A Science Plan for Shark Bay (Gathaagudu)

developed from comprehensive stakeholder engagement

WESTERN AUSTRALIAN
MARINE SCIENCE
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WARNING: Aboriginal and Torres Strait Islander participants are warned that the following publication may contain the names and images of deceased persons, and words and descriptions which may be culturally sensitive.

WAMSI acknowledges Malgana as the traditional custodians of Gathaagudu and their connections to land, sea and community. We pay our respects to their elders past and present and extend that respect to all Aboriginal and Torres Strait Islander peoples.

A Science Plan for Shark Bay (Gathaagudu): developed from comprehensive stakeholder engagement.

This Science Plan is the culmination of a comprehensive review of the research that has been undertaken in Shark Bay over the past 70 years (A Snapshot of Marine Research in Shark Bay (2020)) and prioritised research gaps identified by a large range of stakeholders. The result is a stakeholder-driven plan of action for future research in Shark Bay. This resource forms part of the Western Australian Marine Science Institution's (WAMSI) Shark Bay priorities project. It contributes to the regional understanding and knowledge of the Shark Bay marine environment and has identified future research priorities.

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Shark Bay, also called Gathaagudu meaning 'two bays', is an exceptional place: internationally recognised for its outstanding ecological features and highly valued for its rich Indigenous culture, European history and economic livelihoods. Despite the abundance of incredible ecological and community values, Shark Bay is at a crossroads. It has already been impacted by the changing climate and is particularly vulnerable to predicted extreme climate events. The outlook for Shark Bay is uncertain, unless there is a better understanding of the impacts of climate change and other pressures on the base of the food web, ecosystem health and subsequent flow-on effects. This Science Plan, developed with government, community, Malgana, researchers and other stakeholders, identifies the most important questions to address in Shark Bay, and with help, we can find the answers and a way forward.

WAMSI Research Director Dr Jenny Shaw

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Author Contributions
Dr Jenny Shaw had project and report oversight and carried out the stakeholder interviews and workshops. Both Dr Shaw and Dr Alicia Sutton contributed to the structuring, writing, editing and finalising of the report. Dr Sutton designed and analysed the online prioritisation survey.

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Modified image of a pixel composite mosaic of a time series of satellite observations of Shark Bay (2017. Surface Reflectance 25m Geomedian 2.0.0. Geoscience Australia, Canberra. http://pid.geoscience.gov.au/dataset/ga/120374)

Images above:
Stakeholder engagement workshops and interviews in Denham and Perth.

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Abbreviations and acronyms

AIATSIS	Australian Institute of Aboriginal and Torres Strait Islander Studies
AIMS	Australian Institute of Marine Science
ARC	Australian Research Council
BoM	Bureau of Meteorology
CALM	Department of Conservation and Land Management (now DBCA)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVI	Climate Vulnerability Index
DBCA	Department of Biodiversity, Conservation and Attractions
DEC	Department of Environment and Conservation (now DBCA)
DEE	Commonwealth Department of Environment and Energy (now Department of the Environment)
DOF	Department of Fisheries
DPIRD	Department of Primary Industries and Regional Development
DPLH	Department of Planning, Lands and Heritage
DWER	Department of Water and Environmental Regulation
ECU	Edith Cowan University
EPBC	Environment Protection and Biodiversity Conservation
FRDC	Fisheries Research and Development Corporation
GAT	Gathaagudu Animal Tracking
GDC	Gascoyne Development Commission
iCoAST	Integrated Coastal Analyses and Sensing Technology
IMAS	Institute for Marine and Antarctic Studies
IMOS	Integrated Marine Observing System
IOMRC	Indian Ocean Marine Research Centre
IPA	Indigenous Protected Area
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
MAC	Malgana Aboriginal Corporation
MHW	Marine Heatwaves
NCWHAC	Ningaloo Coast World Heritage Area Council
NESP	National Environmental Science Program
NGO	Non-government Organisation
NMSP	National Marine Science Plan
NRM	Natural Resource Management
OUV	Outstanding Universal Value
PBC	Prescribed Body Corporate
RCP	Representative Concentration Pathway
SB	Shark Bay
SBPMF	Shark Bay Prawn Managed Fishery
SBWHA	Shark Bay World Heritage Area
STEM	Science, technology, engineering, and mathematics
SST	Sea Surface Temperature
TC	Tropical cyclone
TEK	Traditional Ecological Knowledge
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNSW	University of New South Wales
U.S.	United States
UWA	The University of Western Australia
VIMS	Virginia Institute of Marine Science
WA	Western Australia
WAFIC	Western Australian Fishing Industry Council
WAMSI	Western Australian Marine Science Institution
WHA	World Heritage Area
WHP	World Heritage Property
WHS	World Heritage Site

Acknowledgments

This document is the culmination of a large amount of work by many people.

The collaborations, partnerships, research and stakeholder input have made this a comprehensive end-user driven Science Plan. Every piece of information and input is gratefully acknowledged.

WAMSI acknowledges the Shark Bay community and the many stakeholders who contributed to the development of the WAMSI Shark Bay (Gathaagudu) Science Plan. Their participation in interviews, discussions, workshops and surveys over the life of this project has contributed to the extensive coverage of issues, capture of knowledge and prioritisation of gaps.

This report focuses on Gathaagudu (Shark Bay) which is the traditional land and sea country of the Malgana people. Members of the Malgana Aboriginal Corporation, Elders and Traditional Owners were instrumental in sharing their ecological knowledge of Shark Bay during workshops, discussions and surveys.

Gina Lincoln (formerly WAMSI/Mosaic Environmental) contributed to this document and provided significant support to navigate the process of engaging, collaborating and sharing knowledge with the Malgana community and Malgana Aboriginal Corporation.

Professor David Pannell (UWA) provided valuable suggestions on the initial stages of the prioritisation procedure for knowledge gaps.

The Shark Bay Priorities Project partnered with the World Heritage Advisory Committee and its support throughout the process has been appreciated.

Alicia Sutton (WAMSI/Carijoa), uncovered and skilfully synthesised the huge number of publications in the preceding report 'A Snapshot of Marine Research in Shark Bay (Gathaagudu)'. This document identified gaps in the literature which were the precursor to this Science Plan. Alicia also designed the online prioritisation survey and contributed to the writing of the Plan. Her contribution has been immense and is very gratefully acknowledged.

The Steering Group of Gary Kendrick (UWA), Gary Jackson (DPIRD), Alan Kendrick (formerly DBCA) and now Luke Skinner (DBCA) have helped to guide the Science Plan to achieve maximum impact. Each has a passion for the area, exceptional knowledge and a longstanding professional commitment to protect this special place. Their contribution and unflagging enthusiasm have been remarkable. Additional expertise and advice from Luke Twomey (WAMSI) over the life of the project, Anna-Lee Harry (WAMSI) and Aleta Johnston (formerly WAMSI) has been invaluable.

Review of this document by the WAMSI Board, the Department of Jobs, Tourism, Science and Innovation, and Management Agencies (DPIRD, DBCA and DWER) was extensive and thorough. Their thoughtful constructive comments and suggestions were carefully considered and incorporated where appropriate, and are gratefully acknowledged.

Dr Jenny Shaw
WAMSI Research Director

Executive Summary

A Research Focus on Shark Bay

Shark Bay (Gathaagudu) is unique on a global scale. It is home to one of the largest and most diverse seagrass meadows in the world, the largest dugong population in the world, and is one of only two marine locations in the world where you can find Earth's oldest living lifeforms – stromatolites. These unique values helped to establish Shark Bay as a World Heritage Area (WHA) in 1991.

This World Heritage listed area is vitally important to the economic and cultural wealth of the Western Australian community. It is home to some of the most valuable commercial fisheries in WA including Shark Bay Prawns, Scallops and Blue Swimmer Crabs. It is a tourism hotspot with natural wilderness values and a popular recreational fishing destination. It includes terrestrial and marine parks, a culturally rich Indigenous sea country and is recognised globally as an important blue carbon sink.

Scientists throughout WA and the world have been raising concerns about the threats facing this unique environment and popular tourist destination. The marine heatwave in 2011 caused a dramatic loss in seagrass and subsequent negative flow-on effects to the food web and ecosystem health. Since then, the Gascoyne region has experienced severe Tropical Cyclone Seroja, flooding of the Wooramel and Gascoyne rivers, and a warm La Niña summer in 2020/2021 which had marine heatwave water temperatures.

Why a WAMSI-led Shark Bay Science Plan?

Western science has been occurring in Shark Bay for at least seven decades and a wealth of western knowledge has been generated. However, the threats to the Shark Bay marine ecosystem have changed and increased, particularly due to climate change. There is now an urgent need to re-focus research efforts towards addressing these increased pressures on the system and produce outputs that can better inform management actions aimed at alleviating climate change and other anthropogenic threats and pressures on Shark Bay.

WAMSI has played the leading role in WA in bringing marine science research providers together to undertake science and disseminate knowledge to both the decision makers and stakeholders. WAMSI was asked to lead a collaborative, transparent and coordinated research approach for Shark Bay by WAMSI partners. In response, WAMSI has developed a Shark Bay Science Plan that will provide government, universities, industry and philanthropic stakeholders with clear guidance on what knowledge gaps should be prioritised for future research.

The WAMSI Shark Bay Science Plan sets itself apart from other strategic plans across the country by having research priorities determined by a wide and inclusive range of stakeholders, including Traditional Owners, government, industry, community, managers and researchers. Each individual stakeholder voice is considered and incorporated into the Science Plan. If the research priorities are addressed, benefits will flow to all stakeholders.

Collation of Knowledge Gaps from Stakeholders

Identification of knowledge gaps for the Science Plan has been thorough. Gaps were identified from a series of WAMSI-led or WAMSI partner-led workshops relating to science for management, adapting to ecosystem change and assessing climate vulnerability. Most recently, in 2019, was a workshop for identifying priorities for Malgana people, and in 2020, an online Malgana Voices Survey to capture priorities and knowledge gaps. Interviews and workshops were conducted with members of the Shark Bay community and an extensive literature review on the environmental, social and economic values of the Shark Bay marine environment was also conducted in 2020, which highlighted further gaps in knowledge.

Approximately 200 different knowledge gaps were identified for Shark Bay. Following an assessment of whether these gaps had been addressed over time or were being addressed in current projects, 91 knowledge gaps remained for stakeholders to prioritise for future research. Knowledge gaps were assigned to 13 high-level research themes.

Prioritised Knowledge Gaps

The prioritisation of knowledge gaps involved an online survey of 219 stakeholders who ranked the high-level research themes and, if able, scored knowledge gaps under each theme based on four criteria: ecosystem importance, interest, urgency and knowledge.

'Climate change' was the high-level research theme that participants thought needed the most attention when it came to maintaining a healthy functioning marine ecosystem in Shark Bay. The results of the ranking process range from 1) most in need of attention to 13) least in need of attention:

1. Climate change
2. Ecosystem processes and connectivity
3. Seagrass communities
4. Benthic communities (other than seagrass)
5. Incorporation of cultural heritage and Traditional ecological knowledge

6. Management and monitoring
7. Environmental conditions
8. Fish and fisheries
9. Education and communication
10. Habitat and bathymetry mapping
11. Marine megafauna
12. Sustainable economic growth and livelihoods
13. Tourism and visitor use

Of the 91 knowledge gaps prioritised by stakeholders, the gap 'How would food webs shift in the absence of key seagrass species under climate change scenarios?' was scored and ranked as the highest priority overall. This was followed by nine other knowledge gaps with a climate change focus:

1. How would food webs shift in the absence of key seagrass species under climate change scenarios?
2. What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?
3. How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?
4. Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures
5. What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?
6. How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?
7. What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?
8. How will climate change affect primary productivity and the flow of energy in marine systems?
9. What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?
10. Develop indicators and monitoring thresholds for the management of key elements of Outstanding Universal Value of Shark Bay World Heritage Area

All the priorities identified in the Malgana 2019 workshop and Malgana Voices Survey directly link to the top 10 prioritised gaps. In particular, the health of seagrass is prioritised highly by all stakeholders, based on responses to the prioritisation survey and Malgana Voices Survey.

Next Steps to Implementing this Science Plan

The Science Plan is currently unfunded. Given the multiple and diverse gaps in knowledge, WAMSI believes multi-level, strategic attention from a range of government, university, industry and philanthropic partners would be the most appropriate way to implement and undertake these research priorities. Investing in the Science Plan would tackle the most important stakeholder driven knowledge gaps and build resilience in Shark Bay. We estimate funding the highest 10 priority knowledge gaps (Priority 1) would require an investment of around $20 million over the next five years. This estimate was arrived at after consulting with researchers with direct experience in Shark Bay and the specific project areas. We also studied the cost of previous WAMSI science programs when considering the likely project costs. These estimates are notional only. As some of these projects are large in scope, they would likely cover off on many of the other important knowledge gaps of a lower priority (e.g. Priority 2 and 3) as presented in this document.

The pressures facing Shark Bay are urgent to address and could cause widespread loss of key ecological values, fisheries, tourism, economic sustainability, community resilience and regional prosperity and potentially the World Heritage status.

A funded WAMSI Shark Bay Science Plan will guide research to address these pressures. Coordinating research in Shark Bay under a single program such as the WAMSI Shark Bay Science Plan not only facilitates knowledge exchange, it enables the sharing of data, and minimises duplication of research effort. It also provides a cost-effective way of conducting research and transferring knowledge between all interested stakeholders, including Malgana people.

WAMSI will address the implementation of the Plan by drawing on the expertise of the WAMSI Board, WAMSI partners and other interested stakeholders to develop the next steps. This facilitation role will link those with shared interests and seek funding from a broad range of organisations and entities.

1. A spotlight on Shark Bay

Aerial view of Shark Bay | Credit: Australia's Coral Coast

1.1 Why a Science Plan for Shark Bay?

Shark Bay (Gathaagudu) is unique on a global scale. It is home to one of the largest and most diverse seagrass meadows in the world, the largest dugong population in the world, and is one of only two marine locations in the world where you can find Earth's oldest living lifeforms – stromatolites. These unique values helped to establish Shark Bay as a World Heritage Area (WHA) (Fig. 1), and it is one of only 21 out of 1121 WHAs that satisfies all four natural criteria of a World Heritage listing.

This WHA is also vitally important to the WA community. It is home to some of the most valuable commercial fisheries in WA including Shark Bay Prawns, Scallops and Blue Swimmer Crabs. It is a tourism hotspot with excellent recreational fishing opportunities, 'superlative' vistas and opportunities to view a range of marine animals and interact with dolphins. It is a significant site for European history. Shark Bay includes national (terrestrial) and State and Commonwealth marine parks and is a globally important blue carbon sink. The Malgana people are custodians of Gathaagudu and maintain their important and culturally rich sea country.

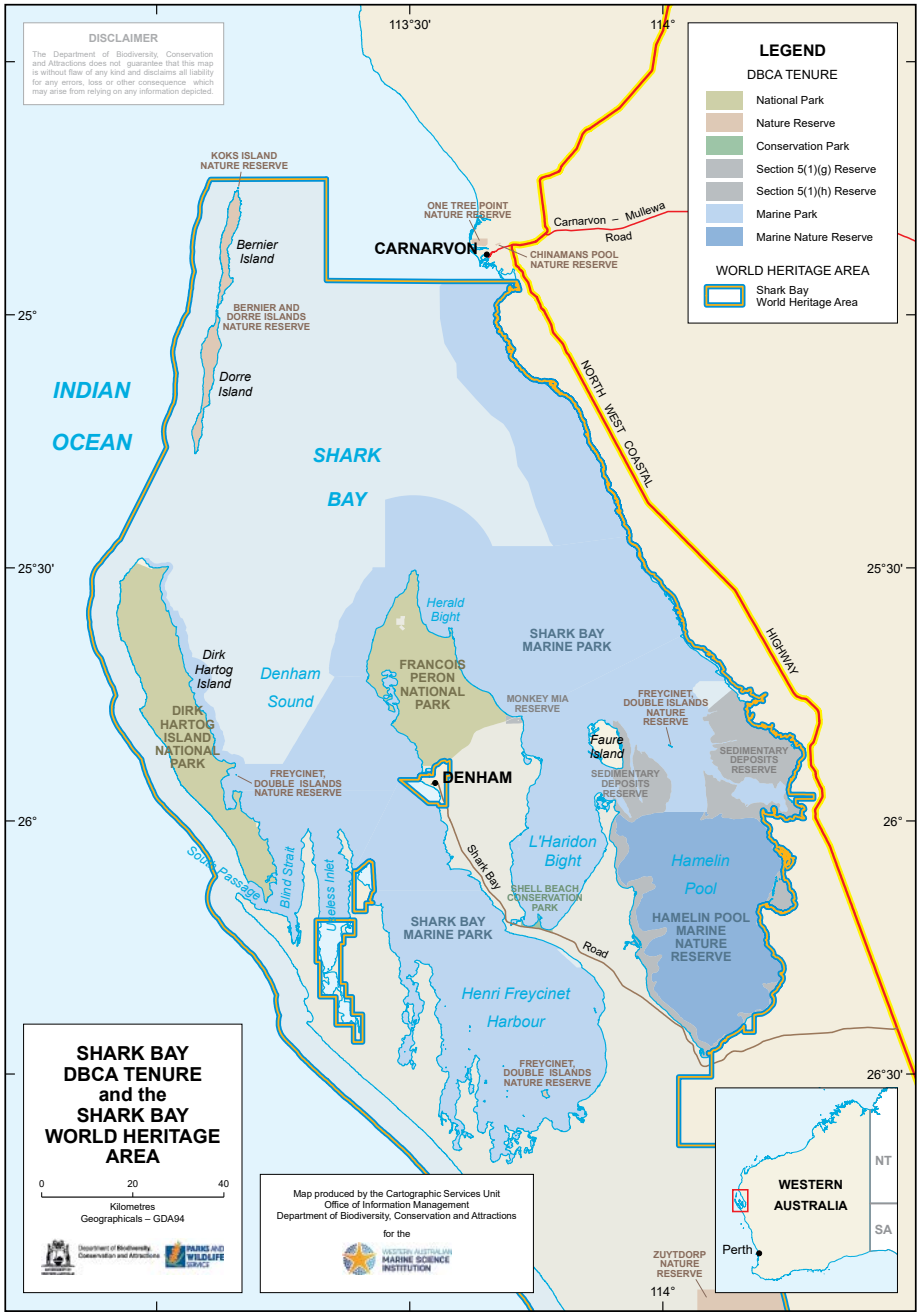


Figure 1: Shark Bay (Gathaagudu) showing the World Heritage Area, Marine Park and Marine Nature Reserve.

Despite international recognition of this iconic area, the unique values of Shark Bay are under threat by climate change and other anthropogenic activities. This will have flow on effects to not only a world-class environment, but a community largely driven by tourism and fishing, with strong Indigenous links to saltwater country.

In 2011, an extreme marine heatwave inundated Shark Bay with 4°C warmer water over two weeks, which coincided with a major flooding of the Wooramel River. The subsequent negative impacts caused the loss of 24 per cent of seagrass within the World Heritage Area and closure of commercial fisheries. These events, plus subsequent years of elevated temperatures in the Bay during summer, caused the community, researchers, managers and industry alike to question what would happen if the whole system collapsed from future extreme events.

While knowledge has been gained on the resilience of the Shark Bay marine system after the events in 2011, there is an urgent need to fill in the knowledge gaps to enable science to inform effective management given the predicted increase in frequency and intensity of extreme events. Since 2011, the Gascoyne region experienced severe Tropical Cyclone Seroja, flooding of the Wooramel and Gascoyne rivers, and a warm La Nina summer in 2020/2021 which had marine heatwave water temperatures. With no action or science focus, there is the threat of widespread loss of key ecological values, loss of large commercial fisheries, loss of economic sustainability through loss of fisheries and tourism, and possible delisting of the World Heritage status.

The WAMSI Shark Bay (Gathaagudu) Science Plan (Science Plan, herein) is a strategic and collaborative plan driven by stakeholders and researchers to provide advice on the current knowledge gaps. These will help inform decision making and management, as well as maintain community resilience and ecological function of the marine environment under a changing climate.

This Science Plan is the first to prioritise knowledge gaps and provide a research focus based on the collective views of such a wide range of stakeholders. The views of Malgana people, community, industry and fishing representatives are combined with the views of researchers, managers and government officers to produce science priorities that have wide-reaching relevance to the environmental, cultural, economic and social values most important to all stakeholders.

1.2 The role of WAMSI

WAMSI was established by the Western Australian Government more than 16 years ago as a collaborative marine science research partnership that operates to benefit all Western Australians. It is a research collaboration comprised of multiple partners including the university sector (The University of Western Australia, Murdoch University, Curtin University, Edith Cowan University), the Commonwealth Australian Institute of Marine Science, ChemCentre, WA Museum and a number of WA Government departments (Primary Industries and Regional Development (DPIRD); Biodiversity, Conservation and Attractions (DBCA); and Water and Environmental Regulation (DWER)) and is funded by the Department of Jobs, Tourism, Science and Innovation (JTSI). Together they represent a broad section of marine science expertise and experience in WA. WAMSI continues to serve as an independent coordinator of strategic and targeted marine science research programs that support better decision making in WA.

The WAMSI Blueprint for Marine Science 2015–2050 provides a strategic framework for marine science priorities in WA that underpin the sustainable development of WA's marine and coastal environment. The Blueprint Refresh 2022–2027, provides a contemporary focus, shaped by changes and advances over the last five years. It has a stakeholder focus to ensure any resulting research agenda is guided by real world priorities and recognises three focus areas – Traditional Owner participation, accessible data and social engagement – that should be addressed through any marine science program. This Science Plan is relevant to several themes identified in the Blueprint Refresh to guide marine science research in WA. This includes ocean and climate change, blue economy, regional cumulative impacts, standards and regulation, and fundamental understanding of biodiversity and ecosystem function.

WAMSI is well placed to undertake the effective stakeholder engagement necessary for this Science Plan, given it has been established as an independent organisation and is perceived that way by stakeholders. WAMSI has played the leading role in WA in bringing marine science research providers together to undertake the science and disseminate this knowledge to both the decision makers and stakeholders. WAMSI has also successfully fostered collaboration and the co-production of knowledge by bringing together different partner organisations. The subsequent translation or interpretation of marine research information into content that is readily accessible by decision-makers and the community has been a successful outcome for WAMSI.

WAMSI requires all researchers working on projects resourced through WAMSI Science Plans to follow a set of principles and guidelines for Indigenous engagement, and these are outlined in section 6.2.3.

1.3 A call to action for a research focus

Shark Bay has had World Heritage status for many decades and is recognised by local, national and international researchers for its Outstanding Universal Value. The pressures facing Shark Bay urgently need to be addressed and could cause widespread loss of key ecological values, fisheries, tourism, economic sustainability, community resilience and regional prosperity and potentially the World Heritage status. Despite this, Shark Bay has not yet had the benefit of coordinated and collaborative scientific effort supported by long term funding. A funded WAMSI Shark Bay Science Plan will guide research to address key pressures. Coordinating research in Shark Bay under a single program such as the WAMSI Shark Bay Science Plan not only facilitates knowledge exchange, sharing of data and minimises duplication of research effort, but it also provides a cost effective way of conducting research and transferring knowledge between all interested stakeholders. There is a risk that unless this Science Plan is endorsed and supported by government agencies, universities, industry and philanthropists, it will become another report with minimal impact.

The Science Plan addresses knowledge gaps consistent with other broader scale Australian marine science plans and State, national and international priorities. An outcome for a coordinated approach would be a Science Plan that would enable free access to data and information that could feed back into these State and national gaps and priorities. Though the Science Plan focuses on the location of Shark Bay specifically, the marine environment is connected across vast scales for which findings in Shark Bay will be widely applicable. Shark Bay is a unique and iconic area, however, not unique in the challenges it faces. Implementation of the Science Plan and associated outcomes will also be beneficial for other coastal locations requiring intervention and management.

1.3.1 Synergies with national and international agreements

The Science Plan was developed with a high-level Steering Group comprising WAMSI partners including from the management agencies of DPIRD and DBCA. The Steering Group provided a holistic approach to the Plan enabling the opportunity for research gaps to be identified in areas where research was required and could also fulfill important management needs.

As a result, this Science Plan could assist management agencies in meeting their legislative objectives and obligations under a number of national and international agreements. For example, research gaps in the Plan could contribute to the goals of the Shark Bay Marine Reserves Management Plan and the management goals, objectives, strategies and actions of the Shark Bay World Heritage Property Strategic Plan.

Below are a number of examples of obligations and priorities the Science Plan directly supports.

1.3.1.1 Australia's obligations as a Party to the World Heritage Convention

Australia is a Party to the World Heritage Convention and is obligated to ensure that the Shark Bay WHA is protected, preserved and passed on to future generations. The Statement of Universal Value is used as a reference document for the protection and management of the WHA.

If values that initially satisfied the World Heritage natural criteria are degraded or lost, such as seagrass meadows, then the Shark Bay WHA is at risk of losing its WHA listing status. This will have significant economic and social consequences for the local community and to the wider national and international community in terms of international standing and obligation.

1.3.1.2 Synergies with the WA State Government

The WA Government is focused on six priorities that will help build the State's prosperity. The Science Plan addresses five of these priorities, which include:

- a strong economy: create jobs
- a bright future: increase participation in STEM
- a liveable environment: increase conservation for future generations
- Aboriginal wellbeing: true partnerships with Aboriginal Western Australians
- regional prosperity: deliver stronger regional economies

1.3.1.2.1 DBCA priorities

The Department of Biodiversity, Conservation and Attractions (DBCA) strategic directions 2022–25 identifies integrity, collaboration, accountability, respect and excellence as core values, which all align with the principles outlined in this Science Plan. More specifically, DBCA released a paper in 2016 (Kendrick et al., 2016) outlining high priorities for strategic marine ecological research for the State's marine parks and reserves, including the Shark Bay marine reserves. The authors specifically state:

> *"While Parks and Wildlife will undertake a number of these projects, this paper is equally focused on identifying opportunities for developing management-related collaborations with the broader marine science community."*

The Science Plan is harnessing that opportunity for collaboration to deliver better science for better management decisions.

For 23 ecological assets listed in CALM Act marine park management plans, Kendrick et al. (2016) highlights 30 high priority research strategies and questions for fundamental research, and 30 high priority research strategies and questions for applied research specifically for the Shark Bay marine reserves. The Science Plan incorporates all these research strategies and questions, which are listed in Section 7.

1.3.1.2.2 DPIRD priorities

The Department of Primary Industries and Regional Development (DPIRD) released its Strategic Intent for 2022-2026 (DPIRD, 2019) which identifies 13 priorities under three strategic outcomes. Of direct relevance to this Science Plan is the priority to deliver, co-invest and collaborate in research and development that drives innovation, protection of natural resources and international competitiveness. This Science Plan addresses a further seven DPIRD priorities for the next four years, including:

- Management systems and programs to sustain and enhance our aquatic, pastoral and agricultural resources
- Provide services and programs that allow the community to access, use and develop our land and aquatic resource on a sustainable basis
- Research and policy leadership in the primary industries and regions to enable transition to a sustainable carbon future as part of our adaptation to climate change
- Collaborate across industry, community and regions to ensure research impact and extension, adoption of new technology, and the development of collective knowledge
- Deliver models of support and targeted programs that empower Aboriginal people to develop and sustain long-term outcomes that strengthen communities
- Build the capacity of community, industry and Aboriginal people to work with us to deliver our priorities
- Policies and programs that encourage sustainable economic development, diversification and job creation with a focus on unlocking land and water resources, building business capacity, and developing and facilitating trade and investment

1.3.1.3 Synergies with the National Marine Science Plan 2015–2025

The National Marine Science Plan (NMSP) provides direction for improving Australia's blue economy potential and outlines high priority science needs to address the challenges facing the marine estate.

The NMSP presents seven grand challenges for Australia and the science needed to address each challenge. The Science Plan includes knowledge gaps that are consistent with the grand challenges of food security, biodiversity, conservation and ecosystem health, urban coastal environments, climate variability and change, and resource allocation.

1.3.1.4 United Nations Decade of Ocean Science for Sustainable Development (2021–2030)

The primary goal of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030) is to "support efforts to reverse the cycle of decline in ocean health and gather ocean stakeholders worldwide behind a common framework that will ensure ocean science can fully support countries in creating improved conditions for sustainable development of the ocean".

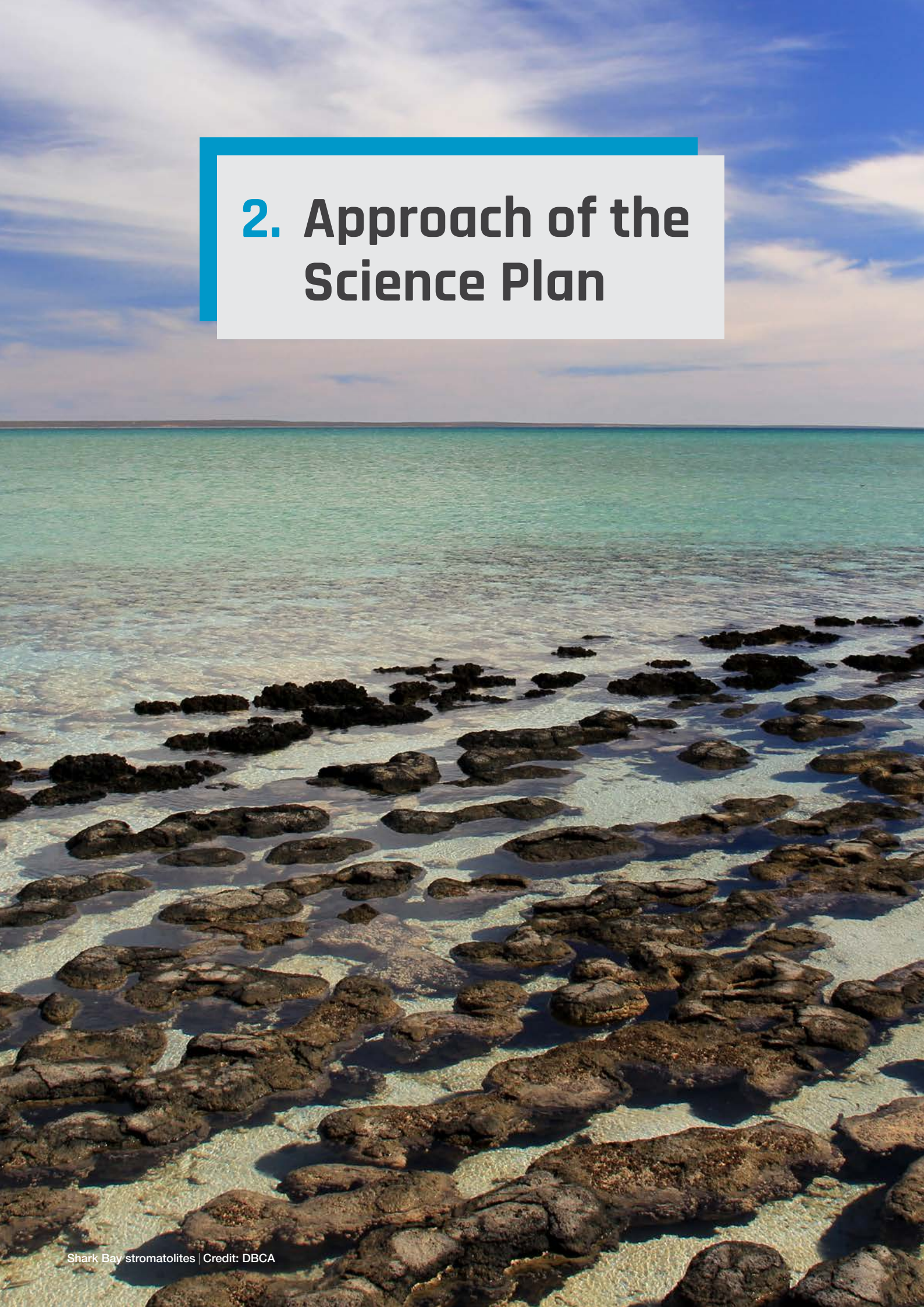
The Decade of Ocean Science recognises that "Scientific understanding of the ocean's responses to pressures and management action is fundamental for sustainable development. Ocean observations and research are also essential to predict the consequences of change, design mitigation and to guide adaptation".

There are ten challenges driving the Decade of Ocean Science, and the Science Plan includes knowledge gaps that can help address at least six of those challenges from a coastal, eastern Indian Ocean perspective:

- Protect and restore ecosystems and biodiversity
- Develop a sustainable and equitable ocean economy
- Unlock ocean-based solutions to climate change
- Increase community resilience to ocean hazards
- Skills, knowledge and technology for all
- Change humanity's relationship with the ocean

Fishing vessels | Credit: Matt Watson SMC

2. Approach of the Science Plan



Shark Bay stromatolites | Credit: DBCA

2.1 Project scope

2.1.1 Objective

The main objective of this project was to engage with stakeholders to provide a strategic, transparent, collaborative Science Plan that will guide research to fill the knowledge gaps required for strategic decisions and management. WAMSI was encouraged to undertake the development of the Science Plan as it is seen as a trusted, independent, collaborative organisation that can draw on its extensive group of State and Federal partners and then provide comprehensive strategic advice.

2.1.2 Geographic scope

The area included in the Science Plan includes Shark Bay State waters and coastal environments bordered in the west and north-west by Dirk Hartog, Dorre and Bernier Islands. The northern extent matches that of the WHA property boundary (ending just below Carnarvon), though the southern extent is restricted to the inner reaches of the Freycinet Estuary and Hamelin Pool.

2.2 Research design

The objective of this Science Plan was achieved using a research design that included comprehensive engagement with stakeholders, including government, industry, Traditional Owners, community, researchers and managers (Fig. 2). Establishing the priorities for Shark Bay came about through a literature review, workshops and surveys with a large variety of stakeholders. It also included a comprehensive prioritisation process.

2.3 Limitations

Limitations are expected for a process that tries to encompass a wide range of stakeholders in delivering prioritised knowledge gaps. The following limitations should be considered when interpreting the information presented in this report:

- COVID-19 restrictions possibly prevented rigorous discussion and widespread consensus on priority knowledge gaps
- Greater input from economists and social scientists may have facilitated a more thorough analysis of economic and social knowledge gaps
- Although knowledge sharing was a part of the development of the Plan, an even greater focus would have enhanced the input of formal Traditional ecological knowledge on the marine environment of Shark Bay
- The community surveys could have been widened to include a larger number of stakeholders with more diverse backgrounds
- Stakeholder participation was unbalanced with researchers dominating the survey results. Engagement from extractive industries and agriculture was limited
- Length of prioritisation survey may have been discouraging to some survey participants/ stakeholders
- Online survey required access to a computer and internet.

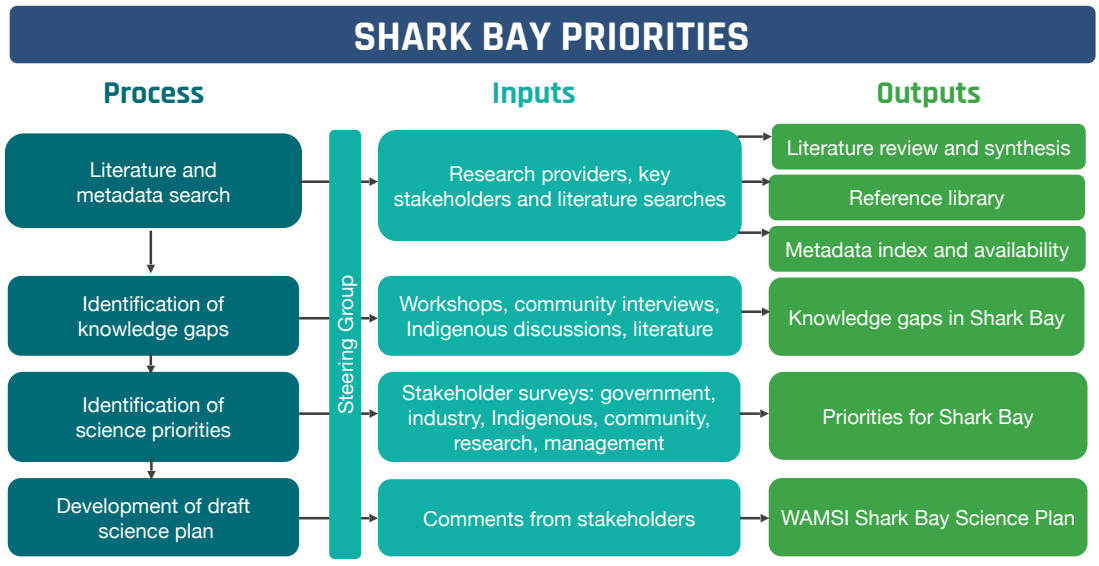


Figure 2: Shark Bay Priorities schema outlining the processes developed in the WAMSI Shark Bay (Gathaagudu) Science Plan.

3. Summary of methodology

Aerial view

A number of different methodologies were used in order to develop the Science Plan. These are summarised below and can be understood in more detail in subsequent chapters.

Literature and metadata synthesis

(see Section 4.0 for more detail)

The WAMSI Shark Bay Literature Review is a comprehensive document encompassing ~748 pieces of literature on the marine and coastal environments of Shark Bay, dating back to 1954. This WAMSI Shark Bay Literature Review underpins the knowledge gaps presented in this Science Plan and provides the background knowledge for identifying priority areas of research. Accompanying the literature synthesis was a metadata summary of ~970 literature/data sources, the majority of which were scientific papers. The majority of the literature/data focused on ecological assets, though many outputs were relevant to more than one ecological asset. DPIRD Fisheries and The University of Western Australia authored the most outputs.

Stakeholder workshops

(see Sections 5.2 and 6.2.2 for more detail)

Workshops were held between 2018 and 2019 that helped to identify knowledge gaps and potential research priorities:

- WAMSI and UWA Workshop: Adapting to ecosystem change in the Shark Bay World Heritage Site – June 2018 https://wamsi.org.au/news/adapting-to-ecosystem-change-in-the-shark-bay-world-heritage-site
- Climate Vulnerability Index (CVI) workshops (Day et al., 2020)
  - Assessing the exposure, sensitivity and adaptive capacity of key World Heritage values to determine the vulnerability of the Outstanding Universal Value – September 2018
  - Assessing economic, social and cultural dependencies upon the SBWHA and their adaptive capacity to climate change to determine the vulnerability of the Community – June 2019
- Community workshops
  - Information sharing and understanding of community values and knowledge gaps. The two participatory workshops were held in Denham and included stakeholders from the business community, primarily tourist operators, and other interested community members – May 2019
- Malgana Workshop – December 2019
  - Addressed the need to return knowledge by delivering a metadata synthesis on all marine science projects that had taken place in Shark Bay over the previous 70 years
- Discussed the processes and protocols for scientists working on sea country and the adapted use of the Kimberley Saltwater Research Protocol – December 2019.

Community interviews

(see Section 5.3 for more detail)

Community interviews were conducted between May and June 2019 in order to better understand the views and values of the Shark Bay community. A total of 56 interviews were conducted across four locations, Denham, Carnarvon, Geraldton and Perth to access a range of participants who had an interest in Shark Bay.

Malgana Voices Survey

(see Section 6.3 for more detail)

The Malgana Voices Survey was an online survey designed to capture the voices of Malgana people from across the community, Malgana Aboriginal Corporation (MAC) and its land and sea management team in a mobile, community-appropriate format. A short animation was produced to describe the survey and encourage people to engage.

Prioritisation survey

(see Section 8.0 for more detail)

Prioritising knowledge gaps that span across ecological, social and economic values is best done in consultation with a range of stakeholders. To accomplish this during COVID-19 restrictions in 2020, an online prioritisation survey was designed using the software Qualtrics. The survey was distributed via email and online to researchers, government, managers, community members, Malgana community, fishing community, industry groups and visitors, and a total of 219 survey responses were received.

4. Existing western science knowledge

Loggerhead turtle | Credit: Nick Thake

4.1 Literature review

A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949 – 2020) (Sutton and Shaw, 2020) is a comprehensive document encompassing ~748 pieces of literature on the marine and coastal environments of Shark Bay. A large portion of the review includes a synthesis of ecological assets including environmental conditions, ecosystem processes, benthic communities, planktonic communities, faunal communities and commercially fished species. The majority of research in Shark Bay has focused on bottlenose dolphins and fisheries, followed by microbial communities, seagrass communities and ecosystem-wide research (predation, foraging). The review also included information on Indigenous interests, social and economic drivers (tourism and fisheries are key drivers), threats and external drivers, current management and planning. Legislative and administrative arrangements were also described.

The WAMSI Shark Bay Literature Review underpins the knowledge gaps presented in this Science Plan and provides the background knowledge for identifying priority areas of research.

4.2 Metadata summary

A metadata synthesis was performed for ~970 literature/data sources and is provided in the accompanying online document WAMSI Shark Bay metadata synthesis (https://wamsi.org.au/research/programs/shark-bay-research/). The aim of the synthesis was to capture as much metadata information as possible, particularly information on data formats, data availability, data repositories and metadata contacts. Where possible, the metadata included was sourced directly from researchers, however, this was not captured for all literature/data sources.

The majority of the literature sourced for the literature review was on ecological assets. Of those ecological assets, 167 literature outputs were for bottlenose dolphins and 132 outputs related to commercial fisheries. Microbialite communities, seagrass communities, marine turtles and elasmobranchs were also popular fields of study (Fig. 3). It should be noted that many research/literature outputs were relevant to more than one ecological asset.

