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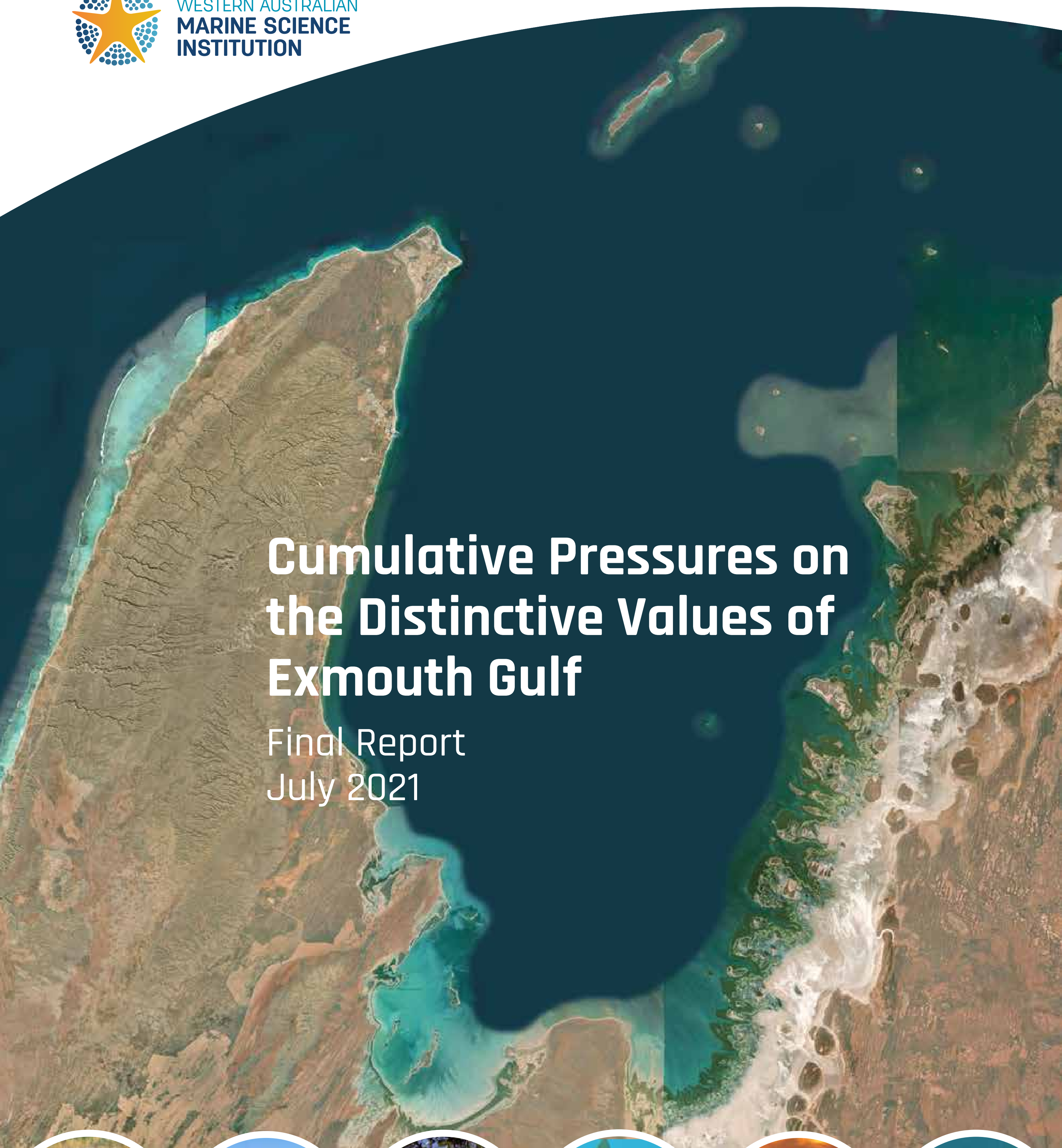

Cumulative Pressures on the Distinctive Values of Exmouth Gulf

Final Report
July 2021

A report to the Department of Water and Environmental Regulation

Cumulative Pressures on the Distinctive Values of Exmouth Gulf: A report to the Department of Water and Environmental Regulation

This report was developed by the Western Australian Marine Science Institution (WAMSI) in partnership with the Environmental Protection Authority (EPA) to help deliver strategic advice to the Western Australian Minister for the Environment under Section 16(e) of the *Environmental Protection Act 1986* on the potential cumulative impacts of the proposed activities and developments on the environmental, social and cultural values of Exmouth Gulf.

The report frames the challenges that such advice requires detailed science-based knowledge of the regional ecosystem components, their dynamics and interactions between the physical and chemical environment. An understanding of previous and planned human interference within the region is also needed to quantify the spatial and temporal impacts and the potential for multiple pressures to interact and exacerbate the detrimental effects on the natural environment.

This report provides a contemporaneous understanding of the Distinctive Values of Exmouth Gulf, the previous, current and forecasted human use of the system, and has drawn on scientific expertise to analyse the relationship between the Distinctive Value and Environmental Pressures of the Exmouth Gulf region.

School of jackfish off the Exmouth coast
(Photo: Tourism Western Australia)

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Main image: GIS image of the Exmouth Gulf (© EPA 2021)

Circle Images (left-right)

- Emus in Cape Range National Park (Photo: Tourism Western Australia)
- Rabbit-proof fence on Giralia Station (Photo: Wendy Thompson)
- Mangroves, Exmouth Gulf (Photo: Rebecca Bateman-John)
- *Plectorhinchus multivittatus* over large *Porite* (Photo: Paul Day)
- Fishing boat at sunset (Photo: Tourism Western Australia)
- Humpback whales, Mother and calf (Photo: Above Photography/DBCA)

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Author Contributions: Alicia Sutton drafted the content of the report, with assistance from Stephanie Hing. Jenny Shaw had report oversight and both Jenny Shaw and Alicia Sutton contributed to the structuring, editing and finalising of the report. Alicia Sutton, Stephanie Hing, Ben Fitzpatrick and Andrew Davenport uncovered the publications used in the literature review and assisted with literature summaries.

Corresponding author and Institution: Jenny Shaw (The Western Australian Marine Science Institution)

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Members of the Nganhurra Thanardi Garrbu Aboriginal Corporation imparted their ecological knowledge to provide a more comprehensive understanding of Exmouth Gulf during meetings with the EPA and WAMSI. This report includes western science knowledge gathered on Nyinggulu (Ningaloo and Exmouth), the traditional land and sea country of the Baiyungu, Yinikurtira and Thalanyji (Jinigudira) people. We pay our respects to their elders past, present and emerging.

The two separate day-long risk assessment workshops were attended by EPA Services, EPA Board, Perspectives Group, WAMSI and subject matter experts from universities government and consultancies. Workshop attendees were instrumental in the qualitative risk assessment process, and their collective knowledge informed robust discussions and risk scoring.

Mangrove, Exmouth Gulf
(Photo: Rebecca Bateman-John)

A number of subject matter experts were additionally engaged to better inform aspects of this report: Rachel Meissner, Mark Cowan (DBCA), Mick O'Leary (UWA), Nicola Browne (Curtin University), Kathleen McInnes (CSIRO), Heather Barnes (DBCA) and Andrew Heyward (AIMS). Additional information to inform this report was provided by Mervi Kangas (DPIRD), Peter Barnes (DBCA), Ralph Talbot-Smith (DoT) and Christopher Cottam (JTSI).

Stephanie Hing, Ben Fitzpatrick and Andrew Davenport are thanked for their assistance in uncovering vast amounts of literature for Exmouth Gulf and for providing summaries that could feed into this report. Paul Day (Carijoa) is thanked for assisting with vessel data and Kelly Waples (DBCA) for assisting with relevant literature.

Many others have contributed to producing this document with advice, suggestions and provision of materials including maps and figures. We very much appreciate and gratefully acknowledge your contributions.

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1. Executive Summary

Flying toward Doole Island, Exmouth Gulf
(Photo: Wendy Thompson)

Exmouth Gulf

Exmouth Gulf is an area of high ecological importance and community value. The marine environment supports a productive prawn fishery, a number of conservation significant species, and an extensive mangrove, salt flat and algal mat system, while the land surrounding supports a unique karst system with subterranean fauna, a high degree of faunal endemism and diverse vegetation complexes. These natural values are highly significant for the local community and support a growing tourism industry centred around a sense of nature and wilderness.

In August 2020, the then W.A. Minister for Environment requested that the Environmental Protection Authority (EPA) provide strategic advice under Section 16(e) of the *Environmental Protection Act 1986* (EP Act) on the potential cumulative impacts on Exmouth Gulf. The request for strategic advice originated from a number of potentially significant development proposals in the Exmouth Gulf region being referred to the EPA under Part IV of the EP Act. These proposals included Subsea 7's Learmonth Pipeline Fabrication Facility, the Shire of Exmouth's Planning Scheme 4 Amendment 1, and K+S Ashburton Salt Project. Since that time, Subsea 7's proposal, and subsequent assessment by the EPA, has been terminated. The EPA is now considering two additional proposals in the Exmouth Gulf; Gascoyne Gateway's Single Jetty Deep Water Port and Renewable Hub, and Z1Z Resort's Ningaloo Lighthouse Resort Project.

Purpose of document

The purpose of this report is to provide research support to assist the EPA in delivering strategic advice to the Minister for Environment on the potential pressures from activities and developments in the Exmouth Gulf. This report provides a review of the literature for Distinctive Values relating to the EPA themes (Sea, Land, Air, Water, and People), it comments on the current state of Distinctive Values, identifies the current and forecasted uses of Exmouth Gulf, and provides an analysis of the relationship between the Distinctive Values and environmental pressures using a qualitative risk assessment process.

Breadth of literature

The extensive review of the literature uncovered over 600 references and provided a snapshot of research over nine decades. Although extensive, it has highlighted the significant gaps in knowledge for a number of values. Importantly, there is limited data and understanding of the connectivity between the values, the impact of increased activities in the area and the linkages or flow-on effects between values.

Qualitative risk assessment

The qualitative risk assessment using a consequence versus likelihood approach targeted eight major activities currently occurring and potentially occurring in Exmouth Gulf: Shipping, Fishing, Climate Change, Mining, Tourism/Visitation, Development, Pastoralism and Defence. While no severe risks to Distinctive Values were identified for the foreseeable future (five-10 years), there were high risks associated with all eight major activities.

Under the Sea theme, high risks were spread across Benthic Communities and Habitats, Marine Fauna, Marine Environmental Quality and Coastal Processes. Seabirds/shorebirds, marine turtles, seagrass, coral trout, humpback whales and dolphins were those Distinctive Values identified as facing the greatest number of high risks. Climate Change pressures, notably marine heatwaves and tropical storms and cyclones, were identified as having the potential to be responsible for the greatest number of high risks under the Sea theme, followed by pollution (oil, fuel, antifoul) from Shipping, recreational fishing (Fishing), and pollution from Tourism/Visitation.

High risks were spread across Flora and Vegetation, Landforms and Subterranean Fauna under the Land theme. Threatened priority flora, vegetation of coastal plains and limestone cliffs and gullies, reptiles, karst systems, stygofauna and troglofauna communities were the Distinctive Values identified as facing the greatest number of high risks. These risks were largely associated with Development pressures, as well as off-road driving associated with Tourism/Visitation and overgrazing associated with Pastoralism.

Under the Water theme, groundwater systems were at high risk from potable water use in relation to Tourism/Visitation and potential contamination (by per- and polyfluoroalkyl substances; PFAS) from Defence activity. Similarly, contamination also rated as a high risk for surface water system.

Intrinsic/wilderness aesthetic under the People theme was faced with high risks in relation to light pollution from residential, industrial and tourism development. Light pollution would impact upon the internationally important 'dark skies' value of the region. Potable water use in relation to Tourism/Visitation was, unsurprisingly, the pressure posing a high risk to the Distinctive Value of potable water.

Assessing cumulative pressures

The process of assessing cumulative pressures highlighted how multiple activities can have a greater impact on a Distinctive Value, which may, normally, not be an issue if one activity was assessed in isolation. Activities can also exert pressures over multiple Distinctive Values, factors and themes. For example, Mining and Climate Change had some level of impact on the Distinctive Values for all five EPA themes of Sea, Land, Water, Air and People. Tourism/Visitation and Development impacted upon four themes, Pastoralism and Defence activities upon three themes, and Fishing and Shipping upon the Sea theme.

While it is important to identify those activities exerting the most pressure, all pressures from all activities contribute towards a cumulative impact on Distinctive Values. Shipping and Climate Change exerted the greatest impact on Distinctive Values of the Sea theme from a cumulative pressures perspective. For the Land, Water, Air and People theme, Development and Mining exerted the greatest pressures.

Sea	Land	Water	Air	People
1 Shipping	1 Development	1 Mining	1 Mining	1 Development
2 Climate Change	2 Mining	2 Development	2 Development	2 Mining
3 Mining	3 Tourism/ Visitation	3 Tourism/ Visitation	3 Climate Change	3 Tourism/ Visitation
4 Tourism/ Visitation	4 Climate Change	4 Climate Change		4 Climate Change
5 Fishing	5 Pastoralism	5 Defence		5 Pastoralism
	6 Defence	6 Pastoralism		6 Defence

Next steps

The main pressures assessed were those of most concern to the community of Exmouth Gulf, based on submissions through the EPA community consultation process, and also considered some of the major likely proposals facing the Gulf. This report was able to provide a measure of how those activities will impact on the environmental values of Exmouth Gulf.

The assessment of cumulative pressures did not account for the potentially amplifying relationships between activities and pressures, nor the natural relationships between Distinctive Values and EPA themes. Thus, the Western Australian Marine Science Institution (WAMSI) makes the following recommendations:

- Undertake a comprehensive analysis of the connectivity between pressures and values to provide a more robust understanding of the cumulative impacts facing Exmouth Gulf.
- In partnership with Traditional Owners, integrate Indigenous knowledge and western science to improve decision making, management and monitoring of the land and sea country of Nyinggulu (Ningaloo and Exmouth).
- Develop a framework to improve our collective ability to enable environmental protection, and to support ecologically sustainable development and cumulative assessment. This should be done through continuous and dynamic integration of knowledge of the drivers, pressures, state and impacts of the region. Our *understanding* will expand as access to that knowledge is fed back and continuously improves through systematic data collection, curation, integration, analysis and use.

Knowledge gaps

This report has also identified a number of knowledge gaps from the literature review and risk assessment process, which are consolidated below. WAMSI acknowledges that the knowledge gaps listed below have not undergone a prioritisation process involving stakeholders. More importantly, the knowledge gaps have not benefited from thorough Traditional Owner input, nor do they represent all the knowledge gaps of Traditional Owners. Future efforts to address knowledge gaps in Exmouth Gulf should be done so in partnership with the Traditional Owners.

Sea

- Comprehensive intertidal and benthic habitat mapping across the whole Exmouth Gulf.
- Understand the current marine soundscape of Exmouth Gulf, the future soundscape based on modelled development activities, and how underwater noise (including seismic) is impacting key taxa and the ecological function of Exmouth Gulf.
- More specific climate change projections (including marine heatwaves) for Exmouth Gulf, and likely impacts to key marine ecosystems and taxa.
- Better understanding of connectivity across the land/sea interface and between Exmouth Gulf and surrounds, such as Ningaloo Reef (including but not limited to: nutrient sources and flows, biogeochemical dynamics, seed banks, recruitment, larval dispersal, nursery areas).
- Better understanding of samphire communities and the reliance on them by other species e.g., the role of samphire for shorebirds (in particular migratory birds).
- Soft sediment infauna and epifauna communities and their role in sediment and water health.
- Exmouth Gulf food webs.
- Better understanding of the elasmobranch species using Exmouth Gulf, particularly listed species such as sawfish, and species that may be relying on the extensive mangrove habitat, such as shovelnose rays.
- Home ranges and habitat use of sea snakes in Exmouth Gulf.

- Diversity of coastal dolphin species using Exmouth Gulf and whether populations are resident, migratory or a mix of both.
- Impact of recreational fishing on targeted and ecologically important fishes, such as coral trout, red emperor and tuskfish.
- Impact of human generated rubbish on marine fauna in Exmouth Gulf, such as manta rays, turtles and seabirds/shorebirds.
- Impacts of coastal infrastructure, such as a port, on marine megafauna (e.g., coastal dolphins, dugongs, whales, elasmobranchs).
- Extent and impact of human disturbances, such as vessel strikes and harassment, occurring to marine fauna.
- Impacts of light pollution on marine fauna (not just turtles).
- Comprehensive understanding of all nutrient sources and flows into Exmouth Gulf.
- Current and comprehensive understanding of water and sediment quality.
- Better understanding of the types of sediments in Exmouth Gulf e.g., grain size, muddy or sandy.
- Impacts of bitterns discharge on marine fauna, flora and water quality, including spatial and temporal modelling specific to Exmouth Gulf.
- More certainty around the impacts of seawater intake for use by industrial salt facilities.
- Extent of potential impacts of oil and fuel spills throughout Exmouth Gulf on the marine environment.
- Potential impacts of antifoulant chemicals, including contemporary copper-based contaminants, on water and sediment quality, and marine life.
- Impacts of potential introduced marine pests and diseases with international shipping on marine fauna and habitats, including coral diseases.

Land

- More specific climate change projections for Exmouth, and likely impacts to key terrestrial ecosystems and taxa.
- Comprehensive flora and vegetation surveys and fine-scale mapping of vegetation complexes.
- Comprehensive surveys and mapping of threatened and priority flora species.
- Contemporary impacts to flora and vegetation complexes, such as overgrazing, pest/feral animals and off-road driving.
- Comprehensive surveys of key and threatened/priority fauna species, including short-range endemic invertebrates.
- Habitat use by key terrestrial fauna and the likely impacts of habitat loss and fragmentation, including salt flats and blue-green algal mats.
- Information on the pathogens (bacteria, fungi, yeast, viruses) and parasites of flora and fauna of the region.
- Impact of enigmatic anthropogenic disturbances such as light, noise, dust, vibrations, and visual disturbances on fauna.
- Better understanding of subterranean faunal communities and the connections between karst systems.
- Impact of groundwater drawdown on karst systems and subterranean fauna.
- Impacts of tourist-related activities on karst systems.
- Understand the impacts of overcapacity (of people) on the environment.
- Better understanding of the impact of flooding events on sewage systems and the impact on the surrounding environment.

Air

- Air Quality Index measurements specific to Exmouth Gulf.

Water

- Extent and locations of groundwater intrusion into Exmouth Gulf.
- Carrying capacity of groundwater and projected sustainability with increasing development.
- Extent of PFAS contamination in groundwater and surface water systems.

People

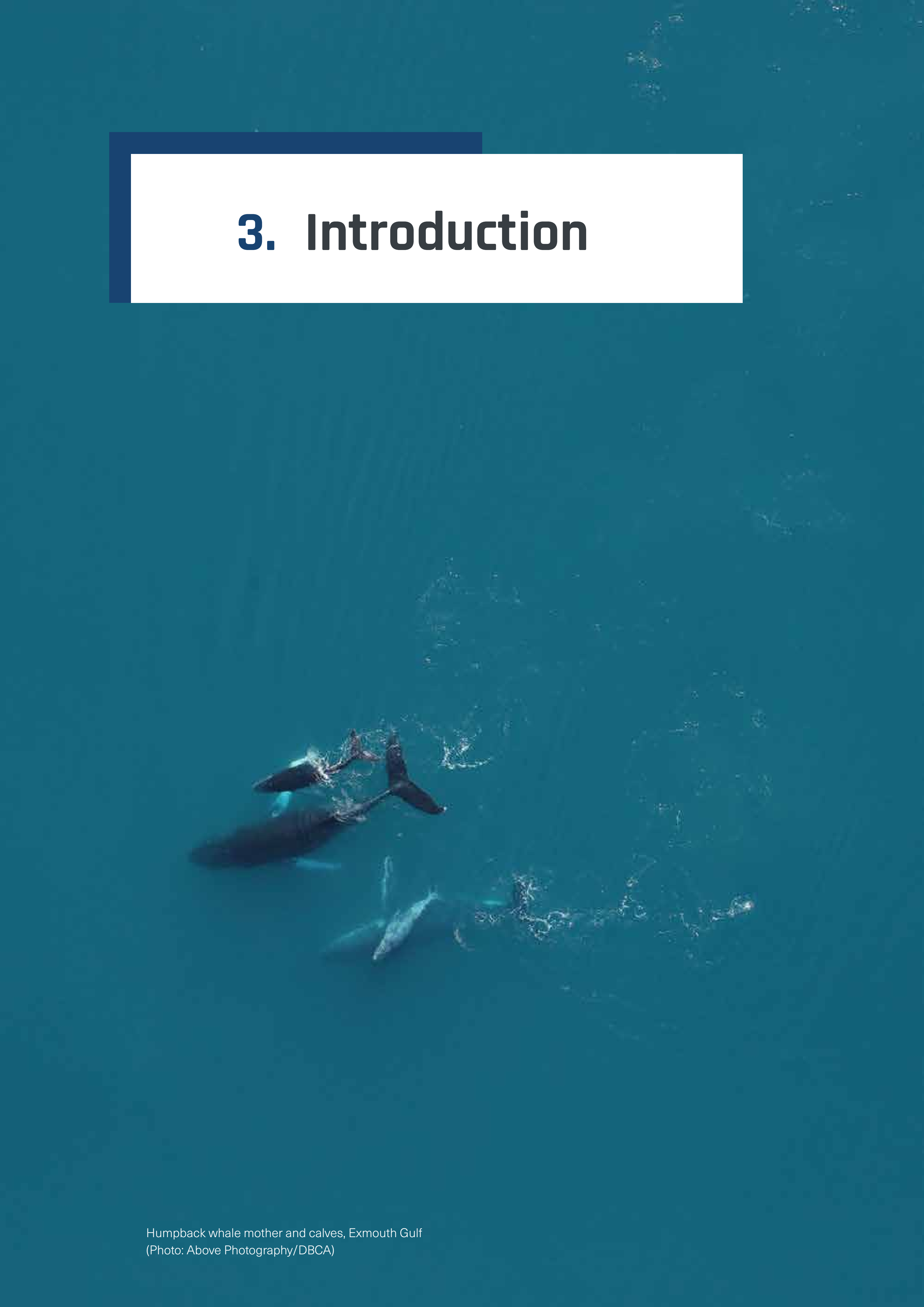
- Carrying capacity of potable water sources given projected high visitation rates, including extremely high visitation projected for the solar eclipse event in 2022.
- Intrinsic/wilderness aesthetic and the impact of off-road driving.
- Better understanding and documentation of culturally important sites.

2. Acronyms

AHC	Australian Heritage Commission
AHD	Australian Height Datum
AIMS	Australian Institute of Marine Science
AMSA	Australian Maritime Safety Authority
BC Act	*Biodiversity Conservation Act 2016*
BP	Before Present
BRDs	Bycatch Reduction Devices
BRUVS	Baited Remote Underwater Video Systems
CALM	W.A. Department of Conservation and Land Management (now DBCA)
CIA	Cumulative Impact Assessment
CO_2-e	Carbon Dioxide Equivalent
CR	Critically Endangered
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Critical Weight Range
DBCA	W.A. Department of Biodiversity, Conservation and Attractions
DEC	W.A. Department of Environment and Conservation (now DBCA)
DoD	Commonwealth Department of Defence
DoF	W.A. Department of Fisheries (now DPIRD)
DPAW	W.A. Department of Parks and Wildlife (now DBCA)
DPIRD	W.A. Department of Primary Industries and Regional Development
DPLH	W.A. Department of Planning, Lands and Heritage
DPSIR	Drivers-Pressures-State-Impacts-Responses
DWER	W.A. Department of Water and Environmental Regulation
ECU	Edith Cowan University
eDNA	environmental DNA
EN	Endangered
ENSO	El Niño Southern Oscillation

EPA	W.A. Environmental Protection Authority
EP Act	*Environmental Protection Act 1986*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ft	Foot/Feet
ftm	Fathoms
g	Grams
GDE	Groundwater Dependent Ecosystems
GHG	Greenhouse Gases
IUCN	International Union for the Conservation of Nature
JTSI	W.A. Department of Jobs, Tourism, Science and Industry
KBA	Key Biodiversity Area
km	Kilometres
LGA	Local Government Area
m	Metres
mg/L	Milligrams per litre
mS/m	Millisiemens per metre
MSC	Marine Stewardship Council
nm	Nautical miles
NRM	Natural Resources Management
NTGAC	Nganhurra Thanardi Garrbu Aboriginal Corporation
PFAS	Per- and Polyfluoroalkyl Substances
RAAF	Royal Australian Air Force
RCP	Representative Concentration Pathway
SAFE	Shared Analytic Framework for the Environment
SEAF	Shared Environmental Analytics Facility
TC	Tropical Cyclone
TDS	Total Dissolved Solids
TSS	Total Suspended Sediment
UCL	Unallocated Crown Land
UQ	University of Queensland
UWA	The University of Western Australia
VU	Vulnerable
W.A.	Western Australia
WABSI	Western Australian Biodiversity Science Institute
WAMSI	Western Australian Marine Science Institution
WWTP	Wastewater Treatment Plant

3. Introduction



Humpback whale mother and calves, Exmouth Gulf
(Photo: Above Photography/DBCA)

In August 2020, the then Minister for Environment (W.A.) requested that the Environmental Protection Authority (EPA) provide strategic advice under Section 16(e) of the *Environmental Protection Act 1986* (EP Act) on the potential cumulative impacts on Exmouth Gulf. The request for strategic advice originated from a number of potentially significant proposals in the Exmouth Gulf region being referred to the EPA under Part IV of the EP Act, including Subsea 7's Learmonth Pipeline Fabrication Facility, the Shire of Exmouth's Planning Scheme 4 Amendment 1, and K+S Ashburton Salt Project. Since that time, Subsea 7's proposal, and subsequent assessment by the EPA, has been terminated. The EPA is now also considering two additional proposals, including Gascoyne Gateway's Single Jetty Deep Water Port and renewable Hub and Z1Z Resort's Ningaloo Lighthouse Resort Project. A third proposal, to realign Yardie Creek Road at Vlamingh Head Lighthouse, is in the early planning stages by Main Roads W.A.. However, few details were known at the risk assessment stage, and development around Vlamingh Head Lighthouse was considered in conjunction with a road realignment rather than considered separately.

These proposals for future developments are in addition to the activities that are already exerting some level of pressure on the marine and terrestrial values of Exmouth Gulf. These include the current pressures of commercial and recreational fishing, tourism, quarrying and pastoralism.

The EPA has agreed to provide advice and recommendations to the Minister on:

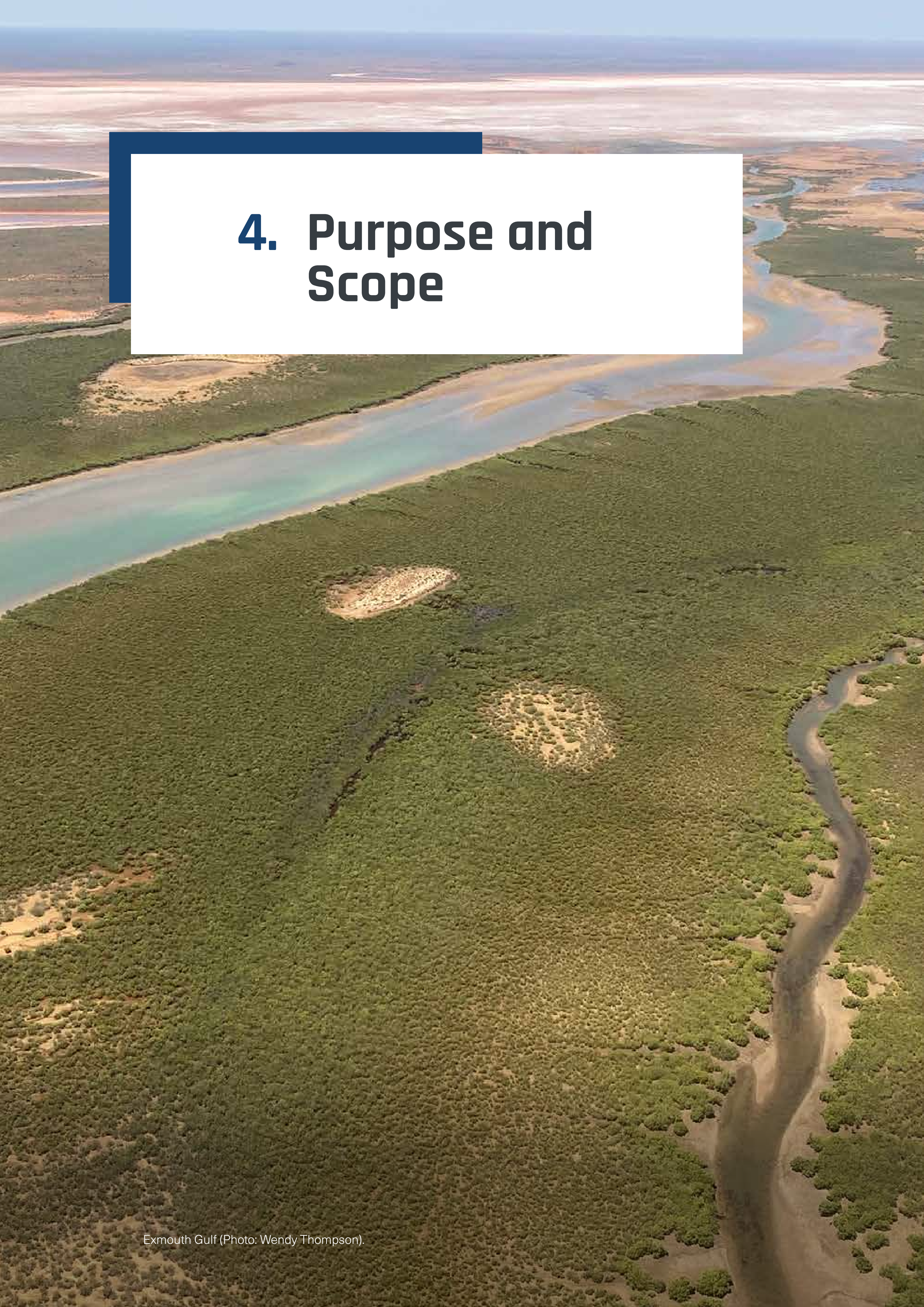
- the current state of the key environmental, social and cultural values, as per the EP Act, in Exmouth Gulf;
- the potential impacts on those values posed by existing activities and developments including, but not limited to, industrial activity (including oil and gas support), transportation and logistics operations, commercial and recreational fishing, and tourism;
- the potential impacts on those values by proposed activities and developments including, but not limited to, Subsea 7's Learmonth Pipeline Fabrication Facility, Gascoyne Gateway's Single Jetty Deep Water Port, and the K+S Ashburton Salt Project; and
- the compatibility of future developments with the key values (environmental, social and cultural values as per the EP Act) in the Exmouth Gulf.

This report was developed by the Western Australian Marine Science Institution (WAMSI) in partnership with the EPA to help deliver strategic advice to the Western Australian Minister for the Environment under Section 16(e) of the *Environmental Protection Act 1986* on the potential cumulative impacts of the proposed activities and developments on the environmental, social and cultural values of Exmouth Gulf.

The report frames the challenges that such advice requires detailed science-based knowledge of the regional ecosystem components, their dynamics and interactions with the physical and chemical environment. An understanding of previous and planned human interference within the region is also needed to quantify the spatial and temporal impacts and the potential for multiple pressures to interact and exacerbate the detrimental effects on the natural environment.

This report provides a contemporaneous understanding of the Distinctive Values of Exmouth Gulf, the previous, current and forecasted human use of the system, and has drawn on scientific expertise to analyse the relationship between the Distinctive Value and environmental pressures of the Exmouth Gulf region.

4. Purpose and Scope



Exmouth Gulf (Photo: Wendy Thompson).

The purpose of this report is to provide research support to assist the EPA in delivering strategic advice to the Minister for Environment on the potential pressures from activities and developments in the Exmouth Gulf.

More specifically, this report:

- provides a review of the literature for identified Distinctive Values relating to the EPA themes: Sea, Land, Air, Water, and People;
- comments on the current state of Distinctive Values;
- identifies the current and forecasted uses of Exmouth Gulf; and
- provides an analysis of the relationship between the Distinctive Values and Environmental Pressures, using a qualitative risk assessment process.

The spatial scope used to guide this report includes the entire waters of Exmouth Gulf out to the state coastal waters limit, inclusive of Muiron, Serrurier and Bessieres Islands, Cape Vlamingh and fringing land around Exmouth Gulf to Urala Station. The dotted ellipse used in Figure 1 is indicative only of the scope area and should be considered as a porous boundary. Figure 2 provides a map of locations mentioned throughout this report (see Appendix 1 for more detail).

The Literature Review, included in this document, is a snapshot of published and grey literature over a period of approximately 70 years. The temporal scope of the forecasted uses identified in this report is between 20 and 30 years. The temporal scope for future potential developments and activities and their consequences, considered in the Risk Assessment process is 5-10 years. It is recognised that 5-10 years is reasonably foreseeable for forecasted uses, but not long enough to consider the full effects of climate change, as current scenarios are using projections out to 20+ years.

