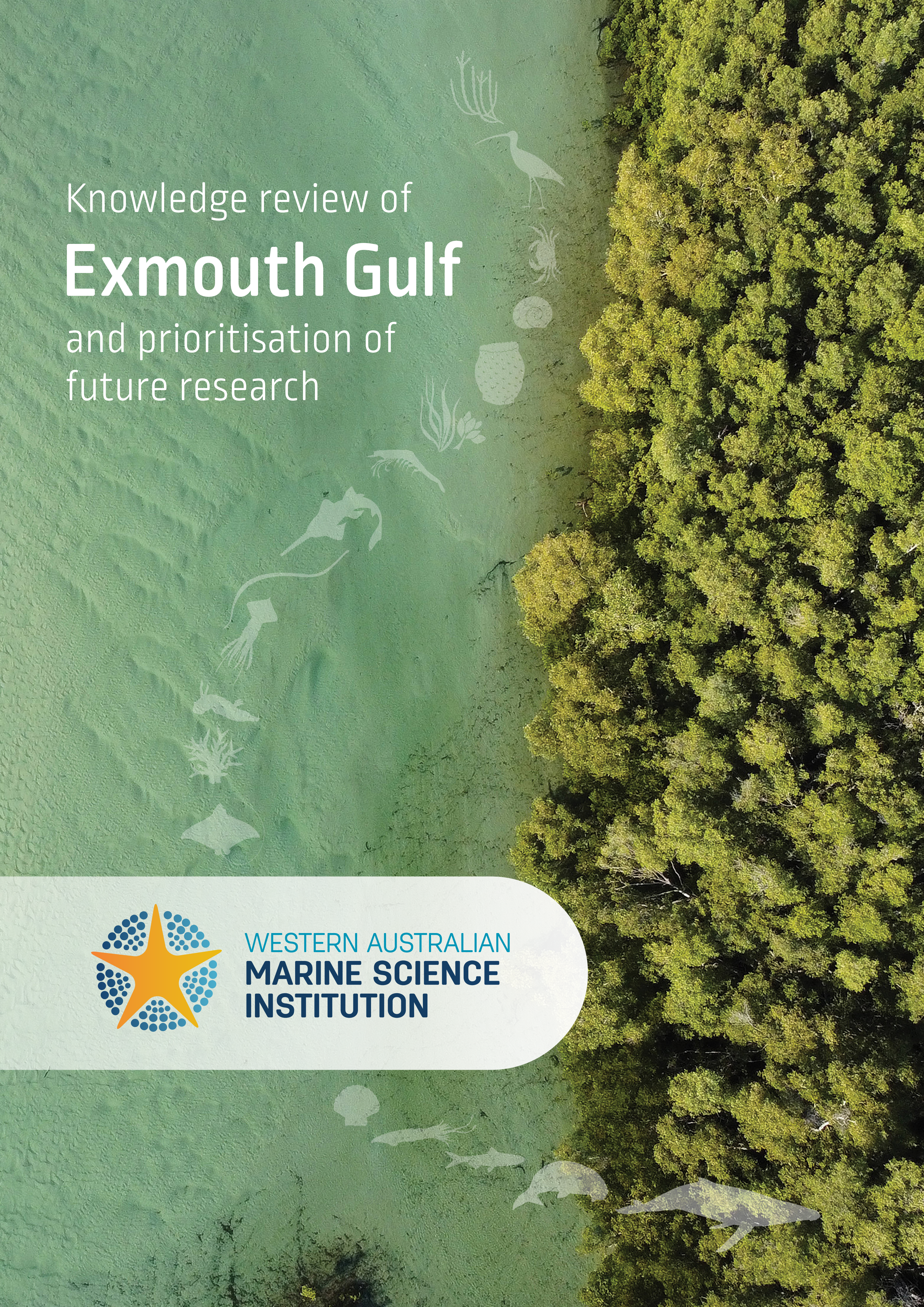
Knowledge review of

Exmouth Gulf

and prioritisation of future research



WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION

> *"This publication is a synthesis of western science knowledge that has been published over many decades.*
>
> *Although a WAMSI document, this work was possible thanks to the collaboration of many dedicated researchers from the WAMSI partnership. Their passion for Exmouth Gulf and enthusiasm for sharing their expertise has helped bring it together.*
>
> *For thousands of years Traditional Owners have known the importance of Nyinggulu, which includes the Gulf, Range and Reef. These areas are seen as a whole, connected, living cultural landscape. We recognise and respect their wealth of knowledge, and deep and ongoing connection to this land and sea.*
>
> *The latest marine heatwave will likely have a significant impact on Nyinggulu. We hope knowledge gaps identified in this publication go some way to improving our western science understanding of this special place and its future management."*
>
> – WAMSI Research Director Dr Jenny Shaw

Knowledge review of Exmouth Gulf and prioritisation of future research

The Exmouth Gulf Taskforce, through the Department of Water and Environmental Regulation engaged the Western Australian Marine Science Institution (WAMSI) to prepare a report synthesising the existing knowledge of the marine and coastal environments of Exmouth Gulf. This report is a synthesis of western science knowledge and has informed the prioritisation of knowledge gaps and identified future high priority research projects. The Exmouth Gulf Taskforce will consider this document as part of its advice to the Minister for Environment, on how future investment into projects (short, medium and long term), can support the ongoing management and protection of Exmouth Gulf.

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Author contributions and acknowledgements

Dr Jenny Shaw had project oversight of the report. Dr Alicia Sutton drafted the contents of the report, with extensive input from Dr Karissa Lear who contributed content, and the artwork featured in the section on elasmobranchs. A range of subject matter experts from the WAMSI partnership were consulted and are acknowledged for their contributions in the document. Drs Sutton and Shaw undertook the structuring, writing, editing and finalising of the publication. Tony Arangio developed the WAMSI maps featured in the document. The Exmouth Gulf Secretariat and Taskforce provided strategic direction and input throughout the development of this report.

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Western Australian Marine Science Institution

The Western Australian Marine Science Institution is a collaboration of State and Federal Government and academic science organisations working together to provide independent marine research for the benefit of the environment, the community and the blue economy.
www.wamsi.org.au

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The State does not necessarily endorse any information, product, process or outcome.

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Front cover: Aerial view Exmouth Gulf mangroves. Michael Tropiano

Above: Underwater views of the Bundegi Sanctuary, Exmouth Gulf. Rebecca Bateman-John

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> *The appendices to this Knowledge Review are available on the WAMSI website:*
> https://wamsi.org.au/research/programs/exmouth-gulf

"Exmouth Gulf habitats support a high biodiversity of marine flora and fauna as well as ecological and conservation significant species, such as sawfish, sea snakes, dugongs, marine turtles, humpback whales and migratory birds."

Olive sea snake. Nick Thake

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Acronyms

AIMS	Australian Institute of Marine Science
ALA	Atlas of Living Australia
AMOSC	Australian Marine Oil Spill Centre
BIA	Biologically Important Area
BRD	Bycatch Reduction Device
BRUVS	Baited Remote Underwater Video Systems
CO_2e	Carbon dioxide equivalent (includes various greenhouse gases)
CR	Critically Endangered
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	WA Department of Biodiversity, Conservation and Attractions
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DD	Data Deficient
DEC	WA Department of Environment and Conservation (now DBCA)
DHW	Degree Heating Weeks
DPIRD	WA Department of Primary Industries and Regional Development
DOT	WA Department of Transport
DSEWPC	Department of Sustainability, Environment, Water, Population and Communities
DWER	WA Department of Water and Environmental Regulation
EAAF	East Asian-Australasian Flyway
EGPMF	Exmouth Gulf Prawn Managed Fishery
EGT	Exmouth Gulf Taskforce
EN	Endangered
ENSO	El Niño Southern Oscillation
EPA	WA Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
IP	Intellectual Property
IMOS	Integrated Marine Observing System
IUCN	International Union for the Conservation of Nature
LC	Least Concern
NE	Not Evaluated
NGO	Non-Government Organisation
NOAA	National Oceanic and Atmospheric Administration, United States of America
NT	Near Threatened
NTGAC	Nganhurra Thanardi Garrbu Aboriginal Corporation
OISST	Optimum Interpolation Sea Surface Temperature
Pers. Comm.	Personal communication
PFAS	Per- and polyfluoroalkyl substances
QR code	Quick Response code
RCP	Representative Concentration Pathway
SST	Sea surface temperature
TEB	Terrestrial Ecosystems Branch (within DWER)
TECs	Threatened Ecological Communities
TSM	Total suspended matter
TC	Tropical Cyclone
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VU	Vulnerable
WA	Western Australia
WAMSI	Western Australian Marine Science Institution
WASCF	Western Australian Sea Cucumber Fishery
YMAC	Yamatji Marlpa Aboriginal Corporation

Acknowledgments

This document is the culmination of extensive work carried out over decades by many people. The research that has been undertaken over this time gives us an additional insight into the diversity and complexity that makes Exmouth Gulf the extraordinary place it is. To be able to capture and synthesise some of this knowledge and to have the opportunity to publish it in a stand-alone document is indeed a privilege.

The Exmouth Gulf Taskforce, Taskforce Secretariat and DWER are gratefully acknowledged for commissioning this work and providing input and advice throughout the process. The Taskforce Strategic Program Manager, Wendy Thompson, enthusiastically and thoughtfully drove the project from its inception. Wendy's attention to detail, policy insights and scientific understanding greatly contributed to the outcome.

WAMSI is a very small team ably lead by our CEO Luke Twomey. Luke's determination to advocate for projects that contribute to a better understanding of significant marine environments is renowned. His leadership and support for every aspect of this project is very much appreciated.

WAMSI's strength is its partnerships. This joint venture partnership includes most of the marine science providers in Western Australia and AIMS in the Commonwealth. It is indeed a privilege to be able to call on our partners and get the best advice and most up-to date knowledge on any topic. In workshops and meetings for this project, there has been excellent uptake by all subject matter experts. They have been willing to attend, collaborate widely, and share knowledge extensively. Although a reflection of the strong and trusted WAMSI partnership, it also demonstrates the passion researchers have for Exmouth Gulf and their desire to better understand and conserve it now and for the future. I thank you all for your contributions.

For the knowledge in this report and associated appendices to be as current as possible, we drew on multiple sources including researchers for academic insight and community members with important local and cultural knowledge. The NTGAC participated in an early workshop, generously shared knowledge and were assisted by the Yamatji Marlpa Aboriginal Corporation.

This following list is not comprehensive, and I apologise for those who have been inadvertently omitted. However, the input from you all has been invaluable and is very gratefully acknowledged: Adam Gartner (O2 Marine), Arani Chandrapavan (DPIRD), Alan Kendrick (WAMSI), Amelia Armstrong (Ningaloo Manta Project), Asha McNeill (Consultant), Ben D'Antonio (UWA), Ben Radford (AIMS), Brett Wolf (Ningaloo Fly Fishing), Caitlin Taylor (DBCA), Camille Grimaldi (AIMS), Catherine Lovelock (UQ), Chris Cleguer (JCU), Chris Fulton (AIMS), Claire Greenwell (MU), Claire Stevenson (DWER), Curt Jenner (CWR), Damien Thomson (CSIRO), Dani Rob (DBCA), David Juszkiewicz (Curtin University), David Morgan (MU), Department of Transport, Emily Lester (Uni of Sydney), Euan Harvey (CU), Fiona Webster (DWER), Gary Jackson (DPIRD), Gary Kendrick (UWA), Glenn Hyndes (ECU), Grace Keast (Sea Slug Census), Grant Griffin (DBCA), Halina Kobryn (MU), Hans Kemps (DWER), Holly Raudino (DBCA), Jess Strickland (UWA), James Gilmour (AIMS), John Totterdell (CETREC WA), Jono Shales (Exmouth Fly Fishing), Karissa Lear (MU), Kate Sanders (University of Adelaide), Kate Sprogis (UWA), Kathryn McMahon (ECU), Kay Davis (AIMS), Kelly Waples (DBCA), Kim Kliska (DBCA), Kym Abrams (DWER), Lyn Irvine (IMFR), Lynda Bellchambers (DPIRD), Matt Hipsey (UWA), Max Stacey (O2 Marine), Mick O'Leary (UWA), Nicole Jones (UWA), Nicole Said (ECU), Oliver Jewell (UWA), Paul Gamblin (AMCS), Richard Pillans (CSIRO), Rachel Newsome (MU), Ralph Talbot Smith (DoT), Rebecca Bateman-John (Fin Focus Research), Rebecca Haughey (DCCEEW), Rebecca Wellard (Minderoo), Renae Hovey (UWA), Ryan Lowe (UWA), Sabrina Fossette (DBCA), Sallyann Gudge (DBCA), Scott Evans (DPIRD), Serena Fletcher (AMCS), Shannon Coppersmith (University of Adelaide), Sharyn Hickey (UWA), Shaun Wilson (AIMS), Sora Marin-Estrella (ECU), Susan Allan (Shire of Ashburton), Tom Holmes (DBCA), Zoe Richards (WAM). The input from every person and organisation has greatly added to a better understanding of Exmouth Gulf. Each contribution is very gratefully acknowledged.

The knowledge in this document is extensive, and as a result: text heavy. We have been fortunate to develop, access and provide explanatory figures and tables, interspersed with photographic images. Most of the images have come from personal collections. They all tell a story, and we are pleased to have access to them. Special thanks to the skilled photographers who have often spent hours obtaining their images: frequently in challenging circumstances. Your skills and generosity are acknowledged, and your photographs have made this document more accessible and comprehensible to all. Thanks to: Alex Hoschke, Andrew McGrath, Birds Eye View, Blue Media Exmouth, Carrie Barclay, C. de los Milagros, Darren Brooks, David Juszkiewicz, David Morgan, DBCA, Grant Griffin, Holly Raudino, Ian Collette, Jenny Shaw, Karissa Lear, Kate Sprogis, Kimberly Kliska, Lyn Irvine, Michael Tropiano, Nick Thake, Nicole Said, Rebecca Bateman-John, Shannon Dee, Sharyn Hickey, Wendy Thompson, Zoe Richards.

Anna-Lee Harry and Cecile O'Connor expertly shepherded the document to publication, Trish Wells and Charli Howard patiently undertook editing, Tony Arangio generated useful maps to orient readers and assisted with the nutrient gap analysis, OOID Scientific skilfully illustrated conceptual nutrient models and Louise Bell Graphic Design produced the set of attractive and engaging documents.

Review of the document was by the WAMSI Board, the Department of Water and Environmental Regulation, including the Exmouth Gulf Taskforce Secretariat, the Marine Ecosystems Branch and Terrestrial Ecosystems Branch (special mention to Fiona Webster, Hans Kemps, Kelly Barnes, Melissa Gaikhorst, Michelle Antao, Robyn Loomes, Sheila Trevisan). Their thoughtful constructive comments were considered and incorporated where appropriate, and their input is gratefully acknowledged.

It is Alicia Sutton however, who has done the bulk of the organisation, structuring and writing required for this publication. Alicia uncovered and synthesised the publications in the previous document 'Cumulative Pressures on the Distinctive Values of Exmouth Gulf'. Alicia then expanded and expertly integrated the new knowledge into this comprehensive and valuable report. She also developed and analysed the prioritisation survey and costings for future research projects. Her contribution and unflagging enthusiasm over the entire project have been remarkable. The document is a credit to her strong networks as well as her exceptional skill and creativity.

We were also very fortunate to enlist the help of Karissa Lear, not only for knowledge on green sawfish, but the synthesis of a large amount of additional material for benthic habitats, marine fauna and anthropogenic pressures. Karissa's passion for Exmouth Gulf, scientific illustrations, networks and excellent writing skills certainly made a significant contribution to the report. Thank you, Karissa.

The companion document: 'State of Exmouth Gulf: reporting analysis and framework 2025', was developed by Luke Twomey, led by Jenny Shaw, written by Asha McNeill with strategic input from Alicia Sutton. Although an excellent policy document, it has drawn on the work undertaken in Exmouth Gulf, and if implemented, will benefit from the comprehensive information now available from this report.

This project has been a delight to work on. Following the earlier risk assessment and cumulative pressures work in Exmouth Gulf, it was a privilege to be approached again by the Taskforce to complete this project. It was always understood to be a WAMSI collaboration, not only with DWER, but our partners. It has been a success, and demonstrated the value of strong teams, collaborative research, knowledge sharing and transparency. I hope this document is a valuable resource for many years to come.

This work represents western science knowledge gathered on Baiyungu and Yinnigurrura Sea Country, the traditional country of the Nyinggulu ganyaranyjarri people. We pay our respects to their elders past, present and emerging.

Jenny Shaw
Research Director
WAMSI

EXECUTIVE SUMMARY

Executive Summary

Exmouth Gulf

Exmouth Gulf is a region of significant ecological, cultural, and economic importance hosting a range of natural values. Biodiverse subtidal and intertidal marine communities and habitats are spread across Exmouth Gulf, including coral reefs, filter feeders, seagrass meadows, mangrove forests and extensive cyanobacterial mats and salt flats.

These habitats support a high biodiversity of marine flora and fauna and as well as ecological and conservation significant species, such as sawfish, sea snakes, dugongs, marine turtles, humpback whales and migratory birds.

The diversity of life is fundamental to the overall health, functioning and stability of the wider Exmouth Gulf ecosystem. The connected environments across land and sea, within and beyond Exmouth Gulf, support nutrient flows and species connectivity, while groundwater and seawater interact to regulate the unique karst system and subterranean fauna of the Cape Range. Exmouth Gulf is deeply connected to the Baiyungu, Yinnigurrura and Thalanyji people, who have sustainably managed and provide stewardship for the region for millennia. Economically, Exmouth Gulf supports local industries and livelihoods, including tourism, pastoralism and recreational fishing, as well as a productive prawn fishery and nursery area. Its proximity to Ningaloo Reef, a World Heritage area, enhances its role as a tourism hub, attracting visitors for snorkelling, diving, and marine wildlife experiences.

Knowledge review, gaps and prioritisation of future research

The Western Australian Marine Science Institution was engaged by the Exmouth Gulf Taskforce through the Department of Water and Environmental Regulation to compile and synthesise existing knowledge on the marine and coastal environments of Exmouth Gulf. This report synthesises western knowledge on ecological connectivity, water and sediment quality, benthic communities and habitats, and marine fauna.

It also addresses how stressors such as climate change and other anthropogenic pressures are impacting on these values. Approximately 500 pieces of literature are included in the knowledge review, spanning newly completed and historical research. Of particular importance is the new knowledge gained for the extent and importance of intertidal habitats along eastern Exmouth Gulf, environmental considerations for coral reefs, habitat use by elasmobranchs and other megafauna, and climate change. A series of reports from the Western Australian Museum highlight the biodiversity of invertebrates and fishes, and how there are still many unidentified and putative species, both collected and uncollected, to systematically and taxonomically address to fully understand the biodiversity in Exmouth Gulf. An emphasis was also placed on synthesising known information on nutrient sources and flows (including a conceptual model) and undertaking a specific nutrient gap analysis to inform future research. In addition to available literature, knowledge statements from 27 subject matter experts are included where current research is underway or not published. Overall, this is a wealth of information that can complement, and be further informed by, the existing and fundamental Traditional Owner knowledge across tens of thousands of years.

Knowledge gaps were collated from various sources, including literature reviews (this report and Sutton & Shaw, 2021), a 2021 workshop with the Nganhurra Thanardi Garrbu Aboriginal Corporation, a qualitative risk assessment process, and informed expert opinion. After refinement and consolidation of similar gaps, 34 knowledge gaps remained that were then organised under nine high-level research themes. The prioritisation of knowledge gaps involved an online survey completed by approximately 340 stakeholders who ranked high-level research themes and, if able, scored detailed knowledge gaps under each theme based on four criteria: ecosystem importance, interest, urgency and knowledge.

The high-level research theme 'Industrial development impacts on coastal and marine environments and recreational activities' was ranked by participants as most in need of attention when considering future research and management in Exmouth Gulf. When filtered by stakeholder group, 9 out of 12 groups included this theme in their top two rankings.

The high-level research themes considered most in need of attention (1) to least in need of attention (9) are:

1. Industrial development impacts on coastal and marine environments and recreational activities (e.g., footprints, noise, clearing)
2. Climate change projections for marine and coastal environments (e.g., sea level rise, marine heatwaves, storms and cyclones)
3. Understanding and maintaining ecosystem health, connectivity, and processes (e.g., nutrient and groundwater flows, spawning and recruitment, land and sea connections, food webs, water and sediment quality)
4. Use of marine and coastal habitats by threatened and protected species (e.g., seagrasses, sponges, corals, mangroves, samphire, feeding areas, nursery areas)
5. Fisheries and fishing effects on important species (e.g., recreational, commercial, charter, bycatch)
6. Effects of increased boating and shipping (e.g., increased sediments in water column, marine pests, fuel and oil spills, vessel strikes)
7. Current and future underwater noise effects on marine life (e.g., seismic activity, vessel noise, construction)
8. Pollution and contamination of the marine environment (e.g., PFAS, bitterns, vessel antifouling, light, marine debris)
9. Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth (e.g., offroad 4WD, anchoring, diving, carrying capacity).

Almost half of the participants proceeded to score some or all the detailed knowledge gaps. The gap '*How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?*' was the highest priority gap, on average, across all participants. Most of the detailed knowledge gaps were concerned with impacts and pressures e.g., development, mining, population growth, habitat degradation, climate change and pollution/contamination. A number of gaps were concerned with better understanding the marine environment and associated flora and fauna.

Recommended high priority projects for future funding

Marine heatwaves are having significant negative impacts on marine life in Exmouth Gulf and proposed coastal developments could soon amplify cumulative pressures. There are still fundamental ecosystem knowledge gaps that need to be better addressed to improve understanding of the marine environment of Exmouth Gulf and surrounds, and how to best manage it under increasing pressures. A loss or change to nutrient sources and flows could pose significant risks to benthic habitats, commercial prawn populations, food webs and species connectivity, and have cultural, social and economic consequences. A suite of research projects is recommended below to address priority knowledge gaps. However, this does not negate the need to address the remaining knowledge gaps, or other gaps that were not captured in this report. Two areas of particular focus are recommended:

- Biogeochemical modelling to address the uncertainties around nutrient sources and flows, and
- Further investigation of conservation listed species, such as sawfish and other elasmobranchs.

Research is fundamental for generating new knowledge whereas fit for purpose monitoring programs are essential for detecting change and analysing trends over time. Monitoring programs are recommended to help address many of the knowledge gaps, and together with the recommended research projects, will help to inform management of the overall health and functioning of the Exmouth Gulf ecosystem. This report provides an opportunity to highlight the importance of data sharing and collaboration so that current and future investment into Exmouth Gulf will ensure the best outcome for the marine ecosystem and stakeholders.

1. INTRODUCTION

1. Introduction

1.1. Exmouth Gulf environment

Exmouth Gulf (Exmouth Gulf) is in northwestern Western Australia, located between the Gascoyne and Pilbara regions (Appendix 9.1). It is a wide, shallow, marine embayment of approximately 2600 km^2.

Importantly, it is the only sheltered embayment in the Pilbara, and one of only a few along the entire Western Australian (WA) coast. It sits adjacent to the Ningaloo Coast World Heritage Area and the economically important Pilbara region off the northwest coast of Australia.

Exmouth Gulf is of high significance environmentally, socially and culturally. It is of ecological importance to marine life, supporting species of conservation significance, such as sea snakes – warliwurruwara, whales – gujawari, dugongs – yardiyarra, marine turtles – majun, and sawfish (Bayungu Dictionary, 2007), as well as a productive prawn fishery and nursery habitat, and recreationally important fish and crab species. It also supports diverse filter feeding and fringing reef habitats, an intertidal system comprised of widespread mangrove (winjit), salt flat and algal mat communities, and an extensive karst system influenced by groundwater and seawater. The economically important tourism, pastoralism and fishing industries (commercial and recreational) contribute to the regional economy in the Shires of Exmouth and Ashburton.

There is currently minimal coastal development around Exmouth Gulf, where shallow waters support feeding and nursery areas for a range of marine species and birdlife, and the land-sea interfaces support a productive and healthy marine environment. The King Reef artificial reef in Exmouth Gulf provides habitat for a diverse range of marine species, supporting fish populations and sustainable recreational fishing in the region. The Navy Pier also provides structure for a wealth of marine life and is a popular dive spot for locals and visitors.

A growing number of coastal developments proposed for Exmouth Gulf resulted in a request for strategic advice from the Environmental Protection Authority (EPA) under Section 16(e) of the *Environmental Protection Act 1986* by the Minister for Environment. In 2021, the EPA provided this advice (EPA, 2021) supported by the Western Australian Marine Science Institution (WAMSI) report on the *Cumulative Pressures on the Distinctive Values of Exmouth Gulf* (Sutton & Shaw 2021). Sutton & Shaw (2021) outlined a suite of knowledge gaps that, if prioritised and answered, would better inform management of Exmouth Gulf and its unique values.

The EPA's strategic advice highlighted the significant pressures facing the environmental, cultural and social values of Exmouth Gulf and recommended high levels of protection. This resulted in a marine park being proposed for the eastern and southern parts of Exmouth Gulf along with Class A reserves for Qualing Pool, Camerons Cave and Exmouth Gulf's islands (Figure 1, Figure 2).

1.2. Exmouth Gulf Taskforce and its objectives

In May 2022, the Exmouth Gulf Taskforce (the Taskforce) was established to 'assist the State Government's broader consideration of strategic issues relating to Exmouth Gulf and its surrounds'.

The Taskforce will provide advice to the Minister for Environment (Minister), including, but not limited to:

- A report within the first two years addressing knowledge gaps identified by the EPA in its report, and through consultation.
- Provide specific recommendations including, but not limited to:
  - Options to deliver a high level of protection for the Cape Range Subterranean Waterways
  - Options to deliver long-term integrated management of land and sea, including the establishment of a secure marine reserve over the wider Gulf area that does not adversely impact existing managed commercial fisheries; and adequately considers recreational and charter fishing
  - Options to inform terrestrial and marine protection planning processes.

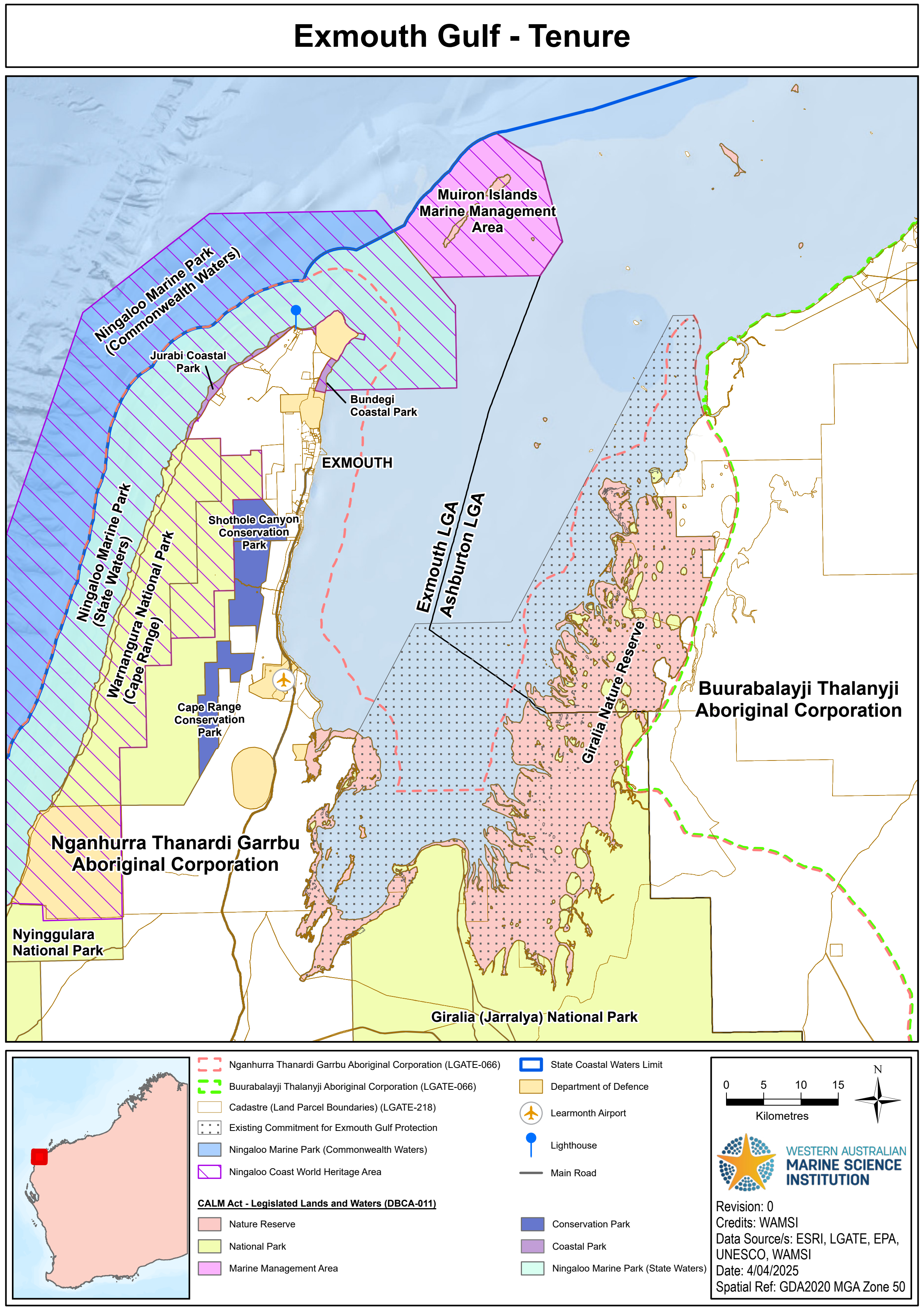


Figure 1: Tenure in Exmouth Gulf.

Figure 2: **Key localities in Exmouth Gulf.**

Research team studying cyanobacterial mat. Shannon Dee

1.3 Approach and scope of this report

WAMSI partnered with the Department of Water and Environmental Regulation (DWER) to deliver a report addressing the knowledge gaps in Exmouth Gulf and surrounds on behalf of the Taskforce.

This report reviews the most current information on the marine and coastal values of Exmouth Gulf and surrounds to assess whether any knowledge gaps identified in EPA (2021) and Sutton & Shaw (2021) have been answered. It also includes additional knowledge published since the 2021 reports.

In this report, the knowledge is synthesised for values relating to benthic communities and habitats, marine fauna, marine environmental quality and coastal processes. In addition, WAMSI was tasked with compiling and synthesising existing information on several focus areas identified by the Taskforce, including:

- Connectivity across the land/sea and between Exmouth Gulf and surrounds
- Nutrient sources and flows into Exmouth Gulf
- Benthic habitat map from existing data
- Water and sediment quality of Exmouth Gulf
- Climate change projections for Exmouth Gulf and likely impacts to key marine ecosystems
- Mitigating impacts to marine megafauna (noise, infrastructure, ship strike etc); and
- Bonefish, dolphins and sawfish in Exmouth Gulf.

The second major component of this report is the prioritisation of knowledge gaps and providing an outline of future high priority research projects, accompanied by approximate costs, timeframes and resourcing requirements. This will enable the Taskforce to provide advice to the Minister on how future investment into projects (short, medium and long term), can support the ongoing management and protection of Exmouth Gulf.

EPA (2021) and Sutton & Shaw (2021) encompassed marine, terrestrial, social, cultural and economic values of Exmouth Gulf. The scope of this report is on the marine and coastal environments only, including those key values that have a connection with the marine environment, e.g., Cape Range Subterranean Waterways (karst systems) and groundwater.

Cyanobacterial mat, Urala. Sharyn Hickey

2. Summary of methodology

Indo-Pacific leopard shark. Rebecca Bateman-John

2. Summary of methodology

2.1. Review of knowledge

The review of knowledge presented in this report builds upon the knowledge synthesised in Sutton & Shaw (2021).

A thorough search of the literature was undertaken using general (e.g., Google Scholar) and biological sciences databases (e.g., Biosis, Scopus, Web of Science, CSIRO e-book Collections, Global Plants). Databases were interrogated using a combination of keywords relating to locations, ecological values and/or species of interest e.g., dolphins AND Exmouth Gulf, macroalgae AND Exmouth etc. For species tables, records obtained from online databases were included if they could be verified against other information sources. Literature and data were also shared by researchers who have recently worked in Exmouth Gulf. Overall, the information gathered for this literature review came from published scientific papers, published and unpublished reports, student theses, and unpublished data. Topics from the focus areas identified by the Taskforce received additional attention to capture all relevant information.

2.2. Nutrient sources and pathways

A better understanding of nutrient sources and flows into Exmouth Gulf was a key focus area for the Taskforce. Given the complexity of this topic, WAMSI facilitated a workshop with 15 researchers and managers from seven organisations who have historically or currently worked on nutrients in Exmouth Gulf. The 15 August 2024 workshop aimed to 1) document all available data and literature on nutrient sources and pathways, 2) review a draft conceptual model of nutrient sources, pathways and nutrient budget estimates and 3) identify knowledge gaps for future research. The current knowledge on nutrient sources and pathways is synthesised in Section 3 and a full workshop report is provided in Appendix 9.2, complete with past and current projects, data sources and next steps.

2.3. Benthic and intertidal habitat mapping

The Taskforce were aware there was no current, published comprehensive, high resolution intertidal and subtidal benthic habitat map for Exmouth Gulf. To improve understanding of Exmouth Gulf ecosystems and habitats for decision makers and other stakeholders, WAMSI aimed to produce a map using publicly available data. A workshop was held 29 May 2024, with 21 participants from 11 State Government agencies and universities who have historically or currently worked on benthic and intertidal habitats in Exmouth Gulf. The purpose of the workshop was to 1) document the existence of benthic habitat data and its availability and 2) decide how best to deliver a comprehensive, high resolution benthic habitat map to the Taskforce.

Each of the organisations outlined their mapping objectives, current approaches and data availability. The full workshop report is synthesised in Appendix 9.3.

The Department of Biodiversity, Conservation and Attractions (DBCA) and Department of Primary Industries and Regional Development (DPIRD) have produced contemporary benthic habitat maps for Exmouth Gulf. As the lead agency for WA's fish and aquatic resources, DPIRD's habitat assessment program began in 2016 to investigate links between Exmouth Gulf Prawn Managed Fishery (EGPMF) effort, recruitment and benthic habitats (DPIRD, 2020). Elements of this program, including mapping critical nursery ground habitats, required multi-season baseline data collection with outputs currently undergoing formal peer review for journal publication, with release expected in early to mid-2025. As the lead agency for conservation of WA's biodiversity, cultural and natural values, DBCA's maps were commissioned in 2024 following the proposal of a marine park within Exmouth Gulf. The mapping aligns with DBCA's responsibilities for marine park planning and conservation and aims to show the location of benthic features of ecological and conservation significance to assist in future management of the Gulf.

Habitat mapping is typically developed to meet specific statutory, scientific, or management objectives. This can result in different categorisation of habitats, different methodologies and modelling outcomes. In a system that is turbid as well as variable seasonally and annually, this can result in quite different looking maps. Given DBCA's lead role in marine park planning, its habitat map has been included in this report for reference (Section 3.4). However, differences in data inputs, classification approaches, and outputs from past, current, or future mapping efforts in Exmouth Gulf by DPIRD, DBCA, Commonwealth Scientific and Industrial Research Organisation (CSIRO) or others (e.g., Loneragan et al.,, 2003; Lyne et al., 2006; Pitcher et al., 2016; DPIRD, 2020; Mellor & Gautier, 2023) are expected and should be interpreted in the context of their scientific merit and intended application, not as inconsistencies (e.g., Figure 3).

Figure 3: An example of how and why benthic habitat maps for the same location (e.g., Exmouth Gulf) can look different. Adapted from Misiuk and Brown (2024; left panel) under a Creative Commons BY 4.0 license.

2.4. Identification of knowledge gaps

The knowledge gaps used in the research prioritisation process were derived from the EPA's 2021 strategic advice (e.g., Sutton & Shaw, 2021), the most recent literature, and specific 'focus areas' identified by the Taskforce through ongoing consultation since EPA (2021). Knowledge gaps were assessed for relevance to the scope (e.g., marine and coastal), and consolidated and refined where possible. Knowledge gaps were also arranged under high-level themes for use in the prioritisation process. A comprehensive description of the methodology is provided in Section 4.1.

2.5. Prioritisation of knowledge gaps

The prioritisation of knowledge gaps for Exmouth Gulf was conducted through an online survey platform to enable broad stakeholder engagement. The online survey consisted of two parts that allowed all stakeholders to participate in the survey, regardless of their level of knowledge of the marine and coastal environments of Exmouth Gulf:

- Part 1 (required): high-level scoring of research themes (nine themes in total)
- Part 2 (optional): scoring of detailed knowledge gaps (36 questions in total)

Part 1 required participants to arrange themes into a rank from: most in need of attention (1) to least in need of attention (9) when considering future research and management in Exmouth Gulf. Part 2 required participants to score individual knowledge gaps based on four criteria: Ecosystem importance, Interest, Knowledge and Urgency.

A description of the prioritisation process is provided in Section 5 and Appendix 9.8.

2.6. Scoping of future high priority research projects

Future research projects were designed to address more than one knowledge gap given many of the gaps were linked and or interdependent on each other. In formulating the projects and costings, the authors reviewed past and current WAMSI science programs and consulted subject matter experts to provide more rigour around the scopes. These projects are purposely broad in scope to allow for refinement by researchers, managers, Traditional Owners and policy setting, and to accommodate and align with any current and future proposed research projects. Importantly, these projects have not been scoped to incorporate cultural science, nor have they been confirmed as priorities by Traditional Owners.

WAMSI Research Director Jenny Shaw and the Taskforce's Strategic Program Manager Wendy Thompson discussing extent of cyanobacterial mats. Carrie Barclay

3. Review of knowledge for Exmouth Gulf

Shannon Dee diving coral reefs of the southern Exmouth Gulf. Nicole Said

3. Review of knowledge for Exmouth Gulf

A literature review of distinctive values in Exmouth Gulf was provided in Sutton & Shaw (2021), which synthesised western science knowledge over nine decades. This current review synthesises this information and any new knowledge since 2021.

Knowledge is structured under headings that would best highlight 1) where fundamental gaps remain, 2) the significance of Exmouth Gulf and 3) the threats and pressures facing the different values. Almost 500 pieces of literature are included along with knowledge statements from 27 subject matter experts. Three reports commissioned by the Taskforce are also included in the synthesis and provided in the appendices:

- Appendix 9.4 Occurrence of marine megafauna along the western margin of Exmouth Gulf, Western Australia, July – October 2023 (Irvine et al., 2025a)
- Appendix 9.5 Absolute abundance and intergroup distances of humpback whales (*Megaptera novaeangliae*) in Exmouth Gulf, Western Australia (Irvine et al., 2025b)
- Appendix 9.6 Exmouth Gulf baseline acoustic monitoring – Final Report (Maxner et al., 2025).

3.1. Climate change

3.1.1. Current knowledge

3.1.1.1. Sea level rise and erosion

Sea level fluctuates year to year depending on large scale climate drivers (e.g., El Niño Southern Oscillation – ENSO, Ningaloo Niño) (e.g., Figure 4). Despite these fluctuations, sea level is rising globally due to melting glaciers and ice sheets in the polar regions, and warming waters causing thermal expansion. For Exmouth Gulf, sea level is estimated to be rising at a rate of 2.8 mm per year (Lovelock, 2021). Continued rise will see low lying intertidal and coastal terrains of Exmouth Gulf experiencing more inundation and erosion, such as for saltmarshes, mangroves, mud, sand, algal mats and salt flats. In Giralia Bay, higher sea levels were believed to be responsible for mangroves recruiting and surviving in higher intertidal areas where cyanobacterial mats were existing (Lovelock, 2021). Intertidal communities will retreat inland in response to sea level rise; however, the ability to adapt is threatened by coastal developments such as salt mining.

Low lying islands characterised by carbonate sands and fringing shallow reef flats are distributed across eastern and southern Exmouth Gulf. A geomorphological examination of Eva, Y, Fly, and Observation Islands found these islands experienced temporal and spatial erosion

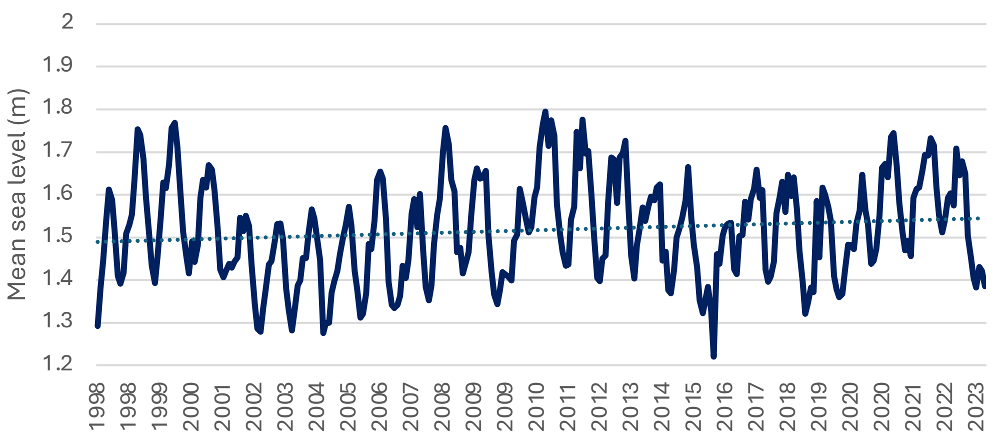


Figure 4: Monthly mean sea level (m) between 1998-2023 for Exmouth Gulf. Data sourced from Bureau of Meteorology.

and accretion in relation to waves, winds, and large-scale climate drivers (e.g., ENSO) (Cuttler et al., 2020). Eva Island, Y Island, Observation Island and Brown Island were assessed as having sensitive characteristics that could make them more suspectable to erosion, inundation and instability (Bonesso et al., 2020).

As the Islands of Exmouth Gulf are important seabird nesting locations and their fringing reefs for carbonate production, it is critical there is a better understanding how they may change with rising sea levels, fluctuating ENSO conditions, winds and cyclones.

Eastern and southern Exmouth Gulf are at most risk of erosion from sea level rise, storms and cyclones due to being relatively flat and comprised of soft sediments and sandy shores. In comparison, large parts of the western margin are dominated by harder, rocky intertidal and subtidal zones, such as unvegetated and vegetated pavement, oyster reefs and rocky reefs (e.g., Bancroft, 2000; RPS Bowman Bishaw Gorham, 2004; Twiggs, 2010; van Keulen & Langdon, 2011; Beckley, 2012; 360 Environmental, 2017).

This is reflected in Exmouth townsite (including buildings and roads) having a relatively lower risk of exposure to inundation compared with other locations across WA (Seashore Engineering, 2024).

3.1.1.2. Water temperatures and ocean extremes

Water temperatures fluctuate in Exmouth Gulf across seasons, with summer months achieving temperatures of ~30°C and winter months ~19–20°C. Three wave buoys (Sofar Smart Moorings) are currently operating in Exmouth Gulf and producing data on surface waves, surface and bottom sea temperatures, two of which produce live data (wawaves.org) (Figure 5). The buoy measurements collected will help to improve understanding of ocean and coastal processes, identify marine heatwaves conditions, as well as improve marine forecasts.

Based on sea surface temperature (SST) data collated between 1982–2025 within Exmouth Gulf, there is evidence to show winter conditions are cooler and occurring earlier and spring conditions are warmer and transitioning faster

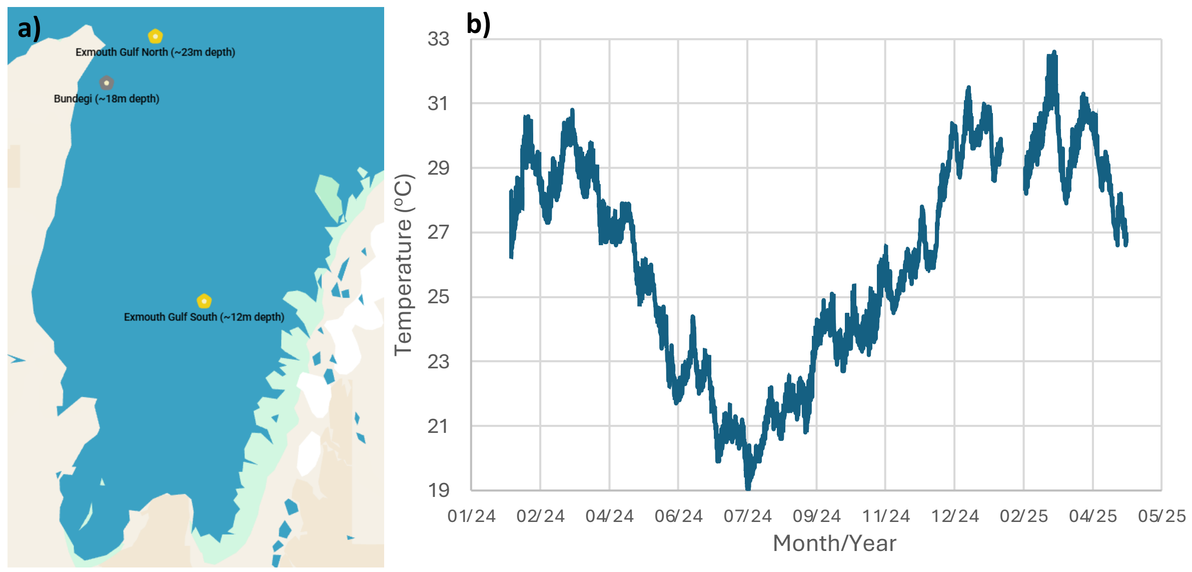


Figure 5: Wave buoys (Sofar Smart Moorings) operating in Exmouth Gulf (a). Exmouth Gulf North and Exmouth Gulf South have been generating live data since February 2024 and Bundegi has been generating data since March 2022 (not live) (UWA, data available at wawaves.org). For example, b) shows sea surface temperature measured by 'Exmouth Gulf South' wave buoy between 7 February 2024 and 28 April 2025. Temperatures peaked to over 32°C in March 2025, which is the warmest ever recorded for Exmouth Gulf. Provided by Nicole Jones, UWA. Data available at wawaves.org

compared to the 1980s (e.g., Figure 6). Ocean extremes, such as marine heatwaves and marine cold spells, have also been documented in Exmouth Gulf. A marine heatwave is defined when warmer than usual SST (warmer than 90% of the previous observations for a given time of year) persists for more than five days (Hobday et al., 2016), and are categorised as Moderate, Strong, Severe and Extreme as per Hobday et al. (2018) (Figure 7). Marine cold spells are defined as the opposite, where prolonged anomalously cold water occurs (Schlegel et al., 2021).

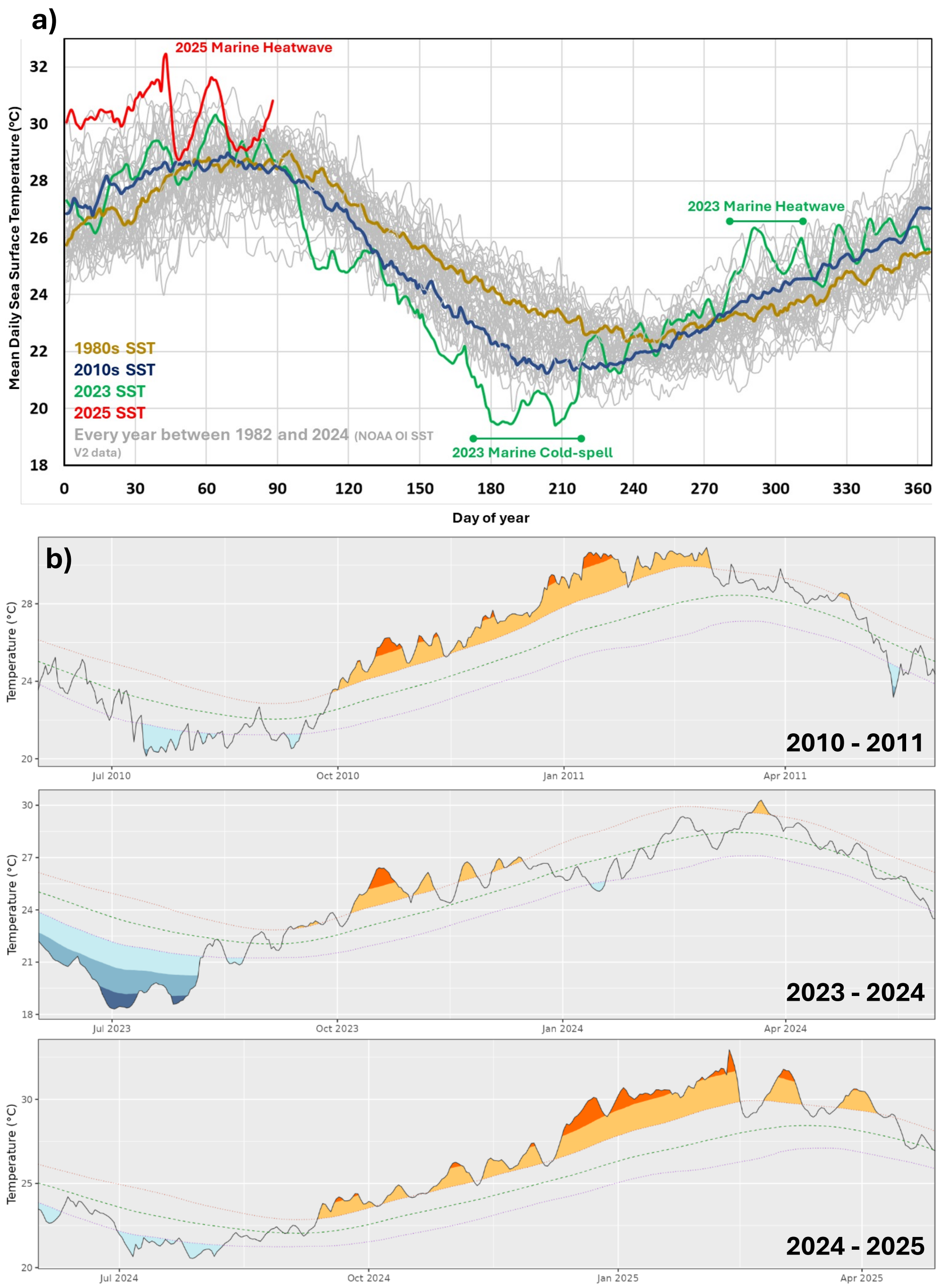


Figure 6: Daily SST within Exmouth Gulf between 1982–2025. Red line represents the continuing high SST marine heatwave conditions in 2025. Supplied by A. Chandrapavan/ DPIRD. b) a closer examination of SST extremes during the 2010/11 marine heatwave, 2023 marine cold spell and marine heatwave, and the 2024/25 marine heatwave within Exmouth Gulf. Source from https://whalemap.ocean.dal.ca/MHW/

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

LiDAR image capture of a tidal creek in Exmouth Gulf.
Collected by Andrew McGrath, Airborne Research Australia

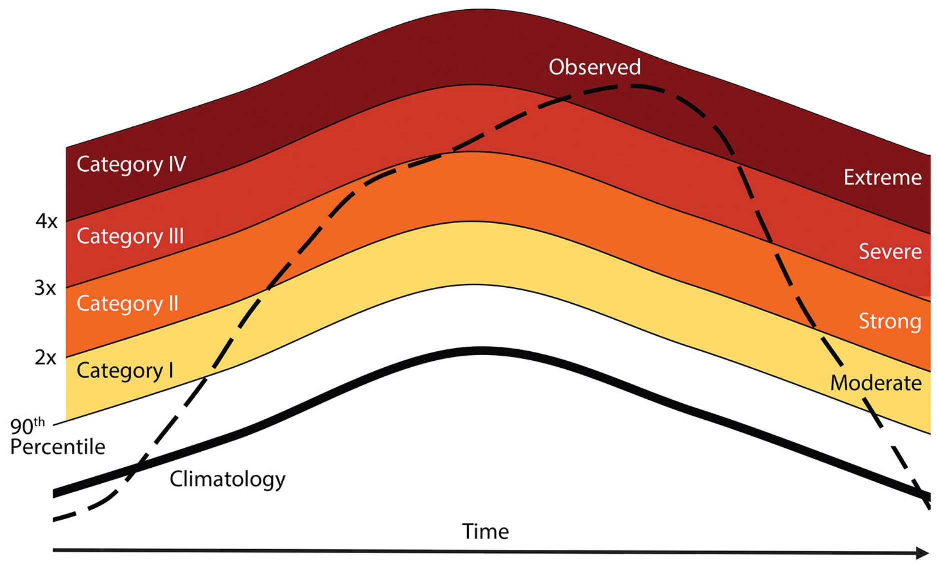


Figure 7: Categorization schematic for marine heatwaves showing the observed temperature time series (dashed line), the long-term regional climatology (bold line), and the 90th percentile climatology (thin line). Multiples of the 90th percentile difference (2× twice, 3× three times, etc.) from the mean climatology value define each of the categories I–IV, with corresponding descriptors from moderate to extreme. Figure and caption taken from Hobday et al. (2018) under a Creative Commons BY 4.0 license – https://creativecommons.org/licenses/by/4.0/

Prior to 2024/25, the most severe marine heatwave on record off the northwest coast of Australia occurred in 2010/11, which had significant impacts to seagrasses, fisheries and other marine life along the Pilbara and Gascoyne coasts, particularly in Shark Bay (Caputi et al., 2016; Kataoka et al., 2018, Feng & Shinoda, 2019; Benthyusen et al., 2020; Strydom et al., 2020). However, at the time of writing this report, a marine heatwave was occurring off the WA coast. Elevated water temperatures of up to 3°C off the northern coast of WA were identified in September 2024 and persisted and intensified to 4–5°C above normal conditions off the Pilbara region, including Exmouth Gulf, in December 2024 (Figure 6; Figure 8). The elevated water temperatures extended to depths of 200 m (N. Jones, pers. comm.). Category 1 to Category 2 marine heatwave conditions were experienced along much of the WA coastline, including the south coast (DPIRD, 2025a). As of April 2025, Category 1 conditions were still occurring off the Kimberley, Pilbara, Gascoyne and south coast regions (DPIRD, 2025b).

The NOAA Coral Reef Watch program uses Degree Heating Weeks (DHW) to measure accumulated heat stress in a location. This measure combines the intensity of daily temperature extremes and the total time when daily temperatures exceed the bleaching threshold over the previous 12 weeks. The number of Degree Heating Weeks in Exmouth Gulf has exceeded previous records (e.g., 2013) by at least ten weeks (Figure 9), highlighting the unprecedented scale of warming. **For comparison, significant coral bleaching is predicted above 4 DHW, coral mortality is expected above 8 DHW, and Exmouth Gulf is approaching 30 DHW.**

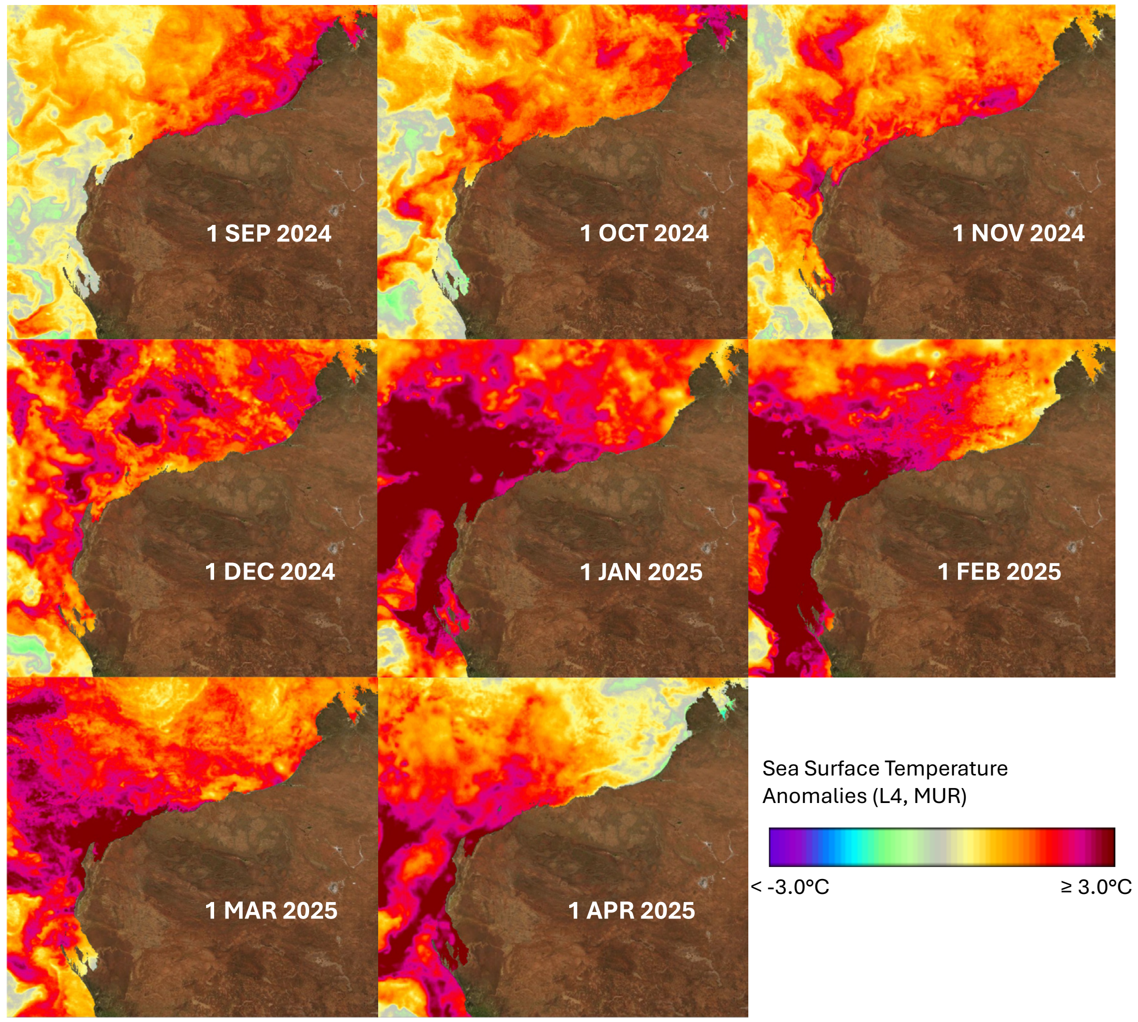


Figure 8: **Sea surface temperature anomalies across the northwest region of WA from September 2024 – April 2025. Imagery sourced from https://soto.podaac.earthdatacloud.nasa.gov/ using data from JPL MUR MEaSUREs Project (2015),** https://doi.org/10.5067/GHGMR-4FJ04

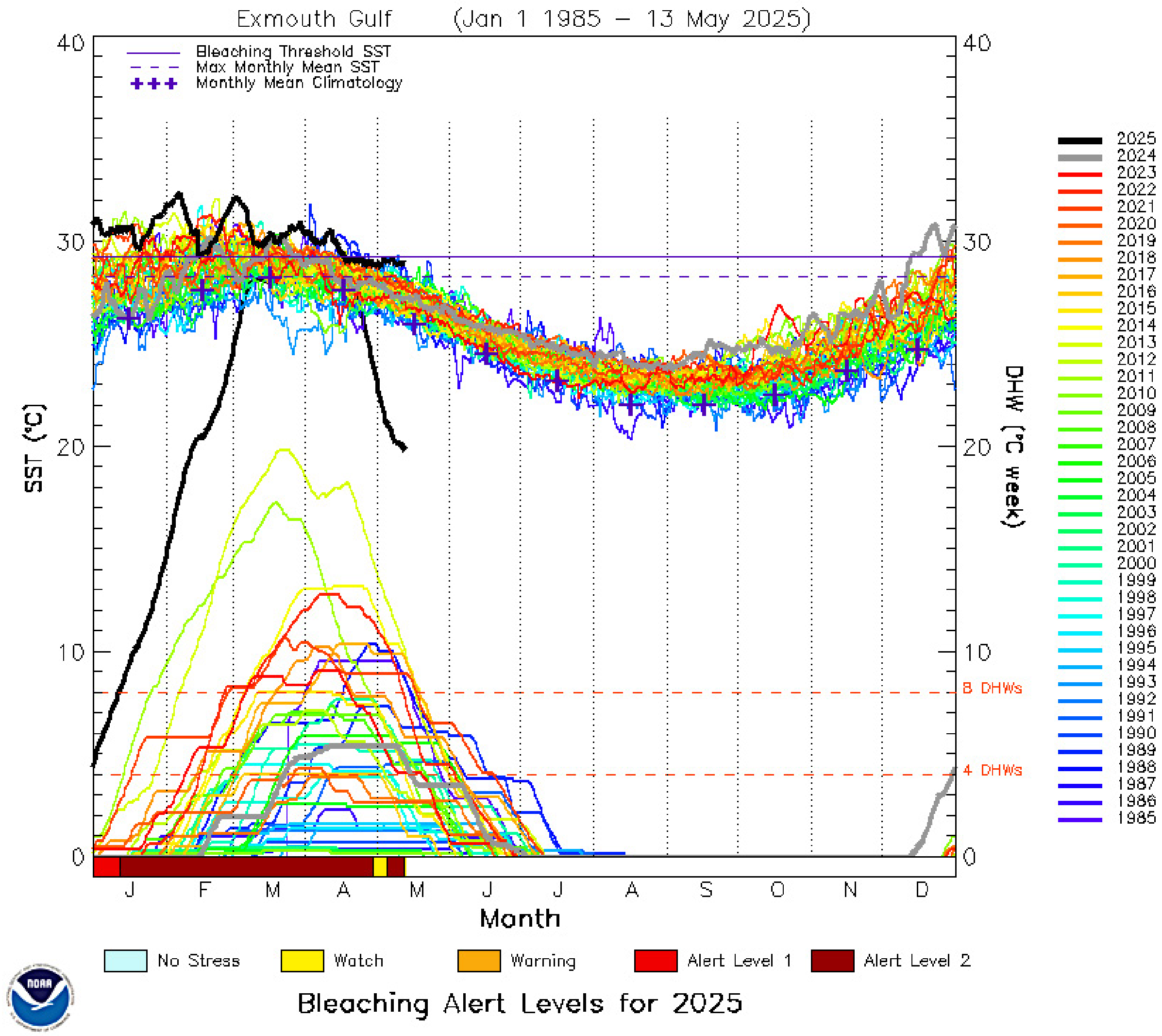


Figure 9: **Multi-year time series graph for Exmouth Gulf showing monthly SST (left axis) and Degree Heating Weeks (DHW) (right axis) for all years between Jan 1985 – April 2025. Taken from the NOAA Coral Reef Watch – Western Australia Experimental 5 km Regional Virtual Station Time Series Graphs.**

The increased SSTs during the 2024/25 marine heatwave have impacted Ningaloo Reef and Exmouth Gulf with records of significant coral bleaching in both areas. A joint Australian Institute of Marine Science (AIMS) and DBCA team of scientists conducted coral bleaching surveys at five sites spread across the western and eastern sides of Exmouth Gulf in early February 2025 (C. Fulton, pers. comm.). A preliminary assessment found 50–80% of coral colonies displayed signs of heat stress (pale, fluorescing or bleached) at each site (e.g., Figure 10), with a wide range in live coral cover across these sites (1–36%). Most coral taxa showed signs of heat stress, with a wide range in coral diversity across the sites. Additional surveys will explore the longer-term responses or corals at these sites, some of which have been visited each year since 2009. Further surveys of seagrass, dugong, fish, invertebrate, algae and coral communities are also planned by DBCA (DBCA, 2025).

Coral biodiversity and health surveys were also conducted at 21 sites across the Ningaloo Marine Park and Exmouth Gulf in March 2025 (Z. Richards and D. Juszkiewicz, pers. comm.), which found significant and widespread bleaching (e.g., Figure 11).

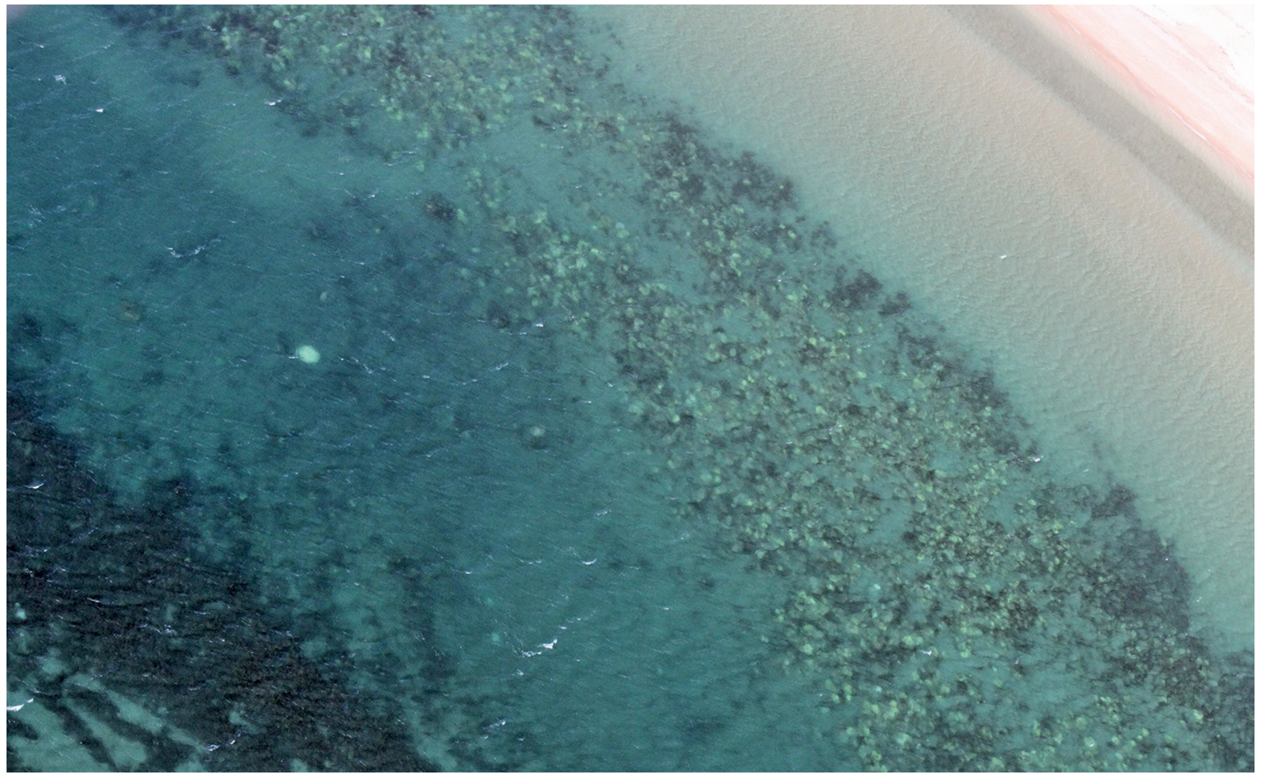


Figure 10: Widespread coral bleaching along the coastline of southwest Exmouth Gulf, photographed in February 2025 during a marine heatwave. Bleached corals (white patches) can be seen stretching alongside the shallow sandy strip. Image: DBCA

Figure 11: Photos of bleached corals in Exmouth Gulf following the 2024/25 marine heatwave. Images: David Juszkiewicz. Images taken during March 2025 field trip funded by the Minderoo Foundation.

At Fly Island in eastern Exmouth Gulf, approximately 80% of scleractinian corals were bleached, many severely including a diversity of corals that are often considered hardy such as *Goniastrea, Pleasiastrea, Platygyra, Turbinaria, Favites* and *Lobophyllia* (Z. Richards, pers. comm.). There was also evidence of recent whole colony or partial mortality amongst corals from the families Acroporidae and Pocilloporidae. Bleached scleractinian corals were also observed at 20 m depth within sponge garden habitats (Z. Richards, pers. comm.).

Following the 2011 marine heatwave there was a significant loss of seagrass in Exmouth Gulf (K. McMahon, pers. comm.), which was predicted to happen again with the 2024/25 marine heatwave. Preliminary findings from an April 2025 survey of a long-term seagrass monitoring site located in the southeastern Exmouth Gulf mostly recorded *Cymodocea* species along transects (N. Said, pers. comm.). *Halodule* and *Halophila* species were almost completely absent from the site, and only a small amount of *Syringodium* was observed. This was predicted given water temperatures were above the thermal optima for these species, but not for *Cymodocea*. At the beginning of March 2025, temperatures recorded at the Exmouth South mooring exceeded 31.5°C for 66 hours over a seven day period (Figure 5; N. Jones pers. com). *Halophila* and *Halodule* are the preferred food source for dugongs, and the flow on effects to this Vulnerable IUCN listed species is to be determined (N. Said, pers. comm.). The flow on effects to the EGPMF is currently under investigation by DPIRD.

Recorded marine heatwaves and their effects on marine life in Exmouth Gulf are provided in Table 1.

Table 1: List of marine heatwaves and associated effects on marine life in Exmouth Gulf.

Marine heatwave event	Effects documented to date	Source
2011 (and Tropical Cyclone Carlos)	Significant bleaching and widespread coral mortality at Bundegi Reef that has not recovered to a pre-2011 state	Moore et al. (2012) Depczynski et al. (2013) Doropolous et al. (2022)
	Seagrass loss	McMahon, pers. comm.
	Low recruitment of western king prawns directly following heatwave peak	Caputi et al. (2019)
	Record low recruitment of brown tiger prawns in the following year (2012) recovered in 2016/2017	Caputi et al. (2019)
2013	Coral bleaching at Onslow	Lafratta et al., 2017
2015/16	Coral bleaching off the Kimberley, no evidence of significant impact for Ningaloo Reef. Exmouth Gulf impacts unknown	Le Nohaïc et al. (2017)
2021	Coral bleaching across Exmouth Gulf	Zweifler et al. (2024) Cartwright et al. (2023)
2024/25 (and Tropical Cyclone Sean)	Coral bleaching along northwest coast, including off the Kimberley, Onslow, in Exmouth Gulf, and Ningaloo Reef.	DBCA (2025) C. Fulton, pers. comm.
	Huge biomass and diversity of benthic fauna, including sponges, soft corals, sea pens, molluscs and other marine life washed up on beaches on the western side of Exmouth Gulf after TC Sean. Rubble was observed on coral indicating that sediment was scoured from the seafloor by cyclone-driven swell and subsequently deposited onto the reef.	Z. Richards and D. Juszkiewicz, pers. comm. Z. Richards, pers. comm.
	Preliminary evidence of *Halodule* and *Halophila* seagrass loss.	N. Said, pers. comm.

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

Few studies have examined the effects of marine heatwaves on marine and coastal environments in Exmouth Gulf. An analysis of mangrove extent along eastern Exmouth Gulf before and after extreme events (marine heatwaves, droughts and cyclones) found marine heatwaves in 2010/11 and 2012/13 did not impact mangroves to the same extent as cyclones and droughts (Stewart-Yates, 2022). Cumulative effects of co-occurring or subsequent extreme events are also likely to intensify under climate change. The high turbidity conditions in Exmouth Gulf are thought to play an important role in the resilience of corals to bleaching (Cartwright, et al., 2024; Zweifler et al., 2024). The marine heatwave in March 2021 provided an opportunity to compare four reefs along a turbidity gradient (Zweifler et al., 2024). Bundegi Reef (clear waters, western margin) was found to be less resilient to heat stress compared to Sommerville Reef (turbid waters, eastern margin), despite Bundegi Reef experiencing lower water temperatures. The heatwave and turbid conditions also impacted coral morphologies in different ways. Encrusting and massive corals were more susceptible to bleaching at turbid sites, whereas branching and foliose corals displayed more resilience. For Bundegi Reef, encrusting and branching corals had lower resilience compared to other corals morphologies surveyed. Preliminary results on the impacts of the 2025 heatwave challenge the notion that corals in the turbid reefs of the eastern Gulf are inherently resilient, as all morphological types were affected (Z. Richards, pers. comm.). The severity of bleaching may have been exacerbated by the combined effects of freshwater input and swell-driven sediment abrasion, which likely interacted with the anomalous thermal conditions (Z. Richards, pers. comm.).

3.1.1.3. Climate drivers

El Niño Southern Oscillation (ENSO) events fluctuate between El Niño, La Niña and neutral. In the ocean, La Niña conditions cause a build-up of warmer waters in the western Pacific Ocean to flow through the Indonesian Archipelago and south along the WA coast. This in turn strengthens the Leeuwin Current, which transports warm tropical waters along the WA coast and as far as Tasmania in strong years (usually strongest in autumn and winter months).

A major driver of marine heatwaves occurring during the summer of a La Niña event is when there is also a Ningaloo Niño, a regional climatic driver whereby southerly winds can collapse and atmosphere-ocean feedback can amplify SSTs off WA (Feng et al., 2013; Kataoka et al., 2013). Under these summer conditions, the Leeuwin Current can carry the warmer water further along the WA coastline where it can have significant negative impacts to different marine habitats and fauna. Marine heatwaves can also occur during El Niño phases (e.g., Le Nohaïc et al., 2017), which is primarily driven by the Australian Summer Monsoon. The ENSO phase transitioned from a La Nina to neutral around ~May 2024, after which marine heatwave conditions developed in September. It is likely the severity of the heatwave event in 2024/25 was related to the delay of the Australian Summer Monsoon (J. Gilmour, pers. comm.).

A comparison of the anomalous SST conditions during the 2024/25 marine heatwave and more typical conditions is provided in Figure 12. The strong wind-driven upwelling from the south, observed 30 Jan 2024, triggers the Ningaloo Current, giving rise to cooler ocean sea surface temperatures across the Ningaloo, Exmouth Gulf and Pilbara regions. This contrasts with the observations on 20 Jan 2025 when a stronger than average Leeuwin Current is moving in a southward direction down the coast, suppressing the Ningaloo Current. Climate drivers like ENSO and seasonal wind dynamics influence ocean temperature variability along the coast. The strength of the Leeuwin Current, subsequent sea level height and sea surface temperatures have previously been linked to single events such as El Niño or La Niña conditions, with warmer waters and even marine heatwave events occurring for example in La Niña years. However, this may be changing with some of these long-held assumptions breaking down. With the current marine 2024/25 marine heatwave, and the warmer global sea surface temperatures, the seasonal patterns may not be as evident, and the anomalous elevated temperatures may prevail.

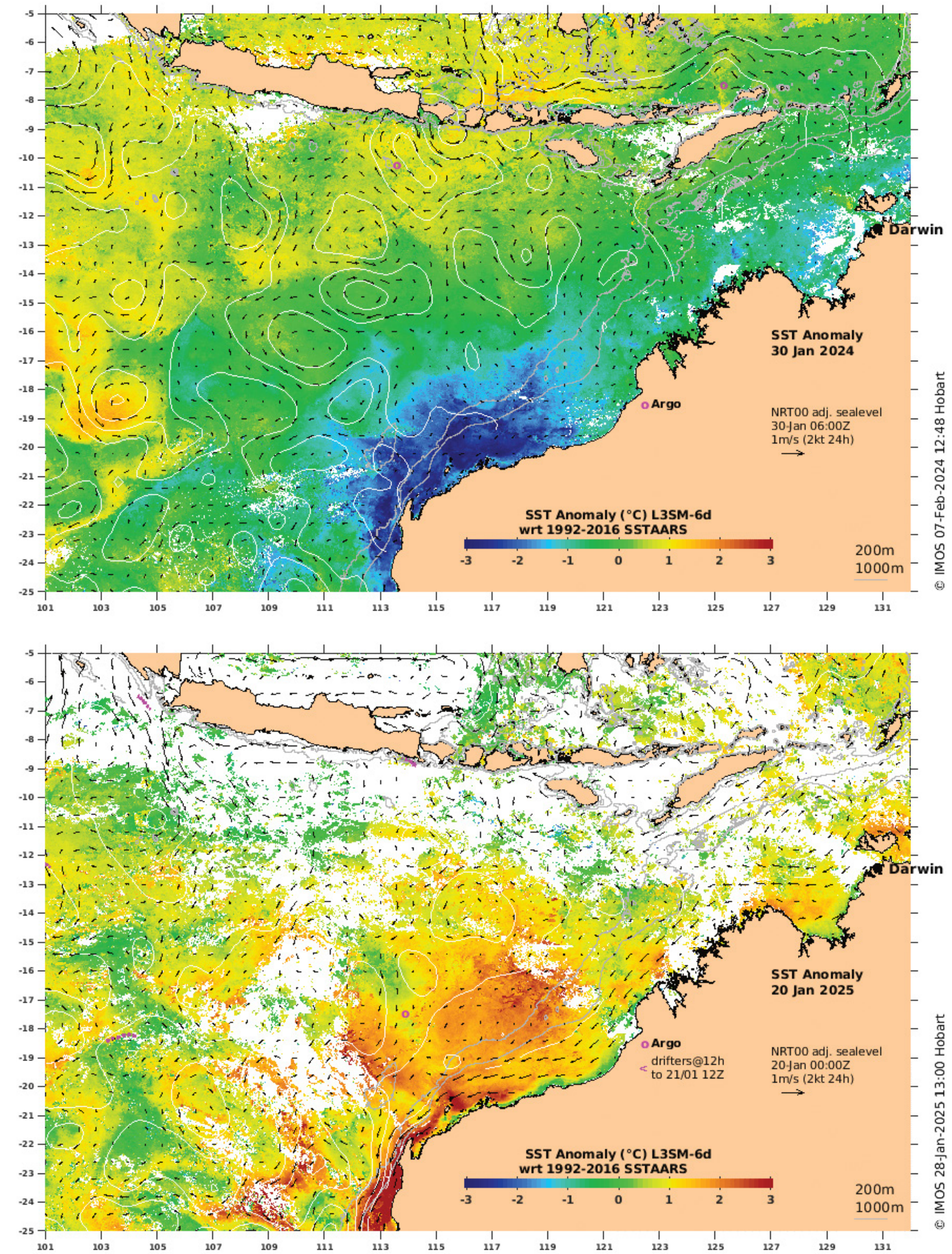


Figure 12: Sea surface temperature anomaly plots comparing the SST conditions from Jan 2024 and Jan 2025. Typical conditions occurred in Jan 2024 where the Leeuwin Current was weakened and the seasonal Ningaloo Current facilitated cooler, upwelled waters off the Pilbara coast. In Jan 2025, the Leeuwin Current was not weakened and transported anomalously warm waters south, increasing the spread and impact of the marine heatwave along the WA coast.

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

3.1.1.4. Rainfall

The average annual rainfall in Exmouth Gulf is ~256 mm (BOM, 2025). Rainfall can be highly variable and influenced by tropical cyclones, particularly during the summer monsoon season (Nov–Apr). Total averaged rainfall across 1900–2023 shows a decreasing trend for the Exmouth region (Figure 13).

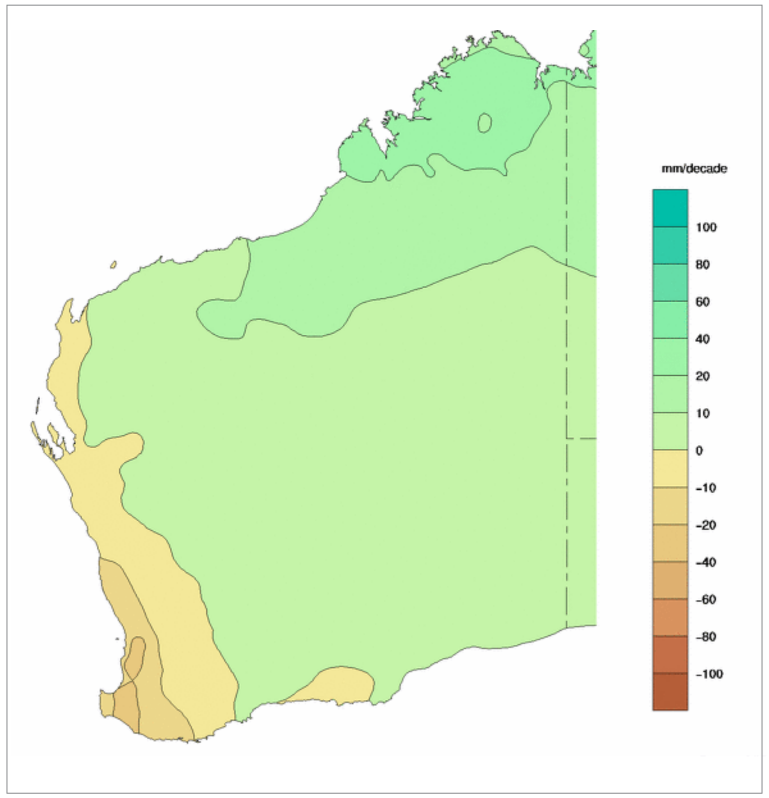


Figure 13: **Trends in total rainfall determined from annual data between 1900-2023. Sourced from BOM.**

3.1.1.5. Cyclones and storms

Exmouth Gulf is highly exposed to tropical cyclones, with an average of three tropical cyclones impacting the wider northwest coast region each year between November to April (Lough, 1998; May et al., 2015; Dufois, 2017, BOM). Four tropical cyclones (TC) have passed directly through Exmouth Gulf since 2010; TC Carlos (2011), TC Iggy (2012), TC Quang (2015), and TC Veronica (2019) (Figure 15).

