will be determined using MixSIAR, a Bayesian stable isotope mixing model incorporating uncertainty and variability. Replicate samples of the same consumer species used for SIA will be used for GCA following traditional methods (e.g. Hyndes et al. 1997, Campbell et al. 2021). GCA data will be compiled and subjected to a range of multivariate statistical techniques (i.e. PERMANOVA, RELATE, ordination and shade plots) to determine the main components of the diet of each species and whether they differ spatially, temporally and with increasing size of the taxa.

Feeding ecology of birds will be examined using direct observations and dropping analysis from the most abundant species from different size classes (representing different feeding guilds) and when possible, listed species under the EPCA Act. Direct observations provide information on shorebird foraging behaviour, inter- and intra-specific interactions, diet and prey selection. Using video recording, collection of at least 20 to 30 observations (from different individuals) per species, per site and per period will occur prior to other sampling (droppings, invertebrate sampling). When possible, birds will be filmed using digiscoping (camera attached to a telescope) (Estrella et al. 2007, Estrella et al 2015). Dropping analysis (Dekinga & Piersma 1993, Estrella and Masero 2010) will offer information about diet and prey selection. At least 20 fresh droppings per species per site per period will be collected from monospecific roosts or from areas where only one species has been observed feeding.

Droppings will be preserved and analysed in the lab. Droppings will be dis-aggregated in filtered water and sieved though a 50 µm mesh. Hard parts of prey (chironomid heads, polychaete jaws, bivalve hinges, crustacean parts etc.) will be identified and measured. When possible, correlations between prey size and prey hard part size will be developed.

### *Objective 3 – Key physical drivers*

The key physical drivers that affect cyanobacterial mat productivity, nutrient cycling including nitrogen fixation and the flow of nutrients with events will be assessed through a combination of field and mesocosm experiments. The drivers investigated will include soil salinity, surface water salinity including addition of fresh water to simulate rainfall events, elevation, tidal inundation frequency, wetting and drying duration and frequency. These variables have been selected because inundation regimes are linked to intertidal elevation, but are modified by wind speed and direction, sea level and sea level variation, evaporative demand influencing salinity, attenuation of tidal flows by mangroves and are known to influence the form of cyanobacterial mats (Lovelock et al. 2010, Prieto-Barajas et al. 2018).The field experiments will start in Year 1 and continue into Year 2 whilst preliminary mesocosm experiments will commence in Year 1, but with most focus in Year 2. Opportunistic sampling is also planned over an event such as a large rainfall event to understand how these events influence the flux of nutrients from the cyanobacterial mats to the marine environment. This event sampling requires an event to occur over the project period which is not too extreme as this will likely limit access. If an event sampling is not possible, the data collected in Objective 1, 2 and 3 can be incorporated into Project B to model the fluxes. For example, the leaf litter production can be used to estimate particulate fluxes and the nutrient pools and flows can be used to estimate dissolved fluxes. Due to logistic reasons, all aspects of this objective will not be conducted at all three sites. For example, it would not be possible to access all sites over an event.

Field and experimental studies will be linked with mapping of cyanobacterial mats in Project A and modelling in Project B to assess how climate (e.g. wind, temperature, humidity) moderates tidal inundation over the intertidal landscapes and NPP and nutrient fluxes of cyanobacterial mats.