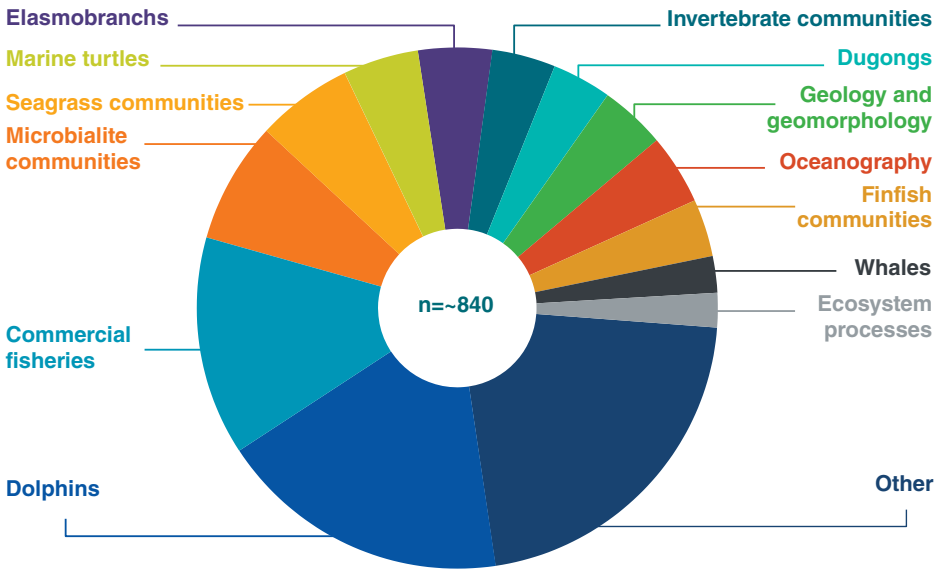


Figure 3: Most common ecological assets researched at Shark Bay. Other includes recreational fisheries, seabirds, coral reef communities, mangrove communities, sea snakes, water quality, algal communities, planktonic communities, hydrology, aquaculture, sediment quality, bathymetry, introduced species and sponges [taken from A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949–2020) (Sutton and Shaw, 2020)]

An indication of the increase in literature outputs over time is given in Fig. 4, and it is of note that outputs were produced for all but seven of the years since 1954. The majority of the literature outputs were scientific papers (~500) followed by reports (~110) (Fig. 5). DPIRD Fisheries (113) and The University of Western Australia (108) authored the most outputs, and several other national and international universities were relatively active in the SBWHA (Fig. 6).

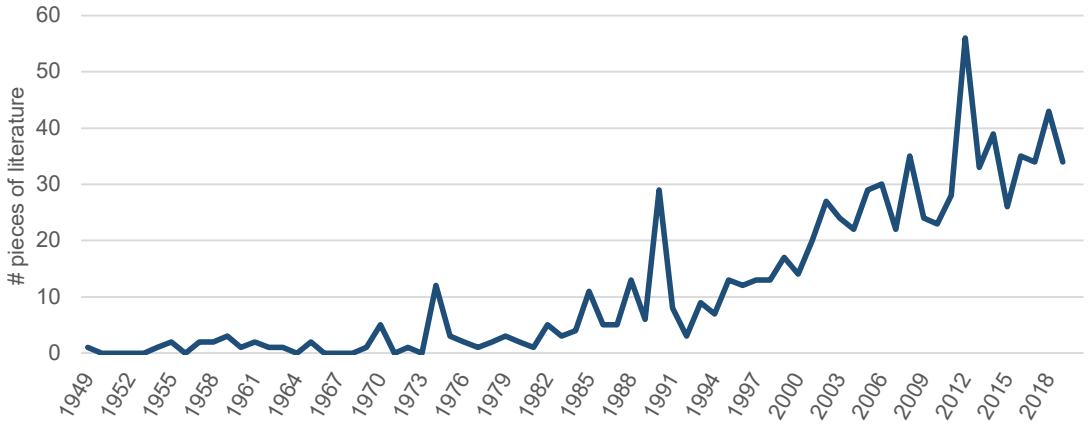


Figure 4: Literature outputs for Shark Bay since 1954 [taken from A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949–2020) (Sutton and Shaw, 2020)].

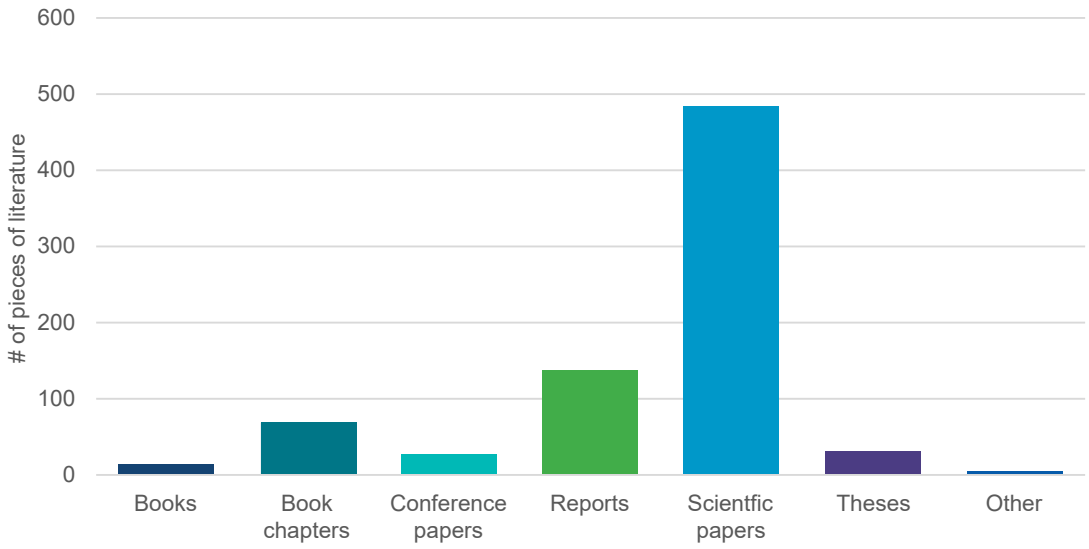
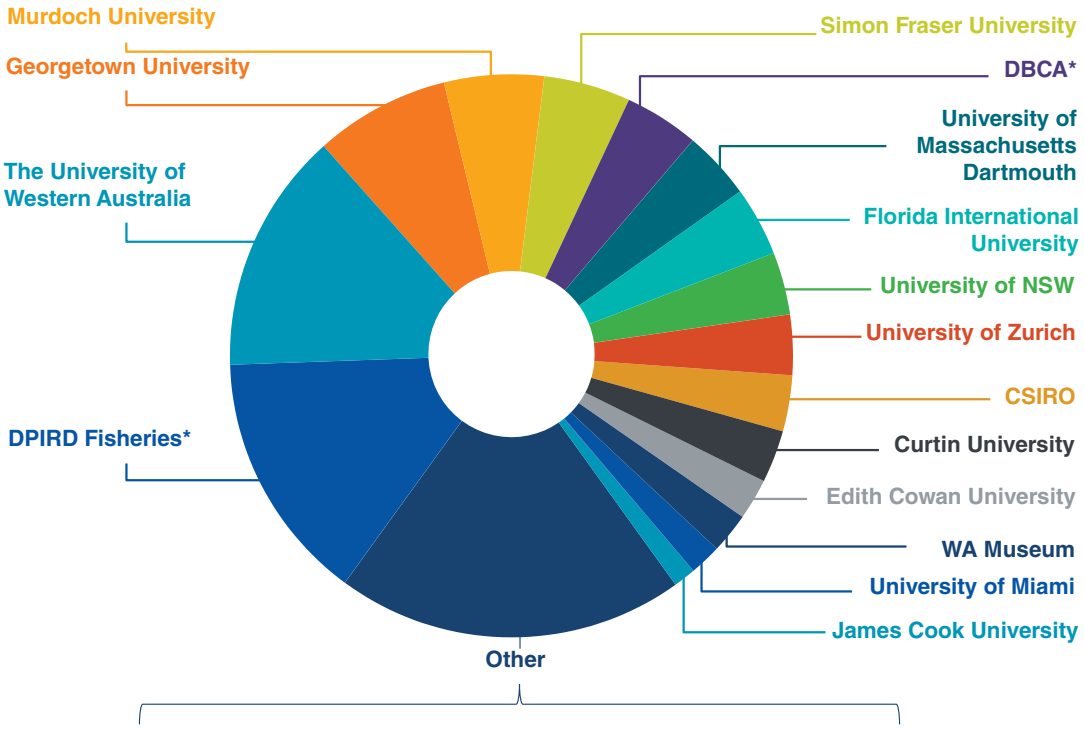


Figure 5: Categories of literature outputs for the WAMSI Shark Bay Literature Review [taken from A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949 – 2020) (Sutton and Shaw, 2020)].



Australia Institute of Marine Science
Australian National University
Australian Venture Consultants
Baas Becking Geobiological Lab
Birdlife WA
Birds Australia WA Inc
British Museum of Natural History
California Academy of Sciences
Conservation Council WA
Centre for Whale Research
Columbia University
Cornell College
CRC for Sustainable Tourism
Dalhousie University
Damara WA
De Montfort University
Department of Agriculture
DPLH*
DWER*
Ecocean
Economic Research Associated
Environment Australia
FRDC
Freie Universitat Berlin
Geological Survey of Canada
Geological Survey of WA
Geosciences Australia
Griffith University
IMAS
JAMSTEC
Kenyon College
La Trobe University
Macquarie University
Massey University
Montana State University
Mote Marine Laboratory
NASA Ames Research Center
Northern Rivers College of Advanced Education
Project Manta
Queen's University Belfast
Queens College
Rangelands NRM
Recfishwest
Rick Scoones & Associates
Smithsonian Institution
Texas A&M University
The Shire of Shark Bay
The University of Adelaide
The University of Hong Kong
The University of Tokyo
Tokyo University of Marine Science and Technology
UMASS-Dartmouth
University College London
University of Bristol
University of Calgary
University of California
University of Cambridge
University of Canberra
University of Canterbury
University of Carolina
University of Colorado
University of Florida
University of Jordan
University of Leeds
University of Maryland
University of Melbourne
University of Michigan
University of New England
University of North Carolina
University of Otago
University of Queensland
University of Rhode Island
University of Southern California
University of St Andrews
University of Sydney
University of Texas
University of the Sunshine Coast
University of Washington
University of Technology Sydney
VIMS
WA Herbarium
Woods Hole Oceanographic Institution
Woodside Energy

Figure 6: Local, national and international institutions and agencies that have led the production of literature outputs for Shark Bay. Only first author institutions details are included. *Includes all previously named departments and amalgamations [taken from A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949 – 2020) (Sutton and Shaw, 2020)].

5. Stakeholder engagement

Denham | Credit: Australia's Coral Coast

5.1 Identification of stakeholders

Potential stakeholders were identified by the project partner organisations, other representative agencies, community groups, previous networks and snowball sampling (Goodman, 1961; Walter, 2010; 2013). The stakeholders that were identified represented individuals and groups from the following sectors:

- Indigenous (Malgana)
- State and Federal government departments
- Research organisations
- Universities
- Non-profit organisations/conservation
- Commercial fishing
- Recreational fishing
- Tourism
- Industry (e.g. mining and tourism)
- Local Shark Bay community

5.2 Workshops

5.2.1 WAMSI and UWA Workshop: Adapting to ecosystem change in the Shark Bay World Heritage Site

In June 2018, a WAMSI and UWA joint workshop on 'Adapting to ecosystem change in the Shark Bay World Heritage Site' was held with 70 science and industry experts at the Indian Ocean Marine Research Centre, The University of Western Australia (Appendix 1) (https://wamsi.org.au/project/2018-shark-bay-workshop/). The aims of the workshop were to identity gaps in knowledge and address whether current management strategies were adequate for responding to future extreme events and climate change. There was a clear call for collaboration among disciplines and institutions to identify and address priority research areas that could support integrated management decisions.

The key outcomes from the workshops were:

- A shared vision for a cross-sectoral focused program to address the integrated management of Shark Bay under global change for the values as outlined in the World Heritage Site documentation and for sustainable tourism, commercial and recreational fishing and industry
- A management and policy response to maintain the resilience in both natural environment and human activities that rely on Shark Bay. The response should incorporate adaptive responses in the local industries to predictions of the effect of climate change to the Shark Bay ecosystem. There is enough prior research to make reasonable assessments of risk, but this research needs to be captured
- Continued focussed research that advances our abilities to predict the effects of climate change in Shark Bay and that supports management responses and interventions to address the lack of understanding of the consequences of ecosystem change
- Lack of understanding of consequences of ecosystem change that will require new management approaches and new and rapid methods to interpret data
- Cross-sectorial sharing should include multidisciplinary teams to integrate research and management. The steps identified were to build multidisciplinary teams around projects; integrate the research program through collaboration; hold more cross-sector workshops/forums for sharing information; identify problems, teams and funding sources and update the WHA
- An assessment of the sustainability of the commercial and recreational fisheries and the current management practices

Outcomes from the workshop were used in subsequent Climate Vulnerability Index workshops that carried out rapid assessments of the exposure, sensitivity and adaptive capacity of Shark Bay World Heritage values (September 2018) and economic, social and cultural values (June 2019) to climate change.

5.2.2 Climate Vulnerability Index (CVI) workshops

Climate Vulnerability Index (CVI) is a rapid assessment tool that was developed by the World Heritage Advisory Committee specifically for World Heritage Properties (Day et al., 2020). The SBWHA was the first World Heritage Area in the world to undergo the CVI assessment. CVI workshops were held to determine the extent to which climate change would impact on the Outstanding Universal Value (OUV) of the SBWHA and to what extent climate change would impact on the economic, social and cultural dependency on the SBWHA. Workshops participants included science and industry experts (Appendix 2 and 3).

The CVI assessment for the SBWHA occurred across two workshops:

1. Denham, Shark Bay (16–19 September 2018): Assessing the exposure, sensitivity and adaptive capacity of key World Heritage values to determine the vulnerability of the Outstanding Universal Value
2. Indian Ocean Marine Research Centre, UWA, Perth (10 June 2019): Assessing economic, social and cultural dependencies upon the SBWHA and their adaptive capacity to climate change to determine the vulnerability of the Community

The aims of the two workshops were to:

- Understand the CVI framework and its application in Shark Bay
- Understand the significant values that comprise the Outstanding Universal Value (OUV) for SBWHA plus the other significant local values for Shark Bay
- Understand the likely future climate change scenarios facing Shark Bay
- Assess the climate change stressors impacting the values of Shark Bay and select key climate change stressors
- Evaluate the vulnerability of the OUV to the key climate change stressors, considering exposure and sensitivity
- Consider the economic, social and cultural dependencies (sensitivity) and adaptive capacity to determine the Community vulnerability
- Progress toward a climate change adaptation strategy and adaptation plan

Based on CSIRO projections for the "Rangelands (South)" sub-cluster of Australia (Watterson et al., 2015), of which Shark Bay falls under, the CVI assessments took place under the climate change scenarios of:

- Extreme marine temperature events: five per decade (determined using coral report analysis for RCP8.5; Heron et al., 2017)
- Doubling of frequency of severe storms
- Air temperature increase of 1°C

These were identified as stressors that would have the greatest potential impact on Shark Bay's OUV (Heron et al., 2020).

The adaptive capacity of the SBWHA to climate change was rated as 'very low' for air temperature change, 'low' for storm intensity and frequency, and 'very low' for extreme marine heat events. Overall, Shark Bay's OUV is considered to be highly vulnerable to climate change (NESP Earth Systems and Climate Change Hub, 2018).

The economic and social adaptive capacity of the local, national and interstate community to climate change was rated as low, and cultural adaptive capacity was rated as moderate. Overall, the Community Vulnerability was considered highly vulnerable to climate change (Heron et al., 2020).

The next steps following the Climate Vulnerability Index (CVI) assessment of the SBWHA are to develop a climate change adaptation strategy and adaptation plan (Day et al., 2020; NESP Earth Systems and Climate Change Hub, 2018). Future management strategies can be guided by the key climate risks for Shark Bay identified in the CVI assessment.

5.2.3 Community workshops

The two workshops were held to update the community on the proposed program and subsequent development of a Science Plan, share knowledge and better understand the community views and values. Also discussed was the information thought to be important to address some of the pressures and impacts affecting the Bay. At each workshop, participants were also interviewed one-on-one or filled out a survey form.

5.2.4 WAMSI Malgana workshop

See Section 6.2.2 for details

5.3 Community interviews

One-on-one semi-structured interviews were conducted across May and July 2019 in order to better understand the views and values of the Shark Bay community. Community participation information and consent forms can be seen in Appendix 4 and 5. Interview participants were asked 20 questions (Appendix 6) that related to:

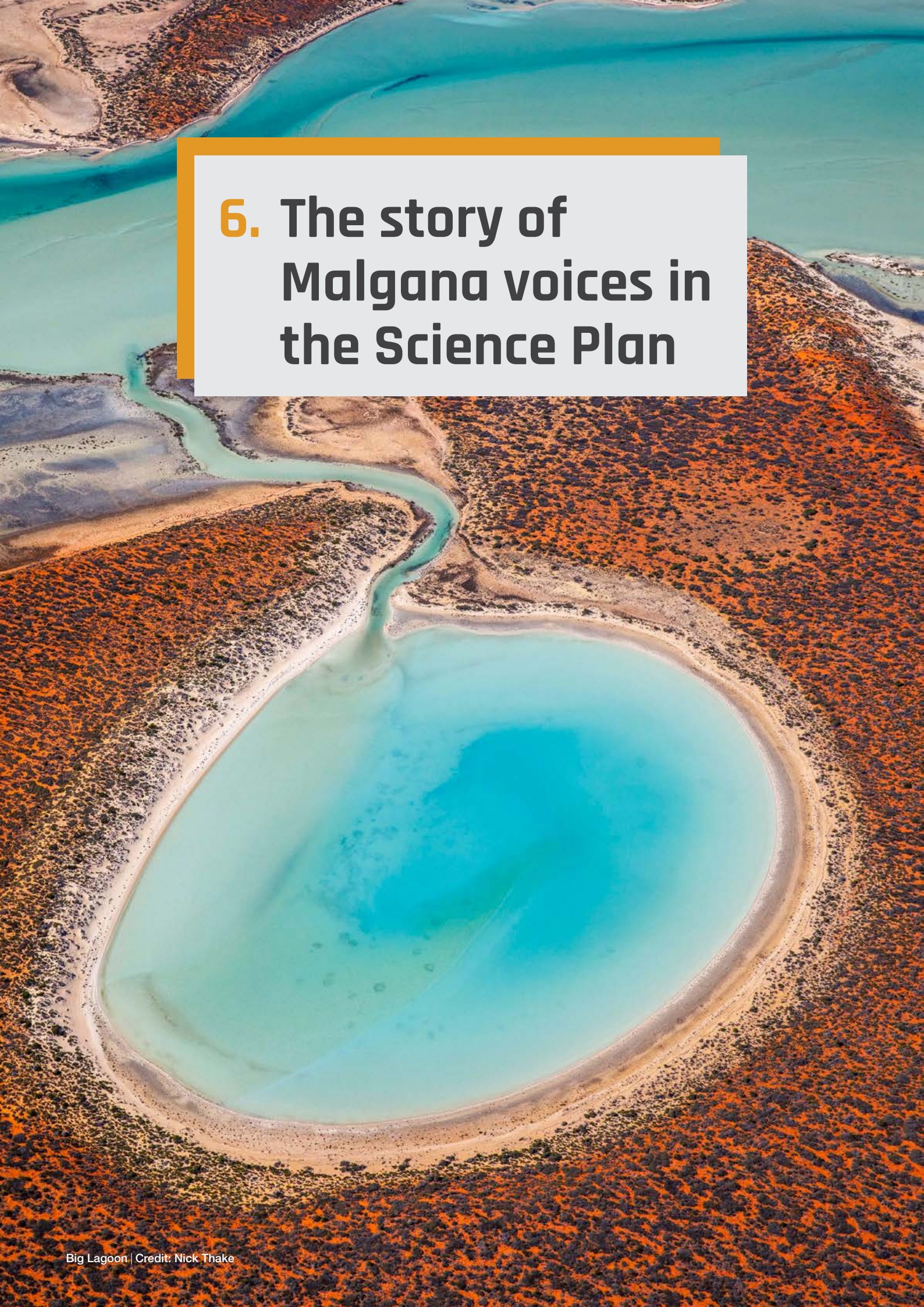
- demography
- the values important to them from living/working in Shark Bay
- climate and environmental changes
- issues and opportunities
- understanding of research undertaken in Shark Bay
- further involvement with the Science Plan

For this document, only those issues relating to knowledge gaps were considered. A total of 56 Shark Bay community members were interviewed across four locations, depending on where community members were located (Appendix 7):

- Denham, Shark Bay
  - 8–11 and 27–29 May 2019
  - 38 interviews
- Perth
  - 17 May, 5 June and 17 July 2019
  - 7 interviews
- Carnarvon
  - 30–31 May 2019
  - 7 interviews
- Geraldton
  - 17–19 June 2019
  - 4 interviews

Dr Jenny Shaw conducting community interviews with Bobby Hoult and Howard Cock; Fishers (top), Garth Dobney: Charter boat operator (bottom left), and Martin Grenside: Manager, Monkey Mia Resort

6. The story of Malgana voices in the Science Plan



Big Lagoon | Credit: Nick Thake

6.1 The Malgana Aboriginal Corporation

The Malgana people are the native titleholders of Gathaagudu (Shark Bay) (NNTR, 2020). The Malgana Aboriginal Corporation (MAC) was formed in 2018 and holds the native title trust on behalf of the Malgana people (ACNC Charity Register, 2022), and is working hard to create social and economic benefits for its members. Since formation, the MAC has undertaken a body of work to establish its Indigenous governance and Prescribed Body Corporate (PBC) functions. At the time of writing, MAC has a membership base in excess of two hundred and sixty people and a board of ten (ACNC Charity Register, 2022). Members live around WA including in Denham, Geraldton, Carnarvon and Perth.

6.2 Malgana research protocol development

6.2.1 Background

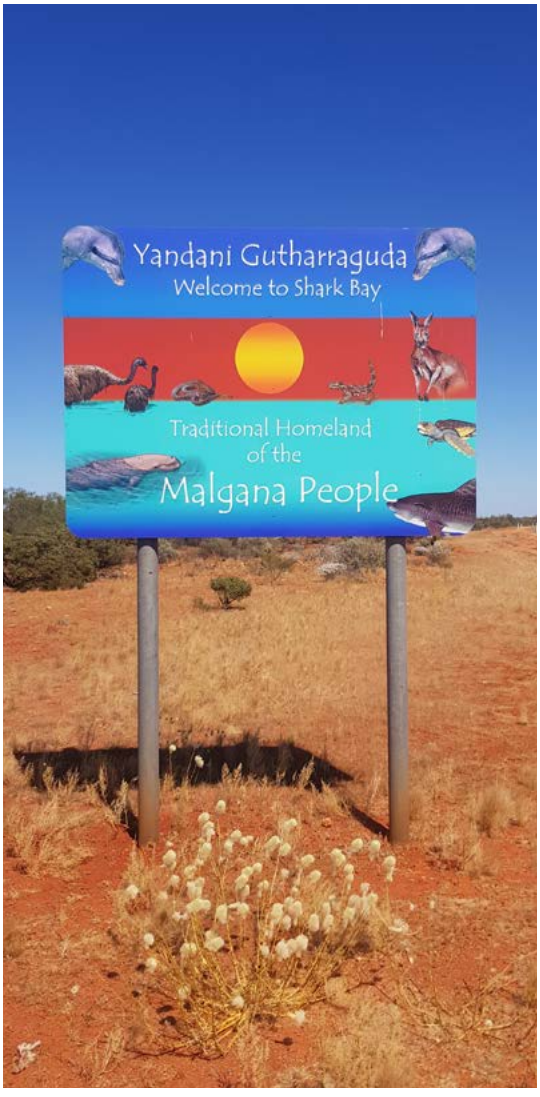
Developing processes and protocols for scientists working on sea country was a key recommendation from the Indigenous workshop hosted by the Australian Marine Sciences Association 2019 conference in WA. At the workshop, WAMSI committed to supporting the development of Indigenous sea country research protocols and processes for Indigenous engagement on a location-specific or regional basis, where project planning or research projects provided the opportunity. Development of the Science Plan provided WAMSI with the opportunity to start this process by supporting the MAC to develop a Malgana Land and Sea Research Protocol.

In August 2019, WAMSI engaged an experienced Community Partnerships and Protocols Lead to navigate the process of engaging with the Malgana community in the post-Native Title determination environment. A foundational process of investment into relationship building with MAC members and the Malgana Land and Sea Management Reference Group (herein referred to as the Reference Group) ensued.

6.2.2 Malgana Workshop

In December 2019, WAMSI arranged a workshop with Malgana in Denham (herein referred to as the 2019 WAMSI Malgana Workshop) (https://wamsi.org.au/news/malgana-people-add-their-voice-to-science-priorities-for-shark-bay/). This brought together Malgana Elders, the Reference Group, Malgana rangers from both DBCA and the Malgana Land and Sea Management Program, and selected WAMSI staff and researchers (Appendix 8). A culturally appropriate agenda, workshop approach and content were collaboratively developed by WAMSI staff, the Malgana Land and Sea Management Coordinator and MAC Chair, with resourcing from WAMSI, The University of Western Australia and oversight from WAMSI partners. The workshop included a mix of Indigenous ''in-camera" sessions and open sessions. The western scientists who attended also presented a first pass return of science knowledge in their area of expertise. The combined approach was considered the most appropriate way of building relationships with the broader science community.

At the 2019 WAMSI Malgana Workshop, the Kimberley Saltwater Research Protocol model was explained and deemed to be a suitable starting point for development of a MAC research protocol (Lincoln et al., 2017). The Kimberley protocol was joint IPA of the Kimberley Saltwater Research Protocol, and its use had been agreed to previously. Amendments to the Kimberley research process were recommended and a model representing how science fits into land and sea country management in Gathaagudu was developed (Fig. 7).



Malgana welcome sign | Credit: Alicia Sutton

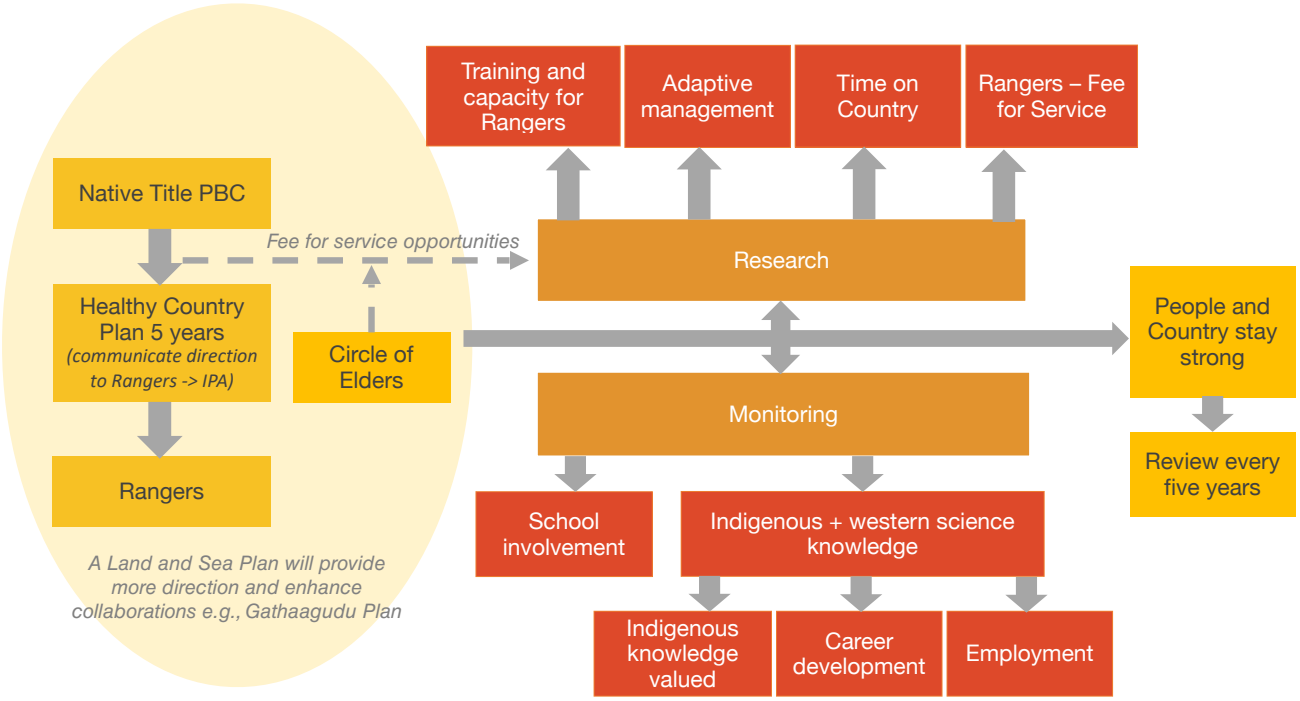


Figure 7: A representation of how science fits in to Land and Sea Management on Gathaagudu (modified from Malgana Science Management, Workshop Outcomes Report 2019).

6.2.3 Current status of guidelines and research protocols

The recommendations around development of the research protocol were provided to the MAC and subsequently endorsed by the Board. MAC lent its support to the development of a Malgana Land and Sea Research Protocol through the Reference Group and advised that MAC would act as the first point of contact for researchers seeking to do research on Malgana Sea Country in the interim.

While support for the protocol exists, its full development has been hindered by COVID-19 and a difficult period of change and challenge for MAC and its Reference Group structures. To provide WAMSI scientists with some direction in the intervening time between the launch of this Science Plan and future development of the Malgana Land and Sea Research Protocol, WAMSI has established guidelines and key principles for researchers to follow (see below). These guidelines and key principles recognise the best practice standards set by the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) Code of Ethics for Aboriginal and Torres Strait Islander Research along with the learnings from the Kimberley Saltwater Research Protocol.

6.2.4 WAMSI Engagement Principles and Guidelines for Researchers working on Gathaagudu

About these principles and guidelines:
These represent best practice principles and associated guidelines that apply to all research projects being planned or undertaken in Gathaagudu (Shark Bay) through WAMSI. These interim guidelines apply as at the publication of this Science Plan and with the intent that Malgana Aboriginal Corporation may build upon them with more local content, detail and specifics within a future Malgana research protocol, which would then replace these guidelines.

These principles and guidelines are a condition of funding for all research projects resourced through the WAMSI Science Plan and act as a guide to all other researchers.

Overarching principles:
Although it appears that port tenure excludes native title recognition, WAMSI recognises the unbroken cultural connection, traditional ownership and custodianship of the Malgana people to Gathaagudu ('two bays'), their traditional sea country. As such, all WAMSI-associated science will operate as if native title applies across the entire Malgana native title determination area.

WAMSI fully supports the well-established principles of mutual respect, reconciliation and Native Title. Through its research programs WAMSI acknowledges and respects the culture, values, practices and knowledge of Indigenous people.

WAMSI acknowledges the depth of Indigenous knowledge held by Malgana people, and that much western science knowledge has been gathered in Gathaagudu with little consideration of Malgana traditional knowledge or involvement and consent of Malgana people.

WAMSI requires all partners proposing to work on Malgana Country to engage meaningfully with the Malgana people, native titleholders of Gathaagudu (Shark Bay). This applies where possible, in all phases of research projects from concept through to the communication of results. All partners proposing to work on Malgana Country must also consider the traditional rights and ownership of Malgana people.

Research conducted through WAMSI will abide by the Code of Ethics for Aboriginal and Torres Strait Islander Research (AIATSIS 2020a) and the associated Guide to Applying the AIATSIS Code of Ethics (AIATSIS 2020b). In lieu of a fully formed Malgana research protocol (much like that established by Kimberley saltwater native title groups in 2017 in partnership with WAMSI; Lincoln et al. 2017) we put forward the following guidelines for all WAMSI research proposed on Gathaagudu, in no particular order:

- WAMSI researchers will be required to ensure they have obtained free and prior consent from the Malgana people before beginning their research and to seek to build partnerships with the Malgana people where appropriate. This will be addressed through direct engagement with the Malgana Aboriginal Corporation and associated Aboriginal Ranger Program Rangers where possible
- Knowledge, practices and cultural expressions of Malgana people must be respected, protected and maintained
- At every stage, research in Gathaagudu must be founded on a process of meaningful engagement. Building relationships based on trust is a key foundation for Malgana research
- Prior to the beginning of the research there should be a shared understanding by all research partners and participants about the potential benefits, management implications, impacts and risks of the research project
- Malgana contributions to research should be appropriately attributed, acknowledged and resourced, including through authorship and communication of findings
- Malgana people involved in research, or who may be impacted by research, should stand to benefit from and not be disadvantaged by the research. Research in Shark Bay should aim to have a positive impact on or for Malgana people
- Research projects should be designed and conducted in a manner that respects Malgana people's right to maintain their connection to Country and to control, protect and develop their lands and resources
- Research projects in Gathaagudu should include appropriate mechanisms and procedures for honest and transparent reporting on the research project. This should include reporting to all parties on the progress of the research, including any changes to the project. Reporting to Indigenous partners and contributors should be in a form that is culturally appropriate, useful and informative
- All researchers are to undertake cultural awareness training
- WAMSI research programs will be discussed with Malgana Aboriginal Corporation to identify projects for shared interest, links with healthy country plans and to discuss appropriate means of providing results and research findings to the Malgana
- All researchers will contact (write formally and by phone) the Malgana Aboriginal Corporation giving a brief, plain English summary of the proposed research as early as possible during the concept stage
- Field planning for WAMSI research will be done with Malgana Aboriginal Corporation Rangers where possible, to ensure that traditional knowledge of species, land and sea is included and so that activities are done in places that are not culturally sensitive
- Early discussions with the Ranger Coordinator (or other designated point of contact) are required for all proposed research, which will involve Malgana Aboriginal Corporation Rangers. These discussions should include benefits, risks, capacity building, training, availability, resources, fee for service opportunities, location and other priorities relevant to the Malgana Aboriginal Corporation Rangers.
- Researchers to offer opportunities for training and capacity building to participating Malgana people appropriate to the scale of the research project where possible, including to Malgana elders, Malgana Aboriginal Corporation Rangers and Traditional Owners
- On completion, all research results must be communicated in plain English and explained to the Malgana Aboriginal Corporation
- Projects should incorporate funding for engagement with the MAC, Rangers, Elders and the wider community as appropriate
- Any immediate issues should be reported to the WAMSI CEO and, if the matter cannot be resolved, referred to the WAMSI Chair.

Top: Malgana Elder Tom Poland studies a seagrass map | Bottom: During a live cross at the launch of 'A Snapshot of Marine Research in Shark Bay (Gathaagudu): Literature Review and Metadata Collation (1949–2020) (Sutton and Shaw, 2020)', UWA Professor Gary Kendrick hands the document over to Malgana Traditional Owner Bobby Hoult and Malgana rangers Alex Dodd, Richard Cross, Klaas Liezenga and Sean McNeair in Denham.

6.2.5 Science return to Malgana people

A critical point of feedback from Malgana people to WAMSI is the need for contemporary science knowledge to be returned and shared back with the Malgana community both as a standard for all science projects on Gathaagudu, and as a larger return of science knowledge from past projects. As custodians and managers of their sea country, Malgana strongly emphasise their need for this knowledge in an accessible format, so they can move forward and achieve best practice management of their interconnected land and seascapes into the future.

At the 2019 meeting in Denham, WAMSI took a significant first step in addressing the need to return knowledge by delivering a metadata synthesis on all published marine science projects collated as part of the Science Plan literature review process. This extensive information set was received in database format by the MAC Chair on behalf of Malgana people.

The final report, A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949–2020) (Sutton and Shaw, 2020), was delivered in person to Malgana people by Professor Gary Kendrick, on behalf of WAMSI, during the Perth and Shark Bay launch on 1 October 2020. Close to 80 participants attended the launch either in person (IOMRC, Perth or DBCA, Denham), or online at https://www.youtube.com/watch?v=dbqK_gRRTvA.

6.3 Malgana Saltwater Science Priorities for a Healthy Gathaagudu

6.3.1 Malgana Voices Survey

Following on from the 2019 WAMSI Malgana Workshop, and in light of the difficulties being experienced both bringing people together and visiting Indigenous communities during the COVID-19 pandemic, the Reference Group asked WAMSI to create an online survey, under its guidance, to make progress against three important areas:

- Collect foundational information to support the future development of a Malgana Land and Sea Research Protocol
- Help get more Malgana voices into the Science Plan
- Record current community priorities and concerns for Gathaagudu to help inform the work of Malgana rangers and to support the development of a future Malgana Healthy Country Plan

With these objectives in mind, WAMSI developed the Malgana Saltwater Science Priorities for a Healthy Gathaagudu Survey (herein referred to as the ‘Malgana Voices Survey’). The Malgana Voices Survey was an online survey designed to capture the voices of Malgana people from the community, the MAC and the Reference Group in a mobile, community-appropriate format. The survey was developed and reviewed in close consultation with the MAC Chair and the Malgana Land and Sea Management Coordinator. The survey was launched in mid-2020 on the MAC social media platforms alongside a short, simple plain English video describing the survey (Appendix 9), its use and intent.

In order to support Malgana elders and other community members to complete the survey, Malgana rangers took it out to the Denham community on mobile devices. Eighteen surveys were completed by individual Malgana community members, which have helped to inform this Science Plan.

Using a deliberate mixture of multiple choice and open-ended questions, the survey was constructed on existing foundational knowledge of the natural and cultural values of Gathaagudu. These were derived from a number of written and oral sources including:

- Malgana contributions to the 2019 WAMSI Malgana Workshop
- Face-to-face Malgana community surveys led by WAMSI in 2019
- Gutharraguda Land and Sea Management Plan (not publicly available at time of writing) (Malgana Native Title Working Group and Rangelands NRM WA, 2016). Note, Gathaagudu and Gutharraguda are both used in this document to refer to the Aboriginal name for Shark Bay
- Community consultations through 2014–2015
- Shark Bay Marine Reserves Management Plan (CALM, 1996)
- Shark Bay World Heritage Property Strategic Plan (DEC, 2008)
- Shark Bay World Heritage information website (www.sharkbay.org/nature/animals).

The questions included in the Malgana Voices Survey are provided in Appendix 10.

Over a period of three months, several Indigenous and western science experts in their field were also consulted around specific sections, content, overall scope and the cultural appropriateness of the information presented.

6.3.2 Early indications of Malgana priority values

The following section should be considered preliminary in nature due to the limited sources of information and the current foundational stage of the MAC. It includes science priorities, recommendations and insight gathered from the 2019 meeting in Denham and the 2020 Malgana Voices Survey. Please note that some aspects of Malgana feedback have been omitted for cultural reasons.

6.3.2.1 Priority values from the 2019 WAMSI Malgana Workshop

During the 2019 WAMSI Malgana Workshop, 18 Malgana participants including key elders, MAC directors, Reference Group members and Malgana rangers undertook a short session to provide early advice on values of immediate priority for science work on Gathaagudu. From this session, several values of Malgana Sea Country were identified as most important by participants:

- Seagrass (highest shared natural value priority among participants)
- Mangroves
- Fish
- Turtles
- Water quality
- Dugongs

Feedback on cultural values was not appropriate to request at this point.

A smaller group of participants (3–4) also highlighted riparian vegetation (sandalwood), seabirds and dolphins as important Malgana Sea Country values.

6.3.2.2 Priority values from the 2020 Malgana Voices Survey

Respondents to the Malgana Voices Survey were asked to identify their top five natural and/or cultural values of Gathaagudu necessary for its overall health. From responses (n = 18), several values were identified as most important:

- Seagrass (n = 15)
- Indigenous cultural practice (n = 11)
- Water quality (n = 8)
- Fish (n = 8)
- Indigenous knowledge (n = 8)

Other values that were identified as important by respondents included:

- Mangroves (n = 6)
- Beaches/dunes (n = 6)
- Turtles (n = 5)
- Groundwater (n = 5)
- Dugongs (n = 4)
- Corals (n = 4)
- Seabirds (n = 2)
- Riparian vegetation (n = 2)
- Sharks and rays (n = 1)
- Dolphins and whales (n = 1)
- Stromatolites (n = 1)
- Sea cucumber (n = 1)

6.3.2.3 Alignment of values across the two datasets

There is clear alignment between the priority values identified from the 2019 WAMSI Malgana Workshop and the 2020 Malgana Voices Survey (Table 1). A basic ranking process was used to bring together the results from these two very different methods for collecting data. Where a value was not ranked, it was assigned the lowest rank (4) with the exception of Indigenous knowledge and Indigenous cultural practice. These latter two values are ranked based on the 2020 Malgana Voices Survey only, which was the only method designed to collect this cultural information.

Using this comparison, participating Malgana people emphasised that:

- The two most important values that need to be healthy for Gathaagudu to remain healthy overall are seagrass and Indigenous cultural practice
- Values that are also very important to overall health include water quality, fish and Indigenous knowledge, followed closely by mangroves (particularly for their nursery value), turtles and dugongs
- There are a range of other values that are important for a healthy Gathaagudu

Table 1: Prioritised values as expressed by Malgana participants at the 2019 workshop and 2020 Malgana Voices Survey submissions.