Three cyclones have also passed nearby in the last two years: TC Lincoln (2024), TC Olga (2024) and TC Sean (2025). Tropical cyclones typically develop during the wet season from November to May due to warm tropical waters, high air temperatures and humidity. Marine and terrestrial environments can be disturbed by high wind speeds, wave damage, torrential rain, storm surge and flooding, even if the cyclones do not pass directly overhead. Following TC Sean, which tracked more than 200 km offshore from Exmouth Gulf, a huge biomass and diversity of benthic fauna washed up on beaches along the western side of Exmouth Gulf, including sponges, soft corals, sea pens, molluscs and other marine life (Z. Richards, pers. comm.) (e.g., Figure 14). Rubble was observed on coral, indicating that sediment was scoured from the seafloor by cyclone-driven swell and subsequently deposited onto the reef.

In 1999, the category five TC Vance caused widespread damage to mangroves in Exmouth Gulf (Paling et al., 2008) that resulted in loss of recruitment and retreat of mangrove edges (e.g., Giralia Bay), (Lovelock et al., 2021) as well as widespread loss of mangroves extent along eastern Exmouth Gulf (Stewart-Yates, 2022). In addition to mangrove loss, TC Vance caused the loss of seagrasses and macroalgae in Exmouth Gulf, which had negative implications for prawn catches and recruitment for the subsequent two years following the event (Loneragan et al., 2013). Soft sediment habitats such as cyanobacterial mats and salt flats can suffer direct removal, which can lower surface elevation, such as observed in 2015 after TC Olwyn (Lovelock et al., 2021). While these examples demonstrated losses to the system, there was also recovery, which may be limited in the future if tropical cyclones become more intense.

Figure 14: **An area of beach near Learmonth Jetty, Exmouth Gulf, showing the diversity and abundance of benthic marine life that washed ashore following TC Sean. A variety of sponges, soft corals, sea pens, ascidians, molluscs, macroalgae, seagrasses and other marine life were affected. Photos taken 22 Jan 2025. Images: Alex Hoschke**

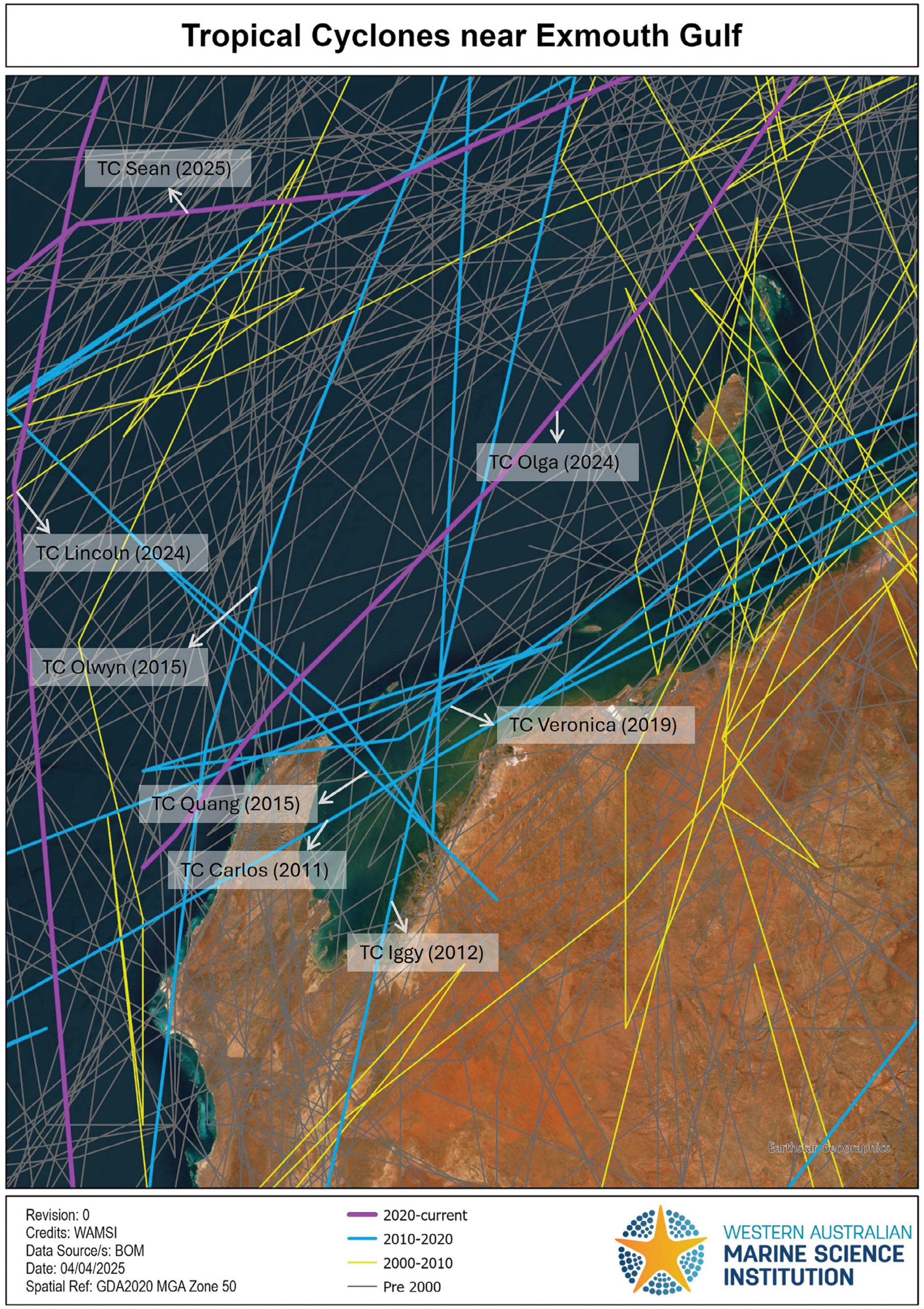


Figure 15: Tropical cyclone tracks from 1907 to April 2025. Sourced from Bureau of Meteorology.

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF


Aerial view Exmouth Gulf salt flats. Sharyn Hickey

3.1.2. Projections

3.1.2.1. Broadscale projections

Currently used regional projections for Exmouth Gulf are based on Bureau of Meteorology's National Hydrological Projections gridded time-series dataset (Oke et al., 2022) and is summarised by DWER in Figure 16. New climate change projections based on the latest global climate models are being developed for the region. These are being produced by DWER under the Climate Science Initiative, in partnership with the New South Wales Government Department of Climate Change, Energy, the Environment and Water, Murdoch University and the Pawsey Supercomputing Research Centre.

Modelling projections are based on four Representative Concentration Pathways (RCPs), which aim to capture future trends based on concentrations of greenhouse gases in the atmosphere. These are defined below as per the Climate Change in Australia website (CSIRO and Bureau of Meteorology, 2025) and referred to in subsequent text.

- RCP8.5 – a future with little curbing of emissions, with a CO_2 concentration continuing to rapidly rise, reaching 940 ppm by 2100
- RCP6.0 – lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100
- RCP4.5 – CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration reaches 540 ppm by 2100
- RCP2.6 – the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing carbon dioxide from the atmosphere. The CO_2 concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100).

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

Temperature

- It is likely there will be continued substantial increases in the average, maximum and minimum temperatures.
- By 2030 warming is projected to increase by about 0.6°C to 1.5°C, when compared with the climate of 1986–2005.
- By 2090, warming is likely to be about:
  - 1.5°C to 3.1°C under a medium-emissions future
  - 3.1°C to 5.6°C under a high-emissions future.

Extreme temperature

- Extreme temperatures are projected to increase.
- Hot days (above 35°C) and very hot days (above 40°C) will become more frequent.
- From 1981 to 2010, the region experienced about 86 days a year above 35°C. By 2050, this could increase to 122 days, or more than one-third of the year.
- Frosts (temperatures below 2°C) are projected to decrease.

Other changes

- The north-west coastline between Exmouth and Broome is the most cyclone-prone region of the Australian coast.
- In the future there may be fewer but more intense tropical cyclones.
- Evapotranspiration is expected to increase.
- Relative humidity is projected to remain stable in 2030. By 2090, it may decrease in winter and other seasons.
- Frosts (temperatures below 2°C) are projected to decrease.

Rainfall

- The impact of climate change on rainfall is uncertain as some models show an increase and some a decrease.
- Predicting Exmouth's future rainfall is difficult because:
  - the region experiences significant seasonal variations influenced by diverse weather systems
  - complex climate drivers associated with monsoonal processes, like tropical cyclones, are difficult to replicate perfectly in climate models.
- Exmouth could either become drier or wetter in the future, so planning for both scenarios is essential.
- Time spent in drought is expected to increase by 2090.
- Extreme rainfall events will be more intense, though the exact size of the increases is uncertain.

Marine and coast

- Sea levels will continue to rise along the Gascoyne and Pilbara coastline. By 2030, sea level rise is projected to increase by 0.07 m to 0.17 m above the 1986–2005 level.
- By 2090 sea level is projected to rise from 0.28 m to 0.65 m under a medium-emissions future, and 0.40 m to 0.85 m under high-emissions future.
- Sea level rise will likely inundate low-lying terrain on the Exmouth Gulf.
- By 2090 warming of coastal waters poses a significant threat to the marine environment, because of increasing sea surface temperatures of between 2.4°C and 3.7°C.
- Biological changes in marine species and increased coral bleaching risk may occur.
- The sea will become more acidic.
- Marine heatwaves in the Exmouth Gulf are currently a focus of research and may become more frequent, extensive, intense and longer.

Figure 16: **Climate change in Exmouth Gulf region Fact sheet (October 2024) compiled by Department of Water and Environmental Regulation.**

3.1.2.2. Exmouth Gulf projections

More specific climatic projections are needed for Exmouth Gulf to better understand how the system will respond to change, particularly when considering current and future cumulative impacts. Exmouth Gulf is a very turbid environment and future predictions have been made for turbidity, SST and other climate anomalies for the whole Gulf to better determine how marginal coral reef communities will be impacted (Cartwright et al., 2024). Turbidity is expected to increase in the central and western areas of Exmouth Gulf under both RCP4.5 and RCP8.5 scenarios (Figure 17) due to changing metocean drivers, such as sea level rise. Mean SST derived from satellite imagery between 2002–2020 show some variation across sites in Exmouth Gulf, though overall show a mean of 25.7°C (Cartwright et al., 2024). The projected percent increase in SST in Exmouth Gulf by 2100 under RCP4.5 (SSP3-7.0) and RCP8.5 (SSP5-8.5) scenarios is 8.2% and 10%, respectively (Figure 18), which equates to future temperatures of above ~27.5°C for many areas of Exmouth Gulf.

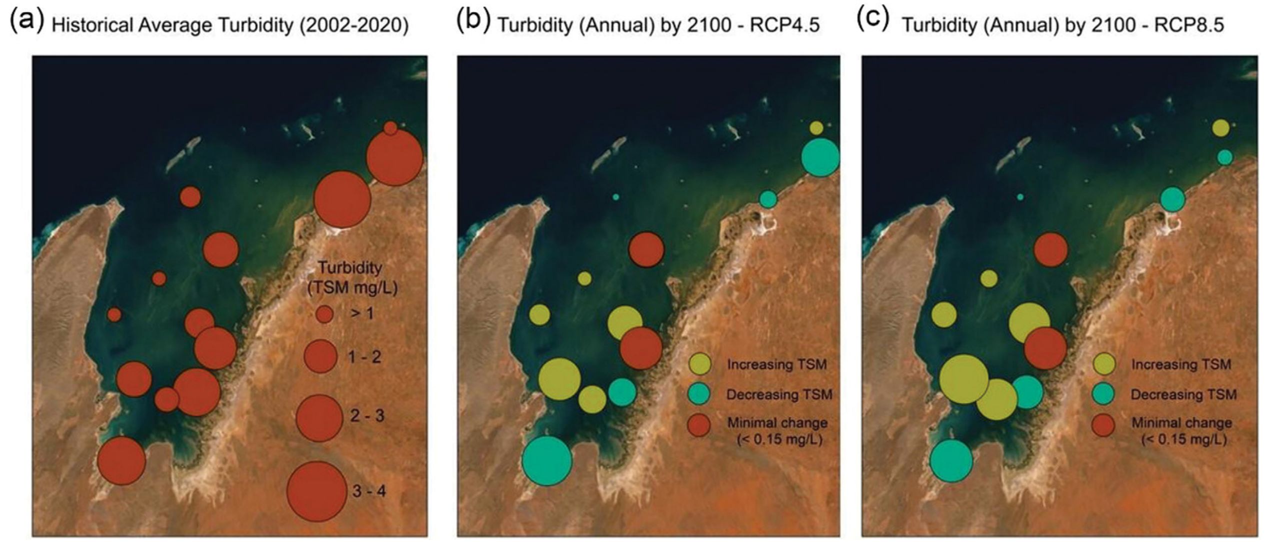
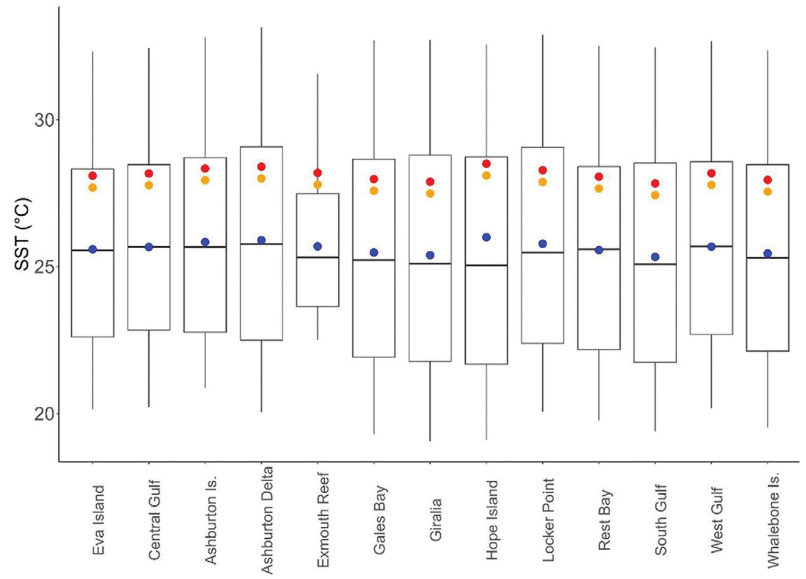


Figure 17: **Turbidity (TSM) in Exmouth Gulf showing (a) historical turbidity (2002–2020) derived from in situ validated, high resolution, remotely sensed MODIS satellite data; (b) projected turbidity for 2100 under middle-of-the-road climate scenario RCP4.5; and (c) projected turbidity for 2100 under high-emission scenario RCP8.5. Size of circle at each location represents level of turbidity (as per (a)). RCP, Representative Concentration Pathway. Figure and caption included with permission from Cartwright et al. (2024).**

Figure 18: **Historical SST variability (boxplots) at 13 sites in Exmouth Gulf, overlayed with historical mean SST (blue circles), future SST under SSP3-7.0 (orange circles), and future SST under SSP5-8.5 (red circles). Historical SST is from 2002 to 2020. Anomalies are above 1984–2014 baseline. Figure and caption included with permission from Cartwright et al. (2024).**



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Alongside increases in SST, the ensemble climate models used by Cartwright et al. (2024) also predicted an increase in westerly and southerly wind forcing, mean sea level and significant wave heights, and a decrease in precipitation and wave period compared to the baseline of historical data, noting seasonal variability. For some coral reefs in Exmouth Gulf, increased sedimentation and further lack of light for photosynthesis could see coral growth and diversity decline and macroalgae cover increase. Although predicted impacts to corals are location and seasonally dependant. For example, areas of higher turbidity may improve the resilience of some corals to marine heatwaves.

While it is important to understand how species currently utilising Exmouth Gulf will be impacted by climate change, it is also important to predict how Exmouth Gulf environment will change as other species expand or contract their ranges based on warming sea temperatures. Coral species richness has been predicted to double in Exmouth Gulf by 2100 under RCP 2.6 and RCP 8.5 scenarios, leading to a suggestion that Exmouth Gulf, along with other mid latitude regions (Ningaloo, Shark Bay and the Houtman Abrolhos Islands), could become high diversity hotspots and refugia for corals based on predicted suitable habitat (Adam et al., 2021) (Figure 19).

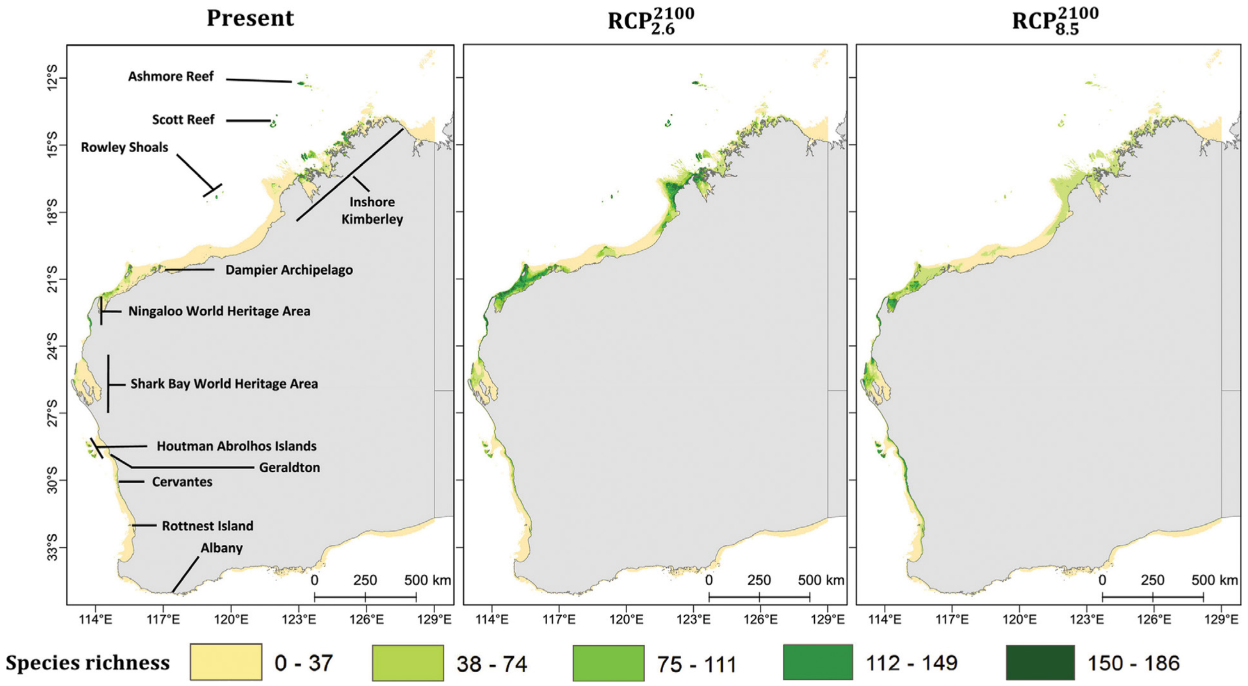

Figure 19: Predicted coral species richness in WA based on habitat suitability using mean-type model data under present-day and future climate conditions – RCP 2.6 (best case) and RCP 8.5 (extreme case) scenario in 2090–2100. Figure and caption included from Adam et al. (2021) with permission.

3.2. Ecological connectivity

3.2.1. Species connectivity

There are likely to be many ecological connections through marine fauna movements and food webs between Exmouth Gulf and surrounding regions, including Ningaloo Reef and the southern Pilbara. For some larger, migratory species, movements of individuals between Exmouth Gulf and surrounding regions have been directly documented. However, there are many fauna groups for which levels of connectivity are unknown. This is particularly true for smaller species that use larval dispersal, such as teleost fishes and invertebrates. Genetic connectivity of corals has been investigated across the northwest region of Australia, as has the connectivity of seagrasses and mangroves. The genetic connectivity of macroalgae between Exmouth Gulf and surrounding regions is not well understood.

Connectivity of individuals or populations between Exmouth Gulf and surrounding areas is important for several reasons. This includes maintaining gene flow and genetic connectivity within and between populations, allowing individual animals access to multiple foraging or reproductive areas, and transporting nutrients in between different habitats and regions via foraging and waste excretion. Connectivity may also allow species to re-colonise an area following local population declines. A high-level summary highlighting some of the trends in dispersal and connectivity of species between Exmouth Gulf and surrounding areas is provided below. Specific examples of connectivity for marine flora and fauna groups are examined in detail in Sections 3.4 and 3.5.

3.2.1.1. Mangroves and seagrasses

Mangroves are pollinated by flying insects, generally on small to moderate spatial scales, and the fertilised propagules disperse using ocean currents. Propagules can remain viable while floating for extended periods, and thus are capable of long-distance dispersal in currents. The most common mangrove species in Exmouth Gulf is *Avicennia marina*. Genetic analyses show that there is high genetic connectivity between Exmouth Gulf and Ningaloo Reef (Mangrove Bay), Onslow, and Dampier (Binks et al., 2019). However, there was significant genetic structuring (subdivided populations) between this 'Pilbara' cluster and Coral Bay, the Montebello Islands, Shark Bay, Broome, and Perth.

Figure 20: Mega-herbivores, such as dugongs, may help to disperse seagrass seeds from within Exmouth Gulf to surrounding areas. Image: Michael Tropiano

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Thus, while *A. marina* is well-connected throughout most of the Pilbara, there are major barriers to gene flow along other areas of the WA coastline, most likely due to gaps in availability of mangrove habitat between populations.

Seagrasses reproduce and disperse in several ways. Seagrasses pollinate via currents, generally on a within-meadow scale, but fertilised propagules can disperse over somewhat longer distances via currents or through herbivory. Clonal seagrass fragments can also disperse via currents if they are separated from the benthos (McMahon et al., 2018). Genetic studies have shown connectivity of *Halophila ovalis* between sites in southern Exmouth Gulf, the Muiron Islands, and Mangrove Bay (McMahon et al., 2017). This species has non-buoyant seeds and is assumed to have limited self-dispersal capability. The moderate levels of genetic connectivity observed may be maintained by the movement of dugongs (*Dugong dugon*) in between these areas (Figure 20). On the other hand, genetic studies of *Halodule uninervis* (also with negatively buoyant seeds) have shown more significant genetic structuring between Exmouth Gulf, Ningaloo Reef, and the southern Pilbara including Thevenard, Rosemary, and Montebello Islands, and Balla Balla (northwest of Karratha) (McMahon et al., 2017; Evans et al., 2021). While connectivity of *Halodule uninervis* between Exmouth Gulf and surrounding areas appears rare, there is evidence for some limited dispersal from Exmouth Gulf over long distances, for example to Thevenard (~100 km) and Balla Balla (~450 km). This long-distance dispersal via currents is unlikely for negatively buoyant seeds and may again be mediated by movements of mega-herbivores.

For a third seagrass species, *Thalassia hemprichii*, Exmouth Gulf marks the approximate southern edge of its distribution. Samples of this species from the Muiron Islands are closely genetically clustered with those collected at Barrow Island. This suggests connectivity within the Pilbara, but findings showed significant genetic structure compared to populations in the Kimberley, Indonesia, and Cocos Islands (McMahon et al., 2017). Given this species has positively buoyant fruits, high dispersal rates within the Pilbara region are not unexpected. Interestingly, almost all gene flow between the Muiron Islands and Barrow Island was detected in a northernly direction, suggesting Exmouth Gulf populations may predominantly act as a source rather than sink for this seagrass species.

3.2.1.2. Corals

Corals rely on current-mediated larval dispersal, but local environmental conditions are also highly determinative of settlement rates and survival in coral recruits.

A few studies have investigated connectivity of hard coral species between Exmouth Gulf and surrounding regions and have in general found strong to moderate genetic connectivity between Exmouth Gulf, Ningaloo Reef, and the Pilbara. For example, strong genetic connectivity between the turbid reef specialist *Turbinaria 'reniformis'* species complex has been found across the Pilbara, including between Exmouth Gulf and Onslow, Montebello Islands, Passage Islands, Dampier, and Balla Balla, with moderate connectivity extending south to Shark Bay (Evans et al., 2021). High genetic connectivity was also observed in the branching coral *Pocillopora damicornis* between the Muiron Islands, Montebello Islands, and Ningaloo Reef, though not with Shark Bay or sites further south (Thomas et al., 2014; Thomas et al., 2017). However, this species showed limited connectivity between Bundegi and Ningaloo Reef (Whitaker, 2006). The stress-tolerant coral *Cyphastrea microphthalma* similarly showed genetic connectivity across the Pilbara and northern Ningaloo (Evans et al., 2019). In this case, some interesting genetic structuring was present within this region, where samples from southern Exmouth Gulf were more admixed (mixing of genes from different populations) with Shark Bay than samples taken along the Ningaloo Coastline or further north in the Pilbara. Admixture with Coral Bay and the Kimberley was also detected more at Bundegi than other Pilbara sites (Evans et al., 2019). This sort of 'genetic patchiness' throughout Exmouth Gulf and the surrounding regions may be due to a mixture of currents, other dispersal barriers, and selection driven by local environmental conditions.

To lend a greater understanding of how currents mediate dispersal in corals, Feng et al. (2016) modelled the fate of larvae of the branching coral *Acropora millepora* in different areas of the Pilbara, including Exmouth Gulf and Ningaloo. This study found that most areas in Exmouth Gulf, and particularly the southern Gulf, have high self-recruitment rather than connectivity with other reefs. The north-central Exmouth Gulf had the highest rate of recruitment from other reefs. Overall, there was some moderate exchange between reefs in Exmouth Gulf, the Onslow region, and Barrow and Montebello Islands. There was also some exchange of larvae from Exmouth Gulf to Ningaloo, but very little in the other direction.

3.2.1.3. Teleosts and invertebrates

Many teleost fish and invertebrate species have larval stages that disperse via currents, with some species capable of long-distance movements as juveniles or adults.

Acropora coral in southern Exmouth Gulf. Shannon Dee

Goniopora coral in Exmouth Gulf. Shannon Dee

In addition to limitations imposed by prevailing currents, the larval stages of many species also have specific settlement or juvenile habitat requirements which can restrict dispersal success or capacity (e.g., Loneragan et al., 2013; Wilson et al., 2016). This may be a particularly prevalent issue in species dispersing between Ningaloo Reef and Exmouth Gulf, where environmental conditions including turbidity, temperature, water flow, and available habitat can vary widely. Further studies investigating genetic differentiation and larval dispersal capabilities of various species across the Ningaloo and Exmouth Gulf regions would help to determine the extent of connectivity between these two habitats.

Very little satellite or acoustic tracking information is available for teleost fishes or invertebrates in Exmouth Gulf to ascertain whether individuals regularly move between Exmouth Gulf and other regions. Genetic information describing connectivity of teleost fish and invertebrate populations in this region is also scarce, although some data are available for commercially important species. For example, the stripey snapper, *Lutjanus carponotatus*, in Exmouth Gulf is genetically distinct to populations in Shark Bay and the Kimberley, but shows high genetic connectivity between Exmouth Gulf, Ningaloo Reef, and the Pilbara region up to approximately Cape Keraudren (DiBattista et al., 2017). Recent studies have also shown that swimmer crabs, *Pelagicus armatus*, found in Exmouth Gulf are genetically distinct from populations in Shark Bay and further south, although some limited connectivity was present between Exmouth Gulf and Shark Bay (Briggs et al., 2024). On the other hand, past genetic studies indicate that there is high connectivity and genetic mixing between stocks of the brown tiger prawn, *Penaeus esculentus*, found in Exmouth Gulf and Shark Bay, which were distinct from those in the Northern Territory and Queensland (Ward et al., 2006). Silverlip pearl oysters, *Pinctada maxima*, in Exmouth Gulf have been shown to comprise a genetically distinct population from stocks in Port Hedland and the Kimberley (Benzie & Smith-Keune, 2006), with potentially little genetic connectivity of this species between Exmouth Gulf and other regions.

3.2.1.4. Marine megafauna

As large animals, most marine megafauna groups (e.g., elasmobranchs, marine turtles, marine mammals) are capable of long-distance movements, and many have high migratory tendencies. As such, it is not surprising that individual animals from several different megafauna species and groups have been recorded moving between Exmouth Gulf and the surrounding regions. For example, satellite tracking of tiger sharks, *Galeocerdo cuvier*, has confirmed individual movements between Exmouth Gulf, Ningaloo Reef, the Pilbara and Kimberley regions, and even to Indonesia and southwestern Australia (Stevens et al., 2009; Ferreira et al., 2015). Acoustic tracking data has also shown transit of other large elasmobranchs such as lemon sharks, *Negaprion acutidens*, between Ningaloo Reef, the southwestern Exmouth Gulf, and the Pilbara, as far north as Point Preston (R. Pillans, R. Bateman, K. Lear, pers. comm.). Photo-ID has confirmed movements of reef manta rays, *Mobula alfredi*, between Exmouth Gulf and northern Ningaloo, Coral Bay, and Shark Bay (Armstrong et al., 2020), and genetic connectivity suggests long-distance movements of adult giant shovelnose rays, *Glaucostegus typus*, between Shark Bay and Exmouth Gulf (Ingelbrecht et al., 2024a). Tagged green sawfish individuals from Ashburton River, a globally important pupping site, have been acoustically detected at Urala Creek North and Urala Creek South in Exmouth Gulf, providing evidence for connectivity between these two regions (Lear et al., 2024a). Many other large elasmobranchs likely transit between Exmouth Gulf and surrounding areas, although whether individuals of smaller species move between regions has not been examined to the same extent. It has been proposed that some species common to both Exmouth Gulf and Ningaloo Reef (e.g., blacktip reef sharks) rely on mangrove nursery habitats in Exmouth Gulf before migrating to the reef once mature. This has not yet been directly examined or confirmed, and the use of Exmouth Gulf as 'Ningaloo's nursery' for elasmobranch species requires further research.

Several species of marine turtles also show direct connectivity between Exmouth Gulf and surrounding regions through movement of individuals. For example, satellite tracking has shown adult female green turtles, *Chelonia mydas*, moving between Exmouth Gulf, Ningaloo Reef, various Pilbara Islands, and Shark Bay (Ferreira et al., 2020). Exmouth Gulf appears to be a particularly important foraging area for turtles nesting in these nearby locations. Recapture of foraging loggerhead turtles, *Caretta caretta*, has also confirmed movement of this species between Exmouth Gulf and Shark Bay (Prince et al., 2012). Conversely, genetic and movement connectivity of sea snakes between Exmouth Gulf and nearby areas is relatively unknown (Udyawer et al., 2016; Udyawer et al., 2018).

Green turtle. Michael Tropiano

Marine mammals have generally shown high connectivity between Exmouth Gulf, Ningaloo Reef, and surrounding areas. Photo-identification of individuals has confirmed movements of both humpback dolphins, *Sousa sahulensis* (Figure 21), and bottlenose dolphins, *Tursiops aduncus*, between Ningaloo Reef, the North West Cape, and western Exmouth Gulf (Hunt et al., 2017; Haughey et al., 2020; Sprogis & Parra, 2022; Sprogis & Waddell, 2022). Multiple movements of satellite-tagged dugongs have also been recorded between eastern Exmouth Gulf and Ningaloo Reef (Cleguer et al., 2024), and migration of dugongs between Exmouth Gulf and Shark Bay has long been hypothesized (Gales et al., 2004). Larger marine mammals including humpback whales, *Megaptera novaeangliae*, and pygmy blue whales, *Balaenoptera musculus brevicauda*, are known for much longer migrations, connecting Exmouth Gulf not just to Ningaloo and the Pilbara, but further to the Kimberley, Indonesia, southwestern Australia, and Antarctica (e.g., Gales et al., 2010; Bestley et al., 2019).

Figure 21: Australian humpback dolphins, *Sousa sahulensis*, move between western Exmouth Gulf, the North West Cape and Ningaloo Reef. Image: Holly Raudino

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3.2.2. Nutrient sources and flows

3.2.2.1. Current knowledge

A comprehensive understanding of all nutrient sources and flows in Exmouth Gulf is lacking. Current western knowledge is largely based on spatially or temporally restricted studies, or localised site investigations and modelling for industry proponents. The nutrient sources and flows discussed and/or investigated in the literature have included cyanobacterial mats, mangrove litter, tidal creeks, groundwater discharge, offshore water and tidal exchange, and minimal terrestrial run-off (e.g., McKinnon & Ayukai 1996; Ayukai & Miller 1998; Brunskill et al., 2001; Lovelock et al., 2009, 2010; Penrose, 2011; Adame et al., 2012b; Loneragan et al., 2013). Tropical cyclones are also acknowledged for their role in generating significant nutrient pulses in the system (e.g., Lovelock et al., 2011), though this has not been quantified in comparison to year-round sources.

The most widespread investigation of nutrients in Exmouth Gulf is that of Brunskill et al. (2001) who mapped nutrient concentrations and trace elements in the sediments across Exmouth Gulf between 1994–1996. Aeolian transport of quartz sand into Exmouth Gulf from salt flats and dune fields, along with erosion of salt flats, mangrove banks, and islands sediments were identified as likely sources of terrestrial nutrients and trace elements (e.g., iron, aluminium, potassium and manganese). However, the rate of nutrient supply from tidal exchange with offshore waters, and marine sources overall, was suggested to be greater than terrestrial sources. Phytoplankton was identified as the key source of organic matter in sediment samples in the basin of Exmouth Gulf, which had good nutritional content. High concentrations of phosphorus (largely inorganic) throughout Exmouth Gulf were a result of the relatively quick decomposition of organic matter and the rapid oxidation of organic carbon and nitrogen in the water column and surface sediments. Conversely, the mangrove and salt flat sediments along eastern Exmouth Gulf had lower concentrations of phosphorus, but higher concentrations of organic carbon and nitrogen. Coastal trapping of nutrients is thought to occur along eastern Exmouth Gulf, though this was not strongly supported by Brunskill et al. (2001).

Further relating to aeolian transport, dust storms can occur in the Exmouth and Pilbara regions, which can have low to moderate Dust Storm Index ratings, depending on the year (Bastin, 2014).

A current project under the WAMSI Mardie Salt Marine Research Program is underway investigating the pathways for nutrients and energy transfer from cyanobacterial mats and other benthic habitats along the west Pilbara coast, including Giralia Bay. Findings are expected late 2025.

3.2.2.2. Gap analysis

One of the focus areas of the Taskforce was gaining a better understanding of the nutrient sources and flows into Exmouth Gulf. Exmouth Gulf supports a highly productive prawn fishery and nursery habitat. Yet there is a lack of certainty around all the sources of nutrients and how significant each of these sources are to the overall nutrient budget in Exmouth Gulf. To date, there has been no comprehensive, Gulf-wide investigation into nutrients and knowledge to date is based on spatially and temporally restricted data. A key message from participants of the WAMSI Exmouth Gulf Nutrient Sources and Pathways Workshop (Appendix 9.2) was that nutrient dynamics differ across seasons within a year, across years and before and after extreme events, such as cyclones.

Given the importance of understanding nutrient dynamics in Exmouth Gulf, a gap analysis on nutrients was undertaken to identify more specifically where there is some knowledge and where there is a complete lack of knowledge. The intent of the gap analysis is to inform future research into nutrient dynamics but to also to act as a starting point for the data collation needed for a biogeochemical model (a key recommendation for future projects in Section 6). Biogeochemical modelling was undertaken as part of the Northwest Shelf Environmental Management Study in the early to mid-2000s, though this encompassed a broader area from North West Cape to north of Port Hedland, with less of a focus on Exmouth Gulf (Herzfeld et al., 2006). The full gap analysis is available upon request and a summary specific to nutrient elements (nitrogen, carbon, phosphorus) is provided in Table 2.

Table 2: A simplified gap analysis identifying where there is some knowledge available on nitrogen, carbon and phosphorus in relation to a particular source, transport pathway, location and environmental state in Exmouth Gulf (coloured cells). Empty cells indicate where no knowledge was publicly available. * within 6 months, ^ within 1 month.

		N conc.	N stocks	N fluxes	C conc.	C stocks	C fluxes	P conc.	P stocks	P fluxes
Nutrient sources	Organic/detrital material	■	■	■	■	■	■	■		■
	Mangroves	■	■	■	■	■	■	■	■	■
	Saltmarshes/samphire									
	Seagrasses									
	Algae									
	Plankton	■		■	■		■	■		■
	Microbes									
	Cyanobacterial mats	■	■	■	■	■	■	■		
	Salt flats	■	■	■	■	■	■	■		■
	Mud flats	■	■	■						
	Bright salt									
	Coastal vegetation									
	Unvegetated sand									
	Benthic sediments and soils	■	■	■	■	■	■	■	■	■
	Water	■	■	■	■	■	■	■	■	■
	Groundwater	■						■		
	Dust particles/eroded soil			■						
	Atmospheric deposition									
	Whale faeces/urine									
	Seabird/shorebird guano									
Nutrient pathways	Tidal creeks/ flushing	■	■	■	■	■	■	■	■	■
	Tidal inundation	■	■	■	■	■	■	■	■	■
	Overland flows/run-off	■	■	■	■	■	■	■	■	■
	Groundwater seepage	■	■	■	■	■	■	■	■	■
	Resuspension of sediments									
	Tidal exchange	■	■	■	■	■	■	■		■
	Upwelling	■	■	■			■	■		■
	Ningaloo Current	■		■	■	■		■		
	Offshore eddies									
	Winds									
	Circulation									
	Coastal trapping									
Location	Northern Gulf	■		■	■		■	■		■
	Southern Gulf	■	■	■	■	■	■	■	■	■
	Central Gulf	■			■		■	■		
	Eastern Gulf	■	■	■	■	■	■	■	■	■
	Western Gulf									
Environmental state	La Nina	■	■	■	■	■	■	■	■	■
	El Nino	■	■	■	■		■	■	■	■
	Pre-cyclone*	■	■	■	■	■	■	■		■
	During cyclone/storm	■	■	■			■	■		■
	Post-cyclone*	■		■	■		■	■		
	Pre-storm/flood^									
	During storm/flood									
	Post-storm/flood^									
	Pre-marine heatwave*									
	During marine heatwave									
	Post-marine heatwave*									
	Summer	■		■	■		■	■		■
	Winter	■		■	■		■	■	■	■
	Spring	■	■	■	■	■	■	■	■	■
	Autumn	■	■	■	■	■	■	■	■	■

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Out of the twenty different nutrient sources listed, 50% have yet to be investigated for nutrient contributions in Exmouth Gulf specifically, including saltmarshes, seagrasses and algae. Some research has examined nutrient pathways, such as tidal creek flushing and tidal inundation, however the importance of sediment resuspension, offshore eddies, winds, water circulation and coastal trapping for transporting nutrients still needs to be ascertained. There has been a lack of focus on nutrient sources and pathways along western Exmouth Gulf compared to other regions of the Gulf. Lastly, field work in and around Exmouth Gulf is challenging and remote, and the capacity to sample nutrients before, during or after significant events or environmental states is not always possible. Some nutrient data exists for pre and post cyclonic events, different seasons and ENSO events, but not so much for non-cyclonic storms and marine heatwaves.

Despite some available knowledge, data on nutrient sources and pathways is still considered to be temporally and spatially patchy. Robust quantification of nutrient sources and transport pathways (e.g., a nutrient budget) for the whole of Exmouth Gulf, and under different environmental conditions is needed, and the nutrient gap analysis can inform where future efforts should be focused. Based on the literature and expert feedback, it is possible to qualitatively identify most of the nutrient sources and transport pathways in Exmouth Gulf, as depicted in the conceptual model (Figure 22). The intent of the conceptual model is to highlight the likely nutrient sources and transport pathways in Exmouth Gulf so as not to perpetuate any one narrative based on limited nutrient investigations.

Nudibranch. Nick Thake

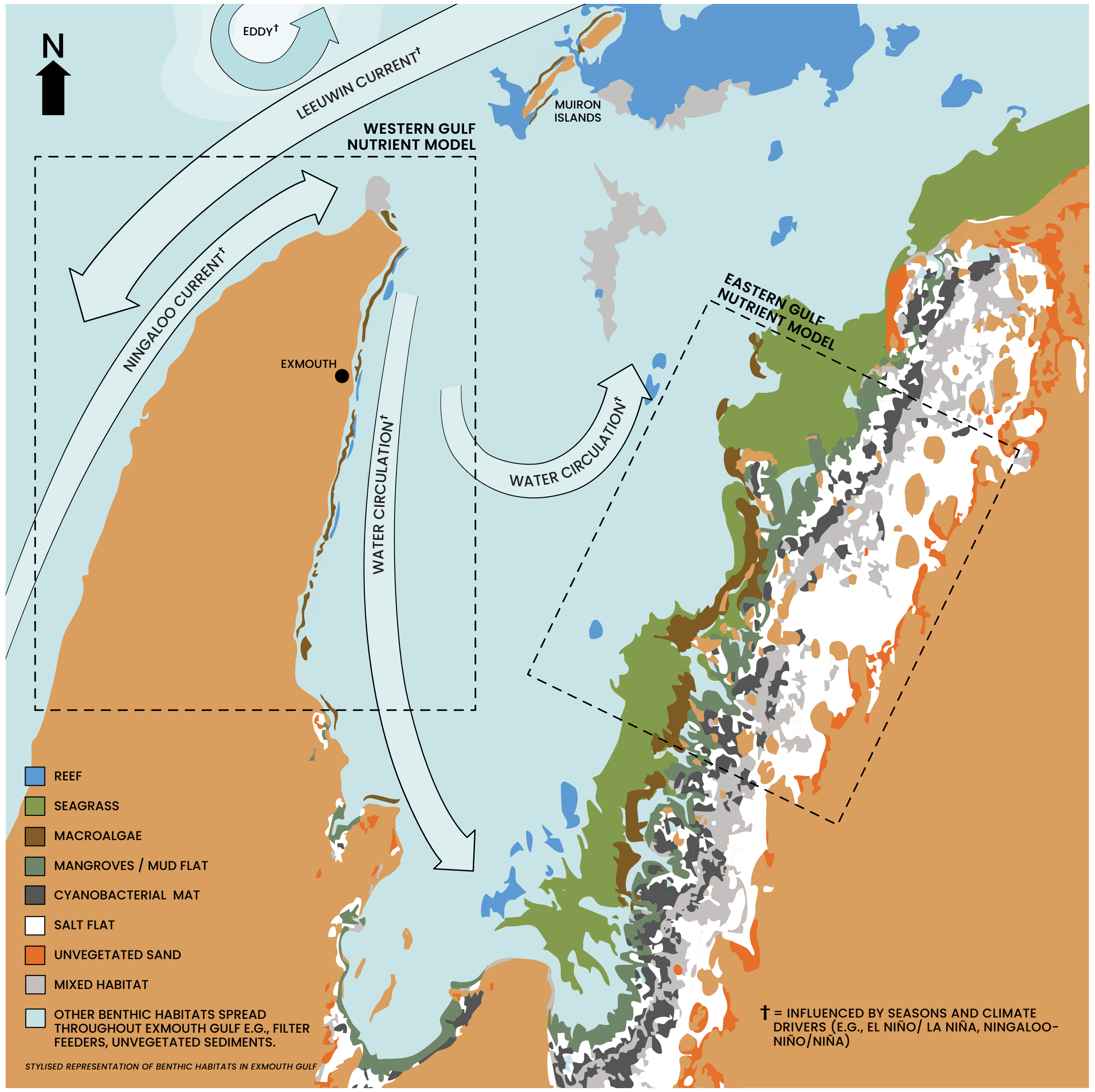

Figure 22: Conceptual models showing the possible nutrient sources and transport pathways in Exmouth Gulf. The model also demonstrates the connectivity between land and sea, and between Exmouth Gulf and surrounding marine environments. A depiction of Exmouth Gulf, its benthic and intertidal habitats (stylised), and hydrology is provided as an overview. Further nutrient sources and transport pathways are shown in the two models: Western Gulf and Eastern Gulf (indicated by the insets). Many nutrient sources and transport pathways are influenced by seasons, large scale climate drivers, and significant weather events, such as cyclones, storms and floods on a range of different time scales. Some of the transport pathways depicted in these models will not occur year-round or consistently across all seasons (e.g., overland flows, water circulation to the southern areas of Exmouth Gulf, Ningaloo Current, Leeuwin Current). The range of nutrient sources and transport pathways included have been informed by knowledgeable people who have worked in Exmouth Gulf. In particular, benthic and intertidal habitats are based on O2 Marine (2024) and Hickey et al. (2023a), respectively, and water circulation inside the Gulf was informed by Grimaldi et al. (in prep). Design: OOID Scientific.

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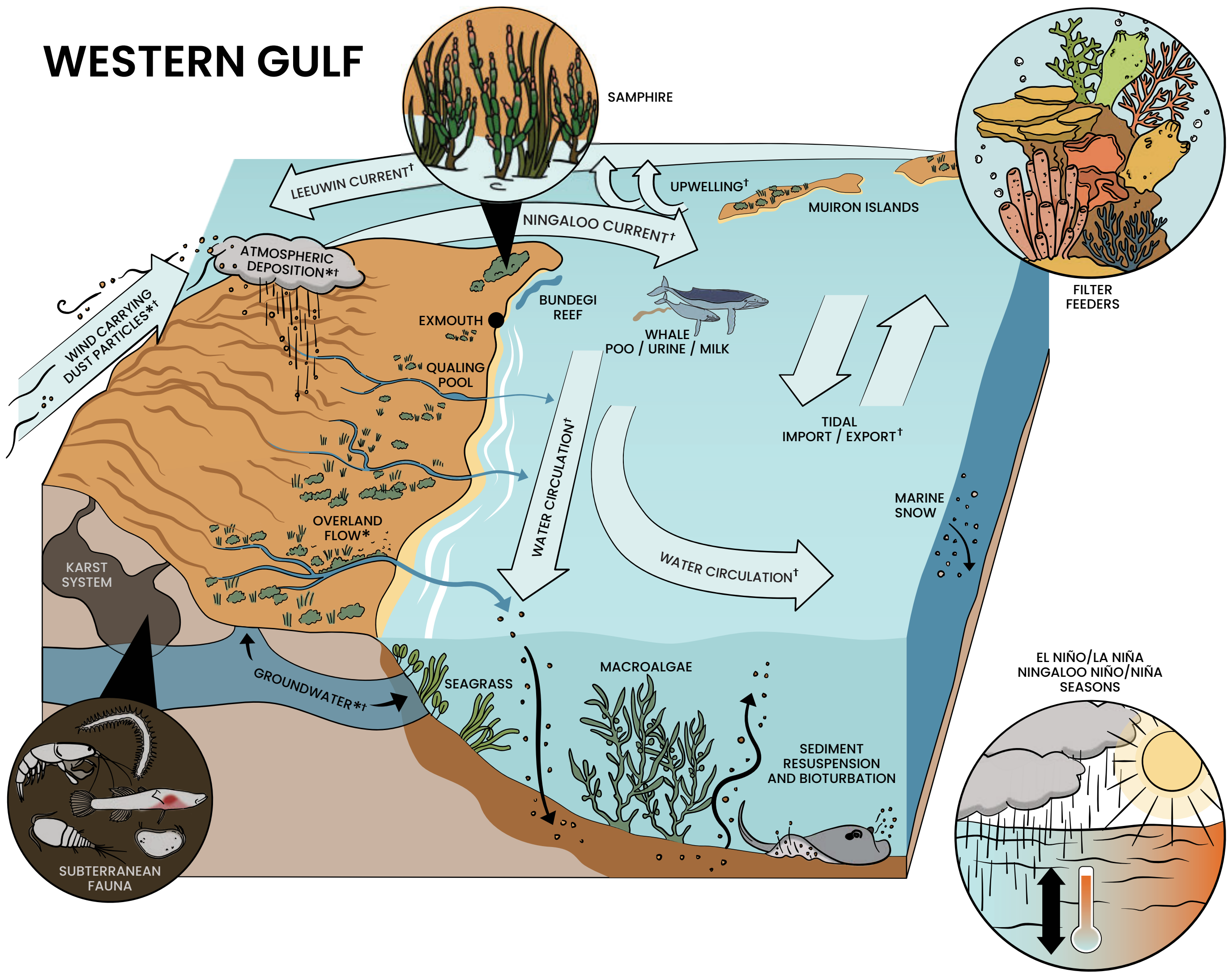

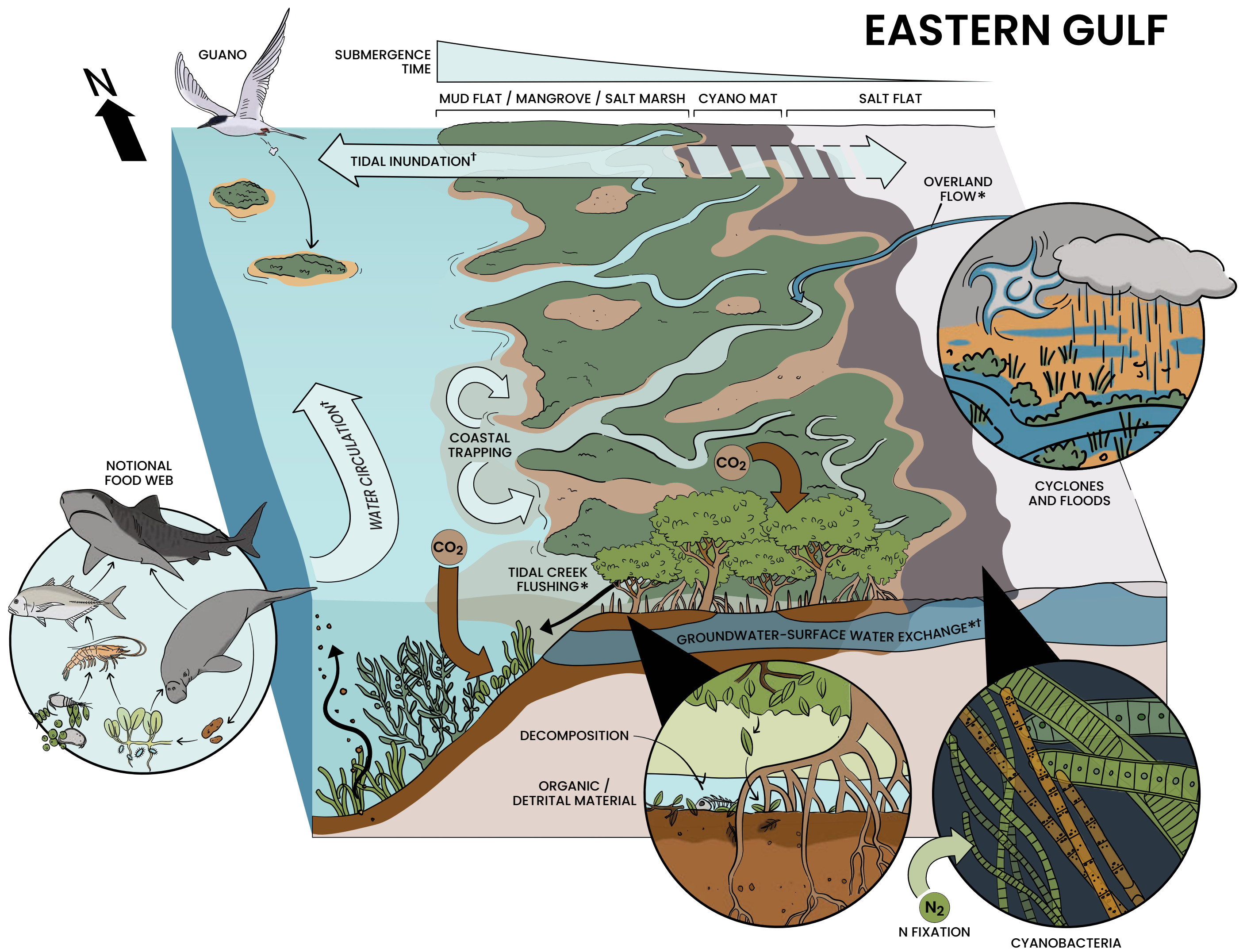

Figure 22: Conceptual models showing the possible nutrient sources and transport pathways in Exmouth Gulf. (*continued from previous page*).

✱ = SEASONAL INFLUENCE OF CYCLONES AND FLOODS

† = INFLUENCED BY SEASONS AND CLIMATE DRIVERS (E.G., EL NIÑO/ LA NIÑA, NINGALOO-NIÑO/NIÑA)

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3.2.3. Hydrological connectivity

3.2.3.1. Tides, wave climate and circulation within Exmouth Gulf

Water circulation in Exmouth Gulf is primarily driven by winds and tidal currents (Massel et al., 1997; Cuttler et al., 2020). Exmouth Gulf has a semi-diurnal tidal cycle (two high and two low tides every day) with a mean tidal range of 1.8 m and spring tides of up to 2.8 m. Tidal currents generally flow in a southwest direction reaching speeds of up to 1 m s^{-1}.

Southwesterly winds dominate during summer driving wind-generated waves (Cuttler et al., 2020). In winter, ocean swell enters Exmouth Gulf from the northwest, and winds can be more variable, tending towards southeasterly winds (Pearce et al., 2015; Cuttler et al., 2020). While this describes 'typical' conditions, wind, waves and swell can be influenced interannually by fluctuations in large scale climate drivers (e.g., ENSO, Indian Ocean Dipole, Ningaloo Niña and Niño).

Recent modelling of seasonal variability in water circulation based on wind provides evidence that waters entering Exmouth Gulf from the northwest during spring, summer, and to some extent autumn, circulate along the western margin towards the southern areas of Exmouth Gulf, and exit out through the northeast (Figure 23, Grimaldi et al., in prep). Based on this, Exmouth Gulf is suggested to be relatively well flushed during these seasons, and less so in winter where circulation is more variable.

3.2.3.2. External coastal currents

The entrance of Exmouth Gulf is exposed to two current systems; the dominant southward flowing Leeuwin Current transporting warm, low salinity waters southwards (Godfrey & Ridgway 1985; Cresswell et al., 1989), and the seasonal inshore northward flowing Ningaloo Current (Taylor & Pearce 1999; Hanson et al., 2005). The warm Leeuwin Current flows strongest during the autumn and winter months where it supresses much of the upwelling of cooler nutrient rich water along the coastline of WA.

During summer, when the southerly winds strengthen, the Leeuwin Current weakens and is pushed further offshore allowing the Ningaloo Current, which brings cooler nutrient rich waters to the surface along the Ningaloo Coast. These cooler upwelled waters increase productivity in the region and can flow around the North West Cape and intrude into Exmouth Gulf between the Cape and Muiron Islands.

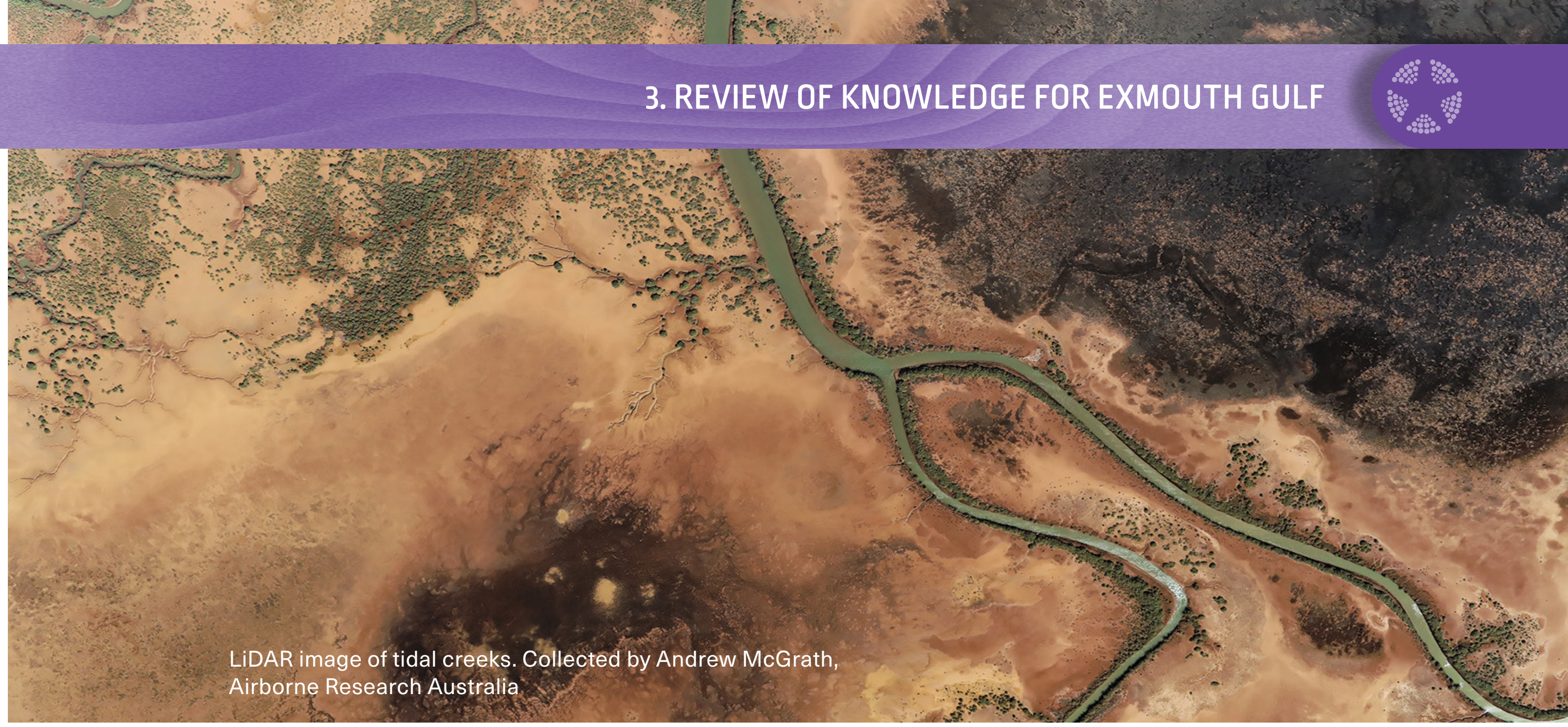
3.2.3.3. Tidal creeks

The eastern flats of Exmouth Gulf are laden with tidal creeks among the mangrove forests and support a wealth of marine life. Tidal creeks can extend up to 2 km inland (Paling et al., 2008). They likely contribute a significant amount of nutrients to Exmouth Gulf when they are submerged during tidal inundation and flooded during high rainfall events and cyclones. Cyclones can generate a lot of sediment movement and cause flow restrictions, redirections or even closures of tidal creeks (Paling et al., 2008).

3.2.3.4. Groundwater

The flow of freshwater from the Cape Range through subterranean waterways bring nutrients into Exmouth Gulf, supporting its ecology. The subterranean waterways empty through channels in the western shallows, and for this reason is understood to attract a variety of marine creatures from dugongs to rays to humpback whales and their calves. Traditional Owners have always had cultural knowledge of this system, which is only now being understood by and reflected in western science. Waters (groundwater; surface waters; subterranean waterways) are the embodiment of the cultural and spiritual values and song-lines of the Cape Range peninsula.

Groundwater is discussed here in relation to saltwater intrusion and discharge in the nearshore marine environment. A more comprehensive description of groundwater is provided in Sutton & Shaw (2021). DWER is currently reviewing groundwater allocation limits across the Exmouth Peninsula (DWER, 2024).



LiDAR image of tidal creeks. Collected by Andrew McGrath, Airborne Research Australia

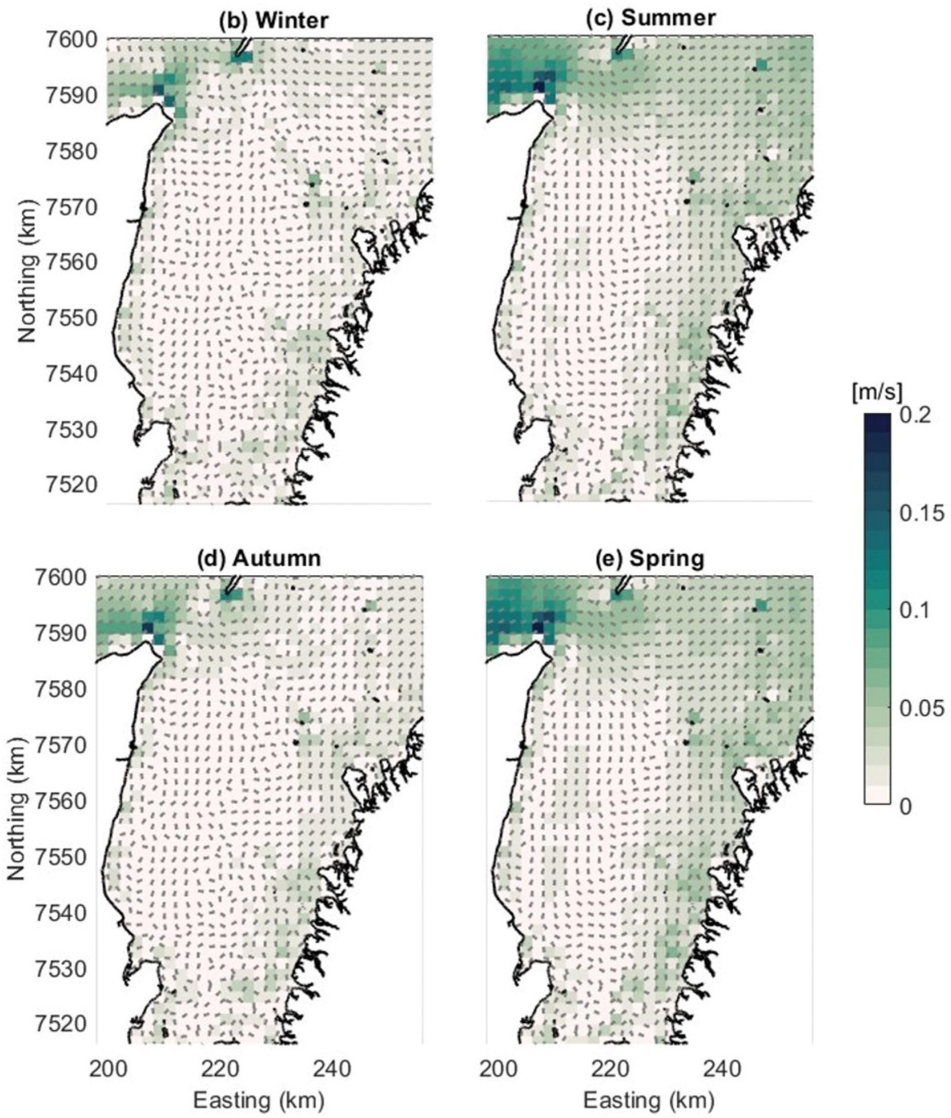


Figure 23: Modelled residual depth-averaged current velocity for a full neap-spring tidal cycle including remotely generated swell (Hs=1 m, Tp = 10 sec) and locally generated waves for winter, summer, spring and autumn conditions. The idealised seasonal wind conditions were calculated from a wind climatology based on the Learmonth weather (ID: 005007; -22.24°N, 114.10°E) between 2000 and 2018. The model was run in Delft3D Flexible Mesh. Used with permission from Grimaldi et al. (in prep).

The Exmouth township relies on groundwater for drinking and irrigation (Saccò et al., 2022; Water Corporation, 2025). Saltwater intrusion into previously fresh groundwater aquifers can occur when the drawdown of groundwater is greater than the replenishment rates, and this is occurring for the Cape Range aquifer system. The karstic limestone aquifer system of Cape Range consists of a freshwater layer, which overlies a transition zone of brackish water resting on the seawater wedge (EPA 1997, 1999) (Figure 24).

The transition zone is located approximately 3.5–5 km inland from the coastline of Exmouth Gulf, depending on location, and the diffusion zone of 20–30 m thick is influenced by tides (Forth, 1972; Martin, 1990; Gilgallon & McGivern, 2018).

Groundwater flow from the Cape Range aquifer system flows eastward towards Exmouth Gulf and is discharged into the ocean (Allen, 1993; Water and Rivers Commission 2000; Collins & Stevens 2010), though it is unclear exactly where submerged groundwater discharge zones exist along the western Exmouth Gulf (Figure 25).

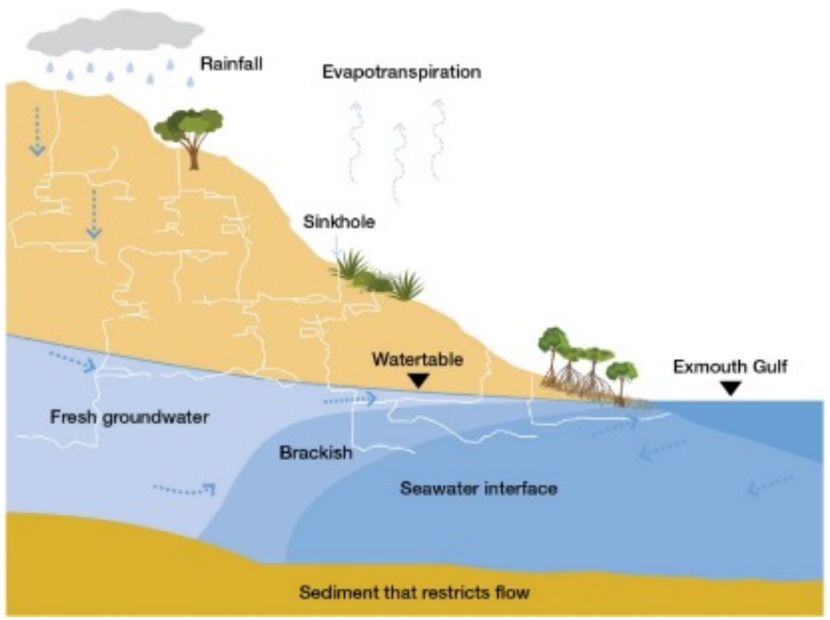


Figure 24: **A conceptual cross-section of the Cape Range limestone groundwater system of the Exmouth peninsula, from Cape Range east to the Exmouth Gulf. Sourced from DWER Exmouth groundwater allocation planning (https://www.wa.gov.au/service/natural-resources/water-resources/exmouth-groundwater-allocation-planning).**

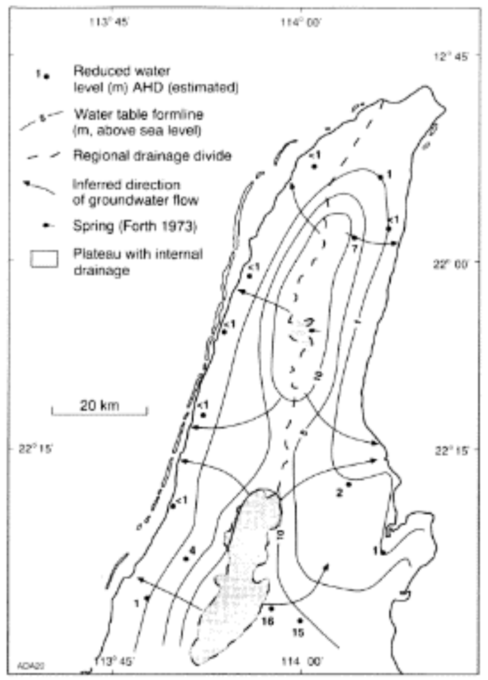


Figure 25: **Inferred direction of groundwater flows from the Cape Range aquifer system. Sourced from Allen (1993).**

A superficial groundwater aquifer is present along eastern Exmouth Gulf, under the intertidal areas and dune fields which slowly flows eastwards (D.C. Blandford & Assoc and Oceanica, 2005; EPA, 2008; AQ2, 2020). Heavy rain flowing over the salt flats has the potential to facilitate the flow of groundwater nutrients into Exmouth Gulf, either through enhanced groundwater flow or exchange with surface waters and is suggested to discharge via throughflow into tidal creeks, mangrove swamps and flats (Oceanica, 2005; EPA, 2008). Following TC Vance and mass mangrove loss, some tidal creek entrances were impounded or completely blocked. Paling et al. (2008) suggested the survival of some mangroves at these creek mouths was due to subsurface groundwater flushing and subsequent reduction in salinity concentrations. High tides inundating the salt flats are also thought to facilitate groundwater exchange (Hickey et al., 2023a). The groundwater under the salt flats is hypersaline and estimated at 0.2–1 m deep, which results in more prevalent surface-groundwater interactions (D.C. Blandford & Assoc and Oceanica, 2005). Recharge of groundwater across the area is generally slow given the relatively flat terrain, high evaporation rates and low permeability of the claypans.

Overall, groundwater discharge into Exmouth Gulf occurs, but no comprehensive or peer-reviewed investigations have been undertaken to discern the flow rates or submerged discharge locations. Groundwater discharge into the nearshore marine environment likely supports mangroves (balancing salinity and increasing nutrient availability; Hayes et al., 2019; Hickey et al., 2021), productive fishing grounds (e.g., Liu & Du, 2022) and seagrass growth (supplying nutrients). A study of seagrass communities bordering a coastal karstic system in Yucatan, Mexico, provides evidence of submarine groundwater discharge, and associated nutrients, influencing the distribution and abundance of species (Kantún-Manzano et al., 2018). Closer to home, DWER is currently investigating groundwater links to nearshore marine ecosystems in the La Grange subregion in the Kimberley (Kilminster et al., in prep), which could help inform similar processes in Exmouth Gulf. Currently, the importance of groundwater contributions is not well understood in Exmouth Gulf.

3.2.3.5. Freshwater input

Freshwater input to Exmouth Gulf as a result of rainfall and run-off is typically very low (Penn & Caputi, 1986; Brunskill et al., 2001). Mean annual rainfall is 240–300 mm per year (Bureau of Meteorology). Cyclone and storm events can generate pulses of freshwater, with tropical cyclones estimated to contribute 20–40% of the freshwater input each year (Wyrwoll, 1993). There are also no major river systems that deliver freshwater to Exmouth Gulf, though flood plumes from the Ashburton River have on occasion, with favourable winds, entered Exmouth Gulf (Cartwright et al., 2023).

3.3. Water and sediment quality

The water and sediment quality in Exmouth Gulf is assumed to be good given the relative lack of coastal development and land use pressures compared to other coastal embayments. Routine water and sediment quality monitoring across Exmouth Gulf is not undertaken and, instead, available information mostly comes from localised studies or site investigations for industry (e.g., Urala Creek). Autumn phytoplankton blooms do occur annually off Ningaloo Reef, but these are not harmful algal blooms that can result from poor water quality. No records of harmful algal blooms have been uncovered for Exmouth Gulf, providing further evidence that water quality is likely high. Exmouth Gulf is shallow and influenced by prevailing winds, which means the water column is often well mixed for large parts of Exmouth Gulf across much of the year.

Exmouth Gulf experiences a greater range in sea temperature as it is less regulated and flushed by open ocean processes and prevailing currents. The southern portion of Exmouth Gulf experiences the highest temperature variability as well as the highest temperatures during the warmer months and lowest temperatures during the cooler months. Wave buoys have been recently deployed to measure sea temperature and wave parameters in the middle and to the north of Exmouth Gulf (e.g., Figure 5), and sea temperature have been monitored annually at the Navy Pier since 2008 (Hoschke & Whisson, 2021). However, no long-term monitoring of temperature has occurred for southern Exmouth Gulf.

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Aside from cyclones and summer rainfall, there is no continuous input of freshwater into Exmouth Gulf. As a result, a salinity gradient is often evident, whereby salinity increases with increasing distance into Exmouth Gulf (e.g., McKinnon & Ayukai, 1996, Ayukai & Miller 1998). High salinity has been measured along eastern Exmouth Gulf in late August and early spring where waters are shallower and evaporation higher (Ayukai & Miller 1998).

The turbidity in Exmouth Gulf is naturally high and levels can fluctuate over daily, monthly, yearly and interannual timescales depending on the driver (e.g., tides, ENSO, Indian Ocean Dipole) (Cartwright et al., 2021; Doropoulos et al., 2022; Cartwright et al., 2023). Mean turbidity is higher for eastern and southern Exmouth Gulf and less so towards the northwest (Cartwright et al., 2021; Doropoulos et al., 2022) (Figure 26). Wind induced resuspension, depth and wave energy can influence turbidity in different regions of Exmouth Gulf. Predictions on future turbidity levels in Exmouth Gulf is provided in Section 3.1.2.2.

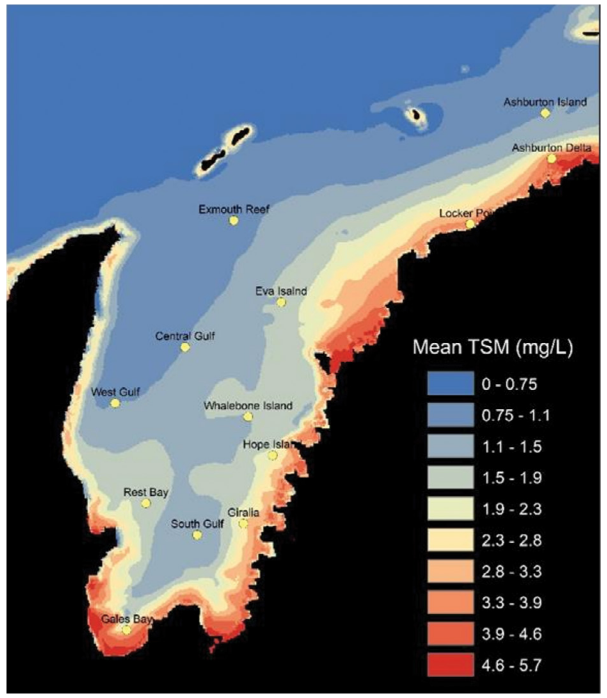

Figure 26: **Mean monthly turbidity (TSM) in Exmouth Gulf from 2002–2020, produced from MODIS-aqua remotely sensed data and a locally calibrated turbidity algorithm. Soured from Cartwright et al. (2021) with permission.**

Chlorophyll *a* concentrations in Exmouth Gulf typically range from 0.2–0.3 mg m^{-3} during late winter and early spring, and can be higher near the entrance of Exmouth Gulf compared to the inner Gulf. Phytoplankton production was highest along the eastern margins (> 30 mg C $m^{-3}d^{-1}$) and mostly below 25 mg C $m^{-3}d^{-1}$ for much of Exmouth Gulf (Ayukai & Miller, 1998), which was reportedly lower than productivity found in other embayments and lagoons in the tropics (McKinnon & Ayukai, 1996; Ayukai & Miller, 1998). A cross-shelf comparison of productivity during the summers of 1997/98 and 1998/99 found particulate nitrogen and average surface chlorophyll *a* concentrations to be higher within Exmouth Gulf than in slope waters outside Exmouth Gulf, while the opposite was found for concentrations of dissolved nitrogen and silicate (Furnas, 2007). Surface concentrations of ammonium (NH4+) were low across shelf and slope stations. Water column nutrients, such as phosphate, nitrate, and nitrite were also considered to be relatively low in Exmouth Gulf during August–September in 1995 (Ayukai & Miller, 1998). These studies suggest that phytoplankton production in Exmouth Gulf may be constrained by limited nutrient availability, though no repeat studies have occurred to examine seasonal or annual variability or encompass all areas of Exmouth Gulf.

Compared to water quality, sediment quality has been comprehensively examined at least once. Sediment type, size, nutrients and trace metals were measured from over 150 sites spanning salt flats, mangroves, tidal creeks, islands, terrigenous dunes and open waters in Exmouth Gulf between 1994–1996 (Brunskill et al., 2001). Carbonate carbon was generally highest along northwestern Exmouth Gulf (> 7 mmol/g) whereas organic carbon has highest along eastern Exmouth Gulf (> 0.4 mmoles/g). Nitrogen concentrations were highest along eastern Exmouth Gulf (> 60 µmol N/g), Giralia Bay and between North West Cape and Muiron Islands, while much of the inner Gulf had lower concentrations (< 30 µmol N/g). Phosphorus concentrations were lowest along eastern Exmouth Gulf (< 510 µmol/g) and highest in northwest and southern Exmouth Gulf (> 20 µmol/g). The results do not suggest high nutrient loads in Exmouth Gulf or issues with eutrophication. The concentration of trace elements (barium, lithium, lead, copper) were relatively low and also provided no evidence of anthropogenic input. However, high concentrations of cadmium (800–1100 pmol/g) along western Exmouth Gulf in

Mangroves. Rebecca Bateman-John

10–20 m water depth were suggested to come from the accumulated waste from the prawn fishery and potentially dead mollusc assemblages, as these two groups are known to have high levels of cadmium.

The distribution of marine elements and trace elements across Exmouth Gulf is reflective of its geology and sediment types, such as carbonate sands, quartz, mud, coralline gravel, shells, limestone lithoclasts and biogenic fragments (Brunskill et al., 2001). This was attributed to the higher concentrations of cobalt, lead and vanadium detected along the upper western margin around Exmouth townsite compared to other sites sampled along the Pilbara coastline in June 2005 (DEC, 2006). Organic chemicals were also tested, such as tributyltin, dibutyltin, benzene group (benzene, toluene, ethylbenzene, xylenes), hydrocarbons, pesticides and polychlorinated biphenyls, and concentrations were all below the analytical Limit of Reporting.

Past and current spatial and temporally patchy datasets exist which, if compiled and standardised, could help towards the development of a better understanding of water and sediment quality and guide where future monitoring efforts should focus.

3.4. Benthic communities and habitats

Exmouth Gulf supports highly diverse habitats within both its subtidal and intertidal range. These habitats are known to shift in extent from year-to-year based on weather, temperature, and other factors (Hickey et al., 2023a), but generally remain consistent in broad location. Subtidal habitats have recently been mapped via underwater video tows (O2 Marine, 2024) (Figure 27), while intertidal habitats have been mapped via aerial and satellite imagery (Hickey et al., in prep) (Figure 28). Characteristics of specific subtidal and intertidal habitats found in Exmouth Gulf, including species composition, area of extent and distribution, ecological significance, and threats, are discussed in the following sections. The WAMSI Mardie Salt Marine Research Program is also underway to identify and quantify the potential effects of sea-level rise on mangroves, samphire and algal mat on the west Pilbara Coast.

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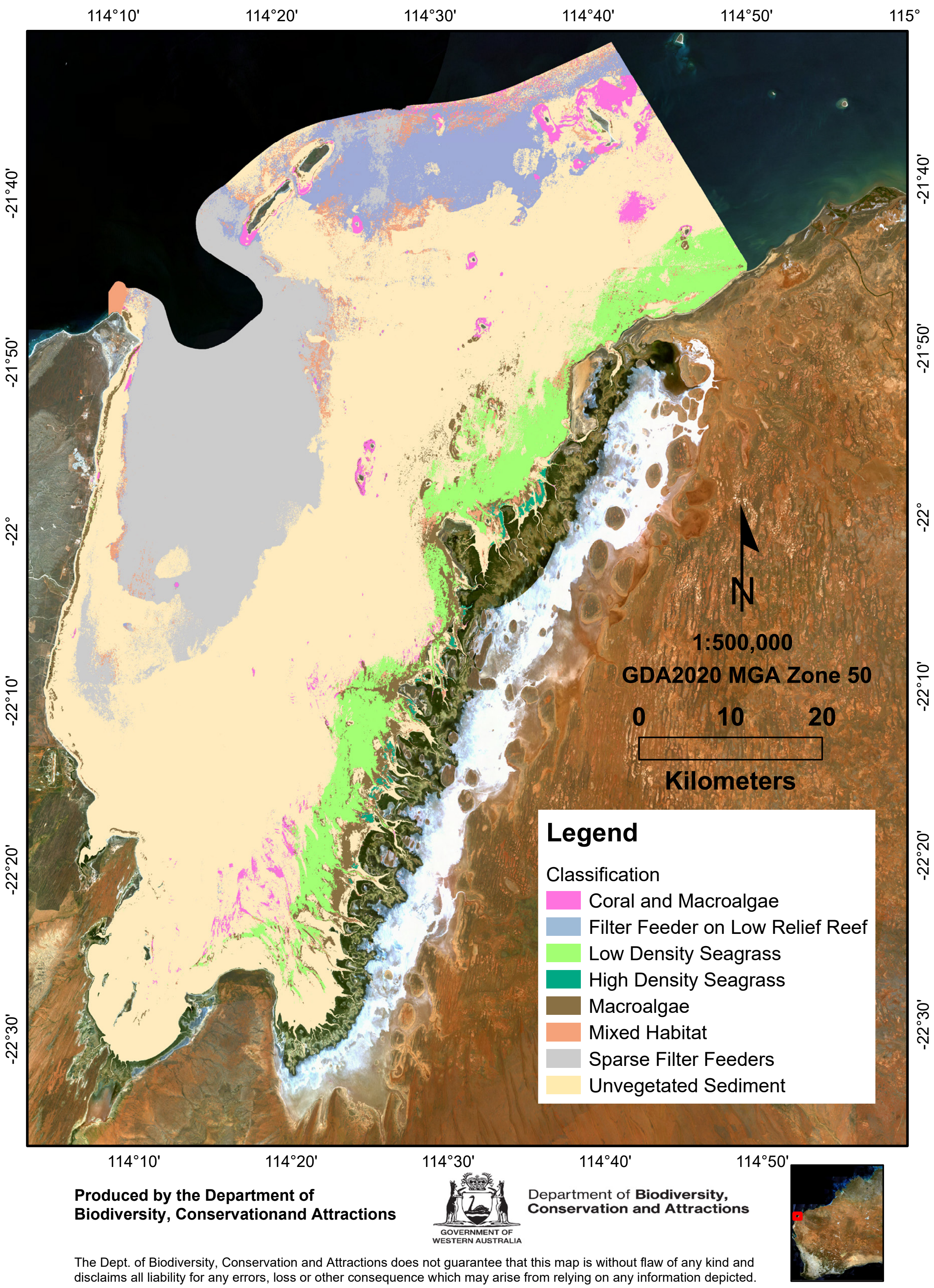

Figure 27: Broadscale benthic habitat map of Exmouth Gulf produced from satellite derived imagery, modelled layers and ground-truthing. Sourced from O2 Marine (2024).