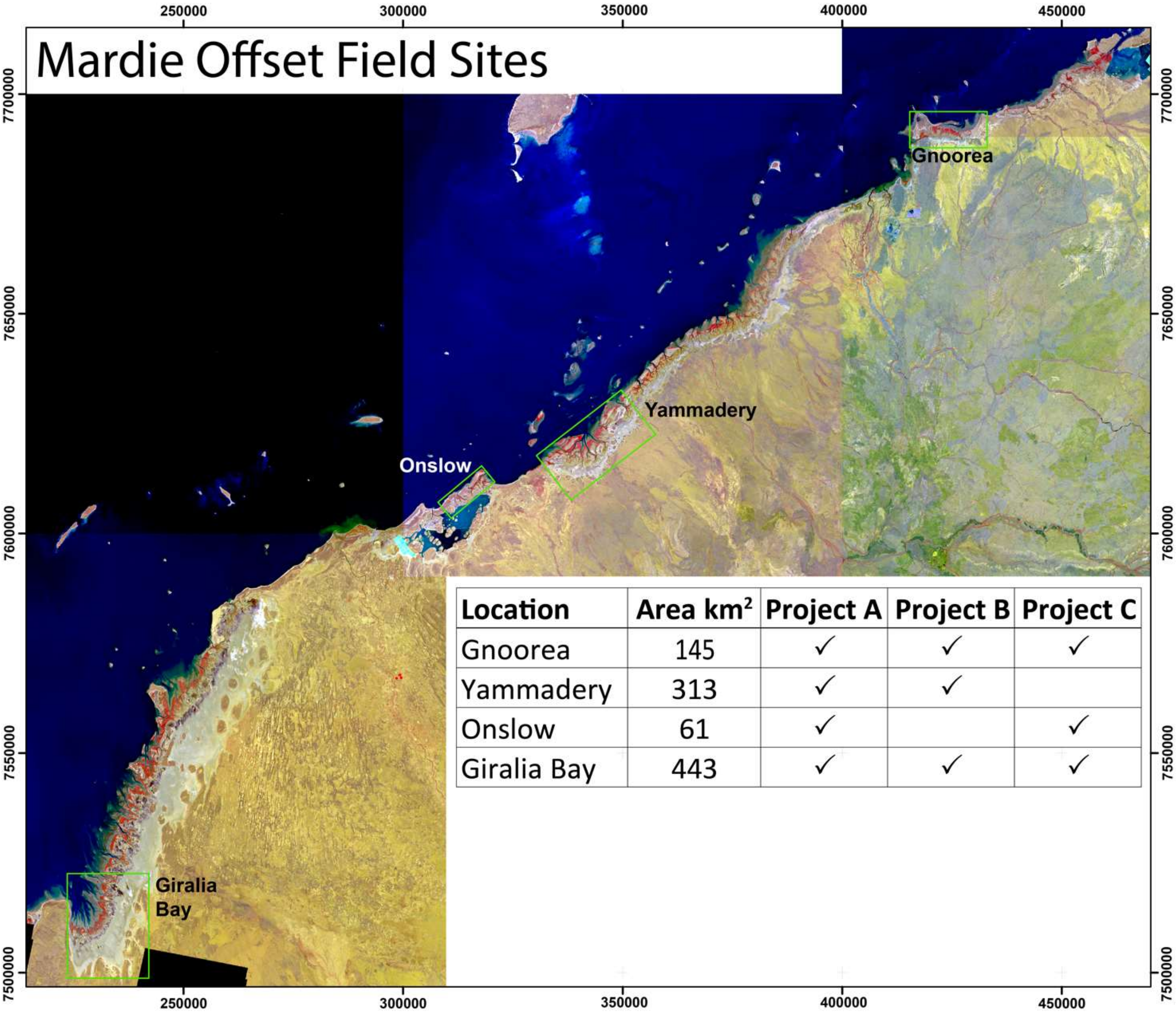
<u>Field experiments</u>

The approach for the field experiments is to assess the associations in the natural environment over gradients to understand potential drivers. As these assessments will take place in the field, it will need to take a different measurement approach to Objective 1 and 2. Firstly, productivity and nutrient fluxes will be assessed over gradients based on elevation/tidal inundation and over tidal cycles (e.g. falling vs rising tide and spring vs neap tides). These gradients will be characterised by elevation with RTK GPS, water level and inundation and salinity using loggers. The photosynthetic activity of the cyanobacterial mats will be assessed using a pulse amplitude modulated (PAM) fluorometer giving an estimate of active or dormant mats. Chamber experiments that measure oxygen evolution and nutrient fluxes will quantify the rates of productivity and nutrient fluxes along this gradient. For example for productivity these small-scale, short-term chamber assessments will measure oxygen evolution using FireSting™ 3 mm robust REDFLASH technology sensors (Pyroscience) following a similar approach to Said et al (2021).

The second proposed approach is to place settlement structures in the field along the established gradient to identify where cyanobacteria mats develop. The colonisation and increase in biomass over time will be an estimate of NPP. The approach of gradients used by Kirwan and Guntenspergen (2015) for evaluating growth of saltmarshes over inundation gradients will be used where a series of PVC pipes of different lengths that represent different levels of elevations/inundation will be deployed in the cyanobacterial mat habitat. Sediment surfaces within the pipes that are colonised by cyanobacteria indicate inundation levels that support cyanobacterial mat development.