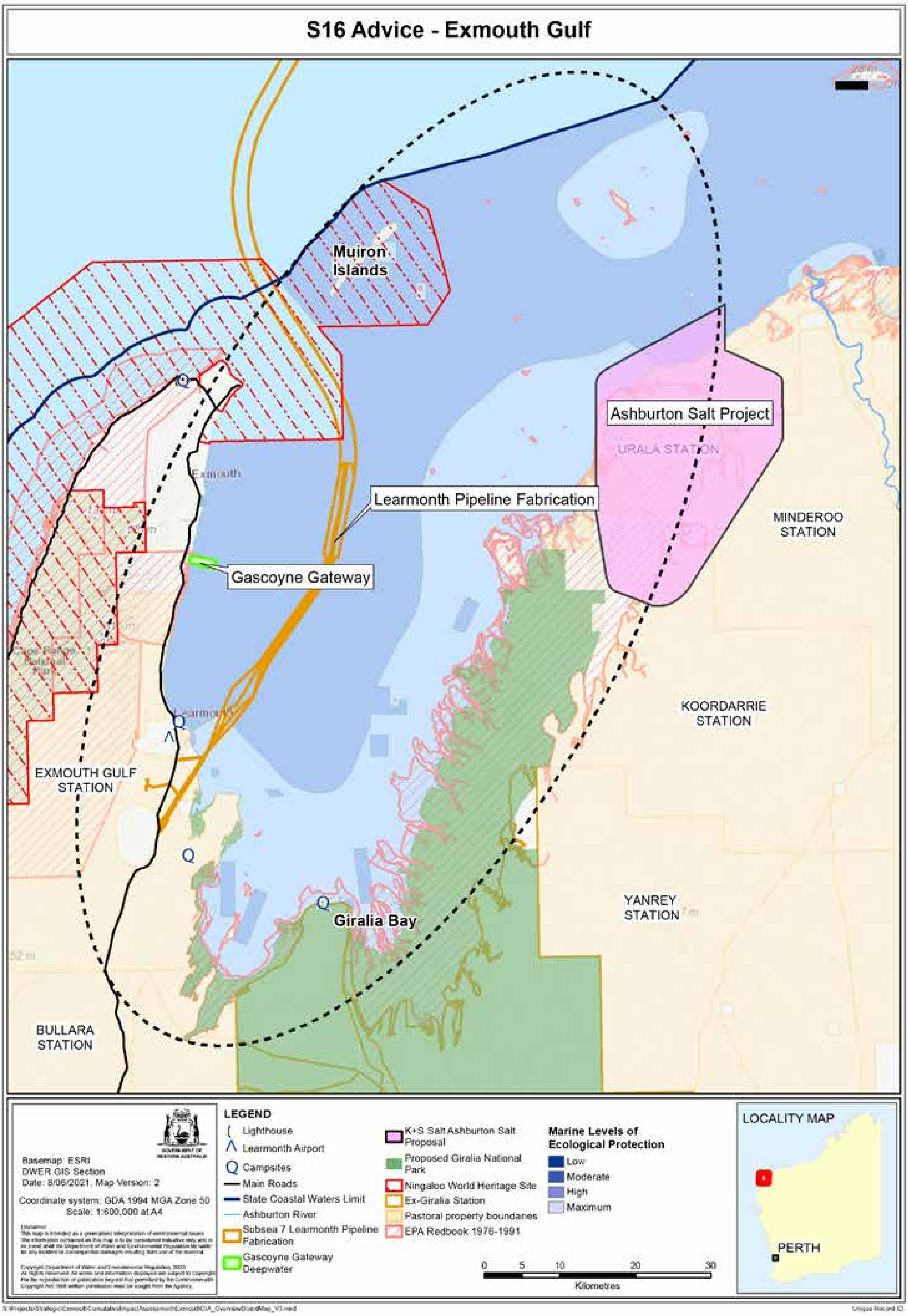


Figure 1: Indicative Spatial Scope of Project Area.

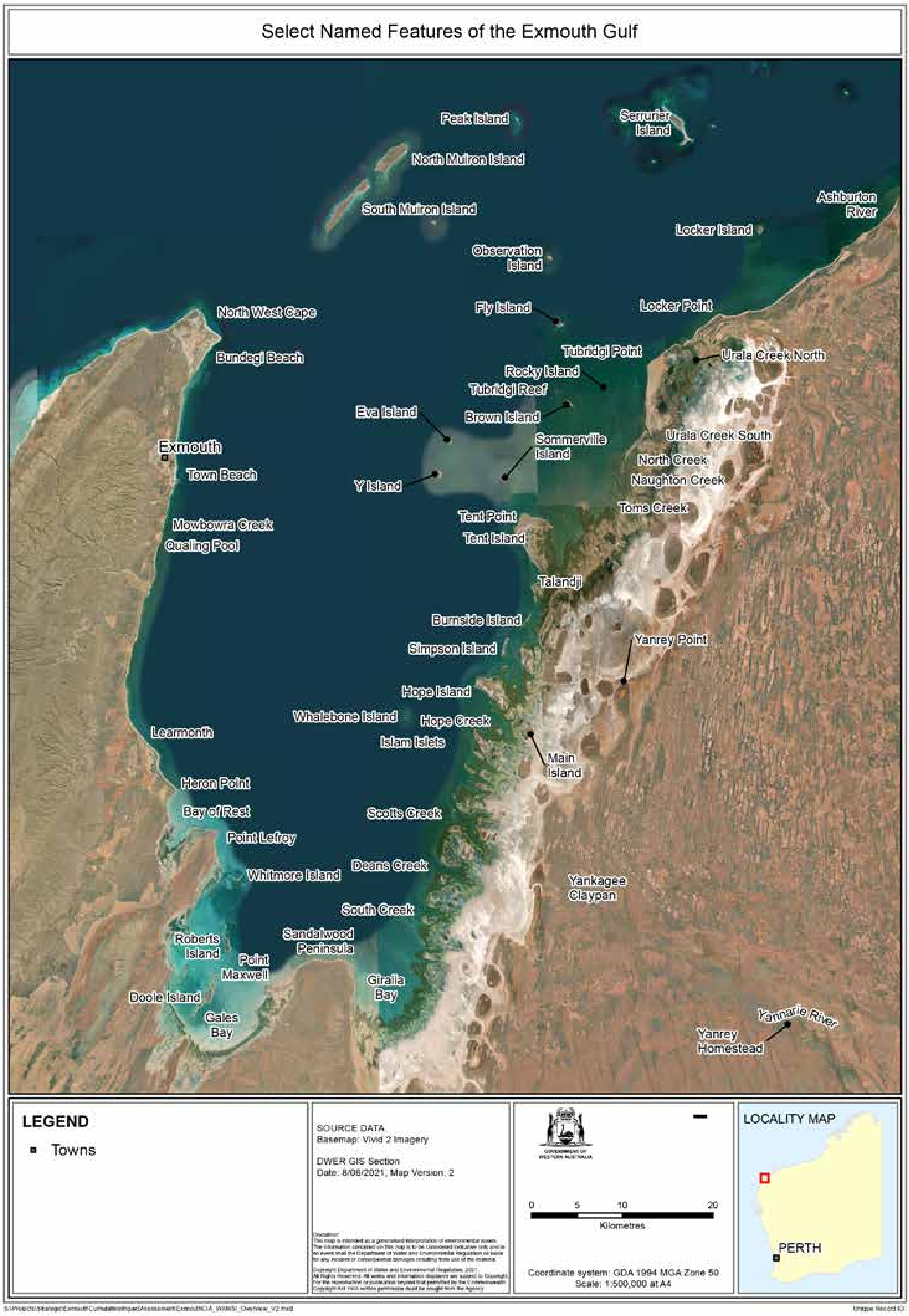
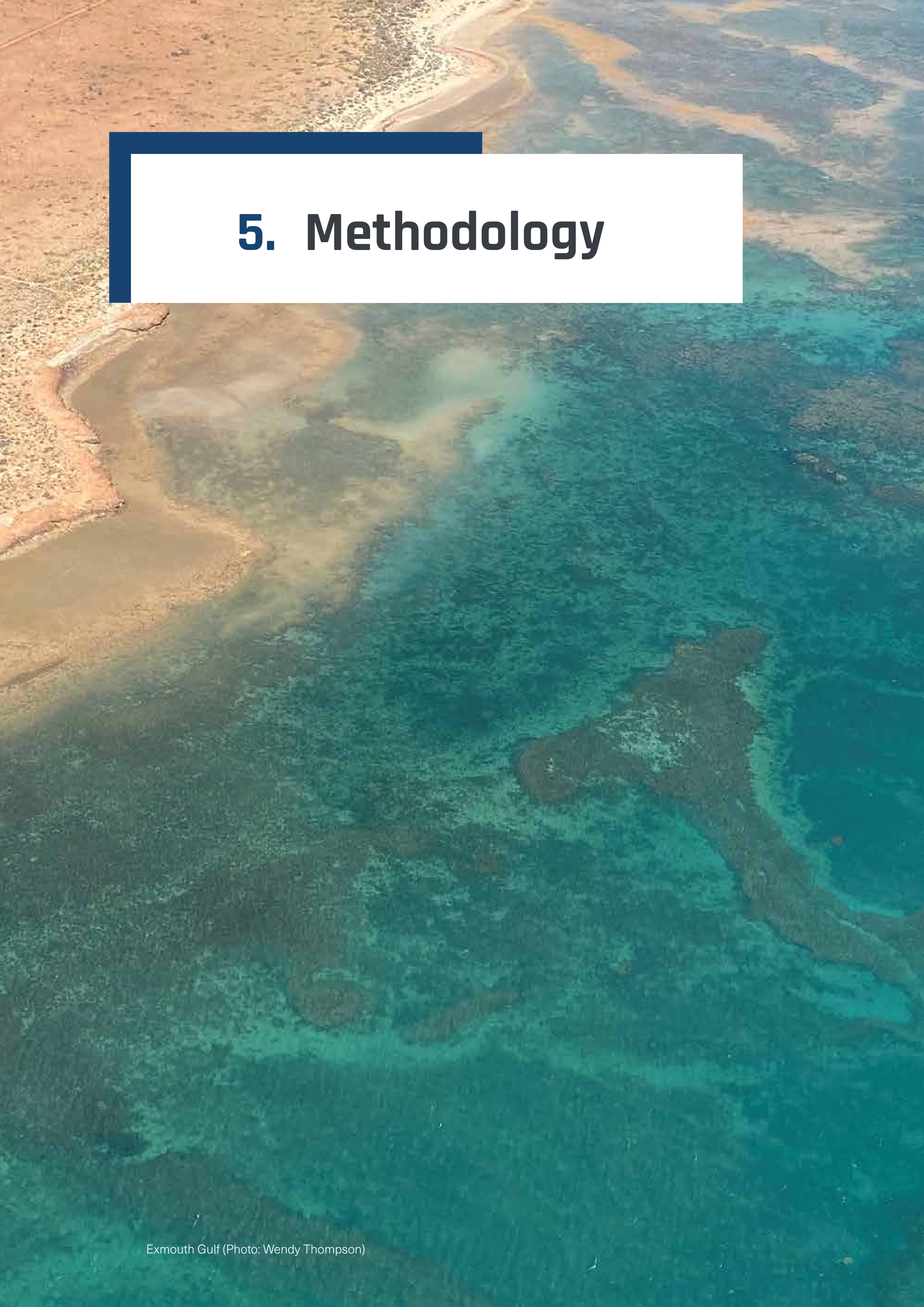


Figure 2: Locations and features of Exmouth Gulf. See Appendix 1 for more detail.

5. Methodology



Exmouth Gulf (Photo: Wendy Thompson)

5.1. EPA Processes

Community and stakeholder engagement

In October 2020, the EPA held initial community conversations and targeted stakeholder consultations. Following this, a public consultation process was undertaken for three weeks (21 October – 11 November) to help inform the strategic advice to the Minister for Environment. This comprised of submissions and interviews. The purpose of the consultation was to collate the community's views on the current and proposed pressures facing Exmouth Gulf and how these pressures may impact on the area's values. The results of the 321 submissions from 316 submitters are available on the EPA website.

The key values and issues of importance identified in the submissions include:

- identification of the ecosystem and biodiversity of Exmouth Gulf, including connectivity with the Ningaloo Reef system
- recognition of the coral reef, mangroves and algal mat communities, and their function within the nutrient cycle
- marine fauna species and habitats within Exmouth Gulf, including marine mammals, reptiles, elasmobranchs, seabirds and fish
- the value of Exmouth Gulf to the local economy, including tourism, industry, scientific research and commercial fishing
- natural and heritage values associated with Exmouth Gulf for Traditional Owners
- the amenity values of Exmouth Gulf, including wilderness and aesthetic qualities for the Exmouth community
- marine and land-based recreational activities undertaken within Exmouth Gulf by the Exmouth community and tourists

The key pressures identified in the submissions include:

- loss of benthic habitats, including dredging and trawling activities that may cause disturbance or destruction of the seabed, coral reefs and mangroves
- climate change and the resilience of the ecosystem to adapt under extreme temperatures, ocean acidification, marine heatwaves and sea level rise
- destruction or degradation of marine fauna habitat, including acoustic pressures, vessel strikes, and depletion of fish stocks
- economic pressures, including unmanaged and unsustainable tourism growth, oil and gas proposals, mineral extraction, marine infrastructure proposals and unregulated shipping through Exmouth Gulf
- potential loss of wilderness and aesthetic values due to additional infrastructure and the presence of industry in Exmouth Gulf. The EPA also received submissions from individuals who opposed industrialisation of Exmouth Gulf because of the presence of existing industry in the wider Pilbara and Gascoyne areas.

A second round of stakeholder feedback was sought through two community meetings held in Exmouth on the 22 March 2021. The purpose of the meetings was to gather relevant information that could help inform the strategic advice, rather than an opportunity for debate or comment on specific proposals. The community meetings were divided into two sessions, and a total of 53 people attended.

Perspectives Group

A Perspectives Group (Appendix 2) was formed to help guide the EPA towards delivering strategic advice to the Minister for Environment. The group consists of EPA Board members and one representative from each of the below sectors:

- Conservation
- Marine/Fisheries
- Exmouth Gulf Community
- Port/Development
- Traditional Owners
- Management and Environment

All decision-making responsibilities remained with the EPA Board.

The role of the Perspectives Group was to:

- Provide constructive advice and input, being considerate of the views of all group members and their respective sectors on:
    - Key Values of Exmouth Gulf, including state of identified values
    - Pressures of activities from existing and proposed activities and developments for Exmouth Gulf
    - Values - Pressures analyses to support cumulative impacts context
    - Inform the EPA Board's broader consideration of strategic issues relating to Exmouth Gulf

The Perspectives Group was involved in the initial planning stages of the risk assessment planning process (detailed further below) and in the risk assessment workshops.

EPA Themes and Factors

The EPA uses a set of defined environmental themes, factors and environmental objectives (Table 1) for the purposes of environmental impact assessment as a way to organise environmental information and structure assessment reports. The EPA has 14 factors organised into five themes: Sea, Land, Water, Air and People (Figure 3, 4, 5, and 6). This report uses these themes, factors and objectives to guide the literature review, risk assessment and cumulative ranking process.

Table 1: EPA themes, factors and objectives. Taken from Environmental Protection Authority (2020) Statement of Environmental Principles Factors and Objectives.

Theme	Factor	Objective
Sea	Benthic Communities and Habitats	To protect benthic communities and habitats so that biological diversity and ecological integrity are maintained.
	Costal Processes	To maintain the geophysical processes that shape coastal morphology so that the environmental values of the coast are protected.
	Marine Environmental Quality	To maintain the quality of water, sediment, and biota so that environmental values are protected.
	Marine Fauna	To protect marine fauna so that biological diversity and ecological integrity are maintained.
Land	Flora and Vegetation	To protect flora and vegetation so that biological diversity and ecological integrity are maintained.
	Landforms	To maintain the variety and integrity of distinctive physical landforms so that environmental values are protected.
	Subterranean Fauna	To protect subterranean fauna so that biological diversity and ecological integrity are maintained.
	Terrestrial Environmental Quality	To maintain the quality of land and soils so that environmental values are protected.
	Terrestrial Fauna	To protect terrestrial fauna so that biological diversity and ecological integrity are maintained.
Water	Inland Waters	To maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected.
Air	Air Quality	To maintain air quality and minimise emissions so that environmental values are protected.
	Greenhouse Gas Emissions	To reduce net greenhouse gas emissions in order to minimise the risk of environmental harm associated with climate change.
People	Social Surroundings	To protect social surroundings from significant harm.
	Human Health	To protect human health from significant harm.

5.2. Distinctive Values

From the public submissions received by the EPA, development proposals and Exmouth Gulf subject matter experts, over 230 values were identified.

The 230+ values were consolidated into Distinctive Values as it was not possible to proceed with meaningful strategic advice using such a large volume of values. Distinctive Values organised under EPA Factors and themes were then used to help guide the literature, risk assessment and cumulative ranking processes. The Distinctive Values are listed in Section 6.

5.3. Pressures and Main Activities

More than 48 pressures were identified under 11 drivers from the public submissions, proposal documentation from assessments under Part IV of the EP Act, and subject matter experts (Table 2).

Prior to the workshops, a small team of WAMSI and EPA staff members decided on which activities and developments were most important to assess, given an assessment on every single activity and pressure was not feasible, and also to reduce overlap and repetition in the risk assessment process (Table 3). The activities could be easily understood by stakeholders and expanded to individual pressures when required. The main activities and issues decided upon reflected the concerns in public submissions as well as included the requirement of the EPA to provide advice to the Minister on proposed activities and developments including, but not limited to, Subsea 7's Learmonth Pipeline Fabrication Facility, Gascoyne Gateway's Single Jetty Port proposal, and the K+S Ashburton Salt Project proposal. The five activities identified for the Sea theme included: Shipping, Mining, Fishing, Climate Change and Tourism/Visitation in no particular order. For the themes of Land, Water, Air and People the activities included Development, Tourism/Visitation, Transport Corridors, Mining, Climate Change, Pastoralism, and Defence also in no particular order.

Pressures associated with oil and gas operations were not included in the risk assessment. Past oil exploration occurred within the Exmouth Gulf scope area, and some mining leases have not yet expired. However, there was strong guidance that no more oil and gas exploration would occur in Exmouth Gulf, at least not within the foreseeable future used to guide this report. In saying this, seismic surveys were assessed given the spatial impact of noise, as was oil spills from general Shipping activities.

The pressure of terrestrial pests and feral animals was included under the activity Pastoralism largely because of feral goats and buffel grass (*Cenchrus ciliaris*). It is recognised that other pests may occur in the landscape independent of Pastoral activities. Introduced marine pests were assessed under Shipping. It is recommended that these additional pressures be assessed in next steps to fully comprehend cumulative impacts.

Table 2: Drivers and pressures identified from public submissions, EPA development proposals and subject matter experts.

Factor	Objective
Natural events: large changes driven by geological events and ocean currents	Tsunamis and earthquakes Cyclones, tropical storms Strong winds and currents
Climate change and severe weather: long-term climatic changes that may be linked to global warming and other severe climatic or weather events outside the natural range of variation that could wipe out a vulnerable species or habitat	Habitat shifting and alteration Drought Storms and flooding Temperature extremes
Natural system modifications: pressures from actions that convert or degrade habitat in service of "managing" natural or seminatural systems, often to improve human welfare	Fire Water use management Clearing Other ecosystem modification
Biological resource use: consumptive use of "wild" biological resources including deliberate and unintentional harvesting effects; also management or control of specific species	Hunting and collecting terrestrial animals Gathering terrestrial plants Fishing and harvesting aquatic resources Logging and wood harvesting
Agriculture and aquaculture: pressures from farming and pastoral activities as a result of agricultural expansion and intensification, including silviculture, mariculture, and aquaculture	Annual and perennial crops Livestock farming Marine aquaculture (fishing and farming)
Invasive and other problematic species and genes: pressures from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity	Invasive species (terrestrial) Invasive species (marine) Pathogens Problematic native species Introduced genetic material
Human intrusions and disturbance: pressures from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources	Marine recreational activities Land recreational activities Military and other activities
Residential and commercial development: human settlements or other non-agricultural land uses with a substantial footprint	Housing and urban areas Commercial and industrial areas Tourism and recreation areas
Transportation and service corridors: long narrow transport corridors and the vehicles/ vessels that use them	Roads and rails Infrastructure corridors: utilities and service lines Flight paths Shipping lanes Dredging Coastal infrastructure: ports, marinas, jetties
Energy production and mining: production of non-biological resources	Oil/gas drilling Mining and quarrying Renewable energy

Factor	Objective
Pollution: pressures from introduction of exotic and/ or excess materials or energy from point and nonpoint sources	Garbage/solid waste Household sewage and waste water Marine pollution Industrial and military effluent/waste Agricultural and forestry effluent/ waste Noise (atmospheric/terrestrial) Noise (marine) GHG emissions and air quality Light spill Other

Table 3: The consolidated set of activities and pressures used in the risk assessment process.

Activity	Pressure	Sea	Land	Water	Air	People
Shipping	Port infrastructure footprint (incl. channel)	✓				
	Vessel strike	✓				
	Noise pollution (vessel)	✓				
	Noise pollution (pile driving & dredging)	✓				
	Pollution (oil, fuel, antifoul)	✓				
	Pests	✓				
	Light pollution	✓				
	Suspended sediments (dredging)	✓				
Mining	Industrial salt facility – footprint	✓	✓	✓		✓
	Industrial salt facility – bitterns discharge	✓				
	Industrial salt facility – seawater intake	✓				
	Industrial salt facility – emissions				✓	
	Industrial salt facility – groundwater drawdown			✓		✓
	O&G – seismic surveys	✓				
	Limestone – footprint		✓	✓		✓
	Limestone – operation		✓			✓
	Limestone – groundwater drawdown		✓	✓		✓
	Limestone – emissions				✓	
	Potash – footprint		✓	✓		✓
	Potash – abstraction of brine					✓
	Potash – emissions				✓	
Fishing	Commercial – physical trawling	✓				
	Commercial – catch	✓				
	Recreational – catch	✓				

Tourism/ Visitation	Disturbance – marine noise	✓				
	Disturbance – marine damage (anchoring/diving)	✓				
	Marine pollution – oil/fuel	✓				
	Marine pollution – rubbish	✓				
	Potable water use			✓		✓
	Terrestrial rubbish		✓	✓		✓
	Human waste		✓	✓		✓
	Camping		✓			
	Off-road driving		✓	✓		✓
Climate Change	Marine heatwaves	✓				
	Tropical storms and cyclones	✓	✓	✓		✓
	Sea level rise	✓	✓	✓		✓
	Fire		✓	✓	✓	✓
	Atmospheric temperatures	✓*	✓	✓		✓
Development	Residential – footprint		✓	✓		✓
	Residential – groundwater drawdown		✓	✓		✓
	Residential – solid waste		✓			✓
	Residential – light		✓			✓
	Residential – noise		✓			✓
	Residential – emissions				✓	
	Industrial – footprint		✓	✓		✓
	Industrial – groundwater drawdown		✓	✓		✓
	Industrial – solid waste		✓			✓
	Industrial – light		✓			✓
	Industrial – noise		✓			✓
	Industrial – emissions				✓	
	Tourism – footprint		✓	✓		✓
	Tourism – groundwater drawdown		✓	✓		✓
	Tourism – solid waste					
	Tourism – light		✓			✓
	Tourism – noise		✓			✓
	Sedimentation		✓			

* for marine turtles only

5.4. Literature Review

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. seagrass AND Exmouth Gulf, macroalgae AND Exmouth etc. Following this, more general searches were conducted using solely the location names, including but not limited to 'Exmouth', 'Muiron Islands' and 'Ningaloo', in order to identify any ambiguous literature or literature that did not fit within the pre-defined headings. Overall, the information gathered for this literature review came from published scientific papers, published and unpublished reports and theses. Searches were also conducted at the Department of Primary Industries and Regional Development (DPIRD) Fisheries library, Department of Biodiversity, Conservation and Attractions (DBCA) library and Department of Water and Environmental Regulation (DWER) website. Reference lists in these literature sources were inspected to find further resources. In addition, relevant resources only available in hard copy were manually retrieved from university library collections and other researchers.

In some instances, the presence of a Distinctive Value within the spatial scope of this report is low, e.g., rock wallabies. However, literature is included for comprehensiveness.

5.5. Current State of Distinctive Values

An assessment of the current state of Distinctive Values in Exmouth Gulf follows a similar framework to that used in Australian Commonwealth Government State of the Environment reporting (SoE 2016 - https://soe.environment.gov.au/). The literature review and comments from subject matter experts have helped to guide the assessment of the current state of values. Given this report also includes a risk assessment involving current and future activities and pressures, the assessment of the current state considers past and current impacts only.

The definitions of each state 'grade' have been adjusted to suit the context of Exmouth Gulf (Table 4). A level of confidence for the 'grade' is also applied to the assessment, which is informed by the literature, and includes High (H), Medium (M) and Low (L) confidence.

Table 4: Confidence scores for Distinctive Values (modified from SoE 2016).

(green)	Very good	Value has been relatively unimpacted in Exmouth Gulf and long-term viability of the Value is positive.
(yellow)	Good	A small portion of the Value has been impacted in Exmouth Gulf, which may threaten long-term viability.
(orange)	Poor	A significant proportion of the Value has been negatively impacted across most or all of Exmouth Gulf, which may threaten long-term viability.
(red)	Very poor	A large proportion of the Value has been negatively impacted in Exmouth Gulf with limited prospects of long-term viability.
(grey)	Unknown	Limited understanding of the Value to assess its current state.

5.6. Current and Forecasted Uses

The current and forecasted uses listed in Section 11 were derived from EPA proposals available on the EPA website, EPA public submissions, collective knowledge from the Perspectives Group, and the Department of Transport website.

5.7. Qualitative Risk Assessment

5.7.1. Procedure and Definition

The Perspectives Group and WAMSI considered a number of options to better understand the impact of the identified pressures against the Distinctive Values of Exmouth Gulf. The large number of values, pressures and data gaps were considered against the time and available resources. The group settled on a qualitative risk assessment approach using consequence and likelihood to assess the impact or risk of a pressure against a Distinctive Value. This formal qualitative risk approach is commonly used, such as for ecosystem-based fisheries management in

Western Australia (Fletcher et al. 2011). The risk assessment process assists in the separation of minor acceptable risks from the major unacceptable risks. The qualitative process also allows stakeholders and experts to see their comments and follow the process from start to finish.

The qualitative approach used is appropriate when dealing with data-poor situations and time constraints that do not allow for a robust quantitative method. The approach can also provide a more simplified, realistic view of a complex situation or system. There is rarely a situation where there is no knowledge, particularly when experts and stakeholders are brought together in a workshop to assign risks. Conversely, there are few situations for which we have full certainty. The risks assigned during the qualitative process are based on discussions among experts and stakeholders, their collective knowledge and experience, and their general agreement on a risk score, rather than reviewing the scientific literature. A qualitative approach recognises that published information to describe a situation is not always available. For those risk scores assigned outside of workshops, by one or two people, scientific literature was reviewed in some situations prior to scoring, in lieu of discussions among experts. Scientific literature is used when assessing data confidence for the risks assigned (see further explanation below).

The consequence ratings ranged from ‘minor’ to ‘severe' and are defined in Table 5. The likelihood rating scale ranged from ‘remote’ to ‘likely’ and ratings are defined in Table 6. The consequence-likelihood approach and rating scales are based upon the Australian & New Zealand and International Standard Risk Analysis (Standards Australia, 2000, 2004; ISO 31000:2018).

From the consequence and likelihood ratings assigned to each issue, the risk matrix shown in Table 7 was used to determine the overall risk level for each pressure/activity against the Distinctive Values. The risk level for each pressure is calculated as the consequence score x likelihood score, with possible risk values ranging between 1 (minor) and 16 (severe).

It is important to note that risk assessments were undertaken based on the understanding and knowledge of proposals and potential activities as at 19 - 24 February 2021 (date of workshops detailed below). Any refined details around proposals or potential activities emerging since then would not have been considered, e.g., exact spatial extent or design of developments and activities. It is also acknowledged that new scientific literature may come to light during the writing of this report and completion of strategic advice by the EPA.

Table 5: Consequence table (Modified from DPIRD 2020).

Environmental Values	
Minor (1)	Impacts are small and localised; minimal effects to the value, population or system
Moderate (2)	The value, population or system is impacted locally and unlikely to recover in 10 years OR the population or system is impacted however is resilient in the medium term (5-10 years)
High (3)	Impacts to a value, population or system, with recovery expected to take longer than 10-15 years
Severe (4)	Impacts to a population or system which limits any prospect of recovery
Social, economic and cultural values	
Minor (1)	Minor impact on value (e.g. spatial extent or quality) but not affecting continued use/ enjoyment/cultural significance
Moderate (2)	Impact on value with an adverse effect on continued use/enjoyment/cultural significance at a local level or displacement of small number of people/users
High (3)	Significant impact on value with an adverse effect on continued use/enjoyment/cultural significance at a local and regional level or displacement of many groups of people/users
Severe (4)	Substantial loss or significant alteration of value or displacement of most people/users

Where 'resilience' is the ability of a value, population or system to recover from an impact and / or maintain structure and function. *Source: Department of Primary Industries and Regional Development (DPIRD) (2020). Western Australian Marine Stewardship Council Report Series No. 17: Ecological Risk Assessment of the Exmouth Gulf Prawn Managed Fishery. DPIRD, Western Australia.*

Table 6: Likelihood table (Modified from DPIRD 2020).

Category	Description of likelihood
Remote (1)	May occur in exceptional circumstances
Unlikely (2)	Will probably not occur
Possible (3)	Could occur at some point
Likely (4)	Expected to occur

Table 7: Risk assessment matrix and risk rankings (Modified from DPIRD 2020).

		Likelihood rating			
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)
Consequence rating	Minor (1)	1	2	3	4
	Moderate (2)	2	4	6	8
	High (3)	3	6	9	12
	Major (4)	4	8	12	16

Negligible (1-2)	Low (3-4)	Medium (6-8)	High (9-12)	Severe (16)

Table 8: Categories and definitions of data confidence for risk assessment scoring under themes: Sea, Land, Water, Air and People.

	Data confidence for risk assessment scoring under themes: Sea, Land, Water, Air	Data confidence for risk assessment scoring under the theme People
Low	Data and information is limited on: presence, numbers, pressure-response relationships, status and/or another relevant area of understanding	Data and information is limited on: local/regional significance, popularity (number of users), potential for impacts on public health and wellbeing, uniqueness
Medium	Data and information is available but not sufficient for a high degree of confidence. Some data is lacking on: presence, numbers, pressure-response relationships, status and/or another relevant area of understanding	Data and information is available but not sufficient for a high degree of confidence. Some data is lacking on: local/regional significance, popularity (number of users), potential for impacts on public health and wellbeing, uniqueness
High	Data and information is available and sufficient for a high degree of confidence	Data and information is available and sufficient for a high degree of confidence

A level of data confidence was applied to the risk assessment scores based on a review of published and unpublished studies, technical reports and grey literature (see Section 8). More clearly, a level was applied based on whether there was a low, medium or high degree of confidence in the assigned risk score for each Distinctive Value x pressure combination based on the literature. The levels of confidence for identified values are presented in Table 8. In considering data confidence, there may have been instances where there is high confidence of a pressure having an impact in general, not just for Exmouth Gulf, but low knowledge of the impacts specifically on a Distinctive Value in Exmouth Gulf. For example, there is high confidence around cyclone predictions, high confidence that a cyclone will impact the Exmouth Gulf area given multiple published impacts, but low confidence about how exactly this will impact certain flora species in Exmouth and the extent and timeframe of those impacts. This type of reasoning would result in a Medium data confidence and similar reasoning was applied for all risk scores and noted in the justification column.

5.7.2. Workshops

The literature review and two stakeholder/expert workshops were used to inform the risk assessment of impacts from current and forecasted activities and developments on Distinctive Values. Two day-long workshops were held in February 2021 focusing on the Sea theme (19 February – Workshop 1) and Land, Air, Water, People themes (24 February – Workshop 2). The workshop attendees consisted of the EPA Perspectives Group and invited subject matter experts (see Appendix 3). Participants were provided with supporting documentation (e.g., maps) which can be found in Appendix 4.

A large face-to-face workshop of experts was not possible due to COVID-19 restrictions. Instead, a limited number of workshop participants attended in person, and a large number of participants attended online from around Australia via a 'Microsoft Teams' video conference. Real-time discussion was facilitated with all participants. Comments, questions and interactions from online participants were facilitated independently by several people and brought to the attention of the primary facilitator to enable real-time interaction and discussion between all participants. Comments and risk scores were recorded on large tables so that all participants could provide input and correct the recording if needed. The hybrid-

WAMSI Research Director, Dr Jenny Shaw facilitates the stakeholder/expert workshop held in February 2021 focusing on the Sea theme (19 February – Workshop 1) (Photo: WAMSI).

style attendance and methods used were successful in capturing the complexities of risk assessment workshops with a diverse range of experts and opinions.

Five main activities were assessed in Workshop 1, which were Mining, Shipping, Fishing, Tourism/Visitation and Climate Change. Six main activities were chosen for assessment in Workshop 2 and included: Mining, Development, Tourism/Visitation, Pastoralism, Climate Change and Defence (Department of Defence). At the beginning of each workshop, these activities were presented to workshop attendees for approval before the risk assessment process began. Attendees were also asked to review the list of Distinctive Values to be assessed, and include any additional values they thought necessary.

5.7.3. Post Workshop Assessment

Any activities, themes and Distinctive Values not assessed during the workshop due to time constraints were assessed after the workshops by a small team of EPA and WAMSI staff, as well as some one-on-one expert consultations. The risk scores and justifications were then circulated back to workshop attendees for comment and approval prior to being finalised. An online word processor was used to allow for reviewing and commenting by attendees so that interactive discussions could still be had in real-time, similar to the in-person workshops.

Transport Corridors was the seventh main activity presented to Workshop 2 attendees, however, was not scored during the workshop. A post-workshop consideration of this activity resulted in its removal given shipping lanes was considered under the 'Shipping' activity for the Sea theme and roads were considered under the 'Development' activity for all other themes.

5.7.4. Objectives

Defining objectives when considering the consequence of an impact or activity are important as different objectives for maintaining a particular value will result in different consequences. The objectives used were those defined by the EPA for each factor (Table 1). The Perspectives Group agreed on a timeframe of between 5-10 years. Beyond that, it was difficult to assess, as there was reduced certainty about the activities that may take place.