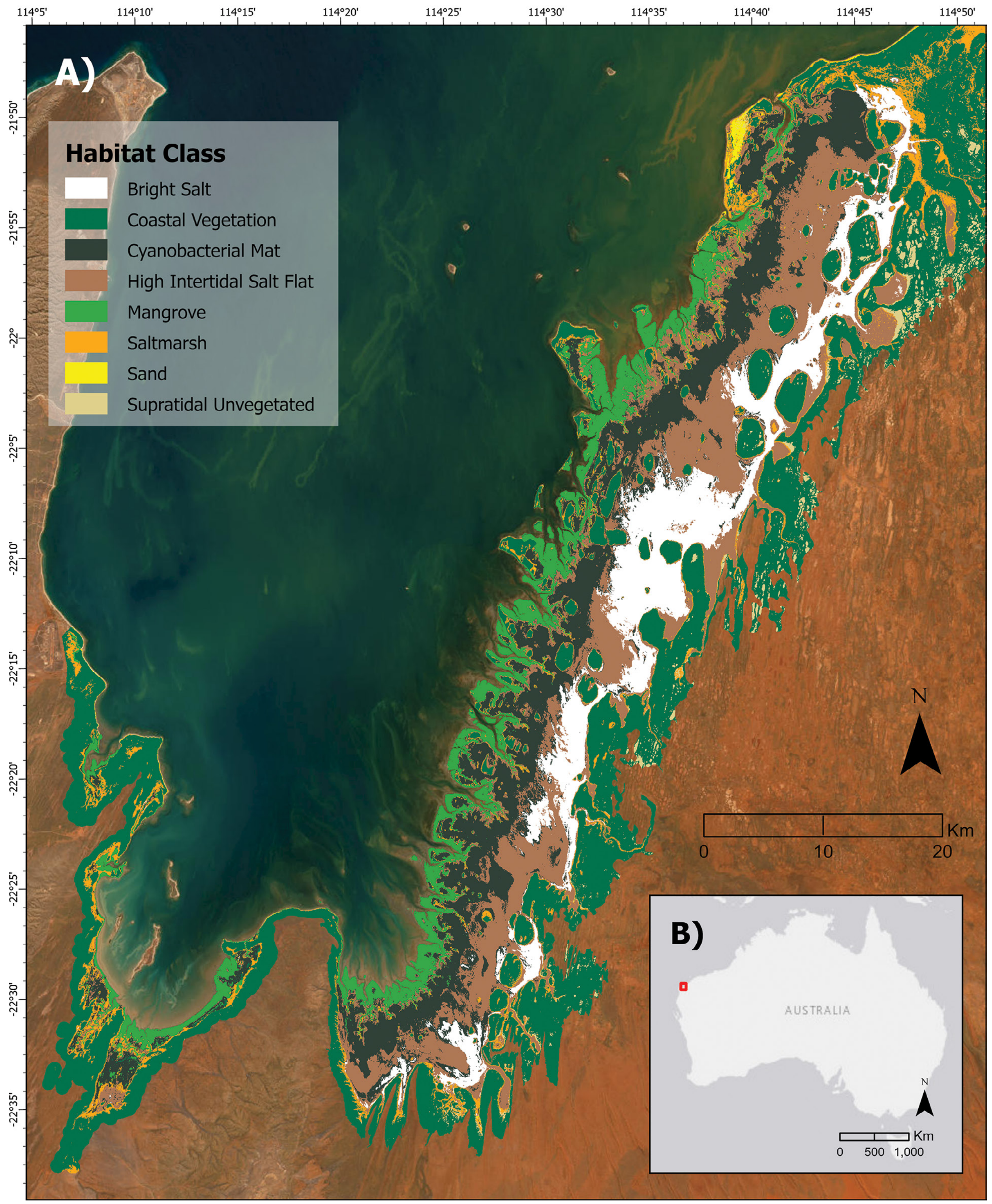

Figure 28: Intertidal habitats of Exmouth Gulf. Adapted from Hickey et al. (2025).

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The benthic communities and habitats in Exmouth Gulf should not be viewed as independent systems. They are highly interconnected and gain substantial ecological value through their interactions with other nearby habitats. For example, all intertidal communities along eastern Exmouth Gulf (mangroves, saltmarsh, cyanobacterial mats, and salt flats) have been listed in the Directory of Important Wetlands since 1992 (site WA007) as an outstanding example of a tidal wetland system in northwest Australia (DCCEEW, 1992). It plays an important ecological role and supports habitat for a range of fauna. The exceptional ecological value of Exmouth Gulf stems in large part from the diversity and interplay of the rich 'habitat mosaic' present in Exmouth Gulf.

3.4.1. Salt flats

3.4.1.1. Distribution and demographics

Salt flats occupy the habitat at the highest zone of the intertidal, sitting at the intersection between terrestrial and marine environments (e.g., Figure 29). Limited research has been undertaken on salt flat communities despite being the dominant intertidal habitat in Exmouth Gulf in terms of coverage. Salt flats occupy extensive areas (over 64,000 ha) of eastern and southern Exmouth Gulf (Hickey & Lovelock, 2022), or approximately 31% of the intertidal wetlands (Hickey et al., 2023a). Including salt flat areas with saltmarsh vegetation and cyanobacterial mats, intertidal salt flats cover approximately 16% of the Exmouth Gulf as a whole (Brunskill et al., 2001).

Salt flats are characterised by areas infrequently inundated by tides (e.g., on high spring tides) and typified by high temperatures. These conditions lead to large amounts of evaporation of tidal or groundwater input, and result in flat landscapes covered with a layer of salt (Hickey & Lovelock, 2022). When inundated, salinity levels in these environments are much higher than incoming tidal waters. Saltmarsh and mangrove species, as well as cyanobacterial mats, can grow on salt flats, however abundances are typically low. The salt flats of Exmouth Gulf, including these areas of cyanobacterial mats and saltmarsh communities, are some of the largest and most intact salt flat ecosystems in WA (EPA, 2008). This section largely focuses on the high intertidal salt flat habitats without cyanobacteria or vegetation.

Figure 29: **Salt flats of the high intertidal zone along eastern Exmouth Gulf. Image: Sharyn Hickey**

3.4.1.2. Ecological significance

Very little research has been done on the ecology of salt flats around Exmouth Gulf, except flats with cyanobacterial mats. Chemical composition of salt flat sediments indicates that they are potentially important sources of elements and nutrients including carbon, nitrogen, and boron compared to other sediments within Exmouth Gulf (Brunskill et al., 2001). They are likely to contribute these and other important nutrients to marine systems through leakage of hypersaline brine into mangrove creeks during tidal inundation or groundwater seepage, as well as by winds blowing salt flat sediments into the marine environment. Salt flats may be a source of primary production for Exmouth Gulf, but the carbon sequestration of this habitat has not been studied and remains unknown (Hickey et al., 2023a).

Fish, small elasmobranchs, and crustaceans have been observed coming onto salt flat areas at high tides in Giralia Bay (Penrose, 2005). While Exmouth Gulf salt flats have not been thoroughly surveyed for seabirds or shorebirds due to access difficulties, saltmarsh and salt flats in other areas of Australia have been shown to offer important feeding and roosting habitat for shorebirds, as well as important feeding areas for insectivorous bats (Spencer et al., 2009). Tracking evidence from GPS-tagged shorebirds corroborates this assumption, suggesting that salt flat areas along the eastern Exmouth Gulf may be important roosting and feeding sites for a variety of shorebirds (S. Marin-Estrella, pers. comm.).

3.4.1.3. Threats

Threats to high intertidal salt flats have not been thoroughly examined in Exmouth Gulf but are likely to be similar to those identified for other intertidal communities, including damage from high intensity storms, sea level rise and erosion (Hickey & Lovelock, 2022). Sea level rise has also been shown to allow mangroves to colonise further up the intertidal zone in Exmouth Gulf, potentially encroaching on salt flat habitat (Lovelock et al., 2021).

Although salt flats also have the potential to shift to higher elevations as sea level rises. As salt flats are characterised by extremes (high salinity and temperatures), it is also likely that any flora and fauna inhabiting the flats are already living at the margins of their physiological tolerances (Hickey & Lovelock, 2022).

Salt flat habitats are also threatened by developments, particularly salt ponds and other solar salt project infrastructure which often focus project developments on unvegetated salt flats. For example, K+S Salt Australia's Ashburton Salt Project proposal on the northeastern margin of Exmouth Gulf would cause direct impact to over 10,600 ha of bare salt flat (K+S Salt Australia Pty Ltd, 2023). Unregulated off-road driving can also destroy or disturb salt flat habitats, including killing vegetation, compacting sediments, causing erosion, and introducing weeds (Kobryn et al., 2017), although the extent of this threat has not been mapped along eastern Exmouth Gulf.

3.4.2. Cyanobacterial mats

3.4.2.1. Distribution and demographics

Cyanobacterial mats can be found in the intertidal zone along eastern and southern Exmouth Gulf, generally situated between mangroves and higher intertidal salt flats (Hickey et al., 2023a). These mats are formed by dense communities of cyanobacteria, or blue-green algae, in areas that are periodically inundated by the tides (e.g., Figure 30). They are made up of various species and structural forms of cyanobacteria depending on the elevation and location, but often predominantly include sheathing cyanobacteria such as *Microcoleus chthonoplastes* and *Oscillatoria* spp. (Adame et al., 2012; Hickey et al., 2023a). Their spatial extent varies over time. For example, between 2013 and 2020, the combined cover of high and low density cyanobacterial mats ranged from approximately 9% to 20% of the intertidal zone of Exmouth Gulf (Hickey et al., 2023a). The variance in cover is likely to be related to changes in the extent of tidal and/or freshwater inundation over time, as well as groundwater-surface water exchange. Mats can also be dislodged by heavy winds and storms and tend to erode in years of high rainfall (Hickey et al., 2023a; Lovelock et al., 2021).

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Figure 30: Dense cyanobacterial mats can form across the intertidal zone along eastern and southern Exmouth Gulf. Image: Shannon Dee

Cyanobacterial mats are functionally active when inundated and, when dry, revert to a desiccated, dormant state (Lovelock et al., 2010; Adame et al., 2012; Chennu et al., 2015; Hickey et al., 2023a). Most mats are located in the high intertidal zone. For example, mats in Giralia Bay are found between approximately 2.3 and 2.7 m above the lowest astronomical tide (Lovelock et al., 2010). As such, most mats remain desiccated for the majority of time, with mats in Giralia Bay estimated to receive tidal inundation only on days with tides above 2.4 m (Lovelock et al., 2010). Once inundated by high tidal flows or occasional rainfall, mats rapidly rehydrate and recover photosynthetic capabilities within 15 minutes (Chennu et al., 2015). Photosynthetic capacity gradually increases over a period of 24–48 hours as the cyanobacteria migrate towards the surface of the mat, and can continue for up to several weeks after inundation (Lovelock et al., 2010). Assuming a conservative period of one week of function after tidal inundation, mats in Giralia Bay and likely elsewhere in Exmouth Gulf are inundated and/or functional for approximately 85 days per year on average (Lovelock et al., 2010; Chennu et al., 2015).

Investigations into the chemical composition of cyanobacterial mats in Exmouth Gulf showed that approximately 24% of the mats are comprised of organic matter, and that several elements are concentrated within the mats compared to surrounding sediments. For example, nitrogen, sulfur, calcium, magnesium, and sometimes phosphorus concentrations were much higher within cyanobacterial mats compared to surrounding sediments (Lovelock et al., 2010; Adame et al., 2012). Mats also contained terrestrially derived elements including iron and aluminium, likely from dust blown over the mats by wind as well as occasional freshwater run-off after storms (Lovelock et al., 2010; Adame et al., 2012).

3.4.2.2. Ecological significance

Cyanobacterial mats are an important source of primary production, nitrogen fixation, and other biochemical pathways for Exmouth Gulf (Lovelock et al., 2010; Adame et al., 2012; Chennu et al., 2015) (Figure 31). Mats also offer habitat and/or foraging areas for multiple faunal groups (e.g., Penrose, 2011). Even with the limited time frame of photosynthetic capacity during or directly post inundation, cyanobacterial mats are estimated to be responsible for up to 15% of the primary production in Exmouth Gulf, sitting above seagrass and macroalgae but below phytoplankton and mangroves in terms of net production of carbon per year (Lovelock et al., 2010). Unlike mangroves, seagrasses, and algae, cyanobacterial communities allocate much of their produced carbon to carbohydrates, which become soluble and readily incorporated into nearshore food webs during inundation (Lovelock et al., 2010). The high primary production of cyanobacterial mats is likely a key factor contributing to the relatively high productivity observed in Exmouth Gulf compared to other typically oligotrophic arid regions in the tropics and subtropics which receive little input of terrestrial nutrients due to limitations in freshwater run-off (Adame et al., 2012; Cartwright et al., 2023).

In addition to primary production, cyanobacterial mats in Exmouth Gulf are important contributors to nitrogen dynamics at an ecosystem scale (Lovelock et al., 2010; Adame et al., 2012). Cyanobacterial mats can fix substantial amounts of nitrogen which can be leached during tidal inundation and provide nutrients to the coastal zone (Paling & McComb 1994, Lovelock et al., 2010). Cyanobacterial mats in Giralia Bay have also been recorded removing significant amounts of nitrogen from nutrient rich flood waters (Adame et al., 2012).

In addition to their biochemical roles in the Exmouth Gulf environment, cyanobacterial mats are an important habitat for a range of fishes and invertebrates (Penrose, 2011), and may be important foraging and roosting areas for shorebirds (S. Marin-Estrella, pers. comm.). Surveys of fish and invertebrates within cyanobacterial mat communities in Giralia Bay found highly diverse faunal assemblages, including 61 fish species (32 families) and nine crustacean species (3 families). In these surveys, both fish and crustaceans were more abundant on mats close to mangrove environments, highlighting the connectivity between these habitats (Penrose, 2011). Stable isotope examinations showed that for all fish species examined within cyanobacterial mat habitats and nearby mangroves, the dominant carbon source originated from cyanobacterial mats. Stomach content analyses suggested that fish were preying on invertebrates feeding directly on cyanobacteria. Carbon originating from cyanobacterial mats, alongside seagrass ecosystems, was also determined to be the dominant source for larger fish species, including the elasmobranch *Glaucostegus typus* (giant shovelnose rays), demonstrating the transfer of energy from cyanobacterial mats to higher order food webs and pelagic environments.

3.4.2.3. Threats and pressures

Threats to cyanobacterial mat communities mainly include processes that physically damage or destroy mats. Cyanobacterial mats in Giralia Bay show relatively slow growth and regaining of function after disturbance. For example, experimentally disturbed patches of cyanobacterial mats had less than half the organic matter and only 14% of the average chlorophyll *a* concentration one year after disturbance (Lovelock et al., 2010). Heavy rainfall, winds, and storms can damage mats and cause them to erode, and thus cyclones and extreme weather events in the region are a concern for these communities (Lovelock et al., 2021). Climate predictions suggest that storm frequency may decrease in Exmouth Gulf in the future, but that storms may become more intense (Knutson et al., 2020). Sea level rise is also a concern, as more regular tidal inundation will increase erosion of mats (Lovelock et al., 2021). Its effects will be most prevalent on gently sloping shorelines including the southern and eastern shores of Exmouth Gulf where cyanobacterial communities reside. Even small increases in sea level may cause major shifts in the area of land inundated by tides.

Figure 31: Cyanobacterial mats are an important source of primary production and nitrogen fixation in Exmouth Gulf, and provide important habitat for a range of fish, invertebrate and shorebird species. Image: Jenny Shaw

3.4.3. Saltmarshes

3.4.3.1. Distribution and demographics

Saltmarshes characterise areas on the high intertidal salt flats which support halophytic vegetation. In Exmouth Gulf, these plant communities are dominated by samphire, which are succulents within the genus *Tecticornia* (Hickey et al., 2023a) (Figure 32). *Tecticornia* spp. are low-lying groundcovers or shrubs which can form dense basal cover in some areas of Exmouth Gulf, but do not contribute to canopy cover (Paling et al., 2008). These communities are most dense on southern and eastern Exmouth Gulf adjacent to mangroves. They are generally located on the seaward edge of the salt flats near the upper margin of mangrove cover and are often interspersed with sparse mangroves (Hickey et al., 2023a). Saltmarsh habitats are occasionally inundated by high tides but are not regularly flooded. The area of saltmarsh coverage within the Exmouth intertidal zone has not recently been quantified due to challenges of identifying this habitat from traditional satellite imagery (Hickey & Lovelock, 2022). However, in 1999 prior to TC Vance, the intertidal areas between Giralia Bay and Urala Creek South supported approximately 7,470 ha of saltmarsh, which declined after the cyclone (Paling et al., 2008). By 2004, saltmarsh had recovered to 6,472 ha with continued growth likely after this point.

Samphire species identified in Exmouth Gulf saltmarsh communities include *Tecticornia indica, T. halocnemoides, T. pruinosa, T. syncarpa, T. auriculata, T. doliiformis, T. pergranulata,* and *T. pterygosperma* (McCreery et al., 2005; Hickey et al., 2023a). Other species found in eastern Exmouth Gulf saltmarsh communities include the shrubs *Neobassia astrocarpa, Lawrencia viridigrisea, Frankenia pauciflora, Suaeda arbusculoides*, and *Muellerolimon salicorniaceum*, the grasses *Eragrostis falcata* and *Sporobolus virginicus*, and occasionally the herbs *Cyperus bulbosus* and *Swainsona pterostylis* (McCreery et al., 2005). No published studies on zonation patterns and environmental tolerances have been identified for Exmouth Gulf. However, other ecophysiological research focusing on salt lakes in WA have demonstrated *Tecticornia* species have different tolerances to salinity, drought and waterlogging, which influences where species grow in relation to the water line (Pederson et al., 2006; Rich et al., 2008; English & Colmer 2011; Konnerup et al., 2015; Moir-Barnetson et al., 2016).

Figure 32: Saltmarsh communities, including samphire (pictured), provide important roosting and foraging areas for marine and terrestrial species. Image: Shannon Dee

3.4.3.2. Ecological significance

Knowledge of the ecological communities using saltmarsh habitats is scarce in Exmouth Gulf resulting, in part, from difficulty accessing the remote high intertidal zone of the eastern side of Exmouth Gulf. However, in other areas of northern Australia, saltmarsh habitats have been identified as important roosting and foraging areas for waterbirds as well as feeding areas for terrestrial birds, insectivorous bats, and various terrestrial mammals, reptiles, and amphibians (Spencer et al., 2009; Saintilan & Rogers, 2013). During spring tides when saltmarshes are inundated, these habitats also become important refuges and foraging areas for many fish and invertebrates, especially crabs and molluscs, and can be sites of targeted larval release of several crab species (Saintilan & Rogers, 2013).

Primary productivity and carbon sequestration of saltmarsh communities has not been examined specifically in Exmouth Gulf. When saltmarsh communities were combined in a predefined modelling class with other salt flat habitats, including cyanobacterial mats, modelled carbon sequestration in soils of this habitat class was greater than that estimated for soils in mangrove areas (total estimated value of 83,302 tonnes CO_2e and 49,642 tonnes CO_2e, respectively) (Hickey et al., 2023a). However, the opposite was found for carbon sequestered in vegetation, with mangroves being the dominant contributor.

3.4.3.3. Threats and pressures

Threats to saltmarsh communities in Exmouth Gulf mainly include destruction or alteration of habitat through anthropogenic (e.g., development) and climate-driven (e.g., cyclones, sea level rise) factors. The development of salt ponds and other infrastructure associated with solar salt projects is a major threat to high intertidal salt flat communities including saltmarshes around Exmouth Gulf and the wider Pilbara region. In addition to direct clearing of saltmarsh communities for infrastructure, the development of salt ponds tends to increase or decrease inundation rates in certain areas of salt flats. Most saltmarsh communities rely on specific levels of tidal inundation, and changes in inundation rates may disrupt survival of saltmarsh plants (Keighery, 2013). The K+S Salt Australia Ashburton Salt Project proposal would have a direct impact on an estimated 168 ha of samphire or saline vegetation communities surrounding Urala Creek North and Urala Creek South (K+S Salt Australia Pty Ltd, 2023). Other direct anthropogenic threats in the region include destruction or disturbance of saltmarshes via off road driving (e.g., Kobryn et al., 2017), although the extent of this threat to Exmouth Gulf saltmarshes has not been quantified.

Saltmarsh habitats are also vulnerable to disturbance or destruction form cyclones. For example, saltmarsh communities on the eastern side of Exmouth Gulf were estimated to have declined by 54% following TC Vance in 1999, though they showed rapid recovery in subsequent years, with coverage back at 87% of pre-cyclone levels five years after the storm (Paling et al., 2008). This recovery rate was more rapid than that of mangroves in the same area, and some previous mangrove habitats were recolonised by samphire communities after the cyclone. This suggests that storm-driven destruction of mangrove habitats could lead to expansion of saltmarsh communities under certain conditions. On the other hand, sea level rise has already shown to support increased colonisation of mangroves within saltmarsh habitats in eastern Exmouth Gulf by increasing inundation rates of these areas (Lovelock et al., 2021).

3.4.4. Mangroves

3.4.4.1. Distribution and demographics

Mangroves occupy the mid-intertidal zone at elevations that receive daily inundation by tides (Lovelock et al., 2021; Hickey et al., 2023a) (Figure 33). Extensive mangrove systems are predominantly found along eastern Exmouth Gulf between Giralia Bay and Urala creek, as well as in the southwestern Gulf between Bay of Rest and Gales Bay (Hickey et al., 2023a). Estimates of baseline mangrove cover (excepting in post-cyclone years) in Exmouth Gulf have ranged from 12,800 ha to over 16,000 ha (Paling et al., 2008; Lovelock et al., 2021; Hickey & Radford, 2022; Hickey et al., 2023a), with the most recent estimate (2021) approximating mangrove cover at over 14,000 ha (Hickey & Radford, 2022). This equates to approximately 5% of all mangrove cover (tropical and arid zone mangroves) identified in WA between Shark Bay and the Northern Territory border (Hickey & Radford, 2022) (Appendix 9.1). In considering just arid zone mangroves, Exmouth Gulf contains a substantial proportion of this class of mangrove within the Pilbara region.

Arid zone mangroves are highly nutrient-limited given the general lack of freshwater run-off and therefore low input of terrestrial nutrients. Most mangrove areas are dominated by *Avicennia marina* (white mangrove with pneumatophores), with *Rhizophora stylosa* (red mangrove with prop root systems) also present in areas of lower salinity (Hickey et al., 2023a). Other mangrove species reported in Exmouth Gulf include *Ceriops tagal* (found in some sheltered mangrove creeks near Hope Island, Tent Island, and Bay of Rest), *Aegiceras corniculatum, Aegialitis annulata,* and *Bruguiera exaristata* (found as scattered individuals in the Tent Island area), and *Sonneratia alba* (reported from Bay of Rest) (Wells, 1983; Humphreys et al., 2005; Vanderklift et al., 2020). Mangrove forests in Exmouth Gulf generally show a strong gradient in tree height, from a 'fringe' band of mangroves approximately 5 m tall along the lower edge of the mangrove zone, transitioning to a scrub forest approximately 2 m tall before fading into salt flat communities (Lovelock et al., 2021). Between the taller mangrove fringe and the scrub forest, the whole mangrove zone spans approximately 130 to 180 m wide across much of the southern and eastern Gulf (Lovelock et al., 2021).

Microbial communities within mangrove roots and surrounding soils differ significantly between fringe and scrub mangroves. In Giralia Bay, scrub mangrove microbial communities (within mangrove roots) were generally more diverse (taxonomically and functionally) compared to fringe mangroves, highlighting the more extreme conditions and environmental variation that scrub mangroves are exposed to (Hsiao et al., 2024). On the other hand, microbial communities in the soil surrounding fringe mangroves in Giralia Bay tended to have greater species richness and diversity than the soil surrounding scrub mangroves (Thomson et al., 2022). The dominant microbial functions within soils from both mangrove zones were respiration of sulfur compounds and chemoheterotrophy (Thomson et al., 2022), while microbial communities within mangrove roots promoted plant growth, sulfur reduction, and various nutrient metabolism pathways (Hsiao et al., 2024).

Figure 33: Tidally inundated mangroves and saltmarsh in Exmouth Gulf, providing important habitat for a diversity of marine and coastal fauna. Image: Sharyn Hickey

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3.4.4.2. Ecological significance

Mangroves have widespread ecological value including as important sources of primary production and carbon sequestration, as coastal protection from storm surge, and as essential habitat for a variety of marine and terrestrial fauna. In Exmouth Gulf, mangroves are one of the most important primary producers and contributors to food webs, with the total fixed carbon production by mangroves (including from both the live canopy and mangrove litter) estimated at 434,977 mg fixed C per year (Lovelock et al., 2010). This is greater than the estimated carbon fixation of all other autotroph classes within Exmouth Gulf including seagrass, algae, phytoplankton, and cyanobacterial mats. Microbial biomass in mangrove areas is also generally twice that measured in higher intertidal zones (Davies, 2018).

As a result of the high primary productivity of mangroves in Exmouth Gulf, these systems also act as important carbon sinks, with an estimated 49,642 tonnes of CO_2e sequestered in Exmouth Gulf mangroves each year (Hickey et al., 2023a). This makes these systems an important source of 'blue carbon,' which can be significant in climate change mitigation (Lovelock et al., 2022; Hickey et al., 2023a).

Mangrove habitats in Exmouth Gulf are also essential habitats for a range of invertebrates, fish, elasmobranchs, marine turtles, other megafauna, and seabirds. Mangroves and mangrove litter offers important food sources for grazers and detritivores including various invertebrates and teleost fishes (e.g., Wells, 1983; Hutchins et al., 1996; RPS Bowman Bishaw Gorham, 2004; Penrose, 2011). These habitats are also likely to be especially important as nursery areas for various teleost fishes and elasmobranchs (including sawfish) which require productive feeding areas and structured, shallow environments to use as refugia for protection from larger predators (e.g., Cerutti-Pereyra et al., 2014; Pillans et al., 2021; Lear et al., 2023; Bateman et al., 2024). Aerial surveys have consistently sighted higher numbers of sharks along the mangrove systems of the eastern Exmouth Gulf compared to other areas surveyed within the Gulf (Irvine & Salgado Kent, 2019), likely due to high numbers of juveniles and small shark species using these habitats.

High numbers of marine turtles are also sighted along mangrove areas in Exmouth Gulf (Preen et al., 1997; Irvine & Salgado Kent, 2019), and these areas are likely to provide important foraging habitats for juvenile green turtles in particular (Prince et al., 2012; Pillans et al., 2022; Vanderklift et al., 2023). Several sea snake species (e.g., the northwestern mangrove sea snake *Ephalophis greyae* and the black-ringed mangrove sea snake *Hydrelaps darwiniensis*) are mangrove specialists and have been reported in Exmouth Gulf mangroves (Humphreys et al., 2005). Larger megafauna, such as humpback dolphins, are known to enter shallow mangrove areas to feed at high tide (Parra & Cagnazzi, 2016). Finally, mangroves are essential habitat for numerous seabirds and shorebirds as well as some terrestrial birds (Johnstone et al., 2013). Many migratory and resident birds forage and roost in mangrove areas in Exmouth Gulf (e.g., Humphreys et al., 2005). As a result, the mangrove-lined eastern Exmouth Gulf has been designated as an Important Bird Area for resident and migratory waterbirds, as per BirdLife International criteria (Dutson et al., 2009).

3.4.4.3. Threats and pressures

Mangroves in Exmouth Gulf face numerous pressures mainly stemming from climate driven disturbance events (e.g., cyclones, marine heatwaves, droughts, and sea level rise), as well as changes in nutrient dynamics (Lovelock et al., 2021). Direct destruction or clearing of mangroves is also a concern for any developments proposed near mangroves within Exmouth Gulf.

One of the most studied threats to mangroves in Exmouth Gulf is damage from cyclones or intense storms. When TC Vance passed through Exmouth Gulf in 1999, it is estimated to have damaged at least 5,700 ha of mangroves, and reduced mangrove cover in 50–55% of Exmouth Gulf mangrove forests (Paling et al., 2008; Stewart-Yates, 2022). This storm was the most destructive climatic event recorded for mangroves in Exmouth Gulf over the last 30 years (Stewart-Yates, 2022). During the storm, most damage was observed in *A. marina* rather than in *R. stylosa*. This was likely due to a combination of defoliation of mangroves from high winds and a substantial increase in sedimentation in mangrove habitats from storm surge that likely buried and smothered the pneumatophores of *A. marina* (Paling et al., 2008). After the storm, many stands of *A. marina* suffered high or total mortality. Some tidal creek entrances were impounded or completely blocked following the storm, leading Paling et al. (2008) suggested the survival of some mangroves at these creek mouths was due to subsurface groundwater reducing salinity concentrations. High seedling recruitment in these areas and young shrubs were observed five years post-cyclone, with mangrove recovery to pre-cyclone levels estimated after approximately 6.5–10 years post-cyclone (Paling et al., 2008; Stewart-Yates, 2022).

Two other notable storms have passed through Exmouth Gulf since, including TC Carlos in 2011, and TC Quang in 2015, causing a decrease of mangrove cover by approximately 11% and 16% in mangrove areas, respectively (Stewart-Yates, 2022). While cyclones in Exmouth Gulf have caused clear damage to mangroves on many occasions, it is notable that mangroves may be less susceptible to cyclone damage in Exmouth Gulf than mangroves in many other areas of Australia (and globally) due to their shorter stature (Paling et al., 2008). Mangroves in Exmouth Gulf rarely exceed a height of 5 m, while mangroves in other regions including further north in Australia and in the Caribbean often exceed 12–20 m height.

Some mangrove areas in the higher intertidal zone of Exmouth Gulf experienced increased growth post-cyclones (Stewart-Yates, 2022). This is likely due to the influx of terrestrial nutrients that flow into mangrove systems as a result of rainfall and freshwater run-off (Lovelock et al., 2011; Stewart-Yates, 2022). Considering that mangroves survive in an arid and nutrient-limited system, the addition of nutrients to mangrove ecosystems via terrestrial run-off during rare periods of rainfall may be important for the overall functioning and growth of these mangroves (Lovelock et al., 2011; Davies, 2018; Adame et al., 2021).

Droughts have also been shown to decrease mangrove cover in Exmouth Gulf. Droughts in the region are typified by low rainfall and high temperatures, and most often occur during El Niño events which concurrently lead to abnormally low sea levels (Lovelock et al., 2017). All of these factors result in especially dry and saline conditions that can exceed mangrove physiological tolerances (Lovelock et al., 2017; Stewart-Yates, 2022). For example, decreases in mangrove cover in 35% and 16% of mangrove area along the eastern Exmouth Gulf were observed during drought events in 2002–2003 and 2012–2013 respectively (Stewart-Yates, 2022). Mangrove disturbance in the first of these events in 2002–2003 was likely exacerbated by the fact that mangroves in Exmouth Gulf were still in early stages of recovery following TC Vance (Stewart-Yates, 2022). This emphasises the high risks to mangroves by cumulative or successive disturbance events.

Marine heatwaves, such as those experienced in Exmouth Gulf in 2010–2011 and 2012–2013, can cause damage to mangroves (decline observed in 11% and 8% of mangroves, respectively) (Stewart-Yates, 2022). However, this damage was generally less than that observed during cyclones or droughts. The 2024/25 marine heatwave will likely have a greater impact than previous marine heatwaves because of the extreme anomalous temperatures and duration of the event. At the time of publication, no estimates of damage or mortality of mangroves were available.

Sea level rise is likely to affect mangrove cover and area of extent. Mangroves rely on a certain level of tidal inundation which sea level rise will generally increase. For mangrove forests to survive in their current location, they require vertical accretion of soils to elevate their intertidal platforms, however, intertidal mangrove areas in Exmouth Gulf are slowly decreasing in elevation due to a range of factors (Lovelock et al., 2021). As a result of this process, along with sea level rise increasing inundation rates, seaward fringing mangrove stands in Exmouth Gulf have experienced very little recruitment or recovery post-cyclone (Lovelock et al., 2021). A retreat of 12 m was observed in the seaward edge of mangroves in Giralia Bay between 1999 and 2015. Increased recruitment of mangroves onto salt flats and cyanobacterial mats have also been observed, likely due to increased inundation rates of these habitats.

Mangroves in Exmouth Gulf have also been subjected to occasional locust plagues. For example, in February 2011 locusts led to between 15–100% foliage lost from every mangrove tree in Giralia Bay (Reef et al., 2012).

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3.4.5. Intertidal sandflats and mudflats

3.4.5.1. Distribution and demographics

Extensive sandflats and mudflats are present in Exmouth Gulf's intertidal zone, characterised by large areas of low-relief non-vegetated sediment. Mudflats are particularly expansive on the seaward side of mangrove ecosystems along the eastern, southern, and southwestern Exmouth Gulf spanning from Bay of Rest to Urala Creek South (Figure 28). Intertidal mudflats are characterised by very shallow elevation slopes, and as a result can span sometimes several hundred metres or more of the intertidal zone while representing only a small difference in tidal depth (Paling et al., 2008). These mudflat and sandflat sediments are dominated by red-brown muddy coarse sand, generally with high organic carbon and nitrogen content (Orpin et al., 1999; Brunskill et al., 2001).

3.4.5.2. Ecological significance

Intertidal mudflats and sandflats host abundant invertebrate communities and are important foraging areas for several megafauna groups in Exmouth Gulf. In 1981, surveys in Bay of Rest found invertebrate communities on mudflat areas to be more abundant and diverse than those within mangrove habitats (Wells, 1983, 1984). Mudflat habitats supported a mean density of 992 invertebrates per square metre, comprised of 112 identified species and dominated by molluscs, crustaceans, and polychaetes (Wells, 1983). Filter-feeding bivalves have been found to be especially abundant in mudflat communities (Wells, 1984; Hutchins, 1994). Most mudflat invertebrates are hypothesised to feed predominantly on detritus supplied by nearby mangrove ecosystems (Wells, 1983, 1984), emphasising the importance of connectivity between mudflat and mangrove ecosystems.

The rich invertebrate fauna occupying intertidal mudflat habitats support foraging for many larger animals. During high tide, intertidal mudflats and sandflats appear to be especially important foraging areas for a variety of elasmobranchs, and particularly for juvenile sharks and rays using shallow areas for protection from larger predators (Penrose, 2011; O'Shea et al., 2013; Oh et al., 2017; Bateman et al., 2024). At low tide, these areas are also essential foraging grounds for a variety of shorebirds, including many migratory species (Johnstone et al., 2013; Onton et al., 2013; Weller et al., 2020).

In addition to their roles as habitat, intertidal mudflats and sandflats also contribute significantly to sediment dynamics in Exmouth Gulf. Mudflats fluctuate between sediments sources and sediment sinks depending on prevailing weather, climate, tides and other factors (Eliot et al., 2011). For example, erosion of mudflats during storms is a major supply of sediment across the eastern and southern Exmouth Gulf, while terrestrial sediments entering Exmouth Gulf from occasional freshwater run-off or major tidal cycles are predominantly deposited in mudflats.

Figure 34: Intertidal sandflats and mudflats of Exmouth Gulf provide important foraging opportunities for a range of shorebird species, including the migratory and Critically Endangered curlew sandpiper, *Calidris ferruginea*. Image: Grant Griffin

3.4.5.3. Threats and pressures

Intertidal mud and sandflat habitats are vulnerable to erosion, especially during cyclones or years with high rainfall when the groundwater table is high (Eliot et al., 2011). These events can also cause substantial re-working of sediments in mudflat habitats (Eliot et al., 2011). Mudflat habitats can also be vulnerable to anchor scouring as bare sediments are generally targeted for anchoring (Mellor & Gautier, 2023). However, this is more common in subtidal areas and there is little vessel traffic along the eastern Gulf where intertidal mudflats are most dominant.

3.4.6. Oyster reefs and rocky intertidal

3.4.6.1. Distribution and demographics

The extent of oyster reefs and rocky intertidal areas in Exmouth Gulf is not well-mapped. Rocky intertidal areas (e.g., limestone pavements) and oyster reefs can be found in intertidal or nearshore areas in the southwestern Exmouth Gulf, particularly surrounding Heron Point and the western side of Gales Bay (360 Environmental, 2017; Sutton & Shaw, 2021). Rocky intertidal areas can also be found surrounding creek mouths on the western side of Exmouth Gulf, and around many of the islands, including the western side of the Muiron Islands (Hutchins et al., 1996; RPS Bowman Bishaw Gorham, 2004; 360 Environmental, 2017; Sutton & Shaw, 2021). Some rocky shorelines and intertidal rock pools can also be found in the northeastern Gulf, including at Turbridgi Point and the western sides of Tent, Burnside, and Simpson Islands (Hutchins et al., 1996). These rocky intertidal areas generally include a mix of bare pavements, macroalgae, and beds of sessile invertebrates including oysters.

Oyster species likely to contribute to intertidal oyster reefs in Exmouth Gulf include *Saccostrea* spp. The genus is currently under taxonomic revision, and the species confirmed in Exmouth Gulf include '*Saccostrea* Lineage A' and *Saccostrea scyphophilla* (Lam & Morton, 2006; Snow et al., 2023; Wells et al., 2024). *Saccostrea* Lineage A tends to dominate in more protected environments, while *S. scyphophilla* is more abundant in exposed environments. However, these trends do not always hold true and both species can be found in mixed beds as well (Snow et al., 2023). Pearl oysters including *Pinctada maxima* are also present in Exmouth Gulf, but more abundant in subtidal areas (Hart & Joll, 2006).

3.4.6.2. Ecological significance

Due to the highly structured nature and variety of microhabitats that rocky intertidal areas provide, these habitats are often considered 'biodiversity hotspots' globally (Thompson et al., 2002; Ghilardi-Lopes et al., 2024). The limited ecological surveys conducted in rocky intertidal zones in Exmouth Gulf have found that these areas provide habitat for diverse invertebrate fauna, especially species which require hard structure, such as a variety of molluscs and barnacles (Hutchins et al., 1996) (Figure 35). Rocky reefs and intertidal rock pools can also provide valuable habitat to a range of teleost fish species (Hutchins et al., 1996).

Figure 35: Rocky and oyster reefs can provide structure and habitat to support a variety of marine life, though have not been comprehensively investigated in Exmouth Gulf. Image: Rebecca Bateman-John

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Rocky intertidal areas provide a natural barrier to erosion and help to stabilise shorelines. Additionally, oysters and other bivalves can substantially contribute to maintenance of water quality and nutrient cycling dynamics through high water filtration rates (e.g., Rennie et al., 2024).

3.4.6.3. Threats and pressures

Threats to rocky shorelines and oyster reefs in Exmouth Gulf are not well established. Threats to these habitats in other areas, that may also be pertinent in Exmouth Gulf, include direct destruction/removal due to shoreline development, sea-level rise, and climate warming (Thompson et al., 2002). As rocky shorelines do not rely on biological components for their base structure, the potential for shifting of habitats to accommodate sea-level rise or other displacement regimes is limited.

3.4.7. Macroalgae

3.4.7.1. Distribution and demographics

Macroalgae is common in Exmouth Gulf and is the dominant benthos within large algal reefs and beds while also contributing to mixed benthic habitats (e.g., mixed coral-algal reefs and mixed seagrass-algal beds). Macroalgal beds are found along the eastern side of Exmouth Gulf, predominantly spanning the area between intertidal mudflats and seagrass beds (O2 Marine, 2024). A thin strip of algal reef also spans the western coastline between Heron Point and Bundegi Reef. Macroalgae was particularly common in benthic towed video surveys in the northeastern Gulf north of Urala Creek North, to the north and northwest of Tent Island, and in shallow areas between approximately Hope Island and Deep Creek in the mid-eastern Gulf. Algal beds on limestone pavements or mixed algal-coral reefs are also common around islands in Exmouth Gulf.

Surveys throughout shallow regions in the Pilbara estimated that there are approximately 222 macrophyte species in the region, with 20–30 species generally found at each site in the northern Exmouth Gulf (Olsen et al., 2018). Algal communities in Exmouth Gulf support all three divisions of algae: brown algae (Ochrophyta), green algae (Chlorophyta), and red algae (Rhodophyta). Species diversity is generally highest in Rhodophyta throughout the Pilbara, although biomass is higher for Ochrophyta. Abundant species in algal reefs and algal beds in Exmouth Gulf include *Lobophora, Dictyota*, and *Sargassum* (Ochrophyta), and *Caulerpa*, *Halimeda*, *Udotea*, and *Penicillus* (Chlorophyta), as well as turfing algae (McCook et al., 1995; Doropoulos et al., 2022; Loneragan et al., 2013). Within seagrass communities, ephiphytic algae genera including *Hydroclathrus, Padina*, and *Sporochnus* (Ochrophyta), and *Hypnea, Asparagopsis, Laurencia, Dictyomenia* and *Gracilaria* (Rhodophyta) are also common (McCook et al., 1995; Loneragan et al., 2013). Crustose coralline algae (Rhodophyta) is also present across coral-algal reef environments, though tends to be less common than other algae in these habitats (Doropoulos et al., 2022). Few studies have investigated seasonal trends in macroalgal growth in Exmouth Gulf, but in 2013 much higher algal biomass was found in northern Exmouth Gulf in November compared to May (Olsen et al., 2018).

In the absence of disturbance events, percent cover of macroalgae in mixed algal-seagrass beds along the eastern side of Exmouth Gulf is generally between 10–20%, depending on the year and location (Loneragan et al., 2013). During coral-algal reef surveys undertaken in March 2021, reef sites throughout the eastern Exmouth Gulf had an average macroalgal cover of approximately 25%, with an additional 13% turfing algal cover; for reef sites in the mid to upper eastern Gulf, macroalgae and turfing algae was more dominant than coral or other benthos (Cartwright et al., 2023). Higher algal cover in reef environments was associated with higher turbidity and higher temperature variation, likely because these characteristics tend to decrease coral cover and allow for greater algal colonisation. Macroalgae may thrive in certain levels of turbidity due to the resuspension of sediments and nutrients, which fuels algal growth.

3.4.7.2. Ecological significance

Macroalgae acts as an important habitat, food source, and primary production pathway in Exmouth Gulf. Several studies have suggested macroalgae are a substantial source of primary production, with the most recent study estimating that macroalgae produces a total net of 17,463 – 50,188 mg C per year (Hickey et al., 2023a). In most cases this net carbon production is higher than that estimated for seagrass and within the range estimated for cyanobacterial mats and mangrove litter (McCook et al., 1995; Lovelock et al., 2010; Hickey et al., 2023a). This high amount of primary production makes algae an important food source for many grazers including fish, invertebrates, green turtles, and potentially dugongs, especially if seagrass levels are low (McCook et al., 1995; Loneragan et al., 2013; Olsen et al., 2018). Macroalgae is also likely to contribute substantial detritus to food webs in Exmouth Gulf, fuelling various detritivores including a variety of invertebrates (McCook et al., 1995).

Macroalgae would provide important structural habitat for a variety of species in Exmouth Gulf (Figure 36). Seagrass and macroalgae surveys in 1999–2006 found some macroalgal beds in the eastern Gulf (predominantly *Sargassum*-dominated beds) with a vertical canopy height of 20–50 cm (Loneragan et al., 2013). The best-studied faunal relationship with macroalgae in Exmouth Gulf is for the commercially important tiger prawn (*Penaeus esculentus*), which requires seagrass and macroalgae for successful settlement of larvae and growth survival of early juvenile phases (Loneragan et al., 2013).

3.4.7.3. Threats and pressures

Macroalgae are often characterised by fast growth and efficient colonisation or re-colonisation, and are one of the more robust types of benthos found in Exmouth Gulf. While disturbance events such as marine heatwaves and cyclones can temporarily reduce algal cover along with their sympatric corals and seagrasses (Loneragan et al., 2013; Mahon et al., 2017), most disruptions tend to lead to stronger dominance of macroalgae in the long-term. For example, environmental stressors that degrade coral environments can open these habitats to increased macroalgal dominance (Olsen et al., 2018; Doropoulos et al., 2022; Cartwright et al., 2023). Algae cover on reefs in Exmouth Gulf is expected to increase in the future as turbidity and temperature variability increase (Cartwright et al., 2024). Disturbance to seagrass environments (e.g., via cyclones) has led to increased cover of macroalgae compared to seagrass during initial recovery stages (Loneragan et al., 2013). Overfishing has also been linked to higher dominance of algae on coral reefs through removal of grazers (Olsen et al., 2018; Cartwright et al., 2023). Herbivorous fishes may be a key control of Ochrophyta in the region, though are in relatively low abundance in the Pilbara and northern Exmouth Gulf compared to other areas such as Ningaloo and the Great Barrier Reef (Olsen et al., 2018).

Figure 36: **Macroalgae beds provide important habitat for a variety of marine fauna species in Exmouth Gulf. Image: Rebecca Bateman-John**

While macroalgae tends to benefit from most disturbance events, there are certain thresholds of environmental change that can be of concern. Macroalgae rely on photosynthesis and therefore light availability and, as such, sea level rise and major increases in turbidity that limit light can decrease algal growth and survival (Cartwright et al., 2024). Increased turbidity and sedimentation can also smother new algal growth and colonisation. Such thresholds may be reached in Exmouth Gulf in the future, as turbidity is projected to increase by up to 63% in some areas of Exmouth Gulf by the end of this century.

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3.4.8. Seagrass

3.4.8.1. Distribution and demographics

Seagrass meadows occupy shallow subtidal areas of soft sediment and are typically found along the eastern side of Exmouth Gulf (O2 Marine, 2024). Most seagrass beds are in areas of < 5 m depth and are characterised by low densities of seagrass, generally of 5–10% cover (McCook et al., 1995) (e.g., Figure 37). Although, seagrass cover varies from year to year and between locations (Loneragan et al., 2013). For example, in a multi-year assessment of seagrass beds in the eastern Exmouth Gulf, average percent cover across survey sites ranged from just 0.5% directly after TC Vance in 1999, to above 50% in 2003 and 2005. Specific sites, such as the area surrounding Whalebone Island, was found to have denser beds (~73% average cover) during peak years. In the most recent benthic habitat assessment conducted in 2024, low- to medium-density seagrass beds (3–25% cover) were estimated to cover approximately 330 km^2 of Exmouth Gulf, while high-density seagrass beds (> 25% cover) were estimated at 12 km^2 (total seagrass cover ~8.1% of Exmouth Gulf benthos) (O2 Marine, 2024).

Seagrass cover in Exmouth Gulf varies seasonally with the highest densities typically found in summer and the lowest in winter. For example, percent cover more than doubled between winter and summer in the southeastern Gulf in 2013–2015 (Vanderklift et al., 2016). Abundance and dominance of specific species also varies over time, likely driven by a combination of factors including disturbance regimes and recent trends in nutrient input (Loneragan et al., 2013; Vanderklift et al., 2016). Several species have been recorded flowering in November in Exmouth Gulf, as well as February elsewhere in the Pilbara, and flowering is likely to occur during summer months (Vanderklift et al., 2016).

Seagrass species reported from the eastern and southern areas of Exmouth Gulf include the broad-leaved species *Cymodocea serrulata, Cymodocea angustata* and *Syringodium isoetifolium*, and the smaller-leaved species *Halodule uninervis, Halophila ovalis, Halophila spinulosa*, and *Halophila descipiens* (McCook et al., 1995; Loneragan et al., 2013; Vanderklift et al., 2016). *Thalassodendron ciliatum* has also been reported near Bundegi, and *Thalassia hemprichii* from South Muiron Island (Vanderklift et al., 2016). Across Exmouth Gulf, *Halophila ovalis, Halodule uninervis, Halophila spinulosa,* and *C. serrulata*, appear to be the most widespread (Loneragan et al., 2013). Beds of different species have different characteristics. For example, *Cymodocea* beds tend to be less dense (rarely over 5% cover) compared to *Halophila* spp. or *Halodule uninervis* beds (average cover > 20%) (McCook et al., 1995). Many beds contain mixed species of seagrasses, and are also interspersed with macroalgae including epiphytes on seagrass. In some cases, macroalgae is more abundant than the seagrass itself. Macroalgal species commonly found in seagrass beds include the genera *Sargassum, Caulerpa, Halimeda, Udotea,* and *Penicillus*, as well as the epiphytic genera *Hydroclathrus, Padina, Sporochnus, Dictyota, Asparagopsis, Laurencia, Dictymenia, Gracilaria*, and *Hypnea* (McCook et al., 1995; Loneragan et al., 2013;). In surveys during September 1994, algae were most common in seagrass beds between Tent Island and Whalebone Island (McCook et al., 1995).

3.4.8.2. Ecological significance

Seagrasses provide several ecosystem services in Exmouth Gulf, including acting as a primary producer, carbon sequestration, stabilising sediment, and providing a food source and habitat to a variety of fauna. Regional surveys of seagrass beds across the Pilbara showed that the southeastern Exmouth Gulf had greater seagrass cover than off Onslow, Bundegi and the Muiron Islands (Vanderklift et al., 2016), though species and seasonal variation was evident. Thus, the ecosystem services offered by seagrasses in Exmouth Gulf are likely of regional importance, especially for dependent fauna such as dugongs.

Recent estimates of primary productivity of seagrasses in Exmouth Gulf approximate that meadows fix up to an estimated net 20,075 mg C per year (Hickey et al., 2023a). The larger extent of seagrass meadows in Exmouth Gulf estimated by recent benthic habitat mapping (O2 Marine, 2024) suggest that this value could be greater. Compared with other primary producers in Exmouth Gulf (e.g., mangroves, cyanobacterial mats, phytoplankton), seagrasses are one of the lesser contributors of carbon to the ecosystem as a whole, but nevertheless are an important source of primary productivity.

Seagrasses are widely known for their essential role as a nursery habitat for many fishes and invertebrates. This includes the commercially important tiger prawn (*Penaeus esculentus*), which obligately uses seagrass and algae as settlement and nursery habitat (Loneragan et al., 2013). Recruitment of this species to the fishery grounds in Exmouth Gulf has been shown to strongly positively correlate with seagrass densities. A variety of other fish and invertebrate species have also been found associated with seagrass habitats in Exmouth Gulf, and large numbers of marine turtles have also been observed in these areas (McCook et al., 1995). Additionally, seagrasses are an essential food source for dugongs, and the extensive seagrass meadows are likely why higher densities of this species are found here compared to other areas of the Pilbara or Ningaloo regions (Preen et al., 1995; Bayliss et al., 2018; Said et al., 2025). Recent studies have also shown that dugongs prefer to forage in sparse seagrass meadows (2–10% cover), especially of *Halophila ovalis* and *Halodule uninervis* (Said et al., 2025), characteristics that dominate seagrass meadows in Exmouth Gulf. Therefore, seagrass ecosystems within Exmouth Gulf are likely to provide ideal habitat and foraging area for dugongs.

3.4.8.3. Threats and pressures

Threats to seagrass meadows in Exmouth Gulf include destruction or disturbance of meadows from climatic (e.g., storms, marine heatwaves) and anthropogenic sources (e.g., development, dredging, anchor scouring). The most significant previous disturbances to Exmouth Gulf seagrasses include damage from TC Vance in 1999, which significantly reduced seagrass cover to < 0.5% on average, for sites where seagrass was still present (1/3 sites) (Loneragan et al., 2013). Recovery of seagrass meadows took several years, with up to 65% of sites having < 10% seagrass cover 18 months after the cyclone, and an average cover of above 50% at most sites by 2001–2003. During recovery, most meadows saw small, fast-growing species such as *Halodule uninervis* and *Halophila* spp. re-colonise first, followed by the slower-growing *Cymodocea* spp. and *Syringodium isoetifolium* two years after the cyclone. This suggests a successional pattern in seagrass species recovery that may be typical in Exmouth Gulf following disturbance events.

Seagrasses can also be vulnerable to marine heatwaves, where prolonged elevated water temperatures can cause heat stress if above the physiological tolerances of seagrasses (McMahon et al., 2017). Seagrass disturbance from marine heatwaves has not been well-documented in Exmouth Gulf specifically. However, marine heatwaves have been shown to decimate seagrass meadows in nearby Shark Bay. A significant decline in tiger prawn recruitment in Exmouth Gulf, similar to that observed after TC Vance in 1999, was again observed in 2012–13 following the marine heatwave event of 2011 (McMahon et al., 2017; Caputi et al., 2019). While seagrass monitoring was not undertaken during this period, observations of very low seagrass cover after this marine heatwave indicate that the decline in tiger prawn recruitment was likely due to decimation of their seagrass nurseries (McMahon et al., 2017; K. McMahon, pers. comm). Preliminary findings from an April 2025 survey in the southeastern Exmouth Gulf suggests the 2024/25 marine heatwave is causing a decline in *Halodule, Halophila* and *Syringodium* seagrasses (N. Said, pers. comm.). This was predicted given water temperatures were above the thermal optima for these species, with temperatures at the beginning of March 2025 exceeding 31.5°C for 66 hours over a seven day period (Figure 5; N. Jones pers. com). For Exmouth Gulf, the 2024/25 marine heatwave is shaping up to be the worst on record for ecosystem impacts.

Seagrasses have relatively high light requirements for autotrophs due to their heavy respiratory load of non-photosynthetic tissue (e.g., rhizomes). As a result, environmental changes that affect light availability can be problematic for seagrasses, including increased turbidity and sea level rise. In the southeastern Exmouth Gulf, turbidity is already often at borderline levels for seagrasses. For example, light intensity in seagrass meadows around Islam Islets was estimated to be too low for seagrass photosynthesis on approximately 6% of days (Vanderklift et al., 2016). The most turbid areas of Exmouth Gulf are generally shallow, nearshore areas where seagrasses are present. Across the last 20 years, the eastern margin, where seagrass density is highest, has shown the highest variability in turbidity (Cartwright, 2022). Overall, mean turbidity has increased in Exmouth Gulf between 2002 and 2020, and is expected to continue to increase.

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This is likely to be especially apparent during strong ENSO events when a variety of other stressors including increased sea temperatures are also present.

Some of the genetic characteristics of seagrasses in Exmouth Gulf can make them especially vulnerable to disturbance. Species with negatively buoyant seeds (e.g., *Halodule uninervis*) have fairly limited between-meadow dispersal, unless assisted by grazers (e.g., dugongs) (McMahon et al., 2017; Evans et al., 2021). As a result, if the local seed bank within a meadow is depleted, there is limited potential for re-colonisation from another meadow, and there is limited genetic connectivity between meadows (Evans et al., 2021). This is particularly prevalent in Exmouth Gulf compared to surrounding regions. Genetic dispersal barriers for *Halodule uninervis* in Exmouth Gulf have been identified with both Ningaloo Reef and the Pilbara, making Exmouth Gulf populations isolated compared to other seagrass populations (McMahon et al., 2017; Evans et al., 2021). *Halodule uninervis* also had some of the highest rates of inbreeding in Exmouth Gulf compared to other populations in the region (Evans et al., 2021). On the other hand, genetic diversity of *Halophila ovalis* in Exmouth Gulf was found to be moderate to high, with no significant between-meadow genetic structuring, but low dispersal at distances of over 5 km (McMahon et al., 2015). Cyclones and other large disturbance events have been shown to decrease genetic diversity (via decreasing clonal richness) for seagrass meadows in Exmouth Gulf (McMahon et al., 2017).

3.4.9. Filter-feeding communities

3.4.9.1. Distribution and demographics

Filter-feeding communities are a dominant subtidal habitat in Exmouth Gulf. These communities are present both on soft sediments (estimated 732 km^2 or 17.4% of benthos), and on low relief limestone reef (estimated 263 km^2 or 6.3% of benthos), covering an estimated 995 km^2, or ~24% of benthos in total (O2 Marine, 2024). Communities on low-relief reef are generally more densely populated and are mostly found between the Muiron Islands and Serrurier Island across northern Exmouth Gulf, as well as around shoals (e.g., Cooper Shoal, Camplin Shoal, Bennett Shoal) throughout the south area of Exmouth Gulf. Sparse filter-feeder communities over soft sediment are found predominantly in the northwestern Gulf at depths greater than 15 m (Figure 27). Extensive filter-feeding communities have also been identified in the deeper channel between North West Cape and Muiron Islands, which was recognised as a 'hotspot' for sponge communities compared to many areas along Ningaloo Coast (Heyward et al., 2010). Filter-feeding communities vary in composition across Exmouth Gulf, but generally consist of a mix of sponges, ascidians, hydroids, bryozoans, and soft corals, including gorgonians (O2 Marine, 2024). Algae and hard corals are also often found mixed with filter-feeder communities. Porifera (sponges) and octocorals (soft corals) are often the dominant larger species within filter-feeding communities of Exmouth Gulf.

Figure 37: Seagrass beds, such as those comprised of *Cymodocea serrulata* and *Halophila ovalis* (pictured), act as primary producers, sequester carbon, stabilise sediments, and provide food and habitat to a variety of marine fauna in Exmouth Gulf provide. Image: Nicole Said

Both groups have very high diversity, including high rates of endemism and many undescribed species. For example, a study surveying sponges across the northwest shelf found 413 species within the 'Pilbara Inshore' region spanning Exmouth Gulf to northeast of Port Hedland (Fromont et al., 2017). Of these, 285 were apparent endemics, not occurring in surrounding regions. Throughout the Pilbara, sponge biodiversity was dominated by the Demospongiae (soft-bodied sponges), and endopsammic sponges dwelling in soft sediments were particularly abundant. The Muiron Islands have been recorded to have very high octocoral diversity compared to surrounding areas, with surveys in 1995 recording 118 octocoral species, dominated by Neptheidae (carnation/tree corals) and Alcyoniidae (leathery corals) (Hutchins et al., 1996). Few gorgonians (e.g., sea fans) were found in these surveys around Muiron Islands but are a prominent component of many sparse filter-feeder beds in the northwest area of Exmouth Gulf (O2 Marine, 2024). They are also common in filter-feeding communities along Ningaloo Reef (Cassata & Collins, 2008). Trawl surveys in Exmouth Gulf identified 59 sponge species and 34 octocoral species occurring on the trawl grounds (Kangas et al., 2007).

A recent literature review of the sessile benthic biodiversity of Ningaloo Reef, Muiron Islands, and Exmouth Gulf confirms the presence of diverse communities of sponges, octocorals, hard corals, ascidians, and anemones in Exmouth Gulf. Additionally, smaller numbers of cerianthids, corallimorphs, zoanthids, bryozoans, and hydrozoans have been documented through museum records, the Atlas of Living Australia, and peer-reviewed sources (Richards et al., in prep). A key finding of this review is the high proportion of species identified only to the level of morphospecies. Most of these classifications have been made by taxonomic experts based on specimens accessioned in Australian museums, and many are likely to represent new species (Z. Richards, pers. comm.). Further taxonomic and systematic study is required to formally describe them. The review also highlights a significant proportion of fauna that may be regionally restricted to Exmouth Gulf, with no recorded occurrences at Ningaloo Reef or Muiron Islands. These include sea pens, tunicates, anemones, and bryozoans (Z. Richards et al., in prep).

Additionally, some dense bivalve beds are present in Exmouth Gulf, including recently discovered razor clam beds in the southern Gulf (see Section 3.5.2.1). These beds are substantial and may be unique regionally and/or nationally. Large macromolluscs, such as the Australian trumpet shell (*Syrnix arunus*), occur in the filter feeding habitats along with other larger molluscs like baler shell (*Melo amphora*) and spider conch (*Lambis lambis*) (Z. Richards, pers comm.).

Several environmental factors affect the occurrence of filter-feeder communities. One of the most important is likely currents and level of exposure. Moderate to high currents are important in providing food supply for filter-feeders and may explain the high densities of filter-feeding communities around the entrance to Exmouth Gulf including around Muiron Islands (Hutchins et al., 1996; Cassata & Collins, 2008). However, areas with extremely high currents may prevent settlement of filter feeders through scouring (Hutchins et al., 1996). Availability of hard structure for settlement of some sponges and soft corals can also contribute to abundance of filter feeders (Cassata & Collins, 2008) and may explain why communities located on limestone low-relief reefs between Muiron and Serrurier Islands are generally denser than those found in the northwestern Gulf (O2 Marine, 2024).

3.4.9.2. Ecological significance

As the predominant 'structured' benthos found in Exmouth Gulf, filter-feeding communities offer important habitat for many species. These habitats support a diverse array of marine life, from fishes, molluscs (including nudibranchs), echinoderms, marine worms and crustaceans, to larger species such as sea snakes, turtles, groupers, sharks, and other elasmobranchs (Z. Richards, pers. comm.) (Figure 38). Many species use sponges as habitats and potential refuges from predators (Kangas et al., 2007; O'Neill et al., 2024). Sponges, soft corals, and other filter-feeders may also represent important food sources for various fishes, invertebrates, and megafauna, though the extent of these communities as food sources in Exmouth Gulf and the role they play in the overall food web is not well known.

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Filter-feeding communities likely play a significant ecosystem role through maintenance of water quality in Exmouth Gulf. Filter-feeding organisms can filter high volumes of water to remove particles including organic and inorganic compounds. For example, sponges play a substantial role in the transfer of carbon from the water column (as particulate or dissolved organic carbon) to the benthos, which can then contribute to various food-webs. They also contribute to silica and nitrogen cycling (Bell et al., 2023). Bivalves are known elsewhere for helping to maintain water quality, by regulating nutrient levels, removing contaminants and particulates, and converting particulate organic matter into useable energy for various food webs (e.g., Cottingham et al., 2023; Rennie et al., 2024).

3.4.9.3. Threats and pressures

Filter-feeders are anchored to the benthos and are at risk from disturbance events including trawling, anchor scouring, and cyclones, which may separate these organisms from the substrate and likely to cause mortality and ecosystem damage. Most anchor scour damage in Exmouth Gulf, from a mixture of recreational and commercial vessels, is centred over sparse filter feeder habitats near the Exmouth townsite as well as an area to the northwest of Muiron Islands, which is also likely to be dominated by filter-feeder communities (Mellor & Gautier, 2023). The extent of damage to these communities from anchor scouring or from cyclones, and recovery rates of filter-feeding fauna have not been quantified in Exmouth Gulf and merit further investigation (Mellor & Gautier, 2023). Trawling also causes major disturbance to the seabed, and the trawl grounds of Exmouth Gulf Prawn Managed Fishery (EGPMF) substantially overlap with mapped filter feeder communities.

The most recent Environmental Risk Assessment for this fishery in 2020 estimated that, between 2012 and 2016, approximately 8.1% of trawl effort in the fishery overlapped with filter-feeder communities (DPIRD, 2020). Recent benthic habitat assessments (O2 Marine, 2024) have mapped extensive filter-feeder communities that overlap with trawled areas. Trawl-related disturbance rates to filter-feeding communities have not been specifically examined in Exmouth Gulf, but in similar fisheries in Shark Bay biodiversity studies found that catches of sponges were significantly decreased during consecutive trawls due to trawls detaching sponges from the benthos (Kangas et al., 2007). In these studies, sponges were determined as one of the most 'catchable' invertebrates, with taller species particularly vulnerable (Kangas et al., 2007).

Filter-feeder communities can also be affected by increases in turbidity, including those related to dredging, seabed disturbance, or climate/weather related factors. High turbidity levels decrease light availability, which is important for photosynthetic symbionts in some sponges and soft corals. Elevated concentrations of suspended sediments can also interfere with filter-feeding apparatuses and result in reduced filtering/feeding capacity, as well as potentially smothering tissue through increased sedimentation (Fromont et al., 2017). Considering average turbidity in Exmouth Gulf is expected to increase into the future (Cartwright, 2022), further increases in turbidity, even if short-term or periodic (e.g., from dredging activities) may be of particular concern. Anomalous thermal stress events can also impact filter-feeding communities, particularly any photosymbiotic organisms such as scleractinian corals or sponges that have a symbiotic relationship with zooxanthellae. Bleached hard corals, soft corals and sponges were all observed at 20 m depth in filter-feeding habitats after the 2025 heatwave event (Z. Richards, pers. comm.).

Figure 38: **Filter feeding communities found throughout Exmouth Gulf, offering important habitat for a diverse array of marine life. Images: Zoe Richards**

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3.4.10. Coral Reefs

3.4.10.1. Distribution and demographics

Coral reefs are found throughout Exmouth Gulf (Figure 39). Recent habitat mapping estimates that approximately 1.9% of the benthos is characterised by reefs with coral and macroalgal cover (O2 Marine, 2024) (Figure 27). Reefs with higher cover of hard corals are mostly found surrounding Bundegi and various islands in the north and northeastern Gulf, especially including the Muiron Islands, Serrurier Island, and Sunday Island, although other islands including Fly and Somerville also have extensive fringing reef communities dominated by hard corals (Z. Richards, pers. comm.). Individual corals or sparse cover of hard corals can also be found throughout shallow areas in Exmouth Gulf. In addition to hard coral cover, reefs surrounding the Muiron Islands and Sunday Island also host abundant and diverse soft corals compared to reefs along the Ningaloo coast, most likely due to the increased turbidity within Exmouth Gulf (Cassata & Collins, 2008; Hutchins et al., 1996).

A total of 37 coral genera were identified in reefs across Bundegi and Eva, Fly, and Somerville Islands, with reefs at the northeastern islands more diverse than those at Bundegi (Zweifler et al., 2024). Dominant hard coral genera in reefs surrounding northeastern islands in the include *Tubinaria, Porites, Pavona*, *Goniastrea*, and *Pocillopora* (Cartwright et al., 2023; Zweifler et al., 2024), while the dominant genus at Bundegi is *Acropora*, with *Pocillopora* and *Cyphastrea* also notable (Doropoulos et al., 2022; Zweifler et al., 2024). New coral biodiversity data collected in 2025 will shed further light on the diversity and abundance of scleractinian corals in Exmouth Gulf and also provide new information about species-level bleaching susceptibility to the 2025 heatwave event (Richards and Juszkiewicz, in prep).

Generally, rocky reefs along the western edge of Exmouth Gulf span shallow areas (< 5 m depth) from Learmonth to Cape Murat and are dominated by algal cover (O2 Marine, 2024). Along the eastern edge, macroalgae is more dominant in southern sites and coral cover increases along a northern gradient (Cartwright et al., 2023). This can be attributed to variation in oceanographic conditions along this gradient.

Hard corals are more abundant in areas with low temperature variation, low turbidity, and high wave action which characterize reefs in the northern areas of Exmouth Gulf. Macrophyte cover, including macroalgae and turfing algae, is higher in areas with moderate levels of turbidity, temperature variation, and wave action, including in reefs along the middle to upper eastern margin. Algal cover has also been shown to be higher and coral cover lower on disturbed or damaged reefs, as algae tends to rapidly colonise areas where corals die (Doropoulos et al., 2022; Zweifler et al., 2024). This subsequently prevents recruitment and larval settlement of corals in the future. Reefs across southern Exmouth Gulf where turbidity and temperature variation tend to be high, and water flow low, are characterized by more algae and bare structure compared to more northern areas (Doropoulos et al., 2022; Cartwright et al., 2023). Coral recruitment in these highly variable environments also appears to be limited by very low larval supply (Doropoulos et al., 2022). However, recent towed video surveys did find isolated patches of hard coral assemblages in the southeastern area of Exmouth Gulf (O2 Marine, 2024) (Figure 27).

3.4.10.2. Ecological significance

While coral reefs cover only a small percentage of Exmouth Gulf they likely support a disproportionately high diversity and abundance of fauna including invertebrates, teleost fishes, and elasmobranchs, many species of which are obligately associated with reef environments (see Section 3.5). Fauna surveys around reef environments in Exmouth Gulf have supported this assumption, with much higher diversities of fish and invertebrates found surrounding the Muiron Islands compared to soft-bottomed habitats in the eastern Gulf (Hutchins et al., 1996). Several shark species are more likely to occur in high relief reef environments compared to less complex habitats throughout Ningaloo, Exmouth Gulf, and the southern Pilbara (Lester et al., 2022). Many fish and invertebrates also have obligate associations with specific species of hard corals and are only found in coral reef environments (Hutchins et al., 1996). Furthermore, the corals are contributing to the sediment available for island growth which is important under sea level rise (Bonesso et al., 2022).

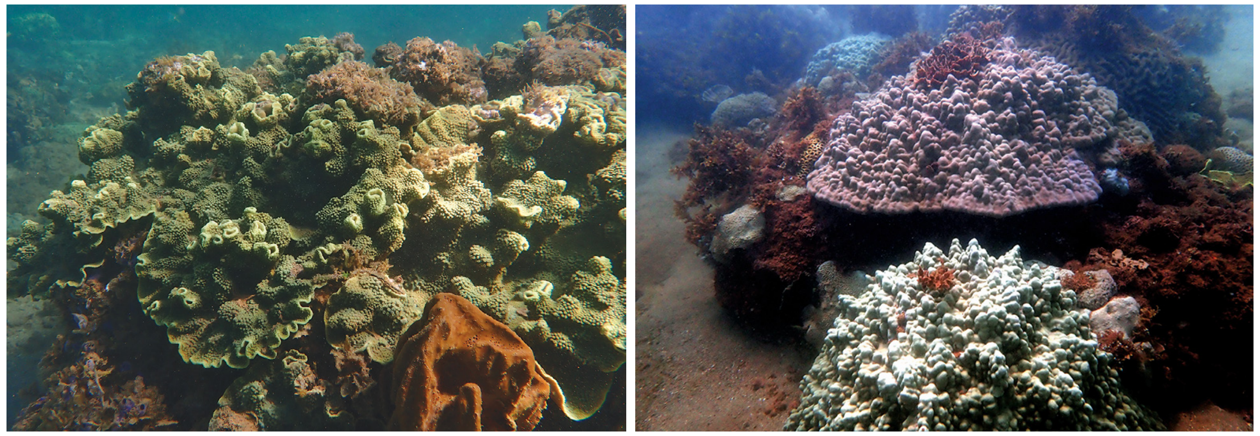

Figure 39: Corals reefs are distributed across Exmouth Gulf. Images: Shannon Dee (left), David Juszkiewicz (right).

3.4.10.3. Threats and pressures

The main pressures facing coral reef environments in Exmouth Gulf relate to climate-driven factors including coral bleaching and mortality from marine heatwaves, destruction to reefs from cyclones, and sea level rise. Aside from the recent 2024/25 marine heatwave and widespread bleaching in Exmouth Gulf, which is discussed in Section 3.1.1.2, Bundegi was the only reef within Exmouth Gulf where bleaching has previously been documented (e.g., Babcock et al., 2020). Prior to 1998, coral cover at Bundegi could exceed 70% at times, but after TC Vance passed through in 1999, coral cover reduced to just ~11% (Babcock et al., 2020). This reduction in cover was from direct destruction of reef structures as well as high sedimentation rates smothering corals (Twiggs & Collins, 2010; Speed et al., 2013). Corals showed signs of rapid recovery following this storm and increased to approximately 30–40% cover when the 2011 marine heatwave struck. This marine heatwave, and the resulting mass bleaching event, led to an estimated 80–90% coral mortality rate at Bundegi (Depczynski et al., 2013; Speed et al., 2013). Compounded by successive marine heatwaves in 2013 and 2014, coral cover was further reduced to <1–2.5% (Babcock et al., 2020). Unlike the period of rapid coral recovery at Bundegi following TC Vance, there has been very little recovery of corals at this site since the successive marine heatwave events (Doropoulos et al., 2022). Reduced brood stock of corals in the region currently indicates that the potential for recovery in the near future is limited. No other reefs within Exmouth Gulf have long-term coral monitoring records.

Several other reefs across the Pilbara, including in Dampier, Barrow and Montebello Islands, and nearshore areas of the southern Pilbara, have shown similar long-term decreases in coral cover and an inability to rapidly recover from successive storm and marine heatwave events (Babcock et al., 2020). Reefs across northern Ningaloo did not shown as much coral mortality in relation to these past events.

The impact of these disturbance events on species diversity remains unknown due to the lack of species-level monitoring. While local extinctions have likely occurred, there is no data to confirm this (Z. Richards, pers. comm.). Additionally, there is no information on how these disturbances, particularly thermal stress events, have affected reproductive fitness, which plays a crucial role in the rate and extent of community recovery (Z. Richards, pers. comm.).

Recent investigations into more turbid reefs including along northern, eastern, and western Exmouth Gulf have revealed some interesting trends in resilience of these more turbid reef sites to disturbances. Apart from Bundegi and the Muiron Islands, most coral reefs in Exmouth Gulf are considered marginal or extreme reefs due to their existence under challenging conditions, including high turbidity and temperature variation (Cartwright et al., 2023). In some cases, reefs in more turbid areas, such as those in the northeastern Gulf, can be more robust to changes in ocean conditions than reefs inhabiting clearer waters such as Bundegi, including being less susceptible to bleaching (Cartwright et al., 2023; Zweifler et al., 2024).

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A study investigating coral bleaching and recovery rates at four reefs within Exmouth Gulf: Sommerville Island (most turbid and highest temperature variability), Eva and Fly Islands (moderate turbidity and temperature variation) and Bundegi (lowest turbidity and temperature variation), found lower rates of bleaching at all three island sites compared to Bundegi during a moderate marine heatwave in March 2021 (Zweifler et al., 2024). This occurred despite these sites recording higher SST anomalies. Similarly, bleaching was reduced at higher turbidity sites along mid-eastern and northeastern Exmouth Gulf compared to the less turbid Muiron Islands in March 2021 (Cartwright et al., 2023).

Turbid water may increase resilience of hard corals by encouraging growth of more robust coral genera that are less sensitive to over-sedimentation and thermal anomalies (e.g., branching and foliose corals vs massive corals). Turbid waters can provide shading, which can decrease UV exposure, and provide higher nutrient content and heterotrophic feeding potential for corals. This, in turn, could decrease their reliance on temperature-sensitive photosynthetic symbionts (Cartwright et al., 2023; Zweifler et al., 2024). A study investigating heterotrophy vs autotrophy rates in the branching coral *Acropora tenuis* confirmed high rates of heterotrophy in turbid reefs at Eva and Somerville Islands, but also saw a similar association in the clearer water reefs at Tantabiddi during periods of high nutrient availability. Additionally, heterotrophy rates at Somerville during the more turbid times of the year decreased, indicating that turbidity levels exceeded feeding thresholds. Overall, the highly variable results indicated that *Acropora* likely changes foraging strategy based on a variety of environmental conditions (Zweifler et al., 2024). Higher turbidity levels do not necessarily lead to lower reliance on symbiont autotrophy in Exmouth Gulf.

In reefs along eastern Exmouth Gulf, moderate turbidity appeared to increase resilience of hard corals to marine heatwaves and bleaching, but only under regimes of moderate temperature variability, suggesting that there may be a combined threshold for temperature variability and turbidity at these reefs (Cartwright et al., 2023). When this combined threshold was exceeded in areas with long-term turbidity and high temperature variability, macroalgae tended to dominate reef environments. These findings suggest that many reefs in Exmouth Gulf are already existing at or near the limits of their turbidity and thermal thresholds.

Future climate predictions for Exmouth Gulf indicate that turbidity levels are likely to increase in many areas of Exmouth Gulf (up to 63% in some locations), and that SST and temperature variability will also increase (Cartwright et al., 2024) (see Section 3.1.2.2). While moderate turbidity may help to buffer effects of elevated SST in some locations, in others (e.g., southern Gulf) it will likely exceed the critical threshold for coral survival and lead to greater dominance of macroalgae. Coral reefs in the middle of the northern Gulf have been identified as historically having the lowest temperature variability of reefs examined in the region and among the lowest turbidity, and therefore may be at especially high risk of experiencing detrimental effects of increased sea temperatures. Unfortunately, new data on the impact of the 2025 marine heatwave on coral communities in Exmouth Gulf indicates the critical threshold for coral survival was most likely exceeded, with widespread and severe bleaching and mortality recorded across the scleractinians (Richards and Juszkiewicz, in prep).

Sea level rise, which will contribute to increased turbidity in Exmouth Gulf, is also a major threat to reefs (Cartwright et al., 2024). Rising sea levels will limit light access to benthic areas where reefs are currently situated.

Disease is a major concern for hard corals globally, and several coral diseases have been found in Exmouth Gulf. Surveys conducted in 2009 identified diseases in 1.3–2.7% of Muiron Island corals including skeletal eroding band, brown band, black band, and atramentous necrosis (Onton et al., 2011). Approximately 5.7% of corals at Bundegi were afflicted with diseases including brown band, skeletal eroding band, white syndrome, growth anomalies, and black band. The rates of disease found across Ningaloo and Exmouth Gulf reefs in these surveys are generally low compared to most regions globally but may increase in prevalence with increasing stress to reefs from other sources such as climate change.

Overall, the forecast increases in turbidity, SST, and sea level alongside increased frequency of disturbance events (major storms and marine heatwaves) is likely to continue the shift from coral to macroalgal cover, already observed in many reefs of Exmouth Gulf, into the future (Doropoulos et al., 2022; Cartwright et al., 2023; Cartwright et al., 2024; Zweifler et al., 2024).

3.4.11. Subtidal unvegetated sediment

3.4.11.1. Distribution and demographics

Large expanses of unvegetated sediment are the most common benthic habitat present in Exmouth Gulf. Unvegetated sediments cover large areas of the southwestern and central Exmouth Gulf, totalling approximately 2,550 km^2 or 60.5% of mapped benthic habitats (O2 Marine, 2024) (Figure 27). Sediments vary in size and type, and in the inner region of Exmouth Gulf where unvegetated sediment habitats are abundant, sediments are dominated by coarse and fine sand and mud, with generally high calcium carbonate content (Orpin et al., 1999; Brunskill et al., 2001).

3.4.11.2. Ecological importance

Despite being the dominant benthos present in Exmouth Gulf, very little ecological research has been conducted within unvegetated habitats, due in part to their perceived lack of structure and low densities of visible fauna. However, bare sediment habitats can support rich infaunal and epifaunal communities, particularly for invertebrates (e.g., Currie & Small, 2005; Pitcher et al., 2009). For example, several commercially important prawn species (e.g., brown tiger prawns, western king prawns) occupy bare sediment habitats in Exmouth Gulf as adults and use these areas for reproduction (Kangas et al., 2015). The productivity and importance of these habitats is demonstrated by the high abundance and diversity of invertebrates and fish encountered in the EGPMF (see Kangas et al., 2007), for which over 50% of the trawl grounds are classed as bare sediment areas (DPIRD, 2020). The subtidal Holocene sediments of Exmouth Gulf were also found to harbour at least 240 species of primarily benthic foraminifera (Haig, 1997).