Laboratory experiments

The field experiments will identify potential drivers of productivity and nutrient fluxes in cyanobacterial mats where the controlled laboratory experiments will enable testing of the drivers under controlled conditions. These results will feed into modelling and enable simulation of scenarios of rainfall or surface flows which are not possible to measure in the field. There are several potential factors that can be tested in these experiments and these will be confirmed following insight from the field work. For example, how salinity from fresh (representing rainfall) to hypersaline (representing cyanobacterial mat conditions) could be manipulated to assess the effect on productivity and nutrient fluxes. Other factors could include the duration and frequency of drying and wetting, and the response time for cyanobacterial mats to become productive. To carry out these experiments, sections of cyanobacterial mat will be removed from the site and transported to mesocosm facilities at ECU. Under controlled day/night conditions cyanobacterial mat will be exposed to a range of treatments. It is envisaged that multiple experiments will be carried out to test a range of different factors (e.g. salinity, wetting and drying duration and frequency). Like in the field experiments, $O_2$ production will be measured over the course of the experiment as an estimate of NPP, as well as nutrient fluxes, and the production of soluble materials (complex carbohydrate films) which is more challenging to measure in the field.




| Location | Area km² | Project A | Project B | Project C |
|---|---|---|---|---|
| Gnoorea | 145 | ✓ | ✓ | ✓ |
| Yammadery | 313 | ✓ | ✓ | |
| Onslow | 61 | ✓ | | ✓ |
| Giralia Bay | 443 | ✓ | ✓ | ✓ |

**Figure 1. Indicative locations for sampling sites for Projects A, B and C. The final locations will be confirmed at the next stage in consultation with the Science Leadership team and considering engagement with traditional owners, logistics and cost of access, future planned activities and relevant historical data.**

| Objective | | Community type | Year 1 | Year 2 | Event | Lead |
|---|---|---|---|---|---|---|
| Obj. 1 | Productivity | Cyanobacterial mat | | | | McMahon & Lovelock |
| | | Mangrove & Saltmarsh | | | | McMahon & Lovelock |
| Obj. 2 | Nutrient transfer & energy flows | Nutrients | | | | Hyndes & Watkin |
| | | Food webs | | | | Hyndes, Marin-Estrella & Tweedley |
| Obj. 3 | Physical Drivers | Cyanobacterial mat | | | | McMahon |

**Figure 2. The timing of the four objectives in Project C.**

## 2 Linkages to other Projects

Project C has strong links and co-dependence with Projects A and B. We will work closely together to ensure the required data is collected at the appropriate spatial and temporal resolution to enable integration and to maximise efficiencies. Mapping of the BCHs in Project A will allow data collected from this study to be scaled up to regional levels, while this study will also provide data for modelling of the potential effects of sea level rise on BCHs and identifying the significance of salt projects in preventing the adaptation of intertidal BCH to sea level rise in Project B. Project C also has synergies with another offset project entitled "Primary productivity and energy transfer between marine ecosystems" being carried out in the Dampier Archipelago by DBCA.

## 3 Project Funds Requested

Requested funds

The budget is based on salary and operational costs over 2.5 years, starting in April 2023. The total funds requested amounts to $1,000,000 that is anticipated to be supported by a total in-kind contribution of $1,284,055 and cash contribution of $100,000 from the partner institutes.

Salaries: A Postdoctoral Fellow will be required to coordinate the extensive field campaigns and undertake key aspects of the laboratory work, along with writing the report (Postdoctoral Fellow Level B Step 1, 1.0 FTE for 2.5 years, $347,142 including 17% oncosts for superannuation, salary tax). A Research Assistant will be required for a 2.5-year period to assist with the field work and extensive laboratory processing for core aspects of the project (HEW5 Step 1, 1.0 FTE, $248,764). A total $15,600 is allocated for consultancy services (Dr Ben Fitzpatrick) for advice on the region during a planning workshop and during the pilot field trip to finalise the field program for sampling trips.