5.8. Cumulative ranking

5.8.1. Introduction

Cumulative impacts assessment (CIA), or cumulative effects assessment, aims to understand the collective impacts, both anthropogenic and natural, from past, present and future activities on a particular value or set of values. There is a growing body of literature that reviews the different methodologies and/or presents new methodologies as it is recognised there is no 'one size fits all' approach (Anthony et al. 2013; Battista et al. 2017; Roudgarmi 2018; Stelzenmuller et al. 2018). There are spatial and temporal considerations, positive, negative and interactive impact considerations, and in the end, the results need to make sense, be interpretable and be fit for purpose for the project in question. Recently, the EP Act has been updated to include 'cumulative effect of impacts of the proposal on the environment' as part of the EPA's consideration.

5.8.2. This Report

This report uses ordinal ranking of cumulative pressures for the following reasons:

- development of a tailored CIA assessment framework was beyond the scope of the advice
- this report considers future activities with uncertain temporal and spatial scales

Major activities are ranked using an ordinal scale based on the averaging and summation of risk assessment scores. This method attempts to provide some sort of 'cumulative score', noting that the scores have no reference or comparability outside of Exmouth Gulf and are not further defined and justified into cumulative risk categories e.g. high, medium or low. Instead, the 'cumulative scores' provide a way to compare different activities and pressures for each Distinctive Value. The logic and process for this methodology is further expanded on below. While this cumulative ranking methodology is sufficient for the purposes of the strategic advice to the Minister for Environment, it should serve as a starting point for which to explore a more robust CIA methodology fit for purpose for Exmouth Gulf. The suggested next steps in the process of cumulative assessment for Exmouth Gulf are described in Section 14.2.

5.8.3. Process

5.8.3.1. Step 1 – Matrix of Risk Assessment Scores

Risk scores (consequence x likelihood) were assigned to Distinctive Values and pressures during risk assessment Workshops 1 and 2 (see Section 5.7.2 Workshops for more detail). These individual risk scores are entered into a matrix layout separated into EPA factors and themes as well as identified pressures and activities. See example Table 9.

Table 9: Risk matrix example used for Exmouth Gulf.

		Activity 1			Activity ...
		Pressure 1	Pressure 2	Pressure ...	
Theme 1					
Factor 1	DV 1	Risk score	Risk score	Risk score	
	DV 2	Risk score	Risk score	Risk score	
	...	Risk score	Risk score	Risk score	
Factor					
Theme ...					

5.8.3.2. Step 2 – Roll Up of Distinctive Values Under the Sea Theme to Reduce Bias

The Distinctive Values presented for the EPA factor 'Marine Fauna' (see Section 6) do not sit at the same hierarchal level as values under other EPA factors. For example, several individual fish species have been identified as Distinctive Values, which are subdivisions under 'Teleosts'. The same is not true for 'Seagrasses' or 'Coral', which are subdivisions under the factor 'Benthic communities and habitats' e.g. there was no further subdivision into 'ephemeral seagrasses' and 'perennial seagrasses' or 'plate corals' and 'staghorn corals'.

This variation in Distinctive Values at different subdivisions resulted due to either environmental significance, social significance, economic significance and/or because knowledge was available and used to justify its subdivision. However, this hierarchal variation introduces some bias for a process that involves summation and averaging. To help prevent this, Distinctive Values were rolled up to the same hierarchal level for the 'Marine Fauna' factor to include one risk assessment score for Crustaceans, Teleosts, Elasmobranchs, Marine reptiles, Marine mammals, and Seabirds/shorebirds. Taking a conservative approach, the final assigned score reflects the highest risk score assigned to the group of Distinctive Values (Table 10).

Table 10: Excerpt of the risk table for Marine Fauna values and Shipping pressures demonstrating the conservative approach of using the highest risk score for elasmobranchs as a group.

	Shipping – port infrastructure footprint (incl. channel)	Shipping – vessel strike	Shipping – noise pollution (vessel)	Shipping – noise pollution (pile driving & dredging)	Shipping – pollution (oil, fuel, antifoul)
Elasmobranchs – rays (shovelnose)	4		3	3	4
Elasmobranchs – rays (manta)	4	2	3	3	6
Elasmobranchs – sawfish	4	2	3	3	4
Elasmobranchs – sharks	4	6	3	3	6
Elasmobranchs	***4***	***6***	***3***	***3***	***6***

5.8.3.3. Step 3 – Summation and Averaging Risks Scores

Two methods of calculation are used in this process: summation and averaging. Both have an advantage and disadvantage:

- Summation of risk scores
  - Advantage: reflects an accumulation of scores
  - Disadvantage: an unbalanced matrix structure can cause bias and over-inflation of cumulative scores
- Averaging of risk scores
  - Advantage: reduces bias and over-inflation in an unbalanced matrix structure
  - Disadvantage: loses resolution and isn't accounting for accumulation

Not all pressures and activities were assessed for each theme or Distinctive Value, not all hemes have the same number of Distinctive Values, and not all activities have the same number of pressures to assess, which results in an unbalanced matrix structure. This makes sense as not all activities will exert pressures on all Distinctive Values, and some themes naturally have more considerations e.g. Sea vs Air (Table 1; Figures 4, 5, and 6).

For each theme, the average of the risk scores from scored Distinctive Values is taken for each pressure. Not all Distinctive Values and pressure combinations were scored, and this does not equate to a zero. For example, blue-green algal mats and salt flats are high intertidal communities and unlikely to be affected by shipping infrastructure. Similarly, vessel strike and shipping noise are unlikely to affect benthic habitats and communities. The justification for taking the average of the risk scores instead of a summation is because there is an uneven number of Distinctive Values under each Theme, and averaging allows for a comparison of cumulative scores between themes. Refer to Table 11 below.

Table 11: Excerpt of the average risk score for Sea Distinctive Values scored against Shipping pressures.

	THEME: Sea	Shipping – port infrastructure footprint (incl. channel)	Shipping – vessel strike	Shipping – noise pollution (vessel)
Benthic habitats and communities	Macroalgae and turf algae	8		
	Seagrass	8		
	Coral	8		
	Sponges and filter feeders	8		
	Sand and mud	4		
	Mangroves	3		
	Samphire	3		
	Blue-green algal mats			
	Reef flats and oyster beds	4		
	Salt flats			
Marine fauna	Crustaceans	4		3
	Bony fishes	3		6
	Elasmobranchs	6	6	3
	Marine reptiles	6	4	3
	Marine mammals	9	8	12
	Seabirds and shorebirds	6		4
Marine environmental quality	Water quality	4		
	Sediment quality	4		
Coastal processes	Geophysical processes	4		
	Hydrodynamic processes	4		
	Nutrient flow	4		
	AVE across values -->	**5**	**6**	**5**

To account for 'cumulative' impacts, the averages for each pressure are then summed to give one score per activity. If an average was taken here again, more resolution would be lost and it would not provide a cumulative calculation. Refer to Table 12 below. The process will result in a comparative table of cumulative scores for each theme and activity.

These scores are then ordered highest to lowest and presented using an ordinal scale (e.g., Table 13). An ordinal scale was used instead of cumulative scores, as scores are not meant to be applied in a quantitative way or imply that one activity has a far higher or lesser quantifiable impact than another activity.

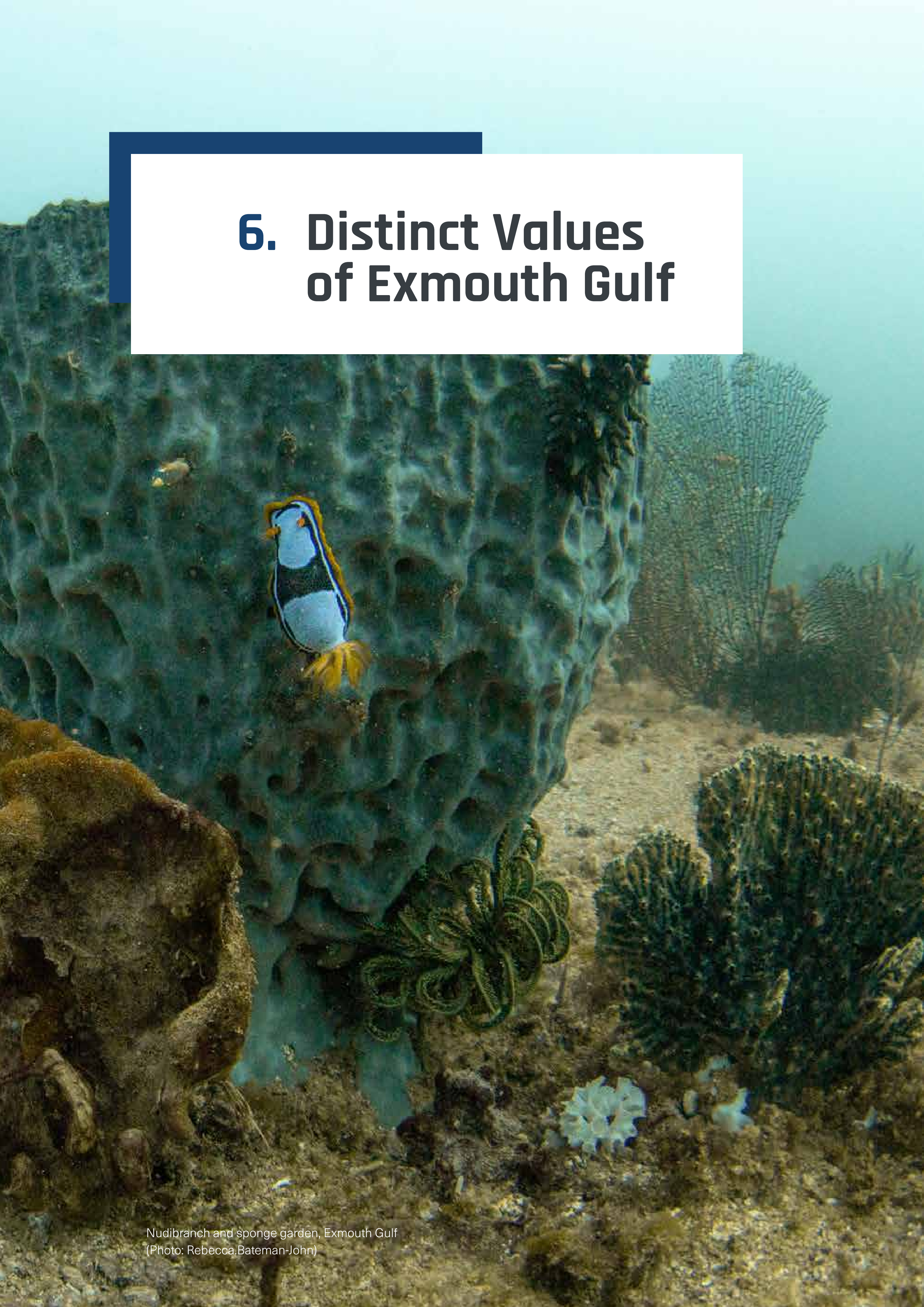
Table 12: Excerpt of cumulative scores for Sea theme scored against Shipping pressures.

Activity: Shipping									
	Shipping – port infrastructure footprint (incl. channel)	Shipping – vessel strike	Shipping – noise pollution (vessel)	Shipping – noise pollution (pile driving & dredging)	Shipping – pollution (oil, fuel, antifoul)	Shipping – pests	Shipping – light pollution	Shipping – suspended sediments (dredging)	Sum
THEME: Sea									
Average across values =>	**5**	**6**	**5**	**4**	**5**	**4**	**5**	**6**	**40**

Table 13: Excerpt of cumulative scores ranked ordinally for each theme and activity.

SEA	Rank
Shipping	1
Climate Change	2
Mining	3
Tourism/ Visitation	4
Fishing	5

6. Distinct Values of Exmouth Gulf



Nudibranch and sponge garden, Exmouth Gulf
(Photo: Rebecca Bateman-John)

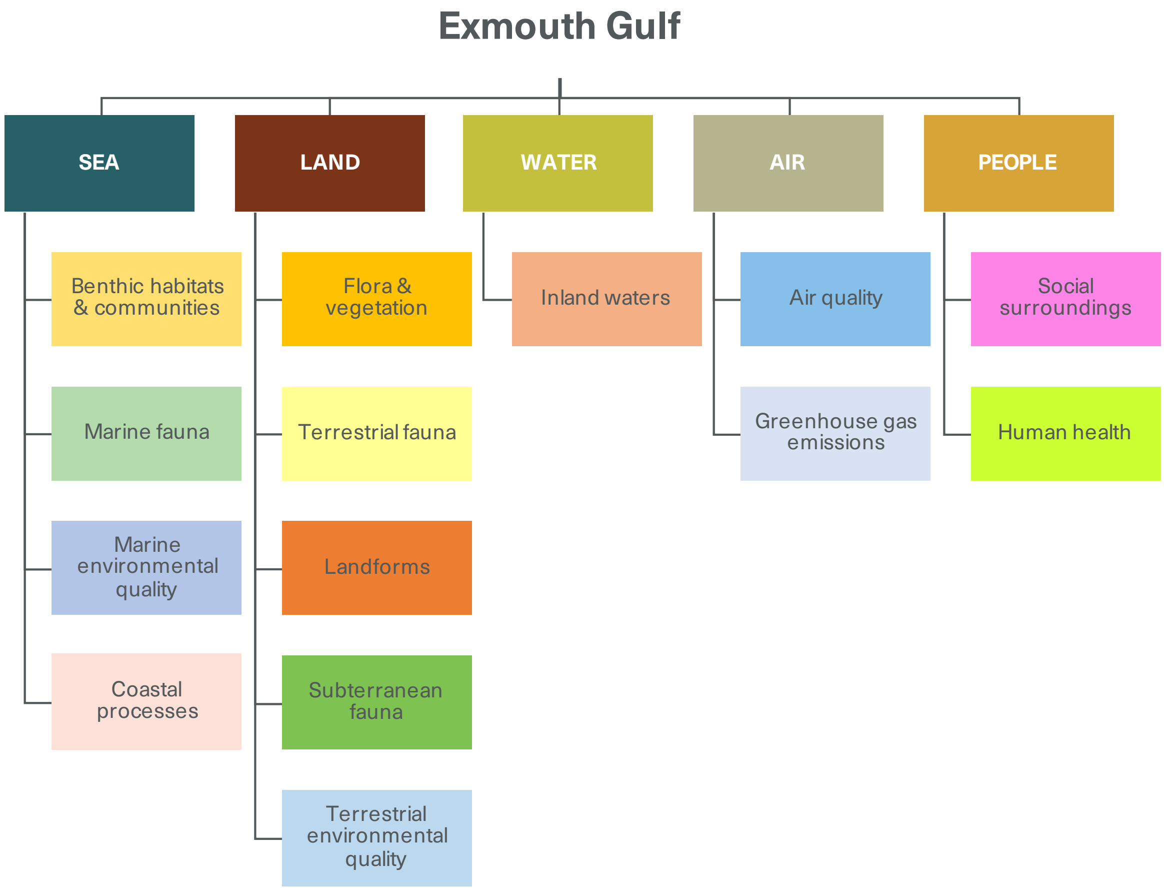


Figure 3: Component tree of EPA Themes and Factors.

The Distinctive Values of Exmouth Gulf are organised under the five EPA themes of Sea, Land, Air, Water, and People and, further still, under predefined Factors that sit under each Theme (Figure 3).

It should be noted that there are many other values recognised as important for a healthy and functioning marine environment, terrestrial environment, and society. However, given the time constraints, only those deemed most significant for this particular scope of works are included. This did not prevent subject matter experts from suggesting the inclusion of additional Distinctive Values, which did occur during the risk assessment workshops and are indicated in the below summaries.

A total of 33 Distinctive Values were identified under the Sea theme (Figure 4). Salt flats, red emperor, tuskfish, shovel nose rays and sharks were added as Distinctive Values during the risk assessment workshop based on suggestions from workshop participants or during post-workshop consultation.

A total of 14 Distinctive Values were identified under the Land theme (Figure 5). The value 'Islands' was added post-workshop during an expert consultation.

Ten Distinctive Values were included under the People theme (Figure 6). During the risk assessment workshops, nine of these were scored as it was unanimously decided by workshops attendees that Aboriginal heritage and culture should not be scored without the input from Traditional Owners, who were not present during the workshops.

The Air and Water themes had the fewest Distinctive Values and included air quality, and groundwater systems and surface water systems, respectively. Though Greenhouse Gas Emissions is a Factor under the AIR theme for EPA, this was not considered relevant for this particular scope of works.

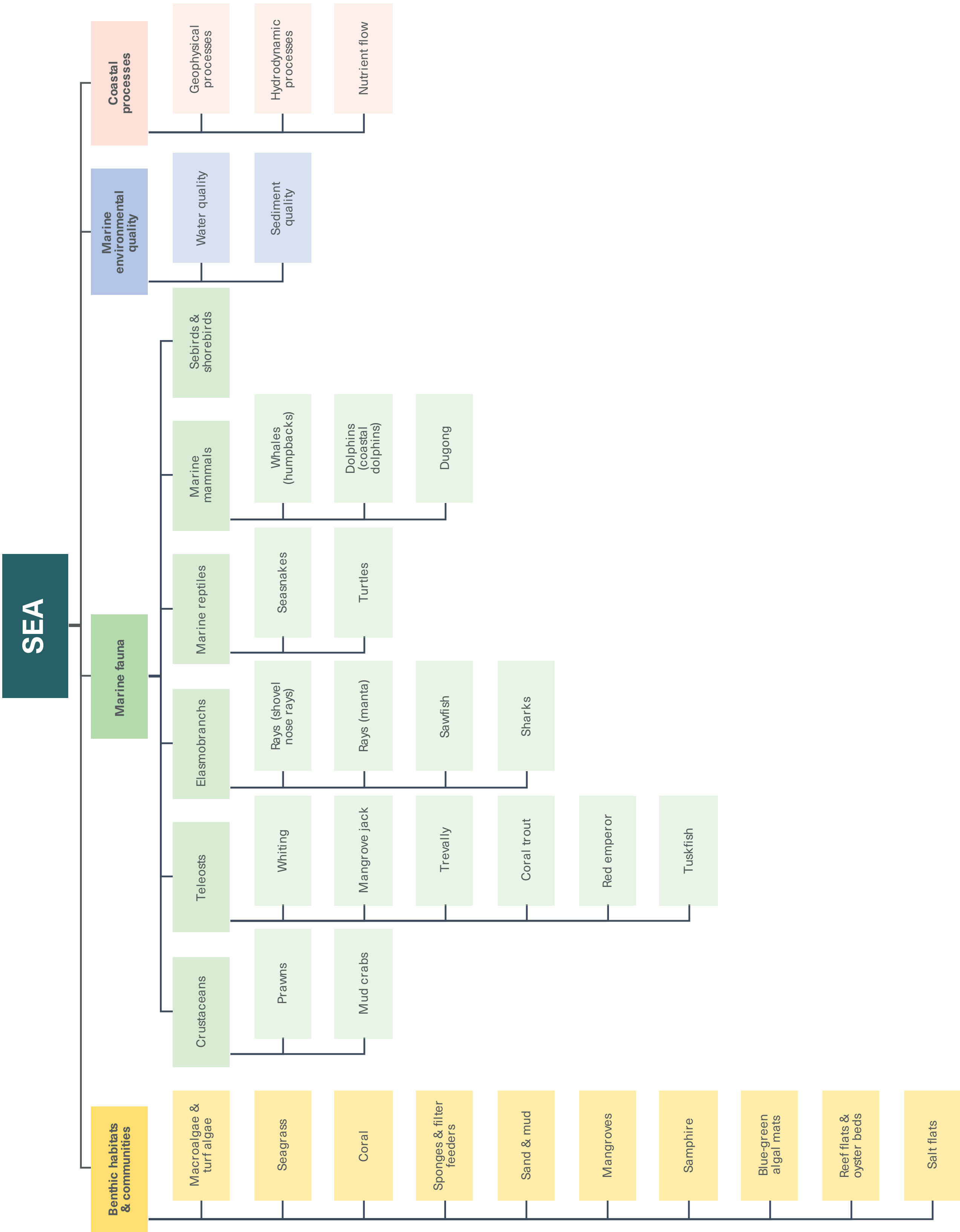


Figure 4: Component tree of Distinctive Values under the EPA Sea theme.

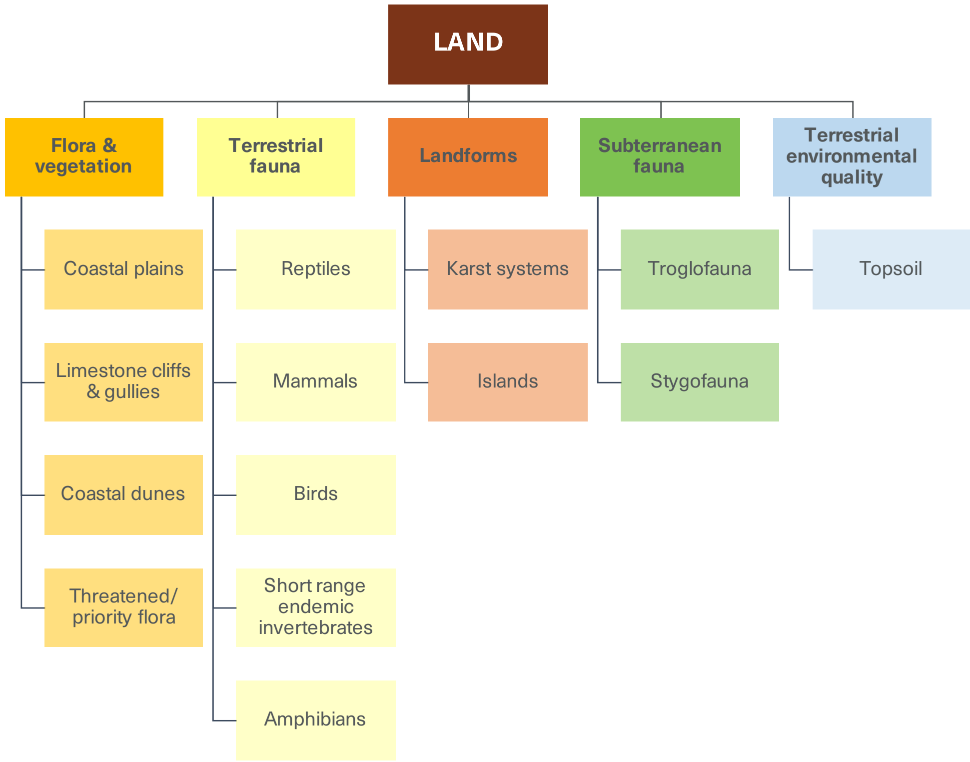


Figure 5: Component tree of Distinctive Values under EPA Land theme.

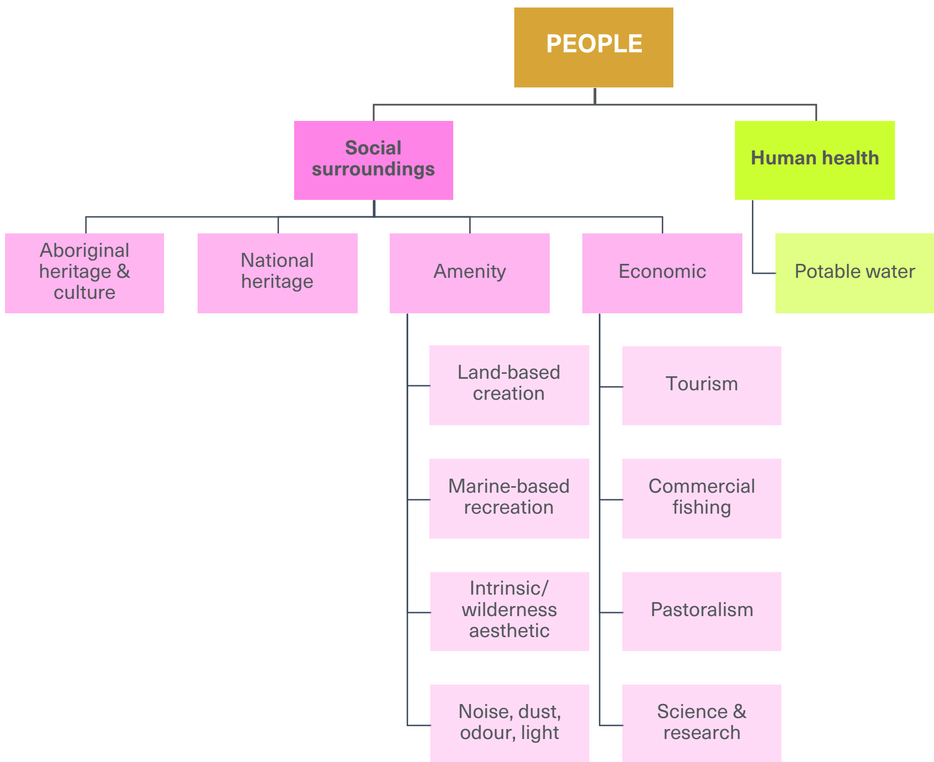


Figure 6: Component tree of Distinctive Values under the EPA People theme.

7. Climate Change and Exmouth Gulf

Benthic habitat, Exmouth Gulf
(Photo: Rebecca Bateman-John)

In a changing climate, Australia will experience greater threats from heatwaves, droughts and bushfires (Bureau of Meteorology 2019). No specific climate change projections have been modelled for Exmouth Gulf, but projections are available on a regional scale for Rangelands North, which is inclusive of Exmouth Gulf and the Pilbara coastline (CSIRO and Bureau of Meteorology 2021). The impacts from climate change pressures are a significant consideration for the marine and terrestrial environments of Exmouth Gulf and associated Distinctive Values. Rising sea levels will impact on coastlines and islands, fluctuating rainfall will impact on groundwater recharge, increased frequency of severe storms will cause erosion, and drought will increase the risk of wildfires. The following projections are taken from the Rangelands North report:

Rainfall

- In the near future (2030), natural variability is projected to predominate over trends due to greenhouse gas emissions.
- Changes to rainfall are possible, but the direction of change cannot be confidently projected given the spread of model results.
- Impact assessment in this region should consider the risk of both a drier and wetter climate.

Temperature

- There is very high confidence in continued substantial increases in projected mean, maximum and minimum temperatures in line with our understanding of the effect of further increases in greenhouse gas concentrations.
- For the near future (2030), the annually averaged warming across all emission scenarios is projected to be around 0.6 to 1.5°C above the climate of 1986–2005.
- By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 3.1 to 5.6°C. Under an intermediate scenario (RCP4.5) the projected warming is 1.5 to 3.1°C.

Extreme temperature

- Extreme temperatures are projected to increase at a similar rate to mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells (very high confidence).
- Where frosts (minimum temperatures under 2°C) occur in the sub-cluster, these are projected to decrease.

Extreme rainfall and drought

- Understanding of the physical processes that cause extreme rainfall, coupled with modelled projections, indicate with high confidence a future increase in the intensity of extreme rainfall events, although the magnitude of the increases cannot be confidently projected.
- Time spent in drought is projected, with medium confidence, to increase over the course of the century.

Marine and coast

- There is very high confidence in future sea-level rise. By 2030 the projected range of sea-level rise is 0.07 to 0.17 m above the 1986–2005 level, with only minor differences between emission scenarios. As the century progresses, projections are sensitive to concentration pathways. By 2090, the intermediate emissions case (RCP4.5) is associated with a rise of 0.28 to 0.65 m and the high case (RCP8.5) a rise of 0.40 to 0.85 m along the Pilbara coast. Under certain circumstances, sea-level rises higher than these may occur.
- Late in the century warming of coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 2.4 to 3.7 °C by 2090 under high emissions. The sea will also become more acidic, with acidification proportional to emissions growth.

Other

- With medium confidence, fewer but more intense tropical cyclones are projected.
- Bushfire in the Rangelands depends highly on fuel availability, which mainly depends on rainfall. With an unclear direction in rainfall projections, it is difficult to determine the direction of fire weather risk expected in future, furthermore, there is low confidence in the magnitude of fire weather projections.
- Potential evapotranspiration is projected to increase in all seasons as warming progresses (high confidence).
- Little change in relative humidity is projected for the near future (2030) while later in the century a decrease is projected in winter (high confidence) and in the other seasons (medium confidence).
- There is little change projected for solar radiation in the near future (2030), and for later in the century, decreased radiation is projected in March-May (medium confidence).

The northwest coast of W.A., including the Exmouth area, is highly exposed to tropical cyclones, with an average of one or two tropical cyclones impacting the coast each year (May et al. 2015). From the 1950s to 1980s, 21 cyclones had crossed the coast between Roebourne and Point Cloates contributing to 40 to 60% of annual rainfall (Hesp and Morrissey 1984). 'Cyclone season' is typically from November to May. Cyclones produce a number of potentially destructive forces including high wind speeds, wave damage, wind borne debris, torrential rain, storm surge and flooding. Modelling predicts that tropical cyclones are likely to decrease in frequency overall but increase in intensity including higher wind speeds, higher precipitation rates and higher storm inundation levels (Knutson et al. 2010). Geomorphological mapping data suggests that the formation of major systems such as the sandy ridges of Giralia Bay, are driven by tropical cyclones storm surges, torrential rain and flooding (May et al. 2018).

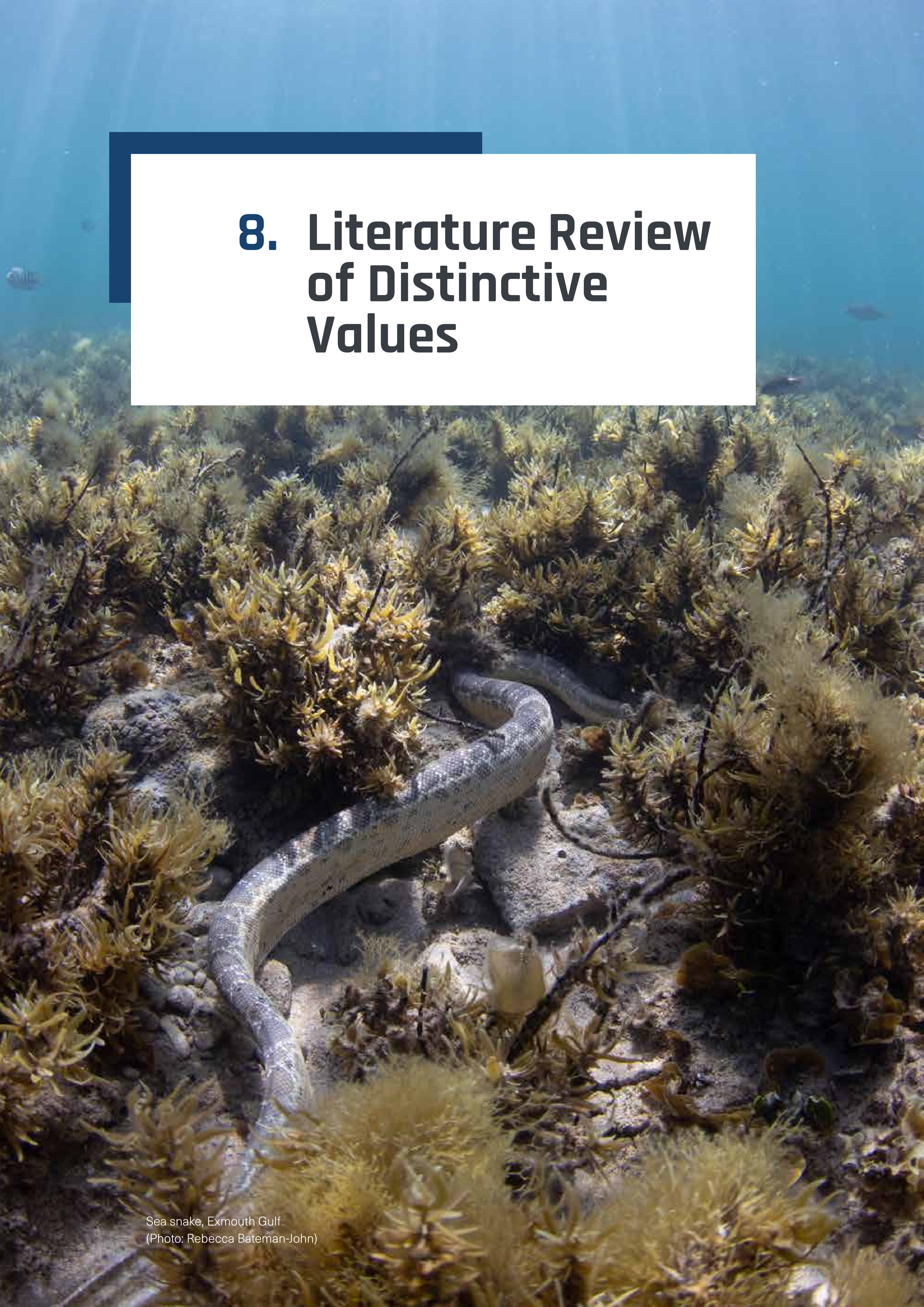
The northwest coast of W.A. is also exposed to tsunamis. Ten tsunamis have hit the W.A. coast since 1858 (May et al. 2015). Despite 8000km of Australian coastline considered at risk of tsunami, there is the misconception that tsunamis are non-existent or are a very low-probability hazard for Australia (Paton et al. 2017). Paton et al. (2017) recommended that increasing tsunami readiness in coastal communities could be facilitated by integrating tsunami preparedness into an 'all-hazards' process i.e., integrating it with discussions around floods, storms, climate change and sea level rise.

Sea level rise will inundate Exmouth Gulf's low-lying coastal terrain including salt marshes, mud and sand flats, lagoons and islands. This will impact on a range of terrestrial flora and fauna, and intertidal habitats such as mangroves, which could eventually face coastal squeeze if developments prevent landward expansion.