3.4.11.3. Threats and pressures

Threats to bare sediment habitats in Exmouth Gulf mainly include direct disturbance, such as through trawling or anchor scouring. Infaunal and epifaunal communities in bare sediment habitats can create extensive networks of tunnels and mucus-lined burrows which help to provide structure and cohesion to sediments (Mellor & Gautier, 2023). When sediments are disturbed, these networks can be destroyed. This can damage the biota that rely on them as well as increase sedimentation and turbidity in these habitats by destabilising sediments (Mellor & Gautier, 2023). While bare sediment communities appear to recover well from one-off disturbance events such as single anchoring events or single trawls, repeated disturbances are likely to have a greater impact, particularly for longer-lived or more fragile invertebrate fauna living in these habitats (Pitcher et al., 2009; Mellor & Gautier, 2023). Depletion rate studies of otter trawls in Exmouth Gulf estimated that trawls on average deplete 38% of polychaetes, 65% of malacostraca (crabs), and 16% of bivalves per trawl in unvegetated habitats (Pitcher et al., 2017). Effects were generally highest in areas where the sediment was dominated by gravel, followed by muddy-sand, sand, and finally mud.

Figure 40: **Areas of relatively unvegetated sediment can provide habitat and foraging opportunities for an array of species in Exmouth Gulf. Image: Rebecca Bateman-John**

3.5. Marine fauna

3.5.1. Zooplankton

3.5.1.1. Biodiversity

Zooplankton is a broad term encompassing a community of animal species across many marine phyla e.g., cnidarians, arthropods, molluscs, chordates. A comprehensive list of species for Exmouth Gulf would be difficult to generate without widespread spatial and temporal sampling as zooplankton are often passive drifters and are transported by water flows and currents. Zooplankton greatly vary in size, ranging from picoplankton (< 2 μm) to megaplankton (> 20cm). A dedicated study of the zooplankton species in Exmouth Gulf using consistent methods has not been undertaken, though some studies have included sampling sites within Exmouth Gulf as part of larger North West Shelf investigations during the summer months. An exception to this was a campaign focusing on copepods undertaken during spring in 1994, which found over 50 species of copepod that, together, dominated the zooplankton assemblage in Exmouth Gulf (McKinnon & Ayukai, 1996). Appendicularians (or larvaceans) as well as mollusc and polychaete larvae were also notably present.

A cross-shelf examination of copepod communities from the northern Gulf to the continental shelf during the summers of 1997–99 found 120 species of copepod, most of which belonged to the Corycaeidae (22 spp.), Oncaeidae (20 spp.), Paracalanidae (15 spp.) and Oithonidae (11 spp.) families (McKinnon et al., 2008). Sampling sites within Exmouth Gulf were characterised by smaller copepods from Paracalanidae and Oithonidae. A dedicated study of ichthyoplankton (fish larvae) that included Exmouth Gulf, shelf and Thevenard Island found the most abundant families to be Gobiidae (e.g., gobies), Pomacentridae (e.g., damselfishes and clownfishes), Carangidae (e.g., mackerels, trevally), Callionymidae (e.g., dragonets), and Monacanthidae (e.g., triggerfish, leatherjackets) (Sampey et al., 2004). Broadening out to other macrozooplankton species and nekton (active, not passive swimmers), Wilson (2001) compiled a catalogue of 313 species from sites sampled within Exmouth Gulf, along Ningaloo Reef and off Onslow during the summer months of 1997–99. Amphipods and krill were the most abundant taxa, followed by copepods, mysids and cumaceans.

3.5.1.2. Habitat use

Zooplankton occupy the entire water column throughout Exmouth Gulf. Some species will spend all life cycle stages in the plankton (holoplankton; e.g., krill and copepods), while others only have planktonic larval stages (meroplankton; e.g., crabs, fish). Many zooplankton species undergo diel vertical migration, whereby they will ascend to surface waters during the night to feed and descend to deeper waters during the day to avoid predation. Exmouth Gulf is shallow compared to the open ocean, and the species found in Exmouth Gulf would be adapted to these coastal conditions and restricted vertical migration. Many species and assemblages found within Exmouth Gulf would also be found in offshore, open ocean waters, where distribution is facilitated by tidal exchange and water circulation.

3.5.1.3. Ecological importance

Zooplankton are at the base of the food web and support a diverse range of higher order consumers as well as ecosystem services (Botterell et al., 2023). There is increased productivity and a higher abundance of zooplankton observed around the North West Cape during the late summer and autumn months due to the Ningaloo Current transporting upwelled, nutrient rich waters (Taylor & Pearce, 1999). This productivity is the one of the key reasons whale sharks and manta rays congregate in the area between March and June every year (Wilson et al., 2001; Reynolds et al., 2017). Zooplankton also aid in nutrient cycling (Botterell et al., 2023), which would help to sustain the productivity of Exmouth Gulf, and carbon sequestration through sinking faecal pellets (Ratnarajah et al., 2023). Without zooplankton, there would be a collapse in food webs across a range of scales.

3.5.1.4. Significance of Exmouth Gulf

The occurrence of zooplankton within Exmouth Gulf would largely be controlled by water circulation, primary productivity and physical properties of the water column (e.g., temperature, salinity and dissolved oxygen). A one-off study on copepod egg production suggested that the relatively low rates of production in Exmouth Gulf were due to a lack of food resources for copepods (McKinnon & Ayukai, 1996), while two other studies found higher zooplankton biomass within Exmouth Gulf compared with the continental shelf (Wilson et al., 2003; Sampey et al., 2004).

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Stingray. Nick Thake

It is unclear to what extent productivity in Exmouth Gulf influences the zooplankton diversity or biomass in surrounding marine environments.

3.5.1.5. Threats and pressures

Threats to zooplankton have not been investigated specifically in Exmouth Gulf, though broadly they would be threatened by increasing water temperatures, ocean acidification, poor water quality, contamination (including microplastics) and a decrease in nutrients (Botterell et al., 2023).

3.5.2. Marine invertebrates

Invertebrates are often poorly documented in marine ecosystems, and Exmouth Gulf has received comparatively little attention compared to Ningaloo Reef and other areas across the northwest region of Australia. Various surveys have reported diversity of invertebrates observed in certain areas of Exmouth Gulf (Table 3), however, the abundances and ecology of these species is less understood. Evidence indicates that the northwestern area of Exmouth Gulf may support comparatively denser invertebrate populations than surrounding areas, including the southern Pilbara, based on invertebrate encounter rates in a regional trawl survey (up to 1140 invertebrates per nautical mile depending on location; Kangas et al., 2006). This section summarises known information about invertebrates within Exmouth Gulf, noting that our knowledge of invertebrate diversity and ecology within Exmouth Gulf is still growing. Information on sponges and corals can be found in Sections 3.4.9 and 3.4.10, and larval stages of many teleost fishes and invertebrates contribute to zooplankton communities, which are reviewed in Section 3.5.1.

Table 3: **Invertebrate species identified during various surveys in Exmouth Gulf.**

Location	Survey method	Time frame	Molluscs	Crustaceans	Echinoderms	Cnidarians	Source
Bay of Rest: intertidal	Physical sample collection	Sep-Oct 1981	Mudflat zone: 66 *Avicennia* zone: 21 *Rhizophora* zone: 6	Mudflat zone: 15 *Avicennia* zone: 17 *Rhizophora* zone: 12 Backflat: 5	Mudflat zone: 6 *Avicennia* zone: 3	Not assessed	Wells (1983)
Muiron Islands and Eastern Exmouth Gulf: intertidal and limited subtidal	Intertidal collecting and subtidal visual snorkel surveys	Aug 1995	655 (378 gastropods, 274 bivalves, 3 polyplacophorans)	52 (39 barnacles, 12 trapezid crabs, 1 eumedonid crab)	92 (18 crinoids, 19 sea stars, 26 brittle stars, 10 urchins, 19 holothurians)	118 octocorals	Hutchins et al. (1996)
EGPMF Trawl grounds	Trawl netting	Mar, Jun/Jul, Nov 2004	89 (25 bivalves, 53 gastropods, 11 cephalopods)	82 (9 stomatopods, 2 isopods, 71 decapods)	73 (16 sea cucumbers, 32 sea stars, 8 urchins, 9 brittle stars, 8 crinoids)	34 octocorals	Kangas et al. (2007)
Sampling locations throughout Exmouth Gulf (intertidal and subtidal)	Physical collection	Jun 2019	137 (124 gastropods, 9 bivalves, 1 chiton, 1 scaphopod, 2 aplacophorans)	128 (incl. 17 barnacles, 94 decapods, 7 isopods)	Not assessed	18 (5 hydrozoans, 12 octocorals, 1 hard coral)	Bush Blitz: Kirkendale et al. (2019), Hosie & Hara (2019)
Whole Exmouth Gulf	Citizen science		734 (180 bivalves, 527 gastropods, 14 cephalopods)	363 (8 Amphipods, 54 copepods, 235 decapods, 5 isopods, 19 stomatopods, 39 barnacles)	175 (59 sea stars, 22 crinoids, 25 urchins, 32 sea cucumbers, 37 brittle stars)	95 (1 cubozoan, 5 hydrozoans, 2 scyphozoans, 9 sea anemones, 25 octocorals, 53 hard corals)	Atlas of Living Australia
Western Exmouth Gulf, Ningaloo Marine Park, Muiron Islands	Underwater visual census, Citizen science	2021-2025 (~Mar & Jun every year)	At least 215 nudibranchs (gastropods)	Not assessed	Not assessed	Not assessed	Sea Slug Census
Muiron Islands, eastern Exmouth Gulf (including Bundegi)	Underwater visual census, Citizen science (mobile macroinvertebrates)	2010–2023	89 (6 bivalves, 2 cephalopods, 81 gastropods)	13 decapods	44 (12 sea stars, 11 crinoids, 8 sea urchins, 13 sea cucumbers)	Not assessed	Reef Life Survey

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3.5.2.1. Molluscs

3.5.2.1.1 Biodiversity

Molluscs are a large group of soft-bodied invertebrates defined by the possession of a mantle, which is an organ that most groups use to produce a shell. Molluscs include gastropods (e.g., marine snails, nudibranchs, abalone), polyplacophorans (chitons), bivalves (e.g., clams, oysters, scallops, mussels), and cephalopods (e.g., octopus, squid, cuttlefish) and are one of the most diverse marine invertebrate phyla globally and within Exmouth Gulf. At least several hundred species are present within Exmouth Gulf including many undefined taxa (Table 3). For example, over 130 marine mollusc species were found during a recent Bush Blitz (Kirkendale et al., 2019), including 66 species that were new to science or had not been named or formalised at the time. In August 1995, a biodiversity survey of the Muiron Islands and eastern Exmouth Gulf identified 655 mollusc species, including 378 gastropods and 274 bivalves, along with three chitons, many of which were endemic to Australia (Hutchins et al., 1996). In 2004, a benthic trawl survey conducted in Exmouth Gulf and the Onslow area found 89 different mollusc species, including 25 bivalves, 53 gastropods, and several species of squid, octopus, and cuttlefish (Kangas et al., 2006). Of the 20 most commonly caught invertebrates within this study, two were molluscs; the fan scallop (*Annachlamys flabellata*), which was mostly caught within the northwestern Exmouth Gulf, and the Papuan cuttlefish (*Sepia papuensis*). Although many records are not verified by experts, Atlas of Living Australia has collated records of 734 different mollusc species within Exmouth Gulf, including 180 bivalve species, 14 cephalopod species, and 527 gastropod species. Twice a year since 2021 (~Mar and Jun/Jul), the citizen science event, Sea Slug Census, has been undertaken in Exmouth Gulf and surrounding areas (namely, western Exmouth Gulf, Ningaloo Marine Park and Muiron Islands). At least 215 nudibranchs were photographed and documented between 2021 and 2023, with results from 2024 and 2025 still to be finalised (G. Keast, pers. comm.).

3.5.2.1.2 Habitat use

Given their high diversity, molluscs are known from all habitats within Exmouth Gulf including soft-bottomed habitats, mangroves, coral and rocky reefs, seagrass beds, and pelagic habitats. However, certain habitats tend to hold greater diversity and abundances of particular groups of molluscs, and individual species are often highly specific in their habitat choice. Mudflats and soft-bottom habitats are generally more important for filter-feeding bivalves, while structured habitats such as mangroves or rocky shores and reefs are often more important for gastropods (Hutchins et al., 1996; Wells, 1984). Even within the same general habitat type, there can be little overlap in species between microhabitats. For example, areas with *Avicennia* mangroves hosted 21 species of mollusc during a 1981 survey in the Bay of Rest while *Rhizophora* mangrove areas hosted only seven species within the same survey (Wells, 1984). More wave-affected western shores of the Muiron Islands had very little overlap in mollusc species compared to the calmer eastern shores (Hutchins et al., 1996). Similar species living in sympatry also often show fine-scale spatial partitioning. For example, in species of Nerites snails examined around the North West Cape, different assemblages were found on the eastern and western shores (Wells, 1979). Where species overlapped, they were found in different areas of the intertidal zone, likely to limit competition.

The limited surveys in Exmouth Gulf indicate that some areas of the Gulf may hold greater mollusc diversity than others. For example, Lyne et al. (2006) found greater densities of mollusc beds in the northwestern Exmouth Gulf and up to the Muiron Islands compared to other areas. Hutchins et al. (1996) found greater diversity in the mudflats surrounding Tent Island compared to Burnside and Simpson Islands and Tubridgi Point. In general, mudflats have been found to host high diversity of molluscs (especially bivalves) compared to other intertidal areas (Wells, 1983; Hutchins et al., 1996), and thus the eastern and southern areas of Exmouth Gulf may be particularly important for molluscs.

Several extensive and dense beds of razor clams (species unconfirmed, but likely either *Pinna bicolor* or *P. linnaeus*) have recently been discovered in the southern Exmouth Gulf in areas characterised by muddy sand substrate (Figure 41; M. O'Leary, pers. comm.). These razor clam beds are regionally significant and are discussed further in the following section.

3.5.2.1.3 Ecological importance

Molluscs hold various ecosystem roles within Exmouth Gulf, including acting as a primary prey source for a variety of mesopredators and holding many functional roles in the development and maintenance of different habitats. For example,

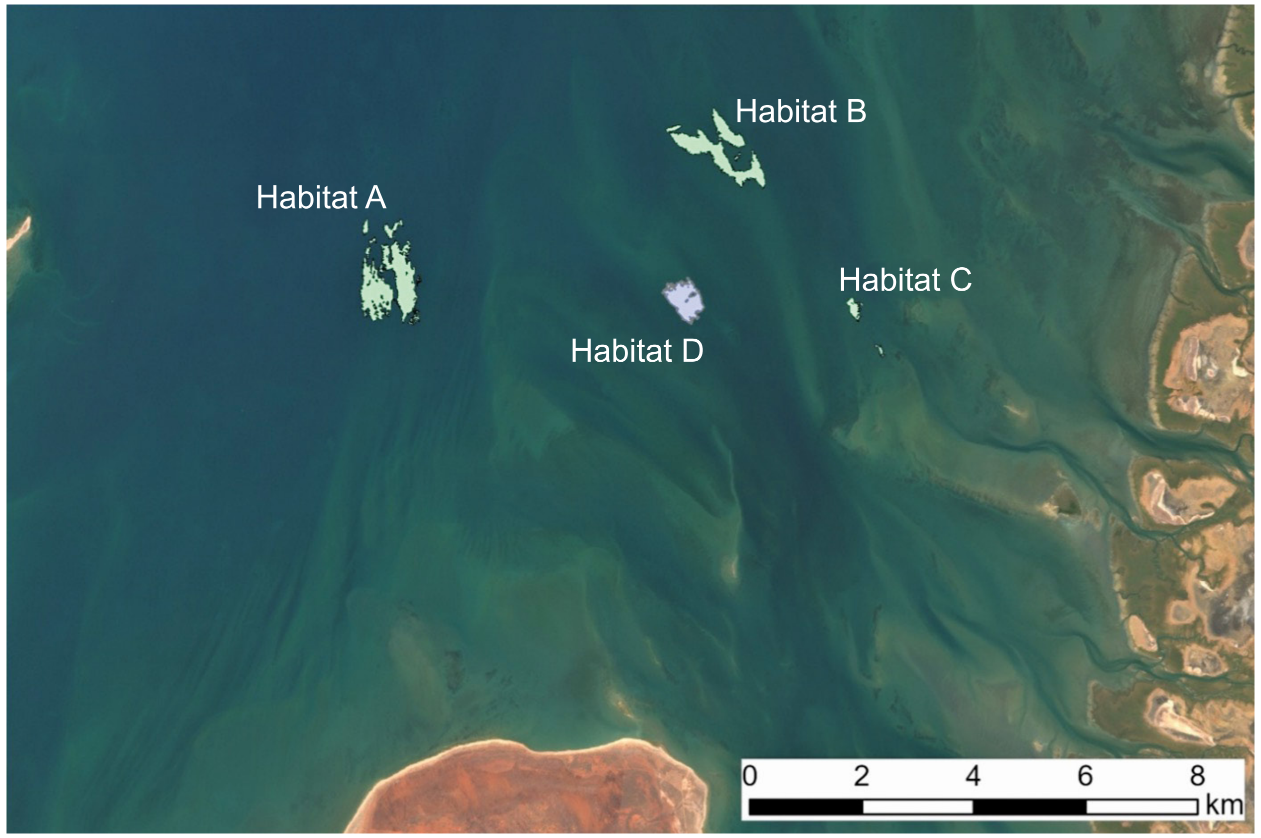

Figure 41: **Mapped habitat of identified razor clam beds in the southern Exmouth Gulf. Habitats A–C are extant beds, while Habitat D is an extinct bed. Habitat A 91 hectares; Habitat B 64 hectares; Habitat C 6 hectares; Habitat D 31 hectares (now extinct). Map and data provided by Mick O'Leary.**

intertidal bivalves and gastropods are a major component of the diet of many shorebird and ray species (O'Shea et al., 2013; DBCA, 2017) as well as various teleost fishes and larger invertebrates (e.g., some cephalopods). The importance of these groups as food sources for teleost fishes is demonstrated by the diversity of invertivorous fish species found in Exmouth Gulf. Fish surveys near Eva and Fly Islands detected a greater proportion of invertivores than herbivores within the nearshore fish fauna (Dee et al., 2023). Cuttlefish and squid are also thought to be a main dietary component for sharks, rays, seabirds, and dolphins in the region, depending on the species (Figure 42).

Filter-feeding bivalves are widely recognised as ecosystem engineers for their reef-building capacity. Oyster reefs are sporadically present through several areas of Exmouth Gulf (see Section 3.4.6) and are likely to offer important benthic structure for a variety of teleost fishes and invertebrates. Dense cockle beds of *Anadara scapha* have been reported to the southwest of Tent Island (McCook et al., 1995). Giant clams (*Tridacna gigas*) have also been identified as important contributors to benthic structure in several areas of Exmouth Gulf, including to the north and northwest of Tent Island and southeast of Muiron Islands (O2 Marine, 2024). Additionally, extensive razor clam beds (likely either *Pinna bicolor* or *P. linnaeus*) have recently been discovered in the southern Exmouth Gulf, with extant beds covering at least 161 hectares of subtidal mudflats (Figure 41). These beds host extremely dense colonies of razor clams (exceeding 25 individuals per m^2), and likely host more than 40 million individuals (M. O'Leary, pers. comm.). Such dense razor clam beds are unique within Australian waters, and potentially globally (M. O'Leary, pers. comm.). Pertinent knowledge on how and why the beds form, what caused localised extinction, their resilience into the future and importance as a habitat to other species is unknown.

Shells from bivalves and gastropods contribute greatly to building island habitats and sandy beaches within Exmouth Gulf. Shells were the most dominant component of island and reefal sediments (comprising 34% of both) surrounding Eva Island in northeastern Exmouth Gulf, among a mixture of coral, limestone, and crustose coralline algae (Bonesso et al., 2022). Shells are also an important component of many different benthic sediments throughout Exmouth Gulf (Brunskill et al., 2001).

Bivalves are important players in bioerosion pathways through their role as macroborers, breaking down corals and other benthic structure (Dee et al., 2023). Some initial research has indicated that bioerosion rates through macroborers may be relatively low within Exmouth Gulf, however, longer-duration surveys are needed to confirm this. Bivalves are also known for their importance in maintaining water quality through their high rates of filter feeding. Mussels have proven essential to the removal of sediments and toxins from the water column in other areas of WA (Cottingham et al., 2023). High concentrations of cadmium found in bivalve shells in Exmouth Gulf and Shark Bay also points to the importance of these animals in filtering heavy metals out of the environment (McConchie & Lawrance, 1991; Brunskill et al., 2001). Filter feeding rates of bivalves and their importance for maintaining water quality has not been quantified within Exmouth Gulf.

Gastropods have influence on ecosystem health and trophic dynamics as primary and secondary consumers. Detritivorous gastropods have been suggested to play key roles in converting primary production into attainable food resources for higher trophic levels, especially in mangrove and mudflat ecosystems such as Bay of Rest (Wells, 1984). Herbivorous gastropods, including some marine snails, have been shown to exert top-down control on macroalgae growth elsewhere (e.g., Wernberg et al., 2008), and likely perform a similar role in Exmouth Gulf. Other gastropod species are predatory or corallivorous and, in some cases, have had detrimental effects on their prey species. For example, Ningaloo Reef has experienced several outbreaks (periods of increased density) of corallivorous gastropods in the genus *Drupella*, which have been tied to massive coral mortality on the reef, especially in the 1980s and 1990s (Armstrong, 2007, 2009; Bessey et al., 2018). This species is also likely to be present within Exmouth Gulf, although its effect of corals here has not been well-studied.

In addition to their ecological significance, molluscs have played an important cultural role in Exmouth Gulf and the surrounding area. Archaeological midden sites found along the Northwest Cape and Ningaloo coastlines are generally dominated by mollusc shells including bivalves, gastropods, and chitons (Morse, 1993b; Przywolnik, 2002). Various species were harvested as a food source, and certain types of shell, including giant clams (*Tridacna gigas*) and baler shells (*Melo melo*), were used to fashion a variety of tools, including water carriers and knives (Morse, 1993b; Przywolnik, 2002; Hook et al., 2024). Tusk shells (class Scaphopoda), cone shells (gastropods in the family Conidae, potentially *Conus dorreensis*), and pearl shell (*Pinctada* sp.) were also used to make shell beads within the North West Cape region (Morse, 1993a) and the wider Pilbara (Hook et al., 2024).

3.5.2.1.4 Significance of Exmouth Gulf

Due to the limited research on molluscs (and most other invertebrates) within Exmouth Gulf, it is difficult to say whether Exmouth Gulf is an especially significant compared to other areas of northwestern Australia. However, given the generally high diversity of molluscs and the levels of endemism in many places throughout Australia, it is likely that Exmouth Gulf houses at least some regionally endemic species and important populations. For example, octopuses have been shown to be particularly abundant in Exmouth Gulf compared to Ningaloo Reef or other areas of the Pilbara, which could be linked to productivity and turbidity within Exmouth Gulf (Jackson et al., 2008). Exmouth Gulf has also been shown to support populations of the commercially important pearl oyster (*Pinctada maxima*) that may be genetically distinct from those elsewhere within Australia (Benzie & Smith-Keune, 2006). The commercial fishery for pearl shell no longer operates in the Gulf. The razor clam beds that have recently been discovered in the southern Exmouth Gulf (Figure 41) are also likely unique within Australian waters, and potentially globally significant (M. O'Leary, pers. comm.).

The diversity of habitats present within Exmouth Gulf is likely to diversify the assemblages of molluscs found there compared to other regions. For example, trawl surveys undertaken in 2004 showed that the assemblages of fish and invertebrates within Exmouth Gulf were generally different to those found in the Onslow region (Kangas et al., 2007). Throughout the southern Pilbara, the greatest diversity and abundance of invertebrate species was also found within Exmouth Gulf, although these analyses were not specific to molluscs.

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3.5.2.1.5 Threats and pressures

Several mollusc species are harvested within Exmouth Gulf. Moderate amounts of squid, cuttlefish, and octopus are recreationally fished within the Gascoyne coast bioregion (Yeoh et al., 2021), though specific harvest numbers have not been assessed for Exmouth Gulf. Squid species caught include northern calamari (*Sepioteuthis lessoniana*) and the *Loligo* squid complex (*Uroteuthis* (*Photololigo*) spp.), while cuttlefish are likely to be primarily the broadclub cuttlefish (*Ascarosepion latimanus*) and pharaoh cuttlefish (*Acanthosepion pharaonis*). The day octopus (*Octopus cyanea*) is also recreationally targeted within the region (Herwig et al., 2012). Squids, cuttlefish, and octopus are also retained by the EGPMF as a byproduct species. Historical catches of squid and cuttlefish were higher than they are today (e.g., > 58 tonnes and > 8.8 tonnes, respectively, between 2003–2005) (Kangas et al., 2015). The annual squid, cuttlefish and octopus harvests between 2017 and 2021 (the last five years quantities were reported) has been, on average, < 3 tonnes, ~5 tonnes and < 1 tonne, respectively (Gaughan & Santoro, 2018, 2019; Gaughan & Santoro, 2020, 2021; Newman et al., 2021; Newman et al., 2023a; Newman et al., 2023b). These catch rates are low compared to most other commercially fished regions of WA, and cephalopods have lower vulnerability life history traits, such as short life spans and large reproductive loads (Desfosses et al., 2024). As a result, the state-wide resource stocks, including in the Gascoyne Coast Bioregion, are considered 'low risk' for cuttlefish and octopus, although the squid stock is considered medium risk due to its higher state-wide harvest (Yeoh et al., 2021; Desfosses et al., 2024). The population sizes and connectivity of squid, octopus, and cuttlefish populations within Exmouth Gulf are not well understood. There is no formal risk assessment process for byproduct species in the EGPMF, though the annual levels of cephalopod harvest within this fishery have been well below the proposed sustainable limits (Kangas et al., 2015).

Figure 42: **Squid (Cephalopoda) are thought to be a significant food sources for sharks, rays, seabirds, and dolphins in Exmouth Gulf, and are a popular recreationally fished species. Image: Rebecca Bateman-John**

Exmouth Gulf supports commercial harvest of pearl oysters (*Pinctada maxima*), as the southern boundary of the Western Australian Pearl Oyster Fishery, which extends north to the Northern Territory border. Five licensees have access to Zone 1 of the fishery which spans from the North West Cape to Port Hedland, including Exmouth Gulf. However, the reported levels of effort within this zone and Exmouth Gulf itself are low (Smith et al., 2023). The most recent risk assessment for this fishery determined Zone 1 to be at 'low risk' with no evidence of declining populations, although the wild stock biomass of the whole fishery is considered a 'medium risk' (Smith et al., 2023). There is, however, a potential risk of the fishery spreading Oyster Oedema Disease or other diseases through translocation of oysters between zones. Oyster Oedema Disease caused high mortality in farmed *P. maxima* within Exmouth Gulf in 2006 (Hart et al., 2016; Smith et al., 2023). To date, this disease has not been detected within wild population of pearl oysters or other species.

Other threats to molluscs within Exmouth Gulf include habitat destruction via benthic trawling, shoreline development, and anchor scouring from recreational and commercial vessels. Anchor scouring has been shown to have caused damage to filter-feeder beds, including molluscs, especially surrounding the Exmouth townsite where there is a high amount of boat traffic (Mellor & Gautier, 2023). Stirring up sediment during anchoring or dredging activities can also be detrimental to filter-feeding molluscs through blocking their filter feeding apparatuses. No surveys of molluscs were conducted prior to the beginning of the trawl fishery in the 1960s, making it difficult to quantify the effects of trawling in Exmouth Gulf (Kangas et al., 2007). However, there is some evidence that show areas heavily trawled have a reduced diversity and/or abundance of molluscs.

Additional broad threats such as increased pollution, rising ocean temperatures, and ocean acidification are known to be of threat to molluscs globally (e.g., Poloczanska et al., 2007). These are also likely threats within Exmouth Gulf, but these effects have not been examined.

3.5.2.2. Crustaceans

3.5.2.2.1 Biodiversity

Crustaceans are a diverse class of marine arthropods notably including crabs, lobsters, and prawns (decapods) as well as barnacles, copepods, amphipods, and isopods. This group (along with terrestrial arthropods) is defined by the presence of a hard exoskeleton. Several hundred crustacean species are likely to be present within Exmouth Gulf (see Table 3), including many that are undescribed. For example, a 2019 "Bush Blitz" survey focusing on decapods and barnacles within Exmouth Gulf identified 128 crustacean species within a few days of surveying including new species (19 unnamed/ unconfirmed, two new to science), and range extensions for 15 species not previously known to occur within the region (Hosie & Hara, 2019). A few crustacean species have been extensively studied due to their commercial importance (e.g., prawns targeted within the EGPMF), but most crustaceans, and the group as a whole, have received little research attention in Exmouth Gulf, similar to many other invertebrates. Our current knowledge of what species occur and where they reside is limited, but together with molluscs, they likely play a very significant ecological role within Exmouth Gulf.

3.5.2.2.2 Habitat use

Most crustaceans start life as planktonic larvae. Some crustaceans remain planktonic for their full life cycle, including many copepods, amphipods, ostracods, and euphausiids (krill). As adults, most decapods are benthic, although a variety of swimmer crab species can also be found in Exmouth Gulf (e.g., blue swimmer crab; *Portunus pelagicus*) which are known to use the full water column. Habitat use of post-larval and adult stages of decapods depends on the species, but overall decapods are found in all major habitats within Exmouth Gulf including soft bottomed flats, seagrass beds, mangroves, and hard benthic structures (Wells, 1984; Hutchins et al., 1996). Habitat use can also change with life stage of decapods. For example, prawns (including the commercially important brown tiger prawn, *Penaeus esculentus*, and western king prawn, *P. latisulcatus*), are known to use shallow water mudflats, mangroves, seagrass, and algal beds in the eastern and southern portions of Exmouth Gulf as nurseries during juvenile stages (Loneragan et al., 2013; Kangas et al., 2015). Adults then migrate to deeper water soft-bottomed habitats to breed.

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Like decapods, barnacles begin life in the plankton but are sessile as adults and require hard substrate to settle on such as rock, shell, or man-made structures (e.g., jetties and sea walls). The rocky shorelines spread sporadically throughout the southwestern part of Exmouth Gulf, as well as rocky islands, are likely particularly important areas for barnacles (e.g., Hutchins et al., 1996).

3.5.2.2.3 Ecological importance

Crustaceans can be a prey source, predator, filter-feeder, and creator of benthic habitat structure in Exmouth Gulf. Likely one of the most important roles that crustaceans play is as a planktonic food source for any variety of taxa including other filter-feeding invertebrates, teleost fishes, and megafauna. For example, in light traps deployed in 1997–1999 in both surface and deep-water habitats in the northern Exmouth Gulf, Ningaloo, and Pilbara regions, various crustaceans made up 96–99% of the zooplankton captured (Wilson et al., 2003). Dominant groups captured included amphipods, copepods, and mysids.

Post-larval crustaceans are also an important prey source for many animals within Exmouth Gulf, notably including shorebirds (DBCA, 2017), teleost fishes, and elasmobranchs (especially rays; O'Shea et al., 2013). For example, shark rays (*Rhina ancylostoma*) have been observed pursuing blue swimmer crabs in Exmouth Gulf (Bateman et al., 2024). Crustaceans may be an especially important food source for this and other threatened shark-like rays within Exmouth Gulf (wedgefish and giant guitarfish), as these rays are known for heavy predation on crustaceans including crabs and prawns (Vaudo & Heithaus, 2011; Milburn et al., 2023).

Crustaceans, especially crabs, can exert high pressure on species and habitats as predators. Ghost crabs (*Ocypode convexa* and *O. ceratophthalma*) have been shown to consume high proportions of loggerhead turtle eggs and hatchlings in the Ningaloo region (Avenant et al., 2024a). Crabs of various species have also been suggested to play key roles in the recycling of detritus in Exmouth Gulf, particularly within mangrove ecosystems (Wells, 1984; Humphreys et al., 2005; Hosie & Hara, 2019). Crab burrowing behaviour within mangrove forests along the northeastern coastline has been suggested to increase the aeration of the soil through bioturbation, which can facilitate mangrove respiration and growth (Alongi et al., 2000; Humphreys et al., 2005). Foraging crabs have also been shown to help distribute mangrove propagules in some mangrove ecosystems within Northern Australia (Robertson, 1991). Crab burrows may offer important structure for a variety of species in mangrove and mudflat areas. For example, mangrove sea snakes (*Ephalophis greyae*) have been observed hunting inside of crab burrows, either for crabs or for small teleost fishes using these habitats (Humphreys et al., 2005). This extends to terrestrial animals, such as for the skink *Ctenotus angusticeps*, which has been observed using supra-tidal crab burrows as shelter in mangrove-adjacent saltmarsh communities along the southwestern Exmouth Gulf (Maryan & Gaikhorst, 2022).

Many parasitic crustaceans can be found in Exmouth Gulf. Parasitic copepods (*Caligus furcisetifer*) and isopods (as gnathiid larvae) have been found parasitising giant shovelnose rays (*Glaucostegus typus*) and green sawfish (*Pristis zijsron*) within Exmouth Gulf and the surrounding area (Ingelbrecht et al., 2024b; Ingelbrecht et al., 2024c). The copepod *Perissopus dentatus* is also a common ectoparasite of carcharhinid sharks within the region (Ingelbrecht et al., 2024c). Parasites can hold important functional roles within ecosystems including as health indicators for host species and as controls for sympatric parasite species.

3.5.2.2.4 Significance of Exmouth Gulf

With the exception of commercially important species, the regional significance of Exmouth Gulf for crustaceans is poorly characterised. However, the diversity and abundance of invertebrates in general is known to be high in Exmouth Gulf compared to some surrounding areas (Kangas et al., 2007). Exmouth Gulf is likely to be a particularly important regional habitat for the many crustacean species which are obligate mangrove or seagrass specialists, considering the higher abundance of these habitats in Exmouth Gulf compared to much of the surrounding coastline.

The importance of Exmouth Gulf for crustaceans as a group can also be inferred from the knowledge gained on the few species of commercial importance. For example, genetic studies on blue swimmer crabs (*Portunus pelagicus*) have shown that the population present in Exmouth Gulf is separate to those found in Shark Bay and the Kimberley (Briggs et al., 2024; Chaplin et al., 2001). Blue swimmer crabs require sheltered bays and estuaries as juveniles and adults, which are uncommon along the northwest coastline. Early work on the genetics of blue swimmer crabs assumed that the separation in the Exmouth Gulf and Shark Bay populations was due to the inadequacy of habitats in between, reducing the capacity of "stepping stone" settlement for this species (Chaplin et al., 2001). However, more recent work has found small populations of swimmer crabs between these large embayments, negating the stepping stone theory, and hypothesized that the genetic separation due to current directions in the northwest was more likely. This theory is supported by similar genetic differentiation between Exmouth Gulf and Shark Bay found in corals, fish, and other invertebrates (e.g., the pearl oyster) using larval dispersal (Benzie & Smith-Keune, 2006; Briggs et al., 2024). Exmouth Gulf also holds stocks of commercially important prawn species that are genetically distinct (though minor) from those in Shark Bay (Kangas et al., 2015; Ward et al., 2006). Considering that many crustaceans rely on currents for larval dispersal, it is likely that Exmouth Gulf may hold crustacean populations that are genetically distinct from surrounding areas for many different species.

The significance of Exmouth Gulf as a nursery for certain decapod crustaceans is demonstrated by the abundance of commercially important prawn species (western king prawn and tiger prawn) found in Exmouth Gulf compared to surrounding regions. Prawn harvest within the Exmouth Gulf is greatest in the centre of Exmouth Gulf and is much greater than in other trawl fisheries in the Pilbara (e.g., Onslow Prawn Managed Fishery to the northeast of Exmouth Gulf) (Loneragan et al., 2013; Kangas et al., 2015). The abundance of prawns in the region is attributed to the proximity to productive nursery areas compared to other habitats within the region, namely seagrass and algal beds for tiger prawns (Loneragan et al., 2013), and shallow mudflats near mangroves for king prawns (Kangas et al., 2015). Crustaceans which rely on similar habitats as nurseries or adult habitats (e.g., many other prawns present in the region) may also be more abundant in Exmouth Gulf compared to other areas.

Figure 43: A large diversity of crustaceans are found in Exmouth Gulf. Image: Nick Thake

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3.5.2.2.5 Threats and pressures

Many crustacean species are harvested within Exmouth Gulf both commercially and recreationally. The EGPMF targets king and tiger prawns but retains several other crustaceans as byproducts, including coral prawns, banana prawns, blue endeavour prawns, blue swimmer crabs, mantis shrimp, and "bugs" or slipper lobsters (Table 4) (Kangas et al., 2015). The most recent State of the Fisheries report indicates that the stocks of western king, brown tiger, and blue endeavour prawns are not likely to be experiencing overfishing, nor are they likely to become overfished (Newman et al., 2023a). Non-target species in this fishery do not undergo a formal stock assessment but have annual catch limits based on past retention rates. The annual retained amount of species as byproduct by the EGPMF is generally well below these limits (Table 4). Sustainability of blue swimmer crab stocks across WA has been assessed as sustainable within the north coast (including Exmouth Gulf) (Johnston et al., 2023).

In addition to commercial catches, several crustacean species are also popular targets of recreational fishers, including blue swimmer crabs, mud crabs (*Scylla* spp.), prawns, and rock lobsters (*Panulirus* spp.). It is difficult to quantify recreational catches of these species within the Exmouth Gulf, but state-wide or regional stocks are generally assumed to be stable given the catch rates in commercial fisheries (Johnston et al., 2023; Newman et al., 2023a).

Other quantified threats to crustaceans within Exmouth Gulf include climate change related pressures, such as marine heatwaves and increased intensity of cyclones which may destroy key habitats. Prawn stocks in Exmouth Gulf declined following the marine heatwave in 2011, which caused widespread death of seagrass beds within southeastern Exmouth Gulf (Caputi et al., 2016). Without functional seagrass beds to use as a nursery habitat, tiger prawns failed to recruit to nursery areas within Exmouth Gulf, resulting in extremely low prawn catches in the EGPMF in 2012 and 2013 (Caputi et al., 2016). Tiger prawn recruitment also failed in Exmouth Gulf following TC Vance in 1999, which destroyed many inshore seagrass and mangrove nursery habitats (Loneragan et al., 2013). Cyclones have also been shown to alter current flow and disrupt larval dispersal of crustaceans and other fauna, which can cause failed recruitment or alter community assemblages in certain habitats (McKinnon et al., 2003).

Table 4: **Targeted and byproduct crustacean catch (in tonnes) retained by the Exmouth Gulf Prawn Managed Fishery for the last five years of available species-specific data (2017–2021) (Gaughan & Santoro, 2019; Gaughan & Santoro, 2020, 2021; Newman et al., 2021; Newman et al., 2023a), and proposed sustainable harvest limits set by the fishery (Kangas et al., 2015).**

Scientific name	Common name	2017	2018	2019	2020	2021	5-year average	Proposed harvest limit
Penaeus latisulcatus	Western king prawn	130	174	194	199	212	182	100–450
Penaeus esculentus	Brown tiger prawn	366	392	418	234	386	359	250–550
Metapenaeus endeavouri	Blue endeavour prawn	217	313	208	237	177	230	120–300
Metapenaeus crassissima	Coral prawn	24.8	20.4	21	17	8	18.2	20–100
Fenneropenaeus indicus	Banana prawn	0	0	1	4	2	1.4	0–60
Portunus pelagicus	Blue swimmer crab	4.5	0.9	6	4	10	5.1	< 40
Thenus orientalis	Bugs/Slipper lobster	3.7	2.8	2	1	2	2.3	< 15
Stomatopoda	Mantis shrimp	1.1	1.2	<1	0	0	0.6	

3.5.2.3. Echinoderms

3.5.2.3.1 Biodiversity

Echinoderms include sea stars (Asteroidea), brittle stars (Ophiuroidea), crinoids (Crinoidea) sea urchins (Echinoidea) and sea cucumbers (Holothuroidea), among other smaller families. They are generally one of the less diverse invertebrate phyla found in marine ecosystems, but 73 species were identified in trawl surveys in the Exmouth Gulf in 2004 (Kangas et al., 2007), and 92 species in targeted invertebrate sampling in the Muiron Islands and eastern Exmouth Gulf in 1995 (Hutchins et al., 1996). Atlas of Living Australia has reported 175 species in the region, dominated by sea stars (59 species) (Table 3). Like other invertebrates, the true biodiversity of echinoderms in Exmouth Gulf requires further examination.

The area surrounding Exmouth Gulf also hosted echinoderms in prehistoric times. Urchin species have been discovered in the fossil records from Giralia Range originating from the Cretaceous period (McNamara, 1987). Pleistocene records of the urchin *Echinometra mathaei* are also present in Cape Range, a species that is still abundant in the region today (McNamara, 1992).

3.5.2.3.2 Habitat use

Echinoderms are predominantly mobile benthic organisms as adults. Many urchins are known to prefer reef habitats (Westlake et al., 2021), while sea cucumbers tend to prefer soft-bottom habitats (e.g., Shiell & Knott, 2010), though habitat preferences vary by species. Trawl surveys have found various echinoderms throughout much of the surveyed areas within Exmouth Gulf, including the pencil urchin (*Heterocentrotus mamillatus*), which was the most abundant echinoderm captured and was predominantly found in the central and northwest areas (Kangas et al., 2007). Echinoderms have also been identified in seagrass beds (McCook et al., 1995), mangrove areas and intertidal mudflats (Wells, 1983), and rock and coral reef areas (Hutchins et al., 1996). Echinoderm assemblages in the Muiron Islands appear to be much more diverse and abundant than those along the eastern side of Exmouth Gulf. Crinoids and sea stars were more plentiful on the exposed western side of the Muiron Islands, while sea cucumbers and urchins preferred the more protected Exmouth Gulf. One of the most diverse and abundant assemblages surveyed was within the channel between the Muiron Islands and North West Cape. This is in line with findings that several echinoderm species in the region prefer areas with high water flow, including the sea cucumber *Holothuria whitmaei* (Shiell & Knott, 2010), and the urchin *Echinometra mathaei* (Johansson et al., 2013) on Ningaloo Reef.

3.5.2.3.3 Ecological importance

Echinoderms serve as a prey source for various invertivores, and influence ecosystem dynamics, erosion rates, and nutrient cycling through their feeding behaviours (Figure 44). Urchins are a desired food source for many fishes, including wrasses, emperors, pufferfish and triggerfish (Johansson et al., 2013; Westlake et al., 2021). Urchins are also known as voracious grazers of algae and plant matter and are important determinants of macroalgal abundance at Ningaloo Reef (e.g., Harris et al., 2021) and likely in Exmouth Gulf as well (Dee et al., 2023). Urchins are also known to benefit coral growth by limiting algal growth, including within the Exmouth region (Langdon, 2012). However, an overabundance of urchins, generally caused by declines in their teleost fish predators, can lead to overgrazing which has been shown to be highly detrimental in algal and seagrass ecosystems within WA (e.g., Langdon et al., 2011). This has not yet been recorded in Exmouth Gulf.

In addition to their role as grazers, urchins are also important in bioerosion pathways. Along with parrotfishes, urchins are generally the main contributors to bioerosion through grazing. However, their relatively low densities at reefs around Eva and Fly Islands in Exmouth Gulf indicate that parrotfish are the more significant of these two grazing groups (Dee et al., 2023). Parrotfishes were also found to be the more significant of the two grazing bioeroders on Ningaloo Reef where bioerosion rates are much higher than in Exmouth Gulf, although urchins were still responsible for an estimated 22% of bioerosion (Thomson et al., 2024). Through bioerosion pathways, urchins can also contribute to the generation of sediments which are used in island-building processes (Bonesso et al., 2022).

Sea cucumbers are predominantly detritivores and hold important roles in nutrient recycling and sometimes bioturbation, depending on the species. The contribution of sea cucumbers to these ecosystem services in Exmouth Gulf has not been well studied. The sea cucumber *Holothuria whitmaei* population was shown to turn over approximately 2–14% of available sediments annually on Ningaloo Reef and were also estimated to crawl over twice the available coral reef sediments each year, distributing nutrients along the way (Shiell & Knott, 2010).

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They therefore are likely to have a substantial contribution to nutrient recycling and enhancement of benthic microalgal communities within the Ningaloo region, particularly during reproductive aggregation periods.

Sea stars are predominantly predators of various invertebrates. Some have been known to cause significant damage to coral reefs through over-grazing, as seen with the crown-of-thorns sea star *Acanthaster planci* (potentially an unresolved species complex). Unlike many other reefs globally, Exmouth Gulf and Ningaloo Reef are unknown to have suffered major outbreaks of this sea star, which tends to flourish in warmer waters (Vanderklift et al., 2020). *Acanthaster planci* has been recorded at the Muiron Islands but was in low abundance with no evidence of feeding scars on corals (Hutchins et al., 1996). The short spined crown-of-thorns sea star (*A. brevispinus*) has also been confirmed as a corallivore at Ningaloo Reef in deeper habitats (20 – 70 m) (Keesing et al., 2023).

The brittle star *Ophiocnemis marmorata* has been commonly observed to associate with jellyfish medusae in the order Semaeostomeae in Ningaloo Reef, 'hitching a ride' on their bells or tentacles (Ingram et al., 2017). Feeding studies have shown that these brittle stars do not consume the jellyfish, but feed on zooplankton, and it is likely that they scavenge plankton from their host's tentacles, defining them as a kleptoparasite (Ingram et al., 2017).

3.5.2.3.4 Significance of Exmouth Gulf

Given the lack of echinoderm knowledge and limited surveys conducted within Exmouth Gulf, it is difficult to determine the significance of Exmouth Gulf compared to surrounding areas. In the limited surveys conducted in the Muiron Islands and eastern Exmouth Gulf in 1995, echinoderm diversity was generally lower than that found across Ningaloo Reef or within the Montebello Islands, but higher than that recorded at Barrow Island (Hutchins et al., 1996). However, many more species are likely to be discovered with further surveys, and the majority of Exmouth Gulf has yet to be surveyed for echinoderms specifically.

3.5.2.3.5 Threats and pressures

The only echinoderm group which is the subject of targeted fishing in the region are sea cucumbers. The Western Australian Sea Cucumber Fishery (WASCF) operates between Exmouth Gulf and the Northern Territory border, although most of the harvest originates from Barrow Island, Nickol Bay, and in the Kimberley (Webster & Hart, 2018; Smith et al., 2024). The main species targeted are the sandfish (*Holothuria scabra*) and redfish (*Actinopyga echinites*), as well as a smaller proportion of black teatfish (*Holothuria whitmaei*) (Smith et al., 2024). There are likely different genetic stocks of these species throughout the fishery, although this has not been assessed. The Pilbara stock of sandfish is considered 'medium risk', while the Pilbara redfish and black teatfish stocks are 'low risk'. Sea cucumbers are also sometimes caught (and discarded) in the EGPMF as bycatch, but are generally different species than those targeted in the shallows by the WASCF (Kangas et al., 2007; Smith et al., 2024). Recreational or customary catch of sea cucumbers in the region is also negligible (Smith et al., 2024), meaning there is little chance of cumulative pressures from multiple fisheries on sea cucumbers in Exmouth Gulf.

Alongside climate change, other threats to echinoderms in Exmouth Gulf are likely to include benthic habitat destruction or disruption from trawling and/or coastal development. For example, repeated trawling in Shark Bay was shown to reduce echinoderm abundance by 41% (Kangas et al., 2007), but the impact of this fishing method on echinoderms within Exmouth Gulf has not been quantified.

3.5.2.4. Cnidarians and Ctenophores

3.5.2.4.1 Biodiversity

Cnidarians include stony corals, zoanthids, coralimorphs, soft corals, sea anemones, jellyfish and hydrozoans, and characterised by the possession of stinging cells (Figure 45). Ctenophores are a separate phylum of gelatinous planktonic organisms which do not possess stinging cells. Salps (planktonic tunicates) are also common gelatinous plankton seen in the region and are touched upon in Section 3.5.3. Apart from stony and soft corals (see Section 3.4.10), research on other cnidarians and ctenophores has been scarce within Exmouth Gulf.

Figure 44: **Sea stars (Asteroidea; pictured) and other echinoderms fulfil a variety of ecosystem services in Exmouth Gulf. Image: Rebecca Bateman-John**

Due to limited directed surveys on cnidarians and ctenophores in Exmouth Gulf or nearby regions, the diversity of this group is not well known. A 2019 'Bush Blitz' survey across Exmouth Gulf in 2019 identified a single ctenophore species, five hydrozoans (whether hydroids or hydrozoan jellyfish is unclear), 12 octocorals (soft corals) and one scleractinian coral (hard coral), although surveys were focused in sponge gardens where soft corals are expected to be more abundant (Gomez & Fromont, 2019). Surveys of gelatinous zooplankton in the Ningaloo region identified eight different species of scyphozoan, hydrozoan, and cubozoan jellyfish, of which the scyphozoans *Crambione mastigophora* (tomato jellyfish) and *Aurelia aurita* (moon jellyfish) were the most common (Ingram, 2015). Atlas of Living Australia contains citizen science records of a single ctenophore species

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(*Neis cordigera*), one cubozoan jellyfish, five hydrozoan jellyfish, two scyphozoan jellyfish, nine sea anemones, 25 soft corals, and 53 hard corals. A new literature review that combined all specimen based and verified visual records of cnidarians in Exmouth Gulf will help to shed more light on the known diversity of cnidarians and the knowledge gaps that exist, especially at the taxonomic level (Z. Richards et al., in prep).

Few jellyfish are known to be resident in Exmouth Gulf or use Exmouth Gulf as reproductive areas (e.g., polyp beds). Rather, oceanic species likely appear in Exmouth Gulf when brought in by tides and currents (J. Strickland, pers. comm.). Scyphozoan jellyfish genera sighted in Exmouth Gulf during such periodic influxes of ocean water include *Cyanea, Crambione, Aequorea*, and *Aurelia*, which often appear alongside various ctenophores and salps. The one exception to this may be the upside-down jellyfish, *Cassiopea* sp., which is a genus known for association with shallow coastal areas. *Cassiopea* sp. have recently been sighted in Exmouth Gulf (Hoschke & Whisson, 2024), although the extent of their occurrence in unknown at present.

Several carybdeid jellyfish (order Cubozoa) which may cause Irukandji syndrome are found in the region and have been the focus of some studies. Confirmed cubozoan species in Exmouth Gulf include *Malo bella*, which is found along the Ningaloo Coast and Dampier Archipelago (Gershwin, 2014; Ingram, 2015) and has been sighted in the central to northern areas of Exmouth Gulf (J. Strickland, pers. comm.). *Keesingia gigas* is also present, found between the Shark Bay and Ningaloo regions including within Exmouth Gulf (Gershwin, 2014; Gershwin & Hannay, 2014; Keesing et al., 2020). Thirty one strandings of *K. gigas* were reported in Exmouth Gulf across ten days in March 2016, and 54 sightings/stranding were reported across Exmouth Gulf and Ningaloo Reef in March–May 2017 (Keesing et al., 2020). Stings of these cubozoans have occurred within Exmouth Gulf and at Ningaloo Reef, including dozens of cases that require hospitalisation each year and elicited symptoms congruent with Irukandji syndrome (Gershwin & Hannay, 2014; Keesing et al., 2020; Strickland et al., 2025).

3.5.2.4.2 Habitat use

Hard and soft corals can be found scattered throughout Exmouth Gulf. Distributions of these benthic communities are discussed more in Section 3.4.10. Little is known about abundance and distribution patterns of anemones within Exmouth Gulf however based on a review of specimen records in Australian Museums there is a more diverse community of Actinaria in Exmouth Gulf than on Ningaloo Reef (Z. Richards et al., in prep).

Ctenophores and most jellyfish are planktonic where occurrence and distribution is largely determined by prevailing winds and currents. These groups tend to be more abundant along Ningaloo Reef and within Exmouth Gulf in autumn (approximately March through June) (Ingram, 2015; Keesing et al., 2016). Some species reliably appear during this season in most years, including tomato jellyfish (*C. mastigophora*), *Aurelia* spp., and the box jellyfish, *M. bella* (Keesing et al., 2016; Keesing et al., 2020; Strickland et al., 2025). Other species such as *K. gigas* may be more irregular (Keesing et al., 2020), although anecdotal reports of this species in the Ningaloo-Exmouth region have occurred each year over at least the past seven years (J. Strickland, pers. comm.). Swarms of tomato jellyfish are noticeably more abundant in some years compared to others. For example, dense swarms of this species have been noted in April/May in 1987, 2000, 2007, 2010, and 2013 along the Ningaloo coastline, likely from ideal combinations of tides, currents and winds aggregating individuals (Keesing et al., 2016). They have been noted in more recent years as well. Within Exmouth Gulf, cubozoans and high densities of other jellyfish are more often sighted in the northwestern area of Exmouth Gulf (Keesing et al., 2020). This is likely due to currents, but also a higher concentration of citizen science and research efforts compared to other hard to access areas of Exmouth Gulf.

3.5.2.4.3 Ecological importance

Corals have widespread ecological significance as habitat building organisms, with coral reefs known to generally support higher diversities of fish and invertebrate species than most other benthic habitat types. More information about coral reefs as benthic habitats can be found in Section 3.4.10. Both hard and soft corals are also a food source for many corallivorous fish and invertebrates in the region (e.g., Armstrong, 2009; Holmes et al., 2017; Keesing et al., 2023). Hard corals also contribute to structure building and sediment deposition in Exmouth Gulf (Bonesso et al., 2022; Dee et al., 2023), while soft corals are known as important filter feeders (e.g., Bryce et al., 2018).

Jellyfish and ctenophores offer an important food source for green turtles in the region, particularly for larger individuals (Vanderklift et al., 2023). Flatback turtles are also known to feed on jellyfish in northwestern Australia (Hounslow et al., 2023), although their diets have not been examined within Exmouth Gulf. Filter-feeding megafauna, including whale sharks and manta rays, may also feed on ctenophores and jellyfish, although they do not appear to target these groups as primary food sources (Taylor, 2007). Various fishes and seabirds may also eat jellyfish and ctenophores (Keesing et al., 2020), though this is not well documented in Exmouth Gulf.

Scyphozoan jellyfish are known to form commensal associations with a variety of species. For example, the brittle star *Ophiocnemis marmorata* is commonly found associated with the moon jelly *Aurelia aurita* in the Ningaloo region, which it may use for protection, distribution, or as a food source by stealing zooplankton caught by the jellyfish (Ingram, 2015; Ingram et al., 2017). Small teleost fishes including carangids have also been found associated with tomato jellyfish in northwestern Australia (Keesing et al., 2016), likely for protection or kleptoparasitism purposes.

3.5.2.4.4 Significance of Exmouth Gulf

The significance of hard and soft coral reef communities is discussed in Section 3.4.10. It is difficult to determine the significance of Exmouth Gulf to other cnidarians and ctenophores given the limited targeted research on these groups in the region. However, several species found in Exmouth Gulf are likely to be regionally endemic, including the cubozoans *K. gigas* and *M. bella* (Gershwin, 2014; Keesing et al., 2020).

3.5.2.4.5 Threats and pressures

Threats to corals and coral reefs are numerous and pressing, including various climate-related threats (e.g., bleaching, increased storm frequency, sea level rise, increased turbidity) as well as direct habitat destruction via anchor scouring or development. Threats to reef ecosystems are discussed further in Section 3.4.10.

On the other hand, there are no major threats known to jellyfish and ctenophores in Exmouth Gulf. While jellyfish are caught within commercial trawl fisheries, species diversity and abundances have not been recorded (Kangas et al., 2007). Changes in current patterns, SST, and eutrophication are likely to alter patterns of jellyfish presence and abundance (Keesing et al., 2016). Globally, most anthropogenic environmental stressors such as warming sea temperatures and eutrophication are generally forecast to increase the abundance of jellyfish and ctenophores in coastal and oceanic environments (Lee et al., 2023).

Figure 45: Sea anemones can provide additional structure and habitat in Exmouth Gulf. Image: Rebecca Bateman-John

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3.5.3. Tunicata

Tunicates belong to the phylum Chordata (vertebrates) because larval stages of this group possess a notochord, although most adult forms more closely resemble sponges or ctenophores morphologically and ecologically. The main groups of tunicates found in Exmouth Gulf include sessile sea squirts (Ascidiacea), and gelatinous planktonic salps (Thaliacea) and larvaceans (Appendicularia), though little is known about larvaceans across WA (Kott, 2005). Sea squirts and salps are present as individual organisms or as colonies. As adults, sea squirts are fastened to various benthic hard structure (e.g., rock, shell, pilings), or rooted in soft sediment (McDonald & Sorokin, 2006). Salps are planktonic and common in ocean currents and can appear as individuals or in large communal chains.

Sea squirts can be found throughout Exmouth Gulf (Kangas et al., 2007) and many species are likley present but poorly understood in Exmouth Gulf. Atlas of Living Australia has recorded observations of 23 different species from 10 families within Exmouth Gulf. In 2004, benthic trawl surveys conducted throughout the EGPMF trawl grounds found sea squirts in nearly every location surveyed, though generally in low abundance (overall the 21st most abundant invertebrate) (Kangas et al., 2007). The greatest densities were found in the northwestern Gulf and southwest of Onslow. Colonies have also been identified in Gales Bay and near Town Beach (McCook et al., 1995). The channel between Muiron Islands and North West Cape is likely to also support an abundance of sea squirts (Kangas et al., 2007).

Salps can be a major component of zooplankton communities. Salps filter-feed on various smaller zooplankton, are an important secondary consumer in many planktonic communities in the northwest of Australia (Brewer et al., 2007). For example, 35% of plankton tows conducted outside of Ningaloo Reef in 1992 contained salps (Taylor, 2007), and salps are likely fed upon by filter-feeding megafauna in the region such as whale sharks (Meekan et al., 2022). Salps may also represent an important food source for marine turtles (Stubbs et al., 2022). While little research on salps has been conducted within Exmouth Gulf specifically, trends in distribution and abundance likely follow those of other gelatinous zooplankton such as jellyfish (see Section 3.5.2.4). If this is the case, salps are most likely encountered in the northwestern area of Exmouth Gulf during periods of ocean water incursion, predominantly in autumn.

The ecosystem services provided by sea squirts within Exmouth Gulf have not been directly studied. In other areas of WA, they are recognised as important filter feeders including for their roles in nutrient cycling and maintaining water clarity, as well as being a prey source or offering shelter to many fish and invertebrates (McDonald & Sorokin, 2006). Similar to sponges, sea squirts are also known for their biochemical production, and several species in the northwest region of Australia, including in Exmouth Gulf, have been biochemically examined for potential medicinal or other uses (e.g., Sala et al., 2023).

Threats to sea squirts in Exmouth Gulf mainly include habitat destruction or disturbance, including through trawling (McDonald & Sorokin, 2006; Kangas et al., 2007), and damage from anchor scouring (Mellor & Gautier, 2023). Benthic communities in the area of the densest anchor scour marks within Exmouth Gulf, surrounding Exmouth Townsite, are dominated by filter feeders including sea squirts (Mellor & Gautier, 2023). The invasive sea squirt *Didemnum perlucidum* has also been confirmed within Exmouth Gulf and throughout the wider Pilbara region, and may outcompete native species (Wells, 2018). No major threats to salps are known in Exmouth Gulf.

3.5.4. Teleost fishes

3.5.4.1. Biodiversity

Exmouth Gulf hosts a diverse assemblage of teleost fishes (bony fishes; referred to as fishes in this section). At least several hundred species have been identified in the region (see Table 5), though some habitats have received less attention than others, such as mangrove areas (McLean et al., 2016; Moore & Allen, 2019). Several recent surveys have identified new species of fish as well as range extensions for previously known species. Moore & Allen (2019) found three new goby species and one unconfirmed species, along with range extensions of up to several hundred kilometres for nine species during a 2019 'Bush Blitz' survey in Exmouth Gulf. Several other species have been recently described from Exmouth Gulf, including the ocellated tonguesole (*Cynoglossus quadriocellatus*) (Fricke, 2020), and the re-described northwestern stonefish (*Dampierosa daruma*) (Matsunuma & Motomura, 2021). Both of these species appear to be endemic to western or northwestern Australia. Further fish surveys within Exmouth Gulf are likely to reveal more new species and range extensions and are essential to understanding how Exmouth Gulf fits into regional fish biodiversity (McLean et al., 2016; Moore & Allen, 2019).

Exmouth Gulf hosts predominantly tropical fishes, although it also marks the approximate edge of some subtropical species' distributions (Hutchins, 1994). For example, a survey of fishes across Muiron Islands and eastern Exmouth Gulf in 1995 found 373 tropical species, but only nine (2.2%) subtropical species, and one temperate species (Hutchins et al., 1996).

Many species or families of fish are closely associated with specific habitat types, and therefore dominant fish families vary by location and habitat throughout Exmouth Gulf. For example, similar to Ningaloo Reef, the most common families found near Muiron Islands included damselfishes, wrasses, and parrot fish which are known for associations with coral reefs and clear water (Hutchins et al., 1996). Damselfishes were also very common across more turbid reefs in Exmouth Gulf including those surrounding Eva and Fly Islands (Dee et al., 2023). Fish assemblages across the eastern Gulf were generally more similar to those found near Dampier Archipelago compared to Ningaloo Reef (Hutchins et al., 1996). These assemblages tended to be less diverse than assemblages at Muiron Islands, and most commonly included grunters, snappers, sea breams, cardinalfish, blennies, and threadfin breams. These families may be more adapted to turbid conditions, and in some cases show a preference for soft-bottomed habitats. Trawl surveys targeting benthic, soft-bottomed habitats throughout Exmouth Gulf also commonly caught sand or mud-associated species including scorpionfishes, breams, grunters, and emperors.

The most common species caught in these surveys included the bullrout, *Paracentropogon vespa*, blotched javelin fish (*Pomadasys maculatus*), threadfin emperor (*Lethrinus genivittatus*), and six-lined trumpeter (*Pelates sexlineatus*) (Kangas et al., 2007).

It is likely that diversity and community assemblage dynamics of fishes in Exmouth Gulf change across the various gradients of turbidity, temperature, and habitat type due to species-specific requirements and preferences. For example, Hutchins et al. (1996) found that fish diversity was higher in the central and eastern areas of Exmouth Gulf compared to the northeast, likely due to periods of prohibitively high turbidity and sedimentation for some species in the northeast. Few comparable fish surveys have been conducted across a wide enough habitat gradient to thoroughly examine how fish assemblages shift throughout environmental and habitat gradients in Exmouth Gulf.

There are likely to be many species that are specifically associated with mangrove and seagrass ecosystems in Exmouth Gulf as well, but these habitats have not been well-surveyed for fishes. Surveys of intertidal cyanobacterial mat habitats in Giralia Bay in 2007 using passive fish nets identified 61 fish species from 32 families, dominated by Atherinidae (silversides), Sillaginidae (whitings), Gobiidae (gobies), and Clupeidae (herrings). The first three families were much more abundant in cyanobacterial mats near mangroves, while the latter family dominated mats without nearby mangroves (Penrose, 2011).

Some of the most common fish groups recreationally targeted by shore- and boat-based fishers in Exmouth Gulf include breams, whiting, mullet, emperors, queenfish, and trevallies (Sumner et al., 2002). The most common groups observed on baited remote underwater video systems (BRUVS) deployments throughout the Pilbara region including North West Cape and Muiron Islands were somewhat similar, including breams, wrasses, tuskfish, emperors, trevallies, and groupers (McLean et al., 2016).

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Table 5: Targeted fish surveys conducted within the Exmouth Gulf or surrounding region, including by various netting methods, physical specimen collection, underwater visual census, diver operated video (DOVs), and baited remote underwater video system (BRUVS).

Location	Survey methods	Time frame	# species identified	Reference
Muiron Islands and northern Ningaloo Reef	Underwater visual census and intertidal collecting	1975–1977	482 (67 families)	Hutchins (1994)
Muiron Islands and eastern Exmouth Gulf	Underwater visual census and intertidal collecting	Aug 1995	383 (70 families)	Hutchins et al. (1996)
Northwest shelf including northwest Exmouth Gulf	Light traps (larval fish)	1997–1999	33 families	Meekan et al. (2006)
EGPMF Trawl grounds	Trawl netting	Mar, Jun/Jul, Nov 2004	285 (83 families)	Kangas et al. (2008)
Ningaloo Marine Park (including Bundegi)	Underwater visual census	2006–2007		Babcock et al. (2008)
Mangroves and cyanobacterial mats in Gales Bay and Giralia Bay	Fyke nets	Oct–Nov and Apr–May 2005–2007	61 (32 families)	Penrose (2011)
Ningaloo Marine Park (including Bundegi)	Underwater transects (juvenile fish only)	2009–2011	120 (22 families)	Depczynski et al. (2011)
Ningaloo Marine Park (including Bundegi)	Underwater visual census, citizen science	Jul–Aug 2012	236	Day et al. (2013)
Exmouth Navy Pier	Underwater video	Mar 1996 April 2001		AIMS (2007)
Exmouth Navy Pier	Pier cam (continuous underwater video)	2005–2009	165 (50 families)	Whisson & Hoschke (2013)
Pilbara Coast including North West Cape and Muiron Islands	BRUVS	May 2014	343 (58 families)	McLean et al. (2016)
Ningaloo Marine Park (including Bundegi)	Underwater visual census	2010–2015		Wilson et al. (2016)
Ningaloo Marine Park (including Bundegi and Muiron Islands)	DOVs, underwater census, and BRUVS	2011–2016		Holmes et al. (2017)
Various sites throughout Exmouth Gulf	Intertidal and underwater collecting, visual ID	Jun 2019	77 (30 families)	Moore & Allen (2019)
Whole Exmouth Gulf	Citizen science		885 (109 families)	Atlas of Living Australia
Muiron Islands, eastern Exmouth Gulf (including Bundegi)	Underwater visual census, citizen science		395	Reef Life Survey

3.5.4.2. Habitat use

Fishes occupy all aquatic habitats within Exmouth Gulf including intertidal, benthic, and pelagic habitats. Reef habitats, such as Bundegi and Muiron Islands, likely house particularly diverse and abundant fish assemblages compared to most other habitats (Hutchins et al., 1996). For example, 1995 surveys identified 348 species around Muiron Island, but only 114 species along the eastern Exmouth Gulf (69 species shared between the two locations). BRUVS surveys throughout the Pilbara including in the Muiron Islands and North West Cape also found higher diversity and abundance of fishes over reefs compared to soft sediments (McLean et al., 2016). Conversely, a trawl and trap-based survey across the Pilbara, Canning, and Kimberley inshore regions found much higher diversity of fish assemblages in soft sediment habitats compared with reef areas (Travers et al., 2010). Within reef habitats in the Ningaloo Marine Park, including at Bundegi Reef, Wilson et al. (2016) found that the abundance of particular coral types had a positive influence on abundance of the damselfish *Pomacentrus moluccensis*. This was likely due to specific habitat requirements of juvenile and sub-adult fish and suggests that species-specific microhabitat preferences during early life stages have a major effect on the population size and distribution for some adult fishes.

A study using light traps to capture larval fishes found that larvae of reef fish, baitfish, and pelagic taxa were all most abundant in the channel between North West Cape and Muiron Islands compared to either further offshore or further into Exmouth Gulf (Meekan et al., 2006). Most reef and pelagic fish larvae were captured near the surface, while baitfishes were more common near the benthos. This study also found that larval abundances of specific fish families was markedly different between years of sampling, which may have been driven by large differences in water temperatures between years (Meekan et al., 2003; Meekan et al., 2006).

3.5.4.3. Ecological importance

Fishes are an important prey source of many animal groups within Exmouth Gulf, including for many elasmobranchs, sea snakes, dolphins, seabirds, and other fishes (Figure 46). Small invertivorous, herbivorous, or planktivorous fishes, alongside many invertebrates, are an important stepping stone for the transfer of nutrients from primary producers to higher tropic levels. For example, the sea mullet *Mugil cephalus* has been observed to directly consume cyanobacteria within the southern Exmouth Gulf as one of the few vertebrates able to digest this important nutrient source (Penrose, 2011). Small fishes including gobies and whiting have also been shown to derive much of their carbon from cyanobacterial food webs (Penrose, 2011). Many fishes also ingest many worms, crustaceans or other small invertebrates, and invertivorous fish have been found to be more dominant than piscivorous fish within multiple areas of Exmouth Gulf and Ningaloo Reef (e.g., Ashworth et al., 2014; Dee et al., 2023). Polychaetes may be a prominent food source for many shallow-water fishes, as the stomachs of all species examined in a study in the southern Exmouth Gulf contained polychaete worms (Penrose, 2011). While fish trophic dynamics have not been well-studied in Exmouth Gulf, such fish mesopredators represent an important trophic pathway for the transfer of nutrients to higher order tropic levels across Ningaloo Reef (Ashworth et al., 2014; Thillainath et al., 2016). Predatory fishes such as coral trouts can also exert substantial top-down control over their prey species and are likely important in the maintenance of balanced food webs within Exmouth Gulf.

In addition to trophic significance, fish also play important roles in algal control and bioerosion. For example, parrot fish are known to significantly influence bioerosion pathways in coral reef systems through grazing. While macro-erosion rates at reefs surrounding Eva and Fly Islands in Exmouth Gulf were low compared to many other reefs globally, most of this macro-erosion was attributed to parrotfish (Dee et al., 2023). Parrotfishes, especially *Chlorurus microrhinos*, were also determined to be important bioeroders on reefs along Ningaloo coast, where macro-erosion rates were comparatively high (Thomson et al., 2024).

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Additionally, reefs around Eva and Fly Islands have also shown high densities of damselfish (44% of recorded fish during dive surveys) (Dee et al., 2023). Some damselfish including *Stegastes* spp. are known to actively maintain algal turf patches on reefs. Higher densities of turfing algae tend to increase micro-erosion rates while decreasing grazing by parrotfish and urchins and therefore macro-erosion rates. As a result, damselfish may play an indirect role in mediating bioerosion rates in Exmouth Gulf reefs (Dee et al., 2023).

Various fish species also perform ecological functions including cleaning duties. Several fish species have been shown to act as cleaner fish at cleaning stations throughout Ningaloo Reef, including *Laboides dimidiatus* and *Thalassoma lunare*, along with the occasional butterfly fish or damsel fish (Ashe, 2016; Coward, 2017). These fish clean parasites, algae, and detritus off client fish, which include a variety of elasmobranchs, other fishes, and sometimes marine megafauna such as turtles. The ecology of cleaning stations including the species involved has not been examined in Exmouth Gulf, but cleaning stations for manta rays are known to occur on the reef edges surrounding Bundgei Reef (A. Armstrong, pers. comm.).

3.5.4.4. Significance of Exmouth Gulf

While the populations and true diversity of fishes within Exmouth Gulf are not completely understood (Moore & Allen, 2019), the limited comparative data available indicates that Exmouth Gulf is likely to be a regionally important area for many different fish species and for fish biodiversity overall. A suite of BRUVS deployed across the southern Pilbara region showed that the main driver of abundance and diversity of fishes was proximity to Exmouth Gulf (McLean et al., 2016). This study suggested that Exmouth Gulf was likely to support nursery habitats for a range of fish species, driving up fish abundance and diversity in nearby waters. For example, small parrotfish and emperor recruits were only found in habitats close to Exmouth Gulf, suggesting they had recently emerged from nursery areas within Exmouth Gulf.

For other species and assemblages studied at Exmouth Gulf reefs, there is evidence they may be distinct from those found on Ningaloo Reef, potentially suggesting relatively limited fish connectivity between these systems (S. Wilson, pers. comm.). For example, coral trout, tuskfish, and certain damselfish were particularly abundant at Bundegi and the Muiron Islands compared to locations along Ningaloo Reef (Babcock et al., 2008; Day et al., 2013). The difference in fish assemblages is likely due to a combination of the different environmental characteristics of Exmouth Gulf (higher temperatures and turbidity) compared to Ningaloo Reef, and limitations in current-driven larval dispersal between the two systems (S. Wilson, pers. comm.). Temporal trends in abundance and diversity of fishes are also often different between Ningaloo Reef and Exmouth Gulf reefs (e.g., Wilson et al., 2016), indicating different drivers of biodiversity in these two systems. A comparison of fish biodiversity and endemism within WA identified the area encompassing Exmouth Gulf, North West Cape, and northern Ningaloo as one of the state's top biodiversity hotspots, both when considering general species richness and diversity of Australian or WA endemics (Fox & Beckley, 2005).

Genetic stocks of fish present in Exmouth Gulf have shown similarities to populations present within the Pilbara region, though tend to be separate from those found in Shark Bay or further north in the Kimberley. For example, the stripey snapper (*Lutjanus carponatatus*), a commercially important species found throughout northwestern Australia, showed a sharp genetic dissimilarity between Shark Bay and more northern populations (DiBattista et al., 2017). A gradual shift was evident between populations found in the Kimberley with those found in the Canning and Pilbara bioregions including in Exmouth Gulf. Similar patterns in population genetic structure of corals, crustaceans, and other fishes have been observed across northwestern Australia (e.g., Evans et al., 2019; Briggs et al., 2024). It is possible that prevailing currents limit larval fish dispersal between Shark Bay and the Pilbara, including Exmouth Gulf, while isolation by distance patterns are typical, spanning from the Exmouth/Ningaloo Region to the Kimberley.

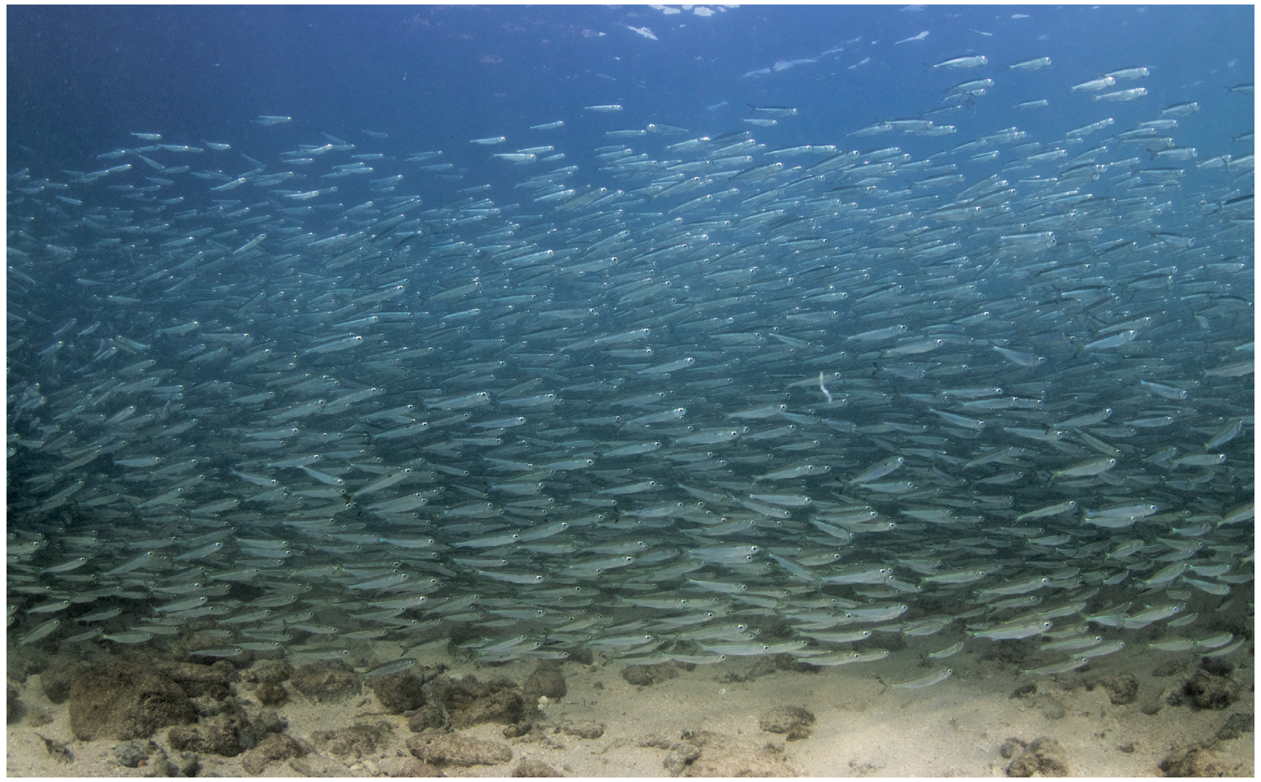

Figure 46: **Schooling fish play a key role in marine food webs in Exmouth Gulf, including as a prey source for many elasmobranchs, sea snakes, dolphins, seabirds, and larger teleost fishes. Image: Rebecca Bateman-John**

Several studies have also shown genetic separation between fish populations in northwest Australia, including Exmouth Gulf, and areas of southeast Asia (Ovenden et al., 2002; Newman et al., 2009).

Two of the three marine fishes listed as Totally Protected Fish species under the WA Fish Resources Management Act 1994 (FRMA) can be found in Exmouth Gulf. These include the potato cod (*Epinephelus tukula*) (McLean et al., 2016), and the Queensland groper (*Epiniphelus lanceolatus*) (Table 6). No teleost fishes with threatened statuses under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) are found in Exmouth Gulf (noting very few marine fishes have been assessed), except for all syngnathids and solenostomids (sea horses and pipefishes). These are listed as Marine under the EPBC Act, and several can be found within Exmouth Gulf (see section 3.5.4.7). Several teleost fishes with global threatened listing statuses on the International Union for the Conservation of Nature (IUCN) red list are present in Exmouth Gulf and the surrounding region (Table 6).

3.5.4.5. Threats and pressures

A variety of fish species are directly harvested by recreational and commercial fisheries within Exmouth Gulf. Little information is available on recreational fishing efforts in Exmouth Gulf specifically. This is true for shore-based recreational fishing as licences are not required and therefore effort is difficult to quantify. However, previous data indicates Exmouth Gulf is particularly important for the shore-based recreational fishing sector. Recent data on shore-based fishing effort in the region are not available, but historical surveys suggest that Exmouth Gulf supports more shore-based recreational fishing effort than any other area within the Gascoyne Region including Ningaloo and Shark Bay.Exmouth Gulf is likely responsible for the majority harvest of most popular shore-based fishes within the Gascoyne region (Sumner et al., 2002). Popular shore-based fishes include various whitings and mullets as well as western yellowfin bream (*Acanthopagrus latus*), spangled emperor (*Lethrinus nebulosus*) and queenfish (*Scomberoides commersonnianus*).

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Table 6: Teleost fishes with state-wide, national, or global threatened or protected statuses that are likely to be found in Exmouth Gulf or nearby waters based on their spatial distributions. Most sources do not list specific locations for sightings, therefore the general location of the surveys with positive identifications for each species are listed; NMP: Ningaloo Marine Park (including Bundegi). TPS: Totally Protected Species, listed by the WA Fish Resources Management Act 1994. IUCN status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated.

Scientific name	Common name	Threatened or protected status	Record location(s)	Source
Epinephelus lanceolatus	Queensland groper	TPS	Ningaloo, Muiron Islands, Exmouth Gulf, south Pilbara	McLean et al. (2016) Hutchins (1994)
Epinephelus tukula	Potato cod	TPS	Ningaloo, Muiron Islands, Exmouth Gulf, south Pilbara	McLean et al. (2016) Hutchins (1994)
Gobiodon axillaris	Red-striped coral goby	VU	Ningaloo	Atlas of Living Australia
Plectroglyphidodon dickii	Dick's damselfish	NT	Muiron Islands, Ningaloo, northwest Exmouth Gulf	Hutchins (1994) Hutchins et al. (1996) Atlas of Living Australia
Cheiloprion labiatus	Biglip damselfish	VU	Ningaloo, Muiron Islands, Ningaloo Marine Park	Hutchins (1994) Depczynski et al. (2011)
Chaetodon trifascialis	Chevron butterflyfish	NT	Muiron Islands, Exmouth Gulf, south Pilbara, northwest Exmouth Gulf, Ningaloo Marine Park	Hutchins (1994) Hutchins et al. (1996) Depczynski et al. (2011) McLean et al. (2016) Day et al. (2013) Atlas of Living Australia
Oxymonacanthus longirostris	Harlequin filefish	VU	Muiron Islands, Ningaloo Marine Park, Exmouth Navy Pier, northwest Exmouth Gulf	Hutchins (1994) Hutchins et al. (1996) Depczynski et al. (2011) Day et al. (2013) Whisson & Hoschke (2013) Atlas of Living Australia
Bolbometopon muricatum	Green humphead parrotfish	VU	Ningaloo, Muiron Islands	Hutchins (1994)
Choerodon schoenleinii	Blackspot tuskfish	NT	Muiron Islands, Ningaloo Marine Park, south Pilbara, northwest, southwest, and eastern Exmouth Gulf	Hutchins (1994) Hutchins et al. (1996) McLean et al. (2016) Day et al. (2013) Babcock et al. (2008) Atlas of Living Australia
Epinephelus fuscoguttatus	Brown-marbled grouper	VU	Exmouth Gulf, south Pilbara, Muiron Islands, North West Cape	McLean et al. (2016) Atlas of Living Australia
Epinephelus polyphekadion	Camouflage grouper	VU	Muiron Islands, Exmouth Gulf, south Pilbara northwest Exmouth Gulf	Hutchins et al. (1996) McLean et al. (2016) Atlas of Living Australia
Sardinella lemuru	Bali sardinella	NT	Exmouth Gulf: trawl grounds	Kangas et al. (2007) Atlas of Living Australia
Argyrosomus japonicus	Mulloway	EN	Central Exmouth Gulf	Atlas of Living Australia
Protonibea diacanthus	Blackspotted croaker	NT	Barrow Island	iNaturalist
Pomatomus saltatrix	Bluefish	VU	Ningaloo, Onslow	Atlas of Living Australia
Nemipterus virgatus	Golden threadfin bream	VU	Ningaloo, south Pilbara	Atlas of Living Australia
Scomberomorus commerson	Narrow-barred spanish mackerel	NT	Muiron Islands, Ningaloo Marine Park	Hutchins (1994) Hutchins et al. (1996) Babcock et al. (2008) Atlas of Living Australia
*Thunnus maccoyii**	Southern bluefin tuna	EN	Ningaloo	Atlas of Living Australia
*Thunnus obesus**	Bigeye tuna	VU	Ningaloo	Atlas of Living Australia
*Istiophorus platypterus**	Sailfish	VU	Muiron Islands, Ningaloo, northwest Exmouth Gulf	Hutchins et al. (1996) Atlas of Living Australia
*Makaira nigricans**	Blue marlin	VU		
*Xiphias gladius**	Swordfish	NT		
Mola mola	Ocean sunfish	VU	North West Cape	Horn (2021)

Table 6 continues on next page

Table 6 continued from previous page

*These species are pelagic and known for associates with deeper water (> 100 m depth). While several have been confirmed present within the Ningaloo region and in some cases within Exmouth Gulf, they are unlikely to frequent Exmouth Gulf due to its shallow nature.