	Combined ranking	2019 WAMSI Malgana Workshop	2020 Malgana Voices Survey
Seagrass	1	1	1
Indigenous cultural practice	1	N/A	1
Water quality	2	2	2
Fish	2	2	2
Indigenous knowledge	2	N/A	2
Mangroves	2.5	2	3
Turtles	2.5	2	3
Dugongs	2.5	2	3
Beaches/dunes	3.5	4	3
Groundwater	3.5	4	3
Corals	3.5	4	3
Seabirds	3.5	3	4
Riparian vegetation	3.5	3	4
Dolphins and whales	3.5	3	4
Sharks and rays	4	4	4
Stromatolites	4	4	4
Sea cucumbers	4	4	4

UWA seagrass researcher Matt Fraser presents on some of the research done on Shark Bay.

6.3.3 Interpretation of responses from the Malgana Voices Survey

From the results of the Malgana Voices Survey, we provide an interpretation of the responses provided for the five most important values for a healthy Gathaagudu Saltwater Country. Given the sample size of 18, results and interpretations are indicative only.

Malgana Elders also have a depth of natural-cultural knowledge and throughout the Malgana Voices Survey, respondents raised the urgent need for the science community to support their Elders to share this with the next generation of Malgana Sea Country custodians.

6.3.3.1 Seagrass

Of the 15 respondents who included seagrass in their top five values, the vast majority said that seagrass is either essential (67%) or very important (27%) to the health of Gathaagudu Saltwater Country. Eleven respondents said seagrass is important for its conservation value, but it is also important for its Indigenous livelihood value (seven respondents), cultural value (six respondents) and economic value (five respondents). All respondents think that more research on seagrass in Gathaagudu should be done and that it should happen urgently (60%) or soon (40%). The views of respondents on the health, threats and knowledge of seagrass are provided in Fig. 8. Ocean warming, more storm/cyclone damage, and other climate change flow on effects were identified as the main threats to seagrass. When participants were asked to identify all threats to seagrass, it included dredging, storm damage from climate change, sediment and nutrient runoff, groundwater impacts, recreational and commercial fishing activities and the reduction in various species who inhabit seagrass meadows.

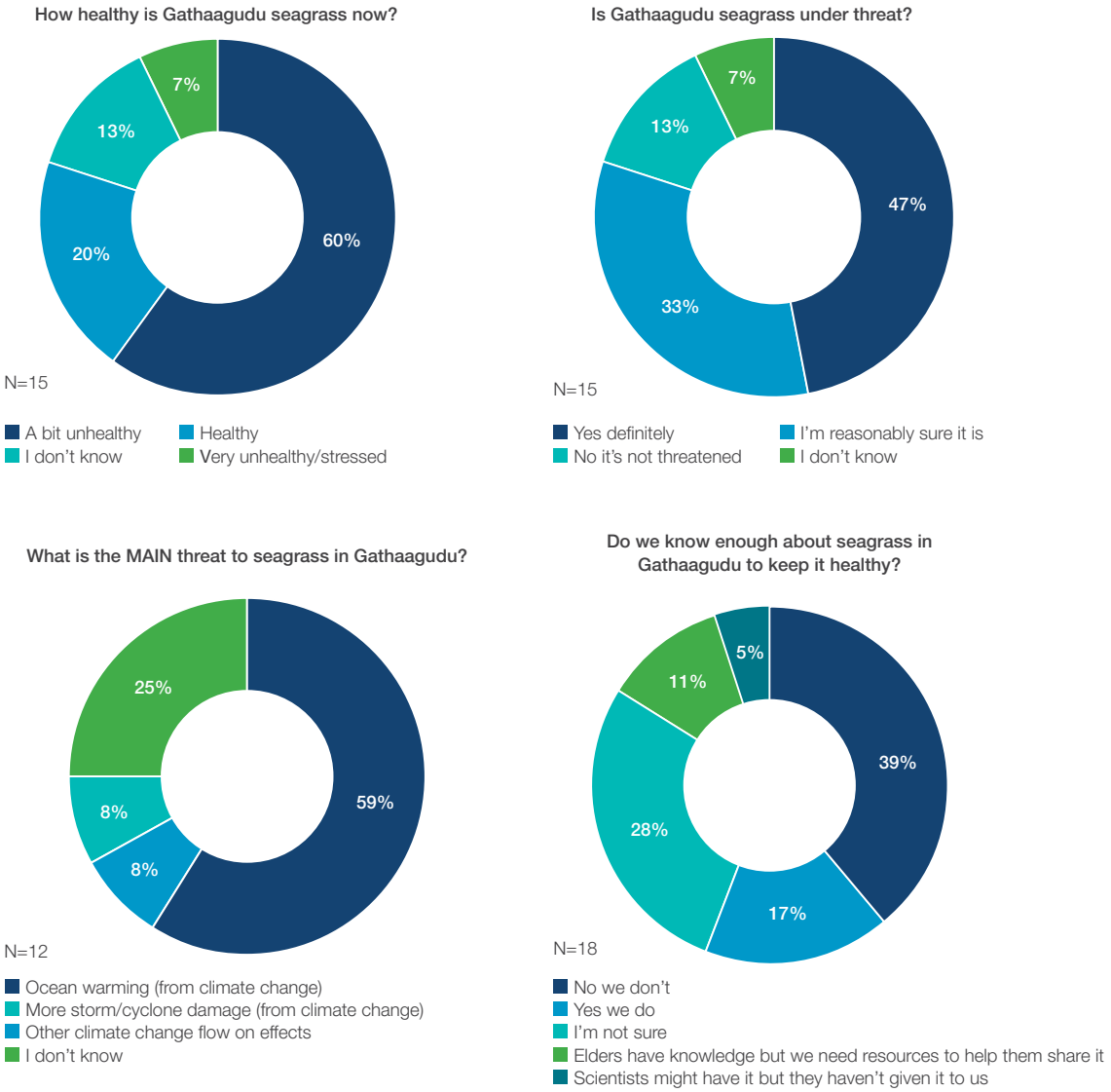


Figure 8: Responses to questions on seagrass in the Malgana Voices Survey.

6.3.3.2 Indigenous cultural practice

Of the 11 respondents who included Indigenous cultural practice in their top five values, the majority said that it is essential (73%) or very important (18%) for the health of Gathaagudu Saltwater Country. Most also believe that Indigenous cultural practice on Gathaagudu is definitely threatened (64%) or are reasonably sure that it is (18%).

Suggestions around how science projects can help Malgana to maintain the health of their cultural practices on Gathaagudu included:

- Building cross-cultural relationships, understandings and two-way knowledges across projects
- Supporting Malgana participation on Country in a way which offers time and space to pass knowledge between generations, as well as between western scientists and Malgana people
- Involving local Malgana community members including children, schools, elders and Malgana rangers in projects from start to finish
- Building the capacity of Malgana people to monitor country and manage on country projects, for example rehabilitation projects
- "Continue working and establishing a closer trusting relationship with the Malgana people living here"
- "By ensuring our barraja (land) and wirriya (sea) country's health is the priority. Healthy barraja and wirriya mean healthy nhurra (mob/family)"

Mangrove roots | Credit: Rachel Austin

6.3.3.3 Water quality

Eight respondents included water quality in their top five values, and all believed good water quality is essential to the health of Gathaagudu Saltwater Country. Most respondents said good water quality is important for its conservation value (88%), but also for its Indigenous livelihood value (75%), cultural value (63%) and economic value (50%). The majority of respondents (75%) thought that there should definitely be more research on water quality and that it should happen urgently (63%) or soon (37%). The views of respondents on the health, threats and knowledge of water quality are provided in Fig. 9. Ocean warming, pollution from boats, ocean acidification and other climate change flow on effects were identified as the main threats to water quality. When participants were asked to identify all threats to water quality, they included dredging, storm damage from climate change, sediment and nutrient runoff, groundwater impacts, recreational and commercial fishing activities and the reduction in various species that inhabit seagrass meadows. Other threats mentioned in reponses included seabed disturbance (industry, development, dredging etc), commercial fisheries, marine debris, sediment and nutrient runoff, groundwater impacts, mining and tourism.

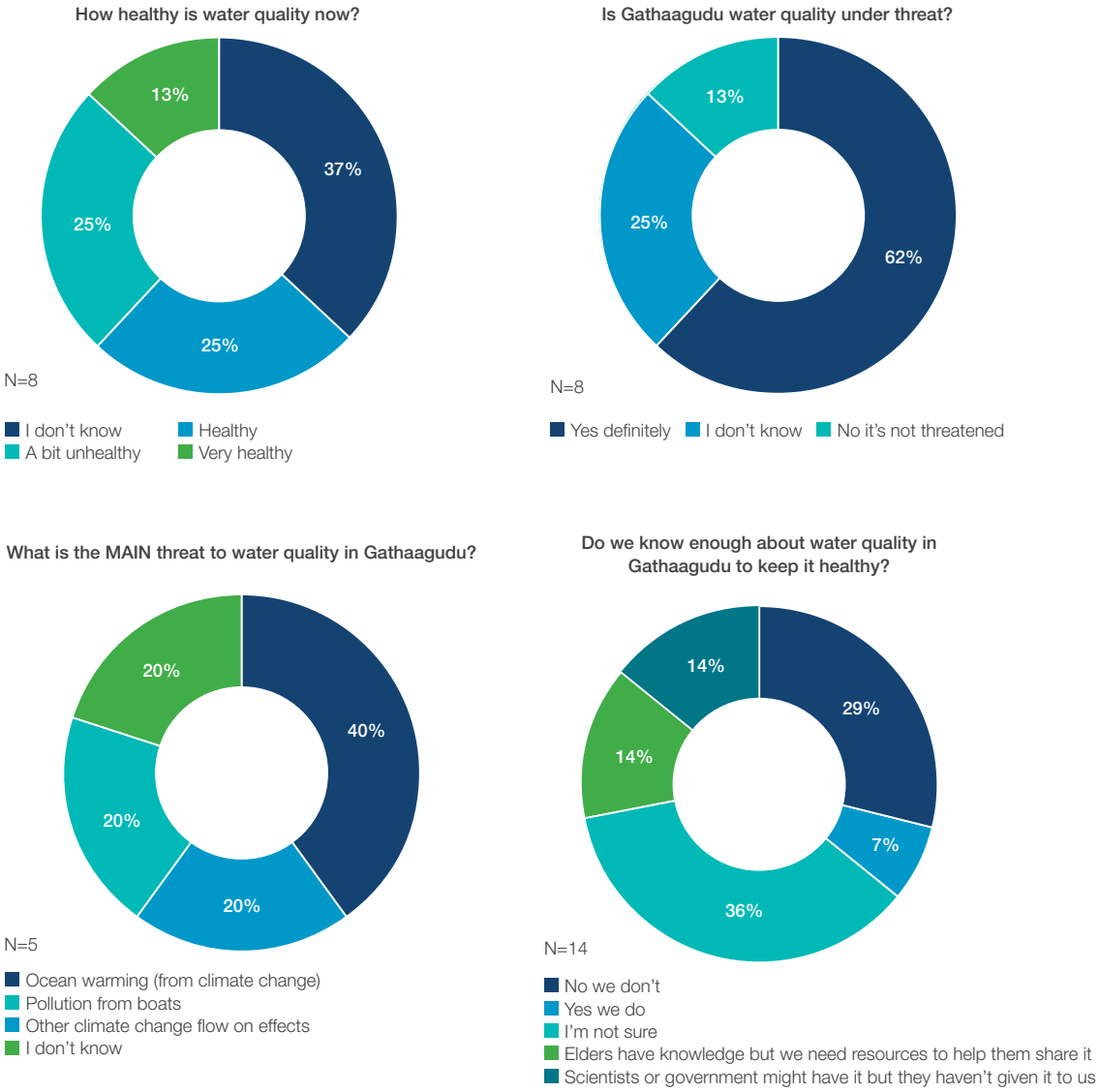


Figure 9: Responses to questions on water quality in the Malgana Voices Survey.

6.3.3.4 Fish

Eight respondents included fish in their top five values and further information was sought on what species of fish are important to respondents. While most respondents think that all fish in Gathaagudu are important (75%), bulhamarda (black snapper) and mulgarda (mullet) are particularly mentioned, as are table species such as bluebone, ngagiya (flathead), mardirra (pink snapper), mulhagadara (whiting), irrumarri (bream), wudgagarri (tailor), and nhuwunu (yellowtail). Respondents answered the rest of the survey while considering the fish they listed as most important to them (e.g. all fish, bulhamarda and mulgarda).

Four respondents (50%) considered fish to be essential to the health of Gathaagudu Saltwater Country and a further 38% thought they are at least very important. Most respondents listed fish as important for their cultural value (75%) followed by Indigenous livelihood value (50%) and conservation value (50%). The economic value of fish is also important for two respondents. Most respondents (n = 6) thought there should be more research on important fish species and that it should happen urgently (4/6) or soon (2/6). The views of respondents on the health, threats and knowledge of fish are provided in Fig. 10.

Of the respondents who think fish are threatened (n = 6), all considered recreational fishing to be the main threat. Other threats mentioned included commercial fishing, habitat loss and ocean warming.

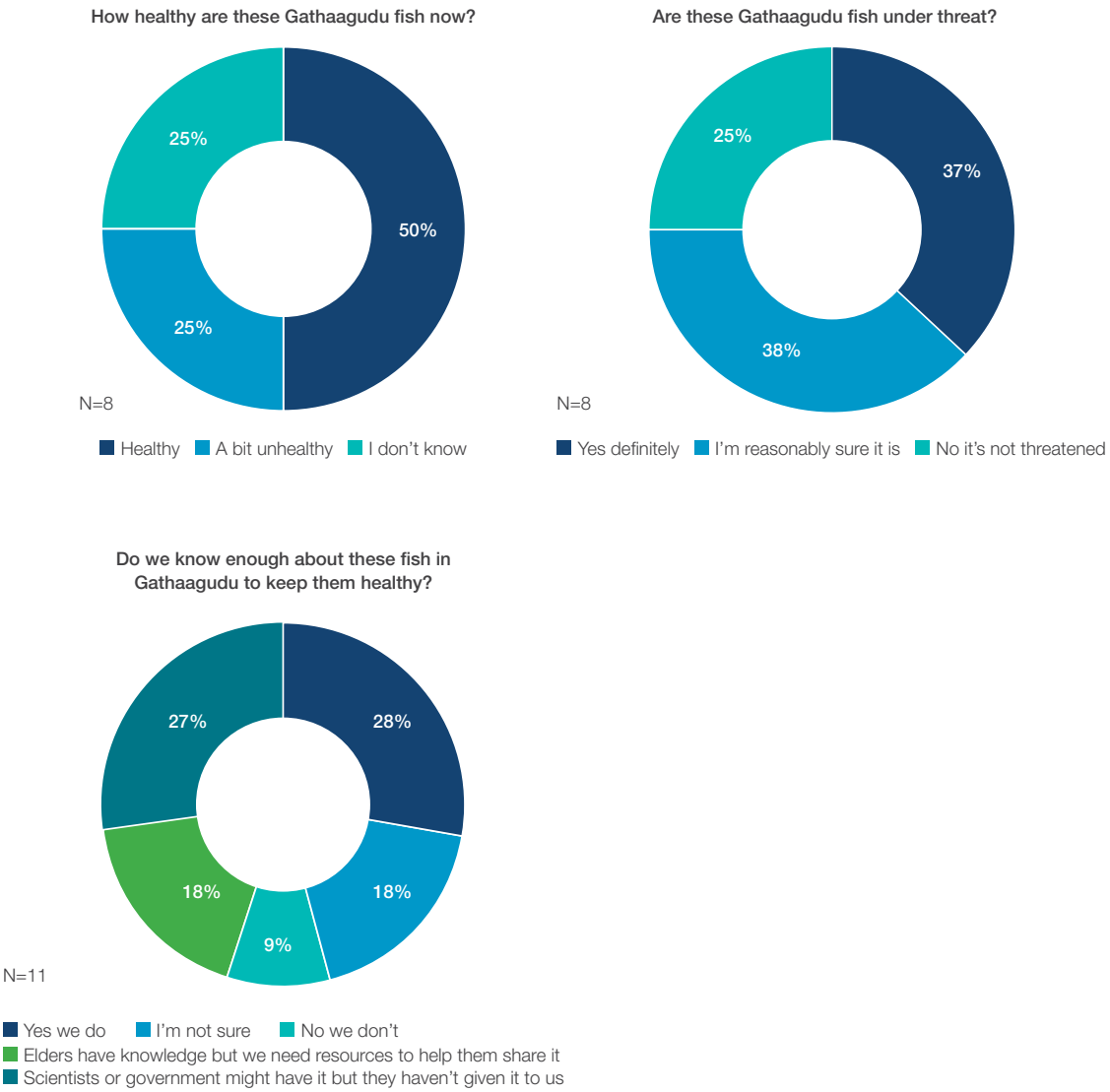


Figure 10: Responses to questions on fish in the Malgana Voices Survey.

6.3.3.5 Indigenous knowledge

Indigenous knowledge was included in the top five values for eight respondents, and most (75%) considered Indigenous knowledge to be essential for the health of Gathaagudu Saltwater Country. One respondent thinks it is very important and one is not sure.

Respondents selected a broad range of ways the science community could support Malgana to look after Indigenous knowledge of Gathaagudu, which included:

- Helping Elders spend time on Country with younger Malgana during science projects
- Helping Malgana develop their own research protocol for future science on Gathaagudu
- Valuing the roles and importance of Malgana Indigenous ecological knowledge in science projects
- Raising awareness in the science community of the need to engage with Malgana in meaningful and appropriate ways
- Raising awareness in the science community of the many benefits of Indigenous Knowledge to science
- Doing cultural awareness training with Malgana before the research starts
- Involving Elders in science projects from planning stages
- Supporting Malgana youth engagement in science projects including school initiatives and interactions with Elders.

6.3.3.6 Other important values

Other important values to respondents are briefly summarised below.

Six respondents included mangroves in their top five values with most considering mangroves to be very important or essential to the health of Gathaagudu Saltwater Country. Mangroves are important for their conservation value, and while half of respondents thought they are currently healthy, they were not sure if they are under threat. The main threat identified by all respondents is storm/cyclone damage from climate change. The level of knowledge on mangroves is generally uncertain, so all respondents think more research is needed.

Beaches and dunes were included in the top five values for six respondents. Half of respondents think beaches and dunes are very important for a healthy Gathaagudu Saltwater Country, and they are largely important for their cultural and conservation value. The majority think that beaches and dunes are unhealthy to some degree and that they are definitely under threat, namely from damage by tourists and visitors. All respondents think there should be more research and most think it is a matter of urgency.

Five respondents included turtles in their top five values. Turtles are considered important or essential to the health of Gathaagudu Saltwater Country, and are important for their cultural, Indigenous livelihood and conservation value. Half of the respondents think turtles are in an unhealthy state, while a third do not know. Turtles are identified as being under threat by three respondents, who think the main threats are loss of habitat and impacts of tourism on nesting grounds. Respondents wanted to see more research on turtles urgently or at least soon.

Groundwater is an important value for five respondents, and it is considered either essential or very important by all. Groundwater is important for its conservation, cultural, Indigenous livelihood and economic value. There is uncertainty around the current health of groundwater, and two respondents think groundwater is unhealthy to some degree. Some respondents think that groundwater is under threat, and some do not know if it is under threat. Extraction by industry is the main threat identified, and more knowledge on groundwater is needed as a matter of urgency.

Four respondents included dugongs in their top five values and considered them essential or very important for a healthy Gathaagudu Saltwater Country. Dugongs are important for their cultural, conservation and Indigenous livelihood value. Some respondents consider dugongs to be healthy and some consider them unhealthy and under threat due to loss of habitat and ocean warming. All respondents think urgent research is needed on dugongs.

Coral is included in the top five values of four respondents. Most said that healthy coral is important for the health of Gathaagudu Saltwater Country, and that it is important for its Indigenous livelihood, cultural, conservation and economic value. The health of coral is not known, and respondents thought coral are either under threat or they didn't know. The main threats identified are shipping and commercial fishing. More urgent research on coral is favoured by respondents.

Riparian vegetation, seabirds, sharks and rays, dolphins and whales, stromatolites and sea cucumber are each shown to have significance for some Malgana survey participants. However, the responses for these values have not been unpacked for the purposes of the Science Plan as they represent only 1 or 2 individual respondents.

6.3.4 Cross-cutting themes

A clear indication of two major areas of resourcing required for future science in Gathaagudu was evidenced by the responses to the Malgana Voices Survey.

1. Against ten of the 18 listed values, some respondents indicated that 'they' didn't know enough but government agencies and/or scientists may have this information and have not shared it with the Malgana community. In this context 'they' can be read as Malgana people invested in managing the natural and cultural values of Gathaagudu
2. Against nine of the 18 listed values, some respondents indicated that they didn't know enough but that Malgana Elders have knowledge and need resources to help them share it

Malgana are keenly aware that there exists a wealth of knowledge about many of their questions and key knowledge gaps, derived from decades of research on Gathaagudu. The need for knowledge to be accessed and shared appropriately with their community has been repeatedly articulated by Malgana people for several years and is reflected in the Malgana Voices Survey, 2019 WAMSI Malgana Workshop and in the Gutharraguda Land and Sea Country Management Plan.

More urgently, there is a critical need to help resource the Malgana community to develop and implement effective, culturally appropriate ways to engage their Elder community in land and sea activities so that the knowledge they collectively hold can be passed down to the next generation of Malgana people and applied to future management decisions. The time critical nature of this work comes from the very real risk of the current generation of senior Elders passing away and this knowledge being lost forever.

WAMSI recognises the importance of this, however, acknowledges that this activity has not been nominated as a priority by the combined Stakeholders for this Plan. Despite this, it is a WAMSI commitment and has been incorporated into the WAMSI Engagement Principles and Guidelines for Researchers Working on Gathaagudu (Section 6.2.4). It will also be incorporated into the Implementation Plan.

Malgana-led workshop, Denham 2019

7. Identifying knowledge gaps

Posidonia australis | Credit: Rachel Austin

7.1 Workshops

7.1.1 WAMSI and UWA Workshop: Adapting to ecosystem change in the Shark Bay World Heritage Site

The WAMSI/UWA Workshop in 2018 identified 43 gaps. Many of these gaps relate to ecosystem understanding and adaptive management (Table 2).

It is noteworthy that this workshop was the first workshop in this process of identifying knowledge gaps for Shark Bay. Many of the gaps will have changed focus and others will have been addressed (see Appendix 11).

Table 2: Gaps resulting from the WAMSI/UWA Workshop in 2018.

WAMSI and UWA workshop gaps
Better understanding of the consequences of ecosystem change
What drives natural and assisted recovery of seagrass?
What are the negative impacts to the ecosystem from fishing, tourism and lack of education?
What are the social and economic benefits of fishing in the Gascoyne region (recreational and commercial)?
What are other options for tourism in Shark Bay?
What is the effect of anticipated intervention to preserve ecosystem function? Will it work and is it the right thing to do?
Understand the impact of seagrass loss. How do we protect what is there and enable/facilitate recovery?
Create rapid response plans for extreme marine events or occurrences where an ecological value is suddenly impacted, and mechanisms to carry out rapid responses
Create a monitoring toolkit
How do we integrate research and knowledge/data across disciplines and sectors?
Develop a resource describing all work in Shark Bay over various disciplines
Are we managing fisheries for sustainability into the future? Are the current approaches adequate?
How connected are populations and stocks inside and outside of Shark Bay?
Better understanding of trophic connectivity between seagrass and fishes in a changing environment
Need fine scale oceanographic models, larval models, connectivity models, inflow and aquifer models
Undertake high resolution bathymetric mapping of the entire Bay
Can we better predict and identify factors that contribute to marine heatwaves?
Undertake habitat mapping to understand abundance and distribution of habitats and use by species in order to better manage fisheries
What are the projections for climate change and environmental factors specific to Shark Bay over the next 10–20 years?
How will sea level rise impact the habitats of Shark Bay? e.g. seagrasses, mangroves, stromatolites
Better understanding of ecosystem links between nutrients, microbes, primary producers, consumers, detritivores
Where are the tipping points for a functioning ecosystem?
Is our top-down understanding of the ecosystem missing? Currently our approach is bottom-up, but are we asking the right questions?
Develop an integrated and shared database that is managed long term by a designated agency
What are the critical parameters for seagrass dieback? e.g. temperature, light availability and length of time
How are pink snapper dynamics and spatial use changing?
What is causing size class changes in prawns, and why has prawn size reduced?
What are the links between seagrass and microphytobenthos?

Why is there no recovery of seagrass in some areas but recovery in other areas? Is landscape scale restoration of seagrass feasible?
What are the flow on effects from the tropicalisation of seagrass assemblages?
Better understanding of pelagic productivity
How can we encourage the community to take ownership and engage with the values of Shark Bay?
How do we capture Indigenous behaviours, values and knowledge, and what knowledge has already been lost?

7.1.2 CVI workshops

While the purpose of the CVI workshops held in 2018 and 2019 was not to identify gaps in knowledge, 15 gaps were raised and recorded during the CVI rapid assessments. These were divided into research gaps and policy and guidance gaps:

Research gaps

- Specific requirements of stromatolites to continue to survive and grow in Hamelin Pool (additional condition data on stromatolites is needed)
- Linkages between marine water conditions, chemical processes, seagrass, and organomineralisation processes in carbonate dominated marine environment, and thresholds for impacts on key attributes of OUV
- Thresholds for the protection of key elements of OUV
- The effect of compounding and interacting factors
- Impact of seagrass loss on integrity of Faure Sill and, therefore, hypersaline environment
- Long-term variability of Faure Sill
- Assessment of dolphin populations since 2014, to determine status since the reported decline to 2014

Policy and guidance gaps

- Consistent monitoring data relevant to OUV of Shark Bay
- Decision making tools to assist in key strategy decisions:
  - do the things we are capable of, or develop capability for dealing with the most significant impacts, or develop capability for the impacts we are likely to be able to influence. Assessment tools are needed to help make these investment decisions
- How to achieve the degree of alignment and integration of strategy, policy and actions required to ensure the required actions are embedded into agency plans and budgets and owned by the agencies
- Resources for specific monitoring of World Heritage values
- Better understanding of Indigenous economic interactions with World Heritage values
- Assessment of overall economic value of SBWHA
- Need for socio-economic long-term monitoring program (also for Ningaloo Coast WH property)
- Need for more information on cultural heritage aspects (Indigenous and non-Indigenous)

Researcher measuring seagrass | Credit: Rachel Austin

7.2 DBCA

The 60 high priority knowledge gaps guiding research and management of Shark Bay by DBCA are divided up into fundamental research and applied research (Table 3). The process and discussion around these gaps are provided in Kendrick et al. (2016). Since this process was completed, a number of these questions have been answered or modified (see Appendix 11).

Table 3: Knowledge gaps for research and management of Shark Bay by DBCA.

ECOLOGICAL ASSET	RESEARCH STRATEGY/QUESTION
Fundamental research	
Cetaceans	Identify habitats of ecological significance for dolphins (e.g. areas used for feeding or reproduction). Describe the distribution, abundance, residency and habitat use of tropical inshore dolphins. What are their movement patterns?
Coral	Describe and map hard coral communities in marine reserves
Coral	How do corals persist under extreme environmental conditions? What factors impede or promote recovery of corals after disturbance?
Coral, mangrove, macroalgal, seagrass, intertidal	What are the relationships between coral reef, macroalgal, seagrass, mangrove, saltmarsh and intertidal communities with regard to, for example, energy transfer, ontogenetic and/or temporal movements of species and biological filtration?
Dugong	Assess the regional significance of marine reserves for dugong (*Dugong dugon*) conservation and the relative importance of marine reserves as dugong habitat. What are the critical seagrass habitats for dugong in parks and reserves, and how are these habitats used by dugong of different ages? How has our knowledge of dugong in parks and reserves been informed by Traditional ecological knowledge?
Dugong	When and why do dugongs move, and over what spatial extent are these movements? How do these movements differ demographically? Determine the genetic structure and connectivity of dugong among different marine reserves
Elasmobranchs	Quantify seasonal whale shark aggregations in the vicinity of Dirk Hartog Island
Filter-feeding invertebrates	What is the distribution and composition of filter-feeding communities within the park? What environmental factors influence the distribution and diversity of filter-feeders?
Finfish, elasmobranchs	How important are large predatory fish to maintaining healthy ecosystems?
Mangrove	Assess the recruitment, growth and physiology of mangroves (*Avicennia marina*) at Shark Bay in relation to environmental factors like salinity
Mangrove	How does variation in the composition and structure of mangrove habitats influence their ecological function? How does this vary in relation to environment factors?
Mangrove	What organisms, or particular life stages of organisms, are associated with mangrove habitats? Is this use dependant on mangroves or opportunistic?
Microbial communities, invertebrates	Describe the diversity and distributions of microbial communities, invertebrates and fish in Hamelin Pool
Reptiles	What is the species composition and relative abundance of sea snakes?
Reptiles	Determine if the Shark Bay sea snake (*Aipysurus laevis pooleorum*) is a different species to the olive sea snake (*A. laevis*)
Salt marsh	What are the composition, distribution and ecological significance of salt marsh?
Seagrass	Assess natural variations in the distribution of perennial seagrasses at various spatial scales
Seagrass, dugong	What processes drive the distribution and abundance of ephemeral seagrasses, and how does this influence dugong behaviour?
Seagrass, invertebrates, finfish	Assess the diversity and distribution of macro-invertebrate and fish species inhabiting different species of perennial seagrass
Seagrass, macroalgae	Describe nutrient dynamics of macroalgal and seagrass communities. Where do the nutrients that sustain large meadows come from and where do nutrients go when algae and/or seagrass breaks down?
Seagrass, macroalgae, finfish, dugong, turtles	How does the distribution of seagrass and algae influence the abundance and species composition of herbivores e.g. finfish, turtles, dugong?

Sediment quality, water quality	Assess relationships between sediment and water quality
Sediment quality, water quality	How do water and sediment quality vary naturally within marine reserves?
Turtles	Identify key foraging sites for marine turtles and the demographics of animals using these areas
Turtles	Identify migration routes and links between nesting and foraging areas. How do these relate to the marine reserve system?
Various	What are the key physical, biological, ecological and chemical processes that link different habitats (e.g. inshore-offshore, benthic-pelagic or lagoonal-deep water) within a marine reserve and how significant are such links?
Various	How does the loss and fragmentation of marine habitats affect connectivity between communities in marine reserves?
Various	Map marine and relevant coastal conservation reserve habitats at a scale and accuracy that is appropriate for conservation planning and/or management
Water quality	Assess sources and cycling of nutrients in Hamelin Pool
Water quality	Assess the spatial and temporal stability of salinity gradients in Shark Bay

Applied research

Birds	Assess the ecology of shore and sea birds, particularly in relation to identifying nesting/roosting areas on mainland beaches, disturbance from human activities and trophic ecology
Coral	How may long-term changes in temperature and currents affect coral reef accretion rates?
Dugong	Assess possible climate change impacts on dugong at the southern edge of their distribution
Dugong	What is the relative impact on dugong of exposure to vessels, particularly in areas of critical habitat?
Finfish	What is the level and ecological significance of by-catch from commercial and recreational fishing?
Finfish	How well are fish populations within marine reserves connected to those outside? To what extent are fish populations inside reserves connected, particularly those within different management zones?
Finfish Invertebrates	How do environmental factors, particularly those affected by climate change, and fishing pressure interact to affect the abundance and diversity of invertebrates and finfish?
Finfish, elasmobranchs	What are the movement patterns of targeted fishes in relation to current management zones?
Finfish, elasmobranchs, invertebrates	Assess the effects of recreational and commercial fishing on marine reserve assets. How has fishing and its impacts changed over time?
Finfish, invertebrates	Identify ecologically relevant and sustainable management targets for the take of fished species
Finfish, invertebrates	Assess spatial and temporal variance in fishing pressure within marine reserves. Identify what species fishers are catching. Where are when are those species being caught?
Geomorphology, turtles, mangroves, birds	How will the coastline change in response to rising sea levels and cyclonic activity? What will be the ecological implications for flora (e.g. mangroves and saltmarsh) and fauna (e.g. birds and nesting turtles)?
Intertidal	Describe the distribution patterns and natural variability of intertidal communities with respect to anthropogenic pressures and management zones
Intertidal, invertebrates, soft-sediment	What invertebrate species are being taken from intertidal habitats? What are the ecological consequences of removing organisms from intertidal areas?
Mangroves	Assess and quantify the nature, level and potential impacts of human activities on mangrove communities within the reserves
Microbial	Assess the potential impacts of climate change on Hamelin Pool and its microbial communities
Seagrass	Map the distribution of different seagrass species, particularly in nearshore areas and/or areas of high human activity
Seagrass	Assess the impact of boat moorings and anchoring on seagrass communities

Sediment quality	What is the concentration of sediment contaminants (e.g. hydrocarbons and antifouling paint) in mooring and anchoring areas relative to appropriate control sites?
Turtles	Assess the level of turtle egg mortality, including that from introduced animals such as foxes, dogs and cats
Turtles	What is the relative importance of anthropogenic and natural processes within marine reserves that influence turtle populations? How do these relate to pressures outside marine reserves?
Various	What will be the impacts of climate change on the Shark Bay marine environment and especially the Faure Sill and Hamelin Pool
Various	What are reliable measures of sub-lethal impacts of climate change on fauna and flora? How will sub-lethal impacts differ among species?
Various	How will the distribution of species change in response to climate change?
Various	How will hydrodynamic regimes change in response to climate change? How will such changes affect propagule dispersion and connectivity between communities in marine reserves? How should this knowledge inform marine reserve planning?
Various	What is the potential vulnerability of species or communities to climate change? Can their susceptibility and/or resilience be identified?
Various	What is the optimal configuration (e.g. number, size and location) of sanctuary zones in marine reserves?
Various	Develop an appropriate understanding and predictive capacity of the circulation and mixing of marine reserve waters, particularly in relation to key ecological processes (e.g. nutrient supply and productivity, recruitment, connectivity) and threats (oil spill, introduced pests)
Various	How do we better integrate local knowledge systems into a comprehensive understanding of the natural environment?
Water quality, macroalgae, seagrass, mangroves	How will climate change affect primary productivity and the flow of energy in marine systems?

Shark and fishes | Credit: Leon Deschamps

7.3 Literature review

The scientific knowledge gaps presented here were generated from a combination of direct suggestions from the literature and an analysis of what was missing from the review: A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949 – 2020) (Sutton and Shaw, 2020) (Table 4). Some of these gaps are already listed in Section 7.1. and 7.2 and are not repeated here. Rather than provide an extensive list of gaps for every single aspect of the marine environment and associated species, gaps relevant to a changing climate and changing ecosystem will be more informative for identifying priority areas of research to assess the ecological resilience of Shark Bay.

Table 4: Knowledge gaps resulting from the review: A Snapshot of Marine Research in Shark Bay (Gathaagudu) Literature Review and Metadata Collation (1949 – 2020) (Sutton and Shaw, 2020).

Environmental conditions
Water and sediment quality
• Influence of water chemistry and changes in environmental conditions on carbonate precipitation and organomineralisation processes • Comprehensive water and sediment quality across Shark Bay, including past and contemporary contaminants • Occurrence and rates of ocean acidification
Hydrology
• Fluxes of fresh water, nutrients and organic matter into Shark Bay and modelling future sediment yields from episodic flooding of the Wooramel River and Gascoyne River • Better understanding of the location and volume of groundwater inputs into Shark Bay, including nutrient and contaminant concentrations
Physical and biological oceanography
• Modelling of the oceanographic environment within Shark Bay, inclusive of local circulation and high resolution, comprehensive bathymetry data
Hamelin Pool
• Short- and long-term patterns of environmental conditions (e.g. temperature, salinity, sea level) • Rates of change in environmental conditions and impacts to marine life • Better understanding of the sources of groundwater • Fresh water runoff from pastoral lands
Ecosystem processes
Coastal zone
• Importance of sand dunes and drifts to the marine environment
Ecological functioning
Habitat loss
• Direct and indirect impacts of habitat loss of key benthic communities (mangroves, seagrasses and corals) on marine life and ecosystem functioning
Interactions
• How key interactions (e.g. competition, predation) driving large scale patterns and ecological feedbacks may change with extreme events and prolonged climate change • Modelling food web shifts in the absence of key seagrass species

Benthic communities

Microbial and microbialite communities

- Conditions influencing microbialite survival and growth, i.e. the importance of groundwater and environmental fluctuations
- Key population shifts and changes in gene/metabolite expression patterns that may help to predict responses to future environmental change
- Linking gene activity to mineral products and stromatolite formation

Coral reef communities

- Are deep sea corals important in re-seeding coral reefs at Shark Bay (Refuge Theory)?

Seagrass communities

- Seagrass resilience and thresholds to resisting pressures and recovering from impacts
- Robust early warning bio-indicators of seagrass stress
- Resilience of restored seagrass meadows

Mangroves and saltmarshes

- Patterns of connectivity and dispersal
- Sediment dynamics of mangrove communities, i.e. sediment porewater salinity, sediment accommodation, erosion and sea level rise

Filter feeding communities

- Diversity and distribution of sponge communities, how they might be impacted by climate change and how that may, in turn, impact on 'sponging' behaviour in dolphins

Other benthic communities

- Identify soft sediment communities

Planktonic communities

- Estimates of zooplankton grazing rates and secondary production for understanding pelagic food web dynamics
- Contribution of phytoplankton primary production to the system
- Understanding annual variation in plankton community dynamics

Faunal communities

Seabirds

- Feeding ecology of shore and sea birds and the influence of extreme events and/or prolonged food web shifts
- Threats to nesting/roosting areas on beaches

Invertebrates

- Better understanding of the invertebrate diversity, distribution and abundance in Shark Bay, including Hamelin Pool

Finfish

- Relative importance of key finfish species nursery, spawning and aggregation sites
- Ecological roles of key finfish species and how that will be impacted by climate change

Marine reptiles

- Potential distribution shifts in green and loggerhead turtles due to seagrass loss and implications for the wider ecosystem

Fisheries

Invertebrates

- Better understanding of the effect of SST on spawning, recruitment and growth for crabs, prawns and scallops
- Better understanding of the effects of seagrass loss on prawns and crabs
- Impact of flooding and the flushing of prawns and crabs into deeper water

Finfish

- Impacts of sharks, environmental effects on recruitment, barotrauma and discarding on Gascoyne Demersal Scalefish Fishery
- Better understanding of the effects of marine heatwaves and seagrass loss on species targeted by the Shark Bay Beach Seine and Mesh Net Fishery
- Assessment of other (less well studied) key species targeted by recreational fishers

7.4 Community interviews

Of particular importance to the Science Plan is the response from interview participants to the question '*what do you think are the major research needs that could help improve the management of Shark Bay into the future?*'. The research needs mentioned from 56 interview responses are provided in Table 5, and a list of interviewees is provided in Appendix 7. These questions were generated from community interviews, however, some of the issues raised can be answered by previous research. Each question was considered by a panel of scientists and some were removed for the prioritisation process as data was available to answer the question. Stakeholders would benefit from the communication of answers to their questions by the agencies and researchers conducting the research (Appendix 11).

Table 5: Knowledge gaps resulting from community interviews undertaken from May–July 2019.

Environmental
Develop a bottom-up understanding of the ecosystem
Impacts of habitat loss of key benthic communities (mangroves, seagrasses and corals) on marine life
Better understanding of nutrient cycles and fluxes
How can increasing phosphorus levels be managed?
Are cadmium levels still high in oysters?
What will be the impacts of increased sediment transport if there are less seagrass roots to maintain stability?
Will Little Lagoon eventually be disconnected from the ocean?
To what extent have mangroves declined in Shark Bay?
Better understanding of molluscs and the changes in mollusc species across time
Better understanding of the invertebrate diversity, distribution and abundance
Impacts of seagrass loss on the marine environment
What is the seagrass restoration potential?
Faunal assemblages of benthic habitats
Quantify the increase in whale numbers over the past 20 years
Understanding impacts to dugongs
How often are sharks targeted by fishers and has shark abundance increased?
When are whale sharks in the area and what are they doing? Are their numbers increasing?
What is the level of fish offal discard into Shark Bay by recreational fishers and has this contributed to the increase in tiger shark numbers?
Increased monitoring of loggerhead turtles
Are turtles on Dirk Hartog Island being negatively impacted by tourists?
Impact of climate change and increased storms on turtle nesting beaches
Better understanding of non-targeted finfish species e.g. their population health, ecological importance
Where do mullet go over the Christmas period?
Has spear fishing caused a decline in particular species (e.g. black spot tusk fish) due to biased fishing effort?
Better understanding of the effect of SST on spawning, recruitment and growth for crabs, prawns and scallops
What are shark depredation rates for recreational fishing?
What are the impacts from visitation on the environment and wildlife?

Social

What proportion of visitors to Shark Bay are recreational fishers?
To what extent has recreational fishing catch and effort changed over time with the increased use of bigger boats and fishing techniques?
Are water sport activities, e.g. wind/kite surfing, too restricted?
Increase community engagement and environmental stewardship
Increase education for recreational fishers on fishing rules, catch handling and sustainable practices
Would local incentives, such as assigning ambassadors, foster and increase environmental stewardship?
Why do people visit Shark Bay?