Like tropical cyclones, marine heatwaves are now being characterised into categories in an attempt to compare events consistently across time and to raise public awareness (Hobday et al. 2018). The causes, predictability and variability of the 2010/2011 marine heatwave off W.A., the Ningaloo Niño, is an ongoing body of research given the severity of the heatwave along the North West Shelf to Shark Bay coast that had impacts on seagrasses through to megafauna (Caputi et al. 2016; Kataoka et al. 2018, Feng and Shinoda 2019; Benthyusen et al. 2020; Strydom et al. 2020). Higher than normal sea surface temperatures occurred for the North West Shelf in early 2021 (up to 2.5°C warmer in the northwest in December and up to 3°C warmer for the central west coast in January), which was forecasted by the Bureau of Meteorology and CSIRO. The warming event coincided with the peak in La Niña conditions. Cooling of waters occurred following a low pressure system that passed through in February (see http://media.bom.gov.au/social/blog/2555/la-nia-and-marine-heatwaves-off-western-australia/). Some coral bleaching has been anecdotally reported for Exmouth Gulf in relation to this event. Climate models project more frequent, extensive, intense and longer-lasting marine heatwaves in the future for Australia (Commonwealth of Australia 2020). A collaborative project is currently underway between CSIRO and the Bureau of Meteorology to develop an experimental seasonal marine heatwave forecast product(s) for Australian waters (see https://research.csiro.au/mri-research-portfolio/home/climate-impacts-adaptation/marine-heatwaves/dynamical-forecasting-of-marine-heatwaves/).

The 2019 Nyinggalu (Ningaloo) Coastal Reserves Draft Joint Management Plan, acknowledges that Ningaloo and Exmouth area supports a number of species and communities that are endemic to the region or at or near the limits of their range which are likely to be particularly vulnerable to climate change (DBCA 2019a). Opportunities for most Australian species to adapt to climate change will be limited due to physical and biotic factors including topography, habitat fragmentation, low capacity for dispersal and the restricted geographic ranges (Hughes 2011). While virtually all species and communities will be affected by climate change in some way, several regions are of particular concern including freshwater and coastal fringe systems including wetlands. Australia's desert mammals, like those found in and around the Exmouth Gulf area, respond to fluctuations in resources. Letnic and Dickman (2010) applied a novel state-and-transition model to well-studied small mammal assemblages in hummock grassland or spinifex. The models can be used to improve understanding of threats such as climate change on mammal assemblages in arid environments in general.

8. Literature Review of Distinctive Values



Sea snake, Exmouth Gulf
(Photo: Rebecca Bateman-John)

8.1. Sea

8.1.1. Benthic Habitats and Communities

8.1.1.1. Salt Flats

Salt flats are a significant and extensive feature of Exmouth Gulf and they are included along with the rest of the east coast of Exmouth Gulf as a wetland of national importance. These flats are one of the largest and relatively intact salt flat ecosystems (or sabkhas) in W.A. (EPA 2008). Flats extend ~1,026km^2 from Locker Point to Sandalwood Peninsula, and range from the 4.5-13km wide (Brunskill et al. 2001; D.C. Blandford and Associates Pty Ltd and Oceanica Consulting Pty Ltd 2005). Blue-green algal mats grow on salt flats and are discussed in Section 8.1.1.2 and saltmarshes are discussed in Section 8.1.1.3. This section summarises literature relating to unvegetated salt flats (~900km^2; Lovelock et al. 2010).

Terrestrial sediments dominate the sediments of salt flats, which are reworked by storm surges, major runoffs and winds (Brunskill et al. 2001; D.C. Blandford & Associates Pty Ltd and Oceanica Consulting Pty Ltd 2005). The rate of sediment accumulation is very low on the salt flats and erosion appears to be occurring in some areas (Brunskill et al. 2001). Superficial sediments are very salty due to high surface temperatures and evaporation, and result in the flats only being suitable for salt-tolerant flora and fauna (Humphreys et al. 2005).

8.1.1.2. Blue-Green Algal Mats

Extensive blue-green algal mats (cyanobacterial mats) occupy the high intertidal zone along the eastern (~85km^2) and southern margins (~20km^2) of Exmouth Gulf. Following the proposal of the Yannarie Solar Salt Project in 2006, which covered 20,000ha along the southeastern margin of Exmouth Gulf (Straits Salt Pty Ltd 2006; EPA 2008; Straits Salt Pty Ltd 2009), surveys were performed to determine the extent and ecological importance of blue-green algal mats (as well as mangroves and salt flats) (Humphreys et al. 2005). Thicker mats were noted to occur where there was more inundation by water, and further inland, mats thinned out with less evidence of activity. Dehydration and high salinity are likely limiters of landward extension, while frequent inundation, unstable substrates and grazing likely limits the seaward extension.

Blue-green algal mats are found in the high intertidal zone and are prone to desiccation (drying out). Using high temporal resolution hyperspectral imaging, liquid chromatography, pulse-amplitude fluorometry, oxygen microsensors and confocal laser microscopy, Chennu et al. (2015) was able to show that within 15 minutes of rehydration, photosynthetic activity had resumed, which was common for terrestrial mats as well.

The productivity in Exmouth Gulf is high enough to sustain a prawn fishery, and it is thought that blue-green algal mats play a significant role in this productivity (Paling and McComb 1994; McKinnon and Ayukai 1996). Some evidence suggests that fixed carbon may enter the food webs of the nearshore environment from soluble carbohydrates produced by mats, and that mats at Exmouth Gulf likely play an important role as carbon fixators and in the overall carbon budget (Lovelock et al. 2010). Cyanobacteria was found to be the main source of carbon in the diets of juvenile whiting (*Sillago burrus)*, silver biddy (*Gerres oyena*), northwest hardyhead (*Craterocephalus capreoli*) and a new Gobiidae species, which feed on invertebrates inhabiting mats (Penrose 2011). Large invertebrates, such as the fiddler crabs (*Uca* spp.), were also highly reliant on cyanobacterial primary production, and are likely directly consuming the mat. The extent to which carbon from mats supports the western school prawn, *Metapenaeus dalli*, was less conclusive, though believed to be important.

Field and lab experiments assessed nutrient exchange during tidal inundation and nitrogen fixation in Giralia Bay during a period of high rainfall, and found that the mats, dominated by *Microcoleus chthonoplastes*, mostly removed nutrients from floodwater during tidal inundation and that nitrogen fixation was a key mechanism for nitrogen incorporation (Adame et al. 2012a). Adsorption of NH^{+}_{4} (ammonium) to the sediment without mats also occurred. Vivanco (2009) concurred with the findings of mats removing nitrogen from floodwater (in the form of nitrogen oxides), the rates of which were variable spatially and temporally.

The energy budgets of photosynthetic microbial mat ecosystems at Exmouth Gulf, Abu Dhabi and Svalbard were assessed using microsensors, HPLC pigment analysis, combined imaging approaches (imaging PAM and hyperspectral imaging), molecular and statistical analyses (Al-Najjar 2010). Light attenuation rates and photosynthetic efficiency were highest in mat samples from Exmouth Gulf, which were dominated by filamentous cyanobacteria. In all mats, most of the light energy absorbed was dissipated as heat, and during periods of high incident irradiance (e.g., midday), less than 1% of light energy was absorbed and used as chemical energy in photosynthesis (Al-Najjar et al. 2012). Higher efficiency was found in mats with a thinner and more densely populated euphotic zone. The links between photosynthetic capacity and microbial community composition of mats from Exmouth Gulf were also compared to mats from United Arab Emirates, Brazil, and Spain, and variability in patterns were evident on a sub-millimetre scale as well as a global scale (Al-Najjar et al. 2014). Nutrient concentrations in the water overlaying the mats in Exmouth Gulf were noted to be extremely high and possibly due to the large biomass of alive and dead insect larvae in sediments.

8.1.1.3. Salt Marshes

Saltmarshes (namely samphire) occur extensively along the eastern intertidal margin of Exmouth Gulf, and also along the southern and western margins (Fitzpatrick et al. 2019). They also often line tidal creeks along with mangroves (Oceanica 2006).

Saltmarshes (e.g. samphire and saltbush) constitute some of the vegetation communities of the coastal plains around Exmouth Gulf (Keighery and Gibson 1993).

8.1.1.4. Mangroves

Mangroves are extensive from Bay of Rest and Gales Bay to all along the eastern margin of Exmouth Gulf (Humphreys et al. 2005; Lyne et al. 2006; Oceanica 2006; EPA 2008; Environmental 2017; Fitzpatrick et al. 2019). The EPA provides a guidance statement of advice to proponents and the public about mangroves along the Pilbara Coast, highlighting their conservation significance, including for areas designated as regionally significant e.g., Bay of Rest and Giralia Bay to Yanrey Flats. Some *Avicennia* can also be found along the western margin towards Cape Murat (RPS Bowman Bishaw Gorham 2004; Environmental 2017). Seven mangrove species have been recorded from Exmouth Gulf and include *Avicennia marina, Aegialitis annulata, Aegiceras corniculatum, Rhizophora stylosa, Ceriops tagal, Bruguira exaristata* and *Osbornia* (RPS Bowman Bishaw Gorham 2004; Humphreys et al. 2005). *Avicennia marina* is the most dominant in the region (~8500 ha), followed by *R. stylosa*. A more detailed account of the distribution of each species is given in Humphreys et al. (2005), along with a discussion of the factors controlling mangrove distribution.

Mangroves in arid environments, such as Exmouth Gulf, typically co-occur with saltmarshes, are mostly tide dominated and receive freshwater flow only from groundwater and sporadic storms (Adame et al. 2020). Mangroves use both fresh and saline water sources for metabolic processes, but the proportion of fresh water used increases with fresh water availability, and growth was correlated with rainfall (Santini et al. 2015).

Mangroves support a diverse array of vertebrate (e.g. mudskippers) and invertebrate fauna, including within and on the mud (whelks, peanut worms, crabs, lobsters), and on stems and leaves of the trees themselves (littorine snails) (RPS Bowman Bishaw Gorham 2004).

The mangroves of Exmouth Gulf are adapted to nutrient limiting conditions, which has formed the focus of several studies. Alongi (2005) examines nutrient-use efficiency in *A. marina* and *R. stylosa*, as well as the below ground

Aerial view of Mangroves, Exmouth Gulf (Photo: Wendy Thompson).

decomposition of organic matter (Alongi et al. 2000). Microbial respiration has been found to be limited by gallic acid, phosphate and ammonium (Davies et al. 2017). Events such as cyclones that result in floodwaters can relieve nutrient limitation and stimulate growth, such as observed for Giralia Bay (Lovelock et al. 2011). However, too much nutrient enrichment can enhance the mortality of mangroves at sites where high salinity is coincident with low rainfall (such as Exmouth Gulf) (Lovelock et al. 2009).

Soil respiration of mangrove forests assessed globally, including those in Exmouth Gulf, are similar to terrestrial forest soils (Lovelock 2008), and the allocation of below ground carbon was also similar between tall mangroves forests and terrestrial forests. Scrub mangroves had greater allocation of carbon belowground, which may reflect unfavourable environmental conditions.

Bacterial communities in soils from mangrove forests across the globe (including Exmouth Gulf) found that bacterial communities varied more within each forest sampled in a country, than between forests in different countries (Thomson 2019).

In order to estimate the biomass of the multi-stemmed mangroves, *A. marina* and *R. stylosa*, allometric relationships between stem diameter and above-ground biomass were assessed and found to differ from trees on the northeast coast of Australia (Clough et al. 1997). Radiocarbon dating was also used to determine the age *A. marina* trees at Giralia Bay (Santini et al. 2013). Seaward fringing trees of approximately 10cm diameter were 48 to 89 years old, and their growth rates ranged from 4 to 5.3mm/year, with wood density decreasing with increases in Pacific Decadal Oscillation Index. Wood densities in general were greater on the seaward fringe in Giralia Bay and growth rates were positively correlated with the size of the xylem and wood density (Santini et al. 2012).

Mangroves can be threatened by sea level rise (Semeniuk 1994) and intense weather events (Sippo et al. 2018). An assessment of a 0.2km^2 area in Exmouth Gulf during 2013, 2014 and 2018 found mangrove seedlings rapidly established at higher elevations in cyanobacterial mats during years with higher sea levels, but had poor survivorship after sea levels dropped, with only stems greater than 21cm tall surviving (Reef and Lovelock 2019). Cyclone Vance caused the loss of 44% (5700 ha) of mangrove cover along the eastern margin of Exmouth Gulf (Paling et al. 2008), largely as a result of sediment deposition or smothering. Mangroves can also be threatened by locust plagues. Mangroves at Giralia Bay were exposed to a locust plague in February 2011, which resulted in the loss of foliage from every tree at ranges between 15-100% (Reef et al. 2012).

8.1.1.5. Sand and Mud Flats

Mud and tidal flats span most of the coastline of Exmouth Gulf, and more extensively so along the eastern margin (Lyne et al. 2006). Throughout much of Exmouth Gulf, extensive sand plains are found, which supports soft sediment communities (Lyne et al. 2006; MBS Environmental 2018a; Fitzpatrick et al. 2019; BMT 2020).

Little attention has been given to intertidal sand flats around the coastline of Exmouth Gulf. Fine sandy habitats are found in the upper littoral zone around Heron Point and, in some instances, soldier crabs (*Mictyris* sp.) and evidence of other intertidal organisms were present (360 Environmental 2017; Fitzpatrick et al. 2019). Beaches are found to support ghost crabs (*Ocypode*) and *Domax* bivalves (RPS Bowman Bishaw Gorham 2004), but have not been thoroughly surveyed.

8.1.1.6. Reef Flats, Rocky Intertidal and Oyster Beds

Low relief subtidal reef is extensive around Bundegi and North West Cape across to Muiron Islands (Bancroft and Sheridan 2000; Beckley and Lombard 2012; van Keulen and Langdon 2011). It is likely that subtidal reef flats are found around many of the islands, such as Eva and Fly Islands, which have shallow reef flats off the northern edges (Dee et al. 2020).

A combination of unvegetated pavement reef and reef with macroalgae, invertebrates and sand/mud veneer can be found around the shores of Heron Point and elsewhere along the southwestern shores of Exmouth Gulf (Environmental 2017; Fitzpatrick et al. 2019).

Rocky intertidal pavements can be found along the western shores of Gales Bay and around islands, such as Tent Island (RPS Bowman Bishaw Gorham 2004). The pavements at Gales Bay support oysters around the mid intertidal zone, and macroalgae on the lower intertidal zone along with small patches of seagrass and coral. Around islands, raised boulders, loose rocks and rock pools create more diverse rocky intertidal habitats and, in turn, support a greater diversity of cryptic mollusc and crustacean species, along with extensive areas of coral cover.

Productive rocky intertidal and subtidal areas occur at all the creek mouths along the western shoreline (pers. comm. DWER). These creek mouths are numerous and prone to high levels of visitation and occasional severe disturbance from flood runoff. The location of these creek mouths can be seen at https://beachsafe.org.au/beach/wa/exmouth/exmouth/qualing-pool.

Tubridgi Point has a limestone pavement/rocky shore and Locker Point has an adjacent nearshore reef (Le Provost Environmental Consultants 1991). In relation to the Griffin Gas Pipeline, benthic habitat was mapped between Serrurier and Bessieres Islands, which revealed patches of limestone platform and limestone pavement along with sandy/silty habitat and gravelly sand (Le Provost Environmental Consultants 1992). Surveys around the islands themselves in 1985 found the northeast of Serrurier Island to have limestone platforms, coral bommies, algae dominated platforms and good fringing corals (Le Provost et al. 1987). Algae flats were also extensive. Along the southeast side of Bessieres Island, there were limestone platforms with fringing coral reef, algal flats interspersed with coral reef, and an intertidal zone with rocky shores and sandy beaches.

Oyster beds are present on intertidal pavements around Heron Point (Fitzpatrick et al. 2019). The rock oyster, *Saccostrea* sp., contributed a significant proportion of the biomass of molluscs found in mudflats (38%), but less so for the biomass in sediments among *Avicennia* mangrove stands, based on surveys conducted around Bay of Rest in 1983 (Wells 1986).

Parasites, diseases and causes of the mortality have been investigated for the rock oyster, *Saccostrea cucullata,* and other bivalves at locations across the North West Shelf of W.A. (Hine and Thorne 2000; Hine and Thorne 2002). A haplosporidian parasite (*Haplosporidium* sp.) occurred in the connective tissue of *S. cuccullata* but not of *S. glomerata* around the islands of northwest Australia, and no infected oysters were sampled in Exmouth Gulf (Hine and Thorne 2002). Only one adult *Pinctada maxima* from the northern islands of Exmouth Gulf was infected with ovoid eosinophilic intranuclear virus-like inclusions (n=415 across the region) and parasites were also noted in *Saccostrea* spp., pen shells (*Pinna* spp.) and hammer shells (*Malleus* spp.) collected from islands (Hine and Thorne 2000). The morphologies and genetics of rock oyster species, *Saccostrea* spp., were compared from locations around Australia and the Indo-Pacific to resolve taxonomy of the species (Lam and Morton 2006). *Putative S. cucullata* from Exmouth were found to be similar to *S. glomerate* from N.S.W., and shell characteristics and morphometrics were not reliable for species differentiation.

8.1.1.7. Macroalgae and Turf Algae

Macroalgae beds are a common vegetated habitat across Exmouth Gulf, occurring along the central, eastern, southern, and western margins, as well as around many of the islands to the north of Exmouth Gulf (Cassata and Collins 2004; Lyne et al. 2006; Babcock et al. 2008a; Cassata and Collins 2008; van Keulen and Langdon 2011; McLean et al. 2016; BMT 2020). Macroalgae has been observed growing in sandy habitats as well as on reef platforms, e.g. Heron Point (360 Environmental 2017; MBS Environmental 2018a) and Hope Point (Oceanica 2006). A hyperspectral mapping exercise of shallow waters (<20m) around Ningaloo Reef, Bundegi and Muiron Islands found that the majority of the substrate/habitat cover was composed of macroalgal and turfing algae communities (54%) (Kobryn et al. 2011; Kobryn et al. 2013). Benthic habitat surveys along the eastern margin of Exmouth Gulf suggested that macroalgae may be contributing significantly to productivity, perhaps more so than seagrass (McCook et al. 1995), though variability in abundance of both vegetation types needs to be considered.

Location specific habitat mapping has been carried out in relation to oil and gas development. Patches of subtidal pavement with algae, along with coral communities, intertidal reef flats and sand were documented for the Chelonia exploration wells around North West Cape and Muiron Islands (Apache Northwest Pty Ltd 1998). Intertidal and shallow water habitats have been mapped between Tubridgi Point and Beadon Point in relation to the Roller Oilfield Development (Le Provost Environmental Consultants 1991). Locker Island is surrounded by subtidal algal covered limestone pavement, coral reef, and subtidal sand (Le Provost Environmental Consultants 1991). Serrurier Island was surrounded by patches of subtidal algal covered limestone pavement, subtidal coral reef, and subtidal sand. Bessieres Island had subtidal algal covered limestone pavement around the whole island, as well as subtidal coral reef on the east side and intertidal limestone pavement around most of the island. Benthic habitat maps were produced for the area off Onslow in relation to the Wheatstone Project in 2009, and the percentage cover of macroalgae and filter feeders to the east of Serrurier Island was found to be 25% and 10% of the mapped area, respectively (URS 2010a). Large stretches of subtidal habitat was also documented east of the island (URS 2010c). North of Serrurier and Bessieres Islands, between 15-70m depth, low profile reef and sand inundated low profile reef with red and brown algae, and sponges, was recorded (Waddington and Kendrick 2009).

Sargassum spp. is a common species across Exmouth Gulf, particularly on limestone pavements along the western margin and around islands, such as Simpson and Tent Islands (Kangas 2003; RPS Bowman Bishaw Gorham 2004). *Sargassum* is also found scattered around Giralia Bay and along the eastern margin of Exmouth Gulf, along with *Padina* and other smaller macroalgal species which are most abundant in summer and autumn (RPS Bowman Bishaw Gorham 2004).

Cyclone Vance in 1999 was reported to cause the loss of macroalgae beds (and seagrass), which then saw a decrease in tiger prawn landings and recruitment two years post disturbance (Loneragan 2003; Loneragan et al. 2013). Recovery of vegetated habitats was strongly correlated with the recovery of prawn recruitment and landings.

Macroalgal fronds provide a surface area for other species to grow, and gene sequencing was used to determine the diversity of dinoflagellate species on fronds, which included the identification of toxic species of the genera *Gambierdiscus, Ostreopsis, Coolia, Prorocentrum* and *Amphidinium* (Kohli et al. 2014).

The chemical defences of seven brown algae species to foraging herbivores was examined using in situ feeding trials at Bundegi, and results suggested that unpalatable tropical brown algae will generally contain lower levels of polyphenolics but higher levels of non-polar lipophilics (Steinberg and Paul 1990). Phenolic compounds are also used for cell wall structure and UV protection in brown macroalgae, and a W.A. coast-wide study, including Exmouth Gulf, found that photosynthetically active radiation and salinity were important drivers of phenolic compound concentrations across latitude (van Hees et al. 2017). Algae was found to be a potential source of the 2,6-dibromophenol compound, though not as much as bryozoans, in endeavour prawns from Exmouth Gulf, which causes a detectable iodoform-like flavour in prawn meat (Whitfield et al. 1988; Whitfield et al. 1992).

8.1.1.8. Seagrass

Seagrass meadows have been known to occur along the eastern, southern and western margins of Exmouth Gulf, and around islands such as Muiron Islands, Burnside Island and Tent Island (Hutchins et al. 1996; RPS Bowman Bishaw Gorham 2004; Lyne et al. 2006; Oceanica 2006; Vanderklift et al. 2016). Coverage estimates for seagrasses are variable across Exmouth Gulf, noting that the extent and abundance of seagrass meadows across the whole Gulf has not been comprehensively mapped. Preliminary quantitative and qualitative surveys along the eastern and southern margin of Exmouth Gulf in September 1994 found surprisingly low coverage of seagrasses (typically <5-10%), given the expansive spread of seagrass meadows across other parts of the North West Shelf (McCook et al. 1995). In 2003, surveys by the Department of Fisheries between Gales Bay and Tent Island found >50% coverage at 75% of sites (69 sites in total) (Kangas 2003). For inner Exmouth Gulf (close to eastern margin), coverage reached close to 60% in some months surveyed between August 2013 and March 2015 (Vanderklift et al. 2016). Overall, inner Exmouth Gulf had a higher mean percentage cover and biomass than Bundgei and South Muiron Island; however, there was variability in cover across months. Inner Exmouth Gulf and Bundegi had greater coverage in March 2015 (57% ± 1.67 and 25.3% ± 3.05, respectively), whereas South Muiron Island was relatively low across the survey

Benthic habitat of the southeast Exmouth Gulf including seagrass, macroalgae, soft corals and ascidians (Photo: Kathryn McMahon).

period except for a peak in December 2014 (9.44% ± 2.71). Different species also exhibited different patterns of temporal variation in abundance.

A series of benthic habitat mapping exercises were undertaken for Subsea 7's Learmonth Pipeline Fabrication Facility's launch and tow pathway (360 Environmental 2017; MBS Environmental 2018a; BMT 2020). Sparse and patchy seagrass beds (*Halophila ovalis* and *Halodule uninervis*) were documented around Heron Point and the Bay of Rest, and were estimated to cover ~110 hectares (1.4% of the total key benthic communities and habitat mapped) (MBS Environmental 2018a).

Fourteen species of seagrass are known to occur across the northwest coast of Australia (12-24°S) (Walker and Prince 1987), and within Exmouth Gulf and nearby islands, *Thalassodendron ciliatum, Thalassia hemprichii, Halophila descipens, H. ovalis, H. uninervis, H. spinulosa, Syringodium isoetifolium, Cymodocea serrulata* and *C. angustata*, have been recorded (McMillan et al. 1983; Walker and Prince 1987; McCook et al. 1995; Schaffelke and Klumpp 1996; Loneragan et al. 2013; McMahon et al. 2015; Vanderklift et al. 2016). *Halophila ovalis* is considered to be the most ubiquitous species across the Exmouth Gulf region, occurring at Bundegi, Muiron Islands and inner Exmouth Gulf, in addition to coastal Pilbara sites (Vanderklift et al. 2016). Out of these three locations surveyed, inner Exmouth Gulf had a higher species richness (5) than Bundegi (2-3) and South Muiron Island (2). Surveys between Gales Bay and Tent Island in 2003 noted *H. spinulosa, S. isoetifolium* and *H. uninervis* as most dominant, particularly at depths of 3-6m.

The genetic diversity of *H. ovalis* from Exmouth was found to be moderate to high over a small spatial scale (60km), and the populations were considered to be genetically resilient (McMahon et al. 2015). The clonal diversity of *H. ovalis* and two other tropical species of seagrass, *T. hemprichii* and *H. uninervis,* were assessed from Shark Bay to Indonesia, inclusive of Exmouth Gulf and Muiron Islands, and found that disturbance and sea surface temperature strongly predicted spatial patterns in clonal richness (McMahon et al. 2017).

One such disturbance that impacted Exmouth Gulf was Cyclone Vance in March 1999. The cyclone was reported to cause the loss of seagrass and macroalgae beds, which then saw a decrease in tiger prawn landings and recruitment two years post disturbance (Loneragan 2003; Loneragan et al. 2013). Seagrass (and macroalgae) recovered two years after the cyclone by way of succession from small colonising species (*H. ovalis* and *H. uninervis*) to larger, broad-leaved species (*C. serrulata* and *S. isoetifolium*), which in turn saw an increase in prawn recruitment and landings.

8.1.1.9. Sponges and Filter Feeders

The Pilbara region (including waters just north of Exmouth Gulf and the offshore islands) supports 1164 sponge species and operational taxonomic units with a high level of endemism, and the Ningaloo (332), Pilbara Nearshore (408) and Pilbara Offshore (413) bioregions are recognised as biodiversity hotspots for sponges (Schönberg and Fromont 2012; Fromont et al. 2016; Fromont et al. 2017). Within the Exmouth Gulf region, fewer sponges have been recorded to date (< 60spp) (Hooper et al. 2002; Hooper and Ekins 2004; Kangas et al. 2007).

Sponges and filter feeding communities are found scattered across Exmouth Gulf and nearby islands (Lyne et al. 2006). The most extensive areas of sponge and filter feeder communities occurs from the Naval Pier to waters offshore between North West Cape and the Muiron Islands, where tidal currents are strongest (RPS Bowman Bishaw Gorham 2004). Communities have also been identified on the slopes of islands inside Exmouth Gulf, such as Y island. Off the northeast tip of North Muiron Island and southwest tip of South Muiron Island, there are well developed and diverse benthic communities, inclusive of encrusting and free-standing sponges, ascidians, and other sessile and mobile invertebrates (Cassata and Collins 2004; Cassata and Collins 2008). *Axinella* sp. Ng3 was recorded in higher abundances at the Muiron Islands compared with other locations in the Ningaloo Marine Park, and *Monanchora* sp. Ng1 and *Oceanapia* sp. Ng1 were also recorded at the Muiron Islands (Fromont et al. 2008).

Benthic habitat, Exmouth Gulf (Photos: Rebecca Bateman-John).

Three years of benthic surveys in the offshore region of the Ningaloo Marine Park and Muiron Islands found high densities of filter feeding and sponge communities, with the highest densities offshore of Gnaraloo, the Muiron Islands, Winderabandi Point, Lighthouse Bay, Point Cloates and in the entrance to Exmouth Gulf (Colquhoun et al. 2007; Heyward et al. 2010).

A survey of the benthic habitats in the proposed footprint of the proposed Learmonth Pipeline Fabrication Facility launch site and tow path recorded the occasional occurrence of filter feeders on soft sediments (BMT 2020). Patches of soft sediments and reef with filter feeders have also been mapped around Heron Point (360 Environmental 2017; MBS Environmental 2018a). Benthic surveys around Hope Point on the eastern margin of Exmouth Gulf found sponges occurring in waters up to 3m deep with up to 30% coverage (Oceanica 2006).

Following Cyclone Vance in 1999, sponges were found uprooted and upturned in Exmouth Gulf (Loneragan et al. 2003).

The genetic diversity and morphology of cyanobacterial symbionts of sponges collected from Exmouth Gulf have been investigated in relation to host associations and biogeography across Australia and the Mediterranean (Usher et al. 2004; Usher et al. 2006).

Images of benthic habitat collected across the North West Shelf were used to determine the coverage of small and large epibenthos at depths between 20-200m, and modelled how distribution was influenced by environmental factors (Fulton et al. 2006). Modelling was stronger for sponges than mangroves, seagrasses and macroalgae, and depth was a key driver of biomass and coverage of benthic habitat.

A body of literature has focused on sponge chemistry, including samples taken from Exmouth Gulf, but these are not elaborated on in this report (e.g. Searle and Molinski 1994a; Searle and Molinski 1994b; Brantley et al. 1995; Searle and Molinski 1995; Gartshore et al. 2018; Salib 2018; Salib and Molinski 2018).

8.1.1.10. Corals

Soft and hard coral communities are spread around the coastal margins of Exmouth Gulf, as well as around islands inside and outside Exmouth Gulf (Lyne et al. 2006; Babcock et al. 2008b; Twiggs and Collins 2010; 360 Environmental 2017; Fitzpatrick et al. 2019). Connectivity and larval dispersal of corals in the area is influenced by prevalent currents in the region, such as the seasonal Ningaloo Current (Taylor and Pearce 1999a). Inside Exmouth Gulf, Bundegi Reef, included in the Ningaloo Coast World Heritage Area, typically defines the extent of people's knowledge of corals in the region. However, coral reefs and bommies also occur more extensively along the west coast and east coast of Exmouth Gulf (pers comm. Mick O'Leary). The low relief reef around Heron Point also supports the growth of hard and soft corals (360 Environmental 2017; Fitzpatrick et al. 2019). A number of shoals in the centre of Exmouth Gulf, such as Cooper Shoal and Bennett Shoals, support communities of soft corals and other benthic invertebrates (pers comm. Kate Sprogis). A diverse community of octocorals (soft corals, sea pens and gorgonians) have been observed around the Muiron Islands (Cassata and Collins 2004; Cassata and Collins 2008; Hutchins et al. 1996). Hutchins (1996) recorded 118 species of octocorals from 23 genera and 11 families, and environmental conditions likely played a role in the occurrence of different species east and west of the Muiron Islands. In contrast, a lower diversity (10 species) and biomass of octocorals were found along the eastern shallow shores inside Exmouth Gulf. A hyperspectral mapping exercise of shallow waters (<20m) waters around Ningaloo Reef, Bundegi and Muiron Islands found that 7% of the mapped area comprised of hard and soft corals, and that dense tabulate corals were most commonly detected (Kobryn et al. 2011; Kobryn et al. 2013). An assessment of whether the 'no-take' zones of the Ningaloo Marine Park (state waters) provided adequate protection for different benthic habitats found that subtidal and intertidal coral communities were adequately protected based on percentage of the total area, but other habitats such as deeper water benthic communities were not (Beckley and Lombard 2012).

Corals inside and outside of Exmouth Gulf have been the subject of surveys following a number of heat stress and bleaching events. To understand relative impacts of two recent widespread coral bleaching events in the Pilbara during the summers of 2011 and 2013, cores of *Porites* spp. were collected from seven sites between Exmouth and the Montebello Islands, to examine Strontium/Calcium and Lithium/Magnesium ratios (Clarke et al. 2019). Trace element anomalies and declines in growth were observed for two of seven sites in the late 1990's, three of seven sites in 2011 and five of seven sites in 2013, which indicates the impacts from marine heatwave are increasing across the region. The greater reduction in growth rate associated with the 2011 heat wave rather than the warmer 2013 event may suggest some level of acclimatisation for colonies of *Porites* spp. Coral cover, mortality and survival was tracked over an 18 month La Niña period at Bundegi Reef, capturing measurements during pre-bleaching, mid-bleaching and post-bleaching conditions (Depczynski et al. 2013). Live coral cover declined 79-92% during January 2011 (mid-bleaching), and massive forms seemed to be less impacted than the dominant *Acropora* and *Montipora* assemblages, which all died. Exmouth Gulf recorded the greatest loss of coral cover (from sites examined between Perth to the Montebello Islands) from mass bleaching and cyclones following the 2011 marine heatwave (Moore et al. 2012). Severe bleaching of turbid water soft and hard corals was also found around the inshore waters (10-15 m) of Onslow following a 2013 heat stress event (Lafratta et al. 2017). Conversely, in water and aerial surveys of coral reefs across the North West Shelf, Cocos Keeling Islands and Christmas Island following a bleaching event in 2016 found little evidence of bleached corals around Ningaloo and inshore Pilbara (Gilmour et al. 2019).

Other disturbance events, such as Cyclone Vance, contributed to prevalence of coral rubble habitat across Exmouth Gulf (Loneragan et al. 2003). Coral rubble is evident at Bundegi and most of the coral was found to be covered in epiphytic algae, rather than macroalgae, during 2012 surveys (Day et al. 2013).