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Boat-based recreational fishing effort can be better tracked through licence applications, but effort specifically for Exmouth Gulf is not available. The most recent fisheries survey of state-wide boat-based effort in 2020/21 indicated about 221,000 hours of effort occurred in the Gascoyne Region, equating to 13% of effort in WA (Ryan et al., 2022). Effort was predominantly made up of line fishing, and mostly occurred between April and August (Ryan et al., 2022). Popular boat-based recreational targets in Exmouth Gulf include a variety of emperors (Lethrinids), golden trevally (*Gnathanodon speciosus*), Spanish mackerel (*Scomberomorus commerson*), and stripey snapper (*Lutjanus carponatatus*) (Sumner et al., 2002). Several charter-based fly-fishermen also operate in Exmouth Gulf, predominantly targeting permit (*Trachinotus* spp.), giant trevally (*Caranx ignobilis*), and queenfish (*Scomberoides* spp.).

Commercially, fishes are mainly harvested in Exmouth Gulf by the Exmouth Gulf Beach Seine Fishery operating in the southwestern Gulf. This fishery targets sea mullet (*Mugil cephalus*), western sand whiting (*Sillago schombergkii* and *S. analis*), Perth herring (*Nematalosa vlaminghi*), and yellowfin bream (*Acanthopagrus latus*) using seine and gillnets (Newman et al., 2004). A small percentage of fishes, mainly mullet and whiting, are retained within the EGPMF (0.1 tonnes on average between 2014–2018, < 0.1% of total retained catch) (DPIRD, 2020). However, many fishes are also caught as bycatch and discarded, though reporting is not mandatory within the fishery. Fishery-independent trawl biodiversity surveys undertaken in 2004, 2014 and 2017 found ~35% of the total catch by weight (including prawns) comprised of fishes that were discarded (DPIRD, 2020). Predominant groups caught include lizardfish (Harpodontidae), threadfin bream (*Nemipterus peronei* and *Scolopsis taeniopterus*), goatfish (*Upeneus* spp.), and trumpeter (*Pelates* spp.). Post-release mortality rates of these fish species from trawl fisheries are largely unknown. However, repeated experimental trawls in the same location over subsequent nights in Shark Bay have shown that some fishes were vulnerable to trawl gear, with high depletion rates during the study (Kangas et al., 2007). These more vulnerable groups included some emperors, tuskfish, whiting, goatfish, grunters, and butterfish.

Without repeated studies of fish populations within Exmouth Gulf and robust baseline data, it can be difficult to ascertain the extent of fishing-induced threats on fishes. However, there is evidence that overfishing is occurring or has occurred for some species within the Exmouth-Ningaloo region. Spangled emperors (*Lethrinus nebulosus*) sampled in northern Ningaloo in 2007/2008 (outside of sanctuary zones) were significantly younger than those sampled off the North West Cape in 1989–1991 (Marriott et al., 2011). Spangled emperors sampled in 2007/2008 in the northern Gascoyne region (Ningaloo and Exmouth Gulf) were also generally younger and showed faster growth and smaller maximum sizes compared to the southern Gascoyne region (south of Coral Bay to Shark Bay). All of these factors indicate potential overfishing of spangled emperor in Ningaloo and Exmouth Gulf, although differences in growth rates could also be due to latitudinal effects (Marriott et al., 2011). Potential declines in abundance of spangled emperors have also been noted across Ningaloo Marine Park (Holmes et al., 2017). Thirty years ago, Hutchins et al. (1996) commented on the decline in large individuals of recreationally fished species at the Muiron Islands in 1995 surveys compared to 1975–77 surveys, including coral trouts (*Plectopoma leopardus* and *P. maculatus*), Malabar cod (*Epinephelus malabaricus*), tuskfish (*Choerodon* spp.) and seaperches and emperors (*Lutjanus* spp. and *Lethrinus* spp.). These species were abundant in surveys in the 1970s, including large individuals, but were relatively rare in 1995, with the decline attributed to recreational fishing.

Other threats to fishes in Exmouth Gulf include climate change, habitat destruction or degradation, particularly for species that rely on specific habitats for settlement or nurseries. This includes destruction of seagrass beds, mangroves, and corals including from direct anthropogenic disturbance (e.g., anchor scouring, trawling, shoreline development), cyclones and marine heatwaves (Day et al., 2013; Loneragan et al., 2013; Caputi et al., 2014; Wilson et al., 2016). For example, declines in corallivorous fishes have been noted at Bundegi following declines in coral condition (Holmes et al., 2017). Climate warming trends are also likely to disrupt currents and change larval dispersal patterns, as well as extend geographical ranges of species southwards (e.g., Gajdzik et al., 2021). This could lead to different assemblages of fish species present in Exmouth Gulf in the future.

3.5.4.6. Bonefish

Bonefish was a focus area for the Taskforce due to their importance as a recreational catch and release species. Much of the research on bonefish has occurred in locations such as the Caribbean Sea and South Pacific, with little to no research efforts on bonefish in Exmouth Gulf or surrounding northwest waters. Historical records of bonefish species carry uncertainty due to highly cryptic morphologies and inconsistent nomenclature, but eight species have currently known distributions across the Indo-Pacific region (Wallace, 2015). Off the northwest coast of WA, *Albula oligolepis* is the most likely occurring species based on distribution and belongs to the *A. argentea* species complex alongside *A. virgata* (Hidaka et al., 2008, Wallace, 2015) (Figure 47). Collections of *Albula* from Exmouth Gulf in October 1984 were used to discern between the two cryptic species (Colborn et al., 2001), which is the only known published record from Exmouth Gulf. This record details nine specimens caught in the 'shallows' of Exmouth Gulf by hook and line.

Anecdotal information from local fly-fishing companies operating in Exmouth Gulf and recreational fishers suggest bonefish do not commonly occur in Exmouth Gulf, at least not in abundances high enough to be regularly observed or caught (B. Wolf, J. Shales, M. Tropiano, G. Jackson, pers. comms.). Instead, they are fished around the Muiron Islands and around Ningaloo Reef where they inhabit large open sandy areas.

While there was agreement that the shallow flats in Exmouth Gulf would seem like ideal habitat for bonefish, these areas are targeted for other prized species, such as permit, giant trevally and queenfish.

In general, bonefish are often observed over soft bottom shallow (< 10 m) habitats, such as sandflats, mudflats and seagrass beds, where they largely feed on small crustaceans, molluscs, polychaetes and some smaller fishes (e.g., Donovan et al., 2015, Fishes of Australia). Bonefish form large spawning aggregations and move offshore to spawn (e.g., Lombardo et al., 2020, Fishes of Australia).

Most bonefish species are listed as data deficient by the IUCN, including *A. oligolepis*, *A. argentea* and *A. virgata* (IUCN, 2025). However, *A. vulpes* is listed as Near Threatened and *A. glossodonta* as Vulnerable due to overfishing and habitat loss (Adams et al., 2012a and Adams et al., 2012b).

Figure 47: Smallscale bonefish, *Albula oligolepis* (top), and Pacific bonefish, *Albula argentea* (bottom). Sourced from Fishes of Australia.

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3.5.4.7. Syngnathids and Solenostomids

Syngnathids (sea horses and pipefishes) and solenostomids (ghost pipefishes) are all listed as 'Marine' (marine species, habitat, or place recognized as a matter of national environmental significance) by the EPBC Act and are protected species within Australia. Many species have been reported within Exmouth Gulf or off the North West Cape which are listed in Table 7. However, many taxonomic changes and updates to distributions within this group have occurred in the last decade, and many species look morphologically similar and can be difficult to identify. Table 7 should be considered as a preliminary list which requires validation and further surveys. Only species with records within Exmouth Gulf or North West Cape which are currently known to occur within WA are listed.

Syngnathids and solenostomids were listed under the EPBC Act in 2001 following recommendations by Convention on International Trade in Endangered Species of Wild Fauna and Flora. This was due to their demand in international trade markets combined with the more vulnerable life-history characteristics compared to most other fishes (e.g., low reproductive potential). However, these families are under limited threat within Australia (Pogonoski et al., 2002). They occupy a range of habitats within Exmouth Gulf including intertidal pools, seagrasses, algal beds, corals, sponge gardens, and even cyanobacterial mats (Hutchins, 1994; Hutchins et al., 1996; Penrose, 2011). From plankton tows in 1997–1998, syngnathid larvae showed high spatial and temporal specificity compared to most other larval fishes, with greater abundance at inshore survey sites within northwestern Exmouth Gulf compared to further offshore of North West Cape or in the Pilbara (Sampey et al., 2004). Syngnathid larvae were most abundant in November and December.

As protected species, syngnathids and solenostomids are not targeted by any fishery in Exmouth Gulf or the surrounding region, but small numbers are caught as bycatch within the EGPMF. Kangas et al. (2006) reported an average of one individual caught per night across the fishery, which were generally deceased at the time of capture given their fragility. More recent reports show variable catches ranging from 0 to 71 individuals annually over the last five years (Gaughan & Santoro, 2019; Gaughan & Santoro, 2020, 2021; Newman et al., 2021; Newman et al., 2023a). The trawl fishery grounds do not significantly overlap with seagrass and algal beds which are thought to be major habitats for sea horses and pipefish. Anecdotal reports also suggest that most of these animals may pass through the trawl nets due to their small size, limiting catches (Kangas et al., 2015). The risk rating to syngnathids and solenostomids in the EGPMF is considered 'negligible' (Kangas et al., 2015).

Given their small home ranges and habitat specificity (Pogonoski et al., 2002), other major risks to these species include habitat destruction or degradation, including in mangrove, seagrass, and soft and hard coral areas.

Sea horse. Nick Thake

Table 7: List of Syngnathids and solenostomids that have been reported within Exmouth Gulf, according to Hutchins (1994), Hutchins et al. (1996), Penrose (2011), Kangas et al. (2015), and citizen science records submitted to Atlas of Living Australia (ALA). Status abbreviations: VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated.

Scientific name	Common name	Global IUCN status	Status under EPBC Act	Source
Hippocampus angustus	Western spiny seahorse	LC	Marine	Kangas et al. (2015)
Hippocampus planifrons	Flat-faced seahorse	LC	Marine	Kangas et al. (2015)
Hippocampus zebra	Zebra seahorse	DD	Marine	Kangas et al. (2015)
Hippocampus kuda	Common seahorse	VU	Marine	ALA
Halicampus brocki	Tasselled pipefish	LC	Marine	ALA
Halicampus spinirostris	Spinysnout pipefish	LC	Marine	Hutchins (1994)
Haliichthys taeniophorus	Ribboned pipehorse	LC	Marine	ALA
Hippichthys penicillus	Beady pipefish	LC	Marine	Penrose (2011)
Dunckerocampus pessuliferus	Yellowbanded pipefish	LC	Marine	ALA
Micrognathus micronotopterus	Tidepool pipefish	LC	Marine	Hutchins (1994) Hutchins et al. (1996)
Phoxocampus belcheri	Black rock pipefish	LC	Marine	ALA
Choeroichthys brachysoma	Pacific shortbody pipefish	LC	Marine	Hutchins (1994) Hutchins et al. (1996)
Choeroichthys latispinosus	Muiron pipefish	DD	Marine	Hutchins (1994)
Choeroichthys suillus	Pigsnout pipefish	LC	Marine	ALA
Trachyrhamphus longirostris	Straightstick pipefish	LC	Marine	ALA
Bulbonaricus brauni	Braun's pughead pipefish	LC	Marine	Hutchins (1994)
Solenostomus cyanopterus	Robust ghostpipefish	LC	Marine	ALA
Solenostomus paradoxus	Ornate ghostpipefish	LC	Marine	ALA
Solenostomus paegnius	Roughsnout ghostpipefish	NE	Marine	ALA

Figure 48: Sea horses, pipefishes and ghost pipefishes can all be found in Exmouth Gulf. Image: Nick Thake

3.5.5. Elasmobranchs

3.5.5.1. Rays

3.5.5.1.1 Biodiversity

Up to approximately 34 ray species are potentially present within the Exmouth Gulf and the Ningaloo area based on published spatial ranges and depth distributions of Australian species (Kyne et al., 2021). These species are listed in Table 8. Of these species, 20 are listed as Vulnerable, Endangered, or Critically Endangered globally by the IUCN though, for most, their populations within Australia are thought to be doing better than the global population. For example, of the 20 species globally listed as Vulnerable or worse, the 2021 Action Plan for Australian Sharks and Rays (Kyne et al., 2021), which evaluated the Australian population status of each species according to IUCN criteria, lists four with a Vulnerable or worse status within Australia, with another five species considered Near Threatened (Table 8). Overall, very few species of ray have had directed ecological or biological research undertaken within the Exmouth region or even on the national or global level. Much of the basic information necessary to assess their ecological importance, population size, and level of threat within Exmouth Gulf is not available. Here we present some general information on rays within Exmouth Gulf, including habitat use, ecological roles, and pertinent threats. Subsequently, we provide more detailed information on three groups of rays common in the region which are globally threatened (e.g., wedgefishes and giant guitarfishes) and/or of high interest to the tourism industry (manta rays). Information on sawfishes is compiled and thoroughly discussed in Section 3.5.5.2.

Table 8: Ray species known or potentially present within Exmouth Gulf, where species' spatial and depth distributions overlap the Exmouth Gulf as determined by Kyne et al. (2021) and the IUCN, or which occur in other published records for the region. Species with confirmed occurrence records within Exmouth Gulf are noted by '**', and species with confirmed records in the wider Ningaloo or Southern Pilbara regions are noted by '*'. Species are listed along with the habitats they are likely to occupy within Exmouth Gulf, and their likely frequency of occurrence, although for many species this is not well known. Their conservation listing statuses according to the IUCN (global status) and the 2021 Australian Action Plan for Sharks and Rays (Kyne et al., 2021), which assessed threatened statuses of each species within their Australian range according to IUCN listing criteria, and their national status under the EPBC Act. Status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated. Occurrence records compiled from a range of sources including Bateman et al. (2024), Kangas et al. (2007), Stevens et al. (2009), Atlas of Living Australia (submissions with photos only), iNaturalist (submissions with photos only), K. Lear, pers. comm.

Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
*Pristis zijsron***	Green sawfish	Juveniles: shallow mudflats and mangrove creeks Adults: offshore benthic	Rare (juveniles and adults)	CR	CR	VU; Migratory
*Pristis pristis***	Freshwater sawfish	Offshore benthic habitats	Rare (adults)	CR	CR	VU; Migratory
*Anoxypristis cuspidata**	Narrow sawfish	Offshore benthic	Rare (adults)	CR	VU	Migratory (threatened assessment due Apr 2025)
*Rhina ancylostoma***	Shark ray	Nearshore and offshore benthopelagic	Rare (adults)	CR	NT	
*Rhynchobatus australiae***	Bottlenose wedgefish	Nearshore and offshore soft-bottomed	Regular (adults, juveniles rare)	CR	NT	
*Rhynchobatus palpebratus***	Eyebrow wedgefish	Turbid, nearshore and likely offshore benthic soft-bottom	Rare (adults)	NT	NT	
*Glaucostegus typus***	Giant guitarfish	Benthic, soft-bottom including mudflats and near mangroves	Common (juveniles and adults)	CR	LC	
*Aptychotrema vincentiana**	Western shovelnose ray	Offshore benthic	Rare	LC	LC	
*Narcinops westraliensis**	Banded numbfish	Offshore benthic, especially near reefs	Rare (juveniles and adults)	LC	LC	
*Hypnos monopterygius***	Coffin ray	Offshore benthic, especially near reefs	Rare (juveniles and adults)	LC	LC	

Table 8 continues on next page

Table 8 continued from previous page

Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
Tetronarce nobiliana	Great torpedo ray	Offshore benthic	Rare	LC	LC	
Bathytoshia brevicaudata	Smooth stingray	Offshore benthic	Rare	LC	LC	
Bathytoshia lata	Brown stingray	Offshore benthic	Rare	VU	LC	
*Pateobatis jenkinsii***	Jenkins whipray	Nearshore and offshore benthic, especially near reefs	Rare (juveniles and adults)	EN	LC	
*Pateobatis fai***	Pink whipray	Nearshore soft-bottom, especially near mangroves and mudflats	Common (juveniles and adults)	VU	LC	
*Maculobatis astra***	Blackspotted whipray	Nearshore soft-bottom, especially near mangroves and mudflats	Common (juveniles and adults)	NT	LC	
*Himantura australis***	Australian whipray	Nearshore soft-bottom, especially near mangroves and mudflats	Common (juveniles and adults)	LC	LC	
Himantura leoparda	Leopard whipray	Nearshore soft-bottom, especially near mangroves and mudflats	Unconfirmed	EN	LC	
Pteroplatytrygon violacea	Pelagic stingray	Offshore pelagic	Rare	LC	LC	
*Urogymnus granulatus**	Mangrove whipray	Nearshore soft-bottom habitats especially near mangroves and mudflats	Rare (juveniles and adults)	EN	LC	
*Urogymnus asperrimus***	Porcupine ray	Nearshore soft-bottom habitats especially near mangroves and mudflats	Regular (juveniles and adults)	EN	LC	
*Pastinachus ater***	Cowtail ray	Nearshore soft-bottom habitats especially near mangroves and mudflats	Common (juveniles and adults)	VU	LC	
*Taeniurops meyeni***	Blotched fantail ray	Nearshore soft-bottom habitats especially near reefs	Rare (juveniles and adults)	VU	LC	

Table 8 continues on next page

Table 8 continued from previous page

Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
*Taeniura lymma***	Blue-spotted lagoon ray	Nearshore habitats	Common (juveniles and adults)	LC	LC	
*Neotrygon australiae***	Australian blue-spotted maskray	Nearshore habitats especially near mangroves and reefs	Regular (juveniles and adults)	NT	LC	
*Neotrygon leylandii***	Painted maskray	Nearshore habitats especially near mangroves and reefs	Regular (juveniles and adults)	LC	LC	
*Neotrygon ningalooensis***	Ningaloo maskray	Nearshore habitats especially near mangroves and reefs	Regular (juveniles and adults)	DD	LC	
*Gymnura australis***	Australian butterfly ray	Offshore benthic habitats	Regular	LC	LC	
*Aetobatus ocellatus***	Spotted eagle ray	Nearshore and offshore pelagic – especially near mangroves	Common (juveniles and adults)	EN	LC	
*Aetomylaeus vespertilio***	Ornate eagle ray	Nearshore and offshore habitats	Rare (adults)	CR	NT	
*Mobula alfredi***	Reef manta	Offshore pelagic, especially near reefs	Regular (adults)	VU	LC	Migratory
*Mobula birostris***	Oceanic manta	Offshore pelagic	Rare (adults)	EN	EN	Migratory
*Mobula thurstoni**	Bentfin devilray	Offshore pelagic	Rare	EN	NT	Migratory
*Mobula eregoodoo**	Longhorned pygmy devilray	Offshore pelagic	Rare	EN	LC	Migratory

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

3.5.5.1.2 Habitat use

The most prevalent and often sighted group of rays in the region are the stingrays (family Dasyatidae), of which a variety of species are common in nearshore waters. Stingrays tend to occupy benthic habitats, especially soft-bottom habitats near to mangroves, mudflats, and reefs. Many species will use the extreme shallows as nursery areas and slowly move into slightly deeper waters as larger adults (e.g., Cerutti-Pereyra et al., 2014). However, many large rays can also be found in shallow areas, especially at high tide when they come onto shallow sand and mud flats to feed (K. Lear, pers. comm.). Some of the most common species observed in nearshore areas of Exmouth Gulf include Australian whiprays (*Himantura australis*), cowtail rays (*Pastinachus ater*), blackspotted whiprays (*Maculabatis astra*), pink whiprays (*Pateobatis fai*), and bluespotted lagoon rays (*Taeniura lymma*) (K. Lear, pers. comm.). In addition to these Dasyatid stingrays, spotted eagle rays (*Aetobatus ocellatus*) and giant guitarfish (*Glaucostegus typus*) are also some of the most sighted ray species in nearshore areas throughout Exmouth Gulf (K. Lear, pers. comm.).

A number of pelagic rays and deeper water benthic rays also inhabit Exmouth Gulf (see Table 8). Pelagic species including manta rays, other mobulid rays, and eagle rays can likely be found throughout Exmouth Gulf. Several benthic ray species with a preference for deeper waters (e.g., butterfly rays – *Gymnura australis*, painted maskrays – *Neotrygon leylandi*, western shovelnose rays – *Aptychotrema vincentiana*) are likely present throughout the deeper benthic habitats of Exmouth Gulf. However, these areas are not well surveyed for elasmobranchs and very little data exists on the diversity and abundance of rays in these habitats.

3.5.5.1.3 Ecological importance

The rays present within Exmouth Gulf are highly diverse, ranging from stingrays to large shark-like rays to electric rays, and occupy a range of ecological niches. Most rays show some similarities in ecology, such as acting as mesopredators within trophic systems by feeding on benthic invertebrates or small fishes and, in turn, being predated upon by large sharks or rays (e.g., O'Shea et al., 2013). Rays, including those present in the Exmouth/Ningaloo region, also act as crucial ecosystem engineers through bioturbation. Many rays feed on animals buried in the sediment, and in doing so create 'feeding pits' that unearth new sediment, expose prey to other species, and help to exchange nutrients and other biological matter through sediment turnover. A study on Ningaloo Reef estimated that stingrays in the region are likely to rework nearly 50% of available soft sediments each year (O'Shea et al., 2011).

3.5.5.1.4 Threats and pressures

Like most elasmobranchs, many species of ray (especially those that attain large sizes at maturity) are slow growing, relatively late to mature, and have few offspring, which makes them vulnerable to and slow to recover from population declines. Overexploitation through high commercial fishing pressure throughout much of the Indian and Pacific Oceans is the reason that many ray species found in northwest Australia are currently threatened globally and in active decline. However, commercial fishing pressure for rays within Australian waters are generally low, with no targeted ray fisheries in the region. As a result, Australia, and northwestern Australia in particular, is often considered to be a 'lifeboat' for many threatened ray species, where populations in Australia are often the last robust populations of a species present globally (Kyne et al., 2021). This is particularly true for sawfishes, wedgefishes, and giant guitarfishes (Moore, 2017; Kyne et al., 2020; Yan et al., 2021), which together are considered the three most threatened marine fish families globally.

Threats to most ray species in Exmouth Gulf include fishing pressure, both commercial through the EGPMF, and recreational. Shoreline development and nearshore habitat destruction may also threaten this group. Apart from sawfishes (see Section 3.5.5.2), no rays currently have threatened statuses under the EPBC Act, and as a result, species-specific reporting of most rays is not mandated within commercial fisheries. The EGPMF employs bycatch reduction devices (BRDs) in their trawls, which in similar fisheries (e.g., Northern Prawn Fishery; Brewer et al., 2006; Campbell et al., 2020) has been shown to significantly reduce bycatch of large rays (except for sawfishes which get snagged by their toothed rostra). However, small ray species or juvenile rays are still caught as bycatch within the EGPMF. Rays appear to make up only a small portion of the reported bycatch in the fishery. For example, rays only made up 0.2% of the catch by weight in fishery-independent surveys within the EGPMF from 2014–2017 (DPIRD, 2020), though specific numbers and species are unknown. While very limited data on bycatch species are available, some of the more commonly caught rays in the EGPMF may include Australian butterfly rays (DPIRD, 2020), and painted maskrays (Kangas et al., 2015).

Levels of recreational fishing for rays within Exmouth Gulf are unknown. Most rays are not often retained for eating, but many fishers value ray meat as bait for other species (e.g., sharks). A few species are known to have good meat for eating within a select fishing community, including wedgefishes and giant guitarfishes (aka shovelnose) (K. Lear, pers. comm.). As most rays lack pointy fins, they are not readily captured in gillnets, and therefore recreational line fishing (baited lines rather than lures) is the most common method for capturing rays.

3.5.5.1.5 Wedgefishes

Three species of wedgefish (family Rhinidae) occur in Australian waters (Figure 49), all of which are found within Exmouth Gulf (Bateman et al., 2024): bottlenose wedgefish (*Rhynchobatus australiae*), eyebrow wedgefish (*Rhynchobatus palpebratus*), and shark rays (*Rhina ancylostoma*). Globally, bottlenose wedgefish and shark rays have a wide Indo-Pacific distribution. Both are considered Critically Endangered by the IUCN, and the Shark Action Plan considers both to be near threatened within Australian waters (Kyne et al., 2021). Eyebrow wedgefish are distributed only within Australia and Papua New Guinea, and likely in Indonesia. The majority of their distribution lies within Australian waters where they are not retained within commercial fisheries, thus are not as imperilled as the other two species. They are considered Near Threatened both globally by the IUCN and within Australia by the Shark Action Plan (Kyne et al., 2021).

In Exmouth Gulf, bottlenose wedgefish are the most observed wedgefish species. Adult females (between approximately 1.5 and 3 m total length) are regularly sighted in nearshore waters, especially on sandy-bottom habitats near the shoreline or near mangroves (Bateman et al., 2024). Whether females are using nearshore habitats as refuges during their non-reproductive years or as warmer 'maternity wards' during gestation to increase gestation rates is unknown at present. Tracking data from wedgefish on Ningaloo Reef indicates that individuals appear to remain within a relatively small area for long periods (up to a year; Lear et al., 2024c). Extended tracking data has shown that some individuals also occasionally move longer distances, including between Ningaloo Reef and the North West Cape (R. Bateman-John, pers. comm.). Further acoustic tracking of adult female wedgefish within Exmouth Gulf is underway, but data are not yet available.

On the other hand, male and juvenile bottlenose wedgefish are rarely sighted in nearshore areas, (Bateman et al., 2024). Anecdotal records of captures of juvenile bottlenose wedgefish (< 1 m total length) in the EGPMF support this hypothesis within Exmouth Gulf (K. Lear, pers. comm.). In fact, small bottlenose wedgefish (mean size 65 cm total length) make up some of the most common ray bycatch in other trawl fisheries within northwestern Australia even with the use of BRDs (e.g., Northern Prawn Fishery; Campbell et al., 2020). The lack of species-specific bycatch reporting in the EGPMF makes it difficult to determine whether this is also the case within Exmouth Gulf or what level of threat the fishery may exert on this species. Bottlenose wedgefish are also the most regularly caught of the three wedgefishes recreationally, predominantly by shore-based fishers on baited lines (R. Bateman-John, pers. comm.). Most wedgefish are reported released, though wedgefish (or "white-spotted guitarfish," as known by most fishers) are also recognised within the recreational fishing community for having high-quality meat for eating (K. Lear, pers. comm.). Additionally, wedgefish have a very high fight response when caught on lines and are occasionally targeted by sport fishers within WA for the fight and skill required with the capture.

Shark rays are the next most sighted wedgefish species. Sightings are relatively rare (e.g., < 40 sightings reported over the last 10 years; Bateman et al., 2024). However, compared to other regions of Australia this rate of sighting is very high, suggesting that Exmouth Gulf and the Ningaloo region are a hotspot for this species. Shark rays are almost exclusively sighted as adults (both males and females). They are not regularly captured by recreational fishers and are not known to be regularly captured in the EGPMF.

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Finally, eyebrow wedgefish are the least commonly reported wedgefish within Exmouth Gulf. This species has not had a confirmed sighting within Exmouth Gulf itself except for a paratype caught in 1954 used in the species description (Compagno & Last, 2008; Bateman et al., 2024). However, four individuals have been captured and acoustically tracked in the Ashburton River area directly to the northeast of Exmouth Gulf. Tracking data from these individuals showed that some repeatedly returned to the Ashburton area for over a year, while others left within a month and were not detected again (K. Lear, pers. comm). Captures and sightings of this species within the Pilbara region and beyond are generally rare. However, the location of sightings suggests that this species may prefer highly turbid waters which would reduce the chance of sightings via snorkel or boating (Bateman et al., 2024).

3.5.5.1.6 Giant guitarfish

Giant guitarfish (*Glaucostegus typus*), also called giant shovelnose rays (Figure 49), are the only member of the giant guitarfish family (Glaucostegidae) found within Australia. Despite their globally Critically Endangered status, they are extremely common throughout Exmouth Gulf, as well as in surrounding areas (Bateman et al., 2024). Neonates, juveniles, and adults are all found within Exmouth Gulf. Large aggregations of juveniles can be repeatedly found in areas such as Giralia Bay, Bay of Rest, and Bundegi mangroves (Penrose, 2011; Bateman et al., 2024), suggesting the presence of regularly used pupping and nursery habitats. In Exmouth Gulf, neonates and juveniles of this species are most commonly found in nearshore areas including the extreme shallows, on soft-bottom habitats close to mudflats and mangroves. Tracking data shows that small juveniles remain in shallow habitats for most of their time (R. Bateman-John, pers. comm.). Adults can be found in extremely shallow areas as well but are known to also extend their range into deeper areas up to 100 m depth (Kyne et al., 2021). They are occasionally caught by shore-based recreational fishers (R. Bateman-John, pers. comm.). Juveniles may also be caught by the EGPMF, but their predominantly shallow distribution may limit this, and BRDs in the fishery likely exclude the capture of large adults. As such, they are not likely to be under threat within Exmouth Gulf, but it is notable that northern Australia, including Exmouth Gulf, offers a globally important refuge for this otherwise highly threatened species (Bateman et al., 2024).

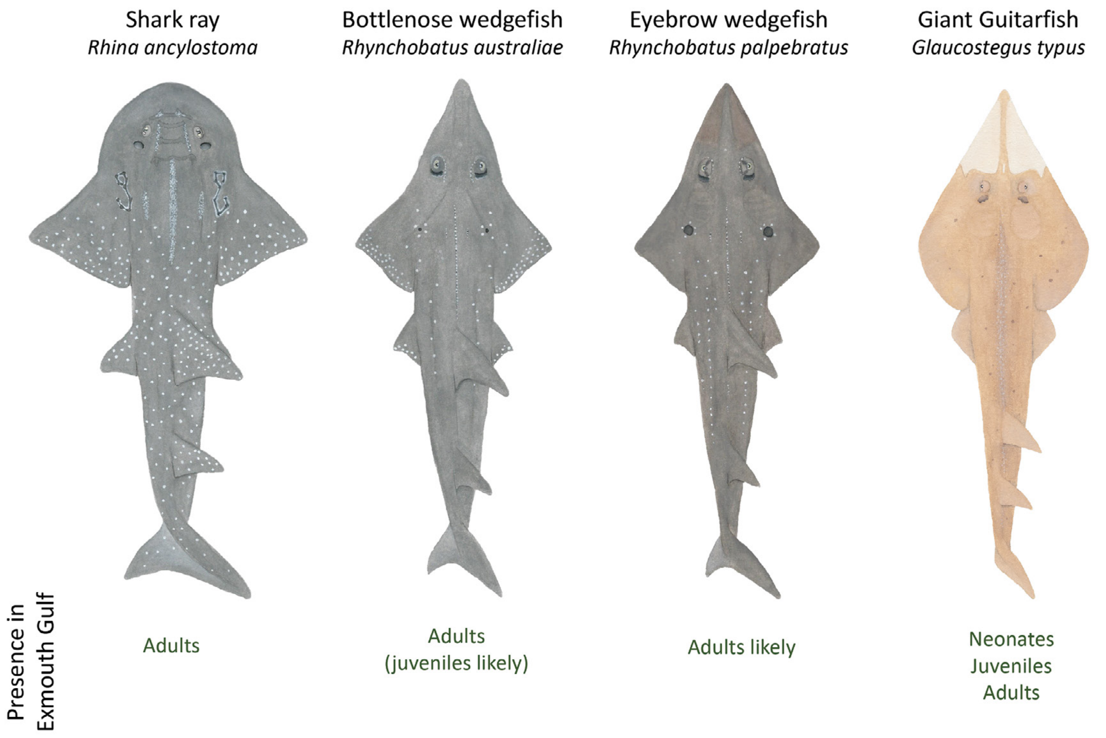

Figure 49: Wedgefish and giant guitarfish species present within Exmouth Gulf, including which life stages are likely to be present based on sightings data and anecdotal records. Illustrations: Karissa Lear

3.5.5.1.7 Manta rays

Manta rays are the most important ray species for the ecotourism industry in the Exmouth and Ningaloo regions. Two species of manta ray are found within Exmouth Gulf: oceanic manta rays (*Mobula birostris*) and reef manta rays (*Mobula alfredi*). Oceanic manta rays are considered Endangered both globally by the IUCN and within Australia by the Shark Action Plan (Kyne et al., 2021). This species is rare throughout the region and within Exmouth Gulf. However, sightings of this species feeding, barrel rolling, and cruising have been confirmed at least near the Exmouth Marina and east of Qualing Pool (e.g., Figure 50; A. Armstrong, pers. comm.). Reef manta rays are listed globally as Vulnerable by the IUCN, and as Least Concern within Australian waters (Kyne et al., 2021). They can be found in Exmouth Gulf all year round, but sightings peak in August through to October (Armstrong et al., 2020). Manta rays are filter feeders and are most often observed feeding on plankton within tide lines that run parallel to the shore in the northwestern Gulf, especially between the Exmouth Marina and the Navy Pier (Sprogis & Parra, 2022; Sprogis & Waddell, 2022; Irvine et al., 2025a). However, survey effort has also been concentrated in this area, and it is likely that manta rays are utilising larger areas of Exmouth Gulf. Cleaning stations for reef manta rays have also been identified at reefs along the western edge of Exmouth Gulf between Exmouth Marina and Bundegi (A. Armstrong, pers. comm.). Reef manta rays are mostly sighted individually or in small groups, but large feeding aggregations of over 100 individuals have been observed within highly productive areas and time periods (e.g., see Figure 50; A. Armstrong, pers. comm.). Courtship behaviour has been documented during larger aggregations, and while pupping areas for manta rays are unknown, the presence of pregnant rays within the region suggests pupping may occur nearby (A. Armstrong, pers. comm.).

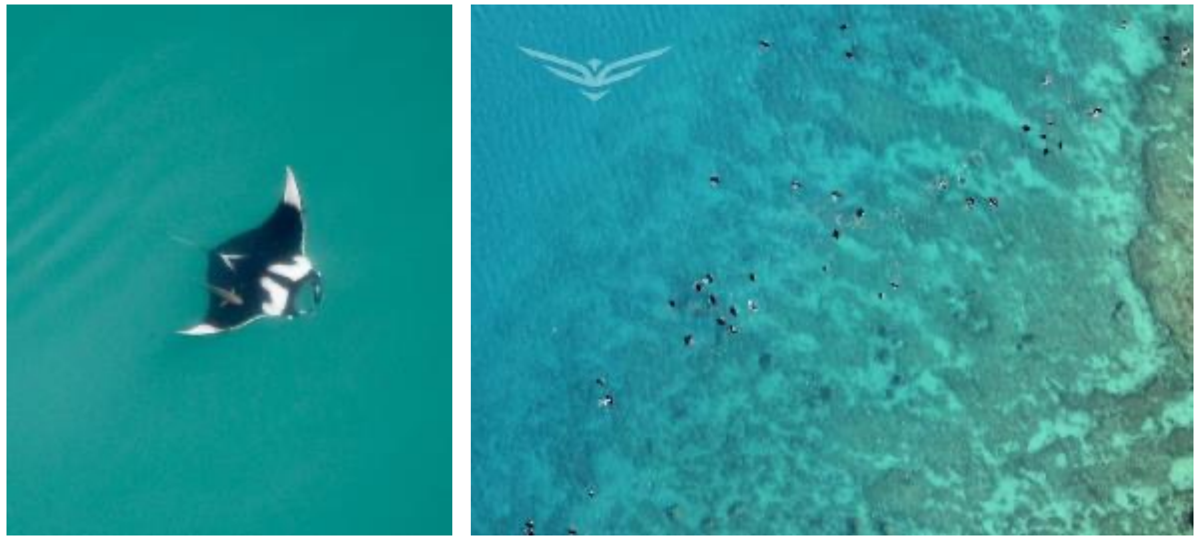

Figure 50: Example of manta ray observations in Exmouth Gulf. Left: confirmed sighting of an oceanic manta ray (*Mobula birostris*) in Exmouth Gulf east of Qualing Pool in 2024. Right: A feeding aggregation of reef manta rays (*Mobula alfredi*) sighted at Bundegi Second Reef in September 2017. Images: Birds Eye View, supplied here with permission.

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Manta rays are highly mobile and often travel long distances. For example, reef manta rays tagged in Exmouth Gulf have been recorded travelling to Muiron Islands, Ningaloo Reef, Coral Bay, Shark Bay, and Pilbara Islands (Armstrong et al., 2020). Photo ID studies have also confirmed resighting of individuals between Exmouth Gulf, Ningaloo Reef, Coral Bay, and Shark Bay (Armstrong et al., 2020) (see Figure 51). This includes confirmed sightings in Exmouth Gulf of individuals known to the tourism industries in Coral Bay and Ningaloo Reef. For example, one individual ("Elle") has been seasonally resident in Coral Bay for the past 19 years and plays a vital role in the Coral Bay manta tourism industry. This individual has been documented using Exmouth Gulf as a feeding area (A. Armstrong, pers. comm.). Even without consistent survey effort for mantas within Exmouth Gulf, individual mantas have been observed consistently returning to Exmouth Gulf to feed across multiple years (A. Armstrong, pers. comm.). Therefore, while manta-directed tourism is not common within Exmouth Gulf itself, Exmouth Gulf appears to provide crucial feeding habitat for mantas travelling to or through several areas essential to the manta tourism industry.

The biggest threat to manta rays within Exmouth Gulf is boat strike. Tagging studies have demonstrated that reef manta rays, including those within Exmouth Gulf, tend to stay within 10–20 m of the surface (Armstrong et al., 2020), including some tagged individuals spending on average 60% of their time within 5 m of the surface within Exmouth Gulf (R. Newsome, pers. comm.). As such, they are extremely vulnerable to vessel strike, and many instances of boat strike injuries on manta rays have been evident within the wider Ningaloo region. For example, over 13% of reef manta rays in the photo ID database at Ningaloo Reef show scarring patterns consistent with boat strike injuries

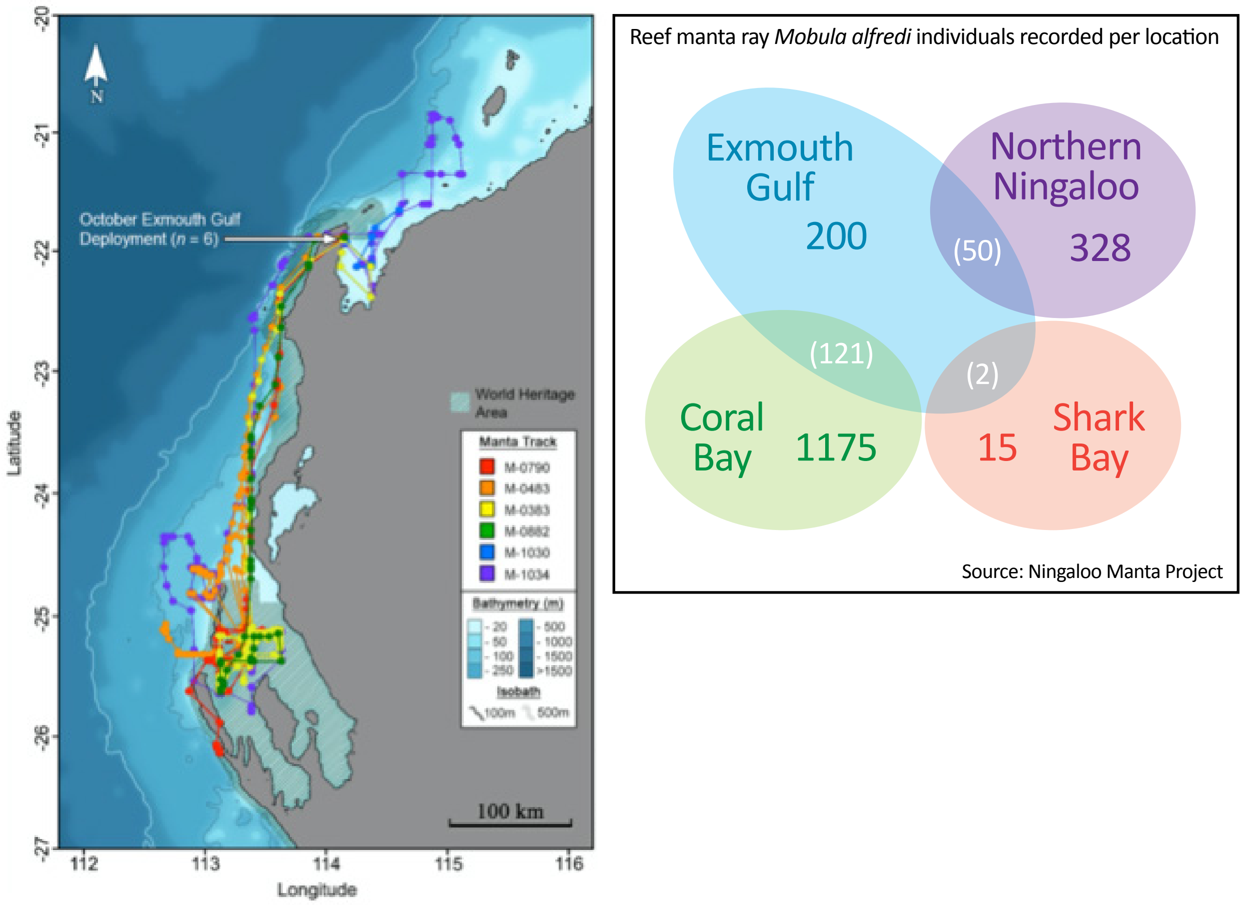


Figure 51: Evidence of connectivity of reef manta rays (*Mobula alfredi*) between Exmouth Gulf and surrounding areas. Left: satellite tracks of six manta rays tagged within Exmouth Gulf in 2016; originally Fig. 3 from Armstrong et al., 2020, supplied here with permission. Above: overlap in photo-identified individuals between Exmouth Gulf, Ningaloo Reef, Coral Bay, and Shark Bay. Supplied by Amelia Armstrong, reprinted here with permission.

(McGregor et al., 2019). Increases in vessel traffic within Exmouth Gulf, including those associated with developments and increased shipping in the region, are therefore of concern to manta rays. This is particularly true within the northwestern Gulf where mantas are most often observed, and where vessel traffic is most dense (Irvine et al., 2025a).

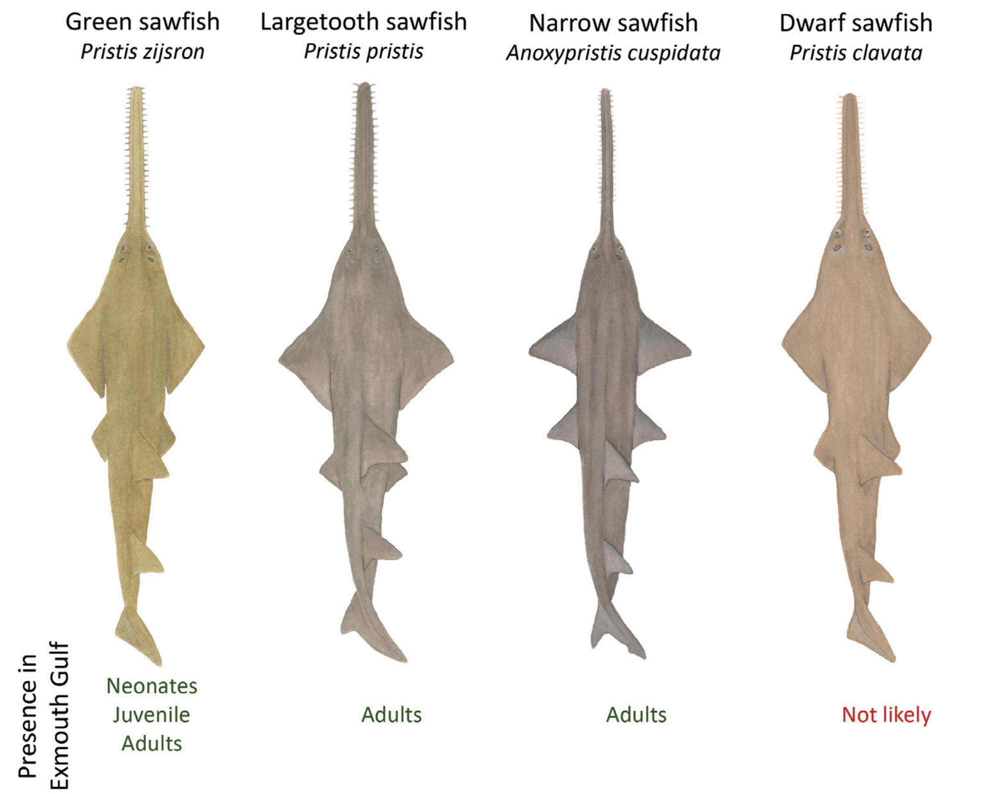
Other threats to mantas within Exmouth Gulf include pollution, entanglement in fishing gear, degradation of habitats, increased turbidity from dredging activities, and changing ocean productivity and alteration of currents resulting from climate change. As filter feeders, manta rays are vulnerable to ingesting marine pollutants including organics, heavy metals, and plastics (Stewart et al., 2018). In particular, plastic pollution offers a distinct threat to manta rays, with data suggesting that filter feeding manta rays likely ingest on average more than two pieces of plastic per hour within Exmouth Gulf (King, 2019). Additionally, while manta rays are not targeted or often caught by commercial or recreational fisheries, multiple instances of manta rays entangled in fishing gear (e.g., trailing lures, fishing lines, hooks) have been observed within Exmouth Gulf (A. Armstrong, pers. comm.). Entanglements pose a risk to the health and mobility of rays. Activities such as coastal developments and dredging which may degrade habitats and increase turbidity in feeding areas also pose a threat to manta rays. Finally, as mantas rely heavily on productive currents for feeding opportunities, changes to current dynamics, plankton productivity levels, and sea temperatures resulting from climate change could exert serious pressure on manta rays in the future (Stewart et al., 2018).

3.5.5.2. Sawfish

3.5.5.2.1 Biodiversity

Four of the world's five species of sawfish occur in Australian waters (Figure 52), and all are threatened and listed as Critically Endangered globally by the IUCN (IUCN, 2025). The vast majority of sawfish sightings within Exmouth Gulf are of green sawfish, *Pristis zijsron*, which are also listed as Vulnerable under the EPBC Act. Green sawfish use Exmouth Gulf and the surrounding coastline as nursery and pupping areas, as well as adult habitat (Bateman et al., 2024). Conversely, the largetooth sawfish, *Pristis pristis* (listed as Vulnerable under the EPBC Act), and narrow sawfish, *Anoxypristis cuspidata* (listed as Migratory under the EPBC Act), are much rarer throughout the region and appear to only use the area as occasional adult habitat, with no sightings of juveniles or neonates within Exmouth Gulf (Bateman et al., 2024). The dwarf sawfish, *Pristis clavata*, has not been sighted south of Port Hedland (Bateman et al., 2024), and is unlikely to occur within Exmouth Gulf. The following synthesis therefore focuses on green sawfish, and mostly draws upon knowledge specific to northwest Australia.

Figure 52: Australia's four sawfish species, including which species and life stages are likely to be present within Exmouth Gulf. Illustrations: Karissa Lear



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3.5.5.2.2 Spatial and temporal distribution

Green sawfish were historically distributed across the Indo-Pacific region (Harry et al., 2022). This range has significantly reduced over time, including around Australia, with northwestern Australia believed to be one of the last strongholds for productive and viable populations in the world (Morgan et al., 2011; Morgan et al., 2015; Harry et al., 2022; Lear et al., 2023; Bateman et al., 2024). The documented distribution of green sawfish in WA waters is from Shark Bay to WA/Northern Territory border (Harry et al., 2022; Bateman et al., 2024). To date, the Ashburton River mouth, near Onslow, has been identified as one of the most consistently used nursery sites known for green sawfish globally (Morgan et al., 2015; Morgan et al., 2017; Lear et al., 2023), and is the most studied. Within Exmouth Gulf specifically, green sawfish have been recorded from the Exmouth Navy Pier on the western margin, all the way south and around to Urala on the eastern margin (Bateman et al., 2024). They are likely to occur throughout the entire Exmouth Gulf (Figure 53).

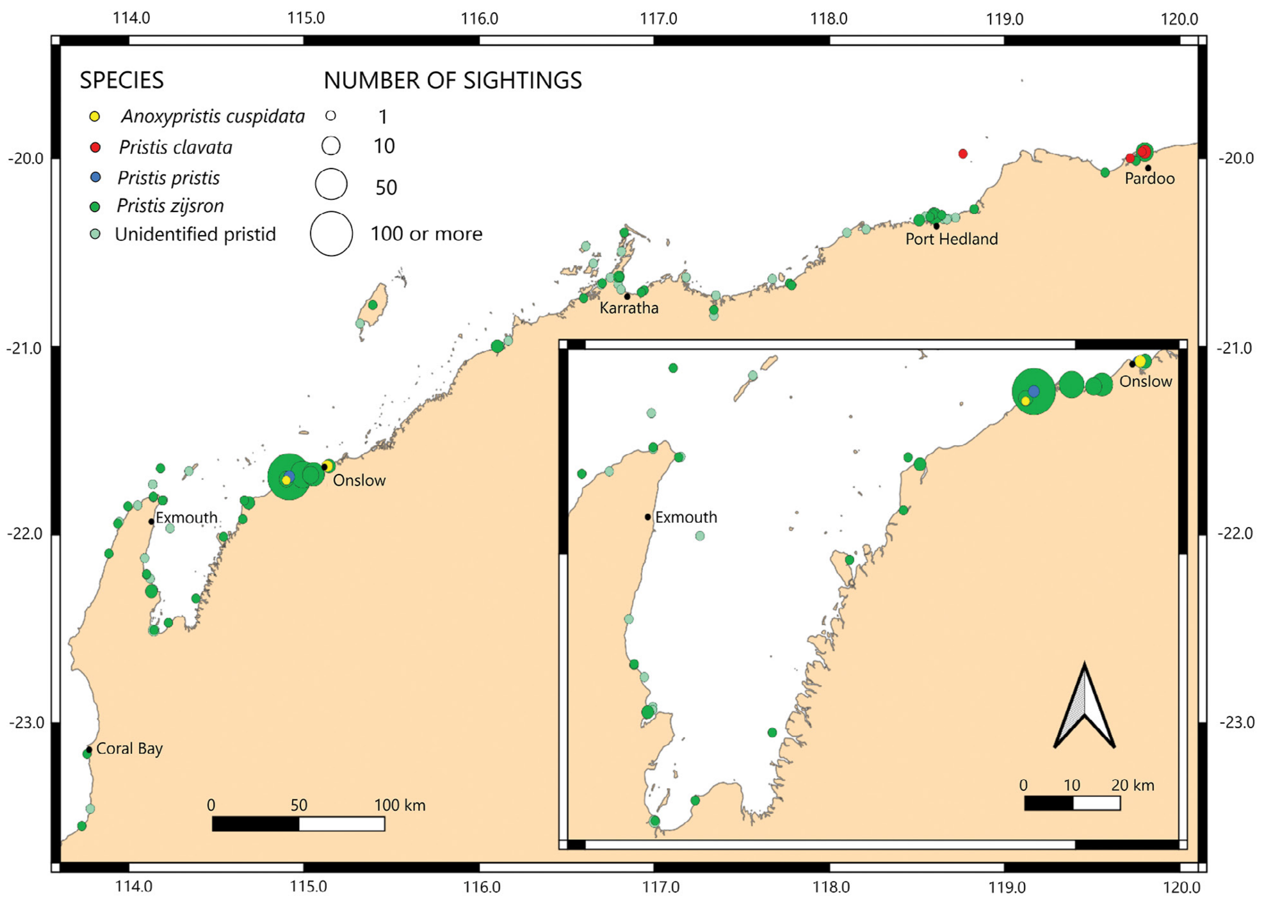

Figure 53: Sightings of sawfish reported in the Pilbara region, with inset map showing Exmouth Gulf specifically. Points are coloured according to species and sized by the number of sightings in each spot. Original figure: Bateman et al., 2024 Fig. 5A.

Compared to other sawfish species that sometimes use freshwater and brackish environments, green sawfish are a fully marine species during all life stages, occupying offshore waters to inshore estuaries and creeks (Phillips et al., 2017). Neonate (<1 year, ~<1.2 m total length) and juvenile (~1–8 years, up to approximately 3 m) green sawfish are distributed along the shallow coastline and are often found near river and estuary mouths, on shallow mudflats, and in mangrove creeks. Neonates and small juveniles limit their distribution to the extreme shallows, often directly along the shoreline, with green sawfish < 1 m in length spending the majority of time in < 50 cm depth (Morgan et al., 2017; Lear et al., 2024b). Neonate and small juvenile sawfish also tend to remain highly resident to the pupping location (their 'primary nursery') for at least their first year of life, or up to approximately 1–1.2 m total length (Morgan et al., 2017; Lear et al., 2024b). As they grow, green sawfish slowly expand their home range into neighbouring creeks and areas, and extend into slightly deeper water, although even sawfish up to 3 m in length are unlikely to be found deeper than 5 m depth (Lear et al., 2024b). Once over approximately 3 m, subadult green sawfish appear to leave nearshore nursery habitats and move into deeper areas (Morgan et al., 2017; Lear et al., 2023; Bateman et al., 2024) and mature between 3.3 and 3.8 m in length (Lear et al., 2023). Adult green sawfish are rarely sighted in shallow areas, and are assumed to occupy deeper, offshore habitats. For example, the Pilbara Trawl Fishery operating in offshore waters northeast of Exmouth Gulf documented ~480 interactions with green sawfish between 2006 and 2022 and found most individuals were adults at over 4 m in length (Harry et al., 2024). Within the approximate depth range of the fishery's operation (50–100 m), the shallowest and deepest catches of sawfish were 48 m and 121 m, respectively.

Juvenile green sawfish can be found in the nearshore waters of Exmouth Gulf and off the Pilbara all year round, particularly given young sawfish are resident to their primary nursery areas for 1–2 years (Morgan et al., 2017). Newborn sawfish, including individuals with visible yolk-sac scars and remnant rostral sheaths, are most often recorded in the Pilbara between August and December, indicating a spring pupping season that peaks in October–November (Lear et al., 2023). This pupping period is likely to be the same within Exmouth Gulf, where newborn sawfish with remnant rostral sheaths (i.e. less than a week old) have been sighted in September in 2021 and 2024 in the southwestern Exmouth Gulf (K. Lear, R. Bateman-John, pers. comm.). The occurrence of mature adults in coastal waters is rare throughout the year, although adult green sawfish likely occupy the deeper areas of Exmouth Gulf year-round (K. Lear, pers. comm.).

3.5.5.2.3 Population connectivity

The connectivity of green sawfish populations across Australia is still being understood. Most genetic studies are localised and focused on nursery areas, and there is a need to compile and connect genetic data from more locations. Species identification was also less reliable prior to 2013 when a large taxonomic revision of sawfishes occurred (Faria et al., 2013), which reduces the pool of genetic data to draw upon. Of the limited broader scale studies that have compared populations in WA, Northern Territory and Queensland, WA was found to have a genetically distinct population, which was also the most genetically diverse population within Australia (Phillips et al., 2011; Phillips et al., 2017). Morphologically, green sawfish in WA waters also have the lowest tooth counts of any other populations in world including compared to Australia's east coast (Lear et al., 2023), further indicating genetic separation of WA population(s) from elsewhere in Australia and globally.

There is evidence that gene flow is restricted over large spatial scales by both males and females, indicating philopatry in both sexes (Phillips et al., 2011; Phillips et al., 2017). Female and male philopatry has also been confirmed for this species within the Ashburton River nursery population, including evidence of the same females and males contributing to the Ashburton River population over more than a decade (Ingelbrecht et al., 2024d). However, it appears that some individuals may migrate long distances and contribute to pups in different locations as well, with kinship studies identifying half-siblings within WA separated by over 500 km (Ingelbrecht et al., 2024a).

Within WA waters, green sawfish have been tagged and sampled at numerous sites to better understand movement and connectivity, such as Ashburton River, Eramurra Creek, Fortescue River, Urala Creek North, and Urala Creek South. Tagged individuals from Ashburton River have been acoustically detected at Urala Creek North and Urala Creek South, providing evidence for connectivity between Exmouth Gulf and

Ashburton River (Lear et al., 2024a). Sawfish were often travelling in pairs, with some pairs travelling between the two areas on more than one occasion (D. Morgan, pers. comm.).

Of over 100 genetic samples taken from individual sawfish in the Onslow region (mainly Ashburton River), close to 90% of individuals were related (full siblings, half siblings, or cousins) (Ingelbrecht, 2024d). Some individuals also showed full and half sibling connections to individuals sampled at Cape Keraudren (north of Port Hedland), Broome, and Barrow Island (Ingelbrecht, 2024a). Of the limited genetic sampling efforts undertaken in Exmouth Gulf, no sibling connections with the Onslow region have so far been found. However, three neonates sampled in the southwestern Exmouth Gulf in September 2021 proved to be full and half siblings with each other and were likely littermates.

3.5.5.2.4 Biology and life history

Like most other rays and sharks, green sawfish give birth to live young. While there is little information on litter size for green sawfish populations off northwest Australia, a litter size of at least five has been recorded for a female from Ashburton River based on genetic data (Ingelbrecht et al., 2024d), and litters of between 6 and 12 have been reported for this species globally (Elhassan, 2018). Females likely produce litters every 2–3 years and are reproductively active for at least up to 12 years (Ingelbrecht et al., 2024d).

Within WA, the size of green sawfish at the time of birth is typically 0.7 – 0.9 m and maturity is reached between ~3.3 – 3.8 m (for both males and females), at around 9 – 10 years of age (Lear et al., 2023). Adult sawfish can grow to over 6 m in length, though are rare to encounter over 5 m. Pups and juveniles typically spend their time in shallow coastal waters in the primary nursery area near where they were born for 1–2 years before slowly expanding their home range into nearby secondary nursery areas (Morgan et al., 2017). Measurements of sawfish at nearshore nursery sites in the Pilbara have ranged from 0.76 cm to 3.2 m in length, which indicates sawfish can continue using nearshore nursery areas for 7 – 8 years. While small juveniles remain in nearshore nursery areas full time, larger juveniles move in and out of coastal areas with the tide and will spend time visiting shallow areas to hunt during incoming and high tides, when the risk of stranding is low (Morgan et al., 2017). Mature sawfish are more often recorded in water depths of ~50–100 m. For example, of the individuals measured during 2002–2010 (n = 25) from the offshore Pilbara Trawl Fishery operating within the 50–100 m depth range, the average length was 408 ± 67 cm (mean ± SD) (Harry et al., 2024). Of very few aged green sawfish, the oldest documented age is ~24 years (in Exmouth Gulf of Carpentaria; Peverell, 2010), but it is suggested green sawfish may live to > 50 years of age (Dulvy et al., 2014). Growth rates of sawfish in the Ashburton River estuary are higher compared with other locations measured within the Onslow region (Lear et al., 2023). This is possibly due to the greater concentrations of nutrients and productivity in these waters supporting prey and hunting opportunities. No growth rate data for green sawfish within Exmouth Gulf are available, but growth rates are likely equivalent to those in the Onslow region (K. Lear, pers. comm.).

Ectoparasite (living on the outside of the host) taxa were detected on 57% of green sawfishes examined (n = 76) between Onslow and Exmouth Gulf (Ingelbrecht et al., 2024c). Two parasites, *Caligus furcisetifer* (copepod) and *Stibarobdella macrothela* (marine leech), were found on young sawfishes (n = 3) from the Bay of Rest in Exmouth Gulf (Ingelbrecht et al., 2024c). These same two species in addition to the monogenean *Dermopristis pterophila* were also found on juvenile sawfish in Urala Creek South (K. Lear, pers. comm.). Understanding parasite and host relationships can better inform parasite coextinctions and flow on effects to marine communities.

3.5.5.2.5 Significance of Exmouth Gulf

Exmouth Gulf supports globally significant habitat for green sawfish, including pupping, nursery, and adult habitats (Figure 54). Due to the remoteness of much of Exmouth Gulf, there is limited information on the population size and habitat use of green sawfish within Exmouth Gulf. However, available sightings data clearly show continuous occupation of Gulf habitats by green sawfish throughout the year and across years (Bateman et al., 2024). This includes regularly used nursery and pupping areas in at least the northeastern and southwestern areas of Exmouth Gulf where green sawfish are likely pupped every year. This makes Exmouth Gulf one of few known places in the world where green sawfish are regularly pupped and observed. Other locations include the Ashburton River mouth and surrounding areas, other parts of the Pilbara coastline, and select tidal creeks in the Kimberley and Northern Territory (all notably within northwestern Australia) (K. Lear, pers. comm.).

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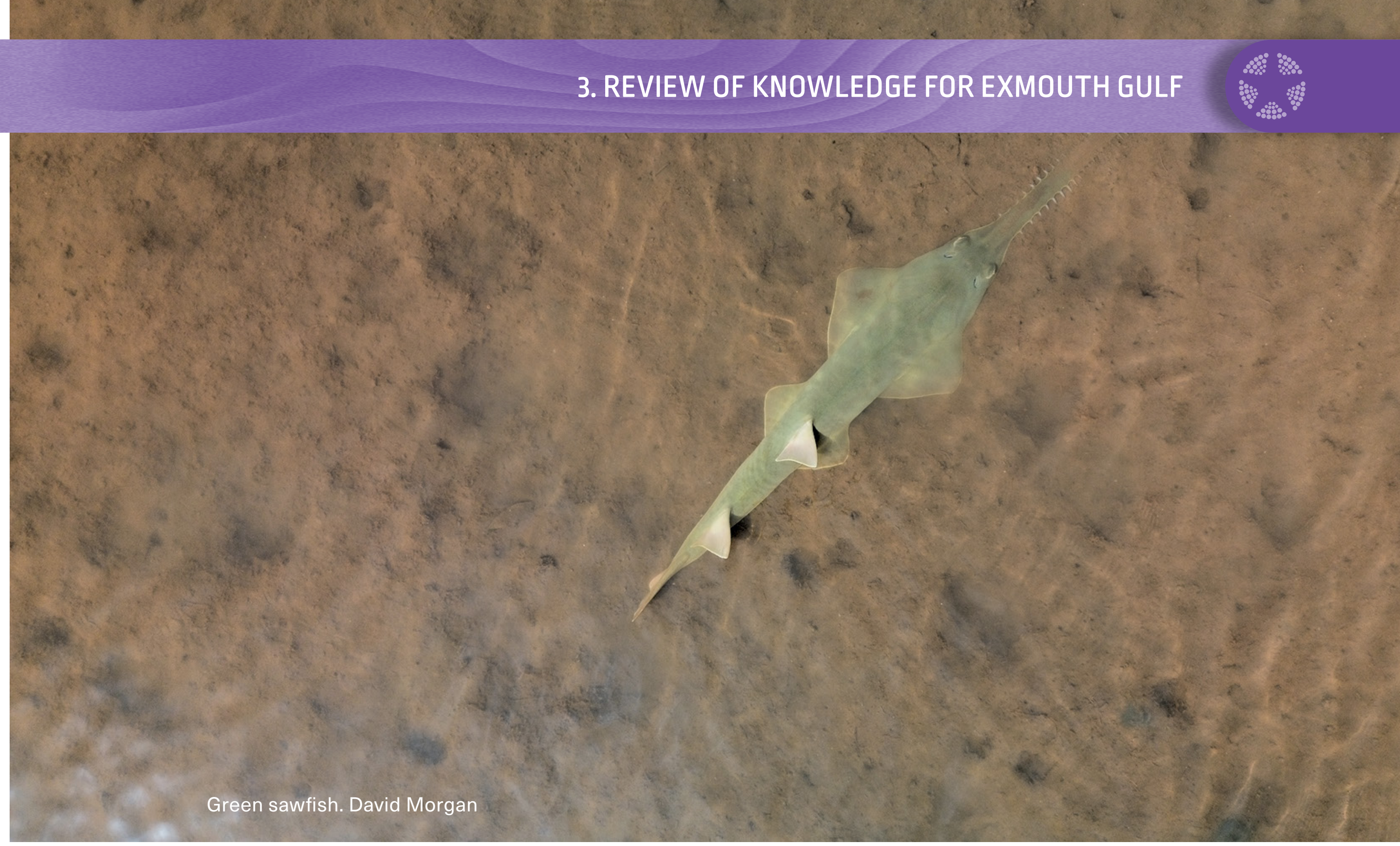

Green sawfish. David Morgan

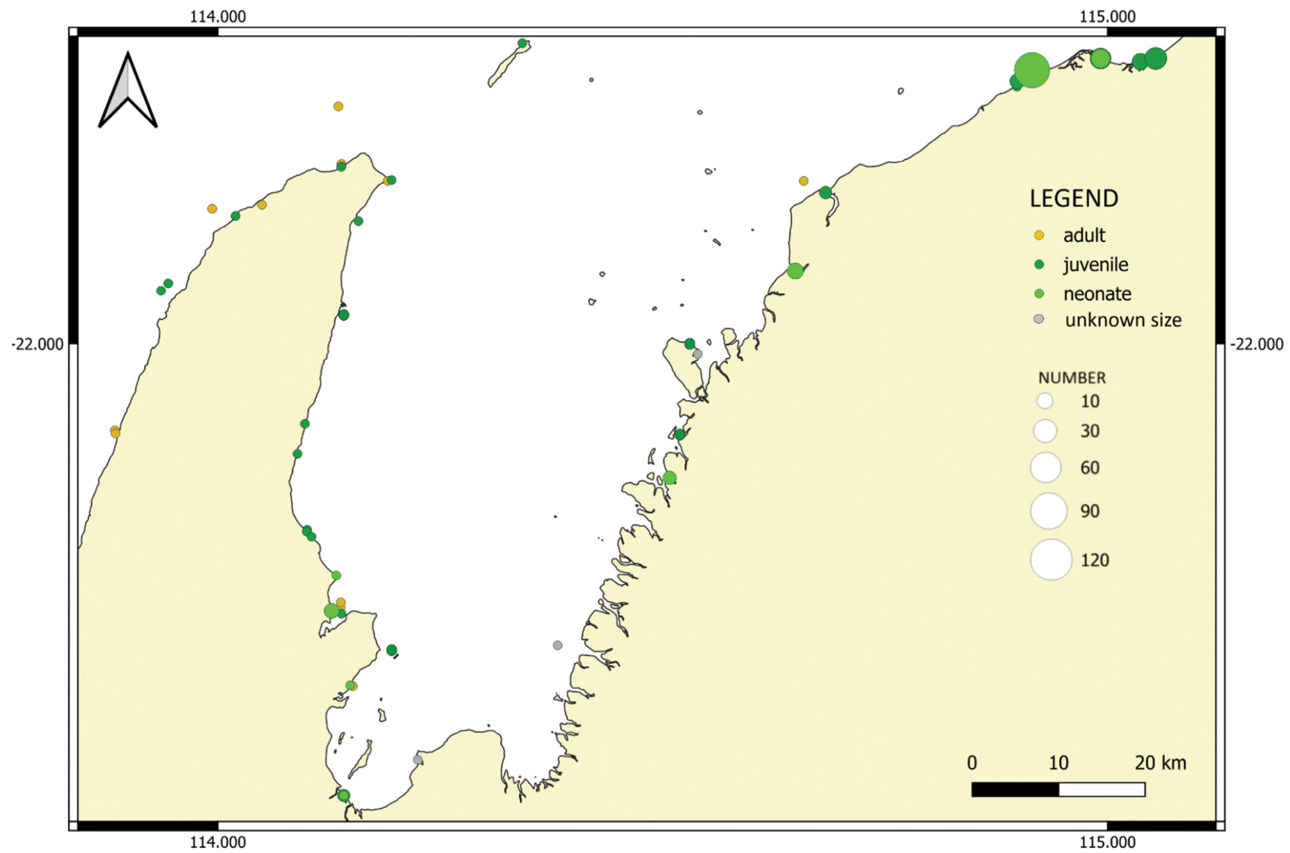

Figure 54: Map of recreational and scientific sightings of green sawfish within Exmouth Gulf, with points coloured according to life stage of the sighted green sawfish and sized according to number. Supplied by Rebecca Bateman-John based on sightings data reported to Fin Focus Research.

Within Exmouth Gulf, newborn green sawfish pups have been observed around Bay of Rest, throughout Gales Bay, near Simpson Island, and in Urala Creeks North and South (Bateman et al., 2024; Lear et al., 2024a) (Figure 54, Figure 55). Of these locations, pups have been sighted in multiple years within Urala Creek South and Bay of Rest. In particular, Urala Creek South appears to act as an annual pupping area and extended nursery habitat, where multiple green sawfish of different age classes are reliably found and likely remain resident for at least several years (Lear et al., 2024a). Additionally, acoustic tracking data has confirmed that sawfish originally pupped in the Ashburton River area (the most regularly used and abundantly occupied of known green sawfish pupping areas/nurseries) use Urala Creeks North and South when they begin to extend their range as larger juveniles. Tracking data has confirmed multiple transits by some large juveniles (>2.5 m length) between the Ashburton

Figure 55: Neonate and juvenile sawfish in Exmouth Gulf. Top: Neonate sawfish with remnant rostral sheath sighted near the Exmouth Gulf Station boat ramp in September 2024 (image: Carla Perez Valls). Bottom: Three small juvenile sawfish in the shallows at Urala Creek South in November 2024. Image: Michael Tropiano

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and Urala areas (K. Lear, pers. comm.). This confirms connectivity between Exmouth Gulf and the globally important Ashburton River nursery and suggests that Exmouth Gulf is an important habitat for subadult to adult sawfish pupped in the Ashburton River region. Given the increasing levels of coastal development to the north of the Ashburton River nursery area, maintaining suitable and productive sawfish habitat within Exmouth Gulf may become especially important for sawfish in the Pilbara region.

Further studies are currently underway to identify additional nursery areas for green sawfish within Exmouth Gulf, including investigating residency and movement patterns of sawfish using Exmouth Gulf, and investigating genetic connectivity of sawfish in Exmouth Gulf with surrounding areas (K. Lear, pers. comm.).

3.5.5.2.6 Threats and pressures

Sawfish species have declined globally due to targeted and incidental capture in fisheries. Their fins and meat are one of the most highly valued within the international shark fin trade, and their toothed rostra make them extremely susceptible to bycatch in all line and net fisheries (Dulvy et al., 2014). They also have intrinsically low rates of population growth due to low reproductive rates and long times to maturity. Commercial fishing, whether targeted or bycatch, remains the most significant threat to all sawfish species internationally and within Australia. In Exmouth Gulf, green sawfish are incidentally caught in the EGPMF, with an average of 11 sawfish interactions (species unspecified) reported each year since 2013/14 (Table 9) (Fletcher & Santoro, 2015; Kangas et al., 2015; Fletcher et al., 2017; Gaughan & Santoro, 2018, 2019; Gaughan & Santoro, 2020, 2021; Newman et al., 2021; Newman et al., 2023a; Newman et al., 2023b). These interactions are likely dominated by green sawfish, but probably also include freshwater and narrow sawfish. Approximately half of captured sawfish are released alive from the EGPMF, although post-release mortality rates for sawfish from trawl fisheries are largely unknown. The number of reported interactions with sawfish has varied and at times increased, which has been attributed to greater awareness, education and improved reporting processes (Kangas et al., 2015). Bycatch grids were implemented in 2007 in the fishery, but reporting on sawfish interactions only began in 2010, limiting an assessment on the effectiveness of the grids at decreasing the number of encounters (Kangas et al., 2015). Green sawfish are also encountered in the Pilbara Trawl Fishery, operating in offshore waters northeast of Exmouth Gulf, with a reported 479 green sawfish caught between 2006–2022 (Harry et al., 2024). This fishery also captured 286 narrow sawfish (*Anoxypristis cuspidata*) during this time frame, and 50 additional sawfish not identified to species level (Harry et al., 2024).

Table 9: Sawfish (species unspecified) encounters with the Exmouth Gulf Trawl Fishery as reported yearly by DPIRD in the State of the Fisheries reports.

Year	Alive	Dead	Unknown	Total
2022/2023	?	?	11	**11**
2021/2022	5	4	1	**10**
2020/2021	3	3	0	**6**
2019/2020	13	0	0	**13**
2018/2019	4	5	1	**10**
2017/2018	3	10	2	**15**
2016/2017	11	9	0	**20**
2015/2016	4	1	1	**6**
2014/2015	1	2	0	**3**
2013/2014	0	0	14	**14**

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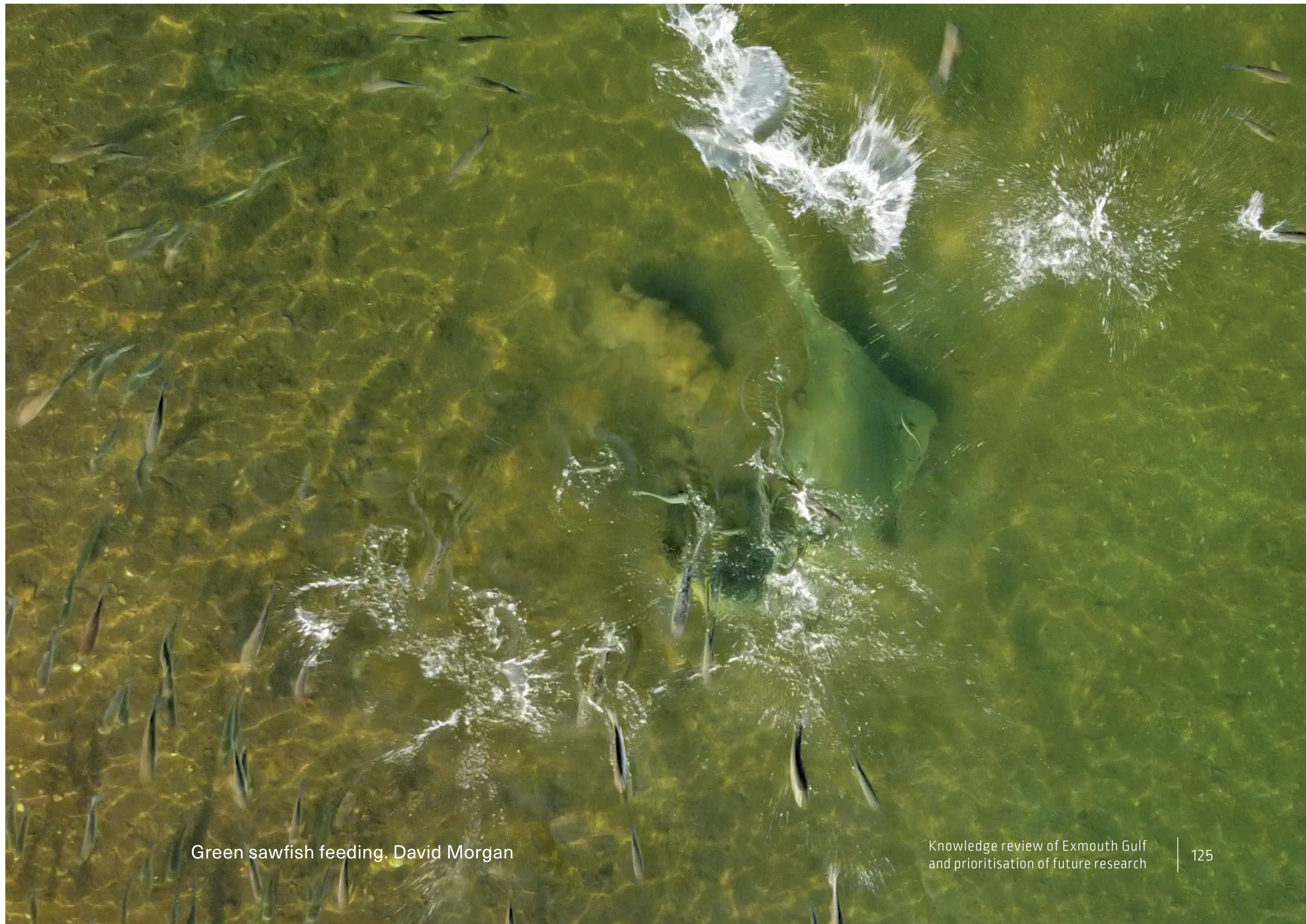
Figure 56: A green sawfish with a previously amputated rostrum caught in the Ashburton River delta in 2011. This sawfish had survived the initial amputation, but tagging data suggests it perished within a year of the photo and exhibited erratic behaviour compared to other sawfish (Morgan et al., 2016). Image: David Morgan

Sawfish are recreationally captured within Exmouth Gulf by both recreational line fishing and recreational gillnet fishing (R. Bateman-John, pers. comm.). As retention of sawfish is illegal in WA, nearly all recreational captures are released alive, though post-release mortality rates are unknown. In some cases, sawfish rostra are removed by recreational (and commercial) fishermen, either as trophies or because they are too difficult for fishers to remove from tangled fishing gear (Dulvy et al., 2014; Morgan et al., 2016; Wueringer et al., 2023) (Figure 56). Sawfish use their rostrum to capture prey, and removal of the rostrum will be fatal to sawfish, if not from the direct trauma of the injury, then from prolonged starvation (Wueringer et al., 2012; Morgan et al., 2016). While no records of rostrum removal have been reported within Exmouth Gulf specifically, they have occurred within the Pilbara Region, including a green sawfish with an amputated rostrum caught in the Ashburton River in 2011 (Morgan et al., 2016; Fig. 5). Four green sawfish with amputated rostra were also found dead in a single night near Karratha in 2023 (https://www.abc.net.au/news/2023-05-15/authorities-investigate-endangered-sawfish-killing-karratha/102347322).

In addition to fisheries captures, coastal development poses a significant risk to green sawfish populations given they utilise shallow waters including shorelines. The Pilbara coastline is a growing industrial region that already includes export facilities for mining, oil and gas, salt mining seawater intakes and outtakes, dredged channels, and sea walls. Coastal developments have also been proposed for Exmouth Gulf and surrounds, such as a deep-water port and salt mine. Physical structures on the seabed can create barriers for sawfish movement, particularly for pup and juvenile sawfish that use shallow coastal waters (Lear et al., 2024b). For example, young green sawfish were recorded turning back rather than going around offloading facilities including a solid rock wall built perpendicular to the shoreline in the vicinity of Ashburton River. There was also evidence of sawfish avoiding dredged channels, indicating depth is a key consideration for movement (Lear et al., 2024b). No studies have directly examined whether the discharge of bitterns from salt mining operations impact sawfish (or other marine fauna and flora) and their movement along the coast. Regulations for existing salt mines, such as Onslow Salt, require bitterns to be discharged on a high tide so bitterns can be flushed out to sea on the outgoing tide. It is unclear how highly concentrated plumes of bitterns from current or future proposed operations could disrupt the movement of sawfish in and out of Exmouth Gulf. Additionally, all types of coastal developments are likely to increase noise and light pollution in nearshore environments, the effects of which on sawfish are unknown.