Economic

Has recreational fishing led to a decrease in tourism because of decreased catch rates at particular locations?
What is the level of habitat destruction from extractive industries and what are the long-term impacts e.g. fishing, mining, dredging?
Increased focus on interpretation for visitors in relation to Monkey Mia dolphins
Tourism impacts and opportunities for sustainable tourism
More economic development for 'Caring for Country'
What is the economic value of Shark Bay?
What are the future opportunities for aquaculture?
What is the economic value of parks and ecological assets (e.g. seagrass, coral, mammals, sharks), and can this lead to a better regard for the environment under the influence of tourism?
What will be the economic impacts from climate change in 20-50 years time (e.g. coastal inundation, cyclones)? Is there an adaptation strategy for Shark Bay?
Do economic interests and fishing out compete sustainability issues?
Develop a socio-economic long-term monitoring program
What are the opportunities for locals to build a career and sustain it into the future while remaining in Shark Bay?
What is the best way to set up the community for sustainable livelihoods?
How can the primary producers (pastoralists and fishers) with long standing social and economic ties to the community be included and not marginalised in Shark Bay?
Better promotion of other towns and locations in Shark Bay to even out the pressure from tourism

Governance

Are bag limits too high for recreational fishing?
Better understanding of fisheries stocks, main spawning areas and connectivity along coast
Is the annual Fishing Fiesta event sustainable, and does it reverse the efforts throughout the year?
Is there too much pressure on large, old and fecund fishes by recreational fishers, and should there be limits on max lengths for these species?
What are the impacts of fishing pressure? What species are being caught, where and how many?
Is the current level of management adequate for adherence to DBCA and DPIRD regulations in relation to tourism and recreational fishing? If not, what level of management is needed?
Generate a community and locally managed data system for the environment that is accessible to the community, Traditional Owners and researchers
Collaboration and sharing of data
Design or expand on existing monitoring of ecological values that span the marine reserves and WH area, including rapid assessment methods

Should there be more sanctuary zones?
Should the marine park and WH boundaries be aligned to streamline management?
What is the carrying capacity for tourism in Shark Bay, and in specific areas of interest e.g. national parks, Herald Bight, Monkey Mia?
Assessment of pollution levels (rubbish and fishing gear) created by tourists and fishers and the impacts on marine and terrestrial fauna
How can tourism peaks be minimised and what would it take to increase the length of stay by visitors in order to reduce peaks e.g. 3 days into 10 days?

External Drivers

How will the distribution of species change in response to climate change?
How will species be impacted by climate change?
What will be the impact of climate change on the marine environment e.g. Faure Sill and Hamelin Pool?
Better understanding of the impacts of heatwaves on the marine environment
How can we mitigate against climate change and is there an adaptation plan?

Malgana

How to achieve an alignment of western management with Malgana management? - i.e., all aspects of the environment are interconnected, not separate
Increased Malgana involvement in the management of islands and parks
Need for more information on cultural heritage aspects (Indigenous and non-Indigenous)
Capturing Indigenous behaviours, values and knowledge. What knowledge has already been lost?
Recognise the rich cultural and Indigenous values as part of WHP values
Will Native Title determination change the fabric of the community i.e., will it bring less acceptance and more racism?
What job opportunities and research training are available now and in the future for Malgana?
What are the most effective avenues for research communication to the Malgana and Shark Bay Community?
What are the best avenues for sharing cultural knowledge with tourists and fishers so they can better understand cultural sensitivities?

Researchers from The University of Western Australia and Australian National University prepare to release a tiger shark (*Galeocerdo cuvier*) captured and fitted with a satellite tag as part of the Gathaagudu Animal Tracking Project | Credit: Michael Taylor/Gathaagudu Animal Tracking Project

7.5 Malgana Voices Survey

From preliminary results of the Malgana Voices Survey, knowledge gaps and questions relating to priority values were raised and are provided in Table 6.

Table 6: Knowledge gaps and questions resulting from the Malgana Voices Survey.

Seagrass
Its role in stabilising the seabed
Its food, antibacterial and medicinal values
Its blue carbon credit value
Its potential commercial values for ecologically sustainable development
Its vulnerability: *"How much time do we have until it is too late?"*
"What are the different species of sea grass in the Shark Bay area?"
"What are the ecological connections and importance of seagrass to fish and megafauna?"
"What can we do as individuals to help the seagrass?"
"How would you tell the seagrass is dying off? What is causing it to die off?"
"Are rehabilitation areas recovering well? Are there areas that have not regrown since the heat wave. If so, can these areas be cultivated by Malgana Rangers with the help of researchers?"
"How can we mitigate the risk of further destruction to our wirriya jalyanu (seagrass) and implement restorative processes by utilising traditional and contemporary Indigenous knowledge and technology?"
Wirriya (sea water) health
The impacts of climate change on seawater health and ways to address this
Assessment of historical water temperature levels, future predictions and the rate of change
"What are the plans for mining in the area?"
"How is the salinity changing in different areas and how does tidal movements affect this?"
"Is our wirriya currently in good condition in both shallow and deep waters? If not, what is affecting it?"
"Are the human impacted areas contributing to a deterioration of wirriya health? Where is the impact origin (e.g. town sites, mine sites, tourism, pastoral leases etc.)?"
"What are the impacts of the salt extraction, shut down of waterways and dredging on water quality?"
"Have the combined impacts of industry on sea water health killed off most of the fish over the last 8 years?"
Fish
Monitor fish take at the jetty, supported by rangers with lawful inspection rights
Define the best way/s and locations to monitor fish populations
"Could aquaculture be used by Malgana people to help with the constant strain from recreational fishing?"
"Are fish reproducing at a rate faster than they are being caught?"
"Could aquaculture be helpful for Malgana peoples to help with the constant strain from recreational fishing?"

Mangroves

Effects of pollution from boating activity and erosion (tidal surge) on new growth

"We need to know more about mangroves overall"

"Are mangroves regenerating at a reasonable rate in and around Gathaagudu?"

"What are the ingredients for healthy mangroves?"

"How can you tell is a mangrove system is healthy or not healthy?"

"What types of mangroves are native to this area? Are they in good or bad health?"

"What are the major threats for our mangrove populations?"

Beach and dunes

"Scientific environmental and biological information about dunes and their part in the ecosystems in Gathaagudu"

"Geological-archaeological research and technology to map and protect our cultural heritage"

"How would you monitor sand dunes and beaches?"

Turtles

We need to monitor the turtles

What is the current proportion of males to females?

What do we know about their breeding cycle and lifespan?

"Where and when are they nesting?"

"Where do they mate, how long do they hold eggs for and when do they lay eggs?"

"How endangered are they?"

Groundwater

"What is the state of our ground water?"

"What industries currently extract water from the Carnarvon basin?"

"How do the pressure and flow vary, how much/has it dropped on land or sea beds and is it within the normal geology/ hydrology of these systems?"

"If unhealthy, how it can be managed and rejuvenated?"

"What impact will a further reduction in groundwater pressure and quality have on the natural environment?"

"Are the freshwater tables are being affected by continual salt mining activities and the bores used more often for road maintenance?"

Dugongs

Research on the population around Shark Bay, their general health and movement patterns

"How healthy/unhealthy are our dugongs?"

"Are they migrating to other waters and why?"

"How is the seagrass loss effecting the health of the dugong?"

Corals

A general need to monitor coral

"What are signs that coral is healthy or dying?"

"How would you monitor the growth of the coral?"

"How is the seagrass loss effecting the health of the dugong?"

7.6 Consolidated gaps

Arriving at a list of knowledge gaps from six different sources that could be used in a prioritisation process was achieved via two main pathways:

1. consolidating gaps by 'rolling up' similar gaps into a reworded and more encompassing gap, and
2. removing gaps where information was, in fact, known or currently being addressed by a research project. Some gaps were also rephrased into a question, rather than a short statement

In Appendix 11, the reader can view the originally identified gap, where the gap came from and where the gap ended up e.g. retained or discarded. Twenty-six gaps were deemed to be sufficiently addressed by the recently completed A Snapshot of Marine Research in Shark Bay (Gathaagudu): Literature Review and Metadata Collation (1949 – 2020) (Sutton and Shaw, 2020) and were not carried further in the prioritisation process. Information or datasets were available for 13 gaps via other sources, and adequate communication is needed rather than further research. For 21 gaps, there are existing or proposed projects underway to address these, so these gaps were also not included in the prioritisation process. From ~ 200 gaps (from all six sources, noting some overlap), 91 remained that were used in the prioritisation process (Table 7). These were organised under 13 high-level research themes.

The consolidation and removal of gaps was performed by the two authors, and the process reviewed by the Shark Bay Steering Group, comprised of DPIRD, DBCA and UWA researchers who had an extensive understanding of past and present research in Shark Bay. The transparency of the process is shown in Appendix 11 and allows users of this Science Plan to refer back to the original gaps if there is doubt surrounding loss of context of the original gap, or whether a gap has been sufficiently addressed by past and current projects. It is recognised that 'sufficiently addressed' does not mean a gap is completely understood, however, it allows for gaps with no knowledge to be prioritised above gaps with some knowledge.

The 13 high-level research themes were derived from a combination of theme headings used in Sutton and Shaw (2020), round-table discussions with the Shark Bay Steering Group and from the wording of the knowledge gaps themselves. Some themes were less specific than others e.g. Ecosystem Processes and Connectivity vs Habitat and Bathymetry Mapping, and this was to accommodate for the large breadth of some knowledge gaps e.g. What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay? Themes needed to be understandable by all stakeholders, while not being too extensive to prohibit participation in the prioritisation process. Where there was uncertainty about the allocation of a knowledge gap to a theme, the Steering Group member or author with the most expertise in that theme or gap, allocated the gap to a specific theme. If a knowledge gap related to more than one theme, this was assigned to the best fitting theme by the member with the most expertise.

Table 7: Final list of knowledge gaps used in the online Shark Bay Prioritisation survey. Order does not represent prioritisation at this stage

Ecosystem processes and connectivity
1. What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?
2. What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities e.g. energy transfer, ontogenetic and seasonal movements, biological filtration?
3. What are the sources of nutrients and how are they cycled in Shark Bay e.g. Hamelin Pool?
4. How will climate change affect primary productivity and the flow of energy in marine systems?
5. How would food webs shift in the absence of key seagrass species under climate change scenarios?
6. Better understanding of benthic productivity within Shark Bay (e.g. seagrasses, macroalgae)?
7. How productive are pelagic waters and what are the seasonal dynamics e.g. phytoplankton and zooplankton?
8. How are Shark Bay corals connected to other corals/reefs along the WA coastline and deeper waters?
9. How genetically connected are fish populations within Shark Bay (not limited to pink snapper)?

Environmental conditions

10. Undertake higher resolution modelling of the oceanographic environment within Shark Bay, inclusive of local circulation, inflow, episodic flooding, and groundwater considerations
11. Better understanding of temporal and spatial environmental conditions (temperature, salinity, sea level) in Shark Bay
12. Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/moorings, natural levels of turbidity and periodic influxes from flooding
13. What is the long-term role of the Faure Sill and its structure and function in maintaining Hamelin Pool?
14. How does local and regional hydrology influence ecological processes (propagule dispersion, nutrient supply, recruitment, connectivity) and threats (oil spills, introduced species) and how can predicted changes to hydrology help inform marine reserve planning?
15. Better understanding of the location and volume of groundwater inputs into Shark Bay (particularly Hamelin Pool and Freycinet Estuary), including nutrient and contaminant concentrations
16. How could the extraction of groundwater influence groundwater pressure and what impact would reduce pressure into the bay have on the benthic communities? e.g. stromatolites, seagrasses, mangroves and salt marshes?
17. What are the important linkages between marine water conditions, chemical processes, seagrass and organomineralisation processes in a carbonate dominated marine environment?
18. How will the loss of seagrass and shifts in the composition of primary producers affect the acidity of the water in Shark Bay, given seagrasses take up carbon dioxide helping to reduce carbonic acid in the water?
19. What will be the impacts of increased sediment transport if there are less seagrass roots to maintain stability?

Climate change impacts

20. How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?
21. What are the climate change associated predictions to changes in freshwater runoff, nutrients and organic matter into Shark Bay?
22. What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?
23. How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?
24. What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?
25. What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?

Benthic communities (other than seagrass)

26. What intrinsic (gene expression and metabolomics) responses and external (environmental) conditions will influence the formation, growth and survival of microbial and microbialite communities under a changing climate?
27. What are the natural and anthropogenic (including climate change) threats to mangroves in Shark Bay?
28. What are the most appropriate indicators to monitor and measure the condition of stromatolites?
29. How do environmental factors (e.g. salinity, sediment dynamics, erosion and sea level rise) influence the rates of recruitment, survival, growth and physiology of mangroves (Avicennia marina) and how do variations in structure influence their ecological function?
30. How does the distribution of algae and seagrasses influence the abundance and species composition of marine fauna?
31. What life stages of organisms are associated with mangrove habitats and is this use dependant or opportunistic?
32. What factors impede or promote growth and recovery (e.g. after a disturbance) of different corals at Shark Bay?
33. How is invertebrate diversity, distribution and abundance in Shark Bay influenced by climate and environmental drivers and other anthropogenic pressures?
34. What is the composition, distribution and ecological significance of salt marshes and other riparian vegetation?

Seagrass communities

35. What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?
36. Is large-scale restoration or protection of seagrass meadows feasible?
37. How can we better understand the role of seagrasses in carbon capture and how will this influence Australia's blue carbon capabilities into the future?
38. What is the current diversity and distribution of macro-invertebrate and fish species inhabiting different species of persistent seagrass?
39. To what extent are human activities having a direct impact on seagrass communities (e.g. boat use)?

Marine megafauna

40. When and why do dugongs move, and over what spatial extent are these movements?
41. Better understanding of how the movements of dugongs differ demographically, and how dugongs of different ages use critical habitats (e.g. seagrass habitats)
42. What is the genetic structure of dugongs in Shark Bay and what level of genetic connectivity is there for dugongs along the WA coast?
43. What is the probable impact of climate change and increased storms on turtle nesting beaches?
44. What are the most important processes (natural and anthropogenic) influencing loggerhead and green turtle populations?
45. What are the key foraging sites for marine turtles and what are the demographics of turtles using these areas?
46. What level of turtle egg and hatchling mortality is caused by feral and native animals?
47. What is the relative importance of nesting and foraging areas within Shark Bay to broader turtle populations along the WA coastline?
48. What are the cause(s) of disease and death of sea turtles in Shark Bay e.g. fibropapillomatosis in turtles?
49. What is the species composition and relative abundance of sea snakes in Shark Bay and how best can they be monitored?
50. What is the trophic ecology of key seabird species and the likely impact of extreme marine events and gradual climate change on these food chains?
51. Have key nesting/roosting areas in Shark Bay remained the same for seabirds/shorebirds over time, and are they expected to change due to climate change?
52. Has shark abundance increased in Shark Bay and why (e.g. is this related to offal discard from recreational fishing)?
53. Develop an improved understanding of the significant habitats for dolphins (e.g. areas used for feeding or reproduction) and, in particular, the demographics, distribution, abundance, residency and habitat use of Australian humpback dolphins
54. How do whale sharks use the Shark Bay region?

Fish and Fisheries

55. How do environmental factors (particularly those affected by climate change) and other impacts (e.g. fishing pressure) affect the abundance and diversity of fished and non-fished species?
56. What are the cumulative impacts of commercial and recreational fishing on the ecological assets in Shark Bay?
57. What are the spatial and temporal patterns of recreational fishing in the marine park and what is the recreational fish take by species and method of catch?
58. Where are the important nursery and spawning sites for priority finfish species in Shark Bay (e.g. Useless Loop)?
59. How genetically connected are fish populations within Shark Bay?
60. What is the ecological importance of fishes that are not targeted by recreational and commercial fisheries?
61. What is the survivorship of released fishes?
62. What are the spatial and temporal patterns of species caught by recreational fishers?
63. Would imposing maximum sizes for species caught increase the sustainability of targeted recreational fish?
64. What finfish species are considered culturally important?
65. What are the ecological impacts associated with the sea cucumber fishery in Shark Bay?
66. What are the impacts on benthic habitats from discarding shells from the scallop fishery?

Habitat and bathymetry mapping

67. Undertake high-resolution (e.g. Lidar) bathymetric and habitat mapping, including inter-annually for shallow waters (e.g. Wooramel coast, large offshore banks off Monkey Mia, Dirk Hartog, Faure Sill and Denham flats)
68. What long-term changes have occurred in Shark Bay due to industrial and other anthropogenic activities (e.g. mining, dredging, trawling, coastal 4WD activities)?

Management and monitoring

69. Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures
70. Develop indicators and monitoring thresholds for the management of key elements of Outstanding Universal Value of Shark Bay World Heritage Area
71. Are the current management structures in Shark Bay (e.g. compliance) adequately resourced to ensure tourists adhere to tourism regulations?
72. Are the current management structures in Shark Bay (e.g. compliance) adequately resourced to ensure recreational fishers adhere to recreational fishing regulations?
73. How do we deliver best practice knowledge return of research to Traditional Owners and the wider Shark Bay community?
74. What would a shared and collaborative database of current monitoring and research programs look like, taking into consideration Indigenous intellectual property and agreed data access models? Identify a local agency/organisation to manage a database
75. What configuration of management zones would most effectively protect and conserve marine biodiversity?
76. Is intervention to preserve ecosystem function (e.g. seagrass restoration) the correct thing to do (e.g. adaptation vs intervention)?
77. How can we better integrate local, State and Commonwealth agencies in the management of Shark Bay? This should be embedded in strategy, policy, and budgets by responsible agencies
78. Would aligning marine park and World Heritage boundaries to streamline management positively benefit conservation values?

Incorporation of cultural heritage and Traditional ecological knowledge

79. What is the process for including cultural and Indigenous values as part of Shark Bay World Heritage Property values?
80. How can the western science community work with Traditional Owners to create more holistic understandings of the Shark Bay environment?
81. Increased knowledge and understanding of cultural heritage values, both Indigenous and non-Indigenous

Sustainable economic growth and livelihoods

82. What is the overall economic value of Shark Bay World Heritage Area and marine reserves, including tourism, fishing, cultural and ecological assets?
83. What are the cost-benefits of the various industries operating in Shark Bay, e.g. tourism, recreational and commercial fishing, salt mining, goat herding, aquaculture?
84. What are the opportunities for sustainable tourism, ecotourism, cultural tourism and job creation?
85. What future economic opportunities are available for Malgana (in sea country research)?

Education and communication

86. What are appropriate ways to share cultural knowledge with tourists and fishers so they can understand and respect cultural sensitivities and the timeless role of Traditional Owners in sea country stewardship/management?
87. What initiatives could be developed to foster and increase environmental stewardship (e.g. ambassadors)?

Tourism and visitor use

88. What is the carrying capacity for tourism in Shark Bay overall and in specific areas of interest (e.g. national parks, Herald Bight, Monkey Mia)?
89. What are the impacts of recreational and commercial (licensed tour operators) access to marine megafauna, particularly in areas of key interest and high pressure?
90. What are the pollution levels (rubbish and fishing gear) created by human activity and the resulting impacts on marine fauna?
91. How can the peak number of tourists be spread out over a greater time period to reduce environmental pressure?

Francios Peron National Park | Credit: Nick Thake

8. Prioritisation process for knowledge gaps

Kayakers on the beach | Credit: Nick Thake

8.1 Prioritisation survey

Prioritising knowledge gaps that span across ecological, social and economic values is best done in consultation with a range of stakeholders. While past effective methods for prioritising knowledge gaps have involved in-person workshops where outcomes are delivered after a few days, this was not feasible during COVID-19 restrictions in 2020-2022. Instead, an online prioritisation survey was designed using the software Qualtrics. An online survey proved to be an effective method for a number of reasons, including:

1. The survey could be disseminated locally, nationally and internationally
2. The survey would be less time intensive compared to attending an in-person workshop for multiple days
3. The survey was accessible 24 hours a day, which meant it could be completed during work hours or at home
4. The survey could be open for a lengthy period of time in order to improve participation
5. The survey was inclusive and could cater to different levels of knowledge, with opt out options
6. The survey structure enabled interrogation of the participant's interest area and/or expertise (category) to better understand the priorities selected

8.1.1 Structure

As participants started the survey, they were provided with introductory information on:

- Why they were receiving the survey
- The purpose of the survey
- The layout of the survey
- The reason for having an online survey as opposed to an in-person workshop
- Where the knowledge gaps came from
- Closing date and contact information

In order to identify stakeholders and relate survey results to different stakeholder groups, participants were asked to select stakeholder categories that applied to them. These included:

- Research
- University
- Government
- Management
- Malgana
- Shark Bay Community
- Tourism
- Mining
- Agriculture
- Fishing
- Visitor to Shark Bay
- Other (could specify)

Following this question, participants were asked to identify the stakeholder group that best described them from the above list. Participants then had the option of identifying their main area of expertise or interest in Shark Bay using free text.

No other demographic information was requested, though participants were asked to enter their email addresses for the purposes of survey integrity (reduce fake emails/bots) and if they wished to enter the draw to win one of six $50 vouchers for participating in the survey.

The scoring component of the online survey was divided into two parts:

1. high-level scoring of research themes (Table 6, Fig. 11), and
2. scoring of detailed knowledge gaps (nested under high-level research themes; Table 6, Fig. 12).

This 2-tiered scoring allowed all stakeholders to participate in the survey, regardless of their level of knowledge of the marine environment of Shark Bay.

Firstly, we wanted to know what high-level research themes stakeholders' thought were in need of more attention in Shark Bay. This was a requirement of participants before they could proceed to the next steps. The online survey provided a mechanism for participants to easily 'drag and drop' high-level research themes into an order from most in need of attention (1) to least in need of attention (13) for maintaining a healthy functioning marine ecosystem in Shark Bay (Fig. 11).

Hamelin Pool Stromatolites sign

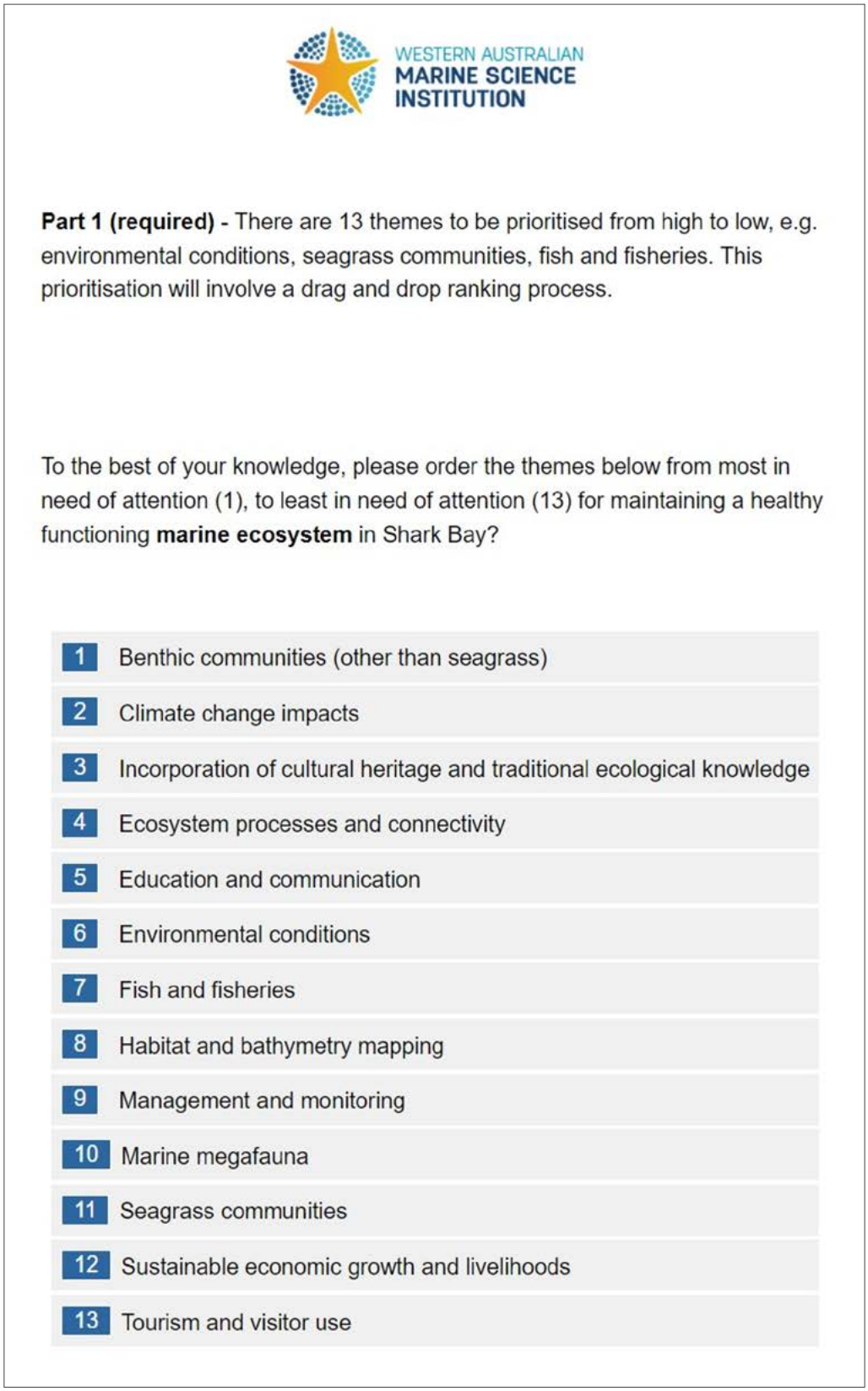


Figure 11: An example of the drag and drop function for ranking high-level research themes from most in need of attention (1) to least in need of attention (13).

Secondly, we wanted to understand which detailed knowledge gaps should be a priority for Shark Bay. This was an optional part of the online survey as it involved another level of scoring complexity and knowledge, and scientific language was often used. Participants were encouraged to continue on in the survey if they had an interest or felt comfortable with their level of knowledge of the marine environment of Shark Bay. Subject matter experts or researchers were further encouraged to spend the extra time scoring detailed knowledge gaps.

Participants choosing to continue on to Part 2 and score detailed knowledge gaps had the option to score all detailed knowledge gaps under all 13 high-level research themes (91 detailed knowledge gaps in total), or they could score a subset of detailed knowledge gaps and high-level research themes. Participants could exit the survey at any time, but they were encouraged to finish all the scoring for a detailed knowledge gap for the score to be valid. The number of detailed knowledge gaps under each of the 13 high-level research themes ranged from 2 to 18. The detailed knowledge gaps were ordered from broad to specific, but this did not imply importance. Participants were provided the opportunity to revise their scoring before leaving the survey. For example, Fig. 12 shows an example of the table and options available for scoring the Ecosystem Importance, Interest, Knowledge and Urgency of detailed knowledge gaps under the high-level research theme, Seagrass Communities.

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Seagrass communities	**Ecosystem Importance** How important do you think this gap is to a healthy ecosystem? 1- not important at all 2- not very important 3- somewhat important 4- moderately important 5- important 6- very important 7- extremely important	**Interest** How important is this gap to your interest in Shark Bay? 1- not important at all 2- not very important 3- moderately important 4- important 5- very important	**Knowledge** How much relevant and existing knowledge are you aware of? 2- very little 3- some 4- significant amounts 5- extensive	**Urgency** Does this gap need to be answered/addressed urgently? 1- not urgent (>20 yrs) 2- long term (>10 yrs) 3- medium term (5-10 yrs) 4- short term (<5 yrs) 5- immediately (<2 yrs)
	1 2 3 4 5 6 7	1 2 3 4 5	2 3 4 5	1 2 3 4 5
What external processes drive distribution, abundance and variation of seagrass communities and how much would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?	O O O O O O O	O O O O O	O O O O	O O O O O
Is large-scale restoration or protection of seagrass meadows feasible?	O O O O O O O	O O O O O	O O O O	O O O O O
How can we better understand the role of seagrasses in carbon capture and how will this influence Australia's blue carbon capabilities into the future?	O O O O O O O	O O O O O	O O O O	O O O O O

Figure 12: An example table for scoring of detailed knowledge gaps under the high-level research theme, Seagrass Communities.

8.1.2 Scoring criteria

Participants were asked to score the detailed knowledge gaps using the four criteria in Table 8: Ecosystem Importance, Interest, Knowledge and Urgency. The criteria and scoring were adapted from Pannell et al. (2013; 2014), and the final scoring and criteria used in the prioritisation survey benefited from discussion with Professor David Pannell from UWA.

To arrive at a final score for a detailed knowledge gap, the following equation was used:

Score = (E + I) × U × (6 - K)

where E = Ecosystem Importance, I = Interest, U = Urgency, and K = Knowledge

Given the Shark Bay marine ecosystem has been threatened, and continues to be threatened by extreme events, and is critical for the survival of fisheries, tourism and livelihoods, Ecosystem Importance was given extra weighting by having a scoring range from 1–7, as opposed to 1–5 for other criteria. Interest was added to Ecosystem Importance, so they were equally influential to the final score, and this reflects WAMSI's goal to involve and elevate stakeholders and their varying views in the prioritisation process. Urgency was made a significant influencer of the score by being a multiplier, which was effective in providing a greater separation between scores of knowledge gaps and further highlighting the priorities. Knowledge was also a significant influencer of the score by being a multiplier, given the prioritisation process is being applied to knowledge gaps. As there is not often a situation where absolutely no knowledge is available, the minimum score of '1' (No knowledge) was removed as a scoring option for the criteria Knowledge. The score for Knowledge was subtracted from six to remove the possibility of a 'zero' value in calculations.

Table 8: Criteria for scoring knowledge gaps in the online Shark Bay Prioritisation survey.

Criteria	Guidance	Scoring	Numeric
Ecosystem Importance: Importance of this issue to a healthy ecosystem	e.g. Scale of the issue, benefits related to the issue	Extremely important Very important Important Moderately important Somewhat important Not very important Not important at all	7 6 5 4 3 2 1
Interest: How important is this issue to your interest in Shark Bay?	e.g. Uniqueness (WHP), Indigenous values and culture, community values	Very important Important Moderately important Not very important Not important at all	5 4 3 2 1
Knowledge: How much existing knowledge is available?	e.g. Is it relevant in addressing the specific issue/question? Is it reliable?	Extensive Significant amounts Some Very little	5 4 3 2
Urgency: Does this question/issue need to be answered/ addressed immediately?	e.g. How vulnerable is the species/ habitat? When do decision-makers need the information for management? Is the species/habitat/process currently under threat?	Immediately (<2 years) Short term (<5 years) Medium term (5–10 years) Long term (>10 years) Not urgent (>20 years)	5 4 3 2 1

8.2 Survey analyses

In order to prioritise detailed knowledge gaps, the following aspects were considered:

1. **Some consistency in participation**. All participants were required to complete Part 1 and rank high-level research themes
2. **Accounting for those detailed knowledge gaps that were not scored**. Some detailed knowledge gaps may not have been scored. This could be due to lack of expertise, lack of time, etc., and it was not assumed it was due to a lack of importance. All detailed knowledge gaps came from a workshop or publication where it was deemed to be important. To account for instances where no scoring occurred, a base score of '1' was assigned so that the final score for the detailed knowledge gap did not result in a '0'
3. **High-level research themes and detailed knowledge gaps should be linked together**. Not all participants would have scored the detailed knowledge gaps. In order for their views to still have an influence on the prioritisation of detailed knowledge gaps, detailed knowledge gaps received 'extra points' in the calculations depending on where the high-level research theme, of which the question belonged to, was ranked in Part 1. All participants had to complete Part 1.

The following steps outline the process taken to arrive at the final scores for each detailed knowledge gap and, in turn, prioritisation of these detailed knowledge gaps:

1. For each of the 91 detailed knowledge gaps, the numeric scores for each criterion (E, I, U, K) were averaged, as the sample size (number of participants scoring) for each detailed knowledge gap differed
2. The equation $(E + I) \times U \times (6 - K)$ was used to obtain scores for each detailed knowledge gap, based off the averaged values for each criterion
3. Detailed knowledge gaps were sorted based on scores from high to low
4. Based on this sort from high to low, a new ordered rank was applied from 91 (high) to 1 (low), as there were 91 questions (noting some questions may have been assigned the same rank if they had the same score)
5. The summed ranks for high-level research themes from 1 to 13 were divided by the number of participants to obtain an average rank for each high-level research theme
6. 'Extra points' were then added to the ordered rank values of detailed knowledge gaps based on high-level research themes. The 'extra points' added to the scores ranged from 13 (if the associated high-level research theme was ranked high at 1) to 1 (if the associated high-level research theme was ranked low at 13). This was an addition rather than a multiplication so that Part 1 did not have an overriding influence on the prioritisation of detailed knowledge gaps
7. Detailed knowledge gaps were then sorted again, from high to low, to obtain the prioritised list. An overall prioritised list was obtained as well as individual stakeholder group prioritised lists

8.3 Metadata

8.3.1 Survey distribution

The online prioritisation survey was distributed via two methods 1) a link sent directly to emails of known participants, or 2) an anonymous link that could be accessed by anyone. Most participants (68%) who entered the survey did so using the link sent directly to them via email.

8.3.2 Validation of survey responses

At the closing time of the online prioritisation survey, a total of 413 surveys entries were recorded. Of this total, 135 entries were identified as illegitimate email bots. A further 57 entries were removed for being incomplete or duplications. The resulting number of survey entries used in further analyses and the below metadata results was 221.

8.3.3 Confidentiality of participants

The emails of most participants (160) in the online prioritisation survey were known as a result of the confidential targeted survey distribution and the option for participants to willingly enter their email addresses when asked (to help ensure validity) (Fig. 13). Thirty-eight participants opted for anonymity (they did not enter their email address, but they were known due to a survey link being sent directly to the email), and 23 participants were completely anonymous. Completely anonymous participants accessed the survey via the anonymous link distributed widely and did not enter their email addresses into the survey. While it is possible that these completely anonymous participants could have been illegitimate bots, an analysis indicated it was unlikely (e.g. the survey scores appeared legitimate, there were no random text entries as in other identified email bot entries, and other email bot entries included a standardised email that aided in clear bot detection).

8.3.4 Demographics of participants

Of the 221 participants, most completed the survey from within Australia (based on the automatically recorded latitude, longitude and time of survey entry). Twenty-six participants were considered international entries, which is not unexpected given the international research interest and groups working in Shark Bay.

Participants were asked to select all the stakeholder groups that applied to them as it is recognised most participants likely fell into more than one group or 'wore many hats'. The stakeholder group with the highest affiliation was 'research' (63%) (Fig. 14), followed by 'university' (42%) and 'government' (29%). Only one and two participants (out of 219) associated with 'agricultural' and 'mining', respectively. The 'other' stakeholder category included 22 entries: 'citizen', 'co-leader of an Indigenous led organisation', 'commercial scientific company', 'community interest', 'conservation NGO', 'consultant', 'former resident', 'Interested marine researcher but not involved in Shark Bay research at the moment', 'Malgana ranger', 'molluscan research', 'owner of property', 'peak Aboriginal organisation', 'spatial', 'strategy, sustainability, Conservation, Interface with business' and 'WHA Advisory Committee'.

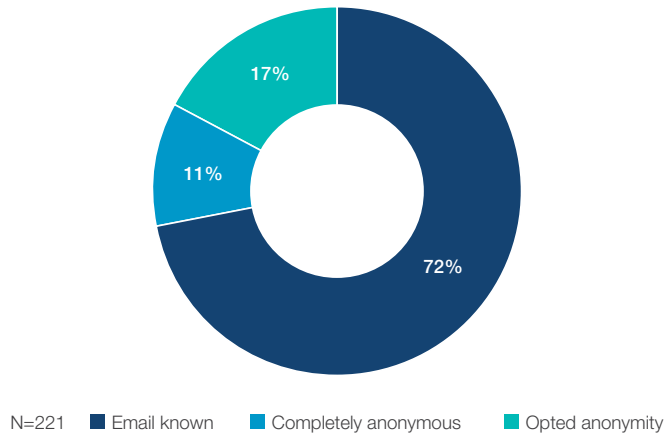

Figure 13: Anonymity of participants in the online Shark Bay Prioritisation survey.

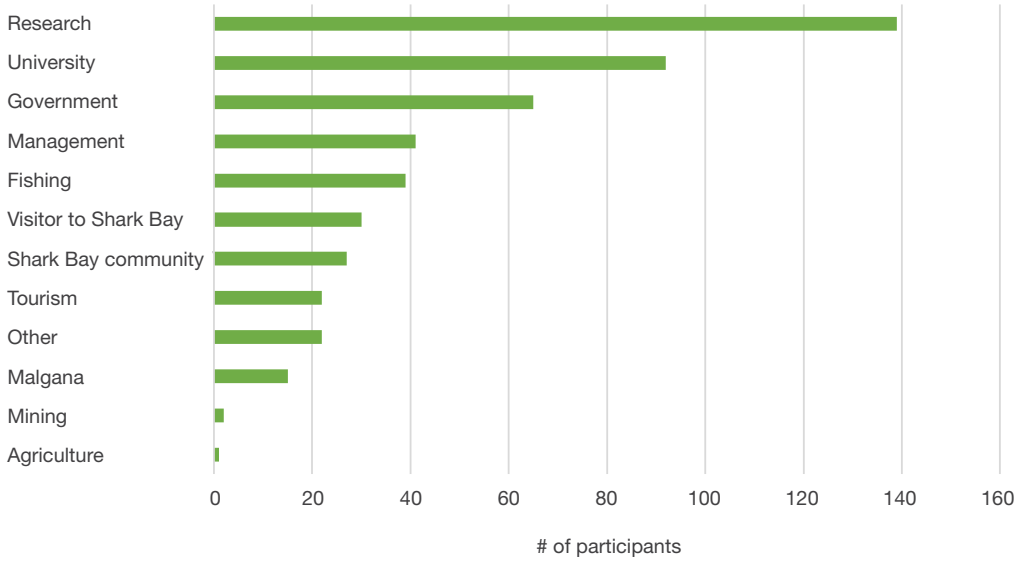

Figure 14: Identification of all stakeholder groups of participants in the online Shark Bay Prioritisation survey.

In order for the prioritised knowledge gaps to be more clearly aligned with a stakeholder group, participants were asked to identify which stakeholder group BEST described them and how they would be answering the survey in line with e.g. 'which hat would they be wearing when scoring'. Once again, 'research' had the highest affiliation (45%) (Fig. 15). 'Government' and 'university' best described 11% and 10% of participants, respectively. All other stakeholder groups were chosen by 7% or less participants, except for 'agriculture' and 'mining', which did not best describe the stakeholder group for any participant. The 'other' stakeholder category included seven entries relating to 'conservation NGO', 'consultant' and 'WHA Advisory Committee'.

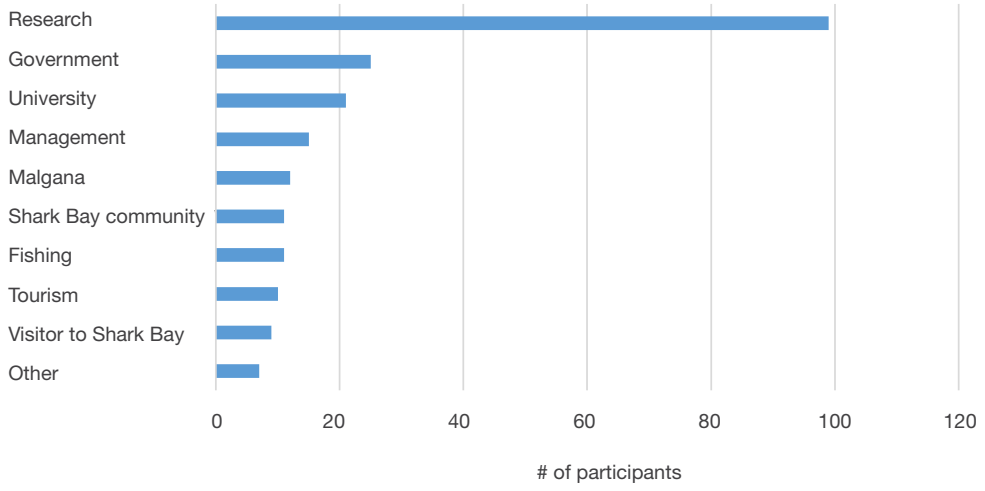

Figure 15: Identification of the stakeholder group that BEST describes the participants in the online Shark Bay Prioritisation survey.

8.3.1.5 Survey completion

As ranking high-level research themes in Part 1 was a requirement, 219 valid entries were made. Of the 219 entries, 139 participants clicked 'yes' to continuing to Part 2 to score the detailed knowledge gaps (Fig. 16). The actual number of valid entries for Part 2 was 119, which meant 20 participants left the survey prior to scoring for reasons unknown.