Operating costs: The field work budget is based on the hire of a vessel ($2000 per day), accommodation ($500 per day, vehicle travel to transport equipment and staff, and flights to transport remaining staff to Exmouth) for 4 field campaigns (2 each in Years 1 and 2). Return flights from Queensland have also been included for C. Lovelock (2 per year in Years 1 and 2, and 1 in Year 3). Budget is also allocated to an opportunistic sampling trip during a high flow event to sample nutrients off the catchment. These costs may need to be modified depending on the final site selection and access requirements to the sites (e.g. the need for helicopters or live aboard boats).

Stable isotopes analyses cost $17 per sample for $\delta13C$ and $\delta15N$ (ECU rates), and $24.50 per sample for $\delta34S$ (UC Davis rates). Nutrient analyses will include dissolved organic and inorganic carbon ($50 per sample at SCU) and dissolved inorganic N and P ($52 per sample at SCU). Costs for DNA and metagenomic sequencing are based on $300 per sample for each form of sequencing at AGRF. Budget is also allocated to an opportunistic nutrient sampling during a high flow event.

Co-investment

In-kind salaries (FTE) are based on the contributions of team member employed at ECU, MU and UQ. It is anticipated that ECU and MU will waive their University Service Charge (USC) on research grant income. For consistency across universities, a 30% USC has been applied to the total funds requested for each institute as in-kind contributions. Other in-kind contributions relate to use of infrastructure such as aquarium and mesocosm facilities, as well as relevant equipment. It is anticipated that ECU and MU will each provide a PhD scholarship, and the Project leads will negotiate a cash contribution from ECU (~$100,000) to contribute towards the operational items on the budget. It is anticipated that these funds will contribute towards equipment and consumables. Multiple salinity and temperature loggers (@$1,800) and water level loggers (@$745) will be required to measure these environmental variables that are likely to form major drivers of NPP and diversity in the BCHs. FireSting probes to measure $O_2$ production will need to be replaced for the project (Total $8,000). In addition, telescope attached to an SLR camera will be required for bird foraging surveys, and additional nets will need to be constructed for fish sampling.

**Table 1. Funds requested from WAMSI**

| Item | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| Salaries-Postdoctoral Fellow (2.5 yrs) | 134,937 | 139,840 | 72,365 |
| Salaries-Research Assistant (2.5 yrs) | 96,672 | 100,254 | 51,838 |
| Consultancy services | 15,600 | | |
| Field costs (boat, vehicle, accommodation) | 83,400 | 83,400 | 14,500 |
| Consumables | 15,000 | 10,000 | 562 |
| Airfares | 7,400 | 7,400 | 900 |
| LiDAR/Hyperspectral data (shared across 3 projects) | 75,000 | | |
| Stable isotope analyses | 15,216 | 15,216 | |
| DNA sequencing analyses | 9,900 | 9,900 | |
| Nutrient analyses | 19,100 | 19,100 | 2,500 |
| **Total** | **472,225** | **381,110** | **142,665** |

**Table 2. Co-investment (staffing)**

| Organisation | Year 1 | | Year 2 | | Year 3 | |
|---|---|---|---|---|---|---|
| | ***FTE*** | ***($'000)*** | ***FTE*** | ***($'000)*** | ***FTE*** | ***($'000)*** |
| G. Hyndes (ECU) | 0.2 | 50 | 0.2 | 50 | 0.2 | 50 |
| K. McMahon (ECU) | 0.2 | 43 | 0.2 | 43 | 0.2 | 43 |
| S. Marin-Estrella (ECU) | 0.1 | 16 | 0.1 | 16 | 0.1 | 16 |
| E. Watkin (ECU) | 0.1 | 25 | 0.1 | 25 | 0.1 | 25 |
| J. Tweedley (MU) | 0.1 | 40 | 0.1 | 40 | 0.1 | 40 |
| C. Lovelock (UQ) | 0.1 | 50 | 0.1 | 50 | 0.1 | 50 |
| **Total** | 0.8 | 225 | 0.8 | 225 | 0.8 | 225 |