Barriers to shoreline movement can cause several problems for sawfish using nearshore areas, including limiting home range size, limiting access to foraging/refuging areas, and limiting the potential for sawfish to avoid unfavourable environmental conditions. Reducing home range sizes and foraging potential is likely to slow growth rates for juvenile sawfish (Lear et al., 2023), while forced migration through deeper areas to avoid shoreline structures may make small sawfish more vulnerable to predation (Lear et al., 2024b). Additionally, it is important for sawfish to be able to leave certain habitats if conditions become unfavourable. For example, tracking data from tagged sawfish using the Ashburton River nursery have shown that individuals leave the river mouth during periods of high rainfall and freshwater pulse events (Morgan et al., 2017). This is likely driven by avoidance of freshwater discharge and the physiological challenges that poses to a predominantly marine fish. Under climate change, the frequency of rainfall events is not well understood for the Pilbara and Exmouth regions, though extreme rainfall events are predicted to be more intense (e.g., Figure 16), which could have implications for sawfish utilising critical foraging and nursery habitats.



Green sawfish feeding. David Morgan

3.5.5.3. Sharks

3.5.5.3.1 Biodiversity

A wide diversity of sharks is present within Exmouth Gulf, potentially including 51 species for which spatial and depth ranges overlap with Exmouth Gulf (see Table 10). Many of these species are morphologically similar and can be difficult for non-experts to identify, especially carcharhinids (whaler sharks). Combined with very little survey effort, especially in deeper areas of Exmouth Gulf, this has made it challenging to identify with certainty which species are present. This is particularly true for deeper water species and small shark species.

The sharks within Exmouth Gulf represent several diverse families, ranging from small, benthic-associated cat sharks to a variety of reef sharks and large, highly migratory species. Species also include those endemic to the northwest of Australia as well as some with global distributions. These sharks occupy a variety of environments within Exmouth Gulf, including nearshore and offshore benthic and pelagic habitats.

The most common shark species documented in nearshore waters, especially on shallow flats and within mangrove creeks in the eastern and southern areas of Exmouth Gulf, are nervous sharks (*Carcharhinus cautus*), lemon sharks (*Negaprion acutidens*; especially juveniles), and blacktip reef sharks (*Carcharhinus melanopterus*; especially juveniles) (K. Lear, pers. comm.). Juvenile spinner sharks (*Carcharhinus brevipinna*) are also reasonably common within certain mangrove creek systems, and adult lemon sharks and great hammerhead sharks (*Sphyrna mokkaran*) are regularly sighted feeding in shallow areas at high tides (K. Lear, pers. comm.). The most common larger species of sharks observed in deeper water and non-structured habitats are tiger sharks (*Galeocerdo cuvier*), as well as sandbar (*Carcharhinus plumbeus*) and dusky sharks (*Carcharhinus obscurus*) (Mitchell et al., 2018; Lester et al., 2022).

3.5.5.3.2 Habitat use

Very few ecological studies on sharks have been undertaken within Exmouth Gulf, and therefore Gulf-specific information about habitat use and ecology is rare. Instead, most information on sharks in Exmouth Gulf comes from bycatch records, anecdotal reports, or opportunistic data gathered while researching other species of interest (e.g., cetaceans). Fortunately, shark ecology for a variety of species has been regularly studied on Ningaloo Reef and in surrounding areas.

Due to the wide diversity of shark species present within Exmouth Gulf, sharks as a group occupy a range of different kinds of habitats and hold different positions within tropic cascades, according to the species. In general, mangrove creeks and shorelines offer important nursery habitat for young sharks (e.g., lemon and blacktip reef sharks; Speed et al., 2016; Oh et al., 2017). Other shark species appear not to use nurseries or have deeper water nurseries, with juveniles rarely seen in nearshore areas (e.g., tiger sharks; Ferreira, 2017). Similarly, adults of some shark species (e.g., lemon and great hammerhead sharks) regularly visit shallow areas to feed (e.g., Moustaka & Strydom, 2020; Pillans et al., 2021; Lubitz et al., 2023), especially at high tide when the risk of stranding is low. Other species are strictly pelagic and do not use shallow habitats. Small benthic sharks, including cat sharks and bamboo sharks, tend to be exclusively found in highly structured benthic habitats such as reefs and sponge gardens (e.g., O'Neill et al., 2024). Some sharks found within Exmouth Gulf are likely to be highly migratory and only visit Exmouth Gulf in passing, while other species (especially smaller sharks) may remain resident within Exmouth Gulf for their full life cycle.

While sharks are abundant throughout much of Exmouth Gulf, areas that appear to be especially important for sharks include Bundegi Reef and the inshore and mangrove areas of the wider Bundegi Sanctuary Zone (Lester et al., 2022; R. Bateman-John, pers. comm.). The shallow mangrove-lined areas along eastern and southern Exmouth Gulf are also likely important areas for sharks as aerial surveys have generally sighted higher numbers of sharks in these areas compared to the rest of Exmouth Gulf (e.g., Irvine & Salgado Kent, 2019). These mangrove creeks and mudflats may offer important nursery habitats and tide-dependent feeding areas for several species. Aerial and drone footage has also captured sharks schooling in the shallows of sandy bays along western Exmouth Gulf, particularly in summer months (R. Bateman-John, pers. comm.).

Table 10: Sharks species with spatial and depth distributions overlapping Exmouth Gulf. Species with confirmed sightings within the Exmouth Gulf/Ningaloo region are listed with an '*' by their scientific name, while species with confirmed sightings within Exmouth Gulf specifically are denoted by '**'. Species are listed along with the life stages if known or likely to be present within Exmouth Gulf and the habitats they are likely to occupy, noting that much of this information is unknown or has not been scientifically verified. Their conservation statuses are listed including their IUCN status (global), and their status in the Australian Action Plan for Sharks and Rays published in 2021 (Kyne et al., 2021), which assessed threatened statuses of each species within their Australian range according to IUCN listing criteria. Where listed, their status under the EPBC Act is also specified. Status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated. Data from various sources including Kyne et al. (2021), Lester et al. (2022), Stevens et al. (2009), social media posts.

Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
*Rhincodon typus***	Whale shark	Nearshore and offshore pelagic	Rare (subadult, adults)	EN	EN	VU; Migratory
*Galeocerdo cuvier***	Tiger shark	Nearshore and offshore pelagic and benthic	Common (adults; juveniles rare)	NT	NT	
*Prionace glauca**	Blue shark	Offshore pelagic	Rare (adults)	NT	NT	
*Carcharodon carcharias***	White shark	Nearshore and offshore pelagic	Rare (adults)	VU	VU	VU; Migratory
*Isurus oxyrinchus**	Shortfin mako shark	Offshore pelagic	Rare (adults)	EN	VU	Migratory
Isurus paucus	Longfin mako shark	Offshore pelagic	Rare (adults)	EN	VU	Migratory
Psuedocarcharias kamoharai	Crocodile shark	Offshore pelagic	Rare (adults)	LC	LC	
*Alopias pelagicus**	Pelagic thresher shark	Offshore pelagic	Rare (adults)	EN	EN	
Alopias superciliosus	Bigeye thresher shark	Offshore pelagic	Rare (adults)	VU	VU	
Alopias vulpinus	Common thresher shark	Offshore pelagic	Rare (adults)	VU	NT	
*Sphyrna lewini***	Scalloped hammerhead	Nearshore and offshore pelagic	Rare (adult, potentially juveniles)	CR	EN	Conservation dependent

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Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
*Sphyrna mokkaran***	Great hammerhead	Nearshore and offshore benthic and pelagic, including shallows	Regular (adults, potentially juveniles)	CR	EN	
*Carcharias taurus***	Grey nurse shark	Nearshore reefs and structured habitats including Navy Pier	Regular (adults, subadults)	CR (NT in WA)	VU	VU; Migratory
Carcharhinus longimanus	Oceanic whitetip	Offshore pelagic	Rare (adults)	CR	CR	Migratory
*Carcharhinus leucas***	Bull shark	Nearshore and offshore pelagic	Occasional (adults, juveniles)	VU	LC	
*Carcharhinus amboinensis**	Pigeye shark	Nearshore and offshore pelagic	Occasional (adults, juveniles)	VU	LC	
*Carcharhinus plumbeus***	Sandbar shark	Nearshore and offshore pelagic	Regular (adults)	EN	NT	
*Carcharhinus falciformis**	Silky shark	Offshore pelagic	Rare	VU	VU	Migratory
*Carcharhinus albimarginatus**	Silvertip shark	Pelagic over benthic structure	Rare	VU	LC	
*Carcharhinus altimus**	Bignose shark	Offshore pelagic	Rare	NT	LC	
Carcharhinus tilstoni#	Australian blacktip shark	Nearshore and offshore pelagic	Regular (adults)	LC	LC	
Carcharhinus limbatus#	Common blacktip shark	Nearshore and offshore pelagic	Regular (adults)	VU	LC	
*Carcharhinus brevipinna***	Spinner shark	Nearshore and offshore pelagic, juveniles inside mangrove creeks	Regular (adults, juveniles)	VU	LC	
Carcharhinus macloti	Hardnose shark	Nearshore and offshore pelagic	Rare	NT	LC	
*Carcharhinus sorrah***	Spot-tail shark	Nearshore and offshore pelagic	Regular	NT	LC	

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Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
*Carcharhinus brachyurus**	Bronze whaler	Offshore pelagic	Rare (adults)	VU	LC	
*Carcharhinus obscurus***	Dusky shark	Offshore pelagic	Regular (adults)	EN	NT	
*Carcharhinus cautus***	Nervous shark	Coastal and offshore including shallows and mangrove creeks	Common (adults, juveniles)	LC	LC	
*Carcharhinus amblyrhynchoides**	Graceful shark	Mangrove creeks (juveniles) and offshore (adults)	Rare	VU	LC	
Carcharhinus fitzroyensis	Creek whaler	Estuaries, mangrove creeks, nearshore waters	Rare	LC	LC	
*Carcharhinus coatesi***	Australian blackspot shark	Inshore waters	Rare	LC	LC	
*Carcharhinus melanopterus***	Blacktip reef shark	Nearshore mangrove and reef	Common (adults, juveniles)	VU	LC	
*Carcharhinus amblyrhynchos***	Grey reef shark	Reef-associated	Regular (adults, juveniles)	EN	NT	
*Triaenodon obesus***	Whitetip reef shark	Reef-associated	Common (adults, juveniles)	VU	NT	
*Rhizoprionodon acutus***	Milk shark	Inshore and offshore pelagic often over sandy areas	Regular	VU	LC	
*Rhizoprionodon taylori***	Australian sharpnose shark	Inshore over soft substrates	Regular	LC	LC	
*Loxodon macrorhinus**	Sliteye shark	Inshore and offshore demersal	Rare	NT	LC	
*Hemigaleus australiensis***	Australian weasel shark	Inshore and offshore pelagic	Regular	LC	LC	
Hemipristis elongata	Fossil shark	Inshore and offshore demersal	Rare	VU	LC	

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Scientific name	Common name	Dominant habitat occupied within Exmouth Gulf	Probable occurrence (life stages present)	Global IUCN status	Australian Action Plan status	Status under EPBC Act
*Negaprion acutidens***	Sickle-fin lemon shark	Nearshore mangrove	Common (adults, juveniles)	EN	LC	
*Nebrius ferrugineus***	Tawny nurse shark	Benthic structured habitats	Regular	VU	LC	
*Stegostoma tigrinum***	Indo-Pacific leopard shark	Nearshore and offshore benthopelagic	Regular (adults)	EN	LC	
*Orectolobus wardi***	Northern wobbegong	Benthic structured habitats	Regular	LC	LC	
*Eucrossorhinus dasypogon***	Tasselled wobbegong	Benthic structured habitats	Regular	LC	LC	
*Chiloscyllium punctatum***	Brownbanded bamboo shark	Benthic structured habitats	Regular	NT	LC	
*Hemiscyllium trispeculare***	Speckled carpetshark	Benthic structured habitats	Regular	LC	LC	
Atelomycterus fasciatus	Banded catshark	Benthic structured habitats	Rare	LC	LC	
Heptranchias perlo	Sharpnose sevengill shark	Offshore benthopelagic	Rare	NT	LC	
Hexanchus griseus	Bluntnose sixgill shark	Offshore benthopelagic	Rare	NT	LC	
*Hexanchus nakamurai**	Bigeye sixgill shark	Offshore benthopelagic		LC	NT	
Squalus megalops	Piked spurdog	Offshore benthopelagic	Rare	LC	LC	
Isistius brasiliensis	Smalltooth cookiecutter shark	Offshore benthopelagic	Rare	LC	LC	

#*Carcharhinus limbatus* and *C. tilstoni* cannot be identified from each other with certainty without genetic confirmation; blacktip sharks of either or both species have been confirmed within the region, but it is unknown which species are represented.

3.5.5.3.3 Ecological importance

Several shark species commonly found in Exmouth Gulf are apex predators (e.g., tiger sharks, hammerhead sharks, a variety of carcharhinid sharks; Lester et al., 2022). There is often large differentiation in diets among these top predators. For example, reef sharks are thought to prey almost exclusively on fishes, but tiger sharks are characterised by a highly generalist and variable diet that includes fishes, turtles, dugongs, seabirds, and cetaceans, among other food items (Simpfendorfer et al., 2001; Ferreira et al., 2017). Great hammerheads are also known for their specialisation in feeding on other elasmobranchs (e.g., Moustaka & Strydom, 2020). Many other shark species (e.g., medium and small carcharhinids) hold important mesopredator roles, mainly feeding on small fishes and/or cephalopods and being predated upon by larger sharks (Speed et al., 2012). Whale sharks (*Rhincodon typus*) are also present (though rarely) in Exmouth Gulf as planktivorous sharks.

3.5.5.3.4 Biology and life history

No studies on shark reproduction have been undertaken within Exmouth Gulf and reproductive biology has been shown to vary by location (e.g., Taylor et al., 2016). While growth rates, age at maturity, and reproductive output have been studied for a variety of shark species in other locations, Exmouth Gulf may show slightly different trends. Different types of sharks have widely varied reproductive and growth rates, though most share some common characteristics. In general, sharks are categorised as K-selected species, with relatively slow growth, late maturity, and limited reproductive output compared to other fauna such as many fishes. These life history characteristics make sharks vulnerable to population declines as they lead to low potential for population growth and recovery, although the level of vulnerability depends on the species. For example, large female tiger sharks have been reported to have up to nearly 60 pups within a litter (Simpfendorfer, 1992; Whitney & Crow, 2007), and one pregnant whale shark (*Rhincodon typus*) was recorded to have up to 300 embryos at varying developmental stages, although reproductive biology of this species is very poorly known (Joung et al., 1996). Grey nurse sharks (*Carcharias taurus*) show adelphophagous reproduction where embryos within each uterus cannibalise each other until only a single pup remains, and therefore this species has a maximum of only two large pups (1 m length at birth) at minimum 2-year intervals. Different shark species also show a variety of growth rates and times to maturity. Some smaller species are estimated to reach maturity within a few years of birth (e.g., milk sharks, *Rhizoprionodon acutus* mature around 1.5 – 2 years old; Harry et al., 2010) and most reef sharks and small-medium carcharhinids mature around 4–7 years of age (e.g., nervous sharks, *Carcharhinus cautus* and blacktip reef sharks, *Carcharhinus melanopterus*; White et al., 2002; Chin et al., 2013). Most large carcharhinids are expected to reach maturity around ~10–15 years of age (e.g., tiger sharks mature around 9–13 years old; Holmes et al., 2015), whereas whale sharks in the region are not expected to reach maturity until over at least 7–10 m total length (Norman & Stevens, 2007), equating to an estimated age of at least 17 years in the Indo-Pacific region (Hsu et al., 2014).

The shark species present within Exmouth Gulf show diverse reproductive modes. The majority are viviparous (give live birth), although in various ways. Most carcharhinids show placentotrophy, where embryos obtain nutrients via placenta. Species such as whale sharks and wobbegongs show lecithotrophy, where embryos obtain nutrients exclusively via yolk sac. Tiger sharks show histotrophy, where embryos obtain nutrients via uterine secretions after depleting their yolk sac energy. Grey nurse sharks are oophagous, with embryos obtaining nutrients via cannibalism of sibling eggs and/or embryos (Blackburn & Hughes, 2024). Alternatively, several shark species within Exmouth Gulf lay egg cases (oviparity) rather than giving live birth, including cat sharks, bamboo sharks, and the Indo-pacific leopard shark (*Stegostoma tigrinum*) (Figure 57) (Blackburn & Hughes, 2024). However, no leopard shark egg cases have been found in Exmouth Gulf specifically and it is unclear if they reproduce in this area (R. Bateman-John, pers. comm.).

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3.5.5.3.5 Threats and pressures

The biggest threat to sharks within Exmouth Gulf is from fishing pressure, both recreational and commercial. The EGPMF historically retained shark bycatch of 2–18 tonnes annually but has not retained bycatch since 2006 following legislative changes (Kangas et al., 2015). Small sharks are still caught as bycatch and released/discarded from the fishery, although BRDs limit the catch of large sharks. After BRDs were implemented in the fishery, shark bycatch was reduced to 3 tonnes annually, making up 0.2% of the fishery catch by weight (Kangas et al., 2015). There is no species-specific reporting of sharks caught in this fishery, therefore the species composition of the catch is unknown. However, the most common species caught in the similar Northern Prawn Fishery are whitecheek sharks (*Carcharhinus coatesi*), blacktip sharks (*Carcharhinus tilstoni/limbatus*), milk sharks (*Rhizoprionodon acutus*) and brownbanded bamboo sharks (*Chiloscyllium punctatum*) (Brewer et al., 2006; Campbell et al., 2020). All these species are also present within Exmouth Gulf and based on size are likely to be vulnerable to trawl catches.

Sharks are caught within Exmouth Gulf by boat- and land-based recreational fishers. Sharks are most commonly caught via line fishing, but small shark species are also highly vulnerable to being caught in recreational gillnets. It is very difficult to quantify the level of fishing effort by recreational fishers (especially shore-based fishers), and to understand which species are most often caught or retained. Knowledge surrounding post-release mortality of recreationally caught sharks, particularly via shore-based fishing, is extremely low (Braccini et al., 2021). A recent state-wide survey in WA suggests that sharks are not often the target of recreational fishers, and that approximately 85% of captured sharks are released (Braccini et al., 2021). The species most often caught within the Gascoyne bioregion, including Exmouth Gulf, were reef sharks, lemon sharks, dusky sharks, and tiger sharks. The commonly retained species included spinner sharks, dusky sharks, bronze whalers, and wobbegongs (Braccini et al., 2021).

Other factors such as shoreline development and underwater noise may also affect sharks, particularly nearshore and shallow-water species. Very little is known about how sharks respond to underwater noise. A single study off the North West Cape and Muiron Islands found that various whaler sharks, lemon sharks, zebra sharks, and hammerheads were less likely to appear and/or had delayed appearance at baited underwater video stations when artificial and simulated orca sounds were playing compared to control treatments (Chapuis et al., 2019).

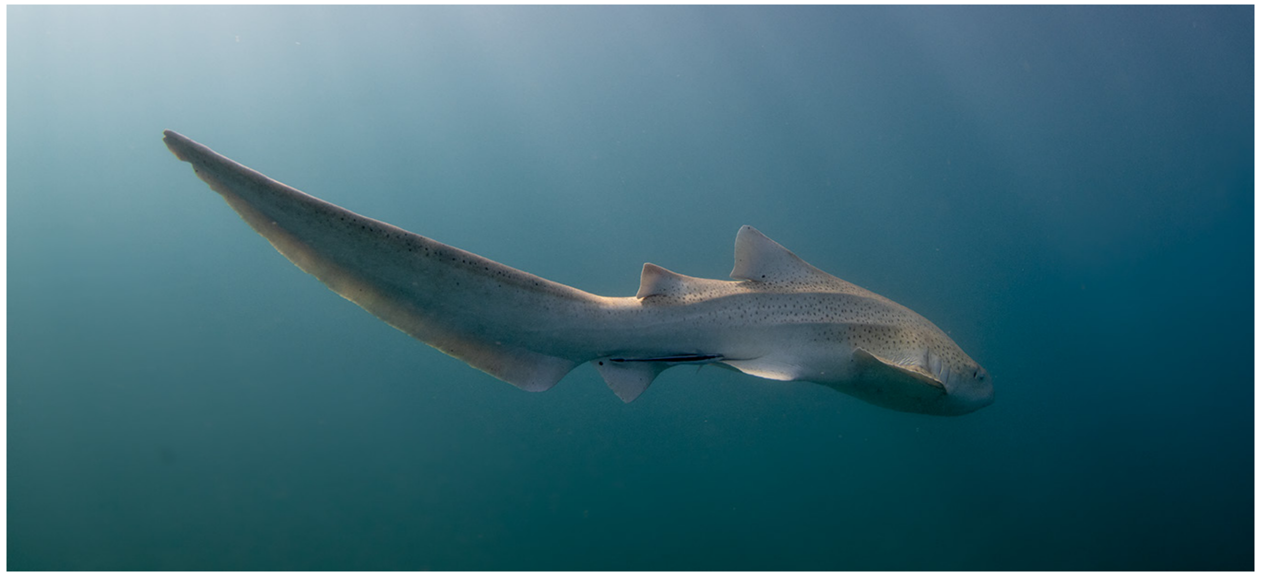

Figure 57: Indo-Pacific leopard sharks are regularly observed in Exmouth Gulf. Image: Rebecca Bateman-John

3.5.5.3.6 Grey nurse shark

Grey nurse sharks, *Carcharias taurus*, are one of the few shark species that are formally protected within Australia, listed as Vulnerable and Migratory under the EPBC Act. They are also considered Critically Endangered globally by the IUCN (though only NT for the WA population). Studies show that the WA subpopulation is genetically separate from the eastern Australian population, and therefore should be managed as a discrete unit (Ahonen et al., 2009). This species is long lived (> 40 years), slow to mature (maturity at 7–10 years old), and has very few offspring (2 pups every ~2–3 years). It also tends to aggregate, which increases its vulnerability to overfishing or targeted threats (Hoschke et al., 2023).

There are currently five known aggregation sites for grey nurse sharks within the WA subpopulation, one of which is the Exmouth Navy Pier in Exmouth Gulf (Hoschke & Whisson, 2016; Hoschke et al., 2023). Grey nurse sharks have been recorded during annual monitoring at the Exmouth Navy Pier from 2007–2021 between approximately May and November, with an average of 5–6 unique individuals present each year as identified by their spot patterns (Hoschke et al., 2023). Compared to all other known aggregation sites, the Exmouth Navy Pier is shallower and nearer to the coast, but likely draws the sharks due to abundant prey availability. Most sharks present are juveniles, with typically only one mature male and one occasionally observed mature female present at the site. The individuals show strong site philopatry, returning to the pier over multiple years, including an individual male returning in at least 13 consecutive seasons.

As grey nurse sharks are fully protected within WA with fishery retention prohibited, they are not likely to be highly threatened by fisheries in the region. The fishing exclusion in place around Exmouth Navy Pier (minimum 800 m in all directions) also likely helps to reduce incidental recreational bycatch (Hoschke et al., 2023). Fishing injuries or trailing gear have not been observed on grey nurse sharks in this area, as opposed to other regions without a protective fishing buffer. However, given these are large, migratory sharks, they are likely present within surrounding areas that are targeted by recreational fishing.

The largest potential threat to this species in Exmouth Gulf is pressure from diving operations at the pier, as diver proximity has been shown to elicit avoidance behaviour of this species (Barker et al., 2010). Exmouth Navy Pier dives are managed by a single company and the pier is not open to the public, therefore pressure from dive tourism on this aggregation site is likely limited.

3.5.5.3.7 Hammerhead sharks

There are two species of hammerhead sharks found within Exmouth Gulf: great hammerheads (*Sphyrna mokkaran*) and scalloped hammerheads (*Sphyrna lewini*). Both species are globally listed as Critically Endangered by the IUCN and considered Endangered within Australia by the Australian Action Plan for Sharks and Rays (Kyne et al., 2021). Scalloped hammerheads are also listed as Conservation Dependent under the EPBC Act, meaning that they are the focus of conservation and management plans, without which they are likely to become threatened. Both species are characterised by slow growth, late maturity (~6–8 years), and relatively low reproductive output (~20–30 pups biannually) (Harry et al., 2011). High fishing pressures throughout their range are the primary driver of their global decline (Rigby et al., 2019a; Rigby et al., 2019b; Kyne et al., 2021)

Within Exmouth Gulf, the most sighted species is the great hammerhead, which is known to come into shallow areas, such as mudflats for feeding at high tide. Great hammerheads are a major predator of rays and smaller sharks in the region (e.g., Moustaka & Strydom, 2020). On the other hand, scalloped hammerheads are rarely seen in the extreme shallows and tend to forage in deeper areas throughout the water column. Both species are almost exclusively seen as large subadults to adults within Exmouth Gulf. However, smaller individuals are also occasionally sighted, and it is possible that nursery areas exist in Exmouth Gulf. Residency and movements of these species are not well known in the Exmouth region, but one female great hammerhead satellite-tagged at Coral Bay showed movements into the southern areas of Exmouth Gulf and subsequently up to the Kimberley coast (Stevens et al., 2009), highlighting their highly migratory nature.

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Like most other sharks, the largest threat to hammerheads within Exmouth Gulf is fishing pressure. Scalloped and great hammerheads are both known for their poor survival following capture in fisheries, even for a short duration, likely due to a heightened stress response (e.g., Butcher et al., 2015). Large hammerheads are unlikely to be caught within the EGPMF due to BRDs, although if juveniles are present in the region they could be at risk. Species-specific reporting of shark catches in the EGPMF would help to understand the level of this threat. However, anecdotal reports do indicate that hammerheads (especially great hammerheads) are caught by recreational fishers within Exmouth Gulf, and are even sometimes targeted by boat-based line fishermen as a large and exciting species to catch (R. Bateman-John, pers. comm.). Given their poor survival once hooked, it is likely that the majority of hammerheads recreationally caught and released still succumb to mortality after capture.

3.5.5.3.8 Whale sharks

Whale sharks (*Rhincodon typus*) aggregate at Ningaloo Reef each year between approximately March and May, although they can be found in the Ningaloo region year-round (Reynolds et al., 2017). They are one of the main species driving the ecotourism industry in the region. While they are regularly sighted offshore of Ningaloo Reef, they are very rarely sighted within Exmouth Gulf, with sporadic records of this species mostly occurring in spring and summer in the northwestern Exmouth Gulf, including by the Muiron Islands (Norman et al., 2016; Atlas of Living Australia). Whale sharks are a pelagic species, traditionally occupying offshore areas of at least 50–60 m depth and aggregating around upwelling zones (Gleiss et al., 2013; Reynolds et al., 2017). Therefore, the relatively shallow Exmouth Gulf may not offer ideal habitat for this species. However, the area directly to the north of Exmouth Gulf and extending throughout the Pilbara along the 200 m isobath has been identified as a Biologically Important Area (BIA) for foraging whale sharks (DCCEEW, 2024). Such BIAs are designated for marine species protected under the EPBC Act.

3.5.5.3.9 Tiger shark

Tiger sharks, *Galeocerdo cuvier*, are one of the most common large shark species seen in Exmouth Gulf. They have been sighted in both deep habitats and shallow nearshore areas including near reefs, mangroves, seagrass, and soft-bottomed habitats, but appear most common in deeper, non-structured habitats (Lester et al., 2022). Behavioural and animal-borne video data from tiger sharks tagged at Ningaloo Reef shows that shallow sandflat habitats are also likely to be important foraging areas for tiger sharks (Andrzejaczek et al., 2019; Andrzejaczek et al., 2020). Preliminary acoustic tracking data from adult tiger sharks shows that many individuals repeatedly return to the southwestern Gulf, which may be a particularly important area for this species (B. D'Antonio, pers. comm.).

Most tiger sharks sighted or captured in Exmouth Gulf are subadult to adults, including individuals up to ~4 m, the majority of which are females (B. D'Antonio, pers. comm.). Similar size ranges and sex ratios have also been noted for tiger sharks occupying Ningaloo Reef (e.g., Andrzejaczek et al., 2019). Small juveniles have also been sighted on BRUVS deployed in deeper areas of Exmouth Gulf (S. Gudge, pers. comm.). Similar to many pelagic species, tiger sharks are not known to use shallow nursery habitats, or to have established nurseries in general (Ferreira, 2017), and juveniles are often absent in nearshore assemblages. Thus, the lack of sightings of neonates or juveniles in Exmouth Gulf could simply be due to a lack of survey or sighting effort in deeper areas.

Preliminary acoustic tracking data from adult tiger sharks within Exmouth Gulf has shown extremely variable behaviour between individuals. Some tracked individuals appear resident to specific areas of Exmouth Gulf, while others move rapidly around the whole Gulf and/or appear to leave and return to Exmouth Gulf (B. D'Antonio, pers. comm.). Satellite tracking of tiger sharks caught near Ningaloo Reef has similarly shown high inter-individual variation in movement patterns. Some tagged sharks stayed or returned to the region for long periods, while others made long-range migrations including between Exmouth Gulf, Rowley shoals, off the Pilbara and Kimberley coasts, Ningaloo Reef, Coral Bay, and Shark Bay, even ranging south as far as Esperance or north to Indonesia (Stevens et al., 2009; Ferreira et al., 2015).

As an abundant apex predator, tiger sharks have the potential to influence food webs and prey species in Exmouth Gulf through top-down control and behavioural effects on prey species (e.g., Heithaus et al., 2012). Given their highly migratory tendencies, it is likely that tiger shark diets vary throughout time and space, but are known to include a variety of fishes, elasmobranchs, sea birds, marine turtles, marine mammals, and sea snakes (Simpfendorfer et al., 2001; Ferreira et al., 2017; Andrzejaczek et al., 2020). Stable isotope analyses of tiger sharks sampled from Ningaloo Reef suggested that their main prey was derived from a mix of seagrass and pelagic food chains, in comparison to Shark Bay that was highly seagrass dominated (Ferreira et al., 2017). Interestingly, tiger sharks at Ningaloo Reef also had stable carbon isotope (δ13C) values that were lower than many reef sharks in the area, suggesting that they may occupy a slightly lower trophic level (Ferreira et al., 2017). However, this could also be due to tiger sharks often preying on megaherbivores such as marine turtles and dugongs, compared to reef sharks with a diet dominated by predatory fishes (Ferreira et al., 2017). In addition to the direct effects of predation, tiger sharks are also known to influence the behaviour and spatial distribution of their prey through eliciting predator avoidance responses (Heithaus & Dill, 2002).

Given their size, tiger sharks are not likely to be taken as bycatch in the EGPMF, although neonates may be small enough to fit through BRDs. Tiger sharks are also not often targeted by recreational fishers, although they may occasionally be caught by boat- and shore-based line fishers. A recent survey estimated that roughly 550 tiger sharks are caught annually by boat- and shore-based recreational fishers and charter fishing boats across WA, with the majority (> 60%) caught within the Gascoyne region (Braccini et al., 2021). Almost all (~97%) were reported released. Tiger sharks are a fairly robust species and have shown high survival rates after capture and release from both commercial and recreational fishing methods (e.g., Whitney et al., 2021; Binstock et al., 2023) including in northwestern Australia (Grosse, 2023). As long as sharks are released in a timely manner, it is likely that most tiger sharks survive incidental recreational captures.

Tiger shark. Nick Thake

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3.5.6. Marine reptiles

3.5.6.1. Marine turtles

3.5.6.1.1 Biodiversity

Five marine turtle species are present within Exmouth Gulf (Table 11). The most common species observed is the green turtle (*Chelonia mydas*), followed by the loggerhead turtle (*Caretta caretta*) and hawksbill turtle (*Eretmochelys imbricata*). All three of these species are known to nest on beaches within Exmouth Gulf, and both juveniles and adults use Exmouth Gulf waters as foraging areas (Prince et al., 2012). Flatback turtles (*Natator depressus*) are also common further north in the Pilbara and nest on islands in the northeastern part of Exmouth Gulf (Fossette et al., 2021; Gammon et al., 2023). However, they are only occasionally seen nesting and/or foraging in other areas of Exmouth Gulf, which marks the approximate southern edge of their distribution in WA (Pendoley et al., 2014). Leatherback turtles are the largest marine turtle species and tend to inhabit deeper offshore waters (Hazel et al., 2024). They are not known to nest within the Exmouth/Ningaloo region and are rarely observed within Exmouth Gulf, although a few sporadic sightings in the area have been confirmed (Hazel et al., 2024). Historical interactions with leatherback turtles in the EGPMF have also been reported in the northern areas of Exmouth Gulf (Prince et al., 2012).

3.5.6.1.2 Habitat use

Most data on marine turtle distribution and habitat use within Exmouth Gulf comes from opportunistic data collected during aerial surveys focused on marine mammals (Preen et al., 1997; Irvine & Salgado Kent, 2019; Sprogis & Parra, 2022; Sprogis & Waddell, 2022). During such aerial surveys for large fauna, it can be very difficult to identify marine turtles to species, and for most distribution data, all species are grouped together simply as 'marine turtle' sightings. These surveys have in general shown that turtles are found throughout Exmouth Gulf, with sightings often concentrated in the shallow eastern and southern parts of Exmouth Gulf (e.g., Preen et al., 1997; Irvine & Salgado Kent, 2019;). However, it is likely that different parts of Exmouth Gulf may be important to different species and may be used by different life stages.

In general, marine turtles require sandy beaches for nesting, with certain species often nesting at different beaches. For example, the Muiron Islands and likely other islands throughout Exmouth Gulf are important rookeries for green, hawksbill, and loggerhead turtles (Tucker et al., 2020), while flatback turtles are more likely to nest on islands in the northeastern part of Exmouth Gulf (Gammon et al., 2023). Satellite tracks from female turtles have shown that flatback, loggerhead, green, and hawksbill turtles that nest in or near Exmouth Gulf come into Exmouth Gulf during their inter-nesting or post-nesting periods, especially for foraging (Thums et al., 2018; Ferreira et al., 2020; Tucker et al., 2020; Peel et al., 2024). Recaptures of adult loggerhead turtles between nesting beaches in Shark Bay and Exmouth Gulf also shows evidence of migration of Shark Bay nesting stocks to Exmouth Gulf, again likely for foraging (Prince et al., 2012).

Juvenile turtles are often sighted within Exmouth Gulf and the surrounding area. As juveniles, most turtles tend to use shallow mangrove or seagrass areas for foraging and protection from predators (e.g., Pillans et al., 2022; Vanderklift et al., 2023), and juvenile green, hawksbill, and loggerhead turtles are known to be present within shallow areas of Exmouth Gulf (e.g., Prince et al., 2012). Juvenile green turtles are abundant in the coastal areas of Exmouth Gulf year-round, especially within the shallow, mangrove-lined southern and eastern parts of Exmouth Gulf which are likely to offer productive foraging areas (D. Rob, pers. comm.). Juvenile green turtles occupying Mangrove Bay on the Ningaloo Coast are highly resident to relatively small home ranges (1.3–1.5 km^2) (e.g., Pillans et al., 2022; Vanderklift et al., 2023). If these characteristics are shared by juvenile green turtles in Exmouth Gulf, juvenile turtles are likely to remain within Exmouth Gulf full time for at least several years until they near maturity. Despite the potential importance of Exmouth Gulf to juvenile turtles for foraging and refuging, the use of Exmouth Gulf by juvenile turtles is poorly understood.

Table 11: **Marine turtle species found within Exmouth Gulf, including their global (IUCN) and national (EPBC Act) conservation statuses. Status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated.**

Scientific name	Common name	Occurrence in Exmouth Gulf	Global IUCN status	Status under EPBC Act
Chelonia mydas	Green turtle	Common	EN	VU, Marine, Migratory
Eretmochelys imbricata	Hawksbill turtle	Regular	CR	VU, Marine, Migratory
Caretta caretta	Loggerhead turtle	Regular	VU	EN, Marine, Migratory
Natator depressus	Flatback turtle	Occasional	DD	VU, Marine, Migratory
Dermochelys coriacea	Leatherback turtle	Rare	VU	EN, Marine, Migratory

3.5.6.1.3 Ecological importance

Sea turtle diets vary by species and life stage. For example, diets of green turtles within the Ningaloo region appear to be dominated by seagrass and macroalgae, with jellyfish and ctenophores contributing more to the diet as green turtles grow (Stubbs et al., 2022). Loggerhead turtles appear to have more of a generalist diet dominated by a variety of invertebrates in most locations, including northwestern Australia (Thomson et al., 2012). Diets of hawksbill and flatback turtles are not well known within Australia (or elsewhere), but likely include a variety of benthic fauna including soft corals, sponges, and other benthic marine invertebrates (Whittock et al., 2016; Fossette et al., 2021). Marine turtles in general hold mid-level trophic positions with ties to a variety of benthic plant, algae, and invertebrate food sources.

Due to their large size and hard shell, adult turtles have few predators within the Exmouth and Ningaloo regions other than tiger sharks, which are known to prey on marine turtles (e.g., Ferreira et al., 2017; Hounslow et al., 2021). However, turtle eggs and hatchlings are an important seasonal food source for a large variety of terrestrial and marine predators. Loggerhead turtle eggs and hatchlings made up 21–62% of the carbon and nitrogen found in ghost crabs (*Ocypode convexa*) on loggerhead nesting beaches at Ningaloo Reef during nesting and hatchling seasons (Avenant et al., 2024a). Monitor lizards and predatory fishes, including sharks, are also known to regularly feed on turtle hatchlings (Wilson et al., 2019; Avenant et al., 2024a). It is likely that sea turtle eggs and hatchlings offer an important seasonal influx of nutrients for food webs, especially for typically nutrient-poor sandy beach areas within the region (Avenant et al., 2024a).

3.5.6.1.4 Significance of Exmouth Gulf

In general, turtle nesting beaches within Exmouth Gulf itself appear to be less common compared to the surrounding Ningaloo and Pilbara coastlines and islands (Rob et al., 2019; DBCA, 2020a; Gammon et al., 2023). However, many islands and areas within Exmouth Gulf have not been thoroughly surveyed for nesting turtles. Areas surrounding the Muiron Islands and the North West Cape, including the northwestern Exmouth Gulf, have been designated BIAs for nesting and inter-nesting green and loggerhead turtles. The Pilbara coastline extending south into the Exmouth Gulf has also been designated a BIA for foraging and inter-nesting for flatback turtles (DCCEEW, 2024). Exmouth Gulf offers important foraging habitat for turtles using nesting locations across northwestern Australia, from Shark Bay to the northern Pilbara (e.g., Prince et al., 2012; Thums et al., 2018; Ferreira et al., 2020). Given the abundance of turtles present within Exmouth Gulf at a variety of life stages, it is likely that this area provides crucial foraging habitat for both juvenile and adult turtles of several species (Figure 58). Observations of mating green and loggerhead turtles have also been noted (Sutton & Shaw, 2021; Sprogis & Parra, 2022). Exmouth Gulf therefore offers regular nesting, reproductive, and foraging habitats for four of Australia's marine turtle species, and is likely to be particularly important as a foraging area for adults and juveniles.

3.5.6.1.5 Threats and pressures

Most threats to marine turtles centre upon disruption of nesting and/or reduction of hatchling success through changes to shoreline habitats. For example, nesting sites for flatback turtles in the northeastern Exmouth Gulf have been hypothesized to be vulnerable to sea level rise and beach erosion (Gammon et al., 2023) as well as destruction from offroad driving (Kobryn et

Figure 58: Marine turtles utilise the habitats of Exmouth Gulf and surrounding beaches for foraging, resting and nesting. Image: Rebecca Bateman-John

al., 2017). Changing temperatures due to climate change are also likely to affect the success rate and sex ratios of turtle nests in the region (Bentley et al., 2020). Predation of marine turtle nests by feral terrestrial predators including red foxes (*Vulpes vulpes*) is another potential threat (DBCA, 2020a). Red foxes have been observed to predate more than a quarter of flatback turtle nests at a Pilbara rookery (King et al., 2023). Prior to feral animal control on the Ningaloo Coast, foxes were estimated to predate up to 70% of sea turtle nests within the World Heritage Area (DEC, 2012). The islands within Exmouth Gulf are largely free of feral predators which provides some refuge from this threat, but nests on beaches that are accessible via the mainland, particularly in the northeastern Exmouth Gulf, may still suffer from fox predation. Egg and hatchling predation by native ghost crabs is also a major threat to marine turtle nests along the Ningaloo coast (Avenant et al., 2024b), but has not been examined for turtle nests in Exmouth Gulf.

Light pollution and shoreline development present issues for turtle hatchlings. Light pollution on or near nesting beaches can disorient hatchlings and reduce their success in reaching the water, or deter females from nesting in their ideal locations (e.g., Kamrowski et al., 2012; Thums et al., 2016). While light pollution risk at turtle nesting beaches within Exmouth Gulf has largely not been assessed, nesting sites on the Ningaloo Coast and at Barrow Island have been identified as among those of the highest risk of light pollution in Australia for green, loggerhead, and flatback turtles (Kamrowski et al., 2012). Given the high rate of coastal development in the Pilbara, this risk is likely to increase. Light pollution and shoreline developments can also pose a risk to hatchlings once they make it to the water by increasing their risk of predation. For example, nearly 70% of flatback turtle hatchlings released near a lighted jetty were predated at a site in the southern Pilbara, compared to 3–23% of hatchlings predated at sites without human structures or artificial lighting (Wilson et al., 2019). In this case, the increased predation threat from artificial light was exacerbated by the presence of a nearshore structure that encouraged predatory fish aggregation.

Fisheries bycatch from the EGPMF is unlikely to exert major pressure on turtles in the region given current catch rates. The introduction of BRDs within the fishery in 2002/2003 reduced turtle bycatch rates by approximately 95% (Kangas et al., 2015). Between 2008 and 2013, the fishery reported between 3–28 turtles caught per year, most of which were returned to the water alive. Captured species included green, loggerhead, and flatback turtles.

3.5.6.2. Sea snakes

3.5.6.2.1 Biodiversity

Exmouth Gulf is a recognised biodiversity hotspot for sea snakes, with at least 11 species from four genera confirmed to occur within Exmouth Gulf, and several others likely to occur due to their presence in surrounding areas (Udyawer et al., 2020; Udyawer et al., 2021; Davenport et al., 2022) (Table 12). In general, sea snake populations within WA have high genetic divergence from other sea snake lineages, and include six species which are endemic to WA (Lukoschek, 2017), four of which are found within Exmouth Gulf (Davenport et al., 2022). Many of these species have limited data available on their ecology and biology and are listed as either data deficient by the IUCN or have not been assessed at a global level (see Table 12). Two species found in Exmouth Gulf, the short-nosed sea snake (*Aipysurus apraefrontalis*) and the leaf-scaled sea snake (*Aipysurus foliosquama*), are listed as Critically Endangered under the EPBC Act due to very limited distributions and recent documented population declines in Ashmore Reef, one of their main areas of occurrence. Both species were thought to be potentially extinct following possible extirpation at Ashmore Reef in the early 2000s until separate breeding populations were discovered in Exmouth Gulf and Shark Bay (Sanders et al., 2015; D'Anastasi et al., 2016; Udyawer et al., 2016).

Table 12: Sea snake species likely to be present within Exmouth Gulf, including their global and national status as listed by the IUCN and the EPBC Act. Status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated. Data from Davenport et al. (2022), Udyawer et al. (2021), Udyawer et al. (2020), S. Coppersmith, pers. comm.

Scientific name	Common name	Occurrence in Exmouth Gulf	Global IUCN status	Status under EPBC Act
Aipysurus apraefrontalis	Short-nosed sea snake	Regular	DD	CR; Marine
Aipysurus duboisii	Dubois' sea snake	Regular	LC	Marine
Aipysurus foliosquama	Leaf-scaled sea snake	Rare	DD	CR; Marine
Aipysurus laevis	Olive sea snake	Common	LC	Marine
Aipysurus mosaicus	Mosaic sea snake	Occasional	LC	Marine
Emydocephalus orarius	Western turtle-headed sea snake	Regular	NE	Marine
Ephalophis greyae	Northwestern mangrove sea snake	Regular	LC	Marine
Hydrophis czeblukovi	Geometrical sea snake	Rare	DD	Marine
Hydrophis kingii	Spectacled sea snake	Rare	LC	Marine
Hydrophis major	Greater sea snake	Common	LC	marine
Hydrophis ocellatus	Spotted sea snake	Common	LC	Marine
Hydrophis peronii	Horned sea snake	Rare	LC	Marine
Hydrophis platurus	Yellow-bellied sea snake	Rare	LC	Marine
Hydrophis stokesii	Stokes' sea snake	Common	LC	Marine
Hydrophis elegans	Elegant sea snake	Common	LC	Marine
Hydrophis macdowelli	Small-headed sea snake	Rare	LC	Marine
Hydrelaps darwiniensis	Black-ringed mangrove sea snake	Rare	LC	Marine

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3.5.6.2.2 Habitat use

Sea snakes can be found throughout Exmouth Gulf, but different species specialise in different types of habitats (Figure 59). Aerial surveys conducted in August through November 2018 suggested that overall abundance of sea snakes may be higher in the northwestern Exmouth Gulf compared to other locations (Irvine & Salgado Kent, 2019), although these surveys were unable to identify snakes to species level. In general, sea snakes in the genus *Aipysurus* are assumed to be associated with coral reefs and benthic habitat structure (Udyawer et al., 2020). However, the Critically Endangered *A. foliosquama* is associated with seagrass and soft-bottomed habitats (D'Anastasi et al., 2016), and *A. apraefrontalis*, *A. laevis*, *A. duboisii*, and *A. stokesii* have been caught within benthic trawls in soft-bottomed habitats in Exmouth Gulf (Kangas et al., 2015; Sanders et al., 2015; D'Anastasi et al., 2016). The recently described WA endemic *Emydocephalus orarius* is also known from soft-bottomed habitats (Nankivell et al., 2020), and most species in the genus *Hydrophis* are assumed to occur more within soft-bottomed habitats (Udyawer et al., 2016; Udyawer et al., 2020). Mangrove and seagrass areas may also be of special importance to some species.

Several species are known to prefer turbid water (Udyawer et al., 2016; Nankivell et al., 2020), which may contribute to why Exmouth Gulf is an important hotspot for sea snakes.

Preliminary data from acoustically tracked individuals of *A. laevis*, *H. major* and *H. stokesii* within Exmouth Gulf show that these species are more commonly detected on the western side of Exmouth Gulf compared to the eastern side (S. Coppersmith, pers. comm.). *Aipysurus laevis* was highly resident to small areas, while *H. stokesii* moved rapidly around different acoustic receivers within Exmouth Gulf. *Hydrophis major* showed very irregular detection patterns indicating this species might use larger areas of Exmouth Gulf or surrounding habitats not covered by the acoustic receiver array (S. Coppersmith, pers. comm.). In general, tagged individuals appeared to mostly remain within Exmouth Gulf rather than travelling long distances to other regions, although there is likely some connectivity with Ningaloo Reef and Coral Bay (S. Coppersmith, pers. comm.). Preliminary genetic studies conducted on these species off the northwest of Australia confirm similar patterns of moderate connectivity between Exmouth Gulf and the Pilbara region, while sea snakes in Shark Bay were genetically distinct (S. Coppersmith, pers. comm.).

Figure 59: Exmouth Gulf is an important hotspot for sea snakes. Image: Kate Sprogis

3.5.6.2.3 Ecological importance

Sea snakes hold mesopredator roles within Exmouth Gulf. Although the species-specific diets are not well-known, sea snakes are generally assumed to feed on a variety of fishes and invertebrates including squid (Fry et al., 2001; Udyawer et al., 2016; Udyawer et al., 2018). Diets are often dominated by benthic fish species including gobies, eels, and catfish (Fry et al., 2001). Stomach content data from snakes collected in the Northern Prawn Fishery show that most species appear to specialise in one to a few fish species or groups (e.g., *A. stokesii*), while others (e.g., *A. laevis*) are thought to be more generalist or opportunistic feeders (Fry et al., 2001).

Predation rates of sea snakes within Exmouth Gulf are not well known, but predators are likely to include white bellied sea eagles (*Haliaeetus leucogaster*) (DBCA, 2017) and tiger sharks (*Galeocerdo cuvier*) (Simpfendorfer et al., 2001).

3.5.6.2.4 Significance of Exmouth Gulf

The North West Shelf, including Exmouth Gulf, is considered a biodiversity hotpot for sea snakes, both within Australia and globally (Udyawer et al., 2016; Lukoschek, 2017). Exmouth Gulf is an important contributor to this biodiversity, conclusively housing 11 of WA's 25 species, with several others likely to also be present in the region or nearby given recent habitat modelling (Udyawer et al., 2020). Exmouth Gulf and surrounding areas support some of the very few remaining and known breeding populations of Australia's two Critically Endangered (EPBC Act) sea snakes (Sanders et al., 2015; D'Anastasi et al., 2016). The turbid, shallow, diverse habitats within Exmouth Gulf, particularly including soft-bottom, seagrass, mangrove, and coral reef habitats, alongside limited levels of human disturbance, are ideal for many sea snake species (Udyawer et al., 2016; Udyawer et al., 2020).

While there are still many unanswered questions about sea snake biology and ecology within Exmouth Gulf, there is comparatively more research on sea snakes within Exmouth Gulf compared to most other locations within Australia. This includes several large-scale ongoing studies which are expected to provide more information about species diversity, movement ecology, genetic connectivity, and effects of trawl fisheries on sea snakes within Exmouth Gulf within the next few years (S. Coppersmith, pers. comm.).

As such, in addition to being a sea snake biodiversity hotspot, Exmouth Gulf is also sea snake research hotspot, and offers the opportunity to provide crucial biological and ecological data on sea snakes found throughout northwestern Australia.

3.5.6.2.5 Threats and pressures

Many species of sea snake have low reproductive rates which makes populations vulnerable to human induced mortality. For example, while reproductive parameters vary by species, most sea snake genera found within Exmouth Gulf give birth to live young and typically have < 10 offspring every 1–3 years, depending on the species (Fry et al., 2001; Udyawer et al., 2016; Shine et al., 2019).

The main direct threat to sea snakes within Exmouth Gulf is via bycatch in the EGPMF. Bycatch reduction devices are not as effective at excluding sea snakes compared to larger fauna. The number of individuals reported as captured varied from 13–1551 each year between 2007 and 2022 (Table 13) (Kangas et al., 2015; Fletcher & Santoro, 2015; Fletcher et al., 2017; Gaughan & Santoro, 2018, 2019; Gaughan & Santoro, 2020, 2021; Newman et al., 2021; Newman et al., 2023a; Newman et al., 2023b). The larger numbers of captures reported in recent years are thought to be due to better education and reporting within the fishery (Kangas et al., 2015). Reported species captured include *A. duboisii*, *A. laevis*, *A. apraefrontalis*, *H. major* and *H. stokesii* (Kangas et al., 2015), and fishery-independent trawl surveys in the region also reported capture of *H. ocellatus*, *A. mosaicus*, *H. elegans*, and *E. annulatus* (Udyawer et al., 2021). The most commonly captured sea snakes in fishery-independent trawl surveys were *A. laevis* and *A. apraefrontalis*. Most sea snakes caught in the EGPMF are released alive, with an average reported at-vessel mortality rate of approximately 8% (Table 13). However, post-release mortality of sea snakes is poorly documented in the EGPMF or other WA trawl fisheries. A study in eastern Australia found that sea snakes showed approximately 20% post-release mortality rates on average, increasing to over 60% in large individuals (Courtney et al., 2010). Mortality rates also varied widely by species. A separate study in the Gulf of Carpentaria with similar trawl methods to the EGPMF found that an average of 40% of sea snakes died following trawl capture (Wassenberg et al., 1994).

Larger species of sea snakes, including *H. elegans*, *H. stokesii*, *A. laevis*, or gravid individuals, have higher at-vessel mortality rates, and are likely more susceptible to post-release mortality as well (Udyawer et al., 2016; Udyawer et al., 2021).

Other risks to sea snakes within northwestern Australia include declining water quality, habitat loss, coastal development, disease, and climate change (Udyawer et al., 2018). Sea snakes also face the risk of boat strike in high-traffic areas, and changes in trophic dynamics and prey abundance stemming from changes in other predator densities (Somaweera et al., 2021). The extent of these threats to sea snakes within Exmouth Gulf specifically is not well known.

Table 13: **Captures of sea snakes reported from the Exmouth Gulf Prawn Managed Fishery between 2007 and 2022 (Fletcher et al., 2017; Fletcher & Santoro, 2015; Gaughan & Santoro, 2018, 2019; Gaughan & Santoro, 2020, 2021; Kangas et al., 2015; Newman et al., 2023a; Newman et al., 2021; Newman et al., 2023b).**

Year	Total	% dead at capture
2007/08	13	Unknown
2008/09	103	Unknown
2009/10	80	Unknown
2010/11	152	1.7%
2011/12	497	9.7%
2012/13	70	Unknown
2013/14	111	5.4%
2014/15	60	16.7%
2015/16	570	13.0%
2016/17	1529	17.5%
2017/18	1551	7.4%
2018/19	1248	6.5%
2019/20	994	5.0%
2020/21	1347	4.5%
2021/22	871	5.9%
Annual average (s.e)	**613 ± 152**	**8.5 ± 1.6%**

3.5.6.3. Crocodiles

Saltwater crocodiles (*Crocodylus porosus*) are common throughout the Kimberley region as well as across the Northern Territory and Queensland, with their core distribution in WA defined only as far south as between Broome and Port Hedland (Halford & Barrow, 2017). Not much is known about their presence or ecology in the Pilbara and Gascoyne regions within WA. Historically, saltwater crocodiles across Australia's north were hunted to near extinction for their skins, until they became protected in WA in 1969, and in the Northern Territory and Queensland soon after. Since protection, populations have spectacularly recovered, with studies in the Northern Territory showing that crocodile populations in many places have likely reached carrying capacity (Fukuda et al., 2011). In WA, the crocodile population in the east Kimberley was considered 'very good' in a recent assessment, although the west Kimberley population was found to be still recovering (Halford & Barrow, 2017).

As these northern populations recover, saltwater crocodiles have been increasingly spotted further south along the northwest coast, and their range has been recognised to extend to Exmouth Gulf for over a decade (Semeniuk et al., 2011). Crocodile sightings throughout the Pilbara and Exmouth regions have been rare, and crocodiles in this region were generally assumed to be vagrants or travelling individuals rather than residents (Semeniuk et al., 2011; Halford & Barrow, 2017). However. there are long-term records of lone male resident crocodiles within a few Pilbara rivers and tidal creeks (Mawson, 2004; Semeniuk et al., 2011). Vagrants have also been observed as far south as Carnarvon (Semeniuk et al., 2011). Sighting rates of crocodiles within the Exmouth and Pilbara regions have rapidly increased over the last few years, particularly since 2023. The Exmouth and Pilbara regional DBCA offices have received reports of at least 12 confirmed sightings and 11 unconfirmed sightings of crocodiles across Exmouth Gulf and Ningaloo reef in 2023–2024 (DBCA, pers. comm.) (Figure 60, Figure 61). This is more sightings than have been reported across the Pilbara in the previous decade combined, according to a Pilbara news article (Shackleton, 2024).

Saltwater crocodiles prefer freshwater habitats (floodplain wetlands and swamps) for nesting, which are scarce throughout the Pilbara due to the low rainfall, with nesting in marine habitats, such as mangrove swamps, rarely observed (Semeniuk et al., 2011).

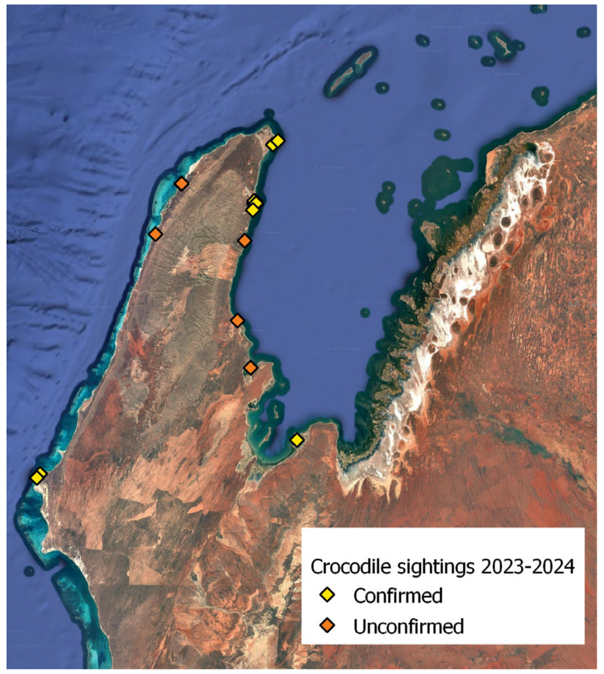

Figure 60: **Saltwater crocodile (*Crocodylus porosus*) sightings within Exmouth Gulf and the Ningaloo region in 2023–2024. During this period there have been 12 confirmed sightings (yellow) and 11 unconfirmed sightings (orange), of likely several different crocodiles. Compiled from community alerts published on Exmouth and Pilbara Parks and Wildlife Facebook Pages and direct communication from Exmouth DBCA Office.**

Additionally, they are thought to require higher temperatures for effective nesting and hatching than are experienced in the Pilbara (Halford & Barrow, 2017). Therefore, Exmouth Gulf is unlikely to offer breeding habitat for saltwater crocodiles. Saltwater crocodiles are highly territorial, and younger subordinate individuals (particularly males) may seek sub-optimal unoccupied habitats outside of their traditional range (Semeniuk et al., 2011). Research into residency patterns, sex ratios, and behaviour of crocodiles occurring off the Pilbara and Exmouth regions is needed to determine how they may be using Exmouth Gulf.

Given expanding saltwater crocodile populations across the northwest, combined with temperature induced range extensions to the south, saltwater crocodiles will likely continue to become more common and/or resident within Exmouth Gulf. Similar trends have been hypothesized for equivalent latitudes in eastern Australia (Hamann et al., 2007). If they become more common within the region, saltwater crocodiles have the potential to enact major shifts within ecosystem dynamics given their apex predator status (Semeniuk et al., 2011). Diets of saltwater crocodiles off the Pilbara have not been studied, but across northern Australia, prey items include a variety of fish, elasmobranchs, sea snakes, marine turtles, birds, and marine and terrestrial mammals (Semeniuk et al., 2011; Whiting & Whiting, 2011; Hanson et al., 2015).

Figure 61: **Saltwater crocodile (*Crocodylus porosus*) sighted in a narrow tidal creek near Sandalwood Landing in the southwestern Exmouth Gulf in August, 2024. Image: Kimberly Kliska**

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Dugong mother and calf. Image: Blue Media Exmouth

3.5.7. Dugongs

3.5.7.1. Habitat use

Dugongs (*Dugong dugon*) can be found in coastal tropical and subtropical areas throughout the Indian and western Pacific Oceans. Within Australia, they range from approximately Shark Bay in WA across the northern part of the continent and south along the east coast to approximately Moreton Bay near Brisbane (Marsh & Sobtzick, 2019). Anecdotal observations have also been documented south of Brisbane to Sydney. Globally, the IUCN lists dugongs as Vulnerable with a declining global population (Marsh & Sobtzick, 2019), and within Australia they are listed under the EPBC Act as Migratory, though do not have a nation-wide threatened listing status. In New South Wales, they are listed as Endangered, and in Queensland they are listed as Vulnerable. In WA, they are specially protected under the *Biodiversity Conservation Act 2016*.

Dugongs occupy shallow coastal waters near to seagrass beds or other productive, soft-bottomed benthic feeding grounds. Exmouth Gulf has long been known to hold important habitat for dugongs (e.g., Preen et al., 1997). Most population estimates for Exmouth Gulf range from approximately 100 to over 4800 dugongs, depending on the year, season, and estimation method used (Preen et al., 1997; Gales et al., 2004; Hodgson, 2007; Bayliss et al., 2018; Bayliss et al., 2019; Tucker, 2023). Combined with movement of dugongs in and out of Exmouth Gulf, this makes it difficult to distinctly determine long-term population trends for dugongs in this region (Hodgson et al., 2008; Bayliss et al., 2018). No significant differences in dugong densities between 1989 and 2007 were found (although with low certainty and survey resolution; Hodgson et al., 2008), though dugong numbers have increased substantially within the Ningaloo-Exmouth region between 2007 and 2018 (Bayliss et al., 2018). Dugongs are most often sighted as individuals, mothers and calves, or within small groups (Preen et al., 1997; Tucker, 2023). Large herds of 44–50 dugongs have also been recorded in Exmouth Gulf

While dugongs have been sighted throughout Exmouth Gulf, including on the western side (e.g., Preen et al., 1997; Sprogis & Parra, 2022; Sprogis & Waddell, 2022; Irvine et al., 2025a), most are found in the shallow habitats throughout southern and eastern Exmouth Gulf where the majority of seagrass beds are located (Hodgson, 2007; Irvine & Salgado Kent, 2019; Cleguer et al., 2021b; Tucker, 2023). Aerial surveys along the western side of Exmouth Gulf in 2023 confirmed sporadic presence of dugongs along the whole western coastline, with more dense sightings in areas between Pebble Beach and Badjirrajirra Creek, and within Gales Bay (Irvine et al., 2025a). Dugong habitat preference within Exmouth Gulf, and sites along the Pilbara coastline, has been shown to be highly correlated with the presence of seagrass beds. A recent study found that areas of sparse seagrass coverage (2–11%) of *Halophila ovalis* and *Halodule uninervis* may be especially important (Said et al., 2025). This likely explains the importance of mid-eastern Exmouth Gulf where seagrass beds, including sparse beds of *Halophila ovalis* and *Halodule uninervis*, tend to be most abundant (McCook et al., 1995; Loneragan et al., 2013). Given the observed spatial and temporal variability in dugong densities across the eastern side of Exmouth Gulf, it is unknown what proportion of dugongs reside in Exmouth Gulf or whether dugongs regularly come in and out of the region. A genetic study is ongoing to help answer this question (C. Cleguer, pers. comm.).

Aerial surveys have shown some changes in abundance of dugongs in Exmouth Gulf between months. For example, Irvine and Salgado Kent (2019) found higher numbers of dugongs in early August and October compared to September and November. Cleguer et al. (2021a) also showed that density distributions of dugongs shift spatially across seasons within Exmouth Gulf. Dugong surveys have generally been conducted across winter months, and further seasonally based surveys are necessary to confirm whether dugongs in Exmouth Gulf regularly undertake seasonal migrations (Tucker, 2023).

3.5.7.2. Ecological importance

Dugongs mainly feed on seagrasses in addition to algae and macroinvertebrates, and they can exert major pressure on seagrass beds through foraging activity (Marsh et al., 2018). Adult dugongs are estimated to consume approximately 7% of their body weight in seagrass/algae each day. They feed by either cropping leaves off the seagrass shoot or excavating the entire plant, disturbing a large amount of sediment in the process (Marsh et al., 2018).

The main seagrasses present in Exmouth Gulf include *Cymodocea serrulata, Halophila ovalis, Halodule uninervis,* and *Syringodium isoetifolium*. These species are sparse in many areas (generally less than 5% cover), however, can have up to 50% cover in certain locations within the southern and eastern Exmouth Gulf (McCook et al., 1995; Loneragan et al., 2013). The areas with sparse seagrass coverage may be especially important for dugongs, as recent findings have shown that dugongs in WA, including in Exmouth Gulf, Shark Bay, and the Pilbara, tend to prefer foraging in sparse seagrass meadows rather than dense seagrass meadows (Bayliss et al., 2019; Said et al., 2025). The effects of dugong herbivory on seagrasses within Exmouth Gulf have not been directly examined. However, in other regions dugong foraging has been shown to significantly increase productivity within seagrass beds by disturbing of seagrass plants, detritus, and sediments, which increases rates of microbial processes and nitrogen fixation (Marsh et al., 2018). Dugong foraging can also reduce detritus levels in seagrass beds and vary the age structure of seagrass communities, which overall is beneficial to seagrass productivity (Marsh et al., 2018). Dugongs are also known to promote seagrass seed dispersal (McMahon et al., 2018). Herbivory by dugongs is therefore likely an important ecological process for maintenance and productivity of seagrass beds within Exmouth Gulf.

3.5.7.3. Significance of Exmouth Gulf

Exmouth Gulf is a significant breeding, nursery, and foraging habitat for dugongs. During aerial surveys of Exmouth Gulf in 1989, 1994, 2017, 2018, and 2022, 12–24% of dugongs sighted were calves (Preen et al., 1997; Irvine & Salgado Kent, 2019; Tucker, 2023; Irvine et al., 2025a). These numbers are an indication of good population health. Dugong densities estimated from recent aerial surveys are also higher within Exmouth Gulf compared to along the Ningaloo coastline (Bayliss et al., 2018). This is expected, given that Ningaloo does not provide as much seagrass habitat as Exmouth Gulf and is less sheltered. Exmouth Gulf is, therefore, likely to be of regional importance for dugongs, and the whole Gulf has also been determined a BIA for breeding dugongs (DCCEEW, 2024). The importance of the area for dugong foraging and

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reproduction also contributed to the international recognition of Exmouth Gulf as an Important Marine Mammal Area by the IUCN marine mammal protected area task force (IUCN-MMPATF, 2022).

Connectivity between Exmouth Gulf and other important dugong habitats in WA including Ningaloo Reef and Shark Bay also speaks to its importance. Aerial surveys suggest that some dugongs are likely to migrate between Shark Bay, Ningaloo Reef, Exmouth Gulf, and further north to the Pilbara depending on food availability (C. Cleguer, pers. comm.). Although, levels of gene flow and genetic connectivity between these areas is yet to be understood. A large migration of dugongs out of Exmouth Gulf south to Shark Bay may have occurred after TC Vance destroyed much of the seagrass cover in Exmouth Gulf in 1999 (Gales et al., 2004). Satellite tracks from dugongs tagged in eastern Exmouth Gulf also showed that within an average 35-day monitoring period, three of five tagged dugongs transited between Exmouth Gulf and Ningaloo Reef, confirming high connectivity between these areas (Cleguer et al., 2024). The ability for dugongs to migrate between these protected and productive habitats when food resources become scarce in one location is likely to be crucial to WA supporting a healthy population of dugongs overall. The dugong population in Shark Bay is internationally significant, with a higher population of dugongs reported there compared to most other areas throughout the species' global range (Preen et al., 1997). The connectivity between Exmouth Gulf and other northwestern Australian dugong habitats is likely to become more important in the future considering that destructive cyclones, marine heatwaves, and other processes that disturb seagrass beds are likely to occur more frequently.

3.5.7.4. Threats and pressures

Direct threats to dugongs within Exmouth Gulf have not been quantified but are likely similar to other locations and include injury or mortality due to boat strikes, entanglement in fishing gear, and behavioural disturbances from boat traffic (Groom et al., 2004; Hodgson & Marsh, 2007).

Boat strike is one of the leading causes of dugong mortality in Queensland (Yeates & Limpus, 2002), exacerbated by dugongs' tendency to occupy surface waters, their low profile in the water, and their typically delayed responses to vessel approaches (Groom et al., 2004). The level of this threat in Exmouth Gulf is unknown at present, but dugong mortalities caused by boat strike have been confirmed in 2018, 2020, and 2021 (Pilbara News, 2018; H. Raudino, pers. comm.). Along the western side of Exmouth Gulf, areas of higher dugong abundance (e.g., between Pebble Beach and Badjirrajirra Creek) were also found to be some of the most highly trafficked areas for recreational vessels, increasing the chances of vessel strike (Irvine et al., 2025a). Vessel noise has also been shown to disturb dugongs, such as disrupting feeding behaviour, especially if a boat passes with 50 m of the animal (Hodgson & Marsh, 2007). Future developments that increase boat traffic in Exmouth Gulf, especially in proximity to seagrass beds, may therefore be of a concern to dugongs. Hodgson (2007) estimates that given the population size, growth and reproductive characteristics of dugongs in Exmouth Gulf, the maximum sustainable level of mortality from any source for the population is approximately four dugong deaths per year.

As dugongs are highly dependent on seagrass meadows, this species is also vulnerable to changes in ocean conditions that affect seagrass abundance. This includes events such as cyclones or marine heatwaves that degrade or destroy seagrass habitat and take several years to recover (see Section 3.4.8) (Gales et al., 2004; Loneragan et al., 2013; Vanderklift et al., 2016). Direct degradation of seagrass habitats through development (e.g., dredging; Vanderklift et al., 2016), and changes in water turbidity are also of concern (Longstaff & Dennison, 1999), as is alteration to groundwater discharge/nutrient profiles that could potentially influence seagrass growth.

3.5.8. Toothed whales and dolphins

3.5.8.1. Biodiversity

Orcas, false killer whales, and four species of dolphins have been recorded in Exmouth Gulf (Table 14). Of the dolphin species, the most common is the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), followed by the Australian humpback dolphin (*Sousa sahulensis*) (Sprogis & Parra, 2022). There have been sporadic sightings of Australian snubfin dolphins (*Orcaella heinsohni*) within Exmouth Gulf (e.g., Hanf et al., 2022) which marks the approximate southern end of their distribution. Snubfin dolphins sighted in Exmouth Gulf may only be occasional visitors to the area or vagrants from populations further north (Sprogis & Parra, 2022). In addition, a single deceased Risso's dolphin (*Grampus griseus*) was reported from a stranding along the western shore of Exmouth Gulf in February 2025 (D. Rob, pers. comm.), though this species is not known to regularly use Exmouth Gulf. Hanf et al. (2022) also reported sightings (via aerial survey) of dolphins within the *Stenella* genus, and six dead spotted dolphins (most likely *Stenella attenuata*) were reported in a stranding in 1997 (Vance & Carter, 2005). *Stenella* dolphins have not been reported by other recent studies and specific species could not be confirmed. False killer whales (*Pseudorca crassidens*) have been sighted within nearshore areas of the Pilbara region (e.g., Hanf et al., 2022) and occasionally within Exmouth Gulf (L. Irvine, pers. comm.). A stranding of one live, wounded, false killer whale also occurred in 2013 within the Bundegi Sanctuary Zone (D. Rob, pers. comm.).

Orcas (*Orcinus orca*) are occasionally seen in Exmouth Gulf and are known to regularly occupy waters off Ningaloo Reef (e.g., Pitman et al., 2015). Directed research on this species within Exmouth Gulf is limited, but at least 24 confirmed sightings of orcas have occurred in Exmouth Gulf over the last decade in addition to eight sightings near the Muiron Islands. Together, these sightings comprise approximately 15% of orca sightings in the Exmouth-Ningaloo region over this time period (J. Totterdell, pers. comm.). Most sightings have occurred in winter, spring, and summer and have been centred along the western side of Exmouth Gulf. This is also where most survey and citizen science effort has occurred. Individual identification has confirmed the presence of at least two different groups of orcas using Exmouth Gulf, one predominantly in winter/spring (40 known individuals), and one in summer (14 individuals) (J. Totterdell, pers. comm.). Both groups have also been sighted along the Ningaloo Coast, and the winter/spring group is known to target humpback whale calves along Ningaloo Reef (Pitman et al., 2015). Attempted humpback calf attacks and/or harassment by this group has been observed in Exmouth Gulf, though no successful predations have been confirmed (J. Totterdell, pers. comm.). Historically, there was also a mass stranding of seven orcas on the western side of Exmouth Gulf in 1997, of which four died and three were re-floated (Vance & Carter, 2005).

The remainder of this section focuses on the two resident dolphin species in Exmouth Gulf: Australian humpback dolphins (further referred to as humpback dolphins), and Indo-Pacific bottlenose dolphins (further referred to as bottlenose dolphins). Given the rarity of records of other species in Exmouth Gulf, these are not further discussed.

Orca. Lyn Irvine

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Table 14: Toothed whales and dolphins that are likely to be found in Exmouth Gulf, along with their global (IUCN) and national (EPBC Act) conservation statuses. Two potential sightings of dolphins from the *Stenella* genus have also been reported within Exmouth Gulf via aerial survey (Hanf et al., 2022), but have not been confirmed or identified to species level. Status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated.

Scientific name	Common name	Occurrence in Exmouth Gulf	Global IUCN status	Status under EPBC Act
Tursiops aduncus	Indo-pacific bottlenose dolphin	Common	NT	Cetacean
Sousa sahulensis	Australian humpback dolphin	Regular	VU	Cetacean, Vulnerable
Orcaella heinsohni	Australian snubfin dolphin	Rare	VU	Cetacean, Vulnerable
Grampus griseus	Risso's dolphin	Rare	LC	Cetacean
Orcinus orca	Orca/killer whale	Occasional	DD	Cetacean, Migratory
Pseudorca crassidens	False killer whale	Rare	NT	Cetacean

3.5.8.2. Habitat use

Bottlenose and humpback dolphins regularly use Exmouth Gulf habitats for foraging, resting, travelling, and reproduction (Hunt et al., 2020; Haughey et al., 2021; Sprogis & Parra, 2022). Aerial surveys have shown that both bottlenose and humpback dolphins can be found throughout Exmouth Gulf (Preen et al., 1997; Irvine & Salgado Kent, 2019; Hanf et al., 2022; Raudino et al., 2023). Aerial surveys have suggested that humpback dolphins appear to prefer the periphery of Exmouth Gulf mostly on the eastern margin, while bottlenose dolphins also use the deeper waters towards the centre of Exmouth Gulf (e.g., Hanf et al., 2022; Raudino et al., 2023). Boat based surveys in the western Gulf between Bundegi and Charles Knife have confirmed this trend, with humpback dolphin groups generally sighted in slightly shallower areas (mean depth 6.4 – 10.3 m; Sprogis & Parra, 2022; Sprogis & Waddell, 2022) compared to bottlenose dolphins (mean depth 10.8 m; Sprogis & Parra, 2022; Sprogis & Waddell, 2022). During these boat-based surveys, bottlenose dolphins were found above a variety of benthic habitats including reef, seagrass, sand, and algal reef areas (Sprogis & Parra, 2022; Sprogis & Waddell, 2022). Humpback dolphins were sighted above reef and mixed-bottom habitats. Locations of these sightings also suggested that shallow intertidal areas around mangroves and near locations with freshwater run-off are important habitats for this species (Hunt et al., 2020; Hanf et al., 2022; Sprogis & Parra, 2022; Sprogis & Waddell, 2022). Alternatively, bottlenose dolphins within the northwestern Gulf and around North West Cape were found to be most common within 1–2 kilometres from shore (Haughey et al., 2021).

Both bottlenose and humpback dolphins are most often seen in small groups within Exmouth Gulf (e.g., Figure 62), though have also been observed in nearshore areas as individuals, single mother-calf pairs, and larger groups of up to 25 or 30 individuals (humpback and bottlenose dolphins, respectively) (Haughey et al., 2020; Sprogis & Waddell, 2022). Interspecific groups containing a mix of the two species are also often observed within Exmouth Gulf and off North West Cape (Raudino et al., 2022; Sprogis & Parra, 2022; Sprogis & Waddell, 2022; Syme et al., 2023). Mixed-species groups tend to be larger (up to 42 individuals), and dolphins are more often observed socialising in mixed species groups compared to foraging and travelling, which are the dominant behaviours in single-species groups (Sprogis & Parra, 2022; Sprogis & Waddell, 2022; Syme et al., 2023). The formation of mixed-species groups may therefore represent important social opportunities for both species of dolphin, including potential alloparenting and the ability for young dolphins to develop and practice social and sexual behaviours (Syme et al., 2023).

Figure 62: Bottlenose dolphins are frequently observed in Exmouth Gulf. Image: Lyn Irvine

Most boat-based and aerial surveys for dolphins within Exmouth Gulf have occurred over limited seasonal time scales, and thus the seasonality of dolphin occurrence within Exmouth Gulf has not been thoroughly investigated. The limited data on seasonal occurrence trends also varies by study and method. For example, occurrence rates for both humpback and bottlenose dolphins were similar in the western Exmouth Gulf between autumn and spring surveys (Sprogis & Parra, 2022; Sprogis & Waddell, 2022), while bottlenose dolphins were significantly more common in winter and spring compared to autumn in the northwestern Exmouth Gulf (Haughey et al., 2021). Alternatively, Irvine and Salgado Kent (2019) generally found higher numbers of dolphins across Exmouth Gulf (via aerial surveys) in August compared to September–November, although sightings were not identified to species level. Similarly, boat-based surveys around the North West Cape found higher abundances of humpback dolphins in autumn/winter than in winter/spring (Hunt et al., 2017). Seasonal patterns in occurrence were not the focus of any of these studies, and differences in weather and visibility between seasons could have affected rates of sightings.

3.5.8.3. Life history

For both humpback and bottlenose dolphins, females tend to give birth to a single calf several years apart to allow the calves to wean. Reproductive intervals have not been determined for either species along northwest Australia, but in Queensland interbirth intervals for humpback dolphins ranged to over six years, and averaged 3.1 years if the calf survived (Hawkins & Dunleavy, 2024). In bottlenose dolphins in Shark Bay, weaning times range from 2.7 to 8 years, with an average interbirth interval of 4.1 years (Mann et al., 2000). Age at first birth for females is also unknown in the Exmouth or Pilbara regions, but in Shark Bay bottlenose dolphins birthed their first calves between approximately 12 and 15 years old (Mann et al., 2000). Female humpback dolphins are thought to reach sexual maturity at around 9–10 years old (Parra & Cagnazzi, 2016).

There have been multiple sightings of newborn calves of both species in Exmouth Gulf across several months. Newborn humpback dolphin calves have been sighted in May and October in Exmouth Gulf and around the North West Cape (Hunt et al., 2019; Sprogis & Parra, 2022; Sprogis & Waddell, 2022), and in March, June, July, September, and October near Onslow and the Montebello Islands (Raudino et al., 2018a; Raudino et al., 2018b). There does not yet appear to be an obvious seasonality to the birthing period within the region. This is contrary to Moreton Bay, Queensland, which has a distinct autumn/winter birthing season (Hawkins & Dunleavy, 2024). Similarly, newborn bottlenose dolphin calves have been sighted within Exmouth Gulf in May and October (Sprogis & Parra, 2022; Sprogis & Waddell, 2022), suggesting that the birthing season for this species in the region may be less restricted than the summer birthing season observed in more southerly populations around Shark Bay and the Perth Metro region (Mann et al., 2000; Smith et al., 2016).

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Calf survival rates are unknown within Exmouth Gulf and the surrounding region. In Shark Bay, bottlenose dolphin calves have been estimated to have a 73% survival rate, while juveniles and adults had 97% and 90% survival rates, respectively (Manlik et al., 2016). In Moreton Bay, Queensland, humpback dolphins have recorded 1-year calf survival rates of 63% on average (Hawkins & Dunleavy, 2024). However, survival rates of calves and older age classes are likely to depend on predator densities, food availability, and other parameters, and will vary by population. Further research into reproductive parameters and survival of both humpback and bottlenose dolphins within Exmouth Gulf would help to estimate the productivity of these populations and their vulnerability to mortality and other threats.

3.5.8.4. Population connectivity

Recent genetic studies of bottlenose dolphins have demonstrated that populations found along the coast of WA most likely originated from a single population further north, which rapidly colonised the coast progressing southwards (Wittwer et al., 2023; Marfurt et al., 2024). This has resulted in a clear example of isolation by distance, with genetic diversity generally declining along a southwards trajectory. Individuals sampled off the North West Cape region were genetically distinct from those in Shark Bay or further south, as well as from Cygnet Bay in the Kimberley. However, they were reasonably similar to other individuals sampled between Coral Bay and Dampier, or depending on the number of subpopulations identified, also including Port Hedland and Broome (Wittwer et al., 2023; Marfurt et al., 2024). Within this broad-scale genetic structure however, there is little information about connectivity and spatial limitations of specific bottlenose dolphin populations, including the those inhabiting the North West Cape area and Exmouth Gulf. Resighting of individual bottlenose dolphins through photo-identification methods have alluded to at least moderate residency or return rates within Exmouth Gulf, with 56 of 199 individuals identified in May 2021 in Exmouth Gulf still present within the same area in October 2021 (Sprogis & Parra, 2022; Sprogis & Waddell, 2022). Approximately half of the individuals sighted in this study in May, and nearly 60% of the individuals sighted in October, had also been previously sighted around North West Cape between Bundegi and Tantabiddi boat ramps in previous years (Sprogis & Parra, 2022). Photo-identification methods employed on bottlenose dolphins between Bundegi and Tantabiddi boat ramps in 2013–2015 classified 58% of identified individuals as "non-residents", with an estimated "resident" population of 141, and an overall population of 370 individual inhabiting this area (Haughey et al., 2020).