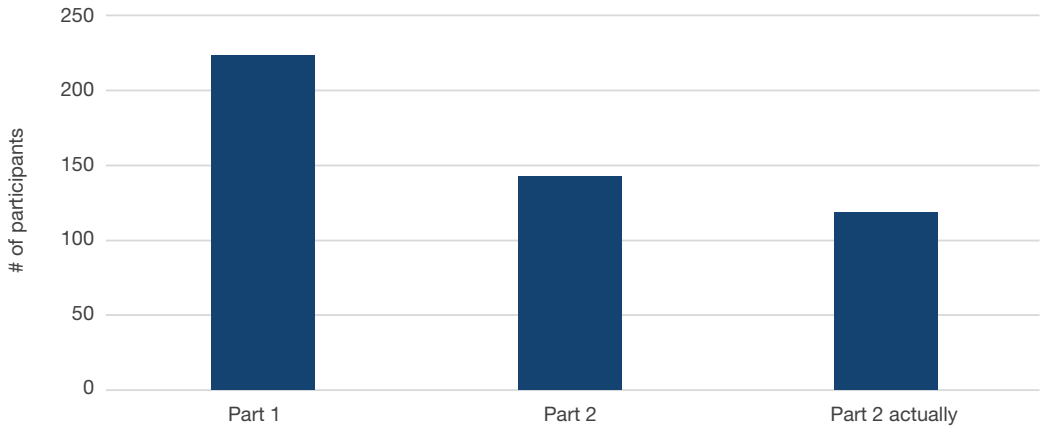

Figure 16: The number of participants who undertook Part 1 and Part 2 of the online Shark Bay Prioritisation survey.

All detailed knowledge gaps were scored at least once, which meant there was no need to apply a base score of '1' for further calculations (see 7.2 Analyses). Nine participants scored all four criteria for all 91 detailed knowledge gaps. The greatest proportion of participants (32) scored between 2 and 19 detailed knowledge gaps (Fig. 17), followed by between 40–59 (26 participants) and 80–91 (25 participants).

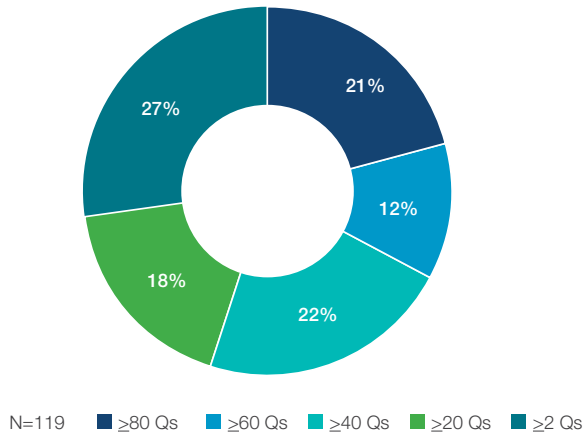

Figure 17: The proportion of questions (maximum = 91) answered by participants of the online Shark Bay Prioritisation survey.

The online prioritisation survey was made available to participants on Friday morning 20th November 2020 and remained open for three weeks. Over 50% of participants completed the survey within the first week (Fig. 18). This dropped to 25% and 22% in the second and third weeks, respectively. The survey was closed on 14 December 2020.

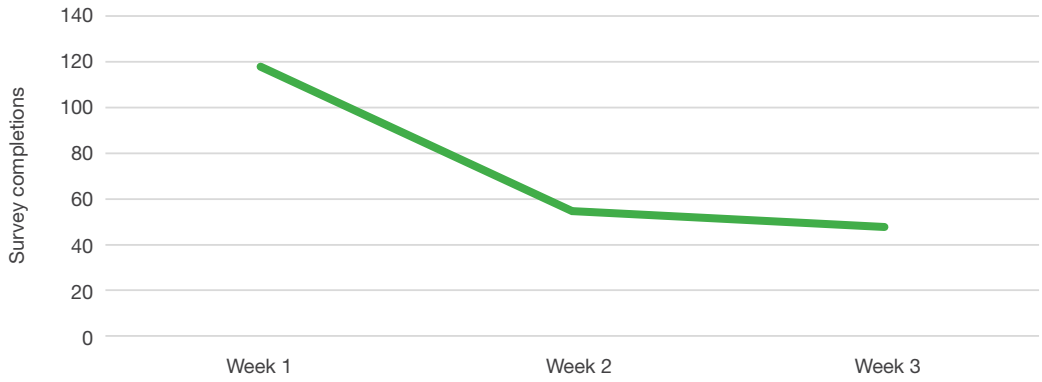

Figure 18: Completion of the online Shark Bay Prioritisation survey across three weeks.

The ranking of high-level research themes in Part 1 of the online prioritisation survey was designed to be relatively quick to complete. The majority (55%) of participants who completed Part 1 (only) took less than five minutes (Fig. 19). Six participants took longer than one hour to complete Part 1 only, and it is likely that the survey was left open on the computer while the participants attended to other tasks (e.g. max recorded was 98 hours). The average time it took for those participants who completed Part 1 only was 6.7 minutes (excluding the six outliers).

Participants who completed Part 1 and Part 2 took longer, as expected, with an average completion time of 48 minutes (Fig. 19). However, given participants could complete a varying number of questions, the variability in completion time was high. The completion time of 17 participants were considered outliers given the completion time ranged from 9–162 hours and, again, was likely a result of the survey being left open on a computer. Of those nine participants who scored all four criteria for all 91 detailed knowledge gaps, the minimum completion time was 11.6 minutes and the longest was close to 5 hours, with an average of 80 minutes.

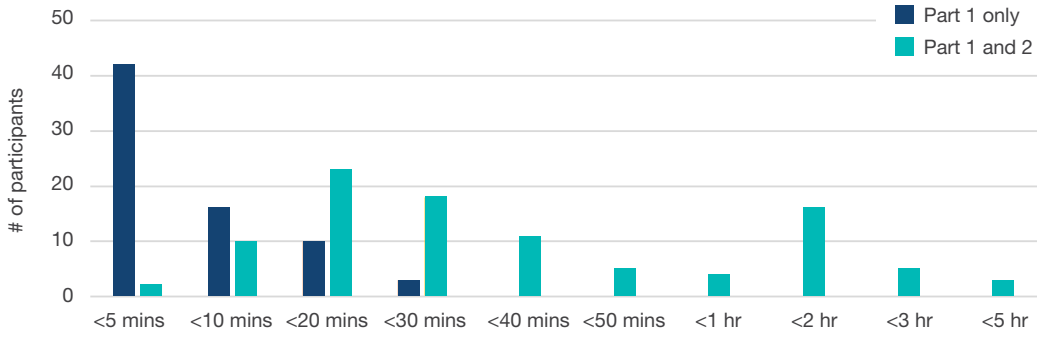

Figure 19: The time taken for participants to complete Part 1 and Part 2 of the online Shark Bay Prioritisation survey.

8.4 Prioritised research themes and knowledge gaps

8.4.1 High-level research themes

For all stakeholder groups combined (n = 219), 'Climate change' was the high-level research theme that participants thought needed the most attention when it came to maintaining a healthy functioning marine ecosystem in Shark Bay (Table 9). This was followed by 'Ecosystem processes and connectivity', 'Seagrass communities', 'Benthic communities (other than seagrass)' and 'Cultural heritage and Traditional ecological knowledge'. The economic themes of 'Sustainable economic growth and livelihoods', and 'Tourism and visitor use', were ranked as in least need of attention for maintaining the marine ecosystem.

Table 9: Ranked order of high-level research themes by participants in the online Shark Bay Prioritisation survey. Rank scores ranged from 1 (highest) to 13 (lowest).

RANK	THEME	AVERAGE	SE
1	Climate change	3.43	0.20
2	Ecosystem processes and connectivity	4.83	0.19
3	Seagrass communities	5.37	0.24
4	Benthic communities (other than seagrass)	6.15	0.22
5	Incorporation of cultural heritage and Traditional ecological knowledge	6.20	0.23
6	Management and monitoring	6.36	0.22
7	Environmental conditions	6.70	0.22
8	Fish and fisheries	6.89	0.21
9	Education and communication	7.87	0.22
10	Habitat and bathymetry mapping	8.72	0.22
11	Marine megafauna	8.92	0.21
12	Sustainable economic growth and livelihoods	9.37	0.23
13	Tourism and Visitor use	10.19	0.24

Ranking of high-level research themes differed among stakeholder groups. 'Climate change' was ranked as most in need of attention for the stakeholder groups: 'Research', 'Government', 'Management', 'University' and 'Tourism' (Table 10). 'Incorporation of cultural heritage and Traditional ecological knowledge' was ranked highest for 'Malgana'. Those participants associated with 'Fishing' thought that 'Fish and fisheries' required the most attention for maintaining a healthy marine environment. 'Fish and fisheries' and 'Education and communication' were ranked as the top two for the 'Shark Bay community' stakeholder group and 'Seagrass communities' was ranked as number one for 'Visitors' to Shark Bay.

'Education and communication' was prioritised highly for stakeholder groups centred around people and their experiences, such as 'Visitors', 'Shark Bay Community' and 'Tourism'. Interestingly, 'Researchers' and 'Government' ranked 'Education and communication' as a lower priority, and lower than any other stakeholder group. There has long been an increasing need to communicate research back to the community and Traditional Owners, and these requests have largely been directed at researchers and government in general. An advantage of this prioritisation process is for stakeholder groups to better understand what is important for each other, so that more synergies across groups can lead to improved overall health of the Shark Bay ecosystem.

The two industry stakeholder groups, 'Fishing' and 'Tourism', ranked 'Sustainable economic growth and livelihoods' higher than other stakeholder groups. This would directly relate to the need to maintain and grow the two industries in Shark Bay with economic primacy. The lack of correlation in ranked high-level themes between some of the stakeholder groups may be due to ecological and non-ecological themes being mixed together, lack of consistent or baseline knowledge and understanding across different groups, and the personal experiences of the participants who took the survey.

The added value of the WAMSI Shark Bay Science Plan is that government agencies, such as DPIRD and DBCA, can focus specifically on the priority knowledge gaps of a particular stakeholder group of their choosing. This detailed information could enable improved understanding of both community and industry with possible relationship benefits.

For example, following a deidentification process, DPIRD can request from WAMSI to view all survey responses of those participants who identified with 'Fishing', and see how knowledge gaps were prioritised. A total of 39 participants chose 'Fishing' as one of the stakeholder groups that represented them, and 11 of these identified 'Fishing' as the best stakeholder group that represented them.

The ability to separate out stakeholder groups is useful given the survey results, and top 20 knowledge gaps for all stakeholder groups combined, were dominated by participants identifying with 'Research'. While eight knowledge gaps prioritised in the top 20 by 'Fishing' participants were included in the combined stakeholder top 20 knowledge gaps, DPIRD is able to also focus on the other 12 prioritised gaps and see that the majority are directly related to fishing or fished species.

Hamelin Pool Stromatolites | Credit: Nick Thake

Table 10: Ranked order of high-level research themes by different stakeholder groups that participated in the online Shark Bay Prioritisation survey.

RANK	RESEARCHERS	GOVERNMENT	MALGANA*	FISHING	MANAGEMENT	SHARK BAY COMMUNITY	UNIVERSITY	VISITOR	TOURISM	ALL COMBINED
1	Climate change	Climate change	Incorporation of cultural heritage and TEK	Fish and fisheries	Climate change	Fish and fisheries	Climate change	Seagrass communities	Climate change	Climate change
2	Ecosystem processes and connectivity	Seagrass communities	Climate change	Management and monitoring	Management and monitoring	Education and communication	Ecosystem processes and connectivity	Climate change	Incorporation of cultural heritage and TEK	Ecosystem processes and connectivity
3	Seagrass communities	Ecosystem processes and connectivity	Fish and fisheries	Benthic communities	Seagrass communities	Climate change^	Incorporation of cultural heritage and TEK	Education and communication	Education and communication	Seagrass communities
4	Benthic communities	Management and monitoring	Ecosystem processes and connectivity	Ecosystem processes and connectivity	Ecosystem processes and connectivity	Seagrass communities^	Benthic communities	Management and monitoring	Tourism and visitor use	Benthic communities
5	Environmental conditions	Benthic communities	Seagrass communities	Climate change	Incorporation of cultural heritage and TEK	Ecosystem processes and connectivity	Seagrass communities	Fish and fisheries	Benthic communities	Incorporation of cultural heritage and TEK
6	Incorporation of cultural heritage and TEK	Environmental conditions	Management and monitoring	Sustainable economic growth and livelihoods	Environmental conditions	Incorporation of cultural heritage and TEK	Environmental conditions	Ecosystem processes and connectivity	Ecosystem processes and connectivity	Management and monitoring
7	Management and monitoring	Fish and fisheries	Education and communication	Environmental conditions	Education and communication	Environmental conditions	Management and monitoring	Incorporation of cultural heritage and TEK	Sustainable economic growth and livelihoods	Environmental conditions
8	Fish and fisheries	Incorporation of cultural heritage and TEK	Benthic communities^	Seagrass communities	Benthic communities	Management and monitoring	Education and communication	Environmental conditions	Fish and fisheries	Fish and fisheries
9	Habitat and bathymetry mapping	Habitat and bathymetry mapping	Environmental conditions^	Education and communication	Fish and fisheries	Tourism and visitor use	Fish and fisheries	Benthic communities	Environmental conditions	Education and communication
10	Marine megafauna	Marine megafauna	Marine megafauna	Marine megafauna	Habitat and bathymetry mapping	Benthic communities	Marine megafauna	Habitat and bathymetry mapping	Seagrass communities	Habitat and bathymetry mapping
11	Education and communication	Education and communication	Habitat and bathymetry mapping	Incorporation of cultural heritage and TEK	Sustainable economic growth and livelihoods	Sustainable economic growth and livelihoods	Habitat and bathymetry mapping	Tourism and visitor use	Management and monitoring	Marine megafauna
12	Sustainable economic growth and livelihoods	Tourism and visitor use	Sustainable economic growth and livelihoods	Tourism and visitor use	Tourism and visitor use	Marine megafauna	Sustainable economic growth and livelihoods	Sustainable economic growth and livelihoods	Marine megafauna	Sustainable economic growth and livelihoods
13	Tourism and visitor use	Sustainable economic growth and livelihoods	Tourism and visitor use	Habitat and bathymetry mapping	Marine megafauna	Habitat and bathymetry mapping	Tourism and visitor use	Marine megafauna	Habitat and bathymetry mapping	Tourism and visitor use
N	99	25	12	11	15	12	21	8	9	219

* different participants to the Malgana Voices Survey
^ ranked at the same level

8.4.2 Detailed knowledge gaps

The top 10 detailed knowledge gaps for all stakeholder groups combined is provided in Table 11. The top 10 were chosen to include enough variability in knowledge gaps and to provide a clearer focus for stakeholders. The ranking of 91 detailed knowledge gaps can be seen in Appendix 12. The question 'How would food webs shift in the absence of key seagrass species under climate change scenarios?' was ranked as the highest priority overall, and this was followed by eight other questions with a climate change focus. Another commonality among the highest ranked questions is that they are large scale, ecosystem encompassing questions that would serve as an umbrella for a multitude of more detailed questions. Scores were averaged across all participants, giving equal weighting to all participants.

Table 11: A prioritised list of the top 10 detailed knowledge gaps, for all stakeholder groups combined, resulting from the online Shark Bay Prioritisation survey.

HIGH-LEVEL THEME	DETAILED KNOWLEDGE GAP	RANK	SAMPLE SIZE
1. Ecosystem processes and connectivity	How would food webs shift in the absence of key seagrass species under climate change scenarios?	1	67
2. Climate change	What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?	2	86
3. Climate change	How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?	3	88
4. Management and monitoring	Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures	4	70
5. Climate change	What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?	4	88
6. Climate change	How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?	5	88
7. Seagrass communities	What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?	5	62
8. Ecosystem processes and connectivity	How will climate change affect primary productivity and the flow of energy in marine systems?	6	66
9. Climate change	What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?	7	87
10. Management and monitoring	Develop indicators and monitoring thresholds for the management of key elements of Outstanding Universal Value of Shark Bay World Heritage Area	8	68

Once again, the priorities for research focus were different among stakeholder groups. While 'Climate change' and 'Ecosystem' related knowledge gaps featured in the top five priorities for all stakeholder groups, there were some clear differences (Table 12). Questions relating to 'Incorporation of cultural heritage and Traditional ecological knowledge' were highly prioritised by 'Government'. Four out of five top priorities for the 'Fishing' stakeholder group were related to 'Fish and fishing'. The 'Shark Bay Community' prioritised questions relating to tourism and fishing pressure. 'Visitors' to Shark Bay prioritised ecosystem/climate change gaps as well as 'What initiatives could be developed to foster and increase environmental stewardship (e.g. ambassadors)?'. The 'Tourism' stakeholder group prioritised 'What is the carrying capacity for tourism in Shark Bay overall and in specific areas of interest (e.g. national parks, Herald Bight, Monkey Mia)?' along with ecosystem/climate change gaps.

Surprisingly, management-related questions such as 'Would aligning marine park and World Heritage boundaries to streamline management positively benefit conservation values?' and 'What configuration of management zones would most effectively protect and conserve marine biodiversity?' were in the top five priorities for 'University' but not 'Management'. For the stakeholder group 'Research', the top five priorities were similar to the overall priorities (Table 10) but included the addition of 'How can the western science community work with Traditional Owners to create more holistic understandings of the Shark Bay environment?'. 'Malgana' prioritised climate change, ecological and megafauna questions.

The number of participants who answered the detailed research questions was low for some stakeholder groups and should be treated with caution. Groups including 'Research', 'Government' and 'University' had larger sample sizes, whereas those representing 'Malgana', 'Community', 'Visitors', 'Fishing' and 'Tourism' were small.

Loggerhead turtle | Credit: Cheryl Cowell

Table 12: A prioritised list of the top five detailed knowledge gaps for each stakeholder group that participated in the online Shark Bay Prioritisation survey. Scores were averaged across participants in each stakeholder group.

Research

1. How would food webs shift in the absence of key seagrass species under climate change scenarios?
2. What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?
3. Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures
4. How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?
5. What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?

Government

1. What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?
2. What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?
3. How can the western science community work with Traditional Owners to create more holistic understandings of the Shark Bay environment?
4. How would food webs shift in the absence of key seagrass species under climate change scenarios?
5. Increased knowledge and understanding of cultural heritage values, both Indigenous and non-Indigenous

Malgana

1. What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?
2. Develop indicators and monitoring thresholds for the management of key elements of Outstanding Universal Value of Shark Bay World Heritage Area
3. What is the genetic structure of dugongs in Shark Bay and what level of genetic connectivity is there for dugongs along the WA coast?
4. What is the probable impact of climate change and increased storms on turtle nesting beaches?
5. What are the most important processes (natural and anthropogenic) influencing loggerhead and green turtle populations?

Fishing

1. What is the survivorship of released fishes?
2. What are the spatial and temporal patterns of species caught by recreational fishers?
3. Are the current management structures in Shark Bay (e.g. compliance) adequately resourced to ensure recreational fishers adhere to recreational fishing regulations?
4. How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?
5. How do environmental factors (particularly those affected by climate change) and other impacts (e.g. fishing pressure) affect the abundance and diversity of fished and non-fished species?

Management

1. What are the climate change associated predictions to changes in freshwater runoff, nutrients and organic matter into Shark Bay?
2. What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?
3. How would food webs shift in the absence of key seagrass species under climate change scenarios?
4. What is the current diversity and distribution of macro-invertebrate and fish species inhabiting different species of persistent seagrass?
5. What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?

Shark Bay community

1. What are the impacts of recreational and commercial (licensed tour operators) access to marine megafauna, particularly in areas of key interest and high pressure?
2. What are the natural and anthropogenic (including climate change) threats to mangroves in Shark Bay?
3. What is the carrying capacity for tourism in Shark Bay overall and in specific areas of interest (e.g. national parks, Herald Bight, Monkey Mia)?
4. What are the spatial and temporal patterns of recreational fishing in the marine park and what is the recreational fish take by species and method of catch?
5. Are the current management structures in Shark Bay (e.g. compliance) adequately resourced to ensure recreational fishers adhere to recreational fishing regulations?

University

1. How does the distribution of algae and seagrasses influence the abundance and species composition of marine fauna?
2. Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures
3. Would aligning marine park and World Heritage boundaries to streamline management positively benefit conservation values?
4. What configuration of management zones would most effectively protect and conserve marine biodiversity?
5. Is large-scale restoration or protection of seagrass meadows feasible?

Visitor

1. How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?
2. How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?
3. What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?
4. What initiatives could be developed to foster and increase environmental stewardship (e.g. ambassadors)?
5. Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures

Tourism

1. What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?
2. How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?
3. What is the carrying capacity for tourism in Shark Bay overall and in specific areas of interest (e.g. national parks, Herald Bight, Monkey Mia)?
4. What are the climate change associated predictions to changes in freshwater runoff, nutrients and organic matter into Shark Bay?
5. What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?

Denham

8.5 Links with Malgana priority values

All of the priorities identified in the Malgana 2019 workshop and Malgana Voices Survey directly link to the top 10 prioritised gaps Table 13. In particular, the health of seagrass is prioritised highly by all stakeholders.

Those detailed knowledge gaps that link with most of the Malgana Priorities included:

- What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?
- How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?
- What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?
- How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?
- How will climate change affect primary productivity and the flow of energy in marine systems?
- What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?
- What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities? e.g. energy transfer, ontogenetic and seasonal movements, biological filtration?

Bottlenose dolphin | Credit: Nick Thake

Table 13: Links between Malgana priorities and the top 10 prioritised knowledge gaps from the online Shark Bay Prioritisation survey.

THEME	KNOWLEDGE GAP	RANK	MALGANA PRIORITIES
1. **Ecosystem processes and connectivity**	How would food webs shift in the absence of key seagrass species under climate change scenarios?	1	Seagrass, Fish, Turtles, Dugongs, Seabirds, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
2. **Climate change**	What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?	2	Seagrass, Water Quality, Fish, Mangroves, Turtles, Dugongs, Corals, Seabirds, Riparian Vegetation, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
3. **Climate change**	How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?	3	Seagrass, Water Quality, Fish, Mangroves, Turtles, Dugongs, Beaches/Dunes, Groundwater, Corals, Seabirds, Riparian Vegetation, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
4. **Management and monitoring**	Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures	4	Indigenous Cultural Practice, Fish, Indigenous knowledge, Groundwater
5. **Climate change**	What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?	4	Seagrass, Fish, Mangroves, Turtles, Dugongs, Corals, Seabirds, Riparian Vegetation, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
6. **Climate change**	How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?	5	Seagrass, Fish, Mangroves, Turtles, Dugongs, Groundwater, Corals, Seabirds, Riparian Vegetation, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
7. **Seagrass communities**	What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?	5	Seagrass, Fish, Turtles, Dugongs, Seabirds, Dolphins and Whales, Sharks and Rays
8. **Ecosystem processes and connectivity**	How will climate change affect primary productivity and the flow of energy in marine systems?	6	Seagrass, Fish, Mangroves, Turtles, Dugongs, Groundwater, Corals, Seabirds, Riparian Vegetation, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
9. **Climate change**	What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?	7	Seagrass, Fish, Mangroves, Turtles, Dugongs, Corals, Seabirds, Riparian vegetation, Dolphins and Whales, Sharks and Rays, Stromatolites, Sea Cucumbers
10. **Management and monitoring**	Develop indicators and monitoring thresholds for the management of key elements of Outstanding Universal Value of Shark Bay World Heritage Area	8	Seagrass, Mangroves, Turtles, Dugongs, Dolphins and Whales, Sharks and Rays, Stromatolites

9. Prospective science to address priorities

Credit: Nick Thake

The prioritisation process outlined in Section 8 has helped to identify Priority 1, Priority 2 and Priority 3 funding goals. The top ten knowledge gaps form Priority 1 funding and are all associated with climate change (Fig. 20), which was the high-level research theme considered most in need of attention by stakeholders. These ten knowledge gaps are all linked and, if answered, tell a story of species change in Shark Bay, the flow on effects to the ecosystem, and the mitigation measures that can be taken to help combat these changes and flow on effects.

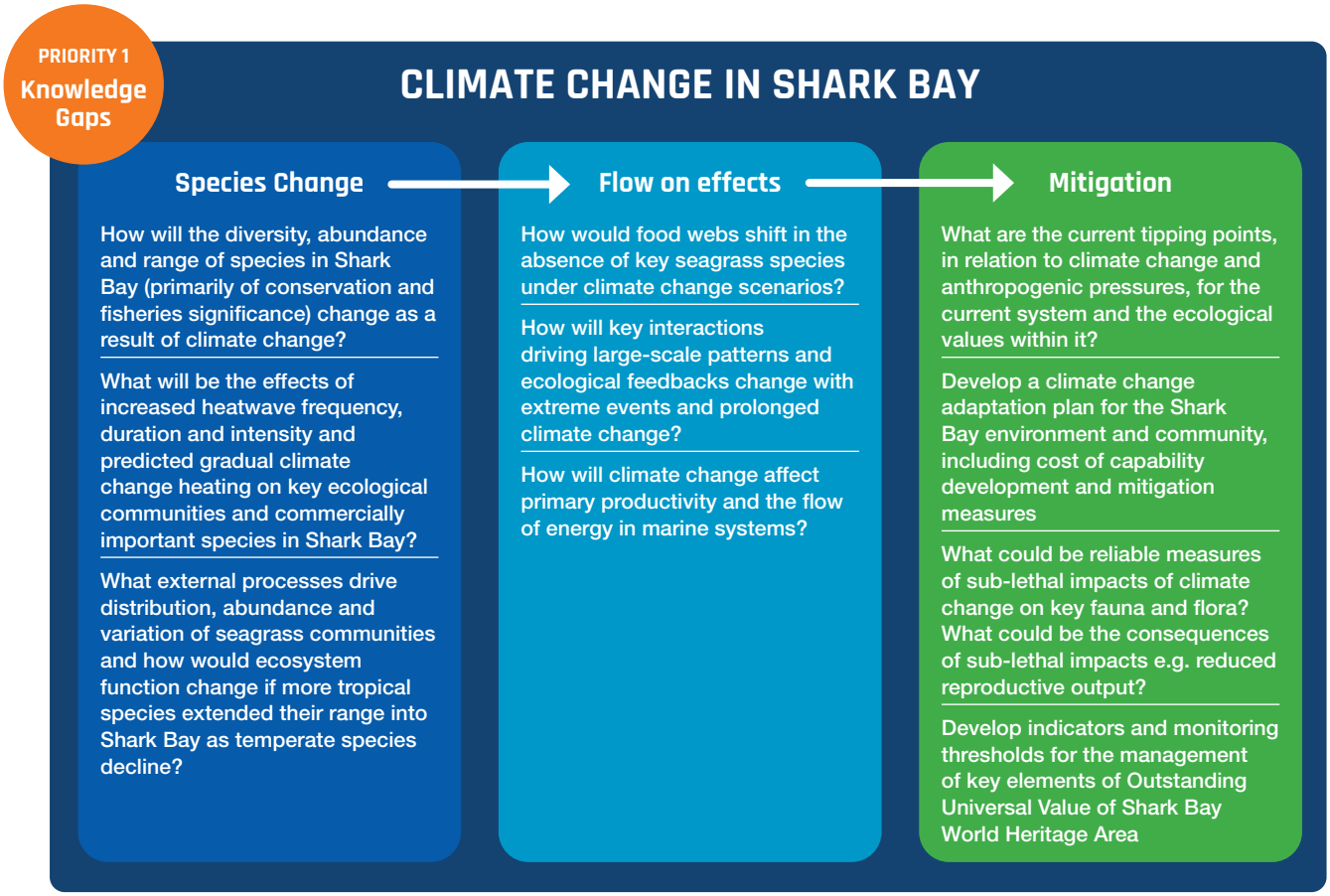

Figure 20: Priority 1 knowledge gaps identified for the WAMSI Shark Bay Science Plan. Priority 1 knowledge gaps have a clear climate change link.

All high-level research themes and knowledge gaps can be grouped into three key focus areas, Ecosystem, Management and People. These focus areas help to highlight funding opportunities that could appeal to different funding bodies. 'Ecosystem' includes themes that directly relate to the health of a functioning ecosystem, 'Management' includes themes that directly improve management strategies, and 'People' includes themes that directly link to social and economic aspects of the marine environment. Given the equal importance of the focus areas, Ecosystem, Management and People, Priority 2 funding focuses on the next five gaps falling under each focus area (excluding the top ten gaps already forming the Priority 1 group) (Fig. 21).

Priority 3 funding incorporates the remaining 66 knowledge gaps (out of a total of 91) spread across the three focus areas, most of which relate to Ecosystem (Fig. 21).

The expectation is that the projects proposed by WAMSI partners for Shark Bay will be guided by the prioritised list of knowledge gaps listed in Section 8 and Figure 20 and Figure 21.

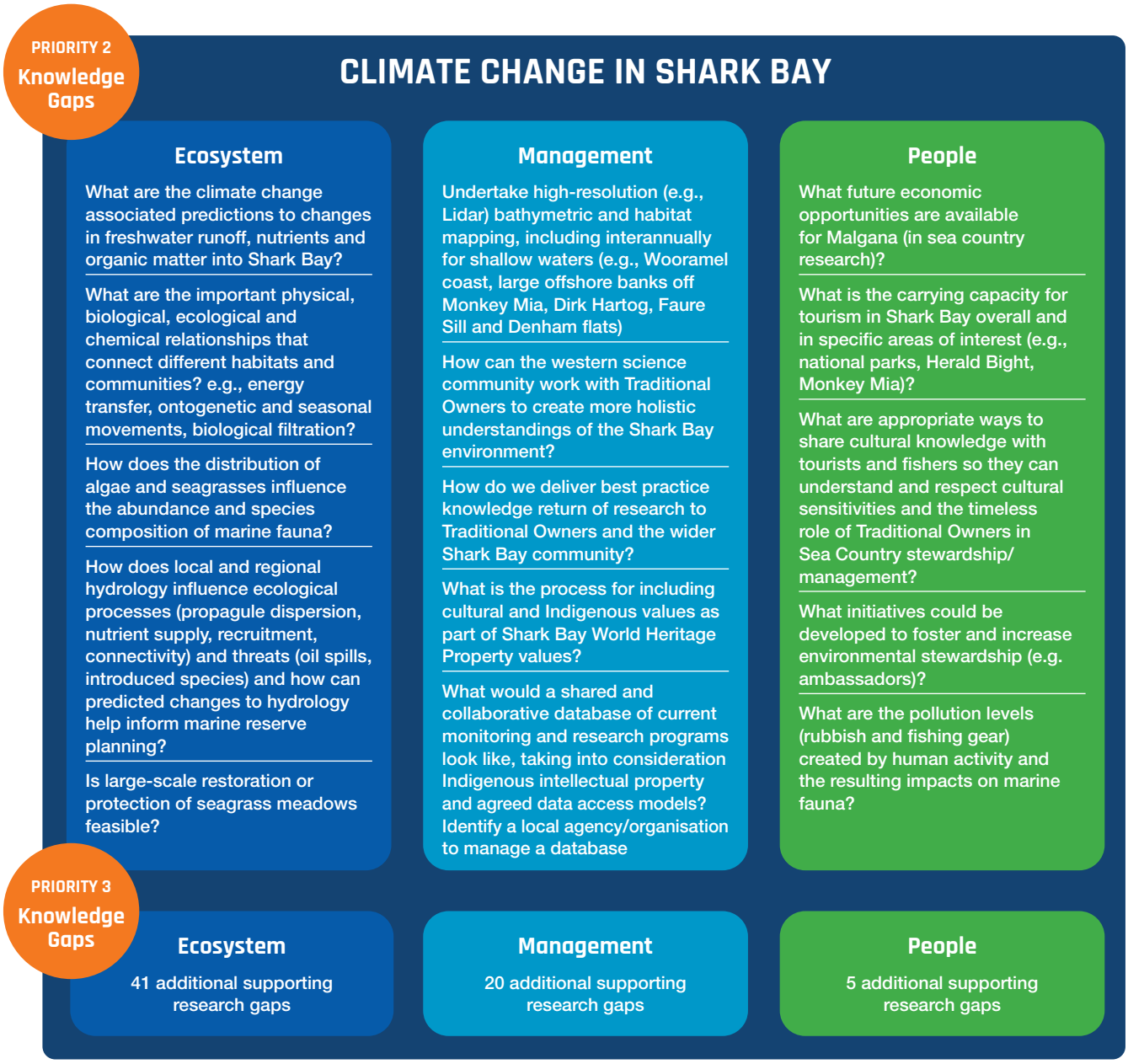

Figure 21: Priority 2 and 3 knowledge gaps identified for the WAMSI Shark Bay Science Plan. Knowledge gaps are divided into three focus areas: Ecosystem, Management and People, but still have an overarching influence of climate change.

The three focus areas, Ecosystem, Management and People, and associated high level research themes are linked and can directly or indirectly influence each other (Fig. 22). For example, all themes will help to inform management in order to maintain the ecological resilience of the marine environment. 'Incorporation of cultural heritage and Traditional ecological knowledge' and 'Environmental conditions' can help to better understand the ecosystem and its health, and 'Fish and fisheries' also plays a key role in ecosystem functioning.

'Climate change' was the highest-ranking research theme for all stakeholders combined, and this Science Plan centres around science that benefits management in order to alleviate the threats from climate change and other anthropogenic activities. As such, the theme of 'Climate change' has been separated out to show the overarching influence of climate change on all three focus areas and associated high level research themes.

In the centre of the Science Plan is maintaining a healthy sea country which is of primary importance to Malgana and very significant to WAMSI and WAMSI partners.

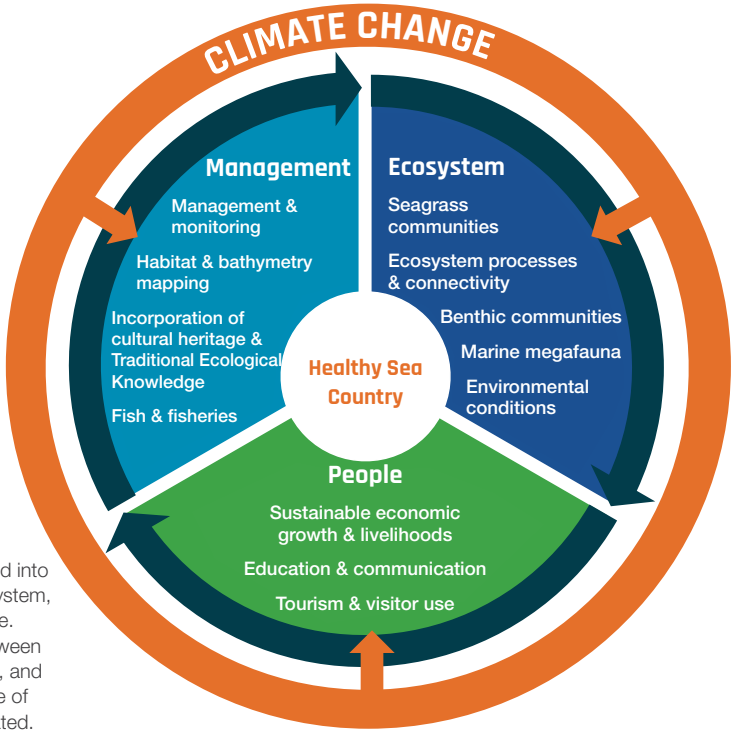

Figure 22: High-level themes and associated knowledge gaps grouped into three focus areas: Ecosystem, Management and People. The connectedness between focus areas and themes, and the overarching influence of climate change is illustrated.

The Science Plan is currently not funded. To address the top 10 gaps identified in this comprehensive Plan we estimate an investment of around $20 million over the next five years. This estimation was arrived at after consulting with researchers with direct experience in Shark Bay and the research themes while also considering the cost of previous WAMSI science programs. These are notional estimates only. This investment would tackle the most important stakeholder driven knowledge gaps and build resilience in Shark Bay. Given the large scale of some of the Priority 1 projects, it is likely that a number of the gaps identified in Priorities 2 and 3 would also be addressed.

Funding of the prioritised knowledge gaps outlined above will address the serious pressures and challenges threatening Shark Bay. In turn, it will enable leveraging of further funding through other programs and entities. WAMSI will address the implementation of the Plan by drawing on the expertise of the WAMSI Board, WAMSI partners and other interested stakeholders to develop the next steps. This facilitation role will link those with shared interests and seek funding from a broad range of organisations and entities. The organisation of priority knowledge gaps into more specific research nodes could be considered through the development of a Science Investment Plan.

A number of current or recently completed projects in Shark Bay are presented in Appendix 13 along with summaries obtained directly from researchers, project websites or funding websites. These projects were not picked up in the preceding stakeholder workshops and interviews because of the timing and are included in the Science Plan to avoid repetition of research effort and encourage collaboration. Some of these projects may help to address the prioritised knowledge gaps presented in this Science Plan, and knowledge exchange between the Science Plan and the projects below will be of benefit for furthering a greater understanding of the impacts of ecosystem change in Shark Bay. While Appendix 13 may not contain a comprehensive list of all current and recently completed projects, particularly international projects, it does represent the level of interest and importance of research at Shark Bay.

Shark Bay (Gathaagudu) is at a critical juncture. It is an iconic area and has been internationally recognised for its abundance of exceptional natural features. Scientists throughout WA and the world are concerned about the demise of this special place which has been experiencing rapid negative environmental changes since an extreme marine heatwave in 2011. The frequency and duration of marine heat waves is increasing, and this has subsequent impacts to the base of the food web, ecosystem health and, in turn, the economy, Indigenous culture and livelihoods.

Stakeholders, including Traditional Owners, government, industry, community, managers and researchers, approached WAMSI to coordinate the development of this Science Plan. The Plan has been completed using a innovative, stakeholder-driven approach that sets a benchmark for collaborative science as well as a strategic way forward. The implementation of the WAMSI Science Plan will help to create a more sustainable future for this world-class destination.