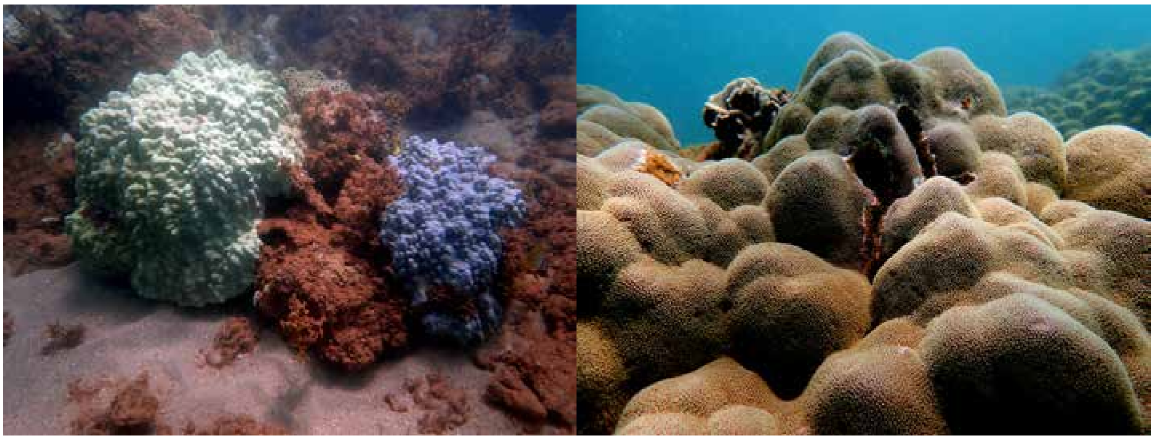
Seven diseases were detected from corals sampled across the Ningaloo Marine Park, including five at Bundegi and four at South Muiron Island (Onton et al. 2011). Brown band disease was most prevalent at Bundgei and skeletal eroding band was most prevalent at South Muiron Island.

Oceanographic modelling was used to investigate the recruitment and connectivity of coral population across the North West Shelf, and though spawning outcomes were highly variable depending on environmental conditions, larvae were predicted to reach suitable reefs within 10 days of spawning (Feng et al. 2016). Most of the important source and sink subregions existed outside marine parks, while highest self-seeding and larval retention areas were found in marine parks.

The population structure of the stress tolerant coral, *Cyphastrea microphthalma*, was examined using microsatellite genetic markers and modelling from samples taken within Exmouth Gulf, Bundegi, Muiron Islands and other locations across the North West Shelf (Evans et al. 2019). Evidence suggested the presence of four genetic clusters, with the Pilbara and northern Ningaloo being distinguished from the Kimberley, Coral Bay and Shark Bay. Collected samples from colonies of *Pocilloppora damicornis* from Muiron Islands and Ningaloo Reef were used to determine genetic lineages (Thomas et al. 2014). Two lineages were found, but reproductive barriers were not completely developed, suggesting that this species may have a high capacity to recover from disturbances if effects are not widespread and sustained across the reef.

A methodological comparison of reef rugosity and coral carbonate production across two reefs located in Exmouth Gulf (Eva and Fly Islands) were examined using traditional chain-and-tape and remote sensing measures (Dee et al. 2020). Rugosities at both reefs were typical for a turbid reef environment, and chain-and-tape methods were deemed more appropriate for quantifying rugosity within carbonate budget studies given the limitations of remote sensing.

A body of work has used corals to better understand historical patterns and events. The exposed fossil coral reef at Point Maxwell (Sandalwood Peninsula) has been estimated to date back to the last Interglacial period (130,000 to 116,000 years BP) (Greenstein et al. 2005). Point Maxwell was compared with the modern reef at Point Lefroy, and elevated turbidity and temperature were suggested to be the main drivers of lower coral diversity observed in the modern day reef (Shepherd 2018). Outcrops of fossil coral reefs can be found inland at Burney Point, Cape Cuvier and Cape Range (Stirling et al. 1998). Coral cores from reefs along the western margin of Exmouth Gulf showed distinct reef facies vertically and laterally that likely reflected changes in the environmental conditions during the Holocene (Twiggs and Collins 2010). Cores taken from *Porites* corals at Bundegi, and elsewhere in the southeast Indian Ocean, were used to reconstruct SST variability and heatwaves across a 215-year timeframe, revealing that marine heatwaves in this region of the Indian Ocean are linked to the Western Pacific Warm Pool on decadal to centennial timescales (Zinke et al. 2015). Cores extracted from corals from Tantabiddi Lagoon and Muiron Islands were used to reconstruct past climate conditions, and secondary precipitation of marine inorganic aragonite may influence conclusions drawn about sea surface changes in the region (Müller et al. 2001).



Massive *Porites*, eastern margin of Exmouth Gulf (Photos: David Juszkiewicz).

8.1.2. Marine Fauna

8.1.2.1. Zooplankton

Much of the literature on zooplankton stems from a suite of scientific voyages that sampled eight stations from inside Exmouth Gulf to the shelf slope (~500m) during the austral summer months between 1997-1999, using plankton light traps and nets.

A comparison of light trap methods (moored and drifting, small and large in size) and catch rates of larval fishes and planktonic invertebrates found that while differences were evident across methods, overall, they reflected the same changes in zooplankton assemblages across an inshore-offshore gradient (Meekan et al. 2001). An analysis of late stage larval fishes showed that baitfishes were mostly captured near the seabed, while reef and pelagic fishes were captured near the surface (Meekan et al. 2006a). Most larval fishes were captured between the North West Cape and Muiron Islands at the boundary between well-mixed inshore waters and stratified offshore waters, likely influenced by upwelling.

An investigation of copepod communities found 120 species and a dominance of small copepods (McKinnon et al. 2008). Onshore-offshore gradients in copepod communities were evident, and El Niño conditions resulted in upwelling and an increase in primary production and copepod abundance during 1997-98.

Otoliths were examined from different life stages of a fast growing sprat, *Spratelloides gracilis*, to provide evidence that selective mortality was acting on size differences within cohorts, more so than age differences between cohorts (Meekan et al. 2006b). Catch and otoliths of *Pomacentrus coeliestis* showed that despite upwelling in the 1997/98 summer, growth was lower than in the 1998/99 summer (when temperatures were higher), suggesting that perhaps temperature was a primary driver of growth over food availability for this reef fish (Meekan et al. 2003).

Bongo net tows from two stations along the 1997-99 transect, as well as an additional station in coastal waters off Onslow, examined tropical fish larvae in relation to El Niña and La Niña periods (Sampey et al. 2004). Abundance and diversity generally increased from October to February. Abundances differed across the two years sampled, but assemblage composition was relatively consistent, and no significant influence of environmental variables on assemblages was found. Sampey et al. (2007) also described the diets of 591 individual fish larvae collected with light traps and found the diversity of prey differed significantly amongst families of fishes, with the majority consuming copepods.

Expanding the spatial extent further, Wilson et al. (2003b) examined the macrozooplankton from light traps along the inner Gulf to outer Gulf transect, as well as from stations off

Onslow and along the Ningaloo Reef coastline. Macrozooplankton had higher abundances during the El Niño summer season where upwelling was evident and chlorophyll was higher, which created an obvious inshore offshore difference in assemblages. The opposite was true for the La Niña summer season, which had limited upwelling and lower chlorophyll. The tropical krill species, *Pseudeuphausia latifrons*, dominated the krill catch, with highest abundances occurring between North West Cape and Muiron Islands (Wilson et al. 2003a). Abundances were also higher during the La Niña period where less upwelling and warmer temperatures prevailed, as opposed to the El Niño sampling season. Evidence was provided for P*. latifrons* producing multiple broods during a season. A study on the distribution and abundance of small pelagic cephalopods from these stations found octopods to be particularly abundant on mid-depth stations of the Exmouth transect, likely due to the turbulent mixing and increased productivity in this region (Jackson et al. 2008). In January 1998, Tropical Cyclone Tiffany passed along the shelf margin in the vicinity of stations and changes in copepod and larval fish communities post cyclone was attributed to the southward transport of water masses along the shelf (McKinnon et al. 2003).

A catalogue of macrozooplankton and nekton from all stations sampled around Ningaloo, Exmouth Gulf and Onslow, was consolidated by Wilson (2001), and included a list of the 313 macrozooplankton and nekton taxa captured in light traps.

Water samples were taken at multiple locations throughout Exmouth Gulf to examine copepod egg production rates of four species, and rates were found to be greater in the southeast of Exmouth Gulf where chlorophyll *a* and particulate nitrogen and carbon were highest (McKinnon and Ayukai 1996).

Strandings of *Keesingia gigas* along the beaches of Exmouth Gulf and the Ningaloo coast in 2016 and 2017 allowed for a more detailed examination of a rarely observed jellyfish (Keesing et al. 2020).

Copepod-elasmobranch associations were investigated between Montebello Islands and Shark Bay, inclusive of Exmouth Gulf and found 17 species of commensal copepod occupying four species of shark. Copepods that occurred on the body surface had a wider geographical distribution than those copepods associated with specific body locations (Newbound and Knott 1999).

8.1.2.2. Marine Invertebrates

Molluscs, crustaceans and echinoderms have formed the focus of marine invertebrate research in Exmouth Gulf. Comprehensive surveys have not been carried out across the whole gulf, though some locations have received more attention. A biological survey of the Muiron Islands and part of the eastern shore of Exmouth Gulf in 1995 found 378 species of gastropod, three species of polyplacophorans and 274 species of bivalves, all of which belonged to the Indo-West Pacific Region and/or were endemic to northern Australian waters (Hutchins et al. 1996). A detailed survey of the invertebrates of Bay of Rest was also undertaken in 1981 and found the most diverse area to be the mud flats (112 species), compared with the mangroves and upper intertidal flat, and all habitats were dominated by molluscs, crustaceans and polychaetes (Wells 1983; Wells 1984). Though the mudflats had more species of molluscs, there was greater density and biomass in the *Avicennia* mangrove zone (Wells 1986). A later survey in 2018 also found the invertebrate fauna at Bay of Rest to be dominated by molluscs (Fitzpatrick et al. 2019). Some information is available on the intertidal communities around Serrurier and Bessieres Islands which were surveyed in relation to the Wheatstone Project in 2009 (URS 2010b). The intertidal environment of Serrurier Island was extensively sandy with some rocky shore at the northern end. Molluscs, bivalves, crustaceans and echinoderms were identified during surveys. Bessieres Island was also sandy with rocks and had a 100m-wide intertidal platform on the west side, where crustaceans, molluscs, scleractinian corals, echinoderms and fish were identified.

Targeted invertebrate species from Exmouth Gulf have also informed several fisheries or aquaculture related studies, such as assessing the ability of pre-recruit abundance to predict catch (Caputi et al. 2014a), assessing stock-recruitment and environment relationships (Penn and Caputi 1986; Caputi et al. 1998), the factors affecting recovery of invertebrates after the 2011 marine heatwave (Caputi et al. 2019), and adapting management practices in response to extreme marine heatwaves (Caputi et al. 2016). To understand the growth, mortality, recruitment and sex ratio of wild silver-lipped pearl oysters, populations in Exmouth Gulf, the Lacepede Islands and 80 Mile Beach were investigated, and specimens collected from Exmouth Gulf had a smaller maximum size and reduced growth rates compared to other locations (Hart and Joll 2006). Diseases and pathogens have been documented for the pearl oyster, *Pinctada maxima*, including specimens from Exmouth Gulf, to aid management decisions on the translocation of stock (Humphrey et al. 1998). A severe mortality event occurred for *P.maxima* production farms in Exmouth Gulf in 2006, and though disease is suspected, this was not confirmed (Jones 2009; Jones et al. 2010). A comparison of trawled versus untrawled areas for prawns in Exmouth Gulf found some evidence that high trawl effort sites had lower faunal abundance (Kangas et al. 2006).

Molluscs

The corallivorous, *Drupella cornus*, caused widespread damage to corals along Ningaloo Reef during an outbreak in the mid-1980s and early 1990s (Armstrong 2009). *Drupella* sp. were found at North Muiron Island and Bundegi sites, and *Drupella rugosa* was noted only to occur at Bundegi sites. *Drupella cornus* was in notable abundances during July - August 2012 from community-assisted reef biodiversity surveys around Ningaloo Reef and Muiron Islands (Day et al. 2013).

A taxonomic review and field guide to cowries of Australia highlights the biogeographical significance of Exmouth Gulf in the radiation of cowries down the West Coast of Australia (Wilson and Clarkson 2004). The intermittent connection between the North West Shelf and Dirk Hartog shelves has led to the intermittent isolation of populations of non-planktonic species, leading to speciation, such as observed for the *Zoila* cowrie species complex.

In order to investigate the source of pearl oyster (*P. maxima*) recruits, the number of adults contributing to the next generation and whether selection occurred after settlement, eight microsatellite markers were used from 1700 pearl oysters sampled from eight northwest Australian and Indonesian locations (Benzie and Smith-Keune 2006). There was indication of genetic differences between Exmouth Gulf and other populations, suggesting it may be a distinct stock.

Recycled oyster, mussel and scallop shells have been used in shellfish reef restoration around Australia. However, there is potential for disease and pests to spread. Diseases and parasites previously found associated with *Saccostrea* from Exmouth Gulf were used to inform a biosecurity focused risk assessment of using recycled shells to construct reefs (Diggles 2020).

In 2004, evidence of Pecten-like shell was found at Exmouth Gulf and Gnaraloo, and after further investigation of shell parameters, resulted in the classification of a new species, *Pecten dijkstrai* n. sp. (Duncan and Wilson 2007; Duncan and Wilson 2012).

Deepwater trawl surveys were conducted around the Muiron Islands during 2006-2008 and Fromont et al. (2008) details the top ten molluscs found with *Arcidae* spp being the most abundant, though notes that the Muiron Islands were relatively under sampled compared with other areas off Ningaloo.

An examination of nerite snails found *Nenta undata* and *N. chamaeleon* to occur along the rocky shores of the western margin of Exmouth Gulf where the waters have a higher silt content, whereas *Nerita plicata* and *N. albicilia* were found along the western shore of the North West Cape where water turbidity is low, indicating ecological segregation (Wells 1979).

Nudibranchs at Bundegi Reef (Left; Photo: Alicia Sutton) and along the eastern margin of Exmouth Gulf (middle and right; Photo: David Juszkiewicz).

Molluscs and bryozoans tend to dominate invertebrate communities in Gales Bay due to turbid conditions, and, in particular, include the dominant hammer (*Malleus*), wing (*Ptera*) and pearl (*Pinctada*) oysters (RPS Bowman Bishaw Gorham 2004).

DNA was extracted from specimens of the nudibranch, *Moridilla brockii*, from Exmouth Gulf and elsewhere across the North West Shelf, which found two morphs of the complex to be new species, one of which is known from Exmouth to the Wessel Islands in the Northern Territory (Carmona and Wilson 2018). *Chromodoris* has relatively recently radiated, and has been shown to have cryptic diversity and mimicry, determined from specimens examined from Exmouth Gulf and elsewhere in Australia (Layton et al. 2020)

Experiments with captured squid and a single air gun off Exmouth showed squid to exhibit a strong startled response to approaching seismic activity, and squid would either jet directly away from the source and/or fire their ink sacs (McCauley et al. 1998a).

Phylogenetic relationships were investigated for species of the genus *Octopus*, and included four species collected from Exmouth Gulf (Acosta-Jofré et al. 2011).

Crustaceans

A biological survey of the Muiron Islands and part of the eastern shore of Exmouth Gulf in 1995 found 39 barnacle species, with richness being greater at the Muiron Islands compared to Exmouth Gulf (Hutchins et al. 1996). Twelve species of trapeziid crabs were also found at the Muiron Islands which, at the time, was the greatest number of trapeziid species collected from a single locality in W.A. waters.

The cyanobacterial mats and mangroves habitats around Gales and Giralia Bay supported 82,996 crustaceans from nine species and three families from a study by Penrose (2011). The majority (98%) of this crustacean catch came from a habitat mosaic of mangroves and blue-green algal mats, as opposed to blue-green algal mats with no fringing mangroves, and the western school prawn, *Metapenaeus dalii*, and palaemonid shrimp, *Palaemonetes atrinubes*, were among the most dominant crustaceans. *Metapenaeus dalii* and *P. atrinubes* were found to migrate to blue-green algal mat with tides during the night only.

The distribution and abundance of rock lobster species was investigated from the Muiron Islands and south along the Ningaloo coastline (Babcock et al. 2008b). Lobster abundance was low for all species at Muiron Islands, as it was for most locations along the Ningaloo coast.

Samples of juveniles and adults of the crab, *Portunus pelagicus*, were obtained from 15 assemblages across W.A. and S.A., which found considerable genetic heterogeneity between samples from Shark Bay and Exmouth Gulf assemblages (Chaplin et al. 2001).

The genetic connection within and among shelf-connected populations of mud crab, *Scylla serrata*, across Australia, including Exmouth Gulf, was examined by Gopurenko and Hughes (2002). Twenty-three distinct haplotypes were identified out of 306 sample, and regional genetic structure was found to broadly correlate with hydrological circulation, likely supporting connectivity among shelf connected populations.

A relatively new species of soldier crab, *Mictyris occidentalis*, was described by Unno (2008) and is found within Exmouth Gulf, as well as between Shark Bay and Broome, and is likely an endemic species. The mangrove lobster, *Thalassina squamifera*, was noted as a new record for Exmouth Gulf during field surveys in May 2018 (Fitzpatrick et al. 2019).

Cadmium occurs naturally in the marine environment, though does accumulate in the tissues of prawns (Francesconi et al. 1995; Schimek 2013). Samples of the coral prawn, *Metapenaepsis crassissima*, taken from Exmouth Gulf and Shark Bay revealed cadmium was up to 100 times more concentrated in female prawns.

An investigation of the impact of lunar phase on daily catch rates of prawns in Exmouth Gulf and Shark Bay, found there was a direct correlation between moonlight and catch rate, with a full moon associated with poorer catch (Harman 2001). More biological information is known for Tiger (*Penaeus esculentus*), Western King (*Penaeus latisulcatus*) and Blue Endeavour (*Metapenaeus endeavouri*) prawns given they are targeted by the primary fishery operating in Exmouth Gulf, and details can be found in Kangas et al. (2015). Cyclone Vance resulted in an immediate significant loss in critical prawn nursery habitat, seagrass and macroalgae, which resulted in a decrease in prawn landings two years after the cyclone (Loneragan et al. 2013). Landings increased as macroalgae and seagrass recovered.

Echinoderms

A total of 18 crinoids, 19 asteroids, 26 ophiuroids, 10 echinoids, and 19 holothurians were collected from the biological survey of the Muiron Islands and part of the eastern shore of Exmouth Gulf in 1995 (Hutchins et al. 1996). The majority of species were recorded at Muiron Islands compared with Exmouth Gulf, and it was expected that more sampling would result in significantly more species.

Deepwater trawl surveys were conducted around the Muiron Islands during 2006-2008 and Fromont et al. (2008) details the top ten echinoderms found, though notes that the Muiron Islands were relatively under sampled compared with other areas off Ningaloo.

The ecology of the grazing urchin, *Echinometra mathaei*, at Ningaloo Marine Park was investigated by Langdon (2012) and include habitat surveys and maps, the influence of sanctuary zone implementation, determination of bioerosion rates, and behaviour of urchins including diurnal patterns. One specimen of *E. mathaei* was discovered in Late Pleistocene reef limestone at Exmouth Gulf, and more fossilised specimens were found at Ningaloo Reef and Cape Range (McNamara 1992).

An early study on echinoderms noted that the North West Cape was the end of the range for many continental species due to abrupt change of habitat from sheltered waters of the Exmouth Gulf (Marsh and Marshall 1983).

The sea star, *Aquilonastra cepheus*, from Exmouth Gulf was included in a revision and description of 13 new species of *Aquilonastra* O'Loughlin based on morphological observations, and evidence indicates that *Aquilonastra* species have local geographical ranges (O'Loughlin et al. 2006).

8.1.2.3. Ascidians

The invasive ascidian, *Didemnum perlucidum*, is a widespread pest species across the Pilbara and has been found at the Exmouth Boat Harbour (Wells 2018).

8.1.2.4. Syngnathids and Solenostomids

Syngnathids (sea horses and pipefish) and solenostomids (ghost pipefish) are relatively understudied taxa in Exmouth Gulf (and across W.A.). Various species of syngnathids and solenostomids occur in Exmouth Gulf as evidenced by being recorded as bycatch for the Exmouth Gulf Prawn Managed Fishery (Kangas et al. 2007; Kangas et al. 2015; Gaughan and Santoro 2019; Gaughan and Santoro 2020). It is anecdotally reported that many syngnathids and solenostomids pass through trawl netting. Variable numbers of syngnathids are recorded in daily logbooks each year, e.g., three alive and one dead during 2018, and 37 alive and 34 dead during 2017. The following species have been recorded during trawl surveys in 2004: *Halicampus grayi, Haliichthys taeniophorus, Hippocampus alatus, Hippocampus angustus, Hippocampus planifrons, Hippocampus zebra* and *Trachyrhamphus bicoarctatus* (Kangas et al. 2006). Kuiter (2001) also reported on *Hippocampus montebelloensis*, which was later found to be a synonym of *Hippocampus zebra*.

The risk to breeding populations of syngnathids from prawn trawling was rated low in 2008 (Kangas et al. 2015) and a Productivity Susceptibility Analysis in 2014 assessed *Hippocampus* species as low.

A comparison of light trap methods along a transect from inside Exmouth Gulf to oceanic waters off the shelf edge captured syngnathids in large moored light traps but not in small moored light traps or drifting light traps (Meekan et al. 2001).

8.1.2.5. Teleost Fishes

8.1.2.5.1. Species Richness and Assemblages

A biological survey of the Muiron Islands and part of the eastern shore of Exmouth Gulf in 1995 found 393 species of fishes, most of which had tropical affinities (97.5%) (Hutchins et al. 1996; Hutchins 2001). Three times more species were found at Muiron Island than the eastern shore of Exmouth Gulf. Species richness around the Muiron Islands was found to be considerably greater than the richness off Dampier Archipelago, and the fish fauna from the eastern shores of Exmouth Gulf were similar to Dampier and the Kimberley. Based on these 1995 surveys, Hutchins et al. (1996) made a note that fishing activities appeared to be having an impact on coral trouts, rock cods, tuskfishes, sea perches and emperors.

Results from a broad-scale fish census across the Ningaloo Marine Park found that Bundegi, the Muiron Islands, Lighthouse Bay and Gnaraloo hosted assemblages that were distinct from more central regions of the Ningaloo Marine Park (Babcock et al. 2008a). The tuskfish species, *Choerodon cyanodus, C. schoenleinii, C. cauteroma* were characteristic of Bundegi and Lighthouse Bay, while coral trout, *Plectropomus* spp., were mainly recorded at Bundegi and the Muiron Islands.Reef biodiversity surveys of the Ningaloo Marine Park, inclusive of Bundegi and Muiron Islands, between July and August 2012 found relatively high fish diversity across 22 sites and a total species count of 236 (Day et al. 2013). The wrasses *Thalassoma lunare* (Moon wrasse), *Thalassoma lutescens* (Green moon wrasse) were most common, as were *Labroides dimidiatus* (Common cleaner fish), *Chlorurus sordidus* (Greenfin parrotfish) and *Scolopsis bilineata* (Two-line monocle bream).

Baited remote underwater video systems (BRUVS) were used to assess the distribution, abundance and diversity of fishes along the Pilbara coast, including just outside Exmouth

Plectorhinchus multivittatus over large *Porites* at Bundegi Reef (Photo: Paul Day).

Gulf (McLean et al. 2016). BRUVS were deployed across a range of habitat types and 343 species of fish were recorded. Abundance and distribution were linked positively with areas of high relief, hard coral cover, reef and macroalgae, and negatively with distance to oceanic waters.

BRUVS were used to investigate the shallow water (<8 m) fish assemblages around Heron Point and Bay of Rest in May 2018 (Fitzpatrick et al. 2019). Forty eight species from 25 families were captured on video footage from 100 deployments, with *Pelates octolineatus* and *Pentapoda vitta* being most abundant.

Otter trawls over soft substratum and fish traps on reef were used to compare fish compositions across the North West Shelf, from Exmouth Gulf to the Kimberley (Travers 2009). A total of 229 species were exclusively recorded over soft substrate and 76 exclusively over reef habitat, while 56 species were captured over both habitats. The Leiognathidae, Carangidae and Terapontidae families dominated in sandy habitats and Lethrinidae and Lutjanidae dominated in reef habitats, and species compositions were related to latitude and water temperature.

King Reef is an artificial reef consisting of six large steel reef units and 49 concrete modules that was deployed in Exmouth Gulf in 2018 (Florisson et al. 2020). Over 90 species of fish had been recorded in two years, which was reportedly much greater than the previous diversity over the sandy habitat.

Bycatch of the Exmouth Gulf Prawn Trawl Managed Fishery includes fishes, and during assessments in 2001-2003, an estimated 396,725 fishes were caught as bycatch, including 22 species targeted by commercial and recreational fishers (Newman et al. 2004).

A comparison of hotspot, biogeographical and complementarity approaches resulted in the identification of 26 priority areas for conservation of coastal fishes along W.A., including coastal waters off Exmouth Gulf (Fox and Beckley 2005).

Habitat connectivity and trophic connectivity was investigated within two contrasting landscape compositions, cyanobacterial mats and mangroves, and cyanobacterial mats minus mangroves in Giralia and Gales Bay (Penrose 2011). A total of 32,330 fish from 61 species within 32 families were caught with fyke nets. A total of 33 species of fish and six species of crustaceans were caught in blue-green algal mat habitat, and 18% of these species are considered commercially important.

Gill et al. (2000) provides a description of the fish *Congrogadus winterbottomi*, which was only recognised from the west Pilbara islands and Exmouth Gulf.

8.1.2.5.2. Population Biology

Bomb radiocarbon dating was used to provide age estimates of *Hyporthodus octofasciatus*, *Etelis carbunculus* and *Lethrinus nebulosus*, which resulted in estimated life spans of at least 43, 35 and 28 years respectively (Andrews et al. 2011).

An evaluation of the connectivity of the Spanish flag emperor, *Lutjanus carponotatus*, across northwest Australia, including Exmouth Gulf, using genotyping-by-sequencing revealed there was significant genetic subdivision between Shark Bay and all northern locations (DiBattista et al. 2017).

Age-based demographic analyses of fish sourced from commercial, independent, charter and recreational fishing and sampling was used to determine the current status of fished stocks of spangled emperor in the Gascoyne region, including Exmouth Gulf (Marriott et al. 2011). Emperors of the northern Gascoyne bioregion, Ningaloo, Exmouth and surrounds, were found to grow faster to reach a shorter maximum length at age, and a younger mean age, and historical effects of fishing was evident.

McIlwain (2002) describes the link between reproductive output and larval supply for the damselfish *Pomacentrus vaiuli*, by monitoring the reproduction of two groups in different habitats, Bundegi and Tantabiddi. Egg clutches, laid on artificial substratum across two breeding seasons, were quantified and egg production timing was similar between groups with the majority of larvae hatching during flood tide either side of sunset.

The population structure of the narrow-banded Spanish mackerel was assessed using stable carbon 13 and oxygen 18 isotopes in the sagittal otolith carbonate from specimens across W.A. (including Bessieres Island), Northern Territory, Queensland and Indonesia (Newman et al. 2009). Four sub-populations were suggested, all Australian signatures were significantly different to Indonesian, and there was no temporal variation in isotope ratios, suggesting that there is unlikely to be substantial movement between these populations. Spatial genetic subdivision was investigated for the goldband snapper (*Pristipomoides multidens*) sampled from Australia (inclusive of Exmouth samples) and Southeast Asia (Ovenden et al. 2002). A clear distinction was evident between Australian and Southeast Asian specimens, and there was also restricted gene flow across northern and western Australia identified, particularly across the Kimberley coast.

Ephemeral sexual dichromatism was evident in males of the cardinalfish *Quinca mirifica* from Exmouth and Ningaloo, which is suggested to be due to the reproductive advantage that it provides to solitary and cryptic species of this family (Vagelli 2014).

Wilson et al. (2016) assessed the relative importance of juvenile abundance and microhabitat availability for shaping population sizes of a microhabitat specialist, the coral-dwelling damselfish *Pomacentrus moluccensis*. Patterns were observed over six years in the Ningaloo region, including Bundegi, and the availability of the preferred juvenile microhabitat (corymbose corals) at settlement was a strong predictor of future abundance, however this varied spatially, with some areas showing branching corals being better predictors.

Experiments with captured fishes and a single air gun off Exmouth showed fishes to exhibit 'alarm' behaviours, such as increased swimming, swimming to the seabed, and/or tightening school structure at an estimated 2-5km from the source of seismic activity (McCauley et al. 1998a). Some fishes received eardrum damage but there was no evidence of increased stress.

8.1.2.6. Elasmobranchs

8.1.2.6.1. Rays

A total of 11,614 records from photo identification databases, aerial surveys and online reports of *Mobula alfredi* (EPBC Act – Migratory, Marine), including records from Exmouth Gulf and Ningaloo Marine Park, were used to describe the geographic distribution of reef and oceanic manta rays in Australian coastal waters (Armstrong et al. 2020a). There is uninterrupted coastal distribution from north of 26°S on the west coast of Australia and 31°S on the east coast. Most of these records related to *M. alfredi*, with *M. birostris* (EPBC Act – Migratory, Marine) sightings occurring less frequently (n=32).

Feeding manta ray in the shallows, south of Exmouth Marina Channel (Photo: Kate Sprogis).

To understand patterns of movement and site use by reef manta rays, *M. alfredi*, satellite telemetry alongside a decade of photographic identification records were analysed (Armstrong et al. 2020b). Tagged rays stayed within coastal shelf waters, preferring depths <20m, and there was connectivity detected between Ningaloo and Shark Bay World Heritage Areas. Manta rays displayed long-term site affinity to some locations in the Ningaloo Marine Park, and there was also indication of repeated emigration and remigration to areas, with 116 occurrences of resights between Exmouth Gulf and Coral Bay.

The healing capacity of a manta ray from Ningaloo Reef, that had lacerations to the pectoral fin from a propeller, was tracked over time, and wounds took close to 300 days to heal to 95% (McGregor et al. 2019). A distinctive scarring pattern was evident. It is possible that wounds from other manta rays, determined from photographic evidence, could also be from vessel strikes rather than failed mating attempts.

Manta rays are filter feeders and are exposed to micro and macro plastics in the water column. The presence and concentration of micro and macro plastics in surface waters and sediments where reef manta rays are known to feed in Exmouth Gulf and Bateman Bay were quantified (King 2019). Plastic concentration was significantly higher in Bateman Bay compared to Exmouth Gulf, with temporal variation in concentrations at both locations. Microplastic and fishing line fibres dominated samples, which have the potential to be consumed by manta rays at a rate of 17.12 pieces/hr in Bateman Bay, and 2.02 pieces/hr in Exmouth Gulf. Both rates are far less than Indonesian comparisons.

Aerial surveys between August and November 2018 in Exmouth Gulf sighted 153 sharks and 329 manta rays (Irvine and Salgado Kent 2019). Sharks were mainly distributed along the shallow waters of the southern and eastern shores, and manta rays were mainly distributed in the northwest region of Exmouth Gulf as well as in shallow waters in the south. These latest survey results concur with previous surveys conducted during 2004-2005 by Jenner and Jenner (2005) and Preen et al. (1995; 1997).

A paratype of the relatively recently described wedgefish *Rhynchobatus palpebratus*, was found in Exmouth Gulf and was used to help define its distribution in the northern waters of Australia (Compagno and Last 2008). Type specimens of the maskray, *Neotrygon ningalooensis*, were collected from across north Western Australia and the Northern Territory, including Bundegi, suggesting that it is relatively widespread (Last et al. 2010).

Maskray, Exmouth Gulf (Photo: Rebecca Bateman-John).

Biological sampling using trawls across Exmouth Gulf during 2004 by Kangas et al. (Kangas et al. 2007) captured five white-spotted shovelnose rays (*Rhynchobatus australiae*).

Several ray species, including the bluespotted fantail ray (*Taeniura lymma*), giant shovelnose ray (*Glaucostegus typus*) and leopard whipray (*Himantura leoparda*), were sighted in shallow waters around Heron Point and Bay of Rest (along with an unidentified species of shark) in May 2018 (Fitzpatrick et al. 2019).

Stomach content and stable isotope analysis of juvenile giant shovelnose rays, *Glaucostegus typus*, found along the eastern margin of Exmouth Gulf, consisted mostly of penaeid prawns and brachyuran crabs, and had a dependence on high intertidal cyanobacterial mat and seagrass based food webs (Penrose 2011). Rays are also potential vectors of carbon transfer from intertidal to subtidal food webs during feeding migrations.

8.1.2.6.2. Sharks

Grey nurse sharks (*Carcharias taurus*; EPBC Act – Vulnerable) have been recorded around Exmouth Gulf and the Muiron Islands by dive operators, recreational divers and commercial shark fishers (Chidlow et al. 2005). Apex sharks (tiger shark *Galeocerdo cuvier and* sandbar shark *Carcharhinus plumbeus*) have also been captured on BRUVs footage in the southern end of Exmouth Gulf and around North West Cape and Muiron Islands (Lester 2021).

Seven species of reef shark were observed in Exmouth during a study on the changes in shark behaviour following exposure to natural (orca call) and artificial noise (Chapuis et al. 2019). These included the sicklefin lemon (*Negaprion acutidens*), bronze whaler (*Carcharhinus brachyurus*), grey reef (*Carcharhinus amblyrhynchos*), dusky (*Carcharhinus obscurus*), sandbar (*Carcharhinus plumbeus*), scalloped hammerhead (*Sphyrna lewini*), and zebra (*Stegostoma fasciatum*) shark. Species responded differently to the sounds, but overall, reef and coastal sharks were less abundant, had fewer interactions with baited rigs and displayed less 'inquisitive' behaviour when both sounds were played.

Several studies had focused on depredation of fishing catches by sharks across Ningaloo and Exmouth, which has been anecdotally reported to have increased. A review on the depredation of fishes caught by commercial and recreational hook and line fisheries is provided by Mitchell et al. (2018). Mitchell et al. (2019) also investigated the behaviour and species of sharks involved in depredation events in Ningaloo Marine Park, including Muiron Islands, using line-mounted video and cameras aimed at a fishing line with baited hooks and fish. Sharks frequently investigated the bait, and the rate of depredation was 9.1%. Sicklefin lemon, blacktip, grey reef and spottail sharks depredated on lethrinid and epinephelid fish used as bait. Baited remote stereo video systems (BRUVs) were used to determine whether repeated occurrences of boats and fish (as food) at the same location would lead to changes in shark behaviour, such as arrival times and first feeding times (Mitchell et al. 2020). Preliminary results showed that the time it took for sharks to arrive and feed on the bait declined over six days.