Humpback dolphins are generally assumed to live within small regional populations that have low dispersal and migration rates, and therefore low gene flow between populations (Brown et al., 2014; Hanf et al., 2016; Parra et al., 2018). Accordingly, genetic studies have demonstrated significant genetic structuring between populations found off the North West Cape to those in Dampier and the Kimberley (Brown et al., 2014; Brown et al., 2017). Although somewhat limited, the information available for residency rates of humpback dolphins within Exmouth Gulf or the wider North West Cape region confirm this trend. For example, resighting rates of individuals through photo identification showed high residency or return rates of individual humpback dolphins within the western Exmouth Gulf between May and October 2021 (e.g., 12 resighted individuals of 21 originally identified; Sprogis & Waddell, 2022). High resighting rates within Exmouth Gulf of individuals originally identified off the North West Cape (71% of humpback dolphins identified within western Exmouth Gulf) also confirm connectivity between Exmouth Gulf and Ningaloo Reef humpback dolphins (Sprogis & Waddell, 2022). A two-year photo mark-recapture study off the North West Cape from Bundegi to Tantabiddi boat ramps also found high resighting rates, estimating that 63% of the population had high site fidelity to the region (Hunt et al., 2017). This fairly resident population also showed a highly complex 'fission-fusion' society, with preferred companionships and casual acquaintances identified between individuals, and fluid small groups often mixing together with no distinct social communities (Hunt et al., 2019). Together, these studies indicate that there is likely a resident population of humpback dolphins in the Exmouth region with individuals travelling around the North West Cape area. Further genetic, tagging, and extended photo mark-recapture studies of humpback dolphins in the region would be helpful in identifying the spatial extent of this population, the area used by individuals, and connectivity between this region and other areas of the Pilbara.

3.5.8.5. Ecological importance

Dolphins are top-level predators, and therefore can exert major top-down control on prey species through trophic cascades. Bottlenose dolphins are known to feed on a variety of teleost fish species and cephalopods. In the Exmouth Gulf and off North West Cape, they have been observed eating mullet (family Mugilidae), longtom (family Belonidae), robust garfish (*Hemiramphus robustus*), and trevallies (Family Carangidae) (Haughey et al., 2021; Sprogis & Parra, 2022). Humpback dolphins may share several prey species with bottlenose dolphins and are thought to have a generalist feeding strategy focused on teleost fishes (Parra & Jedensjö, 2014). Their diet within Exmouth Gulf or WA in general has not been studied, but off the North West Cape, they have been observed feeding on unicorn fish (*Naso* sp.) (Hunt et al., 2020).

The main predators of humpback and bottlenose dolphins in the Exmouth region include orcas, tiger sharks and other shark species, as evidenced by scarring congruent with attempted shark bites on a number of individuals present within Exmouth Gulf and nearby regions (Haughey et al., 2020; Haughey et al., 2021; Sprogis & Parra, 2022). Orcas have been observed killing and eating spinner dolphins (*Stenella longirostris*) in the Ningaloo region (Pitman et al., 2015). It is unclear how important humpback or bottlenose dolphins are as a food source for either sharks or orcas within Exmouth Gulf and the wider Ningaloo and Pilbara regions.

3.5.8.6. Significance of Exmouth Gulf

A comparison of dolphin densities between Exmouth Gulf and surrounding areas shows that Exmouth Gulf is a regional and national hotspot for both humpback and bottlenose dolphins (Sprogis & Parra, 2022). For example, Raudino et al. (2023) compared dolphin abundance estimates from aerial surveys between Exmouth Gulf, the Ningaloo coastline, and the southern Pilbara, and found the highest abundance for both humpback and bottlenose dolphins in Exmouth Gulf compared with other areas. Similarly, boat surveys have found higher sighting rates of bottlenose dolphins in the northwestern Exmouth Gulf compared to the rest of the North West Cape region (Haughey et al., 2021) and Onslow region (Raudino et al., 2018a). The density of humpback dolphins around the North West Cape has been estimated at 0.9 to 1.1 individuals per km^2, which is the highest sighting rate for this species reported to date within northern Australia (Hunt et al., 2017). Given the decline of humpback dolphin populations nationally (e.g., Parra & Cagnazzi, 2016), the presence of a 'hotspot' for this species within Exmouth Gulf and around the North West Cape may become more important in the future.

Humpback whale mother and calves. Holly Raudino

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The variety of behaviours and high rates of calves sighted within Exmouth Gulf also highlights its regional importance. Newborn dolphin calves (with foetal folds showing) of both species have been sighted in Exmouth Gulf, suggesting that the area offers calving and nursery habitat for both humpback and bottlenose dolphins, potentially due to its protected nature and high food availability (Sprogis & Parra, 2022). Additionally, while boat-based survey effort has been higher within Exmouth Gulf and around the North West Cape compared to other regions of the Pilbara, high rates of mother-calf sightings of both bottlenose and humpback dolphins have been found within Exmouth Gulf. This includes 30 different bottlenose dolphin calves (~13% of individuals) and four humpback dolphin calves (~7% of individuals) identified in the western Exmouth Gulf in May, 2021 (Sprogis & Parra, 2022), and roughly two thirds of humpback dolphin groups sighted around the North West Cape in April 2010 supporting calves (Brown et al., 2012). Given the moderate to high residency of both humpback and bottlenose dolphins off the North West Cape region, it is unlikely that individuals migrate into Exmouth Gulf specifically for calving or nursing. Rather, the high number of calf sightings within the area is likely an artefact of the large population sizes of both species compared to other regions. However, it does show that Exmouth Gulf and the North West Cape offer productive habitat for bottlenose and humpback dolphins which allows them to effectively feed and reproduce.

3.5.8.7. Threats and pressures

The greatest threats to dolphins within the Exmouth Gulf region likely relate to disturbance from underwater noise, including vessel noise, dredging, pile driving, and seismic surveys (Hanf et al., 2016; Hunt et al., 2017). Like other cetaceans, underwater noise and/or disturbance from vessel approach can cause changes in behaviour and activity of dolphins. These include initiating energetically costly avoidance behaviours or interrupting foraging, socialising, or resting (Arranz et al., 2021; Sprogis et al., 2020). For example, proposed activities associated with the construction of the terminated Learmonth Pipeline Fabrication Facility proposal in the southwestern Exmouth Gulf were predicted to cause behavioural disruptions to marine mammals present within 5 to 19 km of the site, depending on activity (Koessler et al., 2020). Long-term disturbance from dolphin-watch tourism activities has also been shown to decrease dolphin abundance in other areas of northwestern Australia (e.g., Shark Bay; Bejder et al., 2006), and may also be an issue for Exmouth region. Vessel strike is a threat, as areas of high dolphin occurrence (e.g., Bundegi) substantially overlap with highly used boat ramps and other areas of high vessel traffic (Hunt et al., 2017; Hunt et al., 2020; Haughey et al., 2021; Irvine et al., 2025a).

Decline of prey items for dolphins in Exmouth Gulf could also be of concern, as dolphins have been shown to compete with recreational and commercial fisheries for specific prey species in other regions (Hunt et al., 2020; Haughey et al., 2021). Gaining a greater understanding of the diets of both humpback and bottlenose dolphins within Exmouth Gulf would help to determine the extent of their diet overlap with fished species.

Commercial fisheries bycatch is also known to pose threats to dolphins in other areas of northern Australia, but the level of dolphin interactions reported in Exmouth Gulf fisheries is low. For example, while other trawl fisheries within the region report incidental captures of dolphins even with BRDs in place (e.g., Pilbara Fish Trawl; Allen et al., 2014), the EGPMF has not reported any incidental dolphin captures in over fifteen years (Fletcher & Santoro, 2015; Kangas et al., 2015; Fletcher et al., 2017; Gaughan & Santoro, 2018, 2019; Gaughan & Santoro, 2020, 2021; Newman et al., 2021; Newman et al., 2023a; Newman et al., 2023b). Dolphins have been observed to follow the trawl vessels to feed on discarded catch (Kangas et al., 2015), and in other areas of northern Australia, this behaviour has been shown to alter natural feeding patterns of dolphins and make them more susceptible to injury or bycatch in trawl operations (Chilvers & Corkeron, 2001; Chilvers et al., 2003; Jaiteh et al., 2013; Allen et al., 2014). While the lower level of bycatch discards in the EGPMF compared to other northern trawl fisheries is thought to limit this behaviour (Kangas et al., 2015), this may merit further investigation.

3.5.9. Baleen whales

3.5.9.1. Biodiversity

The most common whale species found in Exmouth Gulf is the humpback whale (*Megaptera novaeangliae*). Several other species have also been sighted (Table 15). Multiple sightings of southern right whales (*Eubalaena australis*), including mother and calf pairs, have occurred (Smith et al., in prep), leading to it being classified as a BIA for this species (DCCEEW, 2024). There have also been seven documented sightings of blue whales (*Balaenoptera musculus*) in Exmouth Gulf between 2016 and 2023, including one mother-calf pair (L. Irvine, pers. comm.). Other species appear to be rare or sporadic (Table 15), but occasional sightings and/or strandings of dwarf minke whales (*B. acutorostrata*), Bryde's whales (*B. edeni*), Omura's whales (*B. omurai*), and Shepherd's beaked whales (*Tasmacetus shepherdi*) have been reported within Exmouth Gulf (Ottewell et al., 2016; Sprogis et al., 2024; Millar et al., 2025; D. Rob and H. Raudino, pers. comms.).

While several whale species may use Exmouth Gulf as occasional habitat, the remainder of this section focuses on humpback whales, which are the only species known to regularly inhabit Exmouth Gulf for extended periods.

3.5.9.2. Habitat use

Humpback whales that use Exmouth Gulf and other areas along the WA coast belong to Breeding Stock D (IWC, 1998). This population of humpback whales feeds in Antarctic waters during summer, and migrates up the WA coastline to tropical breeding grounds in winter (Bestley et al., 2019). During their migration, some whales use Exmouth Gulf as a nursery and resting area (Chittleborough, 1953; Christiansen et al., 2016; Irvine et al., 2018; Sprogis et al., 2024). Humpback whales are present in Exmouth Gulf in low numbers during their northern migration from Antarctica to tropical resting/nursery areas (approximately June–August), but are much more abundant during their southern migration back to Antarctic feeding areas (August–November) (Irvine & Salgado Kent, 2019; Sprogis et al., 2024). Densities are highest in September and October, peaking in mid-late September (Irvine & Salgado Kent, 2019; Sprogis et al., 2024; Irvine et al., 2025a; Irvine et al., 2025b – Appendix 9.4). Repeated surveys in 2018 documented an increase in humpback whale numbers from 285 individuals in early August to 2,980 in late September, before decreasing to 216 in November (Irvine et al., 2025b).

Table 15: **Baleen whale species reported within Exmouth Gulf. With the exception of humpback whales, southern right whales, and blue whales, all other species have only been reported one to a few times, and are not likely to regularly use Exmouth Gulf. Species are reported along with their global (IUCN) and national (EPBC Act) conservation statuses. Status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated. Records collated from multiple sources including Ottewell et al. (2016), Smith et al. (In prep), Millar et al. (2025), L. Irvine, pers. comm., and records of whale strandings in Exmouth Gulf collated by DBCA, via D. Rob and H. Raudino, pers. comm.**

Scientific name	Common name	Occurrence in Exmouth Gulf	Global IUCN status	Status under EPBC Act
Megaptera novaeangliae	Humpback whale	Common	LC	Cetacean, Migratory
Eubalaena australis	Southern right whale	Occasional	LC	EN (VU in WA); Cetacean, Migratory
Balaenoptera musculus	Blue whale (likely pygmy subspecies)	Occasional	EN	EN; Cetacean, Migratory
Balaenoptera acutorostrata	Dwarf minke whale	Rare	LC	Cetacean
Balaenoptera omurai	Omura's whale	Rare	DD	Cetacean, Migratory
Balaenoptera edeni	Bryde's whale	Rare	LC	Cetacean, Migratory
Tasmacetus shepherdi	Shepherd's beaked whale	Rare	DD	Cetacean

The presence of many neonate calves along the Ningaloo coast during their northern migration in July and August suggests that this area, including North West Cape, may also be used as a calving area, but newborn calves are rare in Exmouth Gulf (Irvine et al., 2018; Irvine & Salgado Kent, 2019; Irvine et al., 2025a – Appendix 9.5). During their southern migration when calves are a few months old, mother-calf pairs are particularly abundant in Exmouth Gulf compared to surrounding areas (Sprogis et al., 2024). For example, surveys across Exmouth Gulf between August and November in 2018 recorded calves in 41.1% of all humpback whale groups sighted (Irvine & Salgado Kent, 2019), and encounter rates of mother-calf pairs are typically highest in October (Sprogis et al., 2024). Juveniles, resting females, and adult males (as individuals or in small groups) are also often sighted within Exmouth Gulf (Sprogis et al., 2024; L. Irvine, pers. comm.). Mother-calf pairs are sometimes accompanied by one or multiple male escorts, which are usually unrelated to both the mother and calf (Seeary et al., 2022).

Humpback whales are distributed widely across Exmouth Gulf except for the shallow waters to the east and south (Irvine & Salgado Kent, 2019; Tucker, 2023; Sprogis et al., 2024). Mother-calf groups appear to prefer the central, western and southern portions of Exmouth Gulf (Irvine & Salgado Kent, 2019; Sprogis et al., 2024). During the breeding season, adult humpback whales are fasting (Christiansen et al., 2016), and therefore Exmouth Gulf and the surrounding area is not typically used by humpback whales for feeding.

3.5.9.3. Ecological importance

Humpback whales transport large amounts of essential nutrients from their productive feeding grounds in Antarctic waters to their typically less productive tropical nurseries and resting locations (Roman & McCarthy, 2010), such as Exmouth Gulf. These nutrients are transferred into the ecosystem via waste from whales, including metabolic waste, sloughing skin, and shed placentae. Nutrients can also be transferred more directly through scavenging of whale carcasses or predation on whale calves by local predators including large sharks and orcas (Pitman et al., 2015). Humpback whale calves may represent an essential seasonal food source for orcas in particular, which are regularly observed attacking and predating upon neonate calves migrating northwards through the Ningaloo Marine Park. Numerous scavenging sharks (tiger sharks and other carcharhinids) have also benefitted from these kills. Predation attempts and harassment of humpback whales by orcas has been observed within Exmouth Gulf, but no successful predations on the typically larger southbound calves have been recorded (L. Irvine, pers. comm., J. Totterdell, pers. comm.). As humpback whales do not typically feed while in the Exmouth region, they do not directly influence trophic cascades as a predator. Calves, however, do feed from their mothers, and the extent to which their urine, faeces and milk waste contributes to the nutrient budget in Exmouth Gulf is unknown (e.g., Figure 63).

Figure 63: **Humpback whale mother-calf pairs are abundant in Exmouth Gulf during the southbound migration, and the extent to which the urine, faeces and milk waste from calves contributes to the nutrient budget has not been investigated. Image: Kate Sprogis**

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3.5.9.4. Significance of Exmouth Gulf

Exmouth Gulf is a highly significant nursery and calving area for humpback whales in WA and has been designated a BIA for humpback whales for reproduction and migration (DCCEEW, 2024) (Figure 64). Internationally, Exmouth Gulf and the surrounding area (Ningaloo Reef to Montebello Islands) is also recognised as an Important Marine Mammal Area by the Marine Mammal Protected Areas Task Force for dugongs, humpback whales, and Australian humpback dolphins. The area is recognised for its role in the recovery of humpback whale Breeding Stock D and as the largest known resting area for this population (IUCN-MMPATF, 2022). Exmouth Gulf is also globally recognised as a Key Biodiversity Area under the criteria that it offers critical habitat for resting humpback whales during their migration (Langhammer et al., 2022). The western and central regions of Exmouth Gulf in particular are considered a hotspot for humpback whales compared with nearby regions (Sprogis et al., 2024). Aerial surveys have shown that Exmouth Gulf consistently has the highest encounter rate of mother-calf pairs compared to the surrounding Pilbara and Ningaloo coasts (Sprogis et al., 2024). Part of the reason that this area is likely so beneficial for resting mothers and calves is that is provides calm, shallow protected waters (Sprogis et al., 2024). These conditions are essential for lactating mothers, who have the highest energetic costs of any age class, as they must efficiently rest and focus energy expenditure on nursing their calves (Christiansen et al., 2016; Irvine et al., 2017; Bejder et al., 2019).

3.5.9.5. Threats and pressures

Like most humpback whale populations globally, the Breeding Stock D population was historically decimated by industrial whaling. Since whaling ceased in 1963, this population, along with many others, is believed to have made a remarkable recovery to near pre-exploitation levels (Bejder et al., 2016). The most recent abundance estimate for the Breeding Stock D population is now over 15 years old. In 2008, it was estimated at 26,100 individuals (confidence interval = 20,152–33,272), increasing at a rate of over 10% per year (Salgado Kent et al., 2012). However, no updated assessments have been conducted since, and the current size of the population and trend are unknown.

While the population using Exmouth Gulf appears to be doing well and has limited direct anthropogenic mortality, there are still several concerns for humpback whales in the region, including vessel strike, tourism pressure, underwater noise, and entanglement (Sprogis et al., 2024). For example, studies investigating the effects of vessel noise in Exmouth Gulf have shown that disturbance above approximately 120–122 decibels (a "medium" loudness level for most whale-watching vessels) within 100 m caused resting humpback whales to begin evasive behaviours including diving and swimming away or increasing activity (Sprogis et al., 2020; Arranz et al., 2021). While larger vessels including whale-watching vessels have generally been the subject of noise disturbance studies within Exmouth Gulf, noise and proximity disturbance by recreational vessels are also a major concern for resting humpbacks, particularly considering the frequency of recreational vessel use along the western side of Exmouth Gulf (Irvine et al., 2025a).

In addition to vessel disturbance, noise during construction or otherwise associated with developments can also cause temporary or lasting damage and disruption to whales. For example, various activities associated with the pipeline construction of the now terminated Learmonth Pipeline Fabrication Facility proposal in Exmouth Gulf was estimated to cause permanent hearing damage (threshold shifts) for whales within 80 m, and temporary hearing damage to whales within 1.6 km of the development (Koessler et al., 2020). Behavioural responses to the construction were also expected for whales within 5–19 km of the development.

Behavioural responses to underwater noise including avoidance and heightened activity increase the energy expenditure of resting humpbacks during the period of disturbance (Sprogis et al., 2020). This is of particular concern for lactating mothers given their already high metabolic expenditure during a long period of sustained fasting (Christiansen et al., 2016; Bejder et al., 2019), and for young calves in their early rapid growth stage (Ejrnæs & Sprogis, 2021). Increases in vessel or other underwater noise sources within Exmouth Gulf are also likely to decrease the communication range of humpback whales (Bejder et al., 2019).

Figure 64: Humpback whale group sighted in Exmouth Gulf. Image: Lyn Irvine

Communication between whales is important for mothers and calves (Videsen et al., 2017), as well as for breeding adults that rely on song to attract prospective mates (Bejder et al., 2019). Coastal developments that will result in increased noise during or after construction (e.g., pile driving, increased commercial or recreational vessel traffic) are therefore of major concern for humpback whales.

Vessel strike is also a concern for humpback whales in Exmouth Gulf given that resting mother-calf pairs spend substantial periods of time resting at or near the surface where they are within reach of propellers and ship hulls (Bejder et al., 2019) (e.g., Figure 68). Potential developments in Exmouth Gulf which will increase vessel traffic are therefore a concern for resting whales using this nursery (Bejder et al., 2019; Sprogis et al., 2024). Many guidelines for vessel interactions with humpback whales are based on minimum approach distances, as outlined in the Australian National Guidelines for Whale and Dolphin Watching (Department of Environment and Energy, 2017). These guidelines specify a minimum distance of 100 m for whale and dolphin groups without calves, and 300 m for groups with calves. However, separation distances of humpback whale groups (including with calves) in Exmouth Gulf are often less than the 600 m necessary to pass between groups while

Grey-tailed Tattlers and Ruddy Turnstones. Grant Griffin

complying with these guidelines, especially during periods of peak abundance (Irvine et al., 2025b). The number of humpback whales using Exmouth Gulf has steadily increased over the last decade and is likely to continue to increase. This means that separation distances for humpback groups in Exmouth Gulf are likely to continue to decrease (Irvine et al., 2025b). As a result, it may become increasingly difficult for any vessel to traverse areas of Exmouth Gulf during the humpback season without disturbing whales, including mothers nursing their calves. Alternative management measures, such as seasonal area closures, may become more effective tools for mitigating such disturbance (Irvine et al., 2025b). This is pertinent when considering any development proposals within Exmouth Gulf that could decrease available humpback whale resting habitat or increase vessel traffic in key resting areas (Irvine et al., 2025b).

3.5.10. Seabirds and shorebirds

3.5.10.1. Biodiversity

The seabird and shorebird fauna of Exmouth Gulf and the surrounding region is highly diverse. This includes species resident to the region, as well as migrants that use Exmouth Gulf as a migration stopover, over-wintering area, foraging habitat, breeding habitat, and/or juvenile habitat (DSEWPC, 2012; Johnstone et al., 2013; DBCA, 2017) (see Table 16). The WA coast, including Exmouth Gulf, is part of the East Asian – Australasian Flyway (EAAF), where many migratory species use artic or sub-arctic habitats to breed in the northern hemisphere summer, and migrate to habitats on the Australian coast to "overwinter" during austral summer, where they forage and rest (DSEWPC, 2012). Juveniles of many of these species also remain within this area year-round until they are sexually mature and ready to undertake their annual breeding migrations (DBCA, 2017). Alternatively, there are many other species which migrate on a smaller scale within Australia, or do not undertake annual migrations and are resident year-round (DBCA, 2017).

The majority of shorebird research within Exmouth Gulf consists of shorebird count surveys conducted through Birdlife Australia, and over 500 surveys have been undertaken since 2012 (G. Griffin, pers. comm.). These surveys have confirmed the presence of 27 migratory shorebird species that visit Australia, 11 resident Australian shorebird species, and one shorebird vagrant (the Eurasian Curlew, *Numenius arquata*) (G. Griffin, pers. comm.). Numerous seabirds and other marine-associated bird species were also observed. In combining these records with a variety of other sources, at least 63 different seabird, shorebird, and other waterbird species are regularly associated with the shoreline and marine habitats of Exmouth Gulf (see Table 16). These include sandpipers, curlews, knots, plovers, pratincoles, oystercatchers, terns, gulls, cormorants, pelicans, egrets, herons, and raptors.

In addition to aquatic birds, a variety of terrestrial-associated bird species also use and/or fully rely on shoreline habitats, particularly including mangrove areas and the islands within Exmouth Gulf (Start & McKenzie, 2003; Johnstone et al., 2013). However, these terrestrial species are outside of the current scope of this report and are not further examined here.

Table 16: A non-exhaustive list of seabird, shorebird, and other marine-associated species that have been documented within Exmouth Gulf. Each species' use of Exmouth Gulf (as a resident, non-breeding area only, or breeding area) is noted, with species migrating along the East Asian-Australasian Flyway corridor noted with 'EAAF,' while other migratory species have their hypothesized migration patterns noted in table subscripts. Species' global (IUCN) and national (EPBC Act) conservation statuses are also listed; status abbreviations: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated. Species records have been compiled from a variety of sources: Start & McKenzie (2003), DSEWPC (2012), Johnstone et al. (2013), DBCA (2017), Weller et al. (2020), Dunlop & Greenwell (2022), Graff et al. (2022), Pendoley Environmental (2022), Birdlife Australia; G. Griffin, pers. comm., C. Greenwell, pers. comm.).

Scientific name	Common name	Residency category	Global IUCN status	Status under EPBC Act
Limosa lapponica menzbieri	Bar-tailed godwit	Non-breeding (EAAF)	NT	EN; Marine, Migratory
Limosa limosa	Black-tailed godwit	Non-breeding (EAAF)	NT	EN; Marine, Migratory
Numenius madagascariensis	Eastern curlew	Non-breeding (EAAF)	EN	CR; Marine, Migratory
Numenius arquata	Eurasian curlew	Vagrant (EAAF)	NT	Marine
Numenius phaeopus	Whimbrel	Non-breeding (EAAF)	LC	Marine, Migratory
Numenius minutus	Little curlew	Non-breeding (EAAF)	LC	Marine, Migratory
Calidris ferruginea	Curlew sandpiper	Non-breeding (EAAF)	VU	CR; Marine, Migratory
Calidris tenuirostris	Great knot	Non-breeding (EAAF)	EN	VU; Marine, Migratory
Calidris canutus	Red knot	Non-breeding (EAAF)	NT	VU; Marine, Migratory
Calidris alba	Sanderling	Non-breeding (EAAF)	LC	Marine, Migratory
Calidris ruficollis	Red-necked stint	Non-breeding (EAAF)	NT	Marine, Migratory
Calidris acuminata	Sharp-tailed sandpiper	Non-breeding (EAAF)	VU	VU; Marine, Migratory
Limicola falcinellus	Broad-billed sandpiper	Non-breeding (EAAF)	VU	Marine, Migratory
Charadrius mongolus	Lesser sand plover	Non-breeding (EAAF)	EN	EN; Marine, Migratory
Charadrius leschenaultii	Greater sand plover	Non-breeding (EAAF)	LC	VU; Marine, Migratory
Charadrius ruficapillus	Red-capped plover	Resident	LC	Marine
Charadrius veredus	Oriental plover	Non-breeding (EAAF)	LC	Marine, Migratory
Pluvialis fulva	Pacific golden plover	Non-breeding (EAAF)	LC	Marine, Migratory
Pluvialis squatarola	Grey plover	Non-breeding (EAAF)	VU	VU; Marine, Migratory
Erythrogonys cinctus	Red-kneed dotterel	Resident	LC	
Elseyomis melanops	Black-fronted dotterel	Resident	LC	
Arenaria interpres	Ruddy turnstone	Non-breeding (EAAF)	NT	VU; Marine, Migratory
Himantopus leucocephalus	Pied stilt	Resident	LC	

Table 16 continues on next page

Table 16 continued from previous page

Scientific name	Common name	Residency category	Global IUCN status	Status under EPBC Act
Cladorhynchus leucocephalus	Banded stilt	Non-breeding[1]	LC	
Actitis hypoleucos	Common sandpiper	Non-breeding (EAAF)	LC	Marine, Migratory
Tringa brevipes	Grey-tailed tattler	Non-breeding (EAAF)	LC	Marine, Migratory
Tringa nebularia	Common greenshank	Non-breeding (EAAF)	LC	EN; Marine, Migratory
Tringa stagnatilis	Marsh sandpiper	Non-breeding (EAAF)	LC	Marine, Migratory
Tringa glareola	Wood sandpiper	Non-breeding (EAAF)	LC	Marine, Migratory
Xenus cinereus	Terek sandpiper	Non-breeding (EAAF)	LC	VU; Marine, Migratory
Haematopus fuliginosus	Sooty oystercatcher	Resident	LC	
Haematopus longirostris	Pied oystercatcher	Resident	LC	
Esacus magnirostris	Beach stone-curlew	Resident	NT	Marine
Glareola maldivarum	Oriental pratincole	Non-breeding (EAAF)	LC	Marine, Migratory
Stiltia isabella	Australian pratincole	Non-breeding[1]	LC	Marine
Sternula nereis nereis	Fairy tern	Resident	VU	VU
Sternula albifrons	Little tern	Breeding and non-breeding[2]	LC	Marine, Migratory
Sterna dougallii	Roseate tern	Resident	LC	Marine, Migratory
Sterna hirundo	Common tern	Non-breeding (EAAF)	LC	Marine, Migratory
Gelochelidon nilotica	Gull-billed tern	Non-breeding (EAAF)	LC	Marine, Migratory
Gelochelidon macrotarsa	Australian gull-billed tern	Resident	LC	
Onychoprion anaethetus	Bridled tern	Breeding[3]	LC	Marine, Migratory
Hydroprogne caspia	Caspian tern	Resident	LC	Marine, Migratory
Thalasseus bergii	Crested tern	Resident	LC	Marine, Migratory
Thalasseus bengalensis	Lesser crested tern	Resident	LC	Marine
Chlidonias hybrida	Whiskered tern	Non-breeding[1]	LC	Marine
Ardenna pacifica	Wedge-tailed shearwater	Breeding[4]	LC	Marine, Migratory
Vanellus tricolor	Banded lapwing	Resident	LC	
Vanellus miles	Masked lapwing	Resident	LC	

Table 16 continues on next page

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Table 16 continued from previous page

Scientific name	Common name	Residency category	Global IUCN status	Status under EPBC Act
Phalacrocorax varius hypoleucos	Pied cormorant	Resident	LC	
Anous stolidus	Brown noddy	Non-breeding	LC	Marine, Migratory
Chroicocephalus novaehollandiae	Silver gull	Resident	LC	Marine
Larus pacificus	Pacific gull	Resident	LC	Marine
Pelecanus conspicillatus	Australian pelican	Resident	LC	Marine
Ardea alba	Great egret	Resident	LC	Marine
Egretta garzetta	Little egret	Resident	LC	Marine
Egretta novaehollandiae	White-faced heron	Non-breeding[1]	LC	
Egretta sacra	Eastern reef heron	Resident	LC	Marine
Butorides striata	Striated heron	Resident	LC	
Nycticorax caledonicus	Rufous night heron	Resident	LC	Marine
Pandion haliaetus cristatus	Eastern osprey	Resident	LC	Marine, Migratory
Haliaeetus leucogaster	White-bellied sea eagle	Resident	LC	Marine
Haliastur indus	Brahminy kite	Resident	LC	Marine

[1] Breeds in inland Australia
[2] The population visiting the region consists of an Australian breeding population and non-breeding visitors from Asia
[3] Non-breeding periods are spent offshore
[4] Non-breeding period likely spent in the Indian Ocean tropics

3.5.10.2. Habitat use

Seabirds and shorebirds occupy the majority of coastal habitats found in Exmouth Gulf. Shorebirds including curlews, whimbrels, godwits, plovers, turnstones, sandpipers, and sanderlings are most often associated with sandy beaches or intertidal mudflat areas, which are particularly important as foraging areas (DBCA, 2017; Weller et al., 2020). Tracking information from GPS-tagged shorebirds indicates that the high intertidal zone on the landward side of mangroves (including cyanobacterial mats, sand and mud flats, and salt flats), may also be important roosting and feeding areas for many species of migratory and resident shorebirds (S. Marin-Estrella, pers. comm.). Several species also known for their associations with mangroves, including the lesser sand plover (*Charadrius mongolus*), eastern curlew (*Numenius madagascariensis*), bar-tailed godwit (*Limos lapponica*), whimbrel (*Numenius phaeopus*), grey-tailed tattler (*Tringa brevipes*), sharp-tailed sandpiper (*Calidris acuminata*), terek sandpiper (*Xenus cinereus*), and beach stone-curlew (*Esacus magnirostris*) (DBCA, 2017; Johnstone et al., 2013). The striated heron (*Butorides striata*) is also almost exclusively found within mangrove ecosystems (Johnstone et al., 2013).

Conversely, sandy or rocky beaches including offshore islands are generally more important habitats for tern species (Johnstone et al., 2013; DBCA, 2017). Coastal wetlands and saltmarshes also offer important foraging and breeding habitat for several species (Johnstone et al., 2013).

While shorebirds can be found in abundance in most areas of Exmouth Gulf, the eastern side of Exmouth Gulf with its dense mangroves and extensive intertidal mudflats is expected to be particularly important for migratory shorebirds (Weller et al., 2020). These extensive mangrove, mudflat, and high intertidal systems offer ideal roosting and foraging habitat to a range of shorebird species (Weller et al., 2020). Alternatively, for species which are resident or use the area as breeding habitat, offshore islands can provide important nesting areas protected from terrestrial predators (Start & McKenzie, 2003; Johnstone et al., 2013; DBCA, 2017, 2020b). For example, in surveys conducted between 1988 and 1993, at least 12 different shorebird species were recorded nesting on islands within Exmouth Gulf (Start & McKenzie, 2003).

3.5.10.3. Ecological importance

The diets of seabirds and shorebirds found within Exmouth Gulf can vary widely between species, but most can be categorized as mesopredators. Terns, herons, egrets, pelicans, and cormorants typically consume small to medium sized fish, squid, as well as shallow water species and pelagic baitfish (DSEWPC, 2012; Johnstone et al., 2013; DBCA, 2017). On the other hand, the diet of most shorebirds including plovers, sandpipers, oystercatchers, and curlews largely includes invertebrates, such as crustaceans, molluscs, echinoderms, worms, and aquatic and terrestrial insects (DBCA, 2017; Weller et al., 2020). Several marine birds of prey including ospreys, white-bellied sea eagles, and Brahminy kites are also present in Exmouth Gulf as higher order predators, feeding on a variety of marine life ranging from fish to sea snakes to smaller shorebirds (DBCA, 2017).

Seabirds are large contributors of nutrients to marine ecosystems. While direct predation on shorebirds by marine fauna is likely limited to birds of prey and tiger sharks (e.g., Simpfendorfer et al., 2001), seabirds and shorebirds also contribute large amounts of nutrients to the environment through the deposition of guano (Cumming et al., 2024). This includes transporting nutrients from feeding sites into terrestrial and nearshore roosting and nesting sites (Cumming et al., 2024). While the dynamics of seabird nutrient transfer between habitats within Exmouth Gulf has not been examined, it is likely substantial given the abundance and diversity of seabirds and shorebirds using the various habitats.

Figure 65: Intertidal mangrove areas of Exmouth Gulf provide significant foraging opportunities for a variety of shorebirds. Image: Grant Griffin

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3.5.10.4. Significance of Exmouth Gulf

The diversity and abundance of seabirds and shorebirds present within Exmouth Gulf makes this region highly significant for several individual species and for the group as a whole. To assist with national and international conservation of migratory shorebirds flying through multiple jurisdictions, specific criteria have been set out within the EPBC Act to identify significant shorebird habitats. Internationally important sites for shorebirds are defined as those which host at least 1% of the East-Asian-Australasian Flyway (EAAF) population or global population of one species, or at least 20,000 individual waterbirds overall. Nationally important sites are defined as those which host 0.1% of the Flyway population or global population of a single species, a total of at least 2,000 individual waterbirds, or at least 15 migratory shorebird species (EPBC Act Policy Statement 1.1 Significant Impact Guidelines—Matters of National Environmental Significance 2009).

Under these criteria, Exmouth Gulf qualifies as a nationally and internationally significant shorebird areas for several different species. For example, Exmouth Gulf as a whole, including the entire coastline and all islands, qualifies as an internationally significant area for the eastern curlew (EPBC Act status: CR), grey-tailed tattler, ruddy turnstone (*Arenaria interpres*; EPBC Act status: VU), and pied and sooty oystercatchers (*Haematopus fulginosus* and *H. longirostris*) (Onton et al., 2013; Weller et al., 2020). More recently, the region has been identified as an internationally significant area for sanderlings (*Calidris alba*) (G. Griffin, pers. comm.). Exmouth Gulf also meets the national significance criteria for a further ten species, including seven listed as threatened by the EPBC Act (Onton et al., 2013; Weller et al., 2020). In comparison, the Ningaloo coast meets the national significance criteria for two waterbird species (Onton et al., 2013; Weller et al., 2020), highlighting the diversity and abundance of shorebirds found in Exmouth Gulf compared to other nearby regions.

The Exmouth-Ningaloo region meets the abundance criteria for an internationally significant waterbird area overall, with a count of over 20,000 individual waterbirds during surveys conducted in Oct–Nov 2012, including over 13,000 shorebirds (Onton et al., 2013).

Within this region, Exmouth Gulf and internal islands held by far the greatest abundance of shorebirds and waterbirds, while Muiron and Sunday Islands and the Ningaloo coast were more important for seabirds (Onton et al., 2013). These surveys were spatially limited, particularly along the eastern Exmouth Gulf where many shorebird habitats are difficult to access, and therefore many more shorebirds and waterbirds were likely present during these surveys (Onton et al., 2013).

Many individual sites within Exmouth Gulf are likely to meet the criteria for significant shorebird areas independently. For example, the shoreline surrounding Urala Creek South in the northeastern Exmouth Gulf has been shown to meet the diversity and abundance criteria for a nationally significant shorebird area, and meets the species-specific abundance criteria for a nationally significant site for ten species (Graff et al., 2022). Birdlife Australia shorebird surveys conducted in January 2025 again confirmed that this site held nationally significant numbers (n = 36) of Critically Endangered eastern curlews, along with an area of the southeastern coast north of Deep Creep which supported 39 eastern curlews (G. Griffin, pers. comm.). Nationally significant numbers of the curlew sandpiper were also recorded in February 2019 within the area between Heron Point and Doole Island (G. Griffin, pers. comm.). The number of nationally and internationally significant sites for shorebirds already identified within Exmouth Gulf are based upon sites surveyed by Birdlife Australia, which represent a small proportion of the suitable shorebird habitat available within Exmouth Gulf. More comprehensive surveys covering larger areas would undoubtably find that Exmouth Gulf is of international and national significance to more species of shorebirds (G. Griffin, pers. comm.).

The mangrove areas of the eastern Exmouth Gulf have been designated as an Important Bird Area for resident waterbirds and migratory shorebirds, while Sunday Island in the northern Exmouth Gulf has been designated an Important Bird Area for seabird island species (Dutson et al., 2009). The mangroves along eastern Exmouth Gulf and adjacent salt pans and mud flats have also been identified as a global Key Biodiversity Area due to the abundance of pied oystercatchers and grey-tailed tattlers found there, and Sunday Island for the abundance of roseate terns (KBA, 2025a, 2025b).

In addition to important feeding and overwintering habitats, the islands in and around Exmouth Gulf are also recognised as important breeding areas for resident species. For example, large colonies of wedge-tailed shearwaters are known to nest on the Muiron Islands and Serrurier Island, among others (Dunlop et al., 2002; Cannell et al., 2019). The area surrounding these islands has been recognised as a BIA for breeding wedge-tailed shearwaters (DCCEEW, 2024). Additionally, fairy terns, roseate terns, and crested terns all nest on various islands through Exmouth Gulf (DBCA, 2020b; Dunlop & Greenwell, 2020).

3.5.10.5. Threats and pressures

Seabirds and shorebirds, along with other bird species, have life history traits that make them vulnerable to population declines, such as delayed maturity, long life spans, and low reproductive levels (DSEWPC, 2012). Strong site fidelity and migratory pathways through multiple jurisdictions can also increase the vulnerability of some species (DSEWPC, 2012).

Within Exmouth Gulf, seabirds and shorebirds face several threats dependent on how each species uses Exmouth Gulf. For example, species which rely on mangroves or other high intertidal areas for roosting and foraging may be sensitive to changes in availability or quality of those habitats. Such changes may stem from threatening processes relating to nutrient input, cyclones, marine heatwaves, or coastal disturbance/destruction (see Sections 3.4.3 and 3.4.4). Alternatively, birds that nest on islands in Exmouth Gulf are vulnerable to island shoreline disturbance or erosion. Many of the islands within Exmouth Gulf are low in profile (only 1–2 m above sea level) and are therefore highly vulnerable to sea level rise (DSEWPC, 2012). Such sites are also typically at risk from erosion and increased intensity of tropical storms due to climate change (Cuttler et al., 2020). Nesting and roosting sites are vulnerable to predation from introduced predators including foxes, cats, dogs, and rats (DBCA, 2020b). Prior to feral animal control measures on the North West Cape, feral foxes and dogs destroyed an entire colony of nesting fairy terns near Bundegi over a single night in 2012 (DEC, 2012).

The islands in Exmouth Gulf provide important refuge from feral predators, although accidental human introduction of predators to the islands could be catastrophic to nesting colonies (DBCA, 2020b). Disturbance from human activity such as walking along the shoreline (especially with dogs), off-road driving, boating close to shore, and light pollution are also a concern for nesting and roosting sites (DSEWPC, 2012). Disturbance from off-road vehicles near a fairy tern colony on North West Cape resulted in limited chick production in 2020–2021 (Greenwell & Dunlop, 2023). Protective measures including limiting human access to islands and island shorelines that have been identified as essential for nesting species (DBCA, 2020b).

Human disturbance is also a concern for migratory species which use Exmouth Gulf as a foraging area. Most migratory shorebird species feed on various invertebrates within intertidal sandflats and mudflats, and as such have a limited window of opportunity each day for feeding when tide levels are suitable. Disturbing foraging shorebirds is a recognised threat in other locations, as disturbance of foraging birds during low tide intervals can greatly decrease their potential for energy acquisition (Blumstein et al., 2003). Similarly, disturbance of shorebirds while roosting will increase their energy expenditure and deplete energy reserves (Rogers et al., 2006; Lilleyman et al., 2016). This is of particular concern for migratory species which rely on the build-up of energy reserves within their foraging locations to fuel their long-range migrations (DSEWPC, 2012; Weller et al., 2020).

Avian diseases are another potential threat for shorebirds, especially for migratory species which transit through many areas and have high potential to contract disease. High Pathogenicity Avian Influenza Virus (H5N1 lineage 2.3.4.4b) is a major concern globally at present, infecting and causing high mortality in many different species of captive and wild birds across most of the world, including all continents except for Australia. Migratory shorebirds within the EAAF breed and fly through areas where this disease is present, but the disease has not yet been detected in Australia (Wille et al., 2024).

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3.6. Anthropogenic stressors

3.6.1. Marine debris

Marine debris is widespread across all oceans and coastlines, including Australia (Hardesty et al., 2016; Gacutan et al., 2022). The accumulation rate of marine debris collected and recorded from the coastlines of Ningaloo Reef, Exmouth Gulf and the broader North West Shelf region was relatively low (0–0.1 count/day) compared to other locations across Australia (Gacutan et al., 2022). Marine debris surveys at 17 sites around the North West Cape in May 2021 found transects from Exmouth Townsite to the marina had the highest total counts of marine debris (n = 149, 0.02 items m^{-2}, > 5 mm) spanning nine debris categories (Westlake et al., 2022). Fishing debris was the most common form of debris at Exmouth Townsite (n = 37 items), which accounted for 32% of fishing debris found for the whole study area. Marine debris densities ranged from 0.001–0.02 items m^{-2}, which is comparable to other remote areas within Australia. Micro and macro plastics have also been examined in surface waters of the Ningaloo Marine Park and Exmouth Gulf using surface net tows (n = 102), sediment samples (n = 33) and in-water feeding tows (n = 11) (King et al., 2019). Plastics were present in the majority of surface water tows and sediment samples (92.% and 81.8%, respectively), and 45.0 % of in-water feeding tows (following active feeding trails by manta rays).

3.6.2. Noise pollution

Noise pollution occurs when anthropogenic activities create artificial underwater noise, for example from vessels (both recreational and commercial), construction or development, seismic surveys, and sonar. This additional noise in the underwater environment can initiate stress, alter behaviours, cause avoidance of noisy areas and, in some cases, cause temporary or permanent hearing damage. Underwater noise can also mask or interfere with natural sounds which are important for various biological processes, including for communication and navigation of marine fauna, foraging, and predator avoidance. Underwater noise may be a more significant issue for animals which commonly use sounds or sonar techniques for various purposes, such as cetaceans (see Sections 3.5.8 and 3.5.9). Vessel noises have been confirmed to substantially overlap in frequency with biological noises, such as whale calls, which means vessel noise has high potential to interfere with biological communication (Bejder et al., 2019).

Vessel noise is the most wide-spread source of noise pollution in Exmouth Gulf. Luckily, at present the underwater soundscapes in much of Exmouth Gulf appear to be dominated by biological noises, including sounds of snapping shrimp, humpback whales, dolphins, fish, tidal flows and wind and waves (Bejder et al., 2019; Maxner et al., 2025 – Appendix 9.6). However, in areas of higher vessel traffic, such as around Exmouth Marina, anthropogenic noise sources can dominate (Bejder et al., 2019). At an acoustic recording station near Bay of Rest, between October 2023 and September 2024, noises from both small and large vessels were regularly recorded in April through December, peaking in June – July (Maxner et al., 2025). Vessel noises were recorded for up to 18 hours on some days. Most days had less than 6–8 hours of vessel detection, while some days had no detections of vessel noise. It is likely that the more highly-trafficked areas of Exmouth Gulf, such as off Bundegi, will have much higher contribution of vessel noise to underwater soundscapes.

Vessels in Exmouth Gulf have been recorded to produce between ~125 and 172 dB re 1µPa depending on frequency and vessel type, which is on average ~40–60 dB higher than ambient noise levels (Bejder et al., 2019; Sprogis et al., 2020; Arranz et al., 2021). Noise levels higher than ~125 dB (i.e. most vessels) can elicit behavioural responses in humpback whales, and potentially other sensitive fauna, from 100 m away. Large shipping vessels are much louder and are likely to produce noise levels that interfere with humpback whale communication from 1–2 km away (Bejder et al., 2019). Aerial surveys undertaken between July and October 2023 recorded between 5–70 recreational vessels and 0–5 commercial vessels present on a given day along western Exmouth Gulf, with vessel densities highest in October (during school holidays) (Irvine et al., 2025). Thus, depending on the time of year and location, noise pollution from passing recreational and commercial vessels may be substantial.

While vessels may be the most ubiquitous source of noise pollution in Exmouth Gulf, other activities such as construction and seismic surveys produce less regular but sometimes larger amounts of noise. For example, air guns used in seismic surveys produce around 260 dB re 1µPa, which was shown to affect humpback whales within 4 km (resting mothers at 7–12 km) (McCauley et al.,1998). These noise levels also caused alarm responses in marine turtles from 2 km away, and avoidance behaviour at 1 km.

Alarm responses in fish and squid (including increased activity and tighter schooling) occurred from 2–5 km away from the air gun source, and ear damage to fish was predicted from 2 km away. Air gun noise has been observed to cause lasting damage to ciliary bundles in the inner ear of pink snapper (*Pagrus auratus*) in Exmouth Gulf, which lasted for between 58 and 86 days post-exposure (Fewtrell, 2003).

Coastal developments may also produce substantial noise pollution, especially during construction phases. Pipeline construction associated with the terminated Learmonth Pipeline Fabrication Facility proposal would have produced up to an estimated 180 dB re 1µPa (depending on frequency) (Koessler et al., 2020). These noise levels were estimated to cause behavioural change in marine mammals within 5 – 19 km of the noise source (depending on activity), and potential for permanent and temporary hearing damage in humpback whales at up to 1.6 km away.

3.6.3. Light pollution

Light pollution occurs when artificial light, for example from cities, shoreline developments, lighted piers, gas plant flares, and offshore oil platforms, infiltrates the marine environment and interferes with natural photo-cycles of marine organisms. Artificial light can cause disorientation in animals that rely on natural light sources (e.g., moon) for navigation, disturb natural circadian rhythms, disrupt various behaviours, and make some animals more vulnerable to predation.

Major light sources within Exmouth Gulf include Exmouth townsite (streetlights and sports flood lighting), naval communications base and antenna field, and the light industrial district to the south of Exmouth township (see Figure 66). Much of the eastern and southern areas of Exmouth Gulf are relatively free from light pollution. To the north of Exmouth Gulf, however, are major light sources from gas plants near Onslow and offshore oil rigs to the northwest (Figure 66).

The effects of light pollution are most studied for marine turtles. Artificial light is known to deter adult female turtles from nesting on light-affected beaches, and disorient hatchlings, causing reduced success in finding the sea and properly dispersing after hatching (DCCEEW, 2023). This can be true over long distances, with lights at least 18 km away shown to impact turtles. A study in the Pilbara also found that lighted areas, such as jetties, reduced survival of hatchlings once they reached the water due to the attraction and increased visibility of predators (Wilson et al., 2019). Information describing light levels on turtle nesting beaches within Exmouth Gulf is scarce, but surveys have shown that artificial light sources, including light from Exmouth township and offshore oil platforms, can be seen from nesting beaches around the North West Cape (Pendoley & Mitchell, 2021), and these light sources, along with those near Onslow, are also likely to be visible on turtle nesting beaches on islands across the northern part of Exmouth Gulf.

Artificial light has been shown to affect orientation and navigation in shorebirds, such as grounding, shifting cycles of day and night-time foraging, affecting success of night-time foraging, and in some cases increasing mortality of shorebirds at night-time roosts (DCCEEW, 2023). Light pollution is also known to affect circadian rhythms, foraging cycles, behaviour, and vulnerability to predation in fishes and invertebrates.

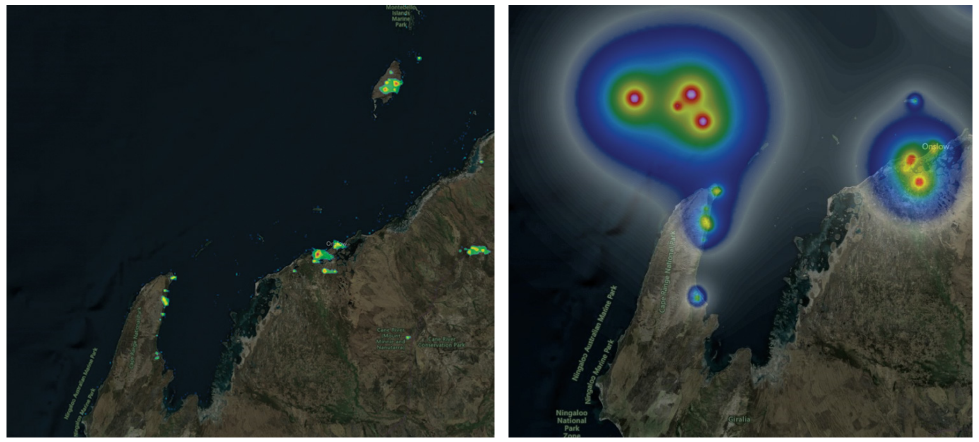


Figure 66: Light pollution in Exmouth Gulf estimated by (A) the Visible Infrared Imaging Radiometer Suite (VIIRS) satellite run by NASA/NOAA (in 2023), and (B) Falchi et al. (2016) (in 2015), both taken from lightpollutionmap.info

3.6.4. Coastal development

Coastal development can be a direct threat to marine fauna and environments, such as through disturbance, alteration, or removal of habitat. This includes not only the habitat within the footprint of the development, but also surrounding habitats that may be affected or made unsuitable for certain marine fauna. Studies have warned of the implications of new developments decreasing available resting habitat for humpback whales in the western area of Exmouth Gulf, given that these animals already appear in very dense numbers through parts of the year (Sprogis et al., 2024; Irvine et al., 2025). Some types of coastal developments in the Pilbara region (e.g., rock wall marinas) have also shown to inhibit movements of coastally associated species, including green sawfish, which rely on the extreme shallows of the shoreline for movement between habitats (Lear et al., 2024b). Developments such as rock walls, retaining walls, or shoreline armouring can remove the interface between the intertidal and subtidal zones, which can significantly decrease habitat connectivity. Developments abutting intertidal zones may also limit the ability of intertidal habitats (e.g., mangroves) to vertically shift up the intertidal zone as a response to sea level rise (e.g., Lovelock et al., 2021). Nearshore developments that change hydrodynamic processes, such as groundwater flow and levels of tidal inundation, are also likely to have major effects on the survival and success of nearshore environments including mangroves and saltmarsh vegetation (e.g., Semeniuk & Cresswell, 2018; Lovelock et al., 2021).

In addition to direct effects on habitats and species from coastal developments, there are associated flow-on effects. These include increases in noise and light pollution during construction and operation (see Sections 3.6.2 and 3.6.3), increases in vessel or shoreline traffic (see Section 3.6.6), and increasing potential for contamination or introduction of invasive species (see Section 3.6.5 and 3.6.8).

At present, developments cover ~5 km (or 2%) of the entire coastline of Exmouth Gulf and are comprised of boat ramps, jetties, the Exmouth Marina, and industrial areas within 200 m of the shore. This does not include 4WD tracks, potential beach camping locations, and other remote access points to the coast.

The only island development in Exmouth Gulf is the Wilderness Island Eco Lodge in the central-eastern Gulf, covering approximately 0.03 ha (and additional tracks) of Wilderness Island.

Several major coastal developments have been proposed within Exmouth Gulf. The K+S Salt Australia Pty Ltd Ashburton Salt Project is proposed on the northeastern coastline of Exmouth Gulf. This proposal seeks to construct solar salt ponds across a development envelop of 20,990 ha, including 10,397 ha of salt evaporation ponds within the high intertidal zone in the vicinity of Urala Creeks North and South (K+S Salt Australia Pty Ltd, 2023). Salt farms present a particular threat to the ability of intertidal communities to adapt to sea level rise due to their large footprint. Proposals of this magnitude are likely to affect significant areas of mangroves, samphire and algal mats from adapting to sea level rise, resulting in the direct loss of these communities and the ecosystem services they provide.

Just prior to printing of this report, the K+S Salt Australia Pty Ltd Ashburton Salt Project proposal was withdrawn.

On the west side of Exmouth Gulf, the Gascoyne Gateway Marine Complex has been proposed near to the Exmouth townsite (Gascoyne Gateway Ltd, 2024). The proposal includes construction of a major port including rock groynes, steel pylon structure, dredged channels, and anchorage locations within a 79 ha marine development envelope and a 119 ha terrestrial development envelope.

The Ningaloo Lighthouse Resort proposal at Vlamingh Head involving the replacement and redevelopment of existing facilities was approved subject to conditions in 2023 (EPA, 2023; State of Western Australia, 2023).

A development application for a Wilderness Camp at the Exmouth Gulf Station has been prepared which will include 27 camping sites along a 25 km section of coastline, but the status of this application is unclear.

3.6.5. Contamination

Contamination can occur from chemicals seeping into the marine environment (e.g., PFAS – per- and polyfluoroalkyl substances, vessel antifouling), oil and fuel spills, and industrial outfall (e.g., bitterns and brine). Currently, no industrial waste is discharged into Exmouth Gulf. However, a salt mining proposal near Tubridgi Point is proposed, which would intake water from Urala Creek South and discharge bitterns north of Urala Creek North (K+S Salt Australia, 2023). The Water Corporation is also scoping potential locations for a seawater desalination plant along western Exmouth Gulf, which would require intake seawater and a submerged location to discharge brine. Brine and bitterns are different. Brine (mostly sodium chloride) is highly saline water that is typically twice the concentration of seawater, and depending on the desalination technology used, can be discharged a few degrees warmer into the environment with traces of cleaning chemicals. Whereas bitterns are the resulting solution after brine is pumped into crystallisation ponds to extract sodium chloride. The resulting dense solution contains highly concentrated amounts of magnesium, calcium, potassium and other ions that are toxic. The discharge of bitterns to the marine environment is likely to impact on benthic communities and marine fauna in or near the seabed within a certain zone. Bitterns also may affect the movement or migration of marine fauna, with bottom dwelling species at greater risk.

Oil spills are not common in Exmouth Gulf. Spills are reported to the Department of Transport (DoT), and based on the last five years, no spills in Exmouth Gulf have been reported (DoT, pers. comm.). The 2018 'Marine Oil Pollution Risk Assessment' identified petroleum facilities and oil tankers as drivers of shoreline exposure in Exmouth Gulf (Navigatus Consulting, 2018). Exmouth Gulf East was rated as having very low risk to exposure but was prioritised very high for protection. The petroleum industry through the Australian Marine Oil Spill Centre (AMOSC) maintains a stockpile of marine pollution response equipment in Exmouth (DoT, 2023). Fuel spills from refilling of recreational and commercial vessels could occur, though the frequency and extent of this is unknown.

Organic chemicals in sediments were tested from five sites in coastal waters extending north and south of Exmouth townsite in 2005 (DEC, 2006). All chemicals, including tributyltin, dibutyltin, benzene group (benzene, toluene, ethylbenzene, xylenes), hydrocarbons, pesticides and polychlorinated biphenyls had concentrations below the analytical Limit of Reporting. The Department of Defence (Defence) undertook testing of PFAS contamination in 2018 around Naval Communication Station Harold E Holt Areas A & B. A management plan incorporating monitoring of groundwater, surface water, seepage water and sediment every six months was subsequently developed. Monitoring in 2021 found that PFAS exposure posed a low risk to people, plants and animals. An ecological risk assessment also determined that PFAS posed a low risk to:

- Marine life at Bundegi Reef
- Lower trophic level terrestrial and aquatic organisms
- Potential for bioaccumulation and biomagnification in avian food chains
- Potential for bioaccumulation and biomagnification in aquatic mammals
- Marine turtles that nest along the beaches
- Recreational anglers

The concentrations of PFAS from detailed site investigations were also determined unlikely to harm prawn stocks or bioaccumulate to harmful levels within the commercial prawn fishery. However, the ecological risk assessment and detailed site investigations did not test for PFAS in marine organisms directly. Risks to PFAS contamination were based on concentrations detected in beach seepage water, low rates of groundwater discharge and high levels of dilution and dispersion in the marine environment. It is unclear whether monitoring is still occurring every six months.

Only two sites along the North West Cape are listed on DWER's Contaminated Sites Database (Figure 67). Both sites were used as naval communications centres and were decommissioned in 1997. Soils contained concentrations of heavy metals, hydrocarbons, asbestos and polychlorinated biphenyls exceeding Ecological Investigation Levels and Health Investigation Levels (draft DoE guidelines 2003). Both sites have now been classified as 'Remediated – Restricted Use' (suitable for commercial/industrial use) following excavation and disposal of contaminate soils and groundwater investigations did not identify any contamination.

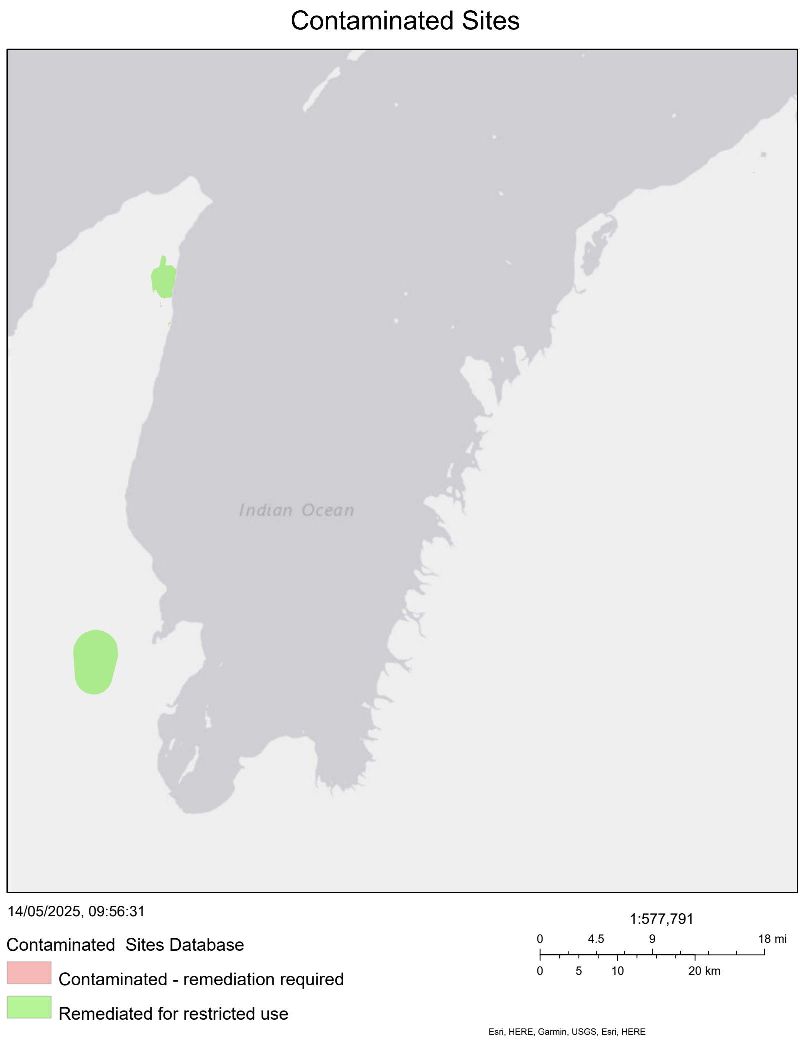


Figure 67: Known contaminated sites near Exmouth Gulf as listed on the DWER Contaminated Sites Database (https://dow.maps.arcgis.com/apps/webappviewer/index.html?id=c2ecb74291ae4da2ac32c441819c6d47). The two sites shown here have been remediated for restricted use.

Antifouling chemicals used to protect recreational and commercial vessels from biofouling organisms have long been highlighted as a risk to marine life (e.g., Negri & Heyward, 2000; Galvao de Campos et al., 2022). The International Convention on the Control of Harmful Anti-fouling Systems on Ships has been in effect internationally since 2008 and this has been implemented into *Australia's Protection of the Sea (Harmful Anti-fouling Systems) Act 2006*. The Convention and Act applies to vessels over 400 gross tonnes that undertake international voyages. There are 52 antifoulant products approved in Australia, and eight biocides used in these products (Lewis, 2020). The WA State Government restricts the use of antifouling paint that contains copper or tin for recreational vessels and recommends Teflon or silicon-based antifouling paints (DoT, 2025). Despite these guidelines, there is currently no way to track what antifouling products recreational vessel users are applying. Water and sediment quality monitoring would help to understand the extent to which antifoulant chemical are leaching into the environment, and this was undertaken by the Department of Water (now DWER) in Perth coastal waters in 2009 (Reitsema, 2008). Hotspots of contamination were found in coastal waters, and sites including sailing clubs and a boat repair facility were found to have significant concentrations of unregistered biocides, such as TBT and Irgarol 1051. The herbicide, Diuron, was also found in significant concentrations given it is used in close to half of the antifoul products registered. To prevent biofouling on farmed pearl oyster, *Pinctada maxima*, shells, field trials using wax-based coatings (including 'PearlSafe') were undertaken in Exmouth Gulf as well as other farms across Australia (de Nys & Ison, 2004). The study did not include an examination of the effects on the marine environment, nor has any study to date in Exmouth Gulf.

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

3.6.6. Vessel strikes

Vessel strikes occur when commercial or recreational vessels drive over or collide with marine fauna, causing injury and/or mortality (e.g., Figure 68). This is particularly relevant for species that spend large amount of time at the surface within reach of vessel hulls, or that breath air, such as marine mammals and reptiles. Many elasmobranchs also often occupy surface waters for thermoregulation or other purposes, including manta rays, whale sharks, and other species.

It can be very difficult to quantify the occurrence of vessel strikes, especially when struck animals die and the carcasses are not found. Dugongs are particularly vulnerable to vessel strike as they are difficult for boaters to see due to their low profile in the water, and tend to have a delayed response to vessel approach (Groom et al., 2004). At least three dugong mortalities have occurred in Exmouth Gulf due to confirmed vessel strike since 2018 (Pilbara News, 2018; H. Raudino, pers. comm.). Many reef manta rays (*Mobula alfredi*) found in the Ningaloo-Exmouth region bare scars attributed to vessel strike, including over 13% of mantas recorded in the Ningaloo Reef photo-ID database (McGregor et al., 2019). Whale sharks along Ningaloo Reef also commonly have scars attributed to vessel strike (~10% of individuals) (Lester et al., 2020), though this may be less of an issue within Exmouth Gulf itself given their low occurrence (see Section 3.5.5.3.8). Resting humpback whales have also been suggested to be vulnerable to vessel strike in Exmouth Gulf given their large size and use of shallow areas for extended periods of resting (Bejder et al., 2019; Sprogis et al., 2024). Vessel strike may also be a problem for sea snakes which can spend a lot of time at the surface. Vessel strike has been hypothesized as a major threat to sea snakes in other areas (e.g., Somaweera et al., 2021), but it is likely very difficult to track this as a source of mortality for sea snakes given carcasses are likely to sink.

While difficult to directly record vessel collisions with marine fauna in Exmouth Gulf, it is reasonable to suggest that the instance of vessel strike increases in areas and time periods of higher vessel use. Vessel densities are generally highest near to boat ramps and accessible launch locations in Exmouth Gulf, as well as main shipping channels, and have been found to generally be most dense within the northwestern area of Exmouth Gulf (Irvine et al., 2025; Maxner et al., 2025). Aerial surveys have also shown that spatial and temporal patterns of vessel use in Exmouth Gulf generally track with those of various marine megafauna groups (Irvine et al., 2025). For example, between July and October 2023, the highest densities of vessels, manta rays, humpback whales, and turtles all coincided in the northwest portion of Exmouth Gulf during September–October (Irvine et al., 2025). The high degree of spatial and temporal overlap in vessel and marine megafauna presence in Exmouth Gulf likely increases the incidence of vessel strike.

Figure 68: Evidence of vessel strike on an adult humpback whale, photographed in Exmouth Gulf. Image: Lyn Irvine

3. REVIEW OF KNOWLEDGE FOR EXMOUTH GULF

3.6.7. Recreational and commercial fishing

Recreational and commercial fishing is common in Exmouth Gulf and can affect species and environments through direct harvest of target species, incidental mortality of bycatch species, destruction or disturbance of habitat through fishing methods, and changing behaviour of marine fauna around fishing operations.

Recreational fishing is common in Exmouth Gulf, including both shore-based and boat-based line fishing, recreational gillnetting, and spearing. Several charter fishing operations are also based in Exmouth Gulf, which mainly include line fishing via bait, lures, or fly fishing. Data on fishing effort and retention rates of the catch are not available for Exmouth Gulf specifically, and fisher surveys would help to establish the level of this stressor on Exmouth Gulf. It is likely that the majority of recreational fishing occurs in areas easily accessible by shore or near to boat ramps (Bundegi, Exmouth Marina, and Learmonth beach launch). The only areas that are currently protected from recreational fishing are the Bundegi Sanctuary Zone and the exclusion zone around the Exmouth Navy Pier at Point Murat. In all other areas, regulations relating to bag limits apply to all fishers similar to other areas across WA. Recreational fishing occurs all year round, and peaks in April through October. Popular target species including breams, mullets, whitings, emperors, queenfish, and trevallies (Sumner et al., 2002; Ryan et al., 2022). Species are also incidentally captured and when released may suffer injury or mortality. Recreational fishing has been shown to change behaviour of predatory fishes including sharks, which have been known to follow the sound of boat motors to depredate on captured fish. Boat ramp surveys estimated that depredation by sharks, dolphins, or large predatory teleost fishes occurs on approximately 42% of recreational boat-based fishing trips in Exmouth Gulf (Mitchell et al., 2018). Depredation by predatory fauna during recreational fishing can increase fishery impacts on target species, and cause injury, entanglement, and/or mortality to depredating species.

The most substantial commercial fisheries in Exmouth Gulf is the EGPMF, which uses otter trawl methods to target prawns, including western king prawns, brown tiger prawns, blue endeavour prawns, and banana prawns. Management of the fishery is based on controls including restrictions on the number of licences, amount of gear, seasonal and spatial openings and closures. The fishery received Marine Stewardship Council Certification in 2015 and was recertified in 2020 for another five years. This fishery retains several byproduct species (incidentally caught but retained) including other crustaceans, squid, and teleost fishes (Kangas et al., 2015); average annual captures of these and target prawn species are summarised in Sections 3.5.2.2 and 3.5.4. Additionally, as trawling is a non-selective fishing method, bycatch can include teleost fishes and invertebrates, as well as some threatened and protected species, such as sawfish and sea snakes (see Sections 3.5.5.2 and 3.5.6.2). However, capture of other faunal groups including marine turtles and large sharks and rays (other than sawfish) has been limited by the mandated use of BRDs in this fishery since 2006 (Kangas et al., 2015). Trawling is also known to cause damage to benthos (e.g., sponges) (e.g., Kangas et al., 2007), and disruption of epifaunal and infaunal communities in bare sediment habitats (Mellor & Gautier, 2023). The discard of bycatch species caught by the fishery has also been shown to change behaviour of some predators, such as sharks and dolphins, which are known to follow the trawl boats to feed on the discarded catch within Exmouth Gulf (Kangas et al., 2007).

There are six boats currently active in the EGPMF, managed by a single licensee. Trawl effort in this fishery fluctuates from year to year but has been reported between approximately 20,000 and 25,000 hours over the last five years (Newman et al., 2021; Newman et al., 2023a, 2023b). Fishing only occurs at night, and the fishery operates between approximately March/April and November each year, and closed for at least five days around each full moon. The eastern and southern side of Exmouth Gulf is also permanently closed to trawling to allow for settlement and survival of juvenile prawns within their seagrass, mangrove, and mudflat nursery habitats. Within the western and central areas of Exmouth Gulf, approximately 22% is trawled each year (DPIRD, 2021). Effort and catches are managed according to the Prawn Resource of Exmouth Gulf Harvest Strategy 2021–2026, which includes setting target fishing levels based on yearly fishery-independent surveys of stock levels to protect against the over-harvest of prawns.

The small Exmouth Gulf Beach Seine Fishery also operates commercially in the southwestern area of Exmouth Gulf. The fishery uses seine and gillnets to target sea mullet (*Mugil cephalus*), western sand whiting (*Sillago schombergkii* and *S. analis*), Perth herring (*Nematalosa vlaminghi*), and yellowfin bream (*Acanthopagrus latus*), as well as sharks (Newman et al., 2003).

Several commercial invertebrate fisheries are also licenced to operate within Exmouth Gulf. The Western Australian Pearl Oyster Fishery (targeting *Pinctada maxima*) has its southern boundary within Exmouth Gulf. Five licensees have access to pearl oyster harvest in Exmouth Gulf via collection by trained divers, mainly within a fishing patch in the southwestern Gulf (Smith et al., 2023). However, effort within Exmouth Gulf is very limited, with most effort in this fishery occurring off the Kimberley coast (Smith et al., 2023). The WASCF also has license to operate within Exmouth Gulf, targeting sandfish (*Holothuria scabra*) and redfish (*Actinopyga echinites*), as well as a smaller proportion of black teatfish (*Holothuria whitmaei*) through hand collection via diving or wading (Smith et al., 2024). However, very little effort from this fishery occurs within Exmouth Gulf, with the majority of effort occurring in Shark Bay, Barrow Island, the Dampier Archipelago, and the Kimberley (Smith et al., 2024).

3.6.8. Marine pests and pathogens

Introduced marine species and pathogens can occur in marine environments but won't always establish to become 'pests' or disease risks unless the environmental conditions are favourable (Wells, 2024). Approximately 70 introduced marine species have been recorded in WA marine waters (Huisman et al., 2008; McDonald et al., 2008; Wells et al., 2009; DoF, 2015; Muñoz et al., 2015; DPIRD, 2023; Wells, 2024), and only ~six were tropical species occurring north from Shark Bay. Some of these can be found on the WA prevention list (~80 species), which comprises species present on the national aquatic pest lists and those of concern to the WA aquatic resources (DPIRD, 2016). Of the 70 species in WA recently reviewed by Wells (2024), over half (~44 species) were introduced from overseas. In 2017, the State-Wide Array Surveillance Program (SWASP) was implemented in 11 ports along the WA coast and uses settlement arrays and DNA sequencing to detect marine pests (Dias et al., 2017; McDonald et al., 2020).

The white colonial sea squirt, *Didemnum perlucidum*, is the only introduced marine species listed as currently occurring in Exmouth Gulf based on the National Introduced Marine Pest Information System (NIMPIS, 2024) (Figure 69). This was also the only species out of 5532 shallow water species documented from the Pilbara region that was identified as a marine pest (Wells, 2018).

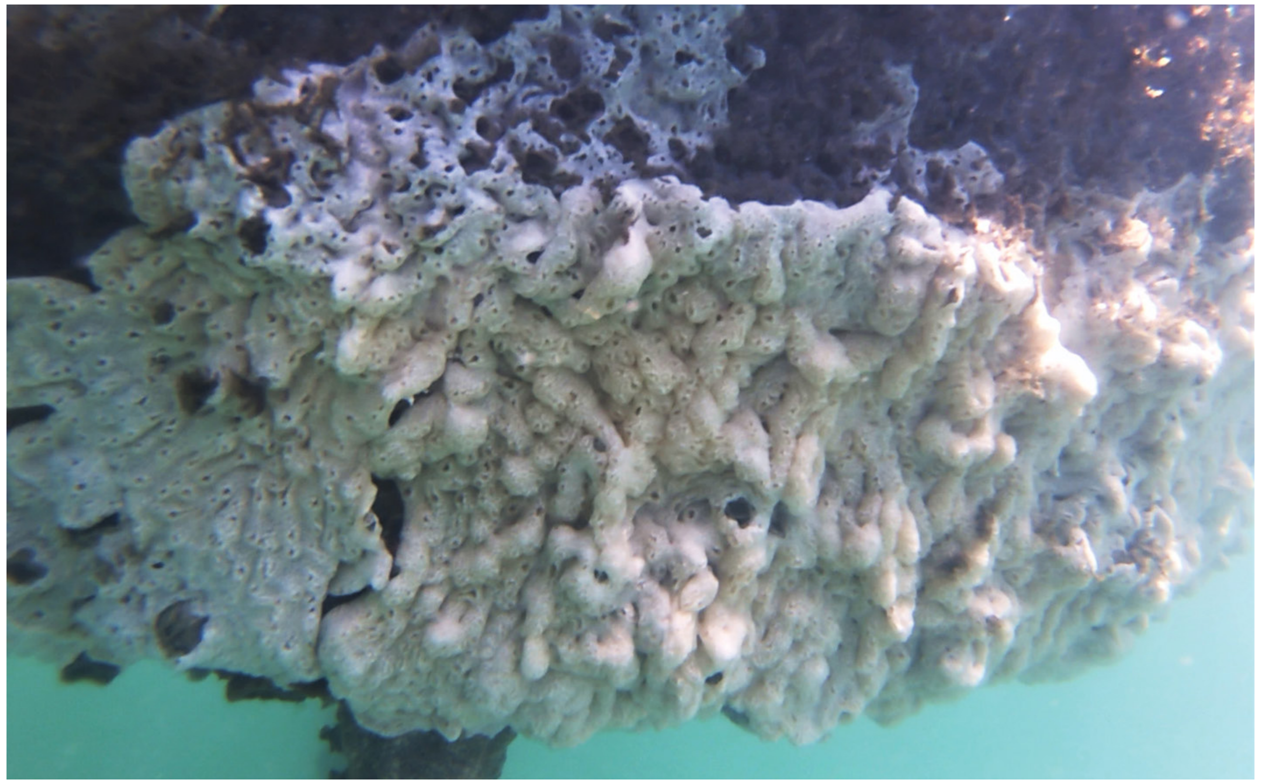


Figure 69: *Didemnum perlucidum*, an introduced colonial sea squirt first found in Exmouth Gulf in 2016. Image: NIMPIS, Carolyn Trewin

The acorn barnacle, *Megabalanus tintinnabulum*, and hydroid, *Antennella secundaria*, have been previously recorded in Exmouth Gulf, though no recent sightings have been published (Watson, 1996; Huisman et al., 2008; Atlas of Living Australia) (Figure 70).

The environmental conditions of the Gascoyne coast were assessed to be compatible for 12 high risk and seven medium risk introduced marine species if they were to establish in the area (Bridgwood & McDonald, 2014). The Exmouth Boat Harbour was not assessed in 2014 alongside ten other ports across WA, however, was assessed in 2006 as being the 'port' with the lowest likelihood of invasive marine species introductions in WA (McDonald, 2008). No regular monitoring of introduced marine species in undertaken in Exmouth Gulf, likely due to the low risk and low vessel visitation compared to other ports in WA. Similarly, pathogens are not regularly monitored in Exmouth Gulf. The only disease documented in Exmouth Gulf was Oyster oedema disease that caused mass mortality (80–100%) of farmed pearl oysters, *Pinctada maxima*, in 2006 (Jones et al., 2010; Hart et al., 2016).

Figure 70: *Megabalanus tintinnabulum* (left) and *Antennella secundaria* (right), two historically recorded introduced species in Exmouth Gulf. Images: Hans Hillewaert (left) and Bernard Picton (right), obtained from the World Register of Marine Species.

3.7. Subterranean fauna and karst systems

A key focus area for the Taskforce is the connectivity of nutrients, energy, flora and fauna across between the land and sea. Groundwater is vital for karst systems and their associated subterranean fauna. Saltwater intrusion due to drawdown on groundwater or from a drying climate can have implications for the water and humidity in caves and the fauna adapted to these conditions. Research is currently underway to better understand these systems and, while not strictly marine or coastal (the scope of this report), a brief summary on subterranean values is provided below. More detailed information can be found in Sutton & Shaw (2021).

The Cape Range Peninsula and its associated limestone karst habitats is globally recognised as a biodiversity hotspot for subterranean fauna, with at least 83 species known, most of which are endemic to the region (Eberhard & Howarth 2021) (Figure 71).

Some of the notable subterranean values of the Cape Range region are:

- The Cape Range Subterranean Waterways are listed as a nationally important wetland and the only Australian wetland listed principally for its subterranean aquatic fauna values (Humphreys, 2000)
- Two subterranean Threatened Ecological Communities (TECs): Camerons Cave Troglobitic Community and the Cape Range Remipede Community (Bundera Sinkhole), which have been recognised as biological hotspots of diversity due to their high number of unique species
- At least 20 conservation significant species listed under WA's *Biodiversity Conservation Act 2016* and/or federal (EPBC Act) criteria
- Of only three subterranean vertebrates known from Australia, two (the blind cave gudgeon *Milyeringa veritas* and blind cave eel *Ophisternon candidum*) inhabit Cape Range karst habitats, the third is restricted to Barrow Island (blind cave fish *Milyeringa justitia*)
- The only known continental anchialine system in the Southern Hemisphere (Bundera Sinkhole) with a unique, endemic stygofauna assemblage.

Several fundamental knowledge gaps need to be addressed to better understand how to conserve and sustainably manage the globally recognised biodiversity hotspot of the Cape Range. These include:

- Full diversity of the subterranean assemblage and exact level of endemism – there has been a lack of comprehensive, systematic surveys and incomplete knowledge of species distributions. Some taxa are likely new species but have not been formally named yet
- Biology and ecologically of species, including population sizes, reproduction, genetic diversity and genetic structure, habitat, food requirements, dispersal ability, tolerance to changes in groundwater physico-chemical properties (salinity, temperature, PFAS, excess nutrients, heavy metals)
- Suitable measures to maintain/protect genetic diversity

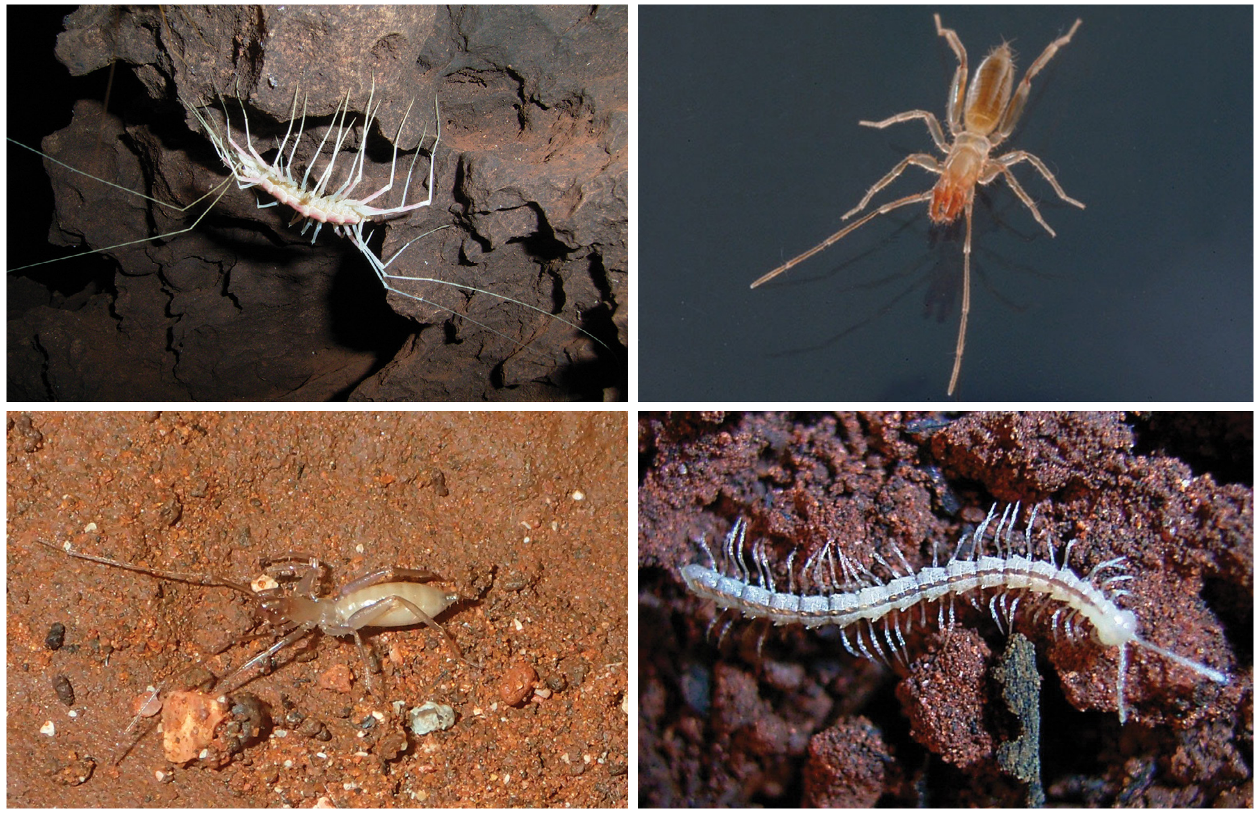


Figure 71: Subterranean fauna of the Cape Range Peninsula. Images: (clockwise from top left) *Scutigeridae* centipede – Darren Brooks; Schizomid – C. de los Milagros; *Stygiochiropus communis* – Darren Brooks; *Draculoides vinei* – Ian Collette.