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Mangroves | Credit: Rachel Austin

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11. Appendices

Fishers | Credit: Nick Thake

11.1 Appendix 1 WAMSI/UWA workshop attendees

WAMSI/UWA WORKSHOP – ADAPTING TO ECOSYSTEM CHANGE IN THE SHARK BAY WORLD HERITAGE SITE						
Name	**Organisation**	**State gov.**	**WHP**	**Fishing/ aquaculture**	**Research**	**NGO**
Peter Jecks	Abacus Fisheries			Y		
Erica Suosaari	Bush Heritage					Y
Dan Gorman	CSIRO				Y	
Ming Feng	CSIRO Marine and Atmospheric Research				Y	
Ben Saunders	Curtin University				Y	
Paul Erftemeijer	Damco Consulting				Y	
Kevin Bancroft	DBCA Marine Science	Y				
Simone Strydom	DBCA Marine Science	Y				
Kelly Waples	DBCA Marine Science	Y				
Alan Kendrick	DBCA Marine Science	Y				
Shaun Wilson	DBCA Marine Science	Y				
Kathy Murray	DBCA Research Remote Sensing	Y				
Therese Morris	Denham/ex-SBWHAC		Y		Y	
Lynda Bellchambers	DPIRD	Y				
Gary Jackson	DPIRD – Fisheries	Y		Y		
Patrick Cavalli	DPIRD – Fisheries	Y				
Nick Caputi	DPIRD – Fisheries	Y				
Mervi Kangas	DPIRD – Fisheries	Y				
Arani Chandrapavan	DPIRD – Fisheries	Y		Y		
David Fairclough	DPIRD – Fisheries	Y		Y		
Bec Oliver	DPIRD – Fisheries	Y		Y		
Jim Penn	DPIRD – Fisheries	Y		Y		
Shane Walters	DPIRD – Fisheries	Y				
Kathryn McMahon	ECU				Y	
Oscar Serrano	ECU				Y	
Paul Lavery	ECU				Y	
Hamish Ch'ng	Far West Scallops			Y		
Ross Hamilton	Hamilton Strategic				Y	
Geoff Diver	Mareterram- Scallop/seafood industry			Y		
James Stoddart	MSCIENCE				Y	
Marnie Campbell	Murdoch University				Y	
Chad Hewitt	Murdoch University				Y	
Marion Cambridge	Plant Biology – UWA Oceans Institute				Y	
John Statton	Plant Biology – UWA Oceans Institute				Y	
Kieran Massie	Rangelands NRM WA					Y

WAMSI/UWA WORKSHOP – ADAPTING TO ECOSYSTEM CHANGE IN THE SHARK BAY WORLD HERITAGE SITE						
Name	**Organisation**	**State gov.**	**WHP**	**Fishing/ aquaculture**	**Research**	**NGO**
Matt Gillett	RecFishWest			Y		
Ylva Olsen	Research Associate, Oceans Institute				Y	
Amanda Oehlert	Rosenstiel School of Marine and Atmospheric Science, Miami				Y	
Diana Walker	SBWHAC		Y		Y	
Neil Loneragan	Murdoch University, School of Biological Sciences and Biotechnology				Y	
Charitha Pattiaratchi	School of Environmental Systems Engineering, UWA				Y	
Bob Hoult	Shark Bay Beach Seine Fishery	Y		Y		
Janet Mann	Shark Bay Dolphin Research Project				Y	
Felicity Horn	Shark Bay Prawn Trawler Association			Y		
Yasunori Sasakura	Shimoda Marine Research Center, University of Tsukuba				Y	
Peter Green	SBWHAC		Y			
Brendan Burns	UNSW				Y	
Simon Allen	UWA				Y	
Yasha Hetzel	UWA Engineering and Mathematical Science/ Oceans Institute				Y	
Belinda Martin	UWA Oceans Institute				Y	
Timothy Langlois	UWA Oceans Institute				Y	
Anita Giraldo	UWA Oceans Institute/School of Biological Sciences				Y	
Kendra Thomas Travaille	UWA Oceans Institute/School of Biological Sciences				Y	
Ana Sequeira	UWA Oceans Institute/School of Biological Sciences				Y	
Elizabeth Sinclair	UWA Oceans Institute/School of Biological Sciences					Y
Renae Hovey	UWA Oceans Institute/School of Biological Sciences				Y	
Gary Kendrick	UWA Oceans Institute/School of Biological Sciences				Y	
Kate Dawson	UWA Oceans Institute/School of Biological Sciences				Y	
Matthew Fraser	UWA Oceans Institute/School of Biological Sciences				Y	
Michael Burton	UWA Resource economics				Y	
Abbie Rogers	UWA School of Agriculture and Environment					
Stephanie King	UWA School of Biological Sciences				Y	
Jane Prince	UWA School of Biological Sciences				Y	
Brenna Waite	UWA Student				Y	
Brendan Gerrard	UWA Student				Y	
Matt Pember	WAFIC			Y		
Caroline Ochieng-Erftemeijer	WAMSI				Y	
Luke Twomey	WAMSI CEO				Y	
Jessica Davis						

11.2 Appendix 2
Climate Vulnerability Index workshop attendees 2018

CLIMATE VULNERABILITY INDEX WORKSHOP 2018- IMPACT OF CLIMATE CHANGE ON OUTSTANDING VALUES								
Name	**Organisation**	**State gov.**	**Commonwealth gov.**	**World Heritage Property**	**Malgana**	**Fishing/ aquaculture**	**Research**	**NGO**
Elisabeth McLellan	Bush Heritage, SBWHAC			Y				Y
Kim Branch	DBCA – Shark Bay Nature Cons	Y						
Steve Nicholson	DBCA District Manager	Y						
Peter Barnes	DBCA Marine	Y						
Alan Kendrick	DBCA Marine Science	Y						
Shaun Wilson	DBCA Marine Science	Y						
Ricky Van Dongen	DBCA Remote Sensing	Y						
Arani Chandrapavan	DPIRD – Fisheries	Y				Y		
Patrick Cavalli	DPIRD – Fisheries	Y						
Gary Jackson (invited)	DPIRD – Fisheries	Y				Y		
Therese Morris	Ex-SBWHAC			Y				
Brendon Bellottie (invited)	Fisheries/Malgana/ SBWHAC			Y	Y	Y		
Scott Heron	James Cook University						Y	
Simon Woodley	NCWHAC Chair			Y				
Mandy Hopkins	NESP ESCC		Y					
Karen Pearce	NESP ESCC		Y					
Vanessa Hernaman	NESP ESCC		Y					
Phil Scott	SBWHAC			Y				
Diana Walker	SBWHAC			Y			Y	
Cheryl Cowell	SBWHAC			Y				
Simon Allen	UWA – Researchers						Y	
Matt Fraser (invited)	UWA Oceans Institute						Y	
Luke Twomey	WAMSI						Y	

11.3 Appendix 3
Climate Vulnerability Index workshop attendees 2019

CLIMATE VULNERABILITY INDEX WORKSHOP 2019 – ECONOMIC, SOCIAL AND CULTURAL DEPENDENCIES UPON THE SBWHA AND IMPACTS OF CLIMATE CHANGE										
Name	**Organisation**	**State gov.**	**Commonwealth gov.**	**Local gov.**	**WHP**	**Malgana**	**Fishing/ aquaculture**	**Tourism**	**Research**	**NGO**
Elisabeth McLellan	Bush Heritage, SBWHAC				Y					Y
Greg Keighery (invited)	DBCA Botanist	Y								
Steve Nicholson (invited)	DBCA District Manager	Y								
Luke Skinner	DBCA Marine Park Coordinator	Y								
Scott Whiting (invited)	DBCA Marine Science	Y								
Alan Kendrick (invited)	DBCA Marine Science	Y								
Kathy Murray (invited)	DBCA Research Remote Sensing	Y							Y	
Saul Cowen (invited)	DBCA Research Scientists	Y							Y	
Colleen Sims (invited)	DBCA Research Scientists	Y							Y	
Lenore Morris	Dept Environment and Energy		Y							
Arani Chandrapavan	DPIRD - Fisheries	Y					Y			
Patrick Cavalli	DPIRD - Fisheries	Y								
Gary Jackson	DPIRD - Fisheries	Y					Y			
Sue Graham-Taylor	Ex- WA Museum	Y								
Brendon Bellottie (invited)	Fisheries/Malgana/ SBWHAC				Y	Y	Y			
Luke Donegan	Fremantle Prison	Y								
Will Alston	Harvest Road Group						Y			
Jon Day	James Cook University								Y	
Scott Heron	James Cook University								Y	
Geoff Diver	Mareterram-seafood industry						Y			
Lynnath Beckley (invited)	Murdoch University								Y	
Joseph Christensen (invited)	Murdoch University								Y	
Andrew Rowland (invited)	RecFishWest						Y			
Felicity Horn (invited)	SB Prawn Trawlers Assn						Y			
Phil Scott	SBWHAC				Y					
Diana Walker	SBWHAC				Y				Y	

CLIMATE VULNERABILITY INDEX WORKSHOP 2019 – ECONOMIC, SOCIAL AND CULTURAL DEPENDENCIES UPON THE SBWHA AND IMPACTS OF CLIMATE CHANGE										
Name	**Organisation**	**State gov.**	**Commonwealth gov.**	**Local gov.**	**WHP**	**Malgana**	**Fishing/ aquaculture**	**Tourism**	**Research**	**NGO**
Cheryl Cowell	SBWHAC				Y					
Geoff Wardle (invited)	SBWHAC				Y					
Libby Mattiske (invited)	SBWHAC				Y					
Laura Gray (invited)	SBWHAC				Y					
Grant Donald (invited)	SBWHAC				Y					
Carrissa Bellottie (invited)	SBWHAC/ Malgana				Y	Y				
Juliane Bush	SBWHAC/GDC	Y			Y					
Mira Vankova (invited)	Shark Bay Tourism Association							Y		
Paul Anderson	Shire of Shark Bay			Y						
Linda Butterly (invited)	Shire of Shark Bay			Y						
David Pannell (invited)	UWA								Y	
Ben White (invited)	UWA								Y	
Andrea Gaynor (invited)	UWA								Y	
Matt Fraser	UWA Oceans Institute								Y	
Anita Geraldo	UWA Oceans Institute								Y	
Belinda Martin	UWA Oceans Institute								Y	
Elizabeth Sinclair	UWA Oceans Institute								Y	
Jenny Shaw	WAMSI								Y	
Alicia Sutton	WAMSI								Y	
Luke Twomey (invited)	WAMSI								Y	

11.4 Appendix 4
Shark Bay Priorities: participant information form

Jenny Shaw
WA Marine Science Institution, M095
The University of Western Australia
35 Stirling Highway, Crawley WA 6009
Tel: (08) 6488 4572
Email: jenny.shaw@wamsi.org.au
www.wamsi.org.au

Participant Information Form

Project title: Shark Bay Priorities
Name of Researchers: Dr Jenny Shaw, Dr Chris Cvitanovic, Dr Alicia Sutton

You are invited to participate in a project to develop a Science Plan for Shark Bay. You have been asked to take part in this project because of your interest and knowledge of Shark Bay.

The project: Shark Bay Priorities, is to understand stakeholder needs and values, as well as identify issues and opportunities for Shark Bay. This information will be compared with research work previously undertaken in Shark Bay and used to identify gaps where further research is required. A prioritisation of the gaps will inform the development of a Science Plan for Shark Bay. The process has been used extensively by Western Australian Marine Science Institution (WAMSI) to develop its Science Plans.

What does participation involve?
Your participation could include being part of a workshop, completing a small survey or being interviewed. Completion of the interview would take approximately 30 minutes. If you would like any further involvement in the project, your input would be appreciated.

Voluntary participation and withdrawal from the study
Your participation is voluntary, and you may withdraw from the study at any time without giving an explanation. There will be no consequences associated with your withdrawal.

Your privacy
Your participation in this study and any information you provide will be treated in a confidential manner.

Possible benefits
The result of this project will be the development of a WAMSI Science Plan. The purpose of the Plan is to develop a case for significant research in Shark Bay to address some of the priority issues facing the Bay.

Possible risks
There are no foreseeable risks associated with the research.

Contacts
If you would like to participate or discuss any aspect of this study please feel free to contact Jenny Shaw by phone at work 6488 4572, or mobile 0401 121 975.

Sincerely
Jenny Shaw

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics office at UWA on (08) 6488 4703 or by emailing to humanethics@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

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M +61 000 000 000
E humanethics@uwa.edu.au
CRICOS Provider Code 00126G

11.5 Appendix 5
Shark Bay Priorities: participant consent form

Jenny Shaw
WA Marine Science Institution, M095
The University of Western Australia
35 Stirling Highway, Crawley WA 6009
Tel: (08) 6488 4572
Email: jenny.shaw@wamsi.org.au
www.wamsi.org.au

Participant Consent Form

Shark Bay Priorities

I, _____ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this research project, realising that I may withdraw at any time without reason and without prejudice.

I understand that all identifiable information that I provide is treated as confidential and will not be released by the investigator in any form that may identify me unless I have consented to this. The only exception to this principle of confidentiality is if this information is required by law to be released.

I agree to have my conversation audiotaped. Yes ☐ No ☐

I agree to be photographed and / or videotaped. Yes ☐ No ☐

_____ _____
Participant signature Date

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.

In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to humanethics@uwa.edu.au

All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

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11.6 Appendix 6
Shark Bay Priorities: community survey questions May 2019

THE UNIVERSITY OF WESTERN AUSTRALIA

WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION

Demographic Information:

Name _____

(The name is only a check for the researcher. Your data is anonymous and only linked to your sector)

1. **What is your age?** (Please circle)
   ≤20 years 21-30 years 31-40 years 41-50 years 51-60 years ≥ 61 years

2. **Where do you live?** Australia – postcode _____
   International – country _____

3. **What is your interest in the area? (**Please circle - multiple answers OK)
   Example: Shark Bay resident / visitor/ researcher/ industry (tourism, fishing, aquaculture, mining, pastoralist, transport) / Government employee /Indigenous / other _____

4. **What is your main interest?** _____

5. **For how many years have you lived in / or visited Shark Bay**? _____

5a. **What year did you arrive or first visit Shark Bay?** _____

Values:

6. **What do you value the most from living / working in Shark Bay?**
   (Please circle - multiple answers OK) *Example: wilderness / pristine environment /landscape and vistas / fishing / small community / isolation / work opportunities / culture / family associations / recreational opportunities / camping / learning opportunities / WHP values / Other*

_____

7. **What is your most important value?** _____

Climate and environmental changes:

8. **Have you noticed any changes to the Shark Bay environment in the last 5-10 years?**
   (Please circle) Yes No

   What are they? _____

_____

9. **What do you think are the most important changes?** Give 1 or 2 examples

_____

10. **Why do you think these changes have occurred?**_____

_____

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CRICOS Provider Code 00126G

Issues and opportunities:

11. Have you any major concerns for Shark Bay? Can include: environment, social, economic, governance

_____

12. Do you think any management intervention could alleviate these issues?

_____

13. What do you see as the future opportunities for Shark Bay?

_____

Research:

14. Considering the issues and opportunities you have just identified; how important do you think scientific research will be in supporting the future of Shark Bay?

_____

15. What previous work/ research are you aware of that has been done in Shark Bay?

_____

16. How, if at all, do you currently access/use scientific knowledge from the region?

_____

17. What do you think are the major research needs that could help improve the management of Shark Bay into the future?

_____

Project involvement:

18. Would you like to be involved in this project and in what way?

For example: limited involvement through to involvement in further workshops and review of the Science Plan.

_____

19. Would you like to be a Shark Bay Stakeholder for the purposes of this project and receive regular updates from WAMSI? (Please circle) Yes No

Provide Email address if relevant_____

20. How would you like to receive further information about the project – if any?

For example: Email, Newsletters, WAMSI bulletin, workshops, via the Shark Bay Inscription Post, Private Facebook Account, Twitter …

_____

Thank you very much for participating in this interview

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11.7 Appendix 7 Community interview participants

SHARK BAY COMMUNITY INTERVIEWS							
Name	**Organisation**	**Denham local**	**Visitor**	**Government**	**Industry**	**Researcher**	**Malgana**
Justin Welsh	Aquaculture		Y		Fishing		
Robert Michael	Aquaculture		Y		Fishing		
Ted Godden	Carnarvon						
Wayne Reece	Carnarvon						
Bruce Tilka	Carnarvon: Fisher		Y		Fishing		
Peter Jecks	Carnarvon: Fisher		Y		Fishing		
Dean Clarke	Carnarvon: Fisheries DPIRD		Y	State			
Darren Baird	Carnarvon: Tackle shop		Y		Fishing		
Janice Baird	Carnarvon: Tackle shop		Y		Fishing		
Greg Ridgley	Charter Boat Operator	Y		Local	Tourism		
Jamie Burton	CRC	Y		Local			
Amy Trezona	DBCA	Y		State			
Gavan Mullan	DBCA	Y		State			
Stephen Nicholson	DBCA	Y		State			
Luke Skinner	DBCA Marine Park	Y		State			
Khayla Wordsworth	DBCA Monkey Mia	Y		State			
Mathew Beulley	DBCA Monkey Mia	Y		State			
Colleen Sims	DBCA, Ex resident		Y	State			
Kieran Wardle	Dirk Hartog Island	Y			Tourism		
Tory Wardle	Dirk Hartog Island	Y			Tourism		
Neroli Needham	Economist	Y					
Gary Desmond	Ex DBCA	Y		State			
Howard Cock	Ex fisher	Y					Y
Greg Finlay	ex Fisheries DPIRD, Ex resident		Y				
Lesley Colliver	Ex resident		Y				
Bianca McNeair	Ex resident, NACC Geraldton		Y	State			Y (MAC)
Sean McNeair	Ex YMAC Ranger	Y			Fishing		Y
John Standring	Fish Processor and Sales	Y			Fishing		
Bobby Hoult	Fisher	Y			Fishing		Y
Denis Hoult	Fisher	Y			Fishing		Y
Travis Feist	Fisheries DPIRD	Y		State			
Brendon Bellottie	Fisheries DPIRD, WHP, Ex resident		Y	State			Y
Janet Mann	Georgetown University, USA		Y			Y	
Karen Gidley	Local Business	Y					
Tamala Sellenger	Local Business	Y			Tourism		

SHARK BAY COMMUNITY INTERVIEWS							
Name	**Organisation**	**Denham local**	**Visitor**	**Government**	**Industry**	**Researcher**	**Malgana**
Amanda	MacAttack	Y			Fishing		
Garth	MacAttack	Y			Fishing		
Joseph Christiansen	Murdoch University		Y			Y	
John Craig	Ocean Park Aquarium	Y			Tourism		
Dean Massie	RAC		Y		Tourism		
Martin Crenside	RAC	Y			Tourism		
Tony Pickworth	RAC		Y		Tourism		
Doug Rowe	Shark Bay Apartments	Y			Tourism		
Joanne Rowe	Shark Bay Apartments	Y			Tourism		
Paul Anderson	Shire CEO	Y		Local			
Cheryl Cowell	Shire President, DBCA, former WHP EO	Y		Local, State			
Darren Capewell	Tour operator	Y			Tourism		Nanda
Mira Vankova	Tour operator	Y			Tourism		
Emma Craig	WH Discovery & Visitor Centre	Y			Tourism		
Julian Bush	WHP		Y		Tourism		
Tom Day	WHP		Y		Horticulture		
Lenore Morris	WHP DEE		Y				
Therese Morris	WHP EO, Consultant	Y		State		Y	
Elizabeth Mattiske	WHP member, Consultant		Y			Y	
Geoff Wardle	WHP member, Ex resident		Y		Pastoral		
Kelly Mullen	WHP, DEE Canberra		Y	Commonwealth			

11.8 Appendix 8 WAMSI/Malgana workshop attendees 2019

WAMSI/MALGANA WORKSHOP 2019 – SHARK BAY						
Name	**Organisation**	**State gov.**	**WHP**	**Malgana**	**Fishing/ aquaculture**	**Research**
Luke Skinner	DBCA Marine Park Coordinator	Y				
Kelly Waples	DBCA Marine Science	Y				
Cody Oakley	DBCA Ranger	Y		Y		
Klaas Liezenga	DBCA Ranger	Y		Y		
Kieran Cross	DBCA Ranger	Y		Y		
Alistair Harry	DPIRD- Fisheries	Y			Y	
Gloria Boddington	Malgana Elder			Y		
Tom Poland	Malgana Elder			Y		
Kathy Oakley	Malgana Elder			Y		
Ada Fosser	Malgana Elder			Y		
Johnny Oxenham	Malgana Land and Sea Country Reference Group			Y		
Richard Hoult	Malgana Land and Sea Country Reference Group			Y		
Bianca McNeair	Malgana Land and Sea Country Reference Group			Y		
Maxine Hansen	Malgana Land and Sea Country Reference Group			Y		
Nick Pedrocchi	Malgana Land and Sea Country Reference Group and Ranger			Y		
Marika Oakley	Malgana Land and Sea Country Reference Group and Ranger			Y		
Sean McNeair	Malgana Land and Sea Management Coordinator			Y		
Richard Cross	Malgana Land and Sea Management Ranger			Y		
Patricia Oakley	Malgana Land and Sea Management Ranger			Y		
Nyikita McNeair	Malgana Land and Sea Management Ranger			Y		
Alex Dodd	Malgana Land and Sea Management Ranger			Y		
Gina Lincoln	Mosaic Environmental					Y
Benny Bellottie	SBWHAC (proxy)		Y	Y		
Bevan Bessen	Tuna Blue facilitation					Y
Ella Bessen	Tuna Blue facilitation					Y
Matt Fraser	UWA Oceans Institute/School of Biological Sciences					Y
Jenny Shaw	WAMSI					Y
Aleta Johnson	WAMSI					Y

11.9 Appendix 9
Example screen grabs of the animation video of online Shark Bay Prioritisation survey for the Malgana community

11.10 Appendix 10 Questions included in the Malgana Voices Survey

Submission Date
Your name (optional)
Your email address (optional – if you want a copy of your survey sent to you)
Which describes you best?
Your age (to make sure old people and young people are heard)?
Your gender (to make sure men's and women's Malgana voices are heard)?

Indicate your TOP FIVE sea country priorities for healthy Gathaagudu (choose up to five)?

Other important values in your top 5:

Indigenous Knowledge

- How important is Indigenous Knowledge to the health of Gathaagudu Saltwater Country overall?
- How would you like to see the science community support Malgana to look after Indigenous knowledge about Gathaagudu?
- What is the MOST IMPORTANT thing the science community could do to help?
- Do you have any other ideas about this you'd like to share?

Indigenous Culture and Practice

- How important is Indigenous culture and practice to the health of Gathaagudu Saltwater Country overall?
- Is Indigenous cultural practice on Gathaagudu Sea Country being prevented or threatened in some way?
- How can science projects help Malgana to maintain the health of cultural practices on Gathaagudu?

Seagrass

- What makes seagrass important to you?
- How important is healthy seagrass to the health of Gathaagudu Saltwater Country overall?
- How healthy is Gathaagudu seagrass now?
- Is Gathaagudu seagrass under threat?
- What are the threats to seagrass in Gathaagudu? (select all that apply)
- What is the MAIN threat to seagrass in Gathaagudu? (select one)
- Do we know enough about seagrass in Gathaagudu to keep it healthy?
- Should there be research done on seagrass in Gathaagudu?
- What question/s would the research about seagrass need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about seagrass in Gathaagudu?

Mangroves

- What makes mangroves important to you?
- How important are healthy mangroves to the health of Gathaagudu Saltwater Country overall?
- How healthy are Gathaagudu mangroves now?
- Are Gathaagudu mangroves under threat?
- What is are the threats to mangroves in Gathaagudu? (select all that apply)
- What is the MAIN threat to mangroves in Gathaagudu? (select one)
- Do we know enough about mangroves in Gathaagudu to keep them healthy?
- Should there be research done on mangroves in Gathaagudu?
- What question/s would the research about mangroves need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about mangrove in Gathaagudu?

Coral

- What makes coral important to you?
- How important is healthy coral to the health of Gathaagudu Saltwater Country overall?
- How healthy is Gathaagudu coral now?
- Is Gathaagudu coral under threat?
- What are the threats to coral in Gathaagudu? (select all that apply)
- What is the MAIN threat to coral in Gathaagudu? (select one)
- Do we know enough about coral in Gathaagudu to keep it healthy?
- Should there be research done on coral in Gathaagudu?
- What question/s would the research about coral need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about coral in Gathaagudu?

Riparian vegetation

- What makes riparian vegetation important to you?
- How important is healthy riparian vegetation to the health of Gathaagudu Saltwater Country overall?
- How healthy is Gathaagudu riparian vegetation now?
- Is riparian vegetation in Gathaagudu under threat?
- What are the threats to riparian vegetation in Gathaagudu? (select all that apply)
- What is the MAIN threat to riparian vegetation in Gathaagudu? (select one)

- Do we know enough about riparian vegetation in Gathaagudu to keep them healthy?
- Should there be research done on riparian vegetation in Gathaagudu?
- What question/s would the research need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about riparian vegetation in Gathaagudu?

Beaches and dunes

- What makes beaches and dunes important to you?
- How important are healthy beaches and dunes to the health of Gathaagudu Saltwater Country overall?
- How healthy are Gathaagudu beaches and dunes now?
- Are beaches and dunes in Gathaagudu under threat?
- What are the threats to beaches and dunes in Gathaagudu? (select all that apply)
- What is the MAIN threat to beaches and dunes in Gathaagudu? (select one)
- Do we know enough about beaches and dunes in Gathaagudu to keep them healthy?
- Should there be research done on beaches and dunes in Gathaagudu?
- What question/s would the research need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about beaches and dunes in Gathaagudu?

Wirriya (sea water)

- What makes healthy water quality important to you?
- How important is healthy water quality to the health of Gathaagudu Saltwater Country overall?
- How healthy is the water quality in Gathaagudu now?
- Is water quality in Gathaagudu under threat?
- What are the threats to water quality in Gathaagudu? (select all that apply)
- What is the MAIN threat to water quality in Gathaagudu? (select just one)
- Do we know enough about water quality in Gathaagudu to keep it healthy? (within our ability)
- Should there be research done on water quality in Gathaagudu?
- What question/s would the research need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about water quality in Gathaagudu?

Healthy groundwater

- What makes healthy groundwater (pressure, amount, flow etc) important to you?
- How important is healthy groundwater to the health of Gathaagudu Saltwater Country overall?
- How healthy is groundwater (pressure, amount, quality, flow etc) in Gathaagudu now?
- Is groundwater health (pressure, amount, quality, flow etc) in Gathaagudu under threat?
- What are the threats to groundwater health (pressure, amount, quality, flow etc) in Gathaagudu? (select all that apply)
- What is the MAIN threat to groundwater health (pressure, amount, quality, flow etc) in Gathaagudu? (select just one)
- Do we know enough about groundwater (pressure, amount, quality, flow etc) in Gathaagudu to keep it healthy?
- Should there be research done on groundwater (pressure, amount, quality, flow etc) in Gathaagudu?
- What question/s would the research need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about groundwater (pressure, amount, quality, flow etc) health in Gathaagudu?

Buyungurra (Turtles)

- What types of turtle in Gathaagudu are important to you? (select all that apply)
- What type of turtle in Gathaagudu is MOST important to you? (select one)
- What makes these turtles important to you?
- How important are these turtles to the health of Gathaagudu Saltwater Country overall?
- How healthy are these turtles now?
- Are these Gathaagudu turtles under threat?
- What threats do these turtles face? (select all that apply)
- What is the MAIN threat to these turtles? (select just one)
- Do we know enough about these turtles in Gathaagudu to keep it healthy?
- Should there be research done on these turtles in Gathaagudu?
- What question/s would the research about these turtles need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about ANY turtles in Gathaagudu?

Wuthuga (Dugong)

- What makes dugong important to you?
- How important are healthy dugong to the health of Gathaagudu Saltwater Country overall?
- How healthy are Gathaagudu dugong now?
- Are Gathaagudu dugong under threat?
- What threats do dugong face? (select all that apply)
- What is the MAIN threat to dugong? (select one)
- Do we know enough about dugong in Gathaagudu to keep it healthy?
- Should there be research done on dugong in Gathaagudu?
- What question/s would the research about dugong need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about dugong in Gathaagudu?

Fish – all types

- What types of Gathaagudu fish are important to you? (select all of the important ones)
- What type of fish in Gathaagudu is MOST important to you? (select one)
- What makes these fish important to you?
- How important are healthy fish to the health of Gathaagudu Saltwater Country overall?
- How healthy are these Gathaagudu fish now?
- Are these Gathaagudu fish under threat?
- What threats do these fish face? (select all that apply)
- What is the MAIN threat to these fish? (select just one)
- Do we know enough about these fish in Gathaagudu to keep them healthy?
- Should there be research done on these fish in Gathaagudu?
- What question/s would the research about these fish need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about ANY fish in Gathaagudu?

Seabirds

- What types of Gathaagudu seabirds are important to you? (select all of the important ones)
- What type of seabirds in Gathaagudu is MOST important to you? (select one)
- What makes these seabirds important to you?
- How important are healthy seabirds to the health of Gathaagudu Saltwater Country overall?
- How healthy are these Gathaagudu seabirds now?
- Are these Gathaagudu seabirds under threat?
- What threats do these seabirds face? (select all that apply)
- What is the MAIN threat to these seabirds? (select just one)
- Do we know enough about these seabirds in Gathaagudu to keep them healthy?
- Should there be research done on these seabirds in Gathaagudu?
- What question/s would the research about these seabirds need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about ANY seabirds in Gathaagudu?

Thaaka (Sharks) and/or rays

- What types of Gathaagudu shark or ray are important to you? (select all of the important ones)
- What type of shark or ray in Gathaagudu is MOST important to you? (select one)
- What makes these sharks/rays important to you?
- How important are healthy sharks/rays to the health of Gathaagudu Saltwater Country overall?
- How healthy are these Gathaagudu sharks/rays now?
- Are these Gathaagudu sharks/rays under threat?
- What threats do these sharks/rays face? (select all that apply)
- What is the MAIN threat to these sharks/rays? (select just one)
- Do we know enough about these sharks/rays in Gathaagudu to keep them healthy?
- Should there be research done on these sharks/rays in Gathaagudu?
- What question/s would the research about these sharks/rays need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about ANY sharks or rays in Gathaagudu?

Irrabuga/yinabuga (dolphin) and whales

- What types of Gathaagudu dolphin or whales are important to you? (select all of the important ones)
- What type of dolphin or whale in Gathaagudu is MOST important to you? (select one)
- What makes these whales/dolphins important to you?
- How important are healthy whales/dolphins to the health of Gathaagudu Saltwater Country overall?
- How healthy are these Gathaagudu whales/dolphins now?
- Are these Gathaagudu whales/dolphins under threat?
- What threats do these whales/dolphins face? (select all that apply)
- What is the MAIN threat to these whales/dolphins? (select just one)

- Do we know enough about these whales/dolphins in Gathaagudu to keep them healthy?
- Should there be research done on these whales/dolphins in Gathaagudu?
- What question/s would the research about these whales/dolphins need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about ANY whales/dolphins in Gathaagudu?

Crustaceans and/or molluscs

- What types of Gathaagudu shells, crustaceans and molluscs are important to you? (select all of the important ones)
- What type of shells, crustaceans or mollusc in Gathaagudu is MOST important to you? (select one)
- What makes these important to you?
- How important are these to the health of Gathaagudu Saltwater Country overall?
- How healthy are they now?
- Are these Gathaagudu shells. crustacean or mollusc under threat?
- What threats do they face? (select all that apply)
- What is the MAIN threat they face? (select just one)
- Do we know enough about these shells, crustacean molluscs in Gathaagudu to keep them healthy?
- Should there be research done on them in Gathaagudu?
- What question/s would the research need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about ANY shells, crustacean or molluscs in Gathaagudu?

Stromatolites

- What makes stromatolites important to you?
- How important are healthy stromatolites to the health of Gathaagudu Saltwater Country overall?
- How healthy are Gathaagudu stromatolites now?
- Are Gathaagudu stromatolites under threat?
- What are the threats to stromatolites in Gathaagudu? (select all that apply)
- What is the MAIN threat to stromatolites in Gathaagudu? (select one)
- Do we know enough about stromatolites in Gathaagudu to keep them healthy?
- Should there be research done on stromatolites in Gathaagudu?
- What question/s would the research about stromatolites need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about stromatolites in Gathaagudu

Sea cucumber

- What makes sea cucumber important to you?
- How important is healthy sea cucumber to the health of Gathaagudu Saltwater Country overall?
- How healthy is Gathaagudu sea cucumber now?
- Is Gathaagudu sea cucumber under threat?
- What are the threats to sea cucumber in Gathaagudu? (select all that apply)
- What is the MAIN threat to sea cucumber in Gathaagudu? (select one)
- Do we know enough about sea cucumber in Gathaagudu to keep it healthy?
- Should there be research done on sea cucumber in Gathaagudu?
- What question/s would the research about sea cucumber need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about sea cucumber in Gathaagudu?

Other important values in your top 5

- What makes this value important to you?
- How important is it to the health of Gathaagudu Saltwater Country overall?
- How healthy is it now?
- Is it under threat?
- What threats does it face?
- What is the MAIN threat it faces?
- Do we know enough about this value in Gathaagudu to keep it healthy?
- Should there be research done on it in Gathaagudu?
- What question/s would the research need to answer?
- How urgent is this research?
- Any final comments, ideas or concerns about this important value in Gathaagudu?

If you have any further comments, please add them here

11.11 Appendix 11 Original knowledge gaps and final results

1 = WAMSI/UWA seagrass workshop; 2 = CVI workshops; 3 = DBCA staff and publication (Kendrick et al., 2016); 4 = A Snapshot of Marine Research in Shark Bay (Gathaagudu): Literature review and Metadata Collation (1949–2020); 5 = Community interviews; 6 = Malgana Voices survey; 7 = Prioritisation process discussion. References for citations used in the literature review can be found in Sutton and Shaw (2020).

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Ecosystem processes and connectivity												
Better understanding of ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores								What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?	Elasmobranchs and seagrass based food webs; tiger shark diet; large sharks occupy a different niche to bottlenose dolphins, smaller sharks and rays – **see section 3.5.3.1 Habitat, resource partitioning and competition and section 3.5.3.2.4 – Diet**; Lack of evidence for a mangrove-based food web for some fish and invertebrates – **see section 3.3.5.2 – Ecosystem services**; diet differences between dolphins who use sponges vs not – **see section 3.5.6.2.5.1 – Tool use**; contribution of seagrass, epiphytes, macroalgae, and other primary producers to the diets of invertebrates through to turtles – **see section 3.3.2 – macroalgal communities and 3.3.1.3 Consumption of seagrass**			
What are the key physical, biological, ecological and chemical processes that link different habitats (e.g. inshore-offshore, benthic-pelagic or lagoonal-deep water) within a marine reserve and how significant are such links?								Rolled up into: What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities? e.g. energy transfer, ontogenetic and seasonal movements, biological filtration	Genetic connectivity studies for pink snapper and other fishes, clams, Pocillopora coral, mangroves, seagrasses, green turtles, loggerhead turtles. Environmental influences on the recruitment of fish and invertebrates. **See section 3.2.1 – Biological connectivity**. Influence Shark Bay Outflow on the flushing of scallop larvae from Shark Bay; environmental influences on scallop recruitment – **see section 3.6.5.1 – spawning and recruitment**			

What are the relationships between coral reef, macroalgal, seagrass, mangrove, saltmarsh and intertidal communities, such as energy transfer, ontogenetic and/or temporal movements of species and biological filtration?								What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities? e.g. energy transfer, ontogenetic and seasonal movements, biological filtration	A range of fish and invertebrate species are found in mangrove habitat in Shark Bay, but this may be for the purposes of shelter and nursing given no evidence to date has shown mangrove production directly supporting these local populations through the food web (Heithaus et al. 2011) – **see section 3.3.5.2 Ecosystem services**			
How does the loss and fragmentation of marine habitats affect connectivity between communities in marine reserves?								Rolled up into: What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities? e.g. energy transfer, ontogenetic and seasonal movements, biological filtration	WA coast study (including Shark Bay sites) found habitat discontinuities formed strong barriers to gene flow among mangrove populations – **see section 3.2.1 – Biological connectivity**	DBCA – looking at ecological consequences of fragmentation		
Is our top-down understanding of the ecosystem missing? Currently our approach is bottom-up, but are we asking the right questions?									Has been studies on habitat partitioning by elasmobranchs, tiger shark predation influences on prey behaviour and thus seagrass consumption; ecological role of tiger sharks; impacts of turtles grazing on seagrass; dugong grazing choices and predator influences on foraging locations; dolphin foraging habits and predation influences; evidence suggests that seagrass beds may be shaped, in part, by the responses of herbivorous fish to predation **see sections 3.4.3 Elasmobranchs, 3.5.4 Marine reptiles, 3.5.6 Marine mammals, 3.5.2 Finfish communities**			
Direct and indirect impacts of habitat loss of key benthic communities (mangroves, seagrasses and corals) on marine life and ecosystem functioning								Rolled up into: What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities? e.g. energy transfer, ontogenetic and seasonal movements, biological filtration	Direct and indirect impacts known from seagrass loss due to 2011 marine heatwave and Wooramel River flooding – **see 3.3.2 Marine heatwave**			
Modelling food web shifts in the absence of key seagrass species								How would food webs shift in the absence of key seagrass species under climate change scenarios?				

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
How will climate change affect primary productivity and the flow of energy in marine systems?								How will climate change affect primary productivity and the flow of energy in marine systems?		Data collected as part of ICoaST project may be useful in addressing this gap, though it is not a specific focus of the project		
Better understanding of pelagic productivity								How productive are pelagic waters and what are the seasonal dynamics e.g. phytoplankton and zooplankton				
Understanding annual variation in plankton community dynamics								Rolled up into: How productive are pelagic waters and what are the seasonal dynamics e.g. phytoplankton and zooplankton?				
Estimates of zooplankton grazing rates and secondary production for understanding pelagic food web dynamics								Rolled up into: How productive are pelagic waters and what are the seasonal dynamics e.g. phytoplankton and zooplankton				
Where do the nutrients that sustain large algae and seagrass meadows come from and where do nutrients go when algae and/or seagrass breaks down?								Better understanding of benthic productivity (e.g. seagrasses, macroalgae)	Dissolved organic material in the water column is found to be mostly derived from seagrass sources, but also terrestrial, planktonic and macroalgal sources within Shark Bay (Cawley et al. 2012) – **see section 3.1.3 – Water quality**. Available inorganic nitrogen and phosphorus was linked to microbial activity across a salinity and phosphorus gradient from Guischenault Point to L'Haridon Bight (Fraser et al. 2018) – **see section 3.1.4 – Sediment quality**			
Assess sources and cycling of nutrients in Hamelin Pool								Assess sources and cycling of nutrients in Shark Bay e.g. Hamelin Pool		Proposal pending-ARC Linkage Gary Kendrick and Matt Fraser		
Are deep sea corals important in re-seeding coral reefs at Shark Bay (Refuge Theory)?								Rolled up into: Better understanding of the connectivity of Shark Bay corals to other corals/ reefs along the WA coastline and deeper waters				

How connected are Shark Bay coral reefs to other reefs along the WA coastline e.g. Abrolhos, Ningaloo								Better understanding of the connectivity of Shark Bay corals to other corals/reefs along the WA coastline and deeper waters	Genetic connectivity work on Pocillopora – **see section 3.3.3.3 Physiology**			
Environmental conditions												
What is the current health status of Gathaagudu Barrija Wirriya maya (land and sea home) and how can we sustain it and reduce further impact?										WAMSI is providing preliminary assistance for the development of a healthy sea country plan with the Malgana Voices Survey		
Where are the tipping points for a functioning ecosystem?								What are the current tipping points, in relation to climate change and anthropogenic pressures, for a functioning ecosystem and the ecological values within it?				
Short and long term patterns of environmental conditions (e.g. temperature, salinity, sea level) in Hamelin Pool								Better understanding of temporal and spatial environmental conditions (temperature, salinity, sea level) in Shark Bay	**See section 10.2 – databases and accessibility** for reference to NationalMap which has an intertidal digital elevation model layer for Shark Bay (25 m spatial resolution). DPIRD have measured temperature, salinity and pH for a subset of samples since 2011 – annually – **see section 10.3 – Monitoring programs**. Surface water, groundwater and rainfall samples were collected in 2011, largely from Western Gulf (could be used for temporal comparison in future) – **see section 3.1.1.1 Water sources and water budgets**. See reference to Logan and Cebulski 1970 – discuss and describe the hydrology of the bay and its stability. Has salinity ranges for different areas that can be used for future comparisons			
Long-term variability of Faure Sill								What is the long-term role of the Faure Sill and its structure and function in maintaining Hamelin Pool?	Growth history of Faure Sill has been documented, and bathymetry changes across one year have been studied using hyperspectral imaging – **see section 3.1.5.2 Hypersaline basins**			

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
What are the effects of compounding and interacting factors on Outstanding Universal Value of SBWHA?											Some info available in CVI document and proposed climate change adaption plan	
Linkages between marine water conditions, chemical processes, seagrass, and organomineralisation processes in carbonate dominated marine environment								What are the important linkages between marine water conditions, chemical processes, seagrass and organomineralisation processes in a carbonate dominated environment?				
How can increasing phosphorus levels be managed?									No mention of a high phosphorus concentration problem, except for unexplained elevated concentrations in 2016 at Monkey Mia. Phosphorus is limited in some areas of the Bay – particularly the more hypersaline waters – **see section 3.1.3 Water quality**. The episodic flooding of the river, and the associated input of nutrients, could be one explanation for why seagrass communities adjacent to the Wooramel River have higher phosphorus concentrations compared with other meadows in the Bay – **see section 3.1.1.3 Flooding**. Not all of Shark Bay is monitored for water quality.		Measured last in 2016 water column or sediment. Fraser et al 2017/18	
What industries are currently extracting water from the Carnarvon basin?								Rolled up into: How will the extraction of groundwater influence groundwater pressure and what impact would reduce pressure into the bay have on the benthic communities? e.g. stromatolites, seagrasses, mangroves and salt marshes				Not really relevant to this project as currently worded
What impact will a further reduction in groundwater pressure and quality have on the natural environment?								How will the extraction of groundwater influence groundwater pressure and what impact would reduce pressure into the bay have on the benthic communities? e.g. stromatolites, seagrasses, mangroves and salt marshes				

Better understanding of the location and volume of groundwater inputs into Shark Bay (particularly Hamelin Pool), including nutrient and contaminant concentrations								Better understanding of the location and volume of groundwater inputs into Shark Bay (particularly Hamelin Pool and Freycinet Estuary), including nutrient and contaminant concentrations	Locations of groundwater input into Hamelin Pool was investigated in the 1980s; Analytical modelling has been used to quantify groundwater influx into Hamelin Pool **see section 3.1.1.2 – Groundwater and surface run-off**			
Is water quality currently at a good level in all areas, shallow and deep, of Shark Bay?								Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/ moorings, natural levels of turbidity and periodic influxes from flooding	Data available for certain location rather than widespread – **see section 3.1.3 – Water quality**			
Comprehensive water and sediment quality sampling across Shark Bay, including past and contemporary contaminants, and mooring and anchoring areas relative to appropriate control sites								Rolled up into: Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/ moorings, natural levels of turbidity and periodic influxes from flooding	Data available for certain location rather than widespread – **see section 3.1.3 – Water quality**			
Are high human impact areas (e.g. town sites, mine sites, tourism, pastoral leases etc..) causing a deterioration in Wirriya (water) quality?								Rolled up into: Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/ moorings, natural levels of turbidity and periodic influxes from flooding	Some information available for Monkey Mia for past contamination (1980s) and more recently recorded levels of elevated nutrients (2016) – **see section 3.1.3 – Water quality**			
Are cadmium levels still high in oysters?								Rolled up under: Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/ moorings, natural levels of turbidity and periodic influxes from flooding	Last published occurrence of high cadmium levels in bivalves was 1991 – **see section 7.2.3 – Heavy metals**			
Assess relationships between sediment and water quality								Rolled up into: Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/ moorings, natural levels of turbidity and periodic influxes from flooding	Some information available in relation to nutrients – **see section 3.1.4 – Sediment quality**			

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
How do water and sediment quality vary naturally within marine reserves?			■					Rolled up into: Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/ moorings, natural levels of turbidity and periodic influxes from flooding				
What will be the impacts of increased sediment transport if there are less seagrass roots to maintain stability?					■			What will be the impacts of increased sediment transport if there are less seagrass roots to maintain stability?				
Influence of water chemistry and changes in environmental conditions on carbonate precipitation and organomineralisation processes				■				Rolled up into: What are the important linkages between marine water conditions, chemical processes, seagrass and organomineralisation processes in a carbonate dominated marine environment?	Benthic photosynthesis and oxygen demand in permeable carbonate sediments was found to be influenced by boundary layer flow – **see section 3.1.4 – Sediment quality**			
Occurrence and rates of ocean acidification				■				Understand how the loss of seagrass and shifts in the composition of primary producers could affect CO2 and acidity			Ocean acidification measured at a very broad scale	
How will hydrodynamic regimes change in response to climate change?			■						Increased flooding of Wooramel River causing increased freshwater influx into Shark Bay; changes to wind patterns – **see section 3.1.1.3 – Flooding and 7.1.2 – Projections for Shark Bay**	Indian Ocean oceanographic/ hydrodynamic projects underway		
Modelling of the oceanographic environment within Shark Bay, inclusive of local circulation, inflow and aquifer considerations	■			■				Undertake higher resolution modelling of the oceanographic environment within Shark Bay, inclusive of local circulation, inflow, episodic flooding, and groundwater considerations				
How will such changes affect propagule dispersion and connectivity between communities in marine reserves, and how should this knowledge inform marine reserve planning?			■					Rolled up under: Better understanding of how local hydrology impacts on ecological processes (propagule dispersion, nutrient supply, recruitment, connectivity) and threats (oil spills, introduced species), and whether predicted changes to hydrology can help inform marine reserve planning				