A survey of 155 fishing boats from Bundegi boat ramp during 2015-16 revealed that shark depredation occurred for 41.9% of fishing trips. A W.A. wide survey of 906 fishers revealed 52% had experienced at least one encounter with depredation while fishing (Ryan et al. 2019b).

A total of 225 tiger sharks were caught using setline fishing gear from the Abrolhos Islands to the North West Shelf, inclusive of outer Exmouth Gulf region to investigate the factors influencing diet (Simpfendorfer et al. 2001). Eighty-four sharks had food in their stomach, while 26 were empty and 66 regurgitated during capture. The composition of diet included turtles, sea snakes, teleost fishes, dugongs and sea birds, and factors influencing diet included the ability to catch large prey, prey availability, profitability and density of prey.

To examine horizontal and vertical movements of whale sharks, pop-up archival tags were attached to 19 individual whale sharks (*Rhincodon typus)* (EPBC Act - Vulnerable, Migratory) at Ningaloo Reef (Wilson et al. 2006).

Long-term movement patterns of six whale sharks were documented, all of which travelled northeast into the Indian Ocean, using both inshore and offshore habitats with extensive vertical movements. One of the six whale sharks used Exmouth Gulf.

Sawfish are encountered in prawn trawls with most documented as being returned to the water alive (Kangas et al. 2015). In 2014, sawfish were assigned a risk rating of low when considering the impacts of prawn trawling on breeding populations. A Productivity Susceptibility Analysis in 2014 assigned a high risk to green, freshwater and dwarf sawfish (*Pristis* spp.). These species are protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). It is believed that increased awareness, education and improved reporting is responsible for the increase in reported sawfish numbers (Gaughan and Santoro 2020).

During 2018, four encounters of alive and five dead sawfish were reported, while in 2017, three alive and ten dead sawfish were encountered and reported (Gaughan and Santoro 2019). Reporting of interactions with sawfish only commenced in 2010, which limits reliable assessments of changes in abundance and, also limits an assessment on whether grids implemented in 2007 have been effective in reducing sawfish numbers (Kangas et al. 2015).

A pupping site for the critically endangered green sawfish, *Pristis zijsron* (EPBC Act - Vulnerable, Migratory), was identified in the Ashburton Estuary, just north of Exmouth Gulf, in 2011. It is potentially the most important nursery area for this species globally (Morgan et al. 2015). The population structure, genetic diversity and evolutionary history of *P. zijsron*, as well as *P. microdon* and *P. clavata*, were investigated by Phillips (2012), which revealed complex life histories that differed for each species.

Juvenile zebra shark, Exmouth Gulf (Photo: Kate Sprogis).

8.1.2.7. Marine Reptiles

8.1.2.7.1. Turtles

Marine turtles use the beaches of islands and coastlines across the North West Shelf for nesting, including immediately outside and around Exmouth Gulf (Fossette et al. 2021; Rob et al. 2019). Aerial surveys designed for humpback and dugongs typically collect observations on marine turtles throughout Exmouth Gulf. Turtles have been observed in Exmouth Gulf year round (Jenner and Jenner 2005), and were most often found in shallow waters (<100m) and across a wide range of water temperatures (25-33°C) (Sleeman et al. 2007). Recent aerial surveys during August - November 2018 sighted 1472 turtles in Exmouth Gulf, which were mainly distributed along the southern and eastern margins of Exmouth Gulf (Irvine and Salgado Kent 2019). These latest survey results concur with previous surveys documenting a similar distribution (Hodgson 2007; Preen et al. 1997; Preen et al. 1995).

Satellite tagging of 35 flatback turtles, *Natator depressus* (EPBC Act – Vulnerable, Migratory, Marine), revealed small inter-nesting ranges and wide migratory corridors to near and far foraging grounds (18-1326km), including extensive use of Exmouth Gulf (Thums et al. 2018). The highest overlap of turtle range with industrial activities occurred during the turtle inter-nesting period (time between egg laying) (94%), while there was 26% overlap during migration and 3% overlap when turtles were foraging. Suitable inter-nesting habitat was modelled to be close to rookeries, which had a high overlap with resource sector hazards (Whittock et al. 2016). Satellite tagging of 96 green turtles, *Chelonia mydas* (EPBC Act – Vulnerable, Migratory, Marine), revealed that 86% migrated to foraging grounds distinct from their rookeries, with foraging distribution including most of the inshore waters of northwestern Australia, including Exmouth Gulf (Ferreira et al. 2020). Satellite tracking of flatback turtles (n = 6) from Ashburton Island in December 2009 revealed interesting habitat between Baresand Point, Bessieres Island, Airlie Island and Coolgra Point, and that though turtles moved regularly through the Wheatstone Project footprint off Onslow, they spent relatively little time there (RPS 2010b). Satellite tagging of 12 loggerhead, *Caretta caretta* (EPBC Act – Endangered, Migratory, Marine), and 13 green turtles from Ningaloo, including six and five, respectively from Muiron Islands, revealed the use of Exmouth Gulf as a foraging and inter-nesting habitat (Tucker et al. 2020). For those turtles that entered Exmouth Gulf, most time was spent along the shallow, eastern side of Exmouth Gulf and around Exmouth Gulf islands.

Early field studies documented the activities of green turtles during the nesting season (~ November -January) at Muiron Islands and around the North West Cape as part of the Western Australian Marine Turtle Project (Prince 1998; Prince 1999). An examination of nesting beaches along the Ningaloo Coast, including the Muiron Islands and Sunday Island, using aerial photogrammetry and on-ground surveys found four species (green, loggerhead, hawksbill and flatback) nesting on Muiron Islands (Rob et al. 2019). South Muiron Island was particularly important for green and loggerhead turtle nesting. Further still, the Ningaloo coast region was identified as an important nesting area for Hawksbill turtles, *Eretmochelys imbricata* (EPBC Act – Vulnerable, Migratory, Marine).

Photogrammetry was also used to identify turtle nesting activity off the Pilbara region, which included some of the islands and coastal areas at the northern end of Exmouth Gulf (Fossette et al. 2021). Y Island, Locker Island and Urala Beach showed evidence of fresh turtle nesting activity at the time of the surveys, defined by the presence of track, nest or body pits on the beach or in sand dunes. Previously in January - February 2009, beaches were visited and visually surveyed across a similar area for turtle nesting activity across 15 days. Bessieres, Serrurier and Locker Islands had high levels of marine turtle activity, and green turtles were the dominant species at Serrurier and Besseieres Islands. Very little activity was reported along the mainland beach between Locker Point

Green turtles, Exmouth Gulf (Photo: Kate Sprogis)

and Urala (Pendoley Environmental Pty Ltd 2009). Surveys in July - August 2009 found high turtle densities at Flat and Locker islands (>50 individuals/km^2) and low to medium densities at Serrurier Island (RPS 2010c). Green turtles comprised most of the foraging turtles, which seemed to favour reef areas around the islands.

Analyses of mitochondrial DNA across 27 green turtle rookeries throughout Australian waters was used to determine population connectivity (Dethmers et al. 2006). Seventeen genetically distinct breeding stocks were identified, consisting of individual or groups of rookeries. Stocks are separated by more than 500km, one of which being the North West Shelf, from North West Cape to Lacepede Islands.

Some of the documented impacts on marine turtles in Australian waters include light pollution, rising air temperatures, disease and entanglements. Less attention has been focused specifically on impacts within Exmouth Gulf and surrounding islands. Prince at al. (2012) reported unusual numbers of sick and dying turtles on a number of occasions between 1990-98, though no obvious cause was identified.

An investigation into the cause of death of floating dead or dying green turtles in Exmouth Gulf in 1997 found that infections from gram-negative bacteria was responsible (Raidal et al. 1998).

Since the implementation of exclusion devices in prawn trawl fisheries in Exmouth Gulf in 2002/2003, an estimated drop of 95% of bycatch of large animals, including turtles, sharks and rays, was observed (Kangas and Thomson 2004). Risks to turtles from prawn trawling are therefore, generally considered low (Kangas et al. 2015). However, loggerheads may be susceptible to reflex asphyxiation if they are submerged for long periods, such as if entangled in a trawl net, so may be at a higher risk compared to other turtle species. The Exmouth Gulf Prawn Managed Fishery has been assessed under the Marine Stewardship Council for sustainability (Kangas et al. 2015), and yearly status reports document the number of marine turtle interactions and bycatch (e.g. Gaughan and Santoro 2019; Gaughan and Santoro 2020). During 2018, logbooks documented interactions with 20 live marine turtles. During 2017, 35 interactions with alive turtles were reported.

Commercial fishing of marine turtles dates back to European settlers, and Exmouth Gulf was a fishing ground for turtles up until the industry closed in 1973 (Halkyard 2009). Historical records show upwards of 55,000 green turtles, and 15,000-32,000 hawksbill turtles were harvested in Western Australia.

Seismic surveys on and around the Muiron Islands in the early 1990s reported no known mortality to marine turtles (Bauer and Kelsall 1991), though there is uncertainty as to whether surveys occurred during peak season for turtles. Experiments with captured green and loggerhead turtles and a single air gun off Exmouth showed turtles to display a general 'alarm' response at an estimated 2km range from an operating seismic vessel, and their behavioural response indicated avoidance at an estimated 1km from the source (McCauley et al. 1998a).

Three flatback and two green rookeries across the northwest coast of Australia (including a green turtle rookery at Ningaloo) were experimentally manipulated with varying temperature exposures to determine if temperature dependant sex differentiation is consistent across marine turtle species and populations (Bentley et al. 2020). The results demonstrate that thermal sex differentiation is both species and population specific, which will help to determine how different species will respond to climate change. Stubbs and Mitchell (2018) found the pivotal temperature that produced an equal sex ratio of green turtles from Ningaloo was 29.2°C, with mixed sexes produced between 27.9° and 30.4°C, and that these temperatures were different to other green turtle populations. Standard Dynamic Energy Budget modelling was developed for the full life cycle of green turtles (Stubbs et al. 2019), and simulated marine heatwave scenarios predicted increasing time between green sea turtle (*Chelonia mydas*) nesting years in scenarios of decreasing food availability (Stubbs et al. 2020). Increased frequency of marine heatwaves (every five years compared to every 20 years) reduced the number of eggs a female produced in her lifetime by ~20%.

An assessment of light pollution across Australia identified the North West Shelf of Australia (including Cape Range) as one of two sites facing the highest potential risk from light pollution (Kamrowski et al. 2012). Altered light horizons are associated with oil and gas facilities on islands outside of Exmouth Gulf (Limpus 2007).

Between 1990-1998, 998 turtles encountered as bycatch during commercial net and trap fishing in the shallow waters of Sandalwood Point, were tagged and released in order to better understand population structure, species composition, growth, development and biology (Prince et al. 2012). Most of the turtles tagged were green turtles (882), followed by loggerheads (92) and hawksbill (24) turtles.

8.1.2.7.2. Sea Snakes

Much of the research on sea snakes from Exmouth Gulf encompasses the broader tropical waters of northern Australia and is concerned with taxonomy and geographic ranges. The species of sea snake documented in Exmouth Gulf to date include *Aipysurus apraefrontalis* (EPBC Act - Critically Endangered, Marine), *A. duboisii, A. foliosquama* (EPBC Act – Critically Endangered, Marine), *A. laevis, A. mosaicus, Emydocephalus annulatus, Hydrophis elegans, H. major, H. ocellatus, H. peronii* and *H. stokesii* (Kangas et al. 2015; Nitschke et al. 2018). Most recently is the description of a sixth genetically distinct sea snake endemic to Western Australia, *Emydocephalus orarius,* which is known from soft-bottomed trawl grounds, including Exmouth Gulf (Nankivell et al. 2020). Specimens of *Aipysurus* collected from Exmouth Gulf, and more widely across Australia and Southeast Asia, helped to differentiate the genetically distinct species of *A. mosaicus*, which was previously identified across Australia as *Aipysurus eydouxii* (Sanders et al. 2012).

The waters of the northwest coast of W.A. are considered a high priority area for conservation of sea snakes given some species collected here have high genetic divergence from other regions across the north coast of Australia (Lukoschek 2017). Genetics from 11 different sea snake species in Exmouth Gulf were used in combination with northern Australian samples to reveal that species from the *Aipysurus-Emydocephalus* clade showed clearer geographic patterns and intraspecific variation than *Hydrophis* species (Nitschke et al. 2018). One species listed as critically endangered after disappearing from Ashmore Reef and surrounds between 1998-2002, *Aipysurus apraefrontalis*, has been identified in Exmouth Gulf, and evidence suggests a discrete population is occurring in the region rather than just vagrant specimens (Sanders et al. 2015; D'Anastasi et al. 2016).

A compilation of records from a variety of methods were used to address data deficiencies in the distribution of the sea snakes *A. apraefrontalis, A. foliosquama, A. fuscus, A. tenuis* and *A. l. pooleorum* across northwest Australia and identify potentially important habitat using predictive models (Udyawer et al. 2020). Exmouth Gulf and reefs around Ashmore were identified as having the most ideal habitat for the *A. apraefrontalis* (Udyawer et al. 2020). Aerial survey data from Exmouth Gulf collected in June 2007 documented the occurrence of sea snakes, though specific species were not identified given surveys were targeting larger megafauna such as dugongs (Hodgson 2007). Aerial survey in Exmouth Gulf during August - November 2018 sighted 41 sea snakes, which were mainly distributed to the northwest of Exmouth Gulf (Irvine and Salgado Kent 2019).

A localised study around Heron Point and Bay of Rest documented numerous sightings of sea snakes in shallow waters close to subtidal reef adjacent to Wapet Creek, including a deceased *Hydrophis czeblukovi* (Fitzpatrick et al. 2019).

The water of the northwest coast of W.A. are considered a high priority area for conservation of sea snakes. (Photo: Rebecca Bateman-John).

Sea snakes can be caught as bycatch when trawling for prawns in Exmouth Gulf, and implementation of bycatch reduction devices is one management strategy in place to help reduce the impact on sea snakes (DoF 2014). During 2018, records of bycatch from the Exmouth Gulf Prawn Managed Fishery included 1167 alive and 81 dead sea snakes. It is believed improved reporting practices are responsible for the increased number of sea snakes recorded as bycatch (Gaughan and Santoro 2019), and that those sea snakes found alive are typically returned alive (Kangas et al 2015). A 2008 risk rating exercise of the impact of prawn trawls on breeding populations of sea snake populations was considered negligible. A 2014 Productivity Susceptibility Analysis assigned a medium risk to sea snakes in general and a low risk to the short-nosed sea snake, *A. apraefrontalis*.

8.1.2.7.3. Crocodiles

The saltwater crocodile, *Crocodylus porosus* (EPBC Act - Migratory, Marine), has been anecdotally recorded in Exmouth Gulf on the rare occasion, but populations have not been established (Halford and Barrow 2017).

8.1.2.8. Marine Mammals

Exmouth Gulf is included in the Ningaloo Reef to Montebello Islands Important Marine Mammal Area, assigned by the IUCN Marine Mammal Protected Areas Task Force (IUCN-MMPATF 2021). The qualifying species include the dugong (*Dugong dugon*), Australian humpback dolphin (*Sousa chinensis*) and humpback whale (*Megaptera novaeangliae*), with the qualifying criteria of 'species or population vulnerability', 'small and resident populations', 'reproductive areas' and 'feeding areas' being met.

8.1.2.8.1. Whales

Exmouth Gulf has long been a recognised resting and nursery area for humpback whales, *M. novaeangliae* (EPBC Act - Vulnerable, Migratory, Cetacean) (Chittleborough 1953; Jenner et al. 2001). The more recent observations of young calves south of North West Cape provides evidence for an extended calving ground 1000km southwest than previously thought, and Exmouth Gulf may potentially be serving as a resting and nursery area for both young northbound calves and older southbound calves (Irvine et al. 2018).

Humpback whales and calf, Exmouth Gulf (Photo: Above Photography/DBCA).

A total of 2772 humpback whales were sighted during aerial surveys in August - November 2018, and calves were sighted on all surveys (Irvine and Salgado Kent 2019). The highest number of calves were sighted from mid-September to mid-October. The majority of whales were resting or milling at the surface. These latest survey results concur with previous surveys conducted during 2004-2005 by Jenner and Jenner (2005).

Animal-borne DTAGs (digital tags) were used to help quantify the behaviour of humpback whale mother/calf pairs in Exmouth Gulf (Bejder et al. 2019). Exmouth Gulf is currently considered a low noise environment (as determined by noise loggers), and a significant proportion of lactating mothers spent time conserving energy by resting close to the surface. These findings indicated that shipping would disturb resting whales and increase their energy expenditure, while also increasing the likelihood of direct ship strike. Shipping would also result in increased noise pollution, which could impact the communication between mothers and calves, and any impacts to the nursery area could potentially compromise calf survivorship and energy reserves for the southern migration (Braithwaite et al. 2015; Bejder et al. 2019). Vocalisation between mothers and calves were low-level during suckling dives, which is suggested to reduce the risk of exposure to predators and male humpback whales (Videsen et al. 2017).

Body condition of humpback whales was assessed using unmanned aerial vehicles (UAVs) in Exmouth Gulf to better understand energetic costs associated with reproduction (Christiansen et al. 2016a). Body condition linearly declined for mature adults and lactating female whales over the duration of the breeding season, while no significant change in body condition for immature whales and calves was observed. A positive linear relationship between female body condition and calf body condition also suggested that females in poorer body condition may invest less energy in offspring compared to females in better body condition. UAV was found to be an effective method for such assessments of humpback whales, and the noise emitted by drones transmitted poorly into the water column, having negligible impact on marine mammals (Christiansen et al. 2016b).

The estimated carrying capacity of the space available in Exmouth Gulf for nursing humpback whales, based on the population growth rate of 10% per year, was between 1187 and 1482 individual whales at any one time (Braithwaite et al. 2012). This is a significant consideration when determining space use of Exmouth Gulf from competing anthropogenic and industrial activities.

Behavioural responses of humpback whales to swim-with-whale activities and vessel noise has also been recently assessed in the Ningaloo Marine Park and Exmouth, respectively. The most common approach by swim-with vessels to humpback whales was in the whale's path of travel, which caused the whales to exhibit vertical and horizontal avoidance behaviours (Sprogis et al. 2017; Sprogis et al. 2020a). The frequency of agonistic behaviours also increased when vessels were <100m away compared to >100m away. These behavioural responses led the authors to provide several recommendations for managing swim-with-whale activities, including avoiding in-path approaches and not putting swimmers in the water with mothers and calves and whales that exhibit agonistic behaviour. Controlled exposure experiments involving vessel noise and resting mother-calf pairs concluded that vessel noise can cause behavioural disturbance, including decreased resting activity, increased respiration rate and increased swim speed, which has implications for whale watching vessels (Sprogis et al. 2020b).

First observations have been made of silver gulls attacking humpback whales, primarily resting mothers and calves, in Exmouth Gulf (Harkness and Sprogis 2020). Gulls make repeated attacks to pre-existing wounds, and whales almost always immediately responded by submerging and performing avoidance behaviours.

Australian humpback dolphin and mangroves, Exmouth Gulf (Photo: DBCA).

Australian humpback dolphin, Exmouth Gulf (Photo: Kate Sprogis)

Resting bottlenose dolphin group with Charles Knife Gorge in the background (Photo: Kate Sprogis)

A seismic survey experiment off Exmouth showed humpback whales to consistently avoid an approaching seismic vessel at a distance of >4km, and where cows and calves were resting, the animals appeared to be more sensitive and avoided the source of activity at an estimated 7-12km (McCauley et al. 1998a; McCauley et al. 1998b). Some individual whales showed some attraction to the single operating air gun, which were likely to be males and likely due to similarities in noise from a breaching event.

Other whale species have been sighted in Exmouth Gulf, including killer whales (*Orcinus orca*; EPBC Act - Cetacean, Migratory), fin whales (*Balaenoptera physalus*; EPBC Act - Vulnerable, Cetacean, Migratory), blue whales (*Balaenoptera musculus*; EPBC Act - Endangered, Cetacean, Migratory) and minke whales (*Balaenoptera*) (e.g., Chittleborough 1953). A stranded Omura's whale (*Balaenoptera omurai*) occurred near the Exmouth Navy Pier in 2015, and given the good condition of the deceased whale, which was likely alive at the time of stranding, it provides a possible range extension in W.A. waters for this relatively rare species typically found across the Indo-Pacific (Ottewell et al. 2016).

8.1.2.8.2. Dolphins

Aerial survey during August - November 2018 sighted 556 dolphins from 179 pods, including 10 calves, and dolphins had a broad distribution across Exmouth Gulf (Irvine and Salgado Kent 2019). These latest survey results concur with previous surveys conducted by Jenner and Jenner (2005) and Preen et al. (1995; 1997). The Indo-Pacific bottlenose dolphin (*Tursiops aduncus*; EPBC Act - Cetacean) and Australian humpback dolphin (*Sousa chinensis*; EPBC Act - Cetacean, Migratory, W.A. - P4) were observed during the 2018 surveys by Irvine (2019), though the total number of dolphin species is difficult to discern from the altitude surveyed (1000ft).

Boat-based surveys of nearshore areas a long the northwest coast of W.A. in 2010 recorded sightings of the Australian humpback dolphin and Indo-Pacific bottlenose dolphin around North West Cape, including the western margin of Exmouth Gulf (Bejder et al. 2012). One recording of a snubfin dolphin, *Orcaella heinsohni* (EPBC Act - Cetacean, Migratory; W.A. - P4), in the southern region of Exmouth Gulf was noted as an additional observation. Additional focus on the Australian humpback dolphin found that lack of a plateau in the cumulative discovery curve of new individuals provides evidence that further work is needed to quantify the total population of Exmouth Gulf (Brown et al. 2012).

Hanf (2015) examined the distribution of coastal dolphins across the western Pilbara region, including Exmouth Gulf, and found that *T. aduncus* was primarily associated with the 20m contour and the Muiron Islands, whereas *S. sahulensis* (now *chinensis*) was associated with intertidal and shallow coastal waters, as well as offshore islands. A relatively dense population of 141 resident and a super population of 370 individual Indo-pacific bottlenose dolphins were estimated to occur in the waters around the North West Cape, suggesting this region is of high importance to this species (Haughey et al. 2020).

To better understand behavioural and evolutionary adaption of echolocation in delphinid species, biosonar clicks were characterised for Indo-Pacific bottlenose dolphin and Australian humpback dolphin in Exmouth Gulf (de Freitas et al. 2015). The source level, frequency and interclick intervals were similar for both species and for similar sized delphinids elsewhere.

Australian humpback dolphins occur in the coastal waters of Exmouth Gulf and form a fission-fusion society (size and composition of the social group changes across time) (Hunt et al. 2017; Hunt 2018; Hunt et al. 2019). Habitat preferences may be explaining the different association patterns observed east and west of the cape, and humpback dolphin occurrence was most strongly predicted to occur in 5-15m depth and <2km from the coast (Hunt et al. 2019; Hunt et al. 2020). The areas with the highest probability of dolphin occurrence overlapped with multiple use areas, and the authors state that shallow, coastal waters should be considered priority areas for the conservation of this Vulnerable listed species.

Sleeman et al. (2007) correlated the relative biomass of fish/cephalopod feeders (dolphins and sharks) with environmental factors, and while a weak correlation was found with changes in sea surface temperature, environmental factors can only describe a small proportion of variation seen in dolphin and other marine megafauna abundances.

8.1.2.8.3. Dugongs

Exmouth Gulf has long been known to have favourable habitat for dugongs (*Dugong dugon*; EPBC Act – Migratory, Marine) (Prince 2001; Prince et al. 1981; Prince et al. 2000), and dugongs can be sighted in Exmouth Gulf and around the North West Cape in shallow waters across most of the year (<100m) (Jenner and Jenner 2005; Sleeman et al. 2007; RPS 2010a).

Aerial survey during August - November 2018 sighted 605 dugongs, including 75 calves, and dugongs were mainly distributed in shallow waters along the eastern and southern margins of Exmouth Gulf (Irvine and Salgado Kent 2019). The distribution of dugongs in Exmouth Gulf from these most recent surveys concur with previous surveys conducted by Jenner and Jenner (2005), Preen et al. (1995; 1997), Hodgson (2007) and Hodgson et al. (2008). Dugongs were reported to be more frequently occurring in Exmouth Gulf (in August) compared with the nearby Wheatstone Project area off Onslow (RPS 2010a).

Unoccupied aerial vehicles (i.e. drones) have been recently assessed for the effectiveness in surveying dugongs, and surveys were carried on the eastern margin of Exmouth Gulf in May and November of 2018 and June of 2019 (Cleguer et al. 2021). A total of 50,482 images from 240 flight surveys were manually viewed, and estimates of dugong abundance ranged from 103 in May 2018 to 47 in June 2019. Overall, the method was found to be feasible, relatively easy to implement, and achieves a good surface coverage, which would have applications beyond dugongs.

Gales et al. (2004) presents population estimates of dugongs at Shark Bay, Ningaloo Reef and Exmouth Gulf before and after Tropical Cyclone Vance. It suggests that a decline in dugong numbers in Exmouth Gulf following the cyclone, and an increase in dugong numbers in Shark Bay over this time period, is strong evidence for population connectivity between these locations, and that such cyclone events and associated seagrass loss can drive a migration of dugongs out of Exmouth Gulf and into Shark Bay.

Dugong mother and calf over sparse seagrass meadows (which they heavily rely on) on the southeast side of Exmouth Gulf (Photo: Christophe Cleguer)

Elemental analysis of a 55 year old dugong tusk from a female in Exmouth Gulf revealed long-term trends and year to year variations in most elements examined (barium, calcium, iron, lithium, magnesium, sodium, phosphorus, strontium and zinc) (Edmonds et al. 1997).

Sodium and zinc correlated with age, but the latter was also correlated with Fremantle sea level, which is a measure of the Southern Oscillation Index.

Dugong off Two Rocks close to shore near Exmouth Industrial Estate (Photo: Kate Sprogis).

8.1.2.9. Seabirds and Shorebirds

8.1.2.9.1. Exmouth Gulf and Islands

Exmouth Gulf and the wider North West Marine Region is utilised by many seabirds including terns, noddies, petrels, shearwaters, tropicbirds, frigatebirds and boobies (DSEWPC 2012). Many of these species migrate over long distances (some >20,000km annually) and spend most of their lives over the open ocean (pelagic). They rely on coastal sites and islands to breed, rest and feed.

Exmouth Gulf Mangroves is designated as an Important Bird Area (IBA) and also qualifies as a Key Biodiversity Area (KBA) based on the IBA (Dutson et al. 2009; Key Biodiversity Areas Partnership 2020). IBAs/KBAs are amongst Earth's most exceptional places for birds and are priority sites for bird conservation. The Exmouth Gulf Mangrove KBA extends 70km from Giralia Bay to Tubridgi Point. The three bird species triggering the KBA criteria include the dusky gerygone (*Gerygone tenebrosa*), pied oystercatcher (*Haematopus longirostris*) and grey-tailed tattler (*Tringa brevipes*) (Key Biodiversity Areas Partnership 2020). The severity of threats to the Exmouth Gulf Mangrove KBA is considered as 'slow but significant deterioration', and while it is recognised further surveys are needed to investigate the real importance of Exmouth Gulf for shorebirds, the Partnership specifically states "*Development proposals must not impact the rainwater inflow to the mangroves*".

Further to the Exmouth Gulf Mangrove KBA, the entire Exmouth Gulf coastline, islands (in particular Sunday Island and Muiron Islands), and the coastline from North West Cape to Point Billie are identified as an internationally important shorebird area (Weller *et al*. 2020). Exmouth Gulf and islands meet the 'species criteria' for International Significance (supporting >1% of the flyway population) for grey-tailed tattler, eastern curlew (*Numenius madagascariensis*) and ruddy turnstone (Onton et al. 2013; Weller et al. 2020). A further 10 species meet the 'species criteria', for National Significance (supporting >0.1% of the flyway population). In addition, Exmouth Gulf also meets the National Significance criteria for 'species abundance' by having a recent 2020 maximum count reaching 11,864 individuals (>2,000 individuals threshold), and 'species diversity' by having a maximum count of 18 species in the area (>15 species threshold). The bar-tailed godwit (*Limosa lapponica menzbieri*), eastern curlew and great knot (*Calidris tenuirostris*) are listed as Critically Endangered (EPBC Act). The lesser sand plover (*Charadrius mongolus*) is listed as Endangered. The greater sand plover (*Charadrius leschenaultia*) is listed as Vulnerable. The ruddy turnstone (*Arenaria interpres*), sanderling (*Calidris alba*), red-necked stint (*Calidris ruficollis*), whimbrel (*Numenius phaeopus*), common greenshank (*Tringa nebularia*) and terek sandpiper (*Xenus cinereus*) are listed as Migratory (see Table 16 in Section 8.2.3.3). Five species are included on the IUCN Red List of Threatened Species: beach stone curlew (Near Threatened), eastern curlew (Vulnerable), great knot (Vulnerable), black-necked stork (Near Threatened) and fairy tern (*Sternula nereis*; Vulnerable) (IUCN 2013).

The wedge-tailed shearwater (*Ardenna pacifica*) is listed under the Japan–Australia Migratory Bird Agreement (JAMBA) and the EPBC Act (Migratory, Marine) (DSEWPC 2012). Australia hosts a large proportion of the global population of wedge-tailed shearwaters, with previous estimates reaching 1.1 million breeding pairs in W.A. (Burbidge et al., 1996). Breeding locations of the wedge-tailed shearwater in the North West Marine Region include Airlie, Bessieres, Serrurier, North and South Muiron and Locker Islands (DSEWPC 2012). Baitfish are an important food source for seabirds including wedge-tailed shearwaters (DBCA 2019a). Cannell et al. (2019) describes wedge-tailed shearwater foraging behaviour around the Muiron Islands. Tagged shearwaters (n=30) travelled to and from the colony for distances ranging from 9-1,854km.

Johnstone (1990) conducted extensive bird surveys of the mangroves of W.A. (n=83 locations) including sites around Exmouth Gulf and the Cape Range peninsula: Gales Bay, Giralia Bay, Bay of Rest, near Learmonth, Mangrove Bay, Low Point and Yardie Creek. Species are described in detail including red colour morphs of mangrove herons (*Butorides striatus*) observed between Devil Creek to Giralia Bay.

A later study of Bay of Rest and surrounds in May 2018 sighted 24 species along the shoreline, including a large resting flock of great knots (50+), grey-tailed tattlers, red-necked stints and the beach stone curlews (Fitzpatrick et al. 2019).

In their December 2013 newsletter, the W.A. Branch of Birdlife Australia reported the results of their extensive aerial and ground bird survey of Exmouth Gulf conducted October/November 2012 (Onton et al. 2013). The survey identified a total of 20,235 individual shorebirds, seabirds and marine birds of prey representing 57 species. A total of 32 species listed as migratory under the EPBC Act were recorded including the fairy tern, listed as Vulnerable.

8.1.2.9.2. Cape Range

Around 30 bird species listed under (JAMBA), China–Australia Migratory Bird Agreement (CAMBA) and/or Republic of Korea- Australia Migratory Bird Agreement (ROKAMBA) have been recorded in the Cape Range National Park (DEC 2010). The osprey (*Pandion haliaetus*; EPBC Act - Migratory, Marine) and lesser sand plover (*Charadrius mongolus*; EPBC Act - Endangered, Migratory, Marine) have also been sighted in the Cape Range National Park (DEC 2010).

8.1.2.9.3. Ningaloo Coast

Within the Ningaloo Coastal Reserves (Red Bluff to Winderabandi), 31 taxa of shorebirds and waders have been recorded, including 21 migratory species protected under the EPBC Act and *W.A. Biodiversity Conservation Act 2016* (DBCA 2019a). New significant sites for seabirds are still being found along the Ningaloo coast. Habitats including the shallow sandy intertidal beaches and rocky shorelines of the Ningaloo coast are important for seabirds and waders to breed, rest and feed. Significant seabird rookeries include Cape Farquhar, Pelican Point, Point Maud and Winderabandi Point. The tidal samphire flats, part of a proposed addition to Jurabi Coastal Park, have previously been noted as significant to migratory birds and waders (Shire of Exmouth et al. 1999).

In the 1970s, bird surveys of the Ningaloo Coast (including North West Cape) determined that eight species of seabird were breeding in the reserves: the caspian tern (*Sterna caspia*; EPBC Act - Migratory, Marine), crested tern (*S. bergii*; EPBC Act - Migratory, Marine), roseate tern (*S. dougallii*; EPBC Act - Migratory, Marine), fairy tern, beach stone curlew (*Esacus neglectus*; EPBC Act - Marine), pied cormorant (*Phalacrocorax varius*), osprey and white-bellied sea eagle (*Haliaeetus leucogaster*; EPBC Act - Marine) (Johnstone 1980). More recently, the 2012 Birdlife survey confirmed the importance of the Ningaloo Coast and Muiron and Sunday Islands as roosting and breeding sites (Onton et al. 2013). Pied oystercatchers, crested terns, Caspian terns, pied cormorants and ospreys were observed nesting.

The Nyinggulu (Ningaloo) Coastal Reserves Draft Management Plan 2019 lists vehicles, foxes, cats and goats as the main threats to shorebirds, waders and seabirds in the area (DBCA 2019a). The Pilbara Inshore Islands Draft Management Plan 2020 identifies the potential impact of mainland-based processing facilities with gas flaring (e.g., Wheatstone) on night migrating birds like wedge-tailed shearwaters (*Ardenna pacifica*) which are reported to fly towards the flare. Developments in the intertidal zone (e.g., managed fisheries) may damage shorebird habitat and food sources.