3.8. NTGAC Sea Country

The Nganhurra Thanardi Garrbu Aboriginal Corporation (NTGAC) are undertaking the Nyinggulu Sea Country Plan. The Plan will include cultural mapping for the reef and range, and a comprehensive seasonal calendar which will be used to inform management of Exmouth Gulf with the Baiyungu Traditional Owners and DBCA. At the time of publication this information was not yet available.

Aerial mangrove roots, Bundegi Sanctuary. Rebecca Bateman-John

4. Knowledge gaps

Scallop. Nick Thake

4. KNOWLEDGE GAPS

4. Knowledge gaps

4.1. Identification of knowledge gaps

The knowledge gaps identified for the prioritisation process primarily stem from previous efforts in Exmouth Gulf.

In 2021, a suite of knowledge gaps relevant to the marine, freshwater and terrestrial environments of Exmouth Gulf were identified by Sutton & Shaw (2021). The report 1) synthesised knowledge of the values of Exmouth Gulf, 2) undertook a risk assessment of these values against activities, and 3) undertook a qualitative assessment of the potential cumulative pressures of the proposed activities and developments on the environmental, social and cultural values of Exmouth Gulf.

These knowledge gaps identified in Sutton & Shaw (2021) originated from various sources, including a literature review, a 2021 workshop with the NTGAC, a qualitative risk assessment process, and informed expert opinion. The knowledge gaps from the qualitative risk assessment process were very specific to a particular value and/or a pressure and were included in this report where a medium and high risk was assigned together with a low to medium confidence in knowledge. Values and pressures that were assigned a low risk, or where confidence in knowledge was high, were not carried forward as a gap in the prioritisation process.

For this current report and prioritisation process, the Taskforce also identified several 'focus areas' through ongoing consultation following the EPA's strategic advice in 2021 (EPA, 2021). These included:

- Description of connectivity across the land/sea and between Exmouth Gulf and surrounds
- Description of nutrient sources and flows into Exmouth Gulf
- Description of water and sediment quality of Exmouth Gulf
- Climate change projections for Exmouth Gulf and likely impacts to key marine ecosystems
- Description and mitigating impacts to marine megafauna (noise, infrastructure, ship strike, etc.)
- Description and synthesis of current information on bonefish, dolphins and sawfish in Exmouth Gulf.

Knowledge on these focus areas was included in Section 3. If remaining gaps in knowledge remained, they were also included in the prioritisation process explained in Section 5.

4.2. Consolidated gaps

The process for consolidating knowledge gaps ready for the prioritisation process included:

1. 'Rolling up' similar gaps into a reworded and more encompassing gap
2. Filtering for gaps relevant to this report's particular scope of works (marine and coastal environment, and land/sea connections)
3. Removing gaps where information has become available since 2021 or is currently being addressed by research projects.

From ~400 knowledge gaps spanning environmental, social, economic and cultural values (largely from the qualitative risk assessment process), 34 gaps that were relevant to this scope of works remained after the consolidation process. These remaining gaps were used in the prioritisation process (Table 17). The consolidation and removal of gaps was performed by the authors of this report who have a comprehensive understanding of past and present research in Exmouth Gulf. The transparency of the process is shown in Appendix 9.7 and allows users to refer back to the original gaps if there is doubt surrounding loss of context of the original gap.

The 34 knowledge gaps were organised under nine high-level research themes (Table 17). High level themes needed to be understood by all stakeholders, while not being too extensive to prohibit participation in the prioritisation process. If a knowledge gap related to more than one theme, it was assigned to the best fitting theme as determined by the authors. In comparison to the shortened themes presented in Shaw & Sutton (2023), the themes used in the Exmouth Gulf prioritisation process were more detailed and provided examples of what the knowledge gaps falling under the theme would relate to. This approach was taken to provide additional clarity to the participants ranking these themes in order of importance, as well as to provide more context when deciding if they proceed further with the prioritisation process.

For example:

Shaw & Sutton (2023)

Theme: Climate change

This report

Theme: Climate change projections for marine and coastal environments (e.g., sea level rise, marine heatwaves, storms and cyclones)

Table 17: Final list of knowledge gaps and high level themes used in the online Exmouth Gulf Research Prioritisation survey. Order does not represent prioritisation at this stage.

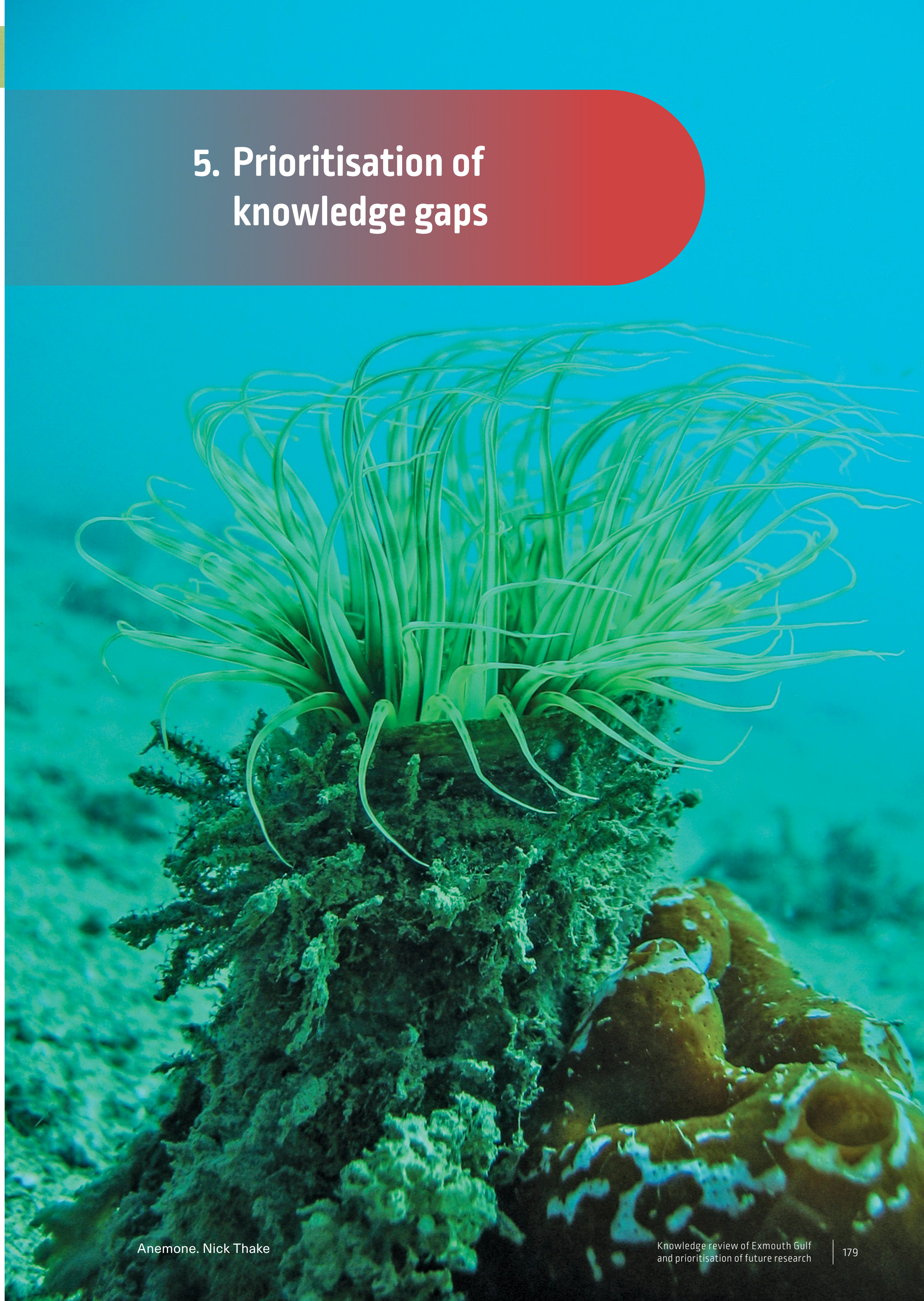
	THEME: Climate change projections for marine and coastal environments (e.g., sea level rise, marine heatwaves, storms and cyclones)
1	What are the specific climate change projections for Exmouth Gulf, and what are the likely effects on key marine and terrestrial ecosystems and taxa?
2	How resilient are benthic habitats and marine fauna to recurring marine heatwaves?
3	How will recurring marine heatwaves affect water quality?
4	What are the effects of current and future climate change pressures, such as storms, cyclones, and sea level rise, on the islands of Exmouth Gulf?
5	What will be the effect of sea level rise on benthic habitats and marine and coastal fauna?
	THEME: Current and future underwater noise effects on marine life (e.g., seismic activity, vessel noise, construction)
6	To what extent is anthropogenic underwater noise currently affecting the soundscape, marine fauna and ecological functions in Exmouth Gulf and how might this change in the future with further coastal development?
	THEME: Fisheries and fishing effects on important species (e.g., recreational, commercial, charter, bycatch)
7	Is recreational fishing causing significant decline to ecologically and recreationally important species?
8	What effect has fishing had on elasmobranch and sea snake populations?
	THEME: Industrial development impacts on coastal and marine environments and recreational activities (e.g., footprints, noise, clearing)
9	What are the possible effects of seawater intake on the surrounding marine environment, and how can we achieve greater certainty about these effects?
10	How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?
11	How will marine based recreation be affected by future coastal development (e.g., footprints, noise, light)?
	THEME: Effects of increased boating and shipping (e.g., increased sediments in water column, marine pests, fuel and oil spills, vessel strikes)
12	What is the natural seasonality of suspended sediments in Exmouth Gulf and how will increases in suspended sediments affect water quality, benthic habitats and marine fauna?
13	What introduced marine pests currently exist in Exmouth Gulf and what risks do current and future pests (from shipping or ocean warming) pose to marine life and habitats?
14	What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments?
15	What is the frequency and consequences of vessel strikes on marine megafauna, including on seabirds and shorebirds?

Table 17 continues on next page

Table 17 from previous page

	THEME: Use of marine and coastal habitats by threatened and protected species (e.g., seagrasses, sponges, corals, mangroves, samphire, feeding areas, nursery areas)
16	How are megafauna and seabirds/shorebirds using specific benthic habitats and to what extent could these associations be affected by habitat damage and degradation?
17	What are the home ranges and habitat uses of sea snakes in Exmouth Gulf?
18	Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays?
19	What is the role of samphire communities in Exmouth Gulf and how are they utilised by other species e.g., migratory shorebirds?
20	Are elasmobranch species utilising Exmouth Gulf and its intertidal habitats seasonally and how reliant are they on these environments?
21	What is the diversity of coastal dolphin species utilising Exmouth Gulf, and are the populations resident, migratory, or a combination of both?
	THEME: Pollution and contamination of the marine environment (e.g., PFAS, bitterns, vessel antifouling, light, marine debris)
22	What is the extent of contaminants in Exmouth Gulf (e.g., PFAS, copper-based) and what effect does this have on the marine food web?
23	What are the effects of bittern discharge on marine fauna and flora, as well as on water and sediment quality?
24	What are the effects of light pollution on marine fauna (including but not limited to sea turtles)?
25	How widespread is pollution (rubbish) and what effect is this having on marine and coastal fauna?
	THEME: Understanding and maintaining ecosystem health, connectivity, and processes (e.g., nutrient and groundwater flows, spawning and recruitment, land and sea connections, food webs, water and sediment quality)
26	How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)?
27	What is the seasonal exchange between the oceanic and Exmouth Gulf waters and how does this influence species recruitment and dispersal?
28	What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?
29	What is the quality and characteristics of water and sediments in Exmouth Gulf?
30	What are the characteristics of sand and mud flat communities and how do they contribute to sediment health?
31	How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)?
	THEME: Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth (e.g., offroad 4WD, anchoring, diving, carrying capacity)
32	To what extent are seabirds and shorebirds being disturbed or injured by human activity (e.g., 4WD)?
33	What is the extent of damage to benthic habitats caused by human activity (e.g., anchoring and diving)?
34	What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on the Gulf?

5. Prioritisation of knowledge gaps



Anemone. Nick Thake

5. PRIORITISATION OF KNOWLEDGE GAPS

5. Prioritisation of knowledge gaps

5.1. Prioritisation survey

The prioritisation of knowledge gaps for Exmouth Gulf followed the same process described in *A Science Plan for Shark Bay (Gathaagudu) developed from comprehensive stakeholder engagement* (Shaw & Sutton, 2023).

An online prioritisation survey was selected from several options suggested to the Taskforce executive. It provided an opportunity to gauge priorities from a range of stakeholders in a transparent and cost-effective way.

The stakeholder groups categorised in the prioritisation survey included:

- Agriculture
- Ashburton community member
- Exmouth community member
- Fishing
- Government (local, state, Commonwealth)
- Local business
- Management
- Mining
- Research/University
- Tourism
- Traditional Owner
- Visitor to Ashburton region
- Visitor to Exmouth region
- Other (could specify).

See Appendix 9.8 for a detailed description of the prioritisation survey approach.

5.2. Metadata

5.2.1. Survey distribution

The online prioritisation survey was distributed via three methods 1) a link sent directly to an email distribution list, 2) an anonymous link that could be accessed by anyone and 3) a QR code included in newsletters, social media posts, and flyers distributed in both Exmouth and Onslow as well as to research organisations. Most participants (65%) accessed the survey using a link in an email, followed by 28% who utilised an anonymous link and 7% who utilised a QR code.

5.2.2. Validation of survey responses

A total of 499 surveys entries were recorded following closure of the online prioritisation survey. After reviewing for illegitimate email bots, duplications, incomplete scoring, 158 entries were removed. The resulting number of survey entries used in further analyses and the below metadata results was 341.

5.2.3. Confidentiality of participants

Over half of the participants (199) chose to include their email addresses at the end of the survey. Completely anonymous participants accessed the survey via the anonymous link or QR code 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, emails were not formatted the same and Qualtrics had capabilities to flag potential bots).

5.2.4. Demographics of participants

Where location information was able to be recorded from IP addresses (n = 266), most of the participants filled the survey out from within WA (87%). Ten percent of participants were based elsewhere in Australia and 2% were based overseas.

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 'Exmouth community member' (20%) (Figure 72), followed by 'Research/University' (18%) and 'Government' (14%). Stakeholder groups 'Mining' and 'Agriculture' had the lowest participation (< 1%). Twenty one participants (3%) identified with other stakeholder groups that weren't predefined, which included 'Consultant', 'Environmental conservation', 'NGO', 'Prescribed Body Corporate', 'Philanthropy', 'Property owner', 'Regional stakeholder', 'Community member/resident (other than Exmouth or Ashburton)', 'Ex-resident and land manager', 'Education', and 'Service provider – Ports'.

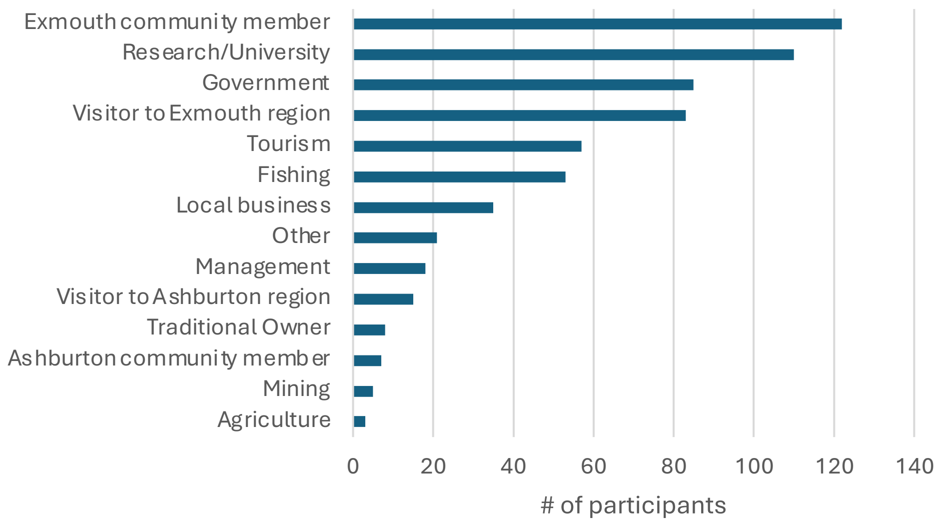


Figure 72: **Identification of all stakeholder groups of participants in the online Exmouth Gulf Research Prioritisation survey.**

Participants were also asked to identify which stakeholder group BEST described them e.g., 'which hat would they be wearing when scoring'. 'Research/University' and 'Exmouth community member' had the highest affiliations (27%, and 26%, respectively) (Figure 73). No participants best identified with 'Agriculture'. Six participants best identified with other stakeholder groups that weren't predefined, including 'Traditional owner legal representative', 'Service provider – Ports', 'Consultant' and 'community member/ resident (other than Exmouth or Ashburton)'.

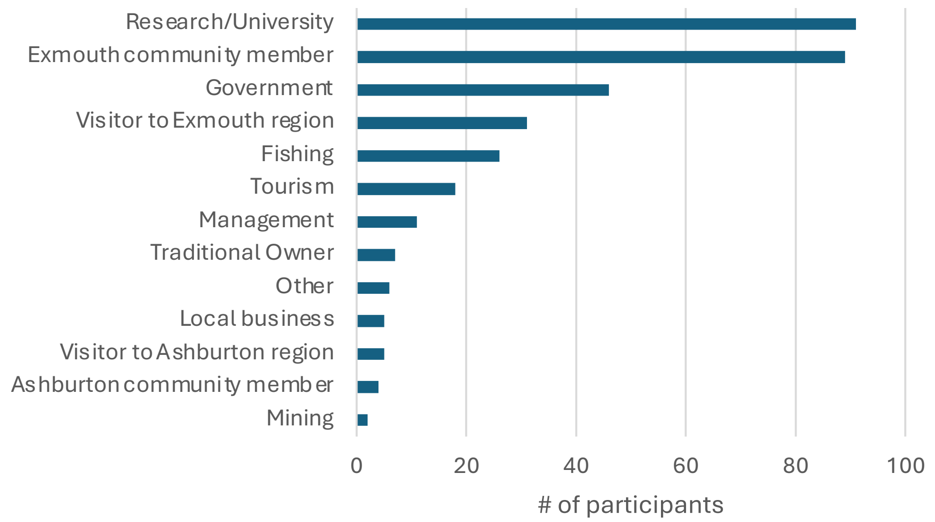


Figure 73: **Identification of the stakeholder group that BEST describes the participants in the online Exmouth Gulf Research Prioritisation survey.**

5.2.5. Survey completion

As ranking high-level themes in Part 1 was a requirement, 341 valid entries were made. Of these entries, 233 participants clicked 'yes' to continuing to Part 2 to score the detailed knowledge gaps (Figure 74), 163 completed the scoring.

Of the 163 participants that completed Part 2, 49 participants (30%) scored all 34 detailed knowledge gaps, while only one participant scored one gap. Most participants (n = 81) scored a minimum of 30 gaps (Figure 75), while 15 participants scored fewer than 10 gaps.

The online prioritisation survey was made available to participants on 31 October 2024 and remained open for approximately five weeks, inclusive of a survey closure extension and reminders over email, newsletters and social media. Most survey completions (40%) occurred during week three, which coincided with a reminder email on the 18 November to complete the survey by the initial deadline of 24 November. Over 50% of participants completed the survey within the first week (Figure 76). The survey was closed officially on 6 December 2024.

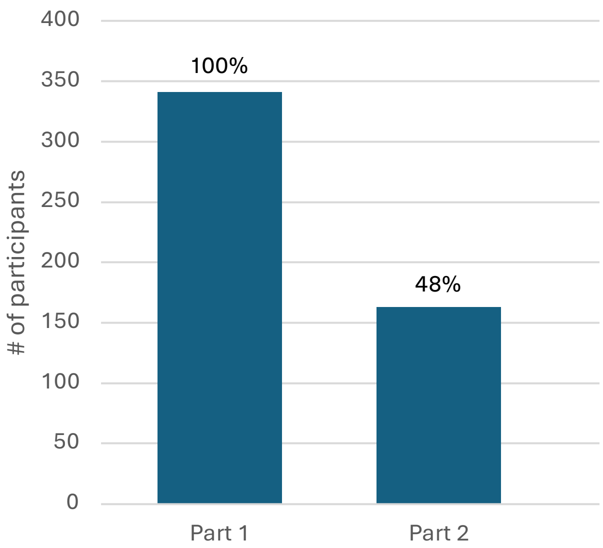


Figure 74: The number of participants who undertook Part 1 and Part 2 of the online Exmouth Gulf Research Prioritisation survey.

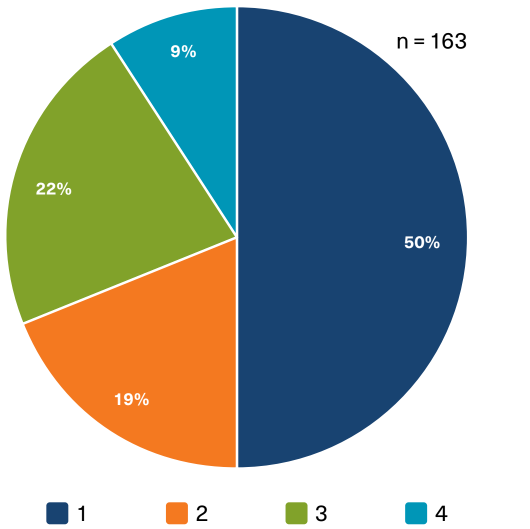


Figure 75: The proportion of questions (max = 34, min = 1) answered by participants in the online Exmouth Gulf Research Prioritisation survey.

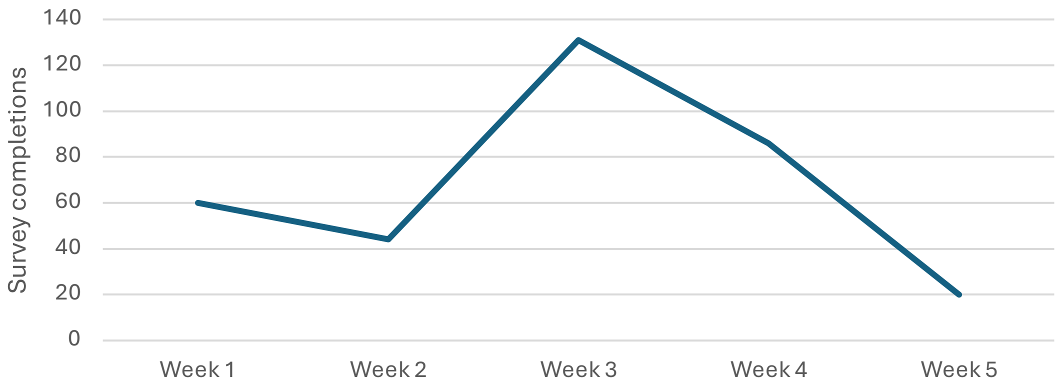


Figure 76: Completion of the online Exmouth Gulf Research Prioritisation survey across five weeks.

The ranking of high-level research themes in Part 1 of the online prioritisation survey was designed to be relatively quick to complete. It took less than 5 minutes for 43% of participants to complete Part 1 (only) (Figure 77). Twenty two participants (13%) took longer than one hour, and it is likely that the survey was left open while the participants attended to other tasks (e.g., max recorded was 20 days). The average time it took for those participants who completed Part 1 only was 8 minutes (excluding the 22 outliers).

The time it took participants to complete Part 1 and Part 2 was longer and variable given the participant could choose the number of gaps they wanted to score. A large proportion (61%) of participants took less than 30 minutes to complete Part 1 and Part 2 (Figure 77). After removing outliers (> 5 hours), the average length of time was 33 minutes. Of the 49 participants who scored all four criteria for all 34 detailed knowledge gaps, the minimum completion time was 14 minutes and the longest was ~3.45 hrs, with an average of 46 minutes.

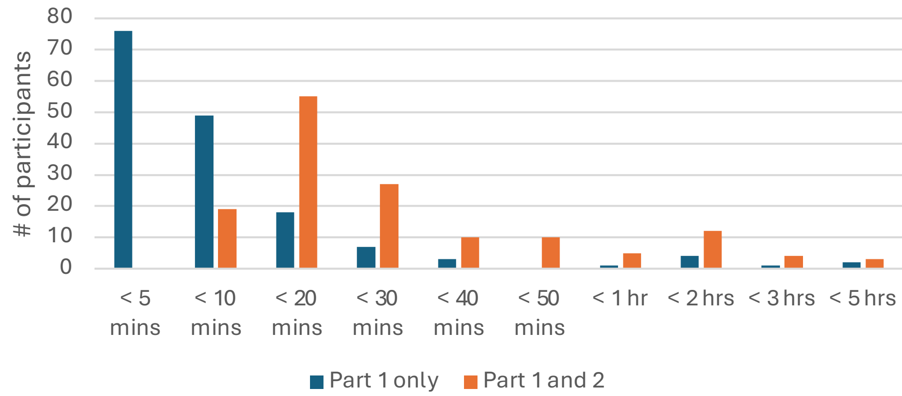


Figure 77: The time taken for participants to complete Part 1 and Part 2 of the online Exmouth Gulf Research Prioritisation survey.

School of yellow sweeper, off Exmouth. Tourism Western Australia

5. PRIORITISATION OF KNOWLEDGE GAPS

5.3. Prioritised research themes and knowledge gaps

5.3.1. High-level research themes

All survey participants (n = 341) were required to rank the nine high-level research themes. Based on an average ranking scores across all participants, *'Industrial development impacts on coastal and marine environments and recreational activities'* was the theme considered to be most in need of future research and management focus (Table 18). This was followed by *'Climate change projections for marine and coastal environments*. The themes *'Pollution and contamination of the marine environment'* and *'Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth'* were considered least in need of future focus.

Given survey responses were linked to stakeholder groups, we can further examine how each stakeholder group differed in theme rankings, where there are synergies that could lead to future collaborations, and how decisions makers can better engage with key issues concerning their respective stakeholder and community groups.

Five out of 12 stakeholder groups (excluding 'Other') thought *'Industrial development impacts on coastal and marine environments and recreational activities'* was in most need of research and management focus (Table 19). These groups included 'Exmouth community member', 'Fishing' 'Research/University', 'Tourism' and 'Traditional Owner'. The 'Research/University' group equally thought *'Climate change projections for marine and coastal environments'* was in most need of research and management focus, which was also supported by 'Government' and 'Visitor to Exmouth region' participants.

Table 18: Ranked order of high-level research themes by participants in the online Exmouth Gulf Research Prioritisation survey. Rank scores ranged from 1 (highest) to 9 (lowest). Rank scores were averaged across all 341 participants.

Rank	Theme	Average	SE
1	Industrial development impacts on coastal and marine environments and recreational activities (e.g., footprints, noise, clearing)	3.31	0.11
2	Climate change projections for marine and coastal environments (e.g., sea level rise, marine heatwaves, storms and cyclones)	4.13	0.15
3	Understanding and maintaining ecosystem health, connectivity, and processes (e.g., nutrient and groundwater flows, spawning and recruitment, land and sea connections, food webs, water and sediment quality)	4.53	0.15
4	Use of marine and coastal habitats by threatened and protected species (e.g., seagrasses, sponges, corals, mangroves, samphire, feeding areas, nursery areas)	4.54	0.12
5	Fisheries and fishing effects on important species (e.g., recreational, commercial, charter, bycatch)	4.78	0.13
6	Effects of increased boating and shipping (e.g., increased sediments in water column, marine pests, fuel and oil spills, vessel strikes)	5.33	0.11
7	Current and future underwater noise effects on marine life (e.g., seismic activity, vessel noise, construction)	5.57	0.13
8	Pollution and contamination of the marine environment (e.g., PFAS, bitterns, vessel antifouling, light, marine debris)	6.25	0.12
9	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth (e.g., offroad 4WD, anchoring, diving, carrying capacity)	6.56	0.14

'Management' participants were most concerned with *'Understanding and maintaining ecosystem health, connectivity and processes'*, 'Ashburton community member' participants with *'Pollution and contamination of the marine environment'*, 'Local business' participants with *'Fisheries and fishing effects on important species'*, 'Mining' participants with *'Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth'* and 'Visitor to Ashburton region' participants with *'Current and future underwater noise effects on marine life'* (Table 19), though these latter four groups had relatively low sample sizes and may not adequately represent the views of those stakeholder groups.

The Themes were understood to be important priorities prior to the survey. Each one was adapted from previous WAMSI and EPA work in Exmouth Gulf (Sutton & Shaw, 2021). Stakeholder comments however, indicated that because each of the Themes were so important, they found it difficult to rank them. It is worth noting that if a Theme was ranked as a lower priority, it indicates a relative score and doesn't mean it has 'no' priority.

Given the perceived community interest in the state of Exmouth Gulf and surrounds, and the wide distribution of the survey invitations, the number of survey respondents were unexpectedly low, i.e. 341 out of potentially thousands of invitations.

Although the results were sufficient for our purposes, a number of reasons could be considered for the response rate:

- Stakeholder fatigue. In recent years, there have been numerous surveys in Exmouth by Government Agencies and the local government. Although WAMSI is not a Government agency or consultancy, feedback from this small community (population ~2800) indicated that the survey was likely another delaying tactic by decision makers to wait for the results of 'yet another survey', rather than taking immediate action to address well known issues. Consequently, feedback indicated some didn't want to participate in 'yet another survey'
- Responses from Ashburton (Onslow) Shire community were relatively low, despite the WAMSI Research Director attending a community forum and speaking about the survey, flyers being distributed around the town, email invitations sent out, as well as well as social media distribution. Anecdotally it was reported that the Onslow community had felt 'left out' and largely 'ignored' by previous stakeholder engagement processes regarding the proposed marine park. This survey may have been perceived as 'too little too late'.

If further surveys are being considered for these communities the above perceptions should be taken into account.

Diver in the sponge gardens of Exmouth Gulf.
Rebecca Bateman-John

5. PRIORITISATION OF KNOWLEDGE GAPS

Table 19: Ranked order of high-level research themes by different stakeholder groups that participated in the online Exmouth Gulf Research Prioritisation survey. Ordered top to bottom based on the sample sizes of each stakeholder group.

Rank	1	2	3
Research/ University	^Climate change projections for marine and coastal environments	^Industrial development impacts on coastal and marine environments and recreational activities	Understanding and maintaining ecosystem health, connectivity, and processes
Exmouth community member	Industrial development impacts on coastal and marine environments and recreational activities	Climate change projections for marine and coastal environments	Current and future underwater noise effects on marine life
Government	Climate change projections for marine and coastal environments	Industrial development impacts on coastal and marine environments and recreational activities	Understanding and maintaining ecosystem health, connectivity, and processes
Visitor to Exmouth region	Climate change projections for marine and coastal environments	Industrial development impacts on coastal and marine environments and recreational activities	Fisheries and fishing effects on important species
Fishing	Industrial development impacts on coastal and marine environments and recreational activities	Fisheries and fishing effects on important species	Understanding and maintaining ecosystem health, connectivity, and processes
Tourism	Industrial development impacts on coastal and marine environments and recreational activities	^Current and future underwater noise effects on marine life	^Fisheries and fishing effects on important species
Management	Understanding and maintaining ecosystem health, connectivity, and processes	Use of marine and coastal habitats by threatened and protected species	Industrial development impacts on coastal and marine environments and recreational activities
Traditional Owner	Industrial development impacts on coastal and marine environments and recreational activities	Current and future underwater noise effects on marine life	Fisheries and fishing effects on important species
Local business	Fisheries and fishing effects on important species	Industrial development impacts on coastal and marine environments and recreational activities	Use of marine and coastal habitats by threatened and protected species
Visitor to Ashburton region	Current and future underwater noise effects on marine life	Industrial development impacts on coastal and marine environments and recreational activities	Effects of increased boating and shipping
Ashburton community member	Pollution and contamination of the marine environment	Effects of increased boating and shipping	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth
Mining	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	^Fisheries and fishing effects on important species	^Effects of increased boating and shipping
All combined	**Industrial development impacts on coastal and marine environments and recreational activities**	**Climate change projections for marine and coastal environments**	**Understanding and maintaining ecosystem health, connectivity, and processes**

Table 19 continues on next page

Table 19 from previous page

Rank	4	5	6
Research/ University	Use of marine and coastal habitats by threatened and protected species	Fisheries and fishing effects on important species	Effects of increased boating and shipping
Exmouth community member	Use of marine and coastal habitats by threatened and protected species	Understanding and maintaining ecosystem health, connectivity, and processes	Effects of increased boating and shipping
Government	Use of marine and coastal habitats by threatened and protected species	Fisheries and fishing effects on important species	Effects of increased boating and shipping
Visitor to Exmouth region	Current and future underwater noise effects on marine life	Use of marine and coastal habitats by threatened and protected species	Effects of increased boating and shipping
Fishing	Effects of increased boating and shipping	Use of marine and coastal habitats by threatened and protected species	Pollution and contamination of the marine environment
Tourism	Climate change projections for marine and coastal environments	Effects of increased boating and shipping	Use of marine and coastal habitats by threatened and protected species
Management	Climate change projections for marine and coastal environments	Effects of increased boating and shipping	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth
Traditional Owner	Effects of increased boating and shipping	Pollution and contamination of the marine environment	Use of marine and coastal habitats by threatened and protected species
Local business	Pollution and contamination of the marine environment	^Effects of increased boating and shipping	^Understanding and maintaining ecosystem health, connectivity, and processes
Visitor to Ashburton region	Climate change projections for marine and coastal environments	Pollution and contamination of the marine environment	Fisheries and fishing effects on important species
Ashburton community member	Use of marine and coastal habitats by threatened and protected species	Climate change projections for marine and coastal environments	Current and future underwater noise effects on marine life
Mining	*Industrial development impacts on coastal and marine environments and recreational activities	*Pollution and contamination of the marine environment	Climate change projections for marine and coastal environments
All combined	**Use of marine and coastal habitats by threatened and protected species**	**Fisheries and fishing effects on important species**	**Effects of increased boating and shipping**

Table 19 continues on next page

Table 19 from previous page

Rank	7	8	9	N
Research/ University	Current and future underwater noise effects on marine life	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	Pollution and contamination of the marine environment	91
Exmouth community member	Fisheries and fishing effects on important species	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	Pollution and contamination of the marine environment	89
Government	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	Pollution and contamination of the marine environment	Current and future underwater noise effects on marine life	46
Visitor to Exmouth region	Understanding and maintaining ecosystem health, connectivity, and processes	Pollution and contamination of the marine environment	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	31
Fishing	Current and future underwater noise effects on marine life	Climate change projections for marine and coastal environments	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	26
Tourism	Understanding and maintaining ecosystem health, connectivity, and processes	Pollution and contamination of the marine environment	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	18
Management	Fisheries and fishing effects on important species	Current and future underwater noise effects on marine life	Pollution and contamination of the marine environment	11
Traditional Owner	Climate change projections for marine and coastal environments	Understanding and maintaining ecosystem health, connectivity, and processes	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	7
Local business	Current and future underwater noise effects on marine life	Climate change projections for marine and coastal environments	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	5
Visitor to Ashburton region	Use of marine and coastal habitats by threatened and protected species	Understanding and maintaining ecosystem health, connectivity, and processes	Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth	5
Ashburton community member	Industrial development impacts on coastal and marine environments and recreational activities	^Fisheries and fishing effects on important species	^Understanding and maintaining ecosystem health, connectivity, and processes	4
Mining	#Current and future underwater noise effects on marine life	#Understanding and maintaining ecosystem health, connectivity, and processes	Use of marine and coastal habitats by threatened and protected species	2
All combined	**Current and future underwater noise effects on marine life**	**Pollution and contamination of the marine environment**	**Disturbance and degradation to marine and coastal values from unmanaged tourism and population growth**	**341**

^, *, # ranked at the same level

5.3.2. Detailed knowledge gaps

The top 15 detailed knowledge gaps averaged across all participants is provided in Table 20, and represents seven out of nine high-level themes. The ranking of the 34 detailed knowledge gaps can be seen in Appendix 9.9.

The highest priority knowledge gap is *'How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?'*. This gap was viewed as one of the most urgent gaps to address (average urgency score = 4.30 ± 0.09 S.E.).

Table 20: A prioritised list of the top 15 detailed knowledge gaps and the associated high-level themes, averaged for all participants (sample size shown for each question), resulting from the online Exmouth Gulf Research Prioritisation survey.

	High-level theme	Detailed knowledge gap	Rank	Sample size
1	Industrial development impacts on coastal and marine environments and recreational activities	How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?	1	119
2	Understanding and maintaining ecosystem health, connectivity, and processes	How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)?	2	123
3	Understanding and maintaining ecosystem health, connectivity, and processes	How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)?	3	123
4	Use of marine and coastal habitats by threatened and protected species	Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays?	4	119
5	Disturbance and degradation to marine and coastal values from unmanaged tourism and population	What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on the Gulf?	5	66
6	Use of marine and coastal habitats by threatened and protected species	How are megafauna and seabirds/shorebirds using specific benthic habitats and to what extent could these associations be affected by habitat damage and degradation?	5	119
7	Pollution and contamination of the marine environment	What are the effects of bitterns discharge on marine fauna and flora, as well as on water and sediment quality?	6	86
8	Climate change projections for marine and coastal environments	How resilient are benthic habitats and marine fauna to recurring marine heatwaves?	7	119
9	Effects of increased boating and shipping	What introduced marine pests currently exist in Exmouth Gulf and what risks do current and future pests (from shipping or ocean warming) pose to marine life and habitats?	8	93
10	Pollution and contamination of the marine environment	What is the extent of contaminants in Exmouth Gulf (e.g., PFAS, copper-based) and what effect does this have on the marine food web?	8	87
11	Use of marine and coastal habitats by threatened and protected species	Are elasmobranch species utilising Exmouth Gulf and its intertidal habitats seasonally and how reliant are they on these environments?	8	114

Table 20 continues on next page

5. PRIORITISATION OF KNOWLEDGE GAPS

Table 20 from previous page

	High-level theme	Detailed knowledge gap	Rank	Sample size
12	Understanding and maintaining ecosystem health, connectivity, and processes	What is the seasonal exchange between the oceanic and Exmouth Gulf waters and how does this influence species recruitment and dispersal?	9	120
13	Understanding and maintaining ecosystem health, connectivity, and processes	What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?	10	123
14	Climate change projections for marine and coastal environments	To what extent is anthropogenic underwater noise currently affecting the soundscape, marine fauna and ecological functions in Exmouth Gulf and how might this change in the future with further coastal development?	13	94

Most of the top 15 detailed knowledge gaps were concerned with impacts and pressures e.g., development, mining, population growth, habitat degradation, climate change and pollution/contamination (Figure 78). Five gaps were concerned with better understanding the marine environment and associated flora and fauna.

There was a high degree of alignment of priorities for the three largest stakeholder groups: 'Researcher/University', 'Exmouth community member' and 'Government'. The following four gaps featured in the top five for the three groups (Table 21):

- How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?
- How will groundwater systems be affected by expansion of mining activities?
- How is Exmouth Gulf influenced by processes and pathways across the land-sea interface?
- Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays?

'Fishing' participants also thought *'How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?'* and *'How will groundwater systems be affected by expansion of mining activities?'* were a priority.

Several gaps also featured across three or more stakeholder groups (Table 21), including:

- What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on Exmouth Gulf?
- What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments?
- What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?
- To what extent is underwater noise currently effecting marine fauna and ecological functions in Exmouth Gulf and how might this change in the future?
- How resilient are benthic habitats and marine fauna to recurring marine heatwaves?

All stakeholder groups, excluding 'Researcher/University', 'Exmouth community member' and 'Government', had a relatively low number of participants scoring gaps, particularly, 'Tourism', 'Management', 'Traditional Owner, 'Local business', 'Ashburton community member', and 'Visitor to Ashburton region' and the priorities presented in Table 21 may not adequately representant the views of those stakeholder groups.

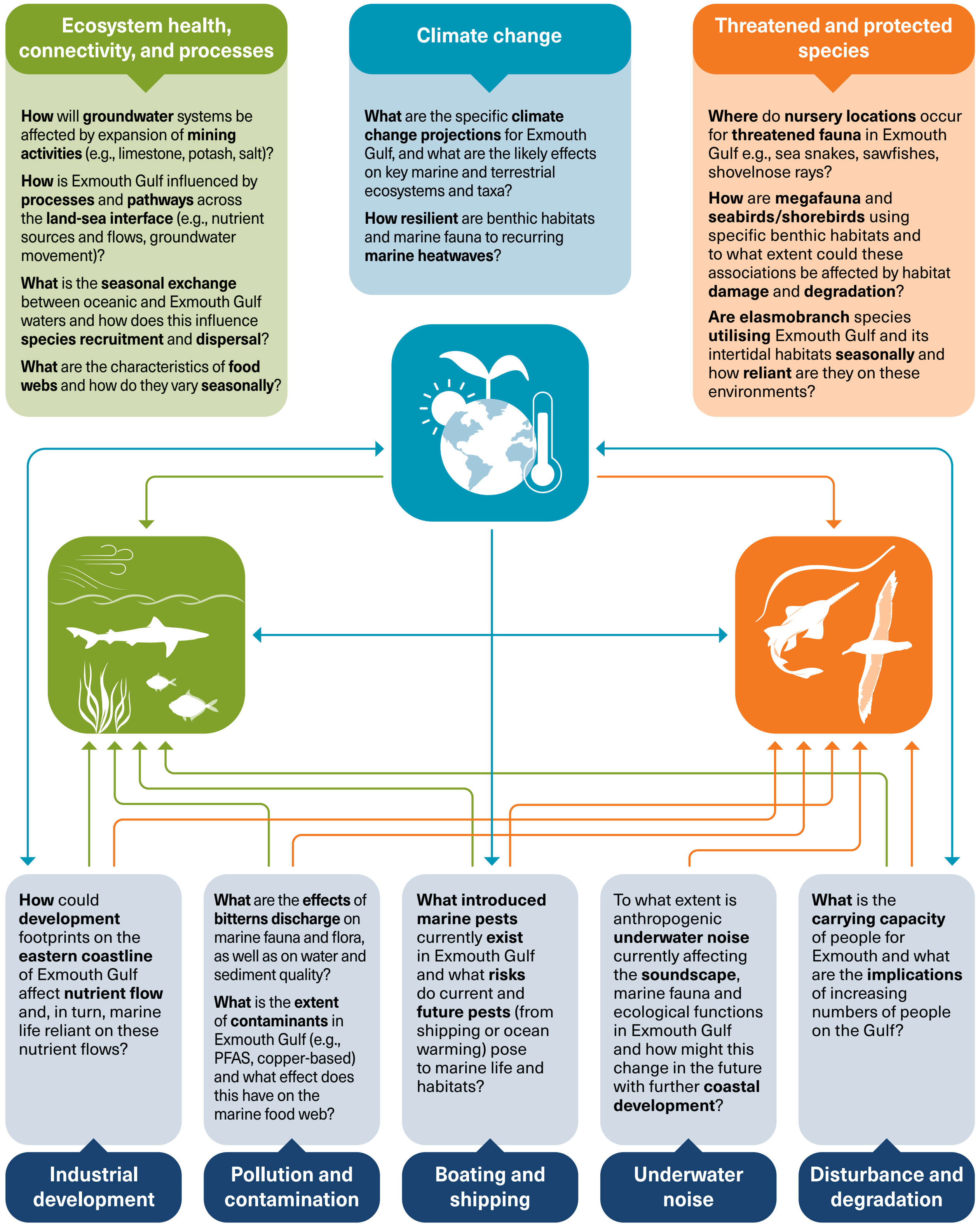


Figure 78: Top 15 knowledge gaps as determined by stakeholders in the WAMSI Exmouth Gulf Research Prioritisation survey, demonstrating linkages between gaps and high-level research themes.

Table 21: A prioritised list of the top five detailed knowledge gaps for each stakeholder group that participated in the online Exmouth Gulf Research Prioritisation survey. Scores for each gap were averaged across participants in each stakeholder group, noting not all gaps were scored by the same number of participants within each stakeholder group (sample size provided). 'Mining' participants did not score any detailed knowledge gaps, and no participants best identified with 'Agriculture'.

	Research/University
1	How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows? (n = 41)
2	How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)? (n = 51)
3	How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)? (n = 49)
4	Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays? (n = 46)
5	What are the effects of bittern discharge on marine fauna and flora, as well as on water and sediment quality? (n = 23)
	Exmouth community member
1	How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)? (n = 23)
2	What is the role of samphire communities in Exmouth Gulf and how are they utilised by other species e.g., migratory shorebirds? (n = 25)
8	How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)? (n = 23)
4	How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows? (n = 26)
5	Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays? (n = 25)
	Government
1	How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows? (n = 15)
2	How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)? (n = 17)
3	How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)? (n = 17)
4	What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on the Gulf? (n = 8)
5	Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays? (n = 15)
	Fishing
1	How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows? (n = 10)
2	How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)? (n = 9)
3	What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments? (n = 6)
4	What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally? (n = 9)
5	What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on the Gulf? (n = 10)

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5. PRIORITISATION OF KNOWLEDGE GAPS

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	Visitor to Exmouth region
1	How will marine based recreation be affected by future coastal development (e.g., footprints, noise, light)? (n = 7)
2	What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments? (n = 5)
8	How will recurring marine heatwaves affect water quality? (n = 7)
4	What are the effects of bittern discharge on marine fauna and flora, as well as on water and sediment quality? (n = 6)
5	What is the extent of contaminants in Exmouth Gulf (e.g., PFAS, copper-based) and what effect does this have on the marine food web? (n=6)
	Tourism
1	What is the frequency and consequences of vessel strikes on marine megafauna, including on seabirds and shorebirds? (n = 4)
2	What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally? (n = 3)
8	What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments? (n = 4)
4	To what extent is anthropogenic underwater noise currently affecting the soundscape, marine fauna and ecological functions in Exmouth Gulf and how might this change in the future with further coastal development?
5	What is the seasonal exchange between the oceanic and Exmouth Gulf waters and how does this influence species recruitment and dispersal? (n = 2)
	Management
1	How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)? (n = 4)
2	What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally? (n = 4)
3	How resilient are benthic habitats and marine fauna to recurring marine heatwaves? (n = 4)
4	To what extent are seabirds and shorebirds being disturbed or injured by human activity (e.g., 4WD)? (n = 2)
5	What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on the Gulf? (n = 2)
	Traditional Owner
1	What is the current marine soundscape of Exmouth Gulf, and how could this be predicted to change with further coastal development? (n = 2)
2	What is the extent of contaminants in Exmouth Gulf (e.g., PFAS, copper-based) and what effect does this have on the marine food web? (n=4)
3	What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments? (n = 5)
4	To what extent is anthropogenic underwater noise currently affecting the soundscape, marine fauna and ecological functions in Exmouth Gulf and how might this change in the future with further coastal development?
5	How widespread is pollution (rubbish) and what effect is this having on marine and coastal fauna? (n = 4)

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	Local business
1	Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays? (n = 1)
2	What is the quality and characteristics of water and sediments in Exmouth Gulf? (n = 2)
3	What are the home ranges and habitat uses of sea snakes in Exmouth Gulf? (n = 1)
4	What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally? (n = 2)
5	What are the specific climate change projections for Exmouth Gulf, and what are the likely effects on key marine and terrestrial ecosystems and taxa? (n = 1)
	Ashburton community member
1	What is the extent of contaminants in Exmouth Gulf (e.g., PFAS, copper-based) and what effect does this have on the marine food web? (n=2)
2	How widespread is pollution (rubbish) and what effect is this having on marine and coastal fauna? (n = 2)
3	What are the effects of light pollution on marine fauna (including but not limited to sea turtles)? (n = 2)
4	What are the specific climate change projections for Exmouth Gulf, and what are the likely effects on key marine and terrestrial ecosystems and taxa? (n = 2)
5	How resilient are benthic habitats and marine fauna to recurring marine heatwaves? (n = 2)
	Visitor to Ashburton region
1	What is the frequency and consequences of vessel strikes on marine megafauna, including on seabirds and shorebirds? (n = 2)
2	To what extent is anthropogenic underwater noise currently affecting the soundscape, marine fauna and ecological functions in Exmouth Gulf and how might this change in the future with further coastal development?
3	What is the current marine soundscape of Exmouth Gulf, and how could this be predicted to change with further coastal development? (n = 2)
4	How resilient are benthic habitats and marine fauna to recurring marine heatwaves? (n = 2)
5	What is the occurrence, extent and severity of fuel and oil spills and is this affecting marine and coastal environments? (n = 2)

6. Recommended high priority projects for future funding

Humpback whale mother and calf, Exmouth Gulf. Holly Raudino

6. RECOMMENDED HIGH PRIORITY PROJECTS FOR FUTURE FUNDING

6. Recommended high priority projects for future funding

There are still fundamental ecosystem knowledge gaps that need to be addressed to better understand the marine environment of Exmouth Gulf and surrounds and how to best manage it under increasing pressures. Exmouth Gulf has been relatively understudied due to its remoteness and hard to access areas. It is not fully understood how such a productive prawn fishery and nursery habitat is sustained, and how important the shallow protected waters are for myriad of ecologically significant and conservation listed species. Given the coastline of Exmouth Gulf is less developed, there has not been a strong focus on environmental impacts.

Following the WAMSI risk assessment work in 2021 (Sutton & Shaw, 2021), it was clear there were significant gaps in knowledge of Exmouth Gulf that could hinder decisions on environmental impacts. The knowledge gaps were compiled and prioritised as described above.

In the prioritisation survey, the top 15 detailed knowledge gaps can be grouped under three core areas that are interlinked: climate change, ecosystem and anthropogenic stressors (Figure 79). Most of the priority knowledge gaps that relate to anthropogenic stressors are framed in the future tense (e.g., how could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flow, because Exmouth Gulf doesn't currently have these pressures). However, coastal development projects are currently proposed for Exmouth Gulf and understanding how different stressors could impact Exmouth Gulf before they become reality would better inform how Exmouth Gulf is managed and how coastal development projects are assessed. The specific impacts of climate change, such as sea level rise, erosion, warmer waters and marine heatwaves is not yet well understood for Exmouth Gulf.

A suite of research projects is recommended in Table 22 to address the top 15 detailed knowledge gaps. This will require a collaborative approach and should build upon recently completed or projects already underway. A focus area for the Taskforce and of this report is nutrient dynamics and quantifying the flows and fluxes in Exmouth Gulf. A biogeochemical modelling project that integrates biological, geological, chemical and physical processes is recommended to address this need, and if undertaken, would underpin many of the recommended projects (e.g., food web modelling, species distributions, marine heatwave effects) and help to address multiple gaps.

Connectivity is also a key focus area, not only for nutrient dynamics, but also for the movement of species between Exmouth Gulf, Ningaloo Reef and other locations. Examples of species connectivity are discussed in Section 3.2.1. However, further research is required to better understand just how many species occurring in other locations are reliant on Exmouth Gulf, for example as a mating ground, nursery area or for the dispersal of larvae. Several projects recommended in Table 22 would help to bridge this knowledge gap, including multi-species habitat modelling, seasonal food web modelling, species distribution and ecological niche modelling, larval dispersal and connectivity modelling, all of which would be validated with data collected from comprehensive field campaigns.

Underpinning most of the recommended projects is the need to fully understand the biodiversity of marine life and habitats in Exmouth Gulf. Though this wasn't listed as a specific gap on its own, or a recommended project (e.g., comprehensive biodiversity surveys, taxonomy and systematics), it is integral to know what species and niche habitats exist in Exmouth Gulf to quantify the magnitude of impact or potential losses from past, current and future pressures. Losses may have already occurred for species yet to be discovered. Projects such as species distribution and ecological niche modelling to predict climate change impacts, seasonal food web modelling, and larval dispersal and connectivity modelling should continue to expand on previous efforts to understand the species and habitat diversity of Exmouth Gulf.

The recommended projects are intended to provide guidance on where to focus attention next. It should not negate the need to address the remaining 21 knowledge gaps, or other gaps that were not captured in this report. These projects are purposely broad in scope to allow for refinement and to accommodate and align with any current and future proposed research projects. Importantly, these projects have not been scoped to incorporate cultural knowledge, nor have they been confirmed as priorities by Traditional Owners.

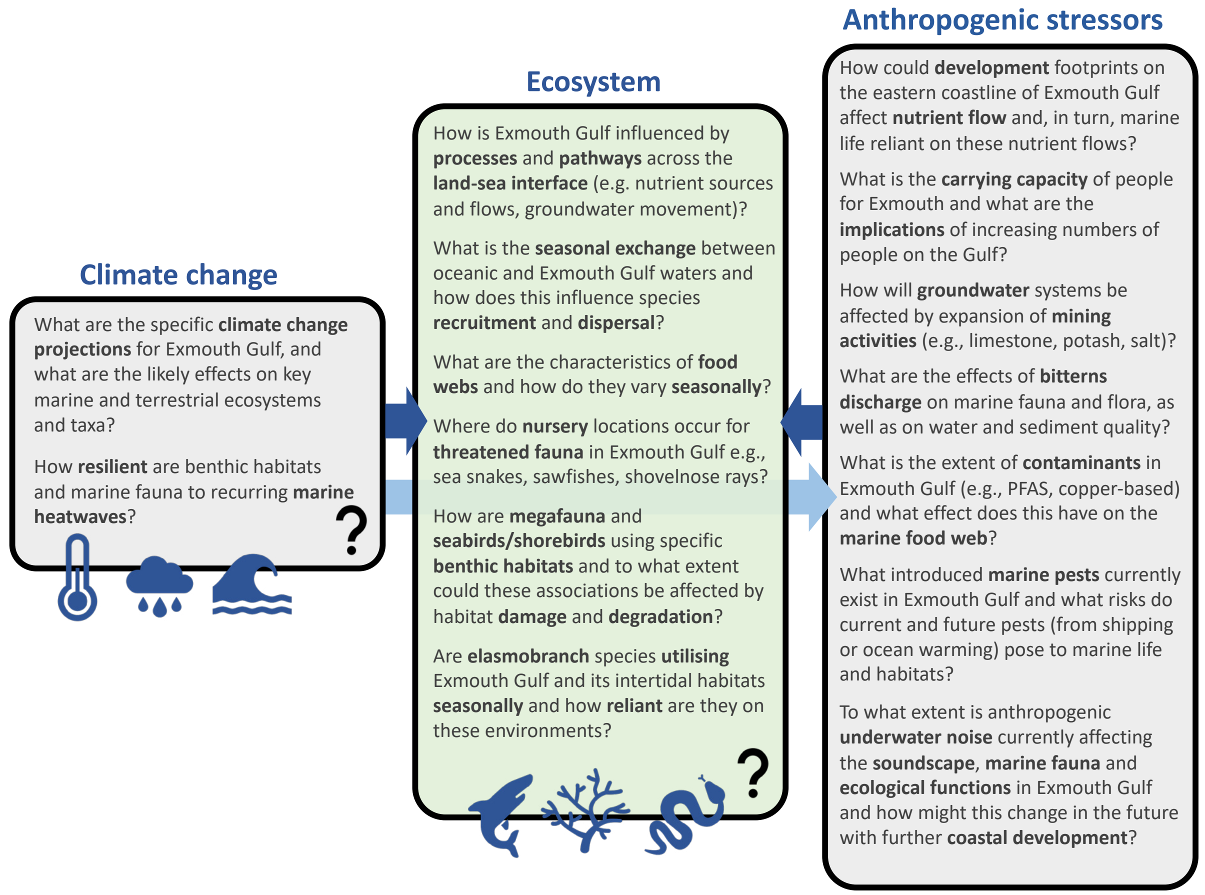

Figure 79: **Prioritised knowledge gaps (top 15) for Exmouth Gulf naturally group under three core areas that are interlinked: climate change, ecosystem and anthropogenic stressors.**

Most of the recommended projects address elements of more than one knowledge gap or can provide data and findings to support other recommended projects. Concurrently running projects could help to save on time and resources. Project lengths range from six months to three years and include project scoping, reporting and data management. Of most importance to the estimated project lengths is the complexity of undertaking field work in Exmouth Gulf. Sites around the margins of the Gulf are not all easily accessible from the land or in water, and the travel required to cover sites could span great distances e.g., hundreds of kms. Weather conditions, particularly strong winds and cyclones can limit the number of suitable field work days. Turbidity is also a strong gradient and factor in the system which could hinder field work related to benthic habitats or marine fauna. Based on decades of field work and, most recently, the WAMSI Mardie Salt Marine Research Program, Exmouth Gulf is an incredibly unpredictable system. An attempt has been made to factor some of this unpredictability into project costings, however, it is likely considerable contingencies would be needed as a safeguard. A breakdown of project estimations can be found in Appendix 9.10, which have been verified, where possible, by subject matter expert and project managers.

Five recommended projects are considered urgent for decision makers (e.g., approved to start within the next 0–2 years) given the window of suitable opportunity, before any proposed coastal developments eventuate. These projects include biogeochemical modelling, seasonal SST forecasts and marine heatwave predictions, forecasting future effects of bitterns discharge, elasmobranch populations and habitat use, and comprehensive subtidal and intertidal benthic habitat mapping. All other projects have a short-term urgency (e.g., approved to start within the next 2–5 years) given they are linked to priority knowledge gaps in Exmouth Gulf.

6. RECOMMENDED HIGH PRIORITY PROJECTS FOR FUTURE FUNDING

Table 22: Preliminary scoping of research projects to address the top 15 knowledge gaps in Exmouth Gulf.

Groundwater mapping, monitoring and modelling	
Urgency:	2–5 years (short term)
Project length:	3 years
Scale/location:	Exmouth Gulf, Cape Range
Est. cost:	$1.3 million
Project elements:	Data collation, comprehensive groundwater measurements, groundwater seep mapping, future scenario modelling

Knowledge gaps addressed:

- How will groundwater systems be affected by expansion of mining activities (e.g., limestone, potash, salt)?
- How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)?

Recently completed/underway projects with relevant data:

- DWER – Groundwater Connections: investigating the link to nearshore marine ecosystems in the La Grange subregion in the Kimberley
- DWER – Climate Science Initiative

Scenario modelling of carrying capacity (people) for Exmouth Gulf	
Urgency:	2–5 years (short term)
Project length:	2 years
Scale/location:	Shire of Exmouth
Est. cost:	$500,000
Project elements:	Data collation, scenario modelling

Knowledge gaps addressed:

- What is the carrying capacity of people for Exmouth and what are the implications of increasing numbers of people on the Gulf?

Recently completed/underway projects with relevant data:

- DPIRD – Statewide Recreational Fishing Survey 2023/24
- DWER – Climate Science Initiative
- DBCA/UWA – Exmouth Gulf spatial use and values: Informing marine park planning

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Biogeochemical modelling	
Urgency:	0–2 years (immediate term)
Project length:	3 years (minimum)
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$3.0 million
Project elements:	Five key components should be investigated to produe a robust biogeochemical model for Exmouth Gulf: • Ocean dynamics and upwelling • Benthic fluxes – sediment water interactions • Tidal creek flows and contribution • In situ pelagic metabolism e.g., nutrient cycling, phytoplankton productivity, flux rates and recycling • Groundwater discharge • Contribution of episodic events

Knowledge gaps addressed:

- How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?
- How is Exmouth Gulf influenced by processes and pathways across the land-sea interface (e.g., nutrient sources and flows, groundwater movement)?
- What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?

** A subject matter expert meeting was held to discuss this scope of works and more detail is provided in Appendix 9.11.*

Recently completed/underway projects with relevant data:

- WAMSI Offset Marine and Intertidal Research Program
- AIMS Blue Carbon Seascapes
- DWER – Climate Science Initiative
- Integrated Marine Observing System (IMOS)/UWA – Coastal Wave Buoys Facility
- UWA/AIMS – Seasonal variability of residence time and ocean exchanges in a semi-enclosed gulf in Northwest Australia
- University of Queensland – Monitoring mangrove tree growth and nutrient limitations, mangrove fertilisation experiments
- ECU – Uptake of nutrients by corals in Exmouth Gulf

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Multi-species habitat modelling	
Urgency:	2–5 years (short term)
Project length:	3 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$1.5 million
Project elements:	Data collation, seasonal marine fauna and benthic surveys, taxonomy and systematics, satellite and acoustic tracking, data collation, habitat modelling (e.g., MaxEnt, BIOMOD)

Knowledge gaps addressed:

- How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?
- Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays?
- How are megafauna and seabirds/shorebirds using specific benthic habitats and to what extent could these associations be affected by habitat damage and degradation?
- How resilient are benthic habitats and marine fauna to recurring marine heatwaves?
- Are elasmobranch species utilising Exmouth Gulf and its intertidal habitats seasonally and how reliant are they on these environments?

Recently completed/underway projects with relevant data:

- University of Adelaide – sea snakes (telemetry, population genomics, connectivity, distribution mapping, fisheries, bycatch interactions, monitoring program)
- Irvine et al. (2025a) – *Total abundance and separation distances of humpback whales (Megaptera novaeangliae) in Exmouth Gulf, Western Australia*
- Irvine et al. (2025b) – *Occurrence of marine megafauna along the western margin of Exmouth Gulf, Western Australia, July-October 2023*
- DBCA/UWA – Exmouth Gulf stereo-BRUVs
- DBCA/DBCA Baiyungu Rangers/Murdoch University/Minderoo Foundation – Exmouth Gulf elasmobranch surveys
- DBCA/CSIRO/Murdoch University/AIMS/DPIRD/IMOS – Several acoustic tracking projects
- Fin Focus Research – Database of sightings
- Recfishwest/Woodside Energy/Curtin University/WA Museum/Blue Media Exmouth/Exmouth Game Fishing Club/ Underwater Focus – Exmouth Gulf King Reef biodiversity study
- UWA – Dugong foraging behaviour and seagrass habitat availability
- UWA – Ranging patterns of bottlenose dolphins off North West Cape

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6. RECOMMENDED HIGH PRIORITY PROJECTS FOR FUTURE FUNDING

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Seasonal food web modelling	
Urgency:	2–5 years (short term)
Project length:	3 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$1.1 million
Project elements:	Data collation, taxonomy and systematics, seasonal stable isotope and eDNA sampling, lab analyses, modelling (e.g., Ecopath and Ecosim)

Knowledge gaps addressed:

- What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?
- How could development footprints on the eastern coastline of Exmouth Gulf affect nutrient flows and, in turn, marine life reliant on these nutrient flows?

Recently completed/underway projects with relevant data:

- WAMSI – Advancing predictions of WA marine heatwaves and impacts on marine ecosystems
- UWA – Dugong foraging behaviour and seagrass habitat availability
- ECU – Uptake of nutrients by corals in Exmouth Gulf
- Said et al. (2025) – *Sparse seagrass meadows are critical dugong habitat: A novel rapid assessment of habitat-wildlife associations using paired drone and in-water surveys*

Forecasting future effects of bitterns discharge in Exmouth Gulf	
Urgency:	0–2 years (immediate term)
Project length:	1.5 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$200,000
Project elements:	Literature review, data collation, plume modelling

Knowledge gaps addressed:

- What are the effects of bittern discharge on marine fauna and flora, as well as on water and sediment quality?

Recently completed/underway projects with relevant data:

- UWA/AIMS – Seasonal variability of residence time and ocean exchanges in a semi-enclosed gulf in Northwest Australia

Assessing future likelihood scenarios of marine pest establishment (climate change and vessels)	
Urgency:	2–5 years (short term)
Project length:	1.5 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$200,000
Project elements:	Data collation, scenario modelling

Knowledge gaps addressed:

- What introduced marine pests currently exist in Exmouth Gulf and what risks do current and future pests (from shipping or ocean warming) pose to marine life and habitats?
- DWER – Climate Science Initiative

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Elasmobranch populations and habitat use	
Urgency:	0–2 years (immediate)
Project length:	3 years
Scale/location:	Exmouth Gulf
Est. cost:	$2.5 million
Project elements:	• Elasmobranch surveys (including sawfish-specific work) • Acoustic tracking of priority species in Exmouth Gulf/Ningaloo Reef • Species distribution mapping and modelling • Genetics and long-term tagging • Post-release mortality of sawfish, wedgefish, other threatened species in recreational and trawl fisheries • ID resource guides

Knowledge gaps addressed:

- Where do nursery locations occur for threatened fauna in Exmouth Gulf e.g., sea snakes, sawfishes, shovelnose rays?
- Are elasmobranch species utilising Exmouth Gulf and its intertidal habitats seasonally and how reliant are they on these environments?
- What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?
- How resilient are benthic habitats and marine fauna to recurring marine heatwaves?

** Further detail on each of the project elements is provided in Appendix 9.12.*

Recently completed/underway projects with relevant data:

- DBCA/DBCA Baiyungu Rangers/Murdoch University/Minderoo Foundation – Exmouth Gulf elasmobranch surveys
- DBCA/CSIRO/Murdoch University/AIMS/DPIRD/IMOS – Several acoustic tracking projects
- DBCA/UWA – Exmouth Gulf stereo-BRUVs
- Fin Focus Research – Database of sightings

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6. RECOMMENDED HIGH PRIORITY PROJECTS FOR FUTURE FUNDING

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Species distribution and ecological niche modelling to predict climate change impacts	
Urgency:	2–5 years (short term)
Project length:	3 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$1.7 million
Project elements:	Data collation, taxonomy and systematics, seasonal marine fauna and benthic surveys, satellite and acoustic tracking, ecological niche modelling

Knowledge gaps addressed:

- How are megafauna and seabirds/shorebirds using specific benthic habitats and to what extent could these associations be affected by habitat damage and degradation?
- How resilient are benthic habitats and marine fauna to recurring marine heatwaves?
- What are the specific climate change projections for Exmouth Gulf, and what are the likely effects on key marine and terrestrial ecosystems and taxa?

Recently completed/underway projects with relevant data:

- WAMSI – Advancing predictions of WA marine heatwaves and impacts on marine ecosystems
- University of Adelaide – sea snakes (telemetry, population genomics, connectivity, distribution mapping, fisheries, bycatch interactions, monitoring program)
- DBCA/UWA Exmouth Gulf stereo-BRUVs
- DBCA/DBCA Baiyungu Rangers/Murdoch University/Minderoo Foundation – Exmouth Gulf elasmobranch surveys
- DBCA/CSIRO/Murdoch University/AIMS/DPIRD/IMOS – Several acoustic tracking projects
- Fin Focus Research – Database of sightings
- DWER – Climate Science Initiative
- IMOS/UWA – Coastal Wave Buoys Facility
- Curtin University/WA Museum/Minderoo Foundation – Benthic habitat surveys to determine 2024/25 marine heatwave impacts
- DBCA/AIMS – Benthic habitat surveys to determine 2024/25 marine heatwave impacts
- UWA – Dugong foraging behaviour and seagrass habitat availability
- UWA – Ranging patterns of bottlenose dolphins off North West Cape

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6. RECOMMENDED HIGH PRIORITY PROJECTS FOR FUTURE FUNDING

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Larval dispersal and connectivity modelling	
Urgency:	2–5 years (short term)
Project length:	3 years
Scale/location:	Whole of Exmouth Gulf and nearby coastal and offshore waters
Est. cost:	$1.3 million
Project elements:	Seasonal data collation and collection, lab analyses, taxonomy and systematics, modelling and simulations

Knowledge gaps addressed:

- How are megafauna and seabirds/shorebirds using specific benthic habitats and to what extent could these associations be affected by habitat damage and degradation?
- How resilient are benthic habitats and marine fauna to recurring marine heatwaves?
- What is the seasonal exchange between the oceanic and Exmouth Gulf waters and how does this influence species recruitment and dispersal?
- What are the characteristics of food webs in Exmouth Gulf and how do they vary seasonally?

Recently completed/underway projects with relevant data:

- UWA/AIMS – *Seasonal variability of residence time and ocean exchanges in a semi-enclosed gulf in Northwest Australia*

Effects of contaminants on marine food webs	
Urgency:	2–5 years (short term)
Project length:	3 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$1.0 million
Project elements:	Water and sediment quality monitoring, terrestrial soil sampling, tissue sampling of marine and coastal flora and fauna, lab analyses

Knowledge gaps addressed:

- What is the extent of contaminants in Exmouth Gulf (e.g., PFAS, copper-based) and what effect does this have on the marine food web?

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Seasonal sea surface temperature forecasts and marine heatwave predictions for Exmouth Gulf	
Urgency:	0–2 years (immediate term)
Project length:	1 year
Scale/location:	Whole of Exmouth Gulf and nearby offshore waters
Est. cost:	$300,000
Project elements:	To build a tool that can achieve seasonal SST forecasts for Exmouth Gulf based on the large-scale ACCESS S2 Bureau of Meteorology forecast. Steps include: • Producing 8-years of high-resolution hind cast simulation using the Regional Ocean Modelling System (ROMS) • Training a machine learning model (using methods already developed for WA coastline south of Exmouth) using the ROMS data. • Testing the model during a key marine heatwave event (that wasn't used in the training) *Note: Estimated cost doesn't include providing SST as an operational product.*

Knowledge gaps addressed:

- How resilient are benthic habitats and marine fauna to recurring marine heatwaves?
- What introduced marine pests currently exist in Exmouth Gulf and what risks do current and future pests (from shipping or ocean warming) pose to marine life and habitats?
- What are the specific climate change projections for Exmouth Gulf, and what are the likely effects on key marine and terrestrial ecosystems and taxa?

Recently completed/underway projects with relevant data:

- WAMSI – Advancing predictions of WA marine heatwaves and impacts on marine ecosystems
- DWER – Climate Science Initiative
- IMOS/UWA – Coastal Wave Buoys Facility

Comprehensive soundscape mapping and modelling future changes based on anthropogenic sources	
Urgency:	2–5 years (short term)
Project length:	2 years
Scale/location:	Whole of Exmouth Gulf
Est. cost:	$800,000
Project elements:	Data collection, modelling: • Record underwater soundscape inside the Gulf (4 recorders) and at entry to and outside of the Gulf for 1 full year (to capture all seasons) • Quantify ambient noise. Compute noise budgets (i.e. contributions of geophony, biophony and anthropophony to the soundscape) • Compare soundscapes inside the Gulf, to entry and outside • Source data on future development of the Gulf (e.g., increased shipping, pile driving for wharf construction) • Model future soundscapes in-, entry- and outside Gulf for Environmental Impact Assessment • Study marine fauna ecology based on the passive acoustic recordings

Knowledge gaps addressed:

- To what extent is anthropogenic underwater noise currently affecting the soundscape, marine fauna and ecological functions in Exmouth Gulf and how might this change in the future with further coastal development?

Recently completed/underway projects with relevant data:

- JASCO Applied Sciences – *Exmouth Gulf Baseline Acoustic Monitoring*

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Comprehensive subtidal and intertidal benthic habitat mapping	
Urgency:	0–2 (immediate term)
Project length:	6 months
Scale/location:	Exmouth Gulf
Est. cost:	$80,000
Project elements:	Data collation, habitat modelling, mapping including confidence and analytical layers

Knowledge gaps addressed:
- Taskforce focus area: comprehensive subtidal and intertidal benthic habitat mapping

Recently completed/underway projects with relevant data:
- DBCA – Benthic habitat mapping
- DPIRD – Benthic habitat mapping
- WAMSI Mardie Salt Marine Research Program
- Gascoyne Gateway Marine Complex – Benthic habitat mapping
- Curtin University/WA Museum/Minderoo Foundation – Benthic habitat surveys to determine 2024/25 marine heatwave impacts
- DBCA/AIMS – Benthic habitat surveys to determine 2024/25 marine heatwave impacts

Research is fundamental for generating new knowledge whereas fit for purpose monitoring programs are essential for detecting change and analysing trends over time. Monitoring programs can help address many of the knowledge gaps and feed data into the research focus areas outlined in Table 22. Some of the recommended future research projects also include opportunities to set up long term monitoring programs that will surpass the project timeframes, helping to inform adaptive management strategies over the next decade. These monitoring programs are outlined in Table 23 and are again, purposely broad to allow for refinement by relevant experts, end users and Traditional Owners.

Table 23: Recommended monitoring programs that could benefit future research projects and adaptive management.

Water and sediment quality monitoring	
Frequency:	Seasonally x 4
Est. annual cost:	TBD
Scale/location:	Whole of Exmouth Gulf, including intertidal areas
Real time oceanographic monitoring	
Frequency:	Hourly/Daily – real time
Est. annual cost:	TBD
Scale/location:	Four locations within Exmouth Gulf
Existing/underway programs:	IMOS, UWA

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6. RECOMMENDED HIGH PRIORITY PROJECTS FOR FUTURE FUNDING

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Marine and coastal flora and fauna monitoring	
Frequency:	Seasonally x 4
Est. annual cost:	TBD
Scale/location:	Whole of Exmouth Gulf, including intertidal areas
Existing/underway programs:	DBCA
Groundwater monitoring	
Frequency:	Seasonally x 4
Est. annual cost:	$580,000
Scale/location:	Coastal margins of Exmouth Gulf and Cape Range (~50 wells/sites)
Existing/underway programs:	DWER
Nutrient sensor arrays	
Frequency:	Hourly/Daily – real time
Est. annual cost:	$140,000 (plus initial equipment and installation costs of $400,000)
Scale/location:	Ten locations – north, east, south, west, central
Acoustic tracking arrays for tagged fauna	
Frequency:	Hourly/Daily – real time
Est. annual cost:	$200,000 (plus initial equipment and installation costs of $200,00)
Scale/location:	25 locations – north, east, south, west, central
Existing/underway programs:	DBCA, CSIRO, Murdoch University, AIMS, DPIRD, IMOS
Shoreline monitoring for sea level rise and erosion	
Frequency:	Annually
Est. annual cost:	$200,000
Scale/location:	10 sites around coastal margins of Exmouth Gulf
Existing/underway programs:	Shire of Exmouth; DoT
Marine pest surveys	
Frequency:	Annually
Est. annual cost:	$30,000
Scale/location:	Western Gulf, e.g., Exmouth Marina, Navy Pier, and boat ramps
Existing/underway programs:	DPIRD

7. Discussion and next steps

Cyanobacterial mat in North Urala at high tide. Shannon Dee

7. Discussion and next steps

The biodiversity, connectedness and ecological significance of Exmouth Gulf make it a unique and highly valued system. This report synthesises western knowledge on ecological connectivity, water and sediment quality, benthic communities and habitats, and marine fauna. It also addresses how stressors such as climate change and other anthropogenic pressures are impacting on these values. Marine heatwaves are having very real and visible impacts on marine life in Exmouth Gulf and proposed coastal developments could soon add significant cumulative pressures. Understanding the ecology of Exmouth Gulf is important for marine spatial planning, conservation and management, and there are still fundamental ecosystem knowledge gaps that need to be better addressed to manage current and future potential pressures.

The current level of anthropogenic activity in Exmouth Gulf is likely sustainable for many of the marine and coastal values (Sutton & Shaw 2021). However, Exmouth Gulf is a sheltered marine embayment adjacent to a resource rich and industrialised region. Two proposals for coastal development are under assessment by the EPA at the time of this report: a deep-water port on the western coastline and salt mine on the eastern coastline. Without fundamental knowledge on the ecological functioning of Exmouth Gulf in its current state, decision making may be hindered when assessing the compatibility of Exmouth Gulf with future population growth, tourism or development.

The most fundamental piece of the 'ecological functioning' puzzle that has been discussed for decades is understanding how nutrients and energy flows through the system. Exmouth Gulf supports one of the largest prawn trawl fisheries in WA, high fauna and flora biodiversity and a suite of conservation significant species, yet it's not clear how they are sustained. There are a variety of nutrient sources in Exmouth Gulf, such as the extensive mangrove forests, cyanobacterial mats, salt flats, tidal creeks, groundwater discharge, benthic and microbial recycling, and oceanic exchange. However, the contribution and interactions of each of these sources is not well understood.

A loss or change to nutrient sources and flows could pose significant risks to benthic habitats, commercial prawn populations, food webs and species connectivity, as well as having cultural, social and economic consequences. The opportunity to gain more certainty around these losses or changes before they occur, through biogeochemical modelling, is recommended as a key next step for Exmouth Gulf. A biogeochemical model will explore the interactions between biological, geological, chemical and physical processes that influence how nutrients and other key elements cycle through the environment and organisms. The data collected for such a model, and the modelled outputs, could then underpin other research, such as food web modelling, species distribution modelling, marine heatwave effects and future impacts of coastal development.

Sawfish and other elasmobranchs rely heavily on a healthy functioning Exmouth Gulf, as do other conservation listed species. While research efforts are underway for elasmobranchs in Exmouth Gulf, projects are in early stages, fragmented, and lack resources to address the wealth of knowledge gaps that still exist for this group of species. Fishing is a current pressure and coastal development a future potential pressure, yet there is, again, uncertainty around the current 'state' of elasmobranchs species in Exmouth Gulf (e.g., Sutton & Shaw 2021) and how they may be impacted in the future. A focused project on elasmobranch populations and habitat use is a key recommendation of this report.

Moving beyond spatially and temporally restricted data that produces a 'snapshot' of findings for Exmouth Gulf will require a collaborative approach that is centred around shared data. New data collected for specific research purposes, project proposals, or from routine monitoring should be designed and considered with a key goal in mind – sharing data to help maintain a healthy functioning Exmouth Gulf ecosystem and inform decision-makers/land managers. Significant WA State government and industry investment has gone into a Pilbara node of a Shared Environmental Analytics Facility operated by WAMSI and the WA Biodiversity Science Institute (WABSI). A coastal mooring system in Exmouth Gulf supported by Department of Jobs, Tourism, Science and Innovation and the National Collaborative Research Infrastructure Strategy will also generate important long-term data.

Striped catfish. Nick Thake

The high priority projects mentioned in Section 6 can build upon on these existing partnerships in the region. For example, a biogeochemical model could be informed by data collected from the coastal mooring network and be hosted on a Shared Environmental Analytics Facility with existing architecture for multiple stakeholders to utilise and continuously improve.

One of the key knowledge gaps resulting from Sutton & Shaw (2021), and one of the priorities for the Taskforce, was the need for a high resolution, contemporary, intertidal and subtidal benthic habitat map of the entire Exmouth Gulf. A workshop was facilitated by WAMSI that brought together the expertise needed to identify the best approach for delivering a 'one size fits all' map. As detailed in Appendix 9.3, there are significant complexities in producing a single habitat map for Exmouth Gulf. Habitats can change seasonally and interannually, habitat classifications can be hindered by highly turbid conditions, and objectives and classification categories can vary depending on the purpose of the map being produced.

Currently, there are three contemporary benthic habitat maps available (or soon to be) for Exmouth Gulf that were produced for specific statutory, scientific, or management objectives: DBCA (marine park planning), DPIRD (fisheries management) and Gascoyne Gateway Marine Complex (coastal development). The differences in data inputs, classification approaches, and outputs from past, current, or future mapping efforts in Exmouth Gulf should be interpreted in the context of their scientific merit and intended application, not as inconsistencies. A combined benthic habitat map with high confidence is required by DWER and the Taskforce and WAMSI proposes a consolidated map with accompanying confidence and analytical layers. This requires sharing of input data (e.g., ground-truthing data and satellite imagery), modelled outputs and methodology (particularly descriptions of classifications). All of these data sources are not currently available but will be within 12 months. The only contemporary subtidal benthic habitat map that is currently available is from DBCA, and contemporary intertidal maps have been produced by Hickey et al. (2023a and in prep). Both the benthic habitat map and the intertidal map are included in this report (Figure 27 and Figure 28). It is recommended that DBCA, DPIRD and Gascoyne Gateway Marine Complex are continued to be engaged and that when data becomes available, all data are shared for the purposes of generating 'fit for purpose' maps that illustrate the variability of the benthic system in Exmouth Gulf.

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