Develop an appropriate understanding and predictive capacity of the circulation and mixing of marine reserve waters, particularly in relation to key ecological processes (e.g. nutrient supply and productivity, recruitment, connectivity) and threats (oil spill, introduced pests)								Better understanding of how local hydrology impacts on ecological processes (propagule dispersion, nutrient supply, recruitment, connectivity) and threats (oil spills, introduced species), and whether predicted changes to hydrology can help inform marine reserve planning				
Climate change impacts												
What are reliable measures of sub-lethal impacts of climate change on fauna and flora? How will sub-lethal impacts differ among species?								What are reliable measures of sub-lethal impacts of climate change on fauna and flora? What are the consequences of sub-lethal impacts e.g. reduced reproductive output?				
How will the distribution of species change in response to climate change?								What changes to abundance and range do species in Shark Bay (primarily of conservation and fisheries significance) face as a result of climate change?	Some research on fisheries species – **see section 3.6.8 Environmental influences on fisheries**; It is predicted that temperate seagrasses will be lost from sub-tropical regions like Shark Bay as marine heatwaves increase in frequency and climate change accelerates. Presently, local adaptation and phenological plasticity is being investigated in the temperate seagrass Posidonia australis in Shark Bay to assess whether populations of this species at their northern range limit have adapted to higher temperatures (Kendrick pers. comm.) – **see section 3.2.2.1 Benthic communities**			

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Will Little Lagoon eventually be disconnected from the ocean?									**See section 3.2.3.1 Landscape vulnerability due to climate change for reference to report by Eliot et al 2012, which says** – "*Future response of the entrance is uncertain, as both tidal exchange and sediment supply are anticipated to increase under projected sea level rise. Over inter-decadal or longer time scales there is risk of lagoon entrance blockage, potentially turning the lagoon into a Birrida if there was insufficient exchange or cross-shore erosion to overcome the rate of alongshore sediment supply (Bruun & Gerritsen 1960). Alternatively, there could be a further northwards migration of the mouth. Tidal flat migration will occur in response to changes to the mouth. The two main coastal process studies that would benefit the assessment are: (1) a storm inundation study; and (2) a sediment budget investigation including sediment transport pathways and volumes in relation to tidal channel restriction and landform mobility with sea level rise. The second study could consider the general approach of Bruun & Gerritsen (1960) to determine if the mouth is likely to stay open under different scenarios of the tidal prism to the approximate gross annual rates of alongshore sediment transport. This could be investigated for a range of potential sediment transport rate scenarios and for present and projected sea levels over time frames suitable for any proposed infrastructure*"			
What are the projections for climate change and environmental factors specific to Shark Bay over the next 10–20 years?									Climate change projections and confidence ratings for Shark Bay are stated on the Climate Change in Australia government website and in the National Environmental Science Program (NESP) Earth Systems and Climate Change Hub report (2018) – **see section 7.1.2 Projections for Shark Bay**			

What is the potential vulnerability of species or communities to climate change? Can their susceptibility and/or resilience be identified?			■	■				It is predicted that temperate seagrasses will be lost from subtropical regions like Shark Bay as marine heatwaves increase in frequency and climate change accelerates – **see section 3.3.1.2 Marine heatwave impacts**. Climate change stressors such as increasing sea surface temperature, changes to the Leeuwin Current, rising sea levels and ocean acidification can impact upon fisheries and the functioning ecosystem in Shark Bay through affecting spawning and recruitment, range and distribution, community compositions and interactions, productivity and the establishment of introduced species – **see section 3.6.8 Environmental influences on fisheries**			
What will be the impacts of climate change (i.e. sea level rise, storms, temperature) on the marine environments of Faure Sill and Hamelin Pool?	■		■	■	■			Predicted impacts of sea level rise have been investigated for Faure Sill; Hamelin Pool: sea level rise could lead to environmental instability, increased sediment transport, lower salinities and a subsequent decline in microbialite communities, which are considered highly susceptible to such environmental changes – **see section 3.2.3.2 Sea level and erosion**; In the face of a changing climate, the challenges for microbial communities in Shark Bay is discussed by Reinhold et al. (2019). A review of the biogeomorphological processes that impact on surficial CO2 sequestration is also given by Morris et al. (2019), which provides a 3D biogeomorphological mapping framework for Hamelin Pool that can be used to understand the impacts of sea level rise – **see section 3.3.4 Microbial and microbialite communities**			
How will key interactions (e.g. competition, predation) driving large scale patterns and ecological feedbacks change with extreme events and prolonged climate change?				■	■		How will key interactions driving large scale patterns and ecological feedbacks change with extreme events and prolonged climate change?	Tiger sharks are key predators in Shark Bay, but because of their more generalist diet, they were found to be relatively resilient to the impacts of the 2011 marine heatwave – **see section 3.5.3.2.2 Habitat**			

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Importance of sand dunes and drifts to the marine environment									**See section 3.2.3.1 Landscape vulnerability due to climate change** for reference to report by Eliot et al 2012, on future coastline changes		DBCA are aware of key areas where there is significant movement e.g. Dirk Hartog Island-Tetradon Loop. Shark Bay known to have a dynamic coastal environment that is periodically arranged by big storms. DBCA are actively managing some of these key areas	
How will the coastline change in response to rising sea levels and cyclonic activity? What will be the ecological implications for benthic habitats, flora and fauna?									The vulnerability of landforms to changing environmental conditions has been assessed for the coastline of Shark Bay, and much of the coastline is considered to have a low vulnerability to changing environmental conditions such as weather, oceanography and climate change (as of 2012) – **see section 3.2.3 Coastal zone processes**.		Some historical work being done by Joseph Christensen	
Better understanding of the impacts of heatwaves on the marine environment								What are the effects of heatwave frequency duration and intensity on top of predicted climate change heating on key ecological and economic organisms and processed in Shark Bay?	A lot was learned from the 2011 heat wave -– research presented throughout literature review e.g. **section 3.2.2 Marine heatwave**		-	
Can we better predict and identify factors that contribute to marine heatwaves?									Causes, variability and predictability of the Ningaloo Niño continues to be investigated (Kataoka et al. 2018; Feng and Shinoda 2019); Shark Bay is more susceptible to extreme temperatures given its shallow depths and sheltered embayment, though cooling from the seasonal Capes Current may alleviate temperatures near the entrances to the Bay – **see section 3.2.2 Marine heatwave**		Holbrook et al 2020 (Australis wide) explain physical mechanisms that cause heatwaves and that there is capability to look at past and real time Marine Heatwaves with monitoring facilities (e.g. IMOS). Authors call for the need to develop better predictive capacity and offer suggestions on how to do this. Also suggest that an improved understanding of physical processes is needed	

Understand the fluxes of fresh water, runoff, nutrients and organic matter into Shark Bay (incl. Hamelin Pool) and model future sediment yields from episodic flooding of the Wooramel River and Gascoyne River								Better understanding of the roles of fresh water, runoff, nutrients and organic matter into Shark Bay (incl. Hamelin Pool) and predicted changes associated with climate change	Projections of streamflow and sediment yield responses of the Wooramel River to global warming scenarios – **see section 3.1.1.3 – Flooding**			
Benthic communities (other than seagrass)												
What invertebrate species are being taken from intertidal habitats and what are the ecological consequences of this?								Rolled up under: Better understanding of the invertebrate diversity, distribution and abundance in Shark Bay, including Hamelin Pool, and associated environmental and anthropogenic pressures				
Describe the distribution patterns and natural variability of intertidal communities with respect to anthropogenic pressures and management zones								Rolled up under: Better understanding of the invertebrate diversity, distribution and abundance in Shark Bay, including Hamelin Pool, and associated environmental and anthropogenic pressures				
How does the distribution of algae influence the abundance and species composition of herbivores?								How does the distribution of algae and seagrasses influence the abundance and species composition of herbivores?				
Could stromatolites survive another heatwave similar to 2011?									Yes, if seagrass was maintained at Faure Sill and salinity levels remained at the level the stromatolites are adapted to – **see section 3.3.4 Microbial and microbialite communities and Reinhold et al. 2019 paper**. How stromatolites will survive other climate change impacts is not well known			
What indicators are there to show that stromatolites are healthy or unhealthy in Shark Bay?								What are the most appropriate indicators to monitor and measure the condition of stromatolites?				
Assess the potential impacts of climate change on Hamelin Pool and its microbial communities									In the face of a changing climate, the challenges for microbial communities in Shark Bay is discussed by Reinhold et al. (2019). Potential impacts are known, but resilience and/or susceptibility is not well understood – **see section – 3.3.4 Microbial and microbialite communities**			

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
What specific requirements or environmental conditions influence survival and growth of microbial and microbialite communities (i.e. importance of groundwater)?								What internal (gene expression and metabolomics) and external (environmental) conditions will influence the formation, growth and survival of microbial and microbialite communities under a changing climate?	For high energy environments, growth rates only just exceed erosion rates. Morphology of stromatolites has been related to environmental influences and biological communities. when the physical geography allows for a high-energy environment, environmental controls largely determine morphology, and where this is a low-energy environment, biological communities largely determine morphology (Suosaari et al. 2019a; Suosaari et al. 2019b) – **see section 3.3.4.4 Lithified formations**			
Key population shifts and changes in gene/metabolite expression patterns that may help to predict responses to future environmental change								Rolled up into: What internal (gene expression and metabolomics) and external (environmental) conditions will influence the formation, growth and survival of microbial and microbialite communities under a changing climate?				
Linking gene activity to mineral products and stromatolite formation								Rolled up into: What internal (gene expression and metabolomics) and external (environmental) conditions will influence the formation, growth and survival of microbial and microbialite communities under a changing climate?				
What indicators are there to show that corals are healthy or unhealthy in Shark Bay?										Currently being addressed by the DBCA Marine Monitoring Program		
Is the current level of coral monitoring adequate for assessing health and detecting health declines?										Currently being addressed by the DBCA Marine Monitoring Program		
How do corals persist under extreme environmental conditions? What factors impede or promote recovery of corals after disturbance?								What factors impede or promote growth and recovery (e.g. after a disturbance) of different corals at Shark Bay?	Some work on a heat-stress tolerant coral and connectivity at Shark Bay by Evans et al. 2019 – **see section 3.3.3.3 Physiology**			

How may long-term changes in temperature and currents affect coral reef accretion rates?								Rolled up into: What factors impede or promote growth and recovery (e.g. after a disturbance) of different corals at Shark Bay?				
What is the distribution and composition of filter-feeding communities (i.e. sponges) within Shark Bay?								Rolled up into- What climate and environmental factors are most significant in determining the distribution and diversity of filter-feeders (e.g. sponges and molluscs) and soft sediment communities overall?	The distribution of sponges was found to be relatively patchy based on presence in only 196 of the 1380 quadrats surveyed in a methodological study in the northern portion of the Western Gulf. Echinodictyum mesenterinum, which are used by dolphins, were found in 4% of quadrats. Other sponges that have been described from Shark Bay include one confirmed and several doubtful species records of the Pione genus – **see section 3.3.6 Sponge communities**			
What environmental factors influence the distribution and diversity of filter-feeders, and how might they be impacted by climate change?								What climate and environmental factors are most significant in determining the distribution and diversity of filter-feeders (e.g. sponges and molluscs) and soft sediment communities overall?				
Identify soft sediment communities								Rolled up into- What climate and environmental factors are most significant in determining the distribution and diversity of filter-feeders (e.g. sponges and molluscs) and soft sediment communities overall?				
How are soft sediment communities influenced by environmental conditions?								Rolled up into- What climate and environmental factors are most significant in determining the distribution and diversity of filter-feeders (e.g. sponges and molluscs) and soft sediment communities overall?				
What are the current threats to mangroves in Shark Bay?								What are the natural and anthropogenic, including climate change, threats to mangroves in Shark Bay?				
To what extent have mangroves declined in Shark Bay?									**See reference to DBCA 2019 report** – Ecological monitoring in the Shark Bay marine reserves 2019	Mangroves are being monitoring by DBCA's Marine Monitoring Program		

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
What indicators are there to show that a mangrove system is healthy or unhealthy. Are mangroves in Shark Bay currently considered healthy?						■				Mangroves are being monitoring by DBCA's Marine Monitoring Program		
What organisms, or particular life stages of organisms, are associated with mangrove habitats? Is this use dependant on mangroves or opportunistic?			■		■			What life stages of organisms are associated with mangrove habitats and is this use dependent or opportunistic?	Some research on fish and invertebrate associations; communities establishing on pneumatophores; dependent shore/ seabirds. Less on life stage associations – **see section 3.3.5.2 Ecosystem services**			
Assess the recruitment, growth and physiology of mangroves (Avicennia marina) at Shark Bay in relation to environmental factors like salinity			■					Investigate the recruitment, growth and physiology of mangroves (Avicennia marina) in relation to environmental factors e.g. salinity.	Distribution in relation to coastal dynamics, habitat and salinity has been assessed for NW coast, which included Shark Bay (Semeniuk 1994) – **see section 3.3.5 Mangrove communities**. Would need more research			
Investigate patterns of connectivity and dispersal for mangroves				■					The genetic diversity and connectivity of A. marina along the WA coastline has been assessed by Binks et al. 2019 – **see section 3.3.5 Mangrove communities**			
Assess and quantify the nature, level and potential impacts of human activities on mangrove communities within the reserves			■					Rolled up into: What are the natural and anthropogenic, including climate change, threats to mangroves in Shark Bay?				
How does variation in the composition and structure of mangrove habitats influence their ecological function? How does this vary in relation to environment factors?			■					How does variation in the composition and structure of mangrove habitats influence their ecological function? Second part of questions rolled up into: Investigate the recruitment, growth and physiology of mangroves (Avicennia marina) in relation to environmental factors e.g. salinity				
Sediment dynamics of mangrove communities i.e. sediment porewater salinity, sediment accommodation, erosion and sea level rise				■				Understand the influence of sediment dynamics, sediment porewater salinity, sediment accommodation, erosion and sea level rise, on mangrove communities				

What is the composition, distribution and ecological significance of salt marshes and other riparian vegetation in Shark Bay?								What is the composition, distribution and ecological significance of salt marshes and other riparian vegetation?				
Better understanding of molluscs and the changes in mollusc species across time								Rolled up under: What climate and environmental factors are most significant in determining the distribution and diversity of filter-feeders (e.g. sponges and molluscs) and soft sediment communities overall?	Body of research that has investigated molluscs, but no long-term studies to show changes across time – **see section 3.5.1.1 Molluscs**			
Better understanding of the invertebrate diversity, distribution and abundance in Shark Bay, including Hamelin Pool								Better understanding of the invertebrate diversity, distribution and abundance in Shark Bay, including Hamelin Pool, and associated environmental and anthropogenic pressures	Older research on this (not Hamelin Pool), but perhaps due for another survey – **see section 3.5.1 Invertebrate communities**			
How do environmental factors, particularly those affected by climate change, and fishing pressure, interact to affect the abundance and diversity of invertebrates?								Rolled up under: Better understanding of the invertebrate diversity, distribution and abundance in Shark Bay, including Hamelin Pool, and associated environmental and anthropogenic pressures				
Seagrass communities												
Impact of seagrass loss on integrity of Faure Sill and, therefore, hypersaline environment									Increased sea level could cause increased erosion of Faure Sill channels, and seagrass loss, due to increased currents, but it may also allow for more colonisation due to increased water heights and a greater spread into Hamelin Pool under reduced salinity conditions (Walker et al. 2012; Taebi et al. in press) – **see section 3.2.3.2 Sea level and erosion**			
How much time is left for the restoration of seagrass before it is too late?								Rolled up under: Is large-scale restoration or protection of seagrass meadows feasible?				
Assess the impact of boat moorings and anchoring on seagrass communities								Assess the impact of boat use on seagrass communities				

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
How can the Shark Bay and Malgana community help to maintain a healthy status for seagrass?						■				NESP project-Assisting restoration of ecosystem engineers through seed-based and shoot-based programs in the Shark Bay WHS		
Identify the native seagrass species of the area and get the latest health status						■			There are 12 species that occur naturally in Shark Bay. Seagrass was severely impacted by the 2011 marine heatwave but there has been some continued recovery – **see section 3.3.1 Seagrass communities**			
To what extent does trawling negatively impact on seagrass meadows?						■			Trawling is reported to take place mostly over shell/sand habitat. Though trawling is not currently considered a significant issue, there is potential for risk to habitat which may warrant an ecological risk assessment – **see section 3.6.9 Fishing method impacts**			
How can we mitigate the risk of further destruction to our Wirriya Jalyanu (seagrass) and implement restorative processes by utilising traditional and contemporary Indigenous knowledge and technology?						■				NESP project-Assisting restoration of ecosystem engineers through seed-based and shoot-based programs in the Shark Bay WHS		
Is large-scale restoration or protection of seagrass meadows feasible, and what is the resilience of restored meadows?	■			■	■			Is large-scale restoration or protection of seagrass meadows feasible?	Some feasibility work done in 2012, but still needs more work – **see section 3.3.1.5 Restoration**			
Are the species used in the restoration process capable of surviving future heat wave events?							■	Rolled up under: Is large-scale restoration or protection of seagrass meadows feasible?				

How does the distribution of seagrass influence the abundance and species composition of herbivores e.g. finfish, turtles, dugong?								Rolled up under: What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?				
Assess the diversity and distribution of macro-invertebrate and fish species inhabiting different species of perennial seagrass								Update knowledge on the diversity and distribution of macro-invertebrate and fish species inhabiting different species of perennial seagrass	Wells et al 1985 look at invertebrates in Posidonia, Amphibolis and sand habitats and diversity and density was found to be greatest in seagrass beds as opposed to bare sand. **See section – 3.5.1 Invertebrate communities**. Numerous studies have looked at fish assemblages inhabiting seagrass meadows – **see section 3.5.2.1 Habitat associations**			
What processes drive the distribution and abundance of ephemeral seagrasses, and how does this influence dugong behaviour?								Rolled up under: What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay and replaced temperate species? Second part of question rolled up under: What are the ecosystem/ trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?				
What drives natural and assisted recovery of seagrass?									Intense fish grazing and bioturbators (e.g. heart urchin) have hindered restoration efforts – **see section 3.3.1.5 Restoration**	NESP project- Assisting restoration of ecosystem engineers through seed-based and shoot-based programs in the Shark Bay WHS		
Assess natural variations in the distribution of perennial seagrasses at various spatial scales								Rolled up under: What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay and replaced temperate species?				

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
What are the flow on effects from the tropicalisation of seagrass assemblages?								What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay and replaced temperate species?				
What are the links between seagrass and microphytobenthos?								Rolled up under: What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?				
Identify indicators of seagrass stress and environmental thresholds, including rapid assessment techniques								Rolled up under: Creation of rapid response/adaptive management plans for extreme marine events, particularly when ecological values are affected and develop thresholds for the protection of key elements of Outstanding Universal Value of SBWHA				
Blue Carbon capabilities of seagrasses in Shark Bay								Better understanding of blue carbon capabilities of seagrasses in Shark Bay	The large extent and high biomass of seagrass meadows at Shark Bay has produced the world's largest carbon stock for a seagrass ecosystem. For example, P. australis mat escarpments of up to 2.8 m thick are found at Big Lagoon, and formations like these can harbour some of the largest organic carbon sinks recorded across the globe – **see section 3.3.1.6 Blue carbon**			
Marine megafauna												
Quantify the increase in whale numbers over the past 20 years									Building on this historical work with additional survey data, estimates of population size for the migrating west coast population of humpbacks has been refined and updated across time – **see section 3.5.6.3.1 Humpback whales for reference to studies on population estimates**		Well known that humpback population has increased. DBCA trying to anticipate cost of managing interactions with increasing population numbers for the whole of WA e.g. entanglements and whale carcasses	

Updated population status of dolphins since 2014												
Identify habitats of ecological significance for dolphins (e.g. areas used for feeding or reproduction). Describe the distribution, abundance, residency and habitat use of tropical inshore dolphins. What are their movement patterns?								a) Better understanding of significant habitats for dolphins, e.g. areas used for feeding or reproduction; and b) Describe the demographics, distribution, abundance, residency and habitat use of Australian humpback dolphins in Shark Bay				
When and why do dugongs move, and over what spatial extent are these movements? How do these movements differ demographically?								When and why do dugongs move, and over what spatial extent are these movements?	Some work on when and why – **see section 3.5.6.1.1 Distribution and population** however all surveys but one summer survey have been conducted in winter, and there is no information available on movement in relation to demographics			
Assess possible climate change impacts on dugong at the southern edge of their distribution								Rolled up under: What changes to abundance and range do species in Shark Bay (primarily of conservation and fisheries significance) face as a result of climate change?				
What is the relative impact on dugong of exposure to vessels, particularly in areas of critical habitat?								Rolled up under: What are the impacts of recreational and commercial (licensed tour operators) access to marine fauna? Particularly in areas of key interest and high pressure				
Assess the regional significance of marine reserves for dugong (Dugong dugon) conservation and the relative importance of marine reserves as dugong habitat. e.g. critical seagrass habitats, how has our knowledge of dugong in parks and reserves been informed by Traditional ecological knowledge?								How are critical habitats, i.e. seagrass habitats, used by dugongs of different ages?			Population surveys are carried out every 5 years along the coast- remained relatively stable over time. Current project on dugong and seagrass distribution winding up for the Pilbara. Traditional ecological knowledge has, in part, informed knowledge of dugongs in parks and reserves	
Determine the genetic structure and connectivity of dugong among different marine reserves								Investigate the genetic structure of dugongs in Shark Bay and determine the level of connectivity of dugongs among different marine reserves				

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
How does the distribution and abundance of ephemeral seagrasses influence dugong behaviour?								Rolled up under: Better understanding of ecosystem/ trophic links between nutrients, microbes, primary producers, consumers and detritivores				
How often are sharks targeted by fishers and has shark abundance increased?								Has shark abundance increased in Shark Bay and why? e.g. is this related to offal discard from recreational fishing?	**See section 3.6.10 Recreational fishing** for reference to Taylor et al 2018 on recreational fishing surveys which quantify shark catches			
Quantify seasonal whale shark aggregations in the vicinity of Dirk Hartog Island								Quantify seasonal whale shark aggregations				
What is the level of fish offal discard into Shark Bay by recreational fishers and has this contributed to the increase in tiger shark numbers?								Rolled up under: Has shark abundance increased in Shark Bay and why? e.g. is this related to offal discard from recreational fishing?				
Increased monitoring of loggerhead turtles										DBCA currently undertaking loggerhead monitoring, and monitoring of ecological values overall will increase as resources permit		
Are turtles on Dirk Hartog Island being negatively impacted by tourists?								Are turtles negatively impacted by tourists, especially on Dirk Hartog Island?				
Impact of climate change and increased storms on turtle nesting beaches								Rolled up under: How will the coastline change in response to rising sea levels and cyclonic activity? What will be the ecological implications for benthic habitats, flora and fauna? e.g. impact of climate change and increased storms on turtle nesting beaches				

What is the species composition and relative abundance of sea snakes in the park?								What is the species composition and relative abundance of sea snakes in Shark Bay?	D'Anastasi et al. (2016b; 2016a) conducted surveys across WA to clarify the distribution of sea snakes and documented the occurrence of two critically endangered species, Aipysurus foliosquama and Aipysurus apraefrontalis, in Shark Bay, further south than previously recorded – **see section 3.5.4.1.1 Diversity and distribution**			
Determine if the Shark Bay sea snake (Aipysurus laevis pooleorum) is a different species to the olive sea snake (A. laevis)									**See literature review for reference to D'Anastasi et al. 2016** who states "*Nine A. pooleorum collected in Shark Bay formed a reciprocally monophyletic clade with A. laevis (PP = 100%, ML, MP bootstraps N95%) consistent with the hypothesis that A. pooleorum was a subspecies of A. laevis based on shared morphological characteristics (large size, imbricate dorsal scales, similarity in head scale plans) (Smith, 1974). Importantly, the A. pooleorum clade was clearly genetically distinct from A. foliosquama and did not include the two snakes from WAM, originally identified as A. pooleorum*"			
Identify key foraging sites for marine turtles and the demographics of turtles using these areas								Better understanding of key foraging sites for marine turtles and the demographics of turtles using these areas	Habitat types have been identified, but not specific locations – **see section 3.5.4.2 Marine turtles for reference to relevant studies**			
Assess the level of turtle egg mortality, including that from introduced animals such as foxes, dogs and cats								What are recent estimates of turtle egg mortality from introduced land animals?	On land, feral cats fitted with data-logger/radio-telemetry collars have been found to opportunistically predate on loggerhead turtle hatchlings (Hilmer et al. 2010) – **see section 3.5.4.2.3 Predation**			
Potential distribution shifts in green and loggerhead turtles due to seagrass loss and implications for the wider ecosystem								Rolled up under: What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?	Loggerheads were less affected by the 2011 marine heatwave due to having a more generalists diet – **Section 3.2.2.3 Megafauna, 3.5.4.2.4 Ecosystem**.			
What is the relative importance of anthropogenic and natural processes within marine reserves that influence turtle populations? How do these relate to pressures outside marine reserves?								Are we doing all we can to effectively manage the turtle populations (loggerheads and greens) when they are in Shark Bay?				

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Identify migration routes and links between nesting and foraging areas. How do these relate to the marine reserve system?								What is the relative importance of nesting and foraging areas within Shark Bay to migrating turtle populations along the WA coastline?				
Identify locations of nesting/ roosting areas and current and potential threats								Have key nesting/roosting areas in Shark Bay remained the same for seabirds/shorebirds over time, and are they expected to change due to climate change?	Pelican Island is a significant rookery for pelicans. 42 breeding sites on islands and islets have been identified. It is believed the population of wedge-tailed shearwaters on Slope Island was negatively a ected by salt works and foxes – **see section 3.5.5 Seabirds and shorebirds**			
Feeding ecology of shore and sea birds and the influence of extreme events and/or prolonged food web shifts								Investigate food chains for key seabird species and the likely impact of extreme marine events and gradual climate change on these food chains	Most ecological studies have been done for pied cormorants – **see section 3.5.5.3 Species specific**			
Fish and Fisheries												
What proportion of visitors to Shark Bay are recreational fishers?											Good data on this collected every 2/3 years by DPIRD. Also, visitor numbers to the region should be available from Shire or DBCA	
What finfish species are considered culturally important?								What finfish species are considered culturally important?	**See section 4.3 Traditional hunting and fishing** for listing of some common species caught			
Are culturally important finfish species healthy and are fishing restrictions needed to ensure healthy populations into the future?											DPIRD responsible for all fish stocks- including those of significance to TOs- All fish stocks currently sustainable	

Better understanding of non-targeted finfish species e.g. their population health, ecological importance								Better understanding of non-target finfish e.g. their population health, ecological importance	Foraging impacts from herbivorous fishes on seagrass meadows is seagrass species dependent, and evidence suggests that seagrass beds may be shaped, in part, by the responses of herbivores to predation (Bessey et al. 2016). The holes and caves in scoured channels between seagrass meadows have also been identified as important for numerous reef fishes (Serrano et al. 2017). A decline has been observed for corallivores (coral dependant fishes) near Bernier and Dorre Islands following the loss of coral cover by approximately 90–95% as a result of 2011 marine heatwave – **see section 3.5.2.1 Habitat associations**. Selected species have formed the focus of dietary studies in Shark Bay – **see section 3.5.2.3 Diet**			
Relative importance of key finfish species nursery, spawning and aggregation sites (e.g. Useless Loop) and can they be sustained into the future?								Investigate the importance of nursery, spawning and aggregation sites for priority finfish species (e.g. Useless Loop) and their long-term sustainability?		Some data will be collected as part of ICoaST project	DPIRD has current knowledge for prawns, crabs, pink snapper	
How do environmental factors, particularly those affected by climate change, and fishing pressure interact to affect the abundance and diversity of finfish?								How do environmental factors, particularly those affected by climate change, and other impacts (e.g. fishing pressure) interact to affect the abundance and diversity of finfish (commercial and non-commercial)?	The influence of the Leeuwin Current on some key species has been investigated – **see section 3.5.2.4 Biological oceanography** and **3.6.8 Environmental influences on fisheries**	Current FRDC (Caputi et al) projects on prawns and pink snapper looking at this: 'Understanding the relationship between commercial prawn species population dynamics, fishing patterns and climate in the Shark Bay World Heritage Area in Western Australia' and 'Where did the Snapper go? Determining factors influencing the recovery of Snapper stocks on the west coast of Australia'		

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Ecological roles of key finfish species, including large predatory fish, and how that will be impacted by climate change			■	■				Better understanding of non-target finfish e.g. their population health, ecological importance				
How well are fish populations connected inside reserves (particularly those within different management zones) and between inside and outside of reserves?			■					How well are fish populations occurring in Shark Bay connected with other populations, inside and outside of reserves?				
Where do mullet go over the Christmas period?					■			Rolled up under: What are the spatial and temporal patterns of species caught by recreational fishers?				
Has spear fishing caused a decline in particular species (e.g. black spot tusk fish) due to biased fishing effort?					■			Rolled up under: What are the spatial and temporal patterns for recreational fishers within the boundaries of the marine park, and what is the recreational fish take by species and method?				
Is the annual Fishing Fiesta event sustainable, and does it reverse the efforts throughout the year?					■			Rolled up under: What are the spatial and temporal patterns for recreational fishers within the boundaries of the marine park, and what is the recreational fish take by species and method?				
Is there too much pressure on large, old and fecund fishes by recreational fishers, and should there be limits on max lengths for these species?					■			Should there be maximum lengths for the larger fishes heavily targeted by recreational fishers?				
Assess spatial and temporal variance in fishing pressure within marine reserves. Identify what species recreational fishers are catching and how much (including species less studied). Where and when are those species being caught?			■	■	■			What are the spatial and temporal patterns for recreational fishers within the boundaries of the marine park, and what is the recreational fish take by species and method?				

Better understanding of fisheries stocks, main spawning areas and connectivity along coast								Better understanding of fisheries stocks, main spawning areas and connectivity along coast (not limited to pink snapper)	**See section 8.2 Fisheries management** for reference to annual fisheries reports on stocks sustainability	Current FRDC Pink snapper project underway- '**Where did the Snapper go? Determining factors influencing the recovery of Snapper stocks on the west coast of Australia**'		
Better understanding of the effects of seagrass loss on prawns and crabs										FRDC project on prawns and ICoaST all working on this- '**Understanding the relationship between commercial prawn species population dynamics, fishing patterns and climate in the Shark Bay World Heritage Area in Western Australia**'		
What is causing size class changes in prawns, and why has prawn size reduced?										FRDC project on prawns and ICoaST all working on this- '**Understanding the relationship between commercial prawn species population dynamics, fishing patterns and climate in the Shark Bay World Heritage Area in Western Australia**'		

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
How are pink snapper dynamics and spatial use changing?	■								Current spatial distribution is relatively well known – **see section 3.6.2 Pink snapper for reference to literature**	Current FRDC Pink snapper project underway- **'Where did the Snapper go? Determining factors influencing the recovery of Snapper stocks on the west coast of Australia'**		
Is recreational (inc. spear fishing) and commercial fishing impacting on ecological assets and are current limits too high or sustainable long term under a changing climate?	■		■		■			An assessment of the cumulative impacts of commercial and recreational fishing on the ecological assets in Shark Bay	**See section 8.2 Fisheries management** for reference to annual State of the Fisheries reports, which includes some information on fisheries impacts on ecological assets		On-going core business for DPIRD – monitoring and assessment of fish stocks (recreational and commercial)	
Better understanding of the effect of SST on spawning, recruitment and growth for crabs, prawns and scallops				■					Some knowledge of temperature effects on crabs, prawns and scallops – **see section 3.6.3 Blue swimmer crabs, 3.6.4 Prawns, 3.6.8 Environmental influences on fisheries**	Focus of current FRDC project- **'Understanding the relationship between commercial prawn species population dynamics, fishing patterns and climate in the Shark Bay World Heritage Area in Western Australia'**		
To what extent has recreational fishing catch and effort changed over time with the increased use of bigger boats and fishing techniques?					■						DPIRD have plenty of data from recreational fishing surveys over 20+ years. Just need to find time to write up	

What are shark depredation rates for recreational fishing										Various DPIRD projects currently underway		
What is the level and ecological significance of by-catch from commercial and recreational fishing?									**See section 8.2 Fisheries management** for reference to annual State of the Fisheries reports, which includes some information on bycatch		On-going core business for DPIRD – monitoring and assessment of fish stocks (recreational and commercial)	
Impact of flooding and the flushing of prawns and crabs into deeper water									Outflow of high salinity waters from Shark Bay to the continental shelf via deep channels could be flushing scallop larvae out of the Bay – **see section 3.6.5.1 Spawning and recruitment**	Some existing understanding but FRDC and ICoAST add to this		
Better understanding of the effects of marine heatwaves and seagrass loss on species targeted by the Shark Bay Beach Seine and Mesh Net Fishery										FRDC and ICoAST projects underway	DPIRD core business	
Is the Gascoyne Demersal Scalefish Fishery being significantly impacted by factors such as sharks, environmental effects on recruitment, barotrauma and discarding?										Current FRDC Pink snapper project underway- **'Where did the Snapper go? Determining factors influencing the recovery of Snapper stocks on the west coast of Australia'**		
What are the movement patterns of targeted fishes in relation to current management zones?							Do the current management zones provide adequate protection for all targeted species?					
Benthic impacts from discarding shells from the scallop fishery							What are the impacts on the benthic environment from discarding shells from the scallop fishery?					
Ecological impacts associated with the sea cucumber fishery in Shark Bay							What are the ecological impacts associated with the sea cucumber fishery in Shark Bay?		Little to no harvesting actually occurs and customary fishing across WA is considered negligible – **see section 4.3 Traditional hunting and fishing**			

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Has recreational fishing led to a decrease in tourism because of decreased catch rates at particular locations?					■						Good data on this collected every 2/3 years by DPIRD. Also, visitor numbers to the region should be available from Shire or DBCA	
Habitat and bathymetry mapping												
Map marine and relevant coastal conservation reserve habitats at a scale and accuracy that is appropriate for conservation planning and/or management			■					Rolled up under: Undertake high-resolution (e.g. Lidar) bathymetric and habitat mapping, including interannually for shallow waters e.g. Wooramel coast, large offshore banks off Monkey Mia, Dirk Hartog, Faure Sill and Denham flats				
Improve habitat mapping (e.g. seagrass, corals, algae, sponges) to cover the entire Bay, particularly in nearshore areas and/or areas of high human activity	■		■					Undertake high-resolution (e.g. Lidar) bathymetric and habitat mapping, including interannually for shallow waters e.g. Wooramel coast, large offshore banks off Monkey Mia, Dirk Hartog, Faure Sill and Denham flats				
Undertake high resolution bathymetric mapping of the entire Bay	■							Rolled up under: Undertake high-resolution (e.g. Lidar) bathymetric and habitat mapping, including interannually for shallow waters e.g. Wooramel coast, large offshore banks off Monkey Mia, Dirk Hartog, Faure Sill and Denham flats				
What is the level of habitat destruction from extractive industries and what are the long-term impacts e.g. fishing, mining, dredging?					■			What impacts have there been to key habitats due to industrial and other anthropogenic activities e.g. mining, dredging, trawling, coastal 4WD activities				

Management and monitoring											
Are water sport activities, e.g. wind/kite surfing, too restricted?											This question relates to the known need for a review and update of the Shark Bay Marine Park Management Plan, which will address optimal sharing of water estate
How to achieve an alignment of western management with Malgana management? - i.e. all aspects of the environment are interconnected, not separate									This is currently being planned under government joint management initiatives		
Is the current level of management adequate for adherence to DBCA and DPIRD regulations in relation to tourism and recreational fishing? If not, what level of management is needed?							a) Are current management structures (e.g. compliance) and resourcing adequate in adhering to tourism regulations? b) Are current management structures (e.g. compliance) and resourcing adequate in adhering to recreational fishing regulations?				
How can we mitigate against climate change and is there an adaptation plan?							Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures			Holbrook et al 2020 talks about proactive response to marine heatwaves- **Australia wide, not specific to SB or included in literature review**	
Increased focus on interpretation for visitors in relation to Monkey Mia dolphins											More of a request than a research gap

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Create rapid response plans for extreme marine events or occurrences where an ecological value is suddenly impacted, and mechanisms to carry out rapid responses								Creation of rapid response/ adaptive management plans for extreme marine events, particularly when ecological values are affected				
Develop thresholds for the protection of key elements of Outstanding Universal Value of SBWHA								Develop thresholds for the protection of key elements of Outstanding Universal Value of SBWHA				
Assess the level of investment needed to develop capabilities for dealing with significant impacts from climate change								Rolled up under: Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures				
What is the effect of anticipated intervention to preserve ecosystem function? Will it work and is it the right thing to do?								What is the likely success of current ecosystem function intervention and is it the correct thing to do? e.g. adaptation vs intervention				
How to achieve a degree of alignment and integration of strategy, policy and actions to ensure the required actions are embedded into agency plans and budgets and owned by the agencies?								Better integration of Local, State and Commonwealth agencies in the management of Shark Bay. This should be embedded in strategy, policy, and budgets by responsible agencies				
Generate a community and locally managed data system for the environment that is accessible to the community, TOs and researchers								Investigate and deliver best practice knowledge return of research to the community and TOs				
Develop an integrated and shared database that is managed long term by a designated agency								Develop capacity for a shared and collaborative database of current monitoring and research programs. Identify a local agency/organisation to manage database			Significant aspects of this are in place. The capacity associated with them is probably more the issue	

Design or expand on existing monitoring of ecological values that span the marine reserves and WH area, including rapid assessment methods	■	■									The DBCA Marine Monitoring Program is doing this as resources permit		
What is the optimal configuration (e.g. number, size and location) of sanctuary zones in marine reserves, and should there be more sanctuary zones that restrict access and preserve current species diversity and abundance?			■		■			Is the current marine reserve configuration and management zones effective at protecting enough habitat and species biodiversity?					
Should the marine park and World Heritage boundaries be aligned to streamline management?			■					Will aligning marine park and World Heritage boundaries to streamline management positively benefit conservation values?					
Increased Malgana involvement in the management of islands and parks					■						Plan for our Parks is currently engaged in this area		
Incorporation of cultural heritage and Traditional ecological knowledge													
Need for more information on cultural heritage aspects (Indigenous and non-Indigenous)		■			■			Increased knowledge and understanding of cultural heritage, both Indigenous and non-Indigenous					
How do we capture Indigenous behaviours, values and knowledge, and what knowledge has already been lost?	■				■			Rolled up under: Increased knowledge and understanding of cultural heritage, both Indigenous and non-Indigenous					
Recognise the rich cultural and Indigenous values as part of WHP values			■					Move to including cultural and Indigenous values as part of the WHP values					
How do we better integrate local knowledge systems into a comprehensive understanding of the natural environment?					■			How do we better integrate local knowledge systems into a comprehensive understanding of the natural environment?					

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
Will Native Title determination change the fabric of the community i.e. will it bring less acceptance and more racism?												Remove as not relevant to this particular marine science project
Sustainable economic growth and livelihoods												
What are the opportunities for sustainable tourism, ecotourism, cultural tourism and job creation?								What are the opportunities for sustainable tourism, ecotourism, cultural tourism and job creation?	See literature review for reference to 2017 Shark Bay Investment Prospectus			
More economic development for 'Caring for Country'												Remove as not relevant to this particular marine science project
Assessment of overall economic value of Shark Bay WHA, including tourism								Assessment of overall economic value of Shark Bay WHA and marine reserves, including tourism, fishing, blue carbon, ecological assets				
What are the future opportunities for aquaculture?									See Literature review for reference to report by Australian Venture Consultants 2016 on aquaculture prospects and feasibility of finfish species and edible oysters. A suite of species are considered as potential candidates for aquaculture in the conditions of Shark Bay (DoF 2004) – see section 6.2 Aquaculture		DPIRD would have something on this	
What is the economic value of parks and ecological assets (e.g. seagrass, coral, mammals, sharks), and can this lead to a better regard for the environment under the influence of tourism								Rolled up under: Assessment of overall economic value of Shark Bay WHA and marine reserves, including tourism, fishing, blue carbon, ecological assets				

Frame the values of the WHP/ park to include the economic, social and cultural values alongside the environmental values to enhance the overall regard for area by the community and tourists alike									DBCA will include an assessment of economic, social and cultural values in their plans – e.g. Plan for our Parks		
What will be the economic impacts from climate change in 20–50 years time (e.g. coastal inundation, cyclones)? Is there an adaptation strategy for Shark Bay?							What will be the economic impacts from climate change in 20–50 years time (e.g. coastal inundation, cyclones)? Second part of question rolled up under: Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures				
Are economic imperatives (e.g. fishing) overriding sustainability?							Undertake a cost-benefit analysis of the various industries operating in Shark Bay e.g. recreational fishing industry				
Develop a socio-economic long-term monitoring program							Develop a socio-economic long-term monitoring program				
What are the opportunities for locals to build a career and sustain it into the future while remaining in Shark Bay?											Remove as not relevant to this particular marine science project
What is the best way to set up the community for sustainable livelihoods?											Remove as not relevant to this particular marine science project
How can the primary producers (pastoralists and fishers) with long standing social and economic ties to the community be included and not marginalised in Shark Bay?							What initiatives could be developed to foster inclusion of the whole of community, including primary producers (fishers and pastoralists)?				

Original question/gap	Gap origin?							What was the end result for the original gap?				
	1	2	3	4	5	6	7	Reworded	Knowledge available in WAMSI literature review?	Current/ proposed project addressing gap	Data available for gap-communication needed	Other
What are the social and economic benefits of fishing in the Gascoyne region (recreational and commercial)?								Rolled up under: Assessment of overall economic value of Shark Bay WHA and marine reserves, including tourism, fishing, blue carbon, ecological assets				
What job opportunities and research training are available now and in the future for Malgana?								What future economic opportunities are available for Malgana (in sea country research?)				
Better understanding of Indigenous economic interactions with World Heritage values												Remove as not relevant to this particular marine science project
Education and communication												
Increase community engagement and environmental stewardship								Rolled up under: Investigate and deliver best practice knowledge return of research to the community and TOs	Some current educational activities happening with schools. Visitor centres at Monkey Mia and Denham and interpretative signs aim to increase education – **see section 5.1.4 Educational and scientific values**			
Increased education for recreational fishers on fishing rules, catch handling and sustainable practices											DPIRD to communicate	
What are the most effective avenues for research communication to the Malgana and Shark Bay Community								Rolled up under: Investigate and deliver best practice knowledge return of research to the community and TOs				
Would local incentives, such as assigning ambassadors, foster and increase environmental stewardship?								What initiatives could be developed to foster and increase environmental stewardship? e.g. ambassadors				

What are the best avenues for sharing cultural knowledge with tourists and fishers so they can better understand cultural sensitivities?								What is the best way to share cultural knowledge with tourists and fishers so they can understand and respect cultural sensitivities?				
Tourism and visitor use												
Why do people visit Shark Bay?									Monkey Mia tends to form part of a multi-destination itinerary. Most visitors planned visits or activities related to the marine or coastal environment, with Monkey Mia, Shell Beach, Denham and Hamelin Pool stromatolites being among the most popular places to visit (Reark Research 1995; Smith et al. 2006a). Viewing dolphins and dolphin interactions had the most participation from visitors at >90% – **see section 6.4 Tourism**			
Better promotion of other towns and locations in Shark Bay to even out the pressure from tourism								Develop management planning to reduce the concentrations of tourists in one place by promoting other locations and towns in the region				
What are the impacts from visitation on the environment and wildlife?								What are the impacts of recreational and commercial (licensed tour operators) access to marine fauna?				
Particularly in areas of key interest and high pressure												
What is the carrying capacity for tourism in Shark Bay, and in specific areas of interest e.g. national parks, Herald Bight, Monkey Mia?								What is the carrying capacity for tourism in Shark Bay, and in specific areas of interest e.g. national parks, Herald Bight, Monkey Mia?				
Assessment of pollution levels (rubbish and fishing gear) created by tourists and fishers and the impacts on marine and terrestrial fauna								Assess the pollution levels (rubbish and fishing gear) created by tourists and fishers and the resulting impacts on marine fauna?				
How can tourism peaks be minimised and what would it take to increase the length of stay by visitors in order to reduce peaks e.g. 3 days into 10 days?								How can the peak number of tourists be reduced and their length of stay increased?				

11.12 Appendix 12 Prioritised knowledge gaps for Shark Bay

All = all stakeholder groups combined; R = Research; G = Government; M = Malgana; U = University; MT = Management; F = Fisheries; T = Tourism; SB = Shark Bay community; V = Visitor. Ordered by All. Top five knowledge gaps are highlighted for each stakeholder group.

Theme	Knowledge gap	All	R	G	M	U	MT	F	T	SB	V
Ecosystem processes and connectivity	How would food webs shift in the absence of key seagrass species under climate change scenarios?	1	1	4	11	21	2	34	11	23	
Climate change	What are the current tipping points, in relation to climate change and anthropogenic pressures, for the current system and the ecological values within it?	2	2	1	5	23	5	47	10	11	4
Climate change	How will key interactions driving large-scale patterns and ecological feedbacks change with extreme events and prolonged climate change?	3	4	7	15	16	7	8	2	21	1
Climate change	What will be the effects of increased heatwave frequency, duration and intensity and predicted gradual climate change heating on key ecological communities and commercially important species in Shark Bay?	4	7	2	11	17	11	6	1	21	6
Management and monitoring	Develop a climate change adaptation plan for the Shark Bay environment and community, including cost of capability development and mitigation measures	4	3	6	5	2	35	8	19	28	4
Climate change	How will the diversity, abundance and range of species in Shark Bay (primarily of conservation and fisheries significance) change as a result of climate change?	5	8	6	15	8	14	3	6	21	2
Seagrass communities	What external processes drive distribution, abundance and variation of seagrass communities and how would ecosystem function change if more tropical species extended their range into Shark Bay as temperate species decline?	5	5	12	20	10	2	10	26	4	10
Ecosystem processes and connectivity	How will climate change affect primary productivity and the flow of energy in marine systems?	6	6	10	11	32	8	39	16	26	
Climate change	What could be reliable measures of sub-lethal impacts of climate change on key fauna and flora? What could be the consequences of sub-lethal impacts e.g. reduced reproductive output?	7	9	10	1	18	4	49	5	22	3
Habitat and bathymetry mapping	Undertake high-resolution (e.g. Lidar) bathymetric and habitat mapping, including interannually for shallow waters (e.g. Wooramel coast, large offshore banks off Monkey Mia, Dirk Hartog, Faure Sill and Denham flats)	8	7	8	8	21	10	6	50	11	
Management and monitoring	Develop indicators and monitoring thresholds for the management of key elements of Outstanding Universal Value of Shark Bay World Heritage Area	8	5	12	2	37	27	30	19	22	4
Climate change	What are the climate change associated predictions to changes in freshwater runoff, nutrients and organic matter into Shark Bay?	9	20	9	11	36	1	11	4	21	8
Incorporation of cultural heritage and Traditional ecological knowledge	How can the western science community work with Traditional Owners to create more holistic understandings of the Shark Bay environment?	10	6	3	23	44	11	54	46	14	
Ecosystem processes and connectivity	What are the important physical, biological, ecological and chemical relationships that connect different habitats and communities? e.g. energy transfer, ontogenetic and seasonal movements, biological filtration?	11	9	36	6	15	16	29	49	24	
Benthic communities	How does the distribution of algae and seagrasses influence the abundance and species composition of marine fauna?	12	23	6	3	1	53	15	29	8	12

Environmental conditions	How does local and regional hydrology influence ecological processes (propagule dispersion, nutrient supply, recruitment, connectivity) and threats (oil spills, introduced species) and how can predicted changes to hydrology help inform marine reserve planning?	12	13	13	13	26	23	53	17	21	
Management and monitoring	How do we deliver best practice knowledge return of research to Traditional Owners and the wider Shark Bay community?	12	10	18	10	20	38	43	8	21	14
Sustainable economic growth and livelihoods	What future economic opportunities are available for Malgana (in sea country research)?	13	10	17	32	4	35	38	22	13	
Tourism and visitor use	What is the carrying capacity for tourism in Shark Bay overall, and in specific areas of interest (e.g. national parks, Herald Bight, Monkey Mia)?	13	12	23	21	12	50	46	3	2	
Seagrass communities	Is large-scale restoration or protection of seagrass meadows feasible?	14	11	18	28	3	22	8	14	20	13
Incorporation of cultural heritage and Traditional ecological knowledge	What is the process for including cultural and Indigenous values as part of Shark Bay World Heritage Property values?	15	15	5	6	13	26	52	41	9	
Benthic communities	What are the natural anthropogenic (including climate change) threats to mangroves in Shark Bay?	16	9	19	38	22	49	21	19	2	10
Education and communication	What are appropriate ways to share cultural knowledge with tourists and fishers so they can understand and respect cultural sensitivities and the timeless role of Traditional Owners in sea country stewardship/ management?	17	14	9	34	38	27	45	23	20	12
Seagrass communities	What is the current diversity and distribution of macro-invertebrate and fish species inhabiting different species of persistent seagrass?	18	16	26	12	8	3	28	18	17	8
Environmental conditions	What will be the impacts of increased sediment transport if there are less seagrass roots to maintain stability?	19	17	15	13	49	45	16	24	20	
Ecosystem processes and connectivity	What are the ecosystem/trophic links between nutrients, microbes, primary producers, consumers and detritivores across Shark Bay?	20	13	42	11	35	9	37	31	16	
Environmental conditions	How will the loss of seagrass and shifts in the composition of primary producers affect the acidity of the water in Shark Bay, given seagrasses take up carbon dioxide helping to reduce carbonic acid in the water?	21	25	14	17	49	28	16	25	20	
Education and communication	What initiatives could be developed to foster and increase environmental stewardship (e.g. ambassadors)?	22	26	11	33	57	30	12	20	17	3
Management and monitoring	What would a shared and collaborative database of current monitoring and research programs look like, taking into consideration Indigenous intellectual property and agreed data access models? Identify a local agency/organisation to manage a database	22	18	14	21	45	8	27	46	15	11
Incorporation of cultural heritage and Traditional ecological knowledge	Increased knowledge and understanding of cultural heritage values, both Indigenous and non-Indigenous?	23	21	4	31	9	14	53	35	11	
Habitat and bathymetry mapping	What long term changes have occurred in Shark Bay due to industrial and other anthropogenic activities (e.g. mining, dredging, trawling, coastal 4WD activities)?	24	32	32	9	30	6	7	38	11	
Management and monitoring	Are the current management structures in Shark Bay (e.g. compliance) adequately resourced to ensure recreational fishers adhere to recreational fishing regulations?	25	31	17	22	14	39	3	32	3	16
Fish and Fisheries	Where are the important nursery and spawning sites for priority finfish species in Shark Bay (e.g. Useless Loop)?	26	22	39	17	42	22	4	42	7	

Theme	Knowledge gap	All	R	G	M	U	MT	F	T	SB	V
Seagrass communities	How can we better understand the role of seagrasses in carbon capture and how will this influence Australia's blue carbon capabilities into the future?	26	18	40	18	19	20	20	8	20	5
Ecosystem processes and connectivity	Better understanding of benthic productivity within Shark Bay (e.g. seagrasses, macroalgae)	27	29	15	6	6	12	41	43	16	
Management and monitoring	Are the current management structures in Shark Bay (e.g. compliance) adequately resourced to ensure tourists adhere to tourism regulations?	27	34	26	22	15	29	5	34	6	11
Management and monitoring	What configuration of management zones would most effectively protect and conserve marine biodiversity?	28	17	30	21	3	28	37	20	19	11
Tourism and visitor use	What are the pollution levels (rubbish and fishing gear) created by human activity and the resulting impacts on marine fauna?	29	17	43	21	20	56	45	10	4	
Environmental conditions	Undertake higher resolution modelling of the oceanographic environment within Shark Bay, inclusive of local circulation, inflow, episodic flooding, and groundwater considerations	30	27	25	17	5	34	31	47	6	
Ecosystem processes and connectivity	What are the sources of nutrients and how are they cycled in Shark Bay (e.g. Hamelin Pool)?	31	24	31	27	14	31	31	26	16	
Sustainable economic growth and livelihoods	What are the opportunities for sustainable tourism, ecotourism, cultural tourism and job creation?	31	29	38	36	11	55	11	30	6	
Ecosystem processes and connectivity	How productive are pelagic waters and what are the seasonal dynamics? (e.g. phytoplankton and zooplankton)	32	27	40	19	29	18	13	44	6	
Fish and Fisheries	How do environmental factors (particularly those affected by climate change) and other impacts (e.g. fishing pressure) affect the abundance and diversity of fished and non-fished species?	33	39	27	30	11	8	3	48	7	
Environmental conditions	How could the extraction of groundwater influence groundwater pressure and what impact would reduced pressure into the bay have on the benthic communities? (e.g. stromatolites, seagrasses, mangroves and salt marshes)	34	21	35	26	53	25	45	30	14	
Benthic communities	How is invertebrate diversity, distribution and abundance in Shark Bay influenced by climate and environmental drivers and other anthropogenic pressures?	35	35	25	14	33	22	45	33	25	10
Marine megafauna	What level of turtle egg and hatchling mortality is caused by feral and native animals?	36	40	33	6	51	8	25	51	31	
Sustainable economic growth and livelihoods	What are the cost-benefits of the various industries operating in Shark Bay (e.g. tourism, recreational and commercial fishing, salt mining, goat herding, aquaculture)?	37	28	33	36	7	59	17	28	6	
Fish and Fisheries	What are the spatial and temporal patterns of recreational fishing in the marine park and what is the recreational fish take by species and method of catch?	38	30	45	27	34	19	13	38	3	
Marine megafauna	What are the key foraging sites for marine turtles and what are the demographics of turtles using these areas?	39	48	14	5	47	9	21	51	22	
Seagrass communities	To what extent are human activities having a direct impact on seagrass communities (e.g. boat use)?	39	27	21	26	18	34	36	20	17	9
Environmental conditions	Better understanding of temporal and spatial environmental conditions (temperature, salinity, sea level) in Shark Bay	40	35	48	25	51	5	26	41	26	
Environmental conditions	Better understanding of the location and volume of groundwater inputs into Shark Bay (particularly Hamelin Pool and Freycinet Estuary), including nutrient and contaminant concentrations	41	33	26	8	28	13	46	39	21	
Marine megafauna	What is the relative importance of nesting and foraging areas within Shark Bay to broader turtle populations along the WA coastline?	41	45	51	6	50	10	31	51	25	

Marine megafauna	What is the probable impact of climate change and increased storms on turtle nesting beaches?	42	44	24	2	34	17	22	43	32	
Environmental conditions	Better understanding of water and sediment quality across the bay, including nutrient baselines around human populations/moorings, natural levels of turbidity and periodic influxes from flooding	43	42	20	8	41	21	51	21	28	
Management and monitoring	Is intervention to preserve ecosystem function (e.g. seagrass restoration) the correct thing to do (e.g. adaptation vs intervention)?	44	46	16	17	25	30	9	18	21	17
Tourism and visitor use	What are the impacts of recreational and commercial (licensed tour operators) access to marine megafauna, particularly in areas of key interest and high pressure?	44	24	53	21	52	52	50	33	1	
Environmental conditions	What are the important linkages between marine water conditions, chemical processes, seagrass and organomineralisation processes in a carbonate dominated marine environment?	45	40	22	13	43	44	45	27	26	
Fish and Fisheries	What are the cumulative impacts of commercial and recreational fishing on the ecological assets in Shark Bay?	45	34	32	30	47	45	17	38	5	
Management and monitoring	How can we better integrate local, State and Commonwealth agencies in the management of Shark Bay? This should be embedded in strategy, policy, and budgets by responsible agencies	45	43	47	29	39	32	36	37	NA	14
Tourism and visitor use	How can the peak number of tourists be spread out over a greater time period to reduce environmental pressure?	46	19	29	21	55	58	50	44	4	
Sustainable economic growth and livelihoods	What is the overall economic value of Shark Bay World Heritage Area and marine reserves, including tourism, fishing, cultural and ecological assets?	47	40	27	29	10	61	14	23	6	
Environmental conditions	What is the long-term role of the Faure Sill and its structure and function in maintaining Hamelin Pool?	48	48	18	4	53	42	53	45	20	
Marine megafauna	What are the most important processes (natural and anthropogenic) influencing loggerhead and green turtle populations?	49	51	37	2	45	15	25	51	30	
Fish and Fisheries	What is the ecological importance of fishes that are not targeted by recreational and commercial fisheries?	50	29	40	29	36	40	21	41	14	
Marine megafauna	Better understanding of how the movements of dugongs differ demographically, and how dugongs of different ages use critical habitats (e.g. seagrass habitats)	50	39	55	10	50	58	23	48	22	
Benthic communities	How do environmental factors (e.g. salinity, sediment dynamics, erosion and sea level rise) influence the rates of recruitment, survival, growth and physiology of mangroves Avicennia marina and how do variations in structure influence their ecological function?	51	42	28	11	24	52	32	24	30	15
Marine megafauna	What is the trophic ecology of key seabird species and the likely impact of extreme marine events and gradual climate change on these food chains?	51	50	51	24	31	47	44	14	10	
Benthic communities	What are the most appropriate indicators to monitor and measure the condition of stromatolites?	52	37	52	30	50	41	35	9	25	20
Fish and Fisheries	How genetically connected are fish populations within Shark Bay?	53	49	28	30	39	33	10	33	16	
Marine megafauna	When and why do dugongs move, and over what spatial extent are these movements?	53	36	30	23	58	54	23	40	22	
Benthic communities	What factors impede or promote growth and recovery (e.g. after a disturbance) of different corals at Shark Bay?	54	48	40	27	34	51	43	12	27	13
Marine megafauna	Has shark abundance increased in Shark Bay and why (e.g. is this related to offal discard from recreational fishing)?	54	47	56	24	51	60	4	14	10	
Benthic communities	What intrinsic (gene expression and metabolomics) responses and external (environmental) conditions will influence the formation, growth and survival of microbial and microbialite communities under a changing climate?	55	38	32	15	48	36	42	39	22	19

Theme	Knowledge gap	All	R	G	M	U	MT	F	T	SB	V
Marine megafauna	What is the genetic structure of dugongs in Shark Bay and what level of genetic connectivity is there for dugongs along the WA coast?	55	41	54	2	58	48	33	48	22	
Fish and Fisheries	What are the spatial and temporal patterns of species caught by recreational fishers?	56	53	44	32	54	30	2	28	13	
Ecosystem processes and connectivity	How are Shark Bay corals connected to other corals/reefs along the WA coastline and deeper waters?	57	48	34	17	53	47	28	36	21	
Management and monitoring	Would aligning marine park and World Heritage boundaries to streamline management positively benefit conservation values?	57	56	49	21	3	51	24	37	7	14
Marine megafauna	Have key nesting/roosting areas in Shark Bay remained the same for seabirds/shorebirds over time, and are they expected to change due to climate change?	58	53	53	24	33	46	40	14	22	
Fish and Fisheries	What is the survivorship of released fishes?	59	55	41	32	46	62	1	19	12	
Fish and Fisheries	What finfish species are considered culturally important?	60	33	46	35	57	63	38	8	18	
Benthic communities	What is the composition, distribution and ecological significance of salt marshes and other riparian vegetation?	61	57	41	24	40	29	30	37	22	7
Ecosystem processes and connectivity	How genetically connected are fish populations within Shark Bay (not limited to pink snapper)?	61	54	48	12	52	37	25	19	21	
Benthic communities	What life stages of organisms are associated with mangrove habitats and is this use dependent or opportunistic?	62	52	48	32	29	58	20	25	25	18
Marine megafauna	How do whalesharks use the Shark Bay region?	63	49	50	7	59	57	44	14	10	
Marine megafauna	What is the species composition and relative abundance of sea snakes in Shark Bay and how best can they be monitored?	64	56	54	24	55	43	40	14	31	
Marine megafauna	What are the cause(s) of disease and death of sea turtles in Shark Bay e.g. fibropapillomatosis in turtles?	65	59	48	24	27	62	18	14	29	
Fish and Fisheries	Would imposing maximum sizes for species caught increase the sustainability of targeted recreational fish?	66	58	57	36	35	49	21	15	15	
Fish and Fisheries	What are the ecological impacts associated with the sea cucumber fishery in Shark Bay?	67	60	54	37	31	24	48	13	19	
Fish and Fisheries	What are the impacts on benthic habitats from discarding shells from the scallop fishery?	68	61	51	33	56	60	19	7	18	
Marine megafauna	Develop an improved understanding of the significant habitats for dolphins (e.g. areas used for feeding or reproduction) and, in particular, the demographics, distribution, abundance, residency and habitat use of Australian humpback dolphins	69	61	58	16	54	64	30	14	29	

11.13 Appendix 13
Current and recently completed projects and programs in Shark Bay

11.13.1 UWA

11.13.1.1 Circumventing demographic processes that limit seagrass restoration

Project description: This project aims to explore a demographic approach for seed-based restoration of seagrasses. Sustainable strategies are needed to restore the structure and function of seagrass ecosystems. Although seed-based restoration has been successfully used for decades in terrestrial ecosystems, failures in seagrass restoration are common because the science of seed-based restoration is grossly underdeveloped, and transitions from dispersed seed, seedling, recruiting juvenile to reproductive adult in seagrasses are poorly understood. Recent demographic approaches in terrestrial vegetation restoration identify transitions most limiting to recruitment and successful establishment. Anticipated outcomes are successful seed-based restoration of seagrasses.

Contact: John Statton

Funding details: ARC Linkage Project, $385,893, 2016–2019

Industry Partners: Shark Bay Salt, BMT Oceanica, Rottnest Island Authority

11.13.1.2 Seagrass adaptation and acclimation responses to extreme climatic events

Project description: This research aims to advance our understanding of how temperate marine plants in their northern limit will respond to the effects of synergistic stressors from extreme events combined with climate change. The research will be conducted in the UNESCO World Heritage site of Shark Bay, where a semi-permanent, salinity gradient maintained by shallow seagrass banks has resulted in unique ecosystems like stromatolites to persist. The project will generate new knowledge in the area of adaptation and acclimation to climate change using a multidisciplinary, whole plant approach to examine the links between phenotypic plasticity, ecophysiological traits, and its genome. Expected outcomes include practical solutions for building resilience to climate change mitigation in marine ecosystems.

Contact: Elizabeth Sinclair and Gary Kendrick

Funding details: ARC Discovery Project, $551,053, 2018–2020

11.13.1.3 Assisting restoration of ecosystem engineers through seed-based and shoot-based programs in the Shark Bay WHS

Project description: This project is a collaboration between scientists and the Shark Bay Malgana Indigenous community to jointly develop seeding and shoot planting methods to assist natural recovery of seagrasses in the Shark Bay World Heritage Site (WHS). The goal is to scale-up existing restoration research to assist recovery of the dominant seagrasses, Amphibolis antarctica and Posidonia australis following the 2011 marine heat wave. The Shark Bay WHS is unique globally for its natural values, including stromatolites, extensive seagrass meadow that have constructed sills and banks over 1,000s of years resulting in restricted exchange with the ocean, unique and abundant marine megafauna including 1/8th of the world's population of dugongs, large populations of sharks and turtles, and one of the longest studied populations of dolphins in the world. The inshore waters of the WHS provides connectivity to the deeper waters of the adjacent Commonwealth Shark Bay Marine Park.

There are two parts to this research – (1) Collection of baseline population genomic diversity and connectivity estimates across the salinity gradient, and (2) Assisting natural recovery of seagrass meadows through the collection of reproductive and vegetative propagules for on-ground restoration activities.

Contact: John Statton and Elizabeth Sinclair

Funding details: NESP Marine Biodiversity Hub, $200,000, 2019–2020. Funding is matched by an equivalent amount of in-kind support and co-investment from project partners and collaborators.

11.13.1.4 Gathaagudu Animal Tracking (GAT) Project

Project description: The Gathaagudu (Shark Bay) Animal Tracking Project (GAT) will investigate the movement and habitat use patterns of key marine megafauna species (such as dugongs-WUTHUGA, turtles-BUYUNGURRA, and tiger sharks-THAAKA) in the World Heritage Area of Shark Bay. The project will use satellite tags and eDNA to identify the interactions between these species and the habitat availability in Shark Bay, such as the extensive seagrass beds, to understand how they may be impacted by climate change.

Contact: Ana Sequeira and Matthew Fraser

Funding details: Jock Clough Marine Foundation, Kemper Shaw, James and Marion Taylor

11.13.1.5 iCoAST

Project description: Coastal environments and ecosystems in Western Australia are facing a time of unprecedented pressures, from a combination of population growth and climate change. Understanding and predicting future changes in our marine environment require mapping and monitoring to assess impacts of current processes. Western Australia's marine estate provides huge economic benefits to industries such as fisheries, trade, and tourism, and also has huge cultural and social significance with 85% of Australia's population living within 50 km of the coast. The purpose of this project is to develop and apply a suite of tools and methods to improve monitoring and current understanding of ecological and physical processes in north-west WA including Gathaagudu (Shark Bay), the Gascoyne, and Perth regions.

Contact: Sharyn Hickey, Ben Radford, Tim Langlois

11.13.1.6 Malgana Sea

Project description: A project aimed at building research capacity within the Malgana by formalising Traditional ecological knowledge and providing training in western marine science.

Funding details: Minderoo Foundation

Contact: Jock Clough Marine Foundation

11.13.2 Murdoch University

11.13.2.1 Pearls, People and Power: Global Commodity History and Material Culture in the Transformation of the Indian Ocean World, 16th–20th Centuries

Sub-project: History of Shark Bay Pearling Industry

Project description: Investigating the origins and evaluating effectiveness of management arrangements between the 1890s and Second World War within the context of changing economic and environmental conditions affecting the local pearling industry.

Contact: Joseph Christensen

Funding details: ARC Discovery Project, $438,058 (in total), 2015–2019

11.13.2.2 Hazards, Tipping Points, Adaptation and Collapse in the Indo-Pacific World Post-1000 CE

Sub-project: Reconstructing cyclones and storm surges from historical (eyewitness) accounts.

Project description: Mathematical modelling of 1921 TC and storm surge event based on archival and other documentary evidence, and relating longer-term environmental effects of the cyclone and storm surge to recent and anticipated climate change impacts in the Shark Bay marine park.

Funding details: ARC Discovery Project, $374,516 (in total), 2015–2019

11.13.3 Curtin University

11.13.3.1 Sulfur Cycling in Toxic Oozes, Microbialites and Petroleum

This project will apply compound specific sulfur isotope analyses to sulfur-rich deposits from extreme environments including sulfidic black oozes (Peel-Harvey estuary); modern microbialites (for example, Shark Bay) and oils/source rocks (established and frontier oil fields). Sulfur isotopic data, integrated with other stable isotopic and molecular data, will greatly assist the study of sulfur biogeochemical cycles and mechanisms of organic sulfurisation at different diagenetic stages or geological ages. The project aims to address national concerns through measuring the respective impact of anthropogenic and natural changes on environments, helping to understand the evolution of life on Earth and contributing to efficient discovery of our natural petroleum systems.

Contact: Kliti Grice

Funding details: ARC Discovery Project, $444,000, 2015–2017

11.13.4 Georgetown University, Washington, D.C., United States

11.13.4.1 Maternal Effects on Ecology, Sociality, and Fitness in a Long-Lived Mammal

Project description: This project provides students with an outstanding research experience in which they can ask and answer significant questions concerning how genetic, social, and ecological factors interact to shape evolutionary processes and fitness. Through data collection on wild Indian Ocean bottlenose dolphins (Tursiops aduncus) at a UNESCO World Heritage Site in Shark Bay, Australia and genetic sample processing and analysis at the University of the Sunshine Coast's GenEcology Research Centre in Queensland, Australia, students will gain hands on experience performing research as part of an international, long-term collaboration. Each student will be involved through 1 of 3 cohorts and focus on a specific theme centred around the overall topic of maternal influence on behaviour and fitness. Students in cohorts 1 and 2 will focus on ecological maternal inheritance and its fitness consequences, and social maternal inheritance and its fitness consequences, respectively, whereas those in cohort 3 will examine how these maternal influences and their fitness consequences extend beyond a single generation within the maternal genetic line. Through this project, students will be contributing to one of the most comprehensive and detailed long-term studies of a wild mammal in an exciting intellectual, cultural, and physical environment. This IRES will directly support at least 4 graduate and 9 undergraduate students.

Contact: Janet Mann

Funding details: National Science Foundation, $249,387, 2016–2019.

11.13.4.2 The Impact of Maternal Effects on Social Plasticity and Fitness Variation in a Long-Lived Mammal

Project description: Studies of long-lived social mammals such as primates, elephants and dolphins repeatedly show that individual social behaviour is linked to survival and reproduction. Yet, few have examined what factors contribute to individual variation in social behaviour within a species or population. For instance, it has yet to be determined why some individuals are more gregarious than others. In mammals, it is known that mothers have a pervasive influence on offspring behavioural development, not just through genetic inheritance, but also through social learning (maternal effects). Here, the research team will focus on how maternal effects influence offspring social development, a key contributor to individual variation in social behaviour. Dolphins in Shark Bay, Australia, are an excellent empirical system for examining these questions because they live in a large open and dynamic social community with over one hundred potential associates to choose from. Long-term data on this social system spans 35+ years and enables this team of scientists to quantify: 1). how a dolphin changes its social behaviour in space and time throughout its development, 2). the extent to which this is influenced by maternal and non-maternal effects, and 3). the extent to which maternal effects provide fitness benefits to offspring. This study will have broad reach, appeal, and implications well beyond the scientific community because it will contribute to wildlife policy, management, and conservation as well as train multiple undergraduate and graduate students and early-career stage researchers in STEM.

Contact: Janet Mann

Funding details: National Science Foundation, $865,593, 2018–2023.

11.13.4.3 The long-term impacts of extreme climate events on the behavioural ecology, fitness and population viability in wild bottlenose dolphins, Australia

Project description: This International Research Experience for Students program will support at least three U.S. undergraduate and two U.S. graduate students each year (15 students in total) to collaborate with researchers in Australia to investigate the long-term impacts of an extreme marine heat wave on a population of Indo-Pacific bottlenose dolphins (Tursiops aduncus) that has been studied since 1984. Students will conduct field work in Shark Bay, WA (a UNESCO World Heritage Site with the highest vulnerability rating according to the Climate Change Vulnerability Index), and then wet-lab work at the University of the Sunshine Coast (Queensland). Students will use behavioural and genetic data to answer three questions regarding the dolphin population: 1) how does individual dolphin behaviour change when their habitat is disrupted? 2) how does the individual's social environment and foraging strategies affect their ability to respond to environmental change? and 3) how does habitat fragmentation affect genetic and social connectivity throughout the population? Students will gain computational, field and wet-lab skills from addressing these research topics, as well as policy skills and broad socio-cultural and biological perspectives on wildlife management from their collaborations with local stakeholders and government researchers. In this program students will be afforded a unique opportunity to study genotype-environment interactions in the wild and bring back tools to apply to local conservation issues and wildlife management in the U.S.

Contact: Janet Mann

Funding details: National Science Foundation, $299,599, 2021–2024.

11.13.5 AIMS

11.13.5.1 Exploring the status of Western Australia's sea snakes

Project description: Sea snakes are a national conservation priority given their declining numbers around Australia, and in particular WA which once was a region of high sea snake abundance. All of Australia's sea snakes are listed marine species under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Two of the species that are endemic to north-western Australia are Critically Endangered (the Leaf-scaled Sea snake, Aipysurus foliosquama, and the Short-nosed Sea snake, Aipysurus apraefrontalis) and one is Endangered (the Dusky Sea snake, Aipysurus fuscus). Pressures affecting sea snakes include fishing and trawling, habitat modification and climate change. The causes of recently observed declines have not been defined, however, and an improved understanding of the population status, abundance and distribution of Australian sea snake populations is needed to assist with EPBC listings and the implementation of management and recovery plans. This project will use existing data to define the species range and distribution of key sea snake species in Australia's North-West Marine Region, examine relative abundance between habitats and identify habitat preferences (where possible). Results of the research will help define species status, identify knowledge gaps, assist in EPBC species listing and recovery planning

where required, and guide effective conservation management of sea snakes in Australian waters.

Contact: Vinay Udyawer

Funding details: NESP Marine Biodiversity Hub, $453,015, project current. Funding is matched by an equivalent amount of in-kind support and co-investment from project partners and collaborators.

11.13.6 CSIRO

11.13.6.1 Indigenous Perspectives of Climate Change and Risk

Project description: The Malgana-led climate response project is a 1.5-year project funded by the National Environmental Science Program Climate Systems Hub. It is an Indigenous-led and co-design research partnership that aims to tailor climate science information to enable risk reduction responses tailored to Malgana Peoples' perceptions of climate-related risk. Under the leadership of Malgana Traditional Owners, this project will test participatory mapping, seasonal calendars, and cascading consequence diagrams as knowledge-sharing tools to build adaptive capacities for Indigenous-led climate adaptation planning. The project will work with a large canvass map to explore how climate change will influence the ecological and cultural values of Malgana land and sea Country. This second phase of the project between CSIRO researchers and Malgana Peoples will identify priority risks, opportunities, and responses for climate adaptation planning.

Contact: Peci Lyons

Funding details: NESP Climate Systems Hub

11.13.7 DPIRD

11.13.7.1 Understanding the relationship between commercial prawn species population dynamics, fishing patterns and climate in the Shark Bay World Heritage Area in Western Australia

Project description: There is growing concern the sustainability of prawns may be at increased risk due to a higher proportion of small prawns in commercial catches and fishery-independent recruitment surveys. The brown tiger prawn stock experienced its lowest recruitment in 3 years. The causes of change in prawn size and the magnitude of recruitment remain unknown, but we can identify some plausible hypotheses. These include slowing of growth with lower winter temperatures, a reduction in productivity, changes to timing of spawning, total fishing pressure and intra-annual fishing patterns. It is possible that changes are influenced by interactions between some or all of these. A higher proportion of smaller prawns in commercial catches has continued despite adjustments to management. In addition, the location of prawns during the season has become less predictable. There is an urgent and immediate need to understand the mechanisms underlying these changes to make the necessary management changes to ensure long-term sustainability. The approach will be to use existing datasets to test hypotheses about potential associations between physical (e.g. temperature, rainfall), biological (e.g. seagrass cover), and fishery (e.g. prawn recruitment) variables that we would expect to occur under plausible cause-effect scenarios. These scenarios will be developed through discussions between researchers with different skill sets and insights from prawn fishers. The study will adopt a multi-disciplinary approach to utilise expertise of researchers with skills beyond conventional fisheries science and management, including oceanography, ecology, data science and mathematics, and research specific to the SBPMF and synthesis of the fishing industry. The objectives clearly address both WARAC and the Prawn IPA key priorities of adaptive approaches to changing climate. The objectives are supported by DPIRD managers and some sections of the Shark Bay prawn trawl industry. An independent review of the prawn fishery conducted in April 2019 by Malcolm Haddon provided recommendations regarding research priorities. The review found the objectives addressed a number of key uncertainties identified in the review and suggested they were urgent.

Contact: Dan Gaughan

Funding details: FRDC, $575,616, 2020–2023

11.13.7.2 Where did the Snapper go? Determining factors influencing the recovery of Snapper stocks on the west coast of Australia

Project description: Ensuring that connectivity and stock dynamics are well understood is crucial to determining the appropriate scale for fisheries management and assessment. There is strong industry and management interest in determining the extent to which connectivity and stock dynamics of snapper along the west coast might have changed over time reflecting changes in environmental conditions and stock abundance. There is a need to reassess the most appropriate scale for management of the snapper resource in WA under the new Aquatic Resources and Management Act. There is a need to evaluate whether active-acoustic methods can improve capacity to monitor the spatial distribution and abundance of snapper in key spawning aggregations and whether these methods are complementary to the existing approaches used to assess snapper stocks in the GCB and WCB and elsewhere in Australia.

Contact: Gary Jackson

Funding details: FRDC, $352,587, 2018–2021

11.13.8 DBCA

11.13.8.1 Aboriginal Ranger Program

Project description: The government recognises the social, cultural and environmental benefits of Aboriginal ranger programs and is aware of the excellent work that has already been undertaken by established Aboriginal ranger groups throughout the State. Such programs have provided an integral step towards improved community wellbeing and reducing poverty through economic opportunities and building leadership in remote and regional communities. Led by the Aboriginal community and Aboriginal organisations with support from the Parks and Wildlife Service at the Department of Biodiversity, Conservation and Attractions and across government, the program is helping Aboriginal organisations manage country and protect the environment across WA in partnership with the public and private sectors. Funding is available for jobs for Aboriginal rangers, training, and community development.

Contact: Aboriginal Ranger Program Coordinator

Funding details: Government of Western Australia, $20 million, 2017–2022

11.13.8.2 Monkey Mia Rejuvenation

Project description: This project will continue the staged rejuvenation of public visitor facilities in the Monkey Mia Conservation Park as outlined in the Monkey Mia Master Plan. Four critical infrastructure elements will be developed to support the welfare of the visiting dolphins, enhance the visitors' dolphin interaction experience and promote and interpret Shark Bay's World Heritage values.

Contact: DBCA

Funding details: Australian Government Australian Heritage Grants Program, $400,000, 2018/2019–current

11.13.9 Rangelands NRM Western Australia

11.13.9.1 Reducing runoff and silt loads impacting the Shark Bay WHA

Project description: The project will address terrestrial threats from both pastoral properties and the conservation estate that contribute to the immediate runoff zone into Shark Bay. Remedial work on these properties will also improve the broader catchment and assist in the conservation of the stromatolites, the Wooramel seagrass bank, Faure Sill and the region's significant biotic communities. Three pastoral leases: Hamelin Station, Wooramel Station and Carey Downs Station will be involved in this project and have up to five days with a soil conservation/ecological expert onsite to conduct recommended erosion control measures. Hamelin Station will also conduct a workshop with the Malgana Community and provide the remediation works as a training exercise for them.

Contact: Rangelands NRM Co-ordinating Group

Funding details: Australian Government Australian Heritage Grants Program, $156,631, 2018/2019–2021

11.13.10 Bush Heritage Australia

11.13.10.1 Hamelin Station Reserve

Project description: The purchase of Hamelin Station Reserve extends the Shark Bay World Heritage Area, completing a connected corridor of nature reserves from Shark Bay via Toolonga Nature Reserve, through crown land to Bush Heritage's Eurardy Reserve and then Kalbarri National Park – a span of over 200km. On purchase our initial focus was to remove sheep and goats, decommission water points, and repair infrastructure. After this, fauna and flora surveys have helped provide baseline information for conservation management planning. Hamelin Station Reserve is a research base for studying the Hamelin Pool stromatolites, providing support for Australian and international scientists, students, volunteers and other research partners. These experts are providing insights that will both protect the Shark Bay World Heritage Area and advance our understanding of early life on Earth.

Contact: Bush Heritage Australia

Funding details: Bush Heritage Australia, 2015–ongoing

11.13.11 Australian Wildlife Conservancy

11.13.11.1 Faure Island

Project description: Faure Island is part of the Shark Bay World Heritage Area, tucked between the Peron Peninsula and mainland Western Australia. Being completely feral-free, the island sanctuary is critically important for the conservation of Australia's threatened mammals and is also a crucial breeding area for seabirds – recognised as a Nationally important wetland and nationally important shorebird habitat area. The field programs at Faure Island include an integrated weed control and fire management program, monitoring for feral animal incursions, wildlife translocations and a regular program of ecological surveys. In collaboration with experienced members of Birdlife Australia, shorebirds have been surveyed annually. The results are used to monitor trends in abundance and species richness of shorebirds visiting Faure Island.

Contact: Australian Wildlife Conservancy

Funding details: Australian Wildlife Conservancy, 1999–ongoing

11.13.12 Industry

11.13.12.1 Tidal Moon

Project description: The Tidal Moon Sea Cucumbers project is a collaboration with three Aboriginal communities, Malgana (Shark Bay), Bayungu (Coral Bay/Exmouth) and Thalanyji (Onslow), aiming to develop a viable commercial sea cucumber business while maintaining cultural heritage and environmental stewardship.

Contact: Michael Wear

Funding details: Regional Economic Development Grants, $250,000, and Indigenous Land and Sea Corporation $92,000, 2019–current.

11.13.12.2 Ngala Children's Services

Project description: The Shark Bay Early Years Multi-Age Complex project involves the construction of a new day care complex primarily to operate Education and Care and other community programs focusing on children up to five years, located in the heart of Denham, next to Shark Bay School.

Funding details: Regional Economic Development Grants, $150,000, 2019–current.

11.13.12.3 Mandalay Holiday Resort

Project description: Mandalay Holiday Resort will receive $125,000 to increase the capacity and quality of caravanning and camping experiences available in Denham and the greater Shark Bay area.

Funding details: Regional Economic Development Grants, $125,000, 2019–current.

11.13.12.4 Abacus Fisheries

Project description: Cold chain capacity – procurement of specialised cold chain and processing equipment to develop a sustainable cut crab product and value add to other seafood.

Funding details: Regional Economic Development Grants, $200,000, 2020–current.

11.13.12.5 Miami Bay Holdings

Project description: Heritage Resort Shark Bay – room refurbishment to meet the growing demand for high-end accommodation in the region.

Funding details: Regional Economic Development Grants, $90,000, 2020–current.

11.13.12.6 Dirk Hartog Island Distilleries Pty Ltd

Project description: The Wirruwana Hub will incorporate a visitor centre, bar and café and act as a gateway for visitors and tour operators on Dirk Hartog Island.

Funding details: Regional Economic Development Grants, $145,434, 2018–current.

Credit: Nick Thake

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