8.1.2.9.4. Pilbara Region

A compilation of historical bird data for the Pilbara region, including Exmouth Gulf, describes the geographic range, status and breeding season of 325 bird species known to occur in the Pilbara region since 1699 (Johnstone et al. 2013).

The Pilbara inshore islands encompass internationally significant sites for grey-tailed tattler (*Tringa brevipes*) and pied oyster catchers (*Haematopus longirostris*) (DBCA 2020a). Eastern curlew (*Numenius madagascariensis*), listed as Critically Endangered in W.A., are found in low numbers all year round on the Pilbara inshore island and require species protection. Beach stone-curlews (*Esacus magnirostris*) are resident on most islands but are easily disturbed by human activity and are declining on the mainland.

Wilson's storm petrels, Exmouth Gulf (Photo: Kate Sprogis).

8.1.3. Marine Environmental Quality

8.1.3.1. Water Quality

8.1.3.1.1. Sedimentation and Turbidity

In 2018, stakeholders expressed concerns about the effect of Subsea 7's Learmonth Pipeline Fabrication Facility on water quality (MBS Environmental 2018b). Modelled Total Suspended Sediment (TSS) loads of 2 mg/L to 30 mg/L were predicted and associated with chain tows. The turbidity logger data showed turbidity levels of 1 NTU (nephelometric turbidity units) prior to the towing of chains. Levels of up to 10 NTU at 1 m off the seabed, were recorded a few minutes after the chain was towed between the logger sites.

In 2019, modelling of possible sediment dispersion from Subsea 7's Learmonth Pipeline Fabrication Facility and model limitations were reported (RPS 2019). Modelling showed that peak TSS concentrations would be encountered when sediment is actively being disturbed. The greatest suspended and deposited concentrations will be seen in shallower waters, where more chain links contact the seabed and the flux rate is higher than in deeper water. Clay and fine silt sediments comprised most of the measured suspended sediments, whereas coarse sand comprised over a third of the seabed sediment composition.

8.1.3.1.2. Water Temperature

In the summer of 2010/2011, record high ocean temperatures were logged over a wide area from Ningaloo (22°S) to Cape Leeuwin (34°S) to >200km offshore (Pearce and Feng, 2013). Peak nearshore temperatures rose to ~ 5 °C above average at some locations, and for Exmouth, the peak temperature reached 31.2°C on the 24 January 2011. The effects of the 2010/2011 marine heatwave two years on found sea surface temperatures (SST) were at least 2°C higher than normal over the preceding three summers in Exmouth Gulf, Shark Bay, and Abrolhos Islands (Caputi et al. 2014b). In early 2013, sea surface temperature anomalies in Exmouth Gulf matched or exceeded those of early 2011 (~3°C above normal). Under future climate change scenarios, ocean temperatures are predicted to increase up to 3°C above the current levels (Pearce et al. 2011). It is almost certain that marine heatwaves will continue to occur.

8.1.3.1.3. Pollution

King (2019) investigated the concentration of micro and macro plastics in surface waters of the Ningaloo Marine Park and Exmouth Gulf using surface net tows (n = 102), sediment samples (n = 33) and in-water tows (n = 11). Plastics were present in 92.3% of surface water tows and 81.8% of sediment samples.

Shipping and extractive industries increase the risk of oil spills (Latimer 2020). Real-time oil spill trajectory forecasting has previously been undertaken near the Muiron Islands (Hubbert 1993). The 2018 'Marine Oil Pollution Risk Assessment' prepared by Navigatus Consulting for the Department of Transport, rated the important wetlands (Exmouth Gulf East) as overall 'very low' risk but 'very high' overall protection priorities (Navigatus Consulting, 2018). Petroleum facilities and oil tankers were listed as key drivers of shoreline exposure.

8.1.3.1.4. Phytoplankton and Productivity

The Leeuwin Current, Ningaloo Current and ENSO cycles influence the variability in planktonic primary production in and around Exmouth Gulf region. While upwelling along the coast is generally supressed by the Leeuwin Current, the seasonal northward flowing Ningaloo Current allows for episodic upwelling and increased primary production around the outer Exmouth Gulf and North West Cape region, which is greatest during El Niño years (Furnas 2007; Hanson and McKinnon 2009).

The drivers of spatial and temporal variability in phytoplankton concentrations were investigated around the Ningaloo, Muiron Islands, Exmouth Gulf, and Pilbara regions (Rousseaux et al. 2012). A pattern during austral autumn emerged whereby mixed layer depths deepened and nutrients and surface chlorophyll increased. The strengthening of the Leeuwin Current during autumn helps to drive a deepening of the mixed layer to ~100m, which leads to an increase in nutrient concentrations.

8.1.3.1.5. Introduced Species and Outbreaks

Water and sediment in the ballast tanks of ships can act as an intercontinental vector for the spread of introduced species, and is a risk for Exmouth Gulf (Williams et al. 1988; Biofouling Solutions 2018; Latimer 2020). To date, the invasive colonial ascidian, *Didemnum perlucidum,* the barnacle Megabalanus tintinnabulum, cnidarian *Antennella secundaria* and the infectious intracellular ciliate pathogen, which caused oyster oedema disease and severe mortality, have been recorded in Exmouth Gulf (Huisman et al. 2008; Biofouling Solution 2018). It should be noted that Exmouth Gulf has not been thoroughly surveyed for introduced species, but it also has fewer artificial structures compared to more developed locations, which are renowned for facilitating incursions of introduced species (Biofouling Solutions 2018). White spot disease has impacted commercial prawn farming in Queensland and poses a very high risk to prawns in Exmouth Gulf if introduced.

The closest port to Exmouth Gulf, Dampier Port, was assessed as having a moderate to high inoculation risk of introduced species based on a risk assessment of available data in 2011 (Bridgwood and McDonald 2014). Some controls specific to reducing the risk of introduced species into Exmouth Gulf includes the use of the Commonwealth Department of Agriculture and Water Resources Quick Domestic Ballast Water (DBW) Risk Assessment Tool and the W.A. DPIRD online 'Vessel Check' Biofouling Risk Assessment Tool. DPIRD also recommends that accurate vessel information be recorded, particularly last port of call data (Bridgwood and McDonald 2014).

Surveys conducted at Bill's Bay (2.5 x 5km) and across ~200km of the Ningaloo coast found 2.3% of coral colonies showed signs of disease (Onton et al. 2011). Seven diseases were identified, 'skeletal eroding band' being the most common (affecting ~1% of colonies).

Increases (often rapid) in the abundance of coral predators above threshold densities are termed 'outbreaks' (Bessey et al., 2018). At Ningaloo Reef in the 1990s, an outbreak of predatory sea snails (*Drupella*) on a scale not seen in the Indo-Pacific, reduced live coral cover by >75% in the back-reef areas (Turner 1994). The driver(s) of the outbreak were unknown but hypotheses included increased runoff, overfishing, increased reef damage or variable larval recruitment. Modelling of *D. cornus* outbreak densities have suggested that the outbreak density at the average level of coral cover for back reef sites at Mandu Reef (17.6 ± 13.7%) is ~0.95 individuals/m^2 reef area (Bessey et al. 2018).

8.1.3.2. Sediment Quality

Sediment quality is an important indicator of factors such as environmental pollution (DEC 2006), terrestrial-marine connectivity (Adame et al. 2012) and climate change resilience (Burgers, 2020). There is an ever-expanding toolkit used to measure sediment quality including geostationary satellite sensors through to monitoring TSS (Dorji and Fearns 2018).

The sediment of Exmouth Gulf is an ecosystem that is home to a variety of organisms. For example, Haig (1997) provides a comprehensive record of the 242 foraminifera species in the Holocene sediment of Exmouth Gulf. The foraminifera of the Exmouth Gulf are mainly benthic species but live individuals are rarely found (Orpin et al. 1999).

Orpin et al. (1999) mapped the sediment distribution patterns in Exmouth Gulf (water depths >5m). Sediment samples contained mud, quartzose fine sand and coarse carbonate sand fractions. The muddiest facies were located in mangrove channels, tidal flats, southwestern flanks and the deeper axial region. Along the North West Shelf, there is a high turbidity zone from the coastline to 20m isobath (Margvelashvili et al. 2006). Areas of maximum resuspension were found to occur in Exmouth Gulf.

Glomalin, a mycorrhizal protein component of soil, can be used as an indicator of terrigenous carbon (derived from the erosion of rocks on land) (Adame et al. 2012b). At Exmouth Gulf, similar to other mangrove systems, glomalin concentrations were low in sediment collected from the landward edge/terrestrial boundary compared to the seaward fringe. These results reflect the area's low annual rainfall, low river inputs and low groundwater flow resulting in little direct terrestrial-marine connectivity. The glomalin is likely to have been transported during tidal and flood events.

Semeniuk (1993) described the range of shore types along the Pilbara Coast, their inter-relationships and the Quaternary evolution of the system. Coastal geomorphology and microbial decomposition of organic matter differ between mangrove forests along the Pilbara to Carnarvon coast (Alongi et al., 2000). For example, different specific carbon oxidation pathways dominate in different mangrove types. Sediment chemistry in lagoonal sands also varies (Alongi et al. 1996). Rates of decomposition, O^2 consumption and CO_2 release were found to be faster in the very fine sand of Mangrove Bay lagoon due to restricted water circulation, a richer benthic community, and geomorphology.

A 2006 Department of Environment and Conservation (DEC) report estimated background concentrations of contaminants (cobalt, lead, vanadium) in marine sediments collected from 24 coastal sites from Exmouth Gulf to Port Hedland (DEC 2006). Exmouth sites had highest concentrations of cobalt, lead and vanadium and were thought to be related to the region's geology.

8.1.4. Coastal Processes

8.1.4.1. Geophysical Processes

The sandy islands in Exmouth Gulf form part of a sand-island archipelago that extends across the Pilbara to Dampier Archipelago. Being sandy islands, there is temporal and spatial erosion and accretion occurring annual and interannual due to winds, waves and ENSO cycles (Cuttler et al. 2020), and these islands are being investigated to determine their sensitivity and future vulnerability to impacts such as climate change (Bonesso et al. 2020).

Based on an island sensitivity index scale ranging from zero (low sensitivity characteristics) to one (high sensitivity characteristics), Eva Island, Y Island, Brown Island and Observation Island sat between 0.6-0.8. Overall, the area of reef platform around an island was found to be a good predictor of and island's area and volume, and reefs may be providing islands with shoreline protection and carbonate production and supply.

A range of studies have sought to understand the role of tropical cyclones in shaping the geomorphology and sediments of Exmouth Gulf over time. Large washover fans (fan-shaped body of sediment that is transported landward by marine waters) occur in some areas around Exmouth Gulf, such as Point Lefroy, and can be useful for reconstructing the history of regional cyclone activity (Brill et al. 2016; Fitzpatrick et al. 2019). From analysing different sediment depositional units, the washover fans at Point Lefroy recorded distinct phases of increased storm-induced (e.g. cyclones) deposition at ~150, ~400, ~900, ~1200-1500, ~2000 and ~2500 years ago. In order to better understand such features as washover fans, drones were used to create high resolution topographic and inundation models using fans in the southern end of Exmouth Gulf as a case study (Callow et al. 2018). Cyclones are also responsible for significant sediment transport within the water, and modelling determined that cyclones of the North West Shelf account for the majority of suspended sediment movement alongshore and cross shore, including southward transport to areas such as Exmouth Gulf (Dufois et al. 2017; Dufois et al. 2018). Eliot et al. (2011) states that the coastal regions of Exmouth Gulf and North West Cape are increasingly influenced by tropical cyclone activity and larger tidal ranges. Analyses of the geomorphology and stratigraphical architecture of washover fans indicated tropical cyclone-induced periods of succession and deposition leading to formation of the palaeosurfaces (May et al. 2017). The formation of sandy ridges at Giralia Bay is thought to be largely driven by tropical cyclones, which can impact sediment transport, erosion and deposition of these ridges moreso than tidal processes (May et al. 2018).

Topographical surveys of tropical cyclone debris lines from Tropical Cyclone Vance (1999) and Tropical Cyclone Chris (2002) at Exmouth Gulf found that Tropical Cyclone Vance caused greater erosion due to greater surge size (Nott and Hubbert 2005). Steedman (1987) estimated the joint probability of storm, wave and surge, and tidal water levels in Exmouth Gulf.

The promontory north of Wapet Creek and spit ridges of the Bay of Rest represent natural sediment cell boundaries (Teal Solutions Environmental Advisory 2019). Monitoring changes in these features (e.g., aerial, beach surveys, photographs, shoreline mapping) could provide insights into regional changes in coastal conditions.

Coral reef islands are expected to undergo major morphological change under a range of predicted climate change scenarios (Perry et al. 2011). In a changing climate, the resilience of coral reef islands such as the Exmouth Gulf islands relies on the balance between the import and export of sediment. Baseline sediment data collected from Eva and Fly Islands in Exmouth Gulf indicated course sand-sized (500 – 1000μm) and predominantly reef-derived sediment (Burgers 2020).

8.1.4.2. Hydrodynamic Processes

Outside Exmouth Gulf, the Leeuwin Current is the dominant current, transporting warm, low salinity waters southwards (Godfrey and Ridgway 1985; Cresswell et al. 1989). The current is strongest in autumn and winter months and largely supresses upwelling of nutrients along the coast. However, during El Niño years, the Leeuwin Current is generally weaker and waters have a shallower mixed layer, allowing cooler waters to occur in the euphotic zone, but not reach the surface (Furnas 2007). The inshore Ningaloo Currents flows north seasonally during the summer when southerly winds are stronger and the Leeuwin Current is weaker and displaced further offshore (Taylor and Pearce 1999b; Hanson et al. 2005). The Ningaloo Current is responsible for the occurrence of cooler surface nutrient rich waters along the Ningaloo coast, which in turn, increases productivity and attracts higher order consumers such as whale sharks. These cooler upwelled waters also flow around the North West Cape and intrude into Exmouth Gulf between the Cape and Muiron Islands.

Inside Exmouth Gulf, waters are relatively protected from open-ocean swell by islands to the north, though some propagation of swell occurs between the North West Cape and Muiron Islands. The tidal cycle in Exmouth Gulf is mixed-semidiurnal, and water circulation is largely driven by tidal currents and winds (Massel et al. 1997; APASA 2005; Oceanica 2006). Tidal currents have a net flow in a southwest direction, can attain speeds of up to 1 m s^{-1} and can circulate clockwise around the Gulf (Dufois et al. 2017). The combination of drivers on water circulation causes high turbidity through the resuspension of sediments (Dee et al. 2020), which is mainly during spring tides.

The hydrological environment remains relatively stable given freshwater sources from rainfall and runoff are very low (Penn and Caputi 1986). Tropical cyclones can change this however, as extreme winds, increased rainfall and runoff can impact turbidity and salinity.

8.1.4.3. Nutrient Flow

Nutrient flow within Exmouth Gulf has not been fully determined. Generally, Exmouth Gulf is thought of as a nutrient limiting environment, given the minimal terrestrial runoff, yet supports a productive prawn fishery. The main source of carbon flow into the system was long thought to come from the expansive blue-green algal mats (McKinnon and Ayukai 1996; Ayukai and Miller 1998; Lovelock et al. 2009), which was later supported by Penrose (2011). Mangrove litter also contributes to high concentrations of organic carbon in sediments along the eastern margin (Brunskill et al. 2001). Tropical cyclones play a role increasing nutrient delivery into the system to relieve nutrient limitation (Lovelock et al. 2011).

The carbon flow between the terrestrial and nearshore coastal environment of Giralia Bay was examined using glomulin (a plant protein found in soils), and concentrations of glomulin adjacent to the terrestrial boundary were very low, due to low annual rainfall, river outputs and groundwater flow (Adame et al. 2012b).

8.2. Land

8.2.1. Flora and Vegetation

8.2.1.1. Vegetation of the Carnarvon Bioregion

The Exmouth Gulf area occurs in the Carnarvon Botanical District within the broader Ereamean Botanical Province. The native flora has a range of forms and features but are all capable of surviving through adverse seasonal conditions (W.A. Planning Commission 2004). The region is semi-arid with annual precipitation 200-250mm, with the possibility of significant cyclonic activity (Kendrick and Mau 2003; Beard 2015). Vegetation of the Carnarvon Botanical District is characterised by mosaic of saline alluvial plains with samphire and saltbush low shrublands, Bowgada (*Acacia ramulosa*) low woodland on sandy ridges and plains, Snakewood (*Acacia xiphophylla*) scrub on clay flats, and tree to shrub steppe over hummock grasslands on and between red sand dune fields (Kendrick and Mau 2003).

Many native plants of the region may be the source of valuable genetics for agriculture (Lawn and Cottrell 2018). For example, *Vigna* is an important agricultural genus that includes major pulse, vegetable, tuber and forage species. There has been a major effort to characterise native *Vigna* for potential genetic improvement of commercial crops. During a 2017 field trip, *Vigna* of the Pilbara region were collected as part of the Australian Native *Vigna* Collection. The central Australia morphotype was found in hard-setting, gravelly red soils in urban drains in Exmouth and at Mowbowra Creek.

8.2.1.2. Flora and Vegetation of the Exmouth Gulf Area

The diversity of flora in the Cape Range peninsula is significant with 46% of the known species of the Carnarvon Botanical District occurring throughout the area. Collections and observations over many decades have revealed a particularly rich and diverse flora, which is unusual considering limestone soils in arid areas are generally recognised as species poor (DEC 2010; W.A. Planning Commission 2004). Small-scale flora surveys have focused upon the Cape Range peninsula of the Exmouth Gulf (Meissner 2011; Keighery and Lilburn 2019) with Keighery and Gibson (1993) surveying the greater Exmouth Gulf area. In addition, rangeland inventory and condition surveys have been conducted on the surrounding pastoral leases (Mitchell et al. 1988; Payne et al. 1988). Examples of flora collected from the Cape Range peninsula can be found in several locations, such as Western Australian Herbarium Florabase, digitised herbarium database, Global Plants, and the Australian Virtual Herbarium (AVH). The area is home to a range of sensitive habitats, unique flora species, uncommon vegetation complexes, endemic species, priority species, disjunct populations and species at the extent of their range (EPA 1989).

A total of 630 taxa of vascular plants, including several weed species, were identified during a survey of flora and vegetation of the Cape Range peninsula by Keighery and Gibson (1993), with flora composed of temperate and tropical species. The plant assemblages are biologically significant in that it represents an overlap between the South West and Eremaean botanical provinces. Distinctive plant groups are associated with the limestone surfaces of the peninsula with the flora varying between the Coral Bay limestone outcrops, Gnargoo and Giralia Ranges, central Cape Range, Rough Range, western coastal plain and sand over limestone (EPA 1989).

The Exmouth Gulf area covers several general vegetation types, the limestone ranges, southern sand dunes, coastal plains on the Cape Range Peninsula, scrub and shrublands in the pastoral areas at the southern end of the gulf, and coastal mangroves on the eastern edge of the gulf (Keighery and Gibson 1993; Meissner 2011). On the Cape Range peninsula, vegetation on the limestone gullies is characterised by *Acacia bivenosa* and *Acacia pyrifolia* and *Eucalyptus prominens* or *Corymbia hamersleyana* over hummock grasslands of *Triodia* aff. *angusta*, while the slopes and crest of the limestone range are characterised by isolated mallee trees of *Corymbia hammersleyana* over open hummock grasslands or shrublands of *Acacia bivenosa* and *Melaleuca cardiophylla*.

The main spinifex complex on the sand dunes country at the southern end of Cape Range consists of hummock grasses, soft spinifex (*T. epactia*) and hard spinifex (*T. basedowii*) with mixed scrub (Beard et al. 2013). Feathertop spinifex (*T. schinzii*) may also occur in the grass layer. Shrub species include Acacia spathulifolia, flame grevillea (*Grevillea eriostachya*), *Hakea stenophylla*, *Hibbertia capensis*, *Mirbelia ramulosa*, *Thryptomene baeckeacea* and *Verticordia* sp.

The coastal plains on the eastern edge of the peninsula are covered with shrublands of *Acacia bivenosa* and *Acacia tetragonophylla* over hummock grasslands of *Triodia epactia* and the introduced Buffel grass (*Cenchrus ciliaris*) (Meissner 2011). At the base of the gulf, the vegetation of the pastoral country is characterised by *Acacia ramulosa* (Bowgada) associated with *Acacia sclerosperma* scrub/shrublands while the eastern coastline is characterised by extensive tidal flats in sheltered embayments supporting mangroves (*Avicennia marina* and *Rhizophora stylosa*) (Kendrick and Mau 2003; Beard et al. 2013).

8.2.1.2.1. Endemic Flora of the Cape Range Peninsula

As of 2019, a total of 21 plant species are identified as endemic to the Cape Range peninsula (Keighery and Lilburn 2019). During the Cape Range Bush Blitz 2019, many of the Cape Range endemics were found in the Commonwealth Bombing Range, lower creek systems and eastern slopes. Keighery and Lilburn (2019) recommended that these areas would be incredibly significant additions to the Cape Range National Park.

Six near-endemic plant species, largely confined to the peninsula, have been documented (Keighery and Gibson 1993). For example, *Hibbertia capensis* is restricted to the Cape range between North West Cape and Ningaloo Station. It is the only *Hibbertia* species found in the semi-arid Cape Range and is widely disjunct from all other *Hibbertia* species. It is not considered to be at risk although its occurrence in an arid environment indicates that it is likely to be adversely affected by climate change (Thiele 2019).

8.2.1.2.2. Rarely Recorded, Unique Flora and Vegetation of the Cape Range Peninsula

A number of significant or poorly known plant species exist in the area (EPA 1989). There are a number of rarely recorded, unique and poorly understood vascular plant taxa in the deep canyons of the northern part of Cape Range such as *Melaleuca bracteata* from Shothole canyon and *Sowerbaea laxiflora* recorded near Mount King in 1956 and not relocated since (Keighery and Lilburn 2019).

Many species appeared to only be found on the southern sand dunes within Cape Range National Park such as *Eucalyptus eudesmioides*, *Calothamnus oldfieldii* and *Mirbelia* spp. The Giralia Anticline Province, immediately south of the head of Exmouth Gulf, contains a very distinct and exclusive vegetation community, Gascoyne bluebush (*Maireana polyplerygia*) (Mitchell et al. 1988).

8.2.1.2.3. Priority Taxa and Ecological Communities of the Cape Range Peninsula

The Cape Range peninsula includes 22 priority taxa, species of conservation significance (DBCA 2019b; Meissner 2011) (Table 14). A 1995 Consultative Environmental Review lists the flowering period of many of these species (Water Authority 1995).

The coastal dune native tussock grassland, dominated by *Whiteochloa airoides* is listed as a Priority Ecological Community (Priority 4 according to the Cape Range National Park Management Plan 2010, Priority 3 according to the 2014 Department of Parks and Wildlife Priority Ecological Communities for Western Australia version 21) (DEC 2010; DPAW 2014). The tussock grasslands of the Carnarvon Basin (Yarcowie) are listed as Priority 1 (DPAW 2014).

Table 14: The 22 priority flora and their habitat found on Cape Range adapted and updated from Meissner, 2011; Priority 2 (P2) species are poorly known from generally ≤5 locations. Priority 3 (P3) species are poorly-known species, recorded from several locations.

Species	Conservation Code	Endemic to Cape Range	Habitat
Acacia alexandri	P3	Y	Stony creeks and limestone slopes
Acacia ryaniana	P2		Coastal sand dunes
Acacia startii	P3		Stony creeks and watercourses
Acanthocarpus rupestris	P3		Limestone hills and creek lines
Brachychiton obtusilobus	P4	Y	Coastal plains and hills
Calandrinia sp. Cape Range (F. Obbens FO 10/18)	P2	Y	Stony creeks and limestone slopes
Calytrix sp. Learmonth (S. Fox EMopp 1)	P1	Y	Limestone plain
Corchorus congener	P3		Coastal plains and hills
Crinum flaccidum	P2		Swamps and creeks
Daviesia pleurophylla	P2		Red sand dunes
Eremophila forrestii subsp. *capensis*	P3	Y	Limestone hills and plains
Eremophila occidens	P2		Limestone hills
Eremophila youngii subsp. *lepidota*	P4		Flats and plains
Grevillea calcicola	P3	Y	Limestone hills
Gymnanthera cunninghamii	P3		Creeklines and coastal plains
Harnieria kempeana subsp. *rhadinophylla*	P2	Y	Base of gorges and limestone hills
Livistona alfredii	P4		Creek lines
Phyllanthus fuernrohrii	P3		Red soil over limestone
Rhynchosia bungarensis	P3		Floodplains and creeks
Stackhousia umbellata	P3	Y	Limestone hills
Tinospora esiangkara	P2	Y	Creek lines
Verticordia serotina	P2	Y	Red sand dunes

8.2.1.2.4. Plants for Which the Cape Range Represents the Limit of Their Range

The Cape Range peninsula is noted for the occurrence of flora species at (or near) the limit of their distribution including 50 temperate species at the northern end of their ranges (Keighery and Gibson 1993). Examples include *Emblingia calceoliflora* on the sandplains, *Santalum spicatum* and *Scaevola crassifolia* on the western coastal dunes. Exmouth is also the northernmost range limit of commercially relevant plant species such as sandalwood (*S. spicatum*) (Smith 2019).

The North West Cape is of high conservation significance, particularly the creeks and semi-permanent wetlands of Yardie Creek, which are a refuge for southern taxa at their northern limits (W.A. Planning Commission 2004). The vegetation communities fringing the coast are of regional significance given their dune stabilisation properties and the difficulties restoring dunes. The Cape Range National Park represents the southern extent of several mangrove species including the spotted mangrove (*R. stylosa*), which appears to be declining locally possibly due to the long-term shallowing of the tidal lagoon (DEC 2010).

8.2.1.2.5. Disjunct Flora

Disjunct flora, species isolated from their main ranges, include the emergent aquatic native bulrush (*Typha domingensis*) at Yardie Creek, which is disjunct from its main range by hundreds of kilometres. Disjunct populations can be due to several reasons, including lack of surveying.

8.2.1.2.6. Refugia

The Cape Range offers refugia for ecologically significant flora. For example, mistletoes, hemi-parasitic plants that are keystone species, are at risk of contraction and extinction due to altered fire regimes (Start 2011). Loss of mistletoes and mistletoe-dependent species can have a cascading effect on regional biodiversity. It is predicted that mistletoe species will continue towards local extinction in the Pilbara region. The calcareous surfaces flanking Cape Range and at the base of Exmouth Gulf, are refugia for several mistletoe species. Wire-leaf mistletoe (*Amyema preissii*) is common there and *Amyema miraculosa* and *Amyema xiphophylla* occur with very localised distributions. The cliffs and gorges of the Range offer some fire shelter for *A. miquelii* on eucalypts and *Amyema benthamii* on *Brachychiton obtusilobus*. Snakewood mistletoe (*A. xiphophylla*) has been described from Giralia Station at the southern end of the Exmouth Gulf (Wege and Start 2020). It is not currently thought to be at risk but may become vulnerable given frequent, large-scale fires and the likelihood of climate change causing further changes to fire regimes.

8.2.1.2.7. Flora and Vegetation of the Exmouth Gulf Islands

A total of 253 plant species from 54 families have been recorded on the Pilbara inshore islands. Island vegetation is dominated by *Acacia* (*A. bivenosa, A. coriacea*) and *Triodia* hummock grasslands and mainly *Spinifex longifolius* on the smaller islands (Kendrick and Mau 2003; Abbott and Wills 2011). The following five priority taxa occur on the gulf islands, *Tephrosia* sp. North West Cape (Priority 2), *Corchorus congener, Gymnanthera cunninghamii, Lepidium biplicatum* and *Carpobrotus* sp *Thevenard* (Priority 3) (DBCA 2020a).

8.2.1.2.8. Vegetation of the Unallocated Crown Land (UCL)

The majority of the coastal land of the Exmouth Gulf is crown land (e.g. crown reserves, unallocated crown land, pastoral leases) (Kolkovski and Machin 2004). While Unallocated Crown Land (UCL) was not included in Keighery and Gibson's (1993) floristic sampling of the Cape Range peninsula, Metcalf and Bamford (2005) and Meissner (2011) documented the vegetation of the UCL including the northern red sand dunes which are under-represented in the conservation reserve (< 1.5%). A total of 270 plant taxa have been recorded within the UCL including 11 priority flora and 89 flora not represented in Cape Range National Park.

Community support has long been expressed for the expansion of the Cape Range National Park (May, 1988). The UCL on the peninsula currently lies outside the National Park. In 1993, the EPA recommended that UCL at the head of the Gulf, Exmouth Gulf station and east coast of the Gulf be included in the National Park (EPA 1993; Meissner 2011). The 2019 Draft Joint Management Plan for Nyinggalu (Ningaloo) Coastal Reserves also proposes that the northern portion of the UCL is added to the National Park (DBCA 2019a).

8.2.1.2.9. Vegetation of the Northern Red Sand Dunes

Twelve taxa are found exclusively within the northern red sand dunes within the UCL on the Cape Range peninsula (Meissner 2011; Metcalf and Bamford 2005). Crests of the dunes, swales and coastal plains are characterised as mixed open shrublands of *Acacia (Acacia spathulata, Acacia bivenosa), Banksia ashbyi* subsp. *boreoscaia* and *Corymbia zygophylla* over *Triodia* hummock grasslands and shrublands of *Acacia* and *Calytrix* species. Associated with this vegetation is a suite of species including *Ficus platypoda, Corymbia hamersleyana, Grevillea calcicola, Corchorus crozophorifolius, Hibbertia capensis, Gossypium robinsonii* and *Eremophila forrestii* subsp. *capensis*.

8.2.1.2.10. Vegetation of the Naval Communication Station Harold E Holt

The Naval Communication Station Harold E Holt (the Base) is located on the northern tip of the Cape Range peninsula. The DoD 2019 PFAS Management Area Plan for the Base describes three terrestrial vegetation units of the peninsula using Beard et al. (2013): (1) Shrub-steppe - hummock grassland (*Triodia*) with scattered shrubs (*Acacia, Grevillea*) or mallee (*Eucalyptus*); (2) Sparse low tree-steppe - hummock grassland (*Triodia epactia*) with sparse eucalypts (*Eucalyptus prominens*); (3) Spinifex complexes - hummock grassland (*Triodia* spp.) with scattered low trees over dwarf shrubs or mixed short grass and mixed spinifex (DoD 2019). Grasslands, coastal strand vegetation and low scrubland have been reported along the coastal plains of the Base. Beach spinifex (*Spinifex longifolius*), prickly saltwort (*Salsola kali*) and beach morning glory (*Ipomea brasiliensis*) reportedly grow sporadically along the shoreline. Low shrub and hummock grass communities occur along the foredunes with pioneer and herb species such as *Ptilotus* spp. and *Euphorbia* spp.

8.2.1.2.11. Vegetation of the Western Cape Range

The Western Cape Range coastal plains support mixed vegetation dominated by saltwater couch (*Sporobulus virginicus*), saltwort (*Frankenia* spp.), saltbush (*Atriplex* spp.) and *Sclerolaena* spp. (Hesp and Morrissey 1984). Vegetation on the alluvial fans is dominated by introduced buffel grass (*Cenchrus ciliaris*) on the western portions and *Acacia* spp. over *Triodia* and *Cenchrus* grasslands on the central and eastern portions. The suitability of the area west of Exmouth for development was assessed. Hesp and Morrissey (1984) concluded that the climate, geophysical characteristics and vegetation of the west Cape Range place severe constraints on any development. In particular, the presence of saline (halopytic) vegetation and high soil and water salinities represent major limitations to development on the Tantabiddi terrace.

8.2.1.2.12. Vegetation of Exmouth Township

In general, three major landscape units are recognised in the Exmouth township (Le Provost et al. 1986). The limestone ranges with cliffs and gullies are covered by *Eucalyptus, Acacia* and *Grevillea* over *Triodia* hummock grasslands as well as *Brachychiton obtusilobus*. The coastal plains are home to *Acacia* sp. over *Triodia* hummock grasslands while recent coastal dunes have a low cover of *Spinifex longifolius, Acanthocarpus preissii, Scaevola* spp. and *Acacia* up to 2 m tall on the landward side. In the 1990s, these habitats were described as "widespread" and in, *"relatively pristine condition with the exception of the coastal dunes"*. Further damage to these habitats has since been described (Kobryn et al. 2017).

8.2.1.3. Vegetation of the Pastoral Country

The area of interest includes 'pastoral country' or 'station country', a land use type that occupies 85% of the arid rangelands of W.A. Vegetation surveys by DPIRD in the 1990s concluded that the majority of pastoral lands in the Pilbara region were in 'good or very good condition' (Van Vreeswyk et al. 2004). However, overgrazing by feral and domestic herbivores has degraded some land and vegetation (Burnside et al. 1995). Pastoral country encompasses native mulga shrubland, saltbush, bluebush and sandplain. In addition, cryptogams (thin layers of algae, lichens, mosses or other small primitive plants) develop over some soils during and after rains. New species of plants are still being discovered in the pastoral country and further analyses may subdivide major species into new species or subspecies (Burnside et al. 1995).

8.2.1.4. New Plant Species Discovered in the Exmouth Gulf Area

New plant species and locations are still being discovered in the area. In 2008, a new species of mallee (*Eucalyptus baiophylla* D. Nicolle and Brooker, sp. nov) was described on the sands and low stony rises of the Giralia Range between Exmouth Gulf and Lake MacLeod (Nicolle and Brooker 2008). A 2018 Flora and Vegetation Field survey found a potentially new Calytrix species 35km south of Exmouth, which was vouchered at the W.A. Herbarium for further study (360 Environmental 2018). Two, as yet unnamed species, were collected over multiple sites during the Cape Range Bush Blitz 2019 (Keighery and Lilburn 2019). That same year, new records added to W.A.'s vascular plant census included *Calandrinia* sp. Cape Range (F. Obbens FO 10/18) (Parker and Percy-Bower 2019). It is likely that further surveys of the area, particularly the gullies, gorges and creek lines, may find new species and populations of priority flora (Meissner 2011). While many areas are difficult to access, the peninsula requires further floristic surveys (Keighery and Lilburn 2019).

8.2.1.5. Threats to Flora and Vegetation of the Exmouth Gulf Area

Threats to flora and vegetation of the area include habitat degradation and destruction associated with development, extractive industries, introduced weeds, tourism/visitation, pastoral activities and climate change. The impact upon groundwater regimes from contamination, increased storm frequency and droughts is also a significant threat. Though flora and vegetation in semi-arid/arid environments are typically highly adapted to irregular precipitation, changes to the availability of water in the environment needs to be considered.

The EPA has previously placed conditions on permit holders to protect the flora and vegetation of the area and avoid damaging priority flora (DWER 2018; EPA 1989). Extraction of basic raw materials (BRM) such as gravel from the Cape Range National Park may also impact on flora (Meissner 2010). Surveys were recommended for priority flora *Corchorus congener* at Commonwealth Pit and Five Mile prior to any excavations and no extractive activities at Mandu Pit due to high biodiversity values (including four Priority flora species) (Meissner 2010). A major risk of the extractive industry is in groundwater contamination from hydrocarbons.

Remote sensing and field validation has established that dune flora adjacent to the Ningaloo Marine Park is generally sparse and is at risk of damage by visitors using a total of 1256km of vehicle tracks near accommodation, sandy beaches and pastoral stations (Kobryn et al. 2017).

Few weeds have been recorded from the peninsula and weed diversity has been described as low (360 Environmental 2018; Keighery and Gibson 1993). Significant weed invasion also occurred in Yardie Creek with infestations of *Emex australis* and *Asphodelus iistulosus* and on the western coastal plain (Keighery and Gibson 1993). Thirty taxa of weed are listed for the area, most occurring around Exmouth township. Buffel grass (*Cenchrus* *ciliaris*), is a significant weed, although a valuable pasture plant, has spread extensively throughout the region, including the national park (Meissner 2010). A 2002 survey of the Ashburton River Catchment including the area south of the head of Exmouth Gulf, found buffel grass had spread extensively since the 1980s (Leighton and Van Vreeswyk, 2004). Buffel grass has been reported in the National Park, western coastal plain and numerous Exmouth Gulf islands including Doole and Roberts Islands where it is potentially a threat (Dixon et al. 2002).

In the 1990s, the Muiron Islands were described as “still in almost pristine condition” despite their relative proximity to the mainland (Bauer and Kelsall 1991). By 2004, the Muiron Islands and adjacent Sunday Islands were reported to be increasingly used for recreation and hydrocarbon exploration which was anticipated to increase in the region over the next decade (W.A. Planning Commission 2004). In 2011, Doole and Roberts Islands were described as little visited and had only 2–3% of their floras introduced (Abbott and Wills 2011). As use of W.A.’s offshore islands increases, invasive flora and fauna pose a particular threat. Non-native plant records for Burnside, Doole, Hope, Large Fly and Peak Islands in the Exmouth Gulf are documented by Lohr et al. (2018).

Settlement and pastoral development has changed the landscape over the last 100 years (W.A. Planning Commission 1996). In some pastoral areas, native grasses have been replaced by annual pastures. Introduced species, especially buffel grass (*Cenchrus ciliaris*), dominates areas previously occupied by native hummock grass (*Triodia*) and bluebush (*Maireana*). Selective overgrazing by sheep, goats and cattle has also exposed areas to wind and erosion. Trampling of vegetation and compaction of the earth are also issues particularly around watering points. The W.A. Planning Commission has previously urged restrictions on stocking rates along the sensitive coastal strip because it is extremely susceptible to wind erosion and dune destabilisation (W.A. Planning Commission 1996).

Sturt's desert pea (*Swainsona formosa*) and the green bird flower (*Crotalaria cunninghamii*) (Photo: Kate Sprogis).

8.2.2. Subterranean Fauna and Karst Systems

Western Australia's subterranean fauna has been recognised as being globally significant because of its extraordinarily high species richness and high levels of endemism (Guzik et al. 2010). The total number of subterranean fauna species is estimated around 4,000, many of which are unnamed or yet to be recorded (Guzik et al. 2010). Humphreys (2018) provides an account of the current state of knowledge of subterranean fauna including biogeography, environmental DNA, biology, ecology, spatial distribution and habitat characteristics in W.A.

Subterranean fauna are animals that live in underground habitats and often display evolutionary adaptations to underground life, particularly reduced pigment and reduced or absent eyes. They are divided into two groups: stygofauna, which are aquatic and live in groundwater; and troglofauna, which are air-breathing and live in caves and underground voids.

The importance of the North West Cape area for subterranean fauna was first recognised by the EPA in the mid 1990's when early research showed that the area contained a rich and unique assemblage of subterranean animals and unusual and diverse subterranean habitats (Humphreys 1993, Knott 1993). The EPA required more knowledge of the subterranean fauna in the area due to an increase in applications to mine the karst limestone. Consequently, the EPA commissioned a report to understand the subterranean values of the region and potential impacts to the karst and fauna from proposed developments (Hamilton-Smith et al. 1998). The report found that the area contained numerous significant landscape, seascape and biological diversity values, including the subterranean fauna, which was notable because it was comprised of rare, relictual and taxonomically diverse species not found anywhere else (UNESCO 2011).

8.2.2.1. North West Cape subterranean fauna and habitats

The Cape Range Peninsula and its associated limestone karst habitats is globally recognised as a biodiversity hotspot for subterranean species, with an estimated 77 species known from the region and numerous species awaiting formal description. Early taxonomy and biology of subterranean fauna in the Exmouth region was largely carried out by Humphreys et al. (1989), Humphreys and Shear (1993), Knott (1993), Shear and Humphreys (1996), Humphreys (2000a) and Harvey et al. (2008) among others.

Much of the fauna is endemic to the region, but the exact level of endemism is unknown due to a lack of comprehensive, systematic survey; incomplete knowledge of the distributions; and unknown status of some taxa that are likely new species but have not been formally named yet. However, it is common for subterranean species to exhibit high levels of endemism and it is likely that the majority of species are restricted to the area (Humphreys 2008). Distinct populations of species also occur due to geographic separation, such as for the troglobitic millipede species, *Stygiochiropus*, which is separated by deep gorges that cut through the Cape Range (Humphreys and Adams 2001). The timing and formation of the karst systems of the Cape Range is suggested to date back to the late Miocene/early Pliocene (Allen 1993; Humphreys 1993; Mylroie et al. 2017).

Some of the notable subterranean values of Cape Range are:

- The only Tertiary orogenic limestone in Australia. This type of limestone is known to host some of the most diverse subterranean fauna communities in the world (Humphreys 2000b).
- 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 2000b). They are also the only example of a mainland karst wetland in arid northwestern Australia.

- 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 (Jaume et al. 2001; Kenrick and Mau 2002; Humphreys and Brooks 2015). The W.A. Biodiversity Audit 2002 lists the stygofauna communities on North West Cape as one of the ecosystems at risk in the Cape Range subregion (Kendrick and Mau 2002).
- At least 20 conservation significant species (see Table 15).
- Of only three subterranean vertebrates known from Australia, two (the blind cave gudgeon *Milyeringa veritas* and blind cave eel *Ophisternon candidum*) inhabit North West Cape karst habitats, the third is restricted to Barrow Island (blind cave fish *Milyeringa justitia*) (Knott 1993; EPA 1996; Moore et al. 2018; Page et al. 2019). Humphreys (2001) describes the versatility of the Cape Range blind cave gudgeon including its opportunistic feeding across a range of prey and scavenged food, and its ability to inhabit a broad range of water chemistries.
- Numerous crustacean species that are the only representatives from their higher classification groups known from Australia or the southern hemisphere. For example, the remipede crustacean species, *Kumonga exleyi*, is only known from the Bundera sinkhole and is also the only representative from this class known from the Southern hemisphere (Yager and Humphreys 1996).
- A unique anchialine fauna assemblage whose closest relatives are not found in neighbouring regions of Australia. Instead, the stygofauna have biogeographic affinities with the North Atlantic and are likely to be ancient relictual taxa that evolved from the Mesozoic Tethys Sea, with their most recent common ancestors likely evolving over 180 million years ago (Humphreys 1994). This fauna provides invaluable information for reconstructing the history of the earth and continental drift.
- A faunal assemblage that is amongst the most diverse in the world and contains numerous relictual taxa of "the highest conservation status" (Morton et al. 1995) that have survived millions of years through changing climates. The troglofauna are most closely related to tropical surface species, which moved underground during unfavourable arid periods. Subsequently, these fauna provide a window into the past and are of significant research interest in fields such as biogeography, responses to changing climates and evolutionary adaptations to harsh environments (Humphreys 2000a).

8.2.2.2. Subterranean habitats: anchialine systems

The North West Cape area contains extensive limestone karst formations and a complex hydrogeology of subterranean waterbodies, including perched freshwater lakes and streams and anchialine waters. The subterranean waterways are recharged by infrequent, high intensity rainfall events (Allen 1993), which also impacts the extent of saltwater intrusion (Leeq 2004).

The anchialine system is particularly notable because these systems are very rare globally. Anchialine systems merge with marine systems at the coast and merge with fresh groundwater inland (e.g., Collins 2010). Anchialine systems are hydrologically complex systems characterised by strong physico-chemical stratification which influences the fauna found within them (Humphreys 2000b). The area where the fresh and saline water mixes is where most of the stygofauna occur. Some stygofauna species are intolerant to changes in water chemistry and so are confined to particular layers and subsequently are vulnerable to changes of the physio-chemical layers (Humphreys 2000a).

8.2.2.3. Conservation listed species and threatened ecological communities

The North West Cape has a number of subterranean fauna that are listed as Threatened or Priority Species under the *W.A. Biodiversity Conservation Act 2016* and EPBC Act (Table 15) (DPAW 2019).

Table 15: Subterranean fauna from the Cape Range and Barrow Island listed as Threatened or Priority Species.

Species	Group	WA BCA	EPBC	Known distribution
Troglofauna				
Bamazomus vespertinus	schizomid arachnid	EN	-	Western cave
Bamazomus subsolanus	schizomid arachnid	EN	-	Eastern caves
Draculoides brooksi	schizomid arachnid	EN	-	
Draculoides julianneae	schizomid arachnid	EN	-	Single western cave
Indohya damocles	pseudoscorpion arachnid	CR	VU	Camerons Cave
Norticola flabella	cockroach	P4	-	Multiple caves
Stygiochiropus isolatus	millipede	VU	-	Camerons Cave
Stygiochiropus peculiaris	millipede	CR	-	Camerons Cave
Stygiochiropus sympatricus	millipede	VU		Single northern cave
Stygofauna				
Bunderia misophaga	copepod crustacean	CR	-	Bundera Sinkhole
Speleophria bunderae	copepod crustacean	CR	-	Bundera Sinkhole
Stygocyclopia australis	copepod crustacean	CR	-	Bundera Sinkhole
Kumonga exleyi	remipede crustacean	E	-	Bundera Sinkhole
Danielopolina kornickeri	ostracod crustacean	CR	-	Bundera Sinkhole
Liagoceradocus brachialis	amphipod crustacean	EN	-	Bundera Sinkhole
Milyeringa veritas	blind gudgeon	VU	VU	From Tulki Well to Point Cloates Lighthouse
Ophisternon candidum	blind cave eel	VU	VU	Cape Range, Barrow Island, parts of Pilbara
Prionospio thalanji	polychaete worm	CR		Bundera Sinkhole
Stygiocaris lancifera	cave shrimp	VU	-	Western caves
Stygiocaris stylifera	cave shrimp	P4	-	Northwestern and northeastern caves

P4 = rare, near threatened or in need of monitoring, VU = Vulnerable, EN = Endangered, CR = Critically Endangered. WA BCA = *W.A. Biodiversity Conservation Act 2016.*

8.2.2.4. Threats and impacts

Potential threats and impacts to the North West Cape subterranean fauna and their habitats include:

- Hydrological changes related to processes such as excessive groundwater abstraction or reinjection of water may result in a loss of habitat for subterranean fauna (Humphreys and Adams 1990; Humphreys 1991).
- Water quality changes from water abstraction or wastewater disposal could cause changes in salinity (Lee 2008), oxygen availability and elements such as nitrogen, which may alter the composition of subterranean faunal assemblages.
- Removal of karst for mining and infrastructure may result in habitat loss (Hamilton-Smith et al. 1998; DEC 2010). Invertebrate Solutions (2017) and Halse (2017), reviewed the potential impact of the proposed Learmonth Bundle Project on subterranean fauna. Though there were no surveys for subterranean fauna available at the time, there was thought to be a high to very high probability that they occurred at the site. Monitoring of subterranean fauna north of the Learmonth RAAF based collected many species unknown from other parts of the Cape Range peninsula.
- Disturbance to caves or sinkholes from visitors and divers, which may cause pollution or alter the chemico-physical attributes of waterbodies (Humphreys et al. 1999; Black et al. 2001; DEC 2012).
- Increased nutrient and sediment loads in the aquifer systems and karst from goats (and euros) grazing near and drinking from sinkholes, and rubbish dumping in caves (DEC 2010). These are typically low-nutrient systems and increased nutrients may alter the system to favour introduced species and result in losses or changes to the faunal assemblages.
- Destabilisation and erosion of soil from surface activities (e.g., mining or overgrazing) leading to clogging of pore spaces (DEC 2010) thereby potentially reducing available habitat and connectivity that could restrict species further.
- Climate change may be a potential threat to subterranean systems, particularly if high intensity rainfall events become less frequent, as predicted by the State of the Climate 2020 report (Commonwealth of Australia, 2020). The Cape Range subterranean habitats are dependent on high intensity rainfall events for recharge so lower rates and levels of recharge may adversely impact subterranean fauna via loss of habitat and reduced connectivity.

8.2.3. Terrestrial Fauna

8.2.3.1. Invertebrates

The literature on terrestrial and freshwater invertebrates in the North West Cape area is limited as most prior studies focused on subterranean invertebrates, and a comprehensive species list does not exist for the region. Despite the paucity of information, the North West Cape hosts a diverse terrestrial invertebrate fauna including arachnids, myriapods (millipedes and centipedes), insects and terrestrial molluscs (Slack-Smith 1993; W.G. Martinick and Associates Pty. Ltd. 1995; Metcalf and Bamford 2005; Theischinger and Hawking 2006).

The North West Cape is one of the most significant areas for Camaenid land snail species richness in arid and semi-arid Australia with at least 18 species known from the area, of which at least five species are endemic to the area (Taylor et al. 2015; DBCA 2019a). The genus *Strepsitaurus* is comprised of four extant species, which are found only in the Cape Range. These species are highly specialised and have limited distribution. For example, *S. milyeringus, S. susieae*, and *S. manduensis* are specialised to rock-face habitat and each of these species is known from a single gorge. Taylor et al. (2015) speculated that other endemic land snail species remain to be found in the numerous isolated gorges on the western face of the Cape Range.

Other endemic species in the area include two millipedes (*Boreohesperus capensis* and *Antichiropus humphreysi*), and an endemic cicada (*Thopha hutchinsoni*), which is restricted to stunted bloodwood (*Corymbia hamersleyana*) growing along ephemeral streams in limestone gullies (Moulds 2008).

A recent survey of the Cape Range organised by the Australian Biological Resources Study (ABRS) Bush Blitz program (Bush Blitz 2021), collected 29 new terrestrial invertebrate species including:

- 24 true bugs (Heteroptera); 2 of these are likely endemic to Cape Range
- 2 moths (*Persectania* BBCR msp.17 and *Euproctis* 'BBCR msp.16'); the latter is likely a short-range endemic species
- 2 trapdoor spiders (*Conothele* sp. 'MYG673' and *Euoplos* sp. 'MYG672')
- 1 endemic pseudoscorpion (*Synsphyronus* sp. 'Cape Range')

The survey was not comprehensive as it focused on specific fauna groups, but it highlights the fact that there is still a lot unknown about the biodiversity of the Cape Range Peninsula.

Specimens collected from the Exmouth area have helped to describe a new species of cicada, *Palapsalta belli* (Emery et al. 2018), and a relatively new genus of wolf spider, *Costacosa* (Framenau and Leung 2013).

Eighteen invertebrate species have been found on Pilbara inshore islands. Native ants include the *Iridomrymex* sp *chasei*, *Polyrhachis ammonoeides*, *Odontomachus ruficeps* and *Melophorus* sp. (probably *M. bagoti*). Australian jewel spiders (*Austracantha minax*) have been recorded on Tent Island. Invertebrates of the inshore islands have been poorly surveyed and further survey work would likely identify many more species (DBCA 2020a).

8.2.3.2. Reptiles and Amphibians

Given the improvements of taxonomy and nomenclature, some information on species presented in past reports or scientific literature is outdated or taxonomically redundant. As such, some historical information has been updated against current W.A. Museum (2021a) and DBCA (2019) checklists or omitted where no longer relevant.

8.2.3.2.1. Terrestrial Reptiles

Approximately 150 species of terrestrial reptile species have been recorded within the North West Cape and surrounds (within a 50km search area, ALA 2021; W.A. Museum 2021a) including Exmouth Gulf and Cape Range. The discovery of new species in the area is ongoing (e.g. Maryan et al. 2007; Doughty, Oliver and Adams 2008; Mecke et al. 2013; Keally et al. 2018; Hoser 2020). The reptile assemblage is typical of the northwest coastal regions and shares a variety of species that have distributions into the semi-arid and arid Gascoyne and the Pilbara bioregions, including offshore islands.

The Exmouth region has been noted as a centre of evolutionary radiation for the lizard genus *Lerista* (Kendrick 1989; McKenzie et al. 2003) with 17 species of this genus being recorded. Sandy habitat units are not well represented in the area (Kendrick 1993), but these isolated areas host unusual reptile assemblage associated with the red dune habitats that are likely to be restricted within the peninsula (Metcalf and Bamford, 2005).

The distributions of many of the region's reptile species extend south along the Ningaloo coast to Shark Bay and Cape Peron, of which the Exmouth region is the northern extent of their range. This includes the Northern heath dragon (*Ctenophorus parviceps*), Kluge's gecko (*Diplodactylus klugei*), ornate stone gecko (*Diplodactylus ornatus*), Exmouth spiny-tailed gecko (*S. rankini*), black-necked whipsnake (*Demansia calodera*), and Northern dotted-line robust slider (*L. miopus*). Due to their associations with coastal and near-coastal habitats, climate change is likely to be a significant risk for these species and their habitats.

To the west, distributions of some species have been separated from their nearest records in the Pilbara by the Giralia anticline in the southern portion of the peninsula (e.g. the jewelled gecko (*Strophurus elderi*), Northern spiny-tailed gecko (*S. ciliaris abberans*), and the Pilbara death adder (*Acathophis wellsei*) (Kendrick 1993).

Perentie lizard, Exmouth township (Photo: Kate Sprogis).

Six endemic reptile species are known from the North West Cape: the Cape Range slider (*Lerista allochira*), which is reliant on the elevate limestone habitats (Kendrick 1993); Splendid blind snake (*Anilios splendidus*); Cape Range clawless gecko (*Crenadactylus tuberculatus*); Teale's delma (*Delma tealei*); Cape Range stone gecko (*Diplodactylus capensis*); and North West Cape gecko (*Gehyra capensis*); while the Ningaloo worm lizard (*Aprasia rostra*) is also only known from Barrow and Montebello Islands. One introduced reptile species, the Asian house gecko (*Hemidacytlus fraenatus*) has been recorded around the built-up urban areas of Exmouth township.

Five species of conservation significance are listed in the W.A. Threatened and Priority Fauna list (DBCA 2019) and are found within the Exmouth Gulf and Cape Range regions:

- Cape Range blind snake (*Anilios* sp. 'Cape Range') Priority 1
- Splendid blind snake (*Anilios splendidus*) Priority 2
- Cape Range stone gecko (*Diplodactylus capensis*) Priority 2
- Cape Range slider (*L. allochira*) Priority 3
- Ningaloo worm lizard (*Aprasia rostrata*) Priority 3

8.2.3.2.2. Amphibians

The frog assemblage of the North West Cape is low compared with other areas of W.A., with just seven frog species recorded. No records of the cane toad (*Rhinella marina*) have been recorded in the region to date.

Typical arid zone frogs include Main's frog (*Cyclorana maini*), Northern burrowing frog (*Neobatrachus aqulionius*) and shoemaker frog (*N. sutor*), little red tree frog (*Litoria rubella*), and the desert spadefoot (*Notaden nichollsi*). The population of the tawny frog (*N. fulvus*) found on the peninsula is disjunct from its predominantly northwest coastal range. Similarly, the gorge toadlet *Pseudophyrne douglasi* is known from only a few records in the northern Exmouth area and Cape Range that likely represent relictual populations of this species, with the next known record over 200km away and is more commonly recorded from the Pilbara (Kendrick 1993).

8.2.3.3. Birds

The terrestrial birdlife of the North West Cape is typical of the Pilbara and Carnarvon Basin regions and has a diverse assemblage with over 240 terrestrial bird species recorded within the cape and surrounds (within a 50km search area, ALA 2021; W.A. Museum 2021b) including Exmouth Gulf and Cape Range. This high number of species is indicative of the variety of habitats available including coastal and dune areas, islands, mangroves, grasslands and woodlands.

The coastal and island habitats are particularly important habitats for birds. Approximately 21 coastal birds and 38 wader and shorebird species have been recorded or are likely to occur in and around Exmouth Gulf and peninsula. The Muiron Islands, a C class reserve, are a significant nesting ground for over 200,000 wedge-tailed shearwater (*Ardenna pacifica*) (Cannell et al. 2019). The sooty tern (*Onychoprion fuscata*) breeds in small numbers on Eva Island April to May (Johnstone et al. 2013). The islands provide habitat to vulnerable species such as the fairy tern (*Sternula neris neris*) that are part of a small, probably sedentary, sub-population between Exmouth Gulf and Dampier Archipelago (Dunlop and Greenwell 2020).

Birds reported on the small islands between Exmouth Gulf and Port Hedland include: the white-breasted woodswallow (*Artamus leucorhynchus*), yellow white-eye (*Zosterops luteus*), bar-shouldered dove (*Geopelia humeralis*), Australian kestrel (*Falco cenchroides*), brown quail (*Coturnix ypsilophora*), Australian pipit (*Anthus australis*), welcome swallow (*Hirundo neoxena*), and zebra finch (*Taeniopygia guttata*) (Abbott and Wills 2011).

The Exmouth Gulf mangroves of the eastern coastline have been listed as a Key Biodiversity Area for the values it provides to migratory shorebirds (KBA Partnership 2020). These intertidal mangal and mudflats provide habitat for specialist species such as mangrove heron (*Butorides striata*), collared kingfisher (*Todiramphus chloris*), mangrove robin (*Peneothello pulverulenta*), eastern reef heron (*Egretta sacra*), mangrove golden whistler (*Pachycephala melanura*), mangrove grey fantail (*Rhipidura phasiana*), beach stone-curlew (*Esacus magnirostris*), gulls and terns, oystercatchers and shorebirds, and large flocks of migratory shorebirds that feed on the rich mudflats in preparation for their 10,000km journey back to the Northern Hemisphere breeding grounds (DBCA 2017b).

Conservation significant species recorded in the area include 10 conservation listed terrestrial bird species and 33 migratory species, including 27 migratory shorebirds (see Table 16). In addition, the area supports migratory coastal and pelagic birds such as terns, boobies, noddies, shearwaters, petrels and albatross (see Section 8.1.2.9). Terrestrial migrants include Southeast Asian species such as Eastern yellow wagtail (*Motacilla tschutschensis*), barn swallow (*Hirundo rustica*) and white-throated needletail (*Hirundapus caudacutus*). Peregrine falcon (*Falco peregrinus*) utilise the coastal and inland cliffs, gorges, along watercourses, swamps, plains and open woodland (Water Authority 1995). The cryptic rufous grasswren (*Malurus whitei* – sometimes recorded as *M. striatus*) has been recorded northeast of the range and at Giralia Station, associated with sandplains and dunes with large hummocks of spinifex.

A number of vagrant bird species have been recorded on the Exmouth peninsula, which is outside of their usual distribution, including white-browed (spotted) scrubwren (*Sericornis maculatus*), Australian raven (*Corvus coronoides*), red-tailed black-cockatoo (*Calyptorhynchus banksii* spp.), barking owl (*Ninox connivens*), painted buttonquail (*Turnix varius*), Bourke's parrot (*Neopsephotus bourkii*), fan-tailed cuckoo (*Cacomantis flabelliformis*) and tawny grassbird (*Cincloramphus timoriensis*). Other rarities include a unique reddish form of the striated heron (*Butorides striata stagnatilis*) that occurs on reddish substrates between Devil Creek and Exmouth Gulf (Johnstone et al. 2013). Smaller forms of Pilbara birds have been noted as occurring in the North West Cape including the grey shrike-thrush (*Colluricincla harmonica kolichisi*) and Western bowerbird (*Chlamydera guttata carteri*) and the recently described subspecies of the rufous grasswren (*Amytornis whitei parvus*) that is likely to be endemic to the region and threatened (Black et al. 2020).

Table 16: Migratory shorebirds and conservation significant terrestrial birds recorded in the Exmouth Gulf study area (within a 50km search area, Atlas of Living Australia 2021; W.A. Museum 2021b; DBCA 2019).

Scientific name	Common name	WA Status	Federal Status (EPBC Act 1999)
Migratory shorebirds			
Limosa lapponica	bar-tailed godwit	Migratory, Vulnerable (Critically Endangered at sub sp. level)	Migratory, Vulnerable (Critically Endangered at sub sp. level)
Limosa limosa	black-tailed godwit	Migratory	Migratory
Limicola falcinellus	broad-billed sandpiper	Migratory	Migratory
Actitis hypoleucos	common sandpiper	Migratory	Migratory
Calidris ferruginea	curlew Sandpiper	Critically Endangered	Migratory
Numenius madagascariensis	Eastern curlew	Critically Endangered	Migratory
Tringa nebularia	greenshank	Migratory	Migratory
Charadrius leschenaultii	greater sand plover	Vulnerable	Migratory, Vulnerable
Calidris tenuirostris	great knot	Critically Endangered	Migratory
Pluvialis squatarola	grey plover	Migratory	Migratory
Tringa brevipes	grey-tailed tattler	Migratory, Priority 4	Migratory
Charadrius mongolus	lesser sand plover	Endangered	Migratory, Endangered
Numenius minutus	little curlew	Migratory	Migratory
Calidris subminuta	long-toed stint	Migratory	Migratory
Tringa stagnatilis	marsh sandpiper	Migratory	Migratory
Charadrius veredus	oriental plover	Migratory	Migratory
Glareola maldivarum	oriental pratincole	Migratory	Migratory

Scientific name	Common name	WA Status	Federal Status (EPBC Act 1999)
Migratory shorebirds (continued)			
Pluvialis fulva	Pacific golden plover	Migratory	Migratory
Calidris melanotos	pectoral sandpiper	Migratory	Migratory
Calidris canutus	red knot	Endangered	Migratory, Endangered
Calidris ruficollis	red-necked stint	Migratory	Migratory
Arenaria interpres	ruddy turnstone	Migratory	Migratory
Calidris alba	sanderling	Migratory	Migratory
Calidris acuminata	sharp-tailed sandpiper	Migratory	Migratory
Xenus cinereus	terek sandpiper	Migratory	Migratory
Numenius phaeopus	whimbrel	Migratory	Migratory
Tringa glareola	wood sandpiper	Migratory	Migratory
Terrestrial birds			
Hirundo rustica	barn swallow	Migratory	Migratory
Apus pacificus	fork-tailed swift	Migratory	Migratory
Plegadis falcinellus	glossy ibis	Migratory	Migratory
Falco hypoleucos	grey falcon	Vulnerable	
Pandion haliaetus	osprey	Migratory	Migratory
Falco peregrinus	peregrine falcon	Other Significant	
Amytornis striatus	striated grasswren	Priority 4	
Hirundapus caudacutus	white-throated needletail	Migratory	Migratory
Motacilla tschutschensis	Eastern yellow wagtail	Migratory	Migratory
Unverified records:			
Elanus scriptus	letter-winged kite	Priority 4	
Amytornis textilis	Western grasswren	Priority 4	

Threats to birds in the region include increased human development for grazing, recreation (e.g. off-road vehicles; fishing refuse) and infrastructure may cause disturbance to birds, loss of habitat and changes in species diversity. For example, more ubiquitous species such as emu (*Dromaius novaehollandiae*), corellas, corvids and silver gulls (*Chroicocephalus novaehollandiae*), that can adapt to human modified habitats through the provision of artificial food (e.g. waste) and water resources (e.g. dams and irrigation) may increase. Silver gulls are known to prey on other bird species and their eggs, crowding other birds at breeding sites, and prey on hatchling turtles (DBCA 2017c). Recently, silver gulls were recorded pecking humpback whale (*Megaptera novaeangliae*) mothers and calves resting on the surface in Exmouth Gulf (Harkness and Sprogis 2020). Inland activities, such as irrigation or groundwater drawdown, may have indirect impact to birds through the alteration of rainwater inflow into mangrove areas (KBA Partnerships 2020).

Climate change is predicted to impact the birds of the region through similar processes affecting coastal and arid zone birds throughout Australia. Increased storm events, increased temperature, and sea level rise may impact the important mudflat and mangrove habitats (Ellison 2015; Ward et al. 2016). Climate change is expected to impact terrestrial birds through the changes to the distribution and extent of available wetland habitats (Roshier et al. 2001) and changing distributions of dryland bird species (van der Wal et al. 2013).

8.2.3.4. Mammals

At least 42 species of terrestrial mammal species have been recorded within the North West Cape and surrounds (within a 50km search area, ALA 2021; W.A. Museum 2021) including Exmouth Gulf and Cape Range. However, the total number of mammal species for the area is likely to be higher.

The assemblage is typical of the arid zone and Pilbara region, but fossil records indicate that since European colonisation, approximately half of the original mammal fauna of the Cape Range area has become locally extinct (Baynes and Jones 1993; Baynes and McDowell 2010). For example, some usual Pilbara species are locally extinct, including the northern quoll (*Dasyurus hallucatus*) and bilby (*Macrotis lagotis*). In addition, cave subfossil records from Cape Range have the highest concentration of the central rock rat (*Zyzomys pedunculatus*) more than anywhere else in its distribution (Baynes and Jones 1993), but now it appears the species is locally extinct.

No endemic mammal species are recognised in the area. However, three endemic Pilbara species have distributions that include the North West Cape: the little red kaluta (*Dasykaluta rosamondae*); the Pilbara ningaui (*Ningaui timealeyi*); and the western pebble mound mouse (*Pseudomys chapmani*).

Species of conservation significance include the black-flanked rock-wallaby, *Petrogale lateralis lateralis* (Endangered, *Biodiversity Conservation Act 2016* [BC Act]; EPBC Act 1999), that inhabits steep escarpments, rocky outcrops, overhangs and caves of Cape Range and is regularly observed at Mandu Mandu, Pilgonaman Gorges and Yardie Creek (DoE 2016); the brush-tailed mulgara (*Dasycercus blythi* [Priority 4]) that has been recorded in the southern areas of the cape near Giralia Station. In addition, the golden-backed tree-rat (*Mesembriomys macrurus* [Priority 4[), the water-rat, rakali (*Hydromys chrysogaster* [Priority 4]) and the long-tailed dunnart (Sminthopsis longicaudata [Priority 4]), occur in the Cape Range National Park (DEC 2010) but no specimen records for these species exist from the area. Mounds of the western pebble mound mouse (*Pseudomys chapmani* [Priority 4]) were noted on the Cape Range coastal plains and described as 'moderately common and fairly widespread' in the Exmouth borefield area including one active mound (Water Authority 1995), but there are no confirmed records available in the Atlas of Living Australia database. A record of the Pilbara leaf-nosed bat (*Rhinonicteris aurantia* Pilbara form [Vulnerable BC Act 2016; EPBC Act 1999]) is known from a W.A. Museum specimen collected at Milyering Visitor Centre in 2006 and reported as "found" and may be a potential vagrant to the area. North of the Exmouth Gulf, a specimen of the western barred bandicoot (*Perameles bougainville*) was collected around Onslow in 1909, but the species is considered extinct in the Pilbara region and is now only known from extant and reintroduced populations in Shark Bay and Mt Gibson Station.

Some of the offshore islands provide conservation management for species that are threatened on the mainland due to few introduced predators and competitors and protection from fire (Short and Smith 1994; Ottewell et al. 2014). Translocation programs have attempted to introduce selected species for conservation and protection. Two species have been translocated to Doole Island: the Shark Bay mouse (*Pseudomys fieldi*) was unsuccessful possibly due to predation by goannas and cyclonic tidal surges (DEC 2012b; Seddon et al. 2015; DBCA 2020a); and the introduction golden bandicoot (*Isoodon auratus barrowensis*) that was considered successful (Mawson 2004) but may be susceptible to erosion of genetic diversity over time given the small population (Ottewell et al. 2014). Nearby, the northern short-tailed mouse (*Leggadina lakedownensis*) was translocated to Serrurier Island. In addition, the reintroduction of the brush-tailed possum to Cape Range National

Park from Barrow Island was reported to have failed due to fox predation (DEC 2012). According to the ‘Pilbara Inshore Islands Management Plan 2020’, Doole, Roberts, North West Doole, Whitmore, Sandalwood Landing, Burnside, Simpson, Tent and Muiron Islands are still declared ‘other than class A’. However, it is proposed for them to become Class A reserves (DBCA 2020a).

At least twelve species of bat have been recorded on the Cape Range peninsula and around