**Table 3. Co-investment (cash and in-kind)**

| Organisation | Year 1 | | Year 2 | | Year 3 | |
|---|---|---|---|---|---|---|
| | ***Cash ($'000)*** | ***In-kind ($'000)*** | ***Cash ($'000)*** | ***In-kind ($'000)*** | ***Cash ($'000)*** | ***In-kind ($'000)*** |
| ECU | 78.1 | 77 | 19.5 | 77 | 2.4 | 77 |
| MU | | 33 | | 33 | | 33 |

## 4 Timing and Deliverables

Timing

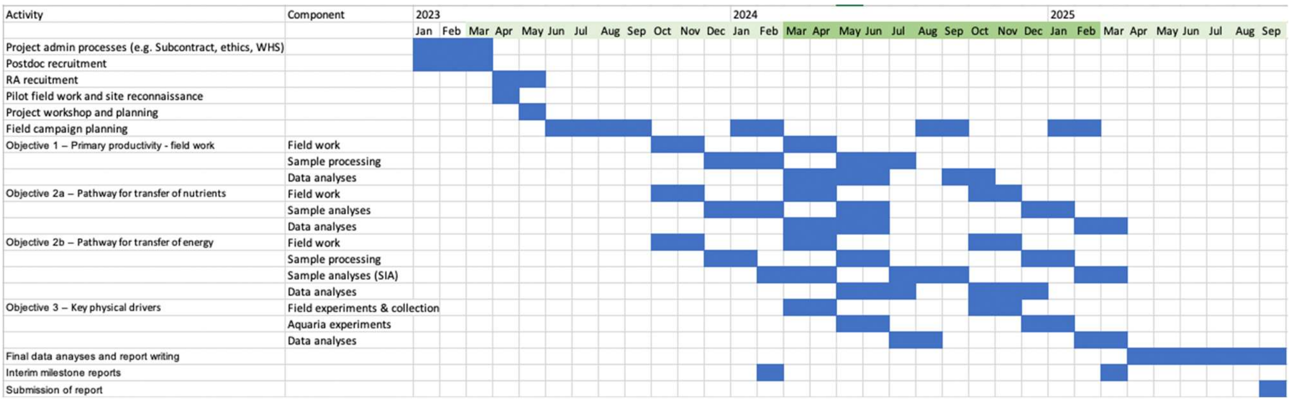
A 2.5-year timeline is needed for Project C due to the: (1) breadth and complexity of the project objectives; (2) timing of administrative procedures to initiate the project including subcontract signing; (3) timing of the optimal period for field work; and (4) remote location of sampling. Based on an assumed December 2022 sign-off on the Project C agreement, administrative and recruitment processes could not begin until January 2023. Administrative processes would involve the drafting and signing of a subcontract with Murdoch University, along with approval processes for ethics and Work, Health and Safety procedures. Recruitment of high-quality Postdoctoral Fellow could take 3 months, resulting in a potential April 2023 start for project activities. In addition, time will be required to negotiate our research activities with the native title holders in the region. Due to budgetary constraints and environmental conditions in the Pilbara region, field sampling will occur over 2 seasons to capture seasonal variability, with sampling occurring in Apr/May and Oct/Nov for Year 1 and in Apr/May in Year 2. An opportunistic sampling trip is allocated in Year 2 for a high flow event. These periods avoid or minimise field work extreme heat and cyclonic conditions that occur in the region during the wet season. Two years are required to ensure that the breadth of the work required for the project's objectives is manageable, with field work associated with Objectives 1 and 2 predominantly carried out in Year 1, and Objective 3 carried out in Year 2. This means that the first field trip could not take place until Oct/Nov 2023, with subsequent seasons occurring in Apr/May and Oct/Nov 2024 and Apr/May 2025. However, pilot field work will be carried out at a selected site in April 2023 to inform a workshop in May 2023 that will help finalise the sampling program. Activities outside of these times will be based on field campaign preparation, sample processing, sample analyses, preliminary data analyses and aquaria/mesocosm experiments as outlined in the schedule below. Significant time (2+ months) is required for sample analyses (e.g. stable isotopes and DNA). The final 6 months of the project will be allocated to finalising the data analyses, paper and report writing. Annual milestone reports will provide summaries of results and findings to date (February 2024 and 2025), and interim results can be provided as written documents or presentations to DWER when required.

<u>Deliverables</u>

Milestone reports: February 2024 and 2025

Final report: September 2025

**Table 1 – Project C schedule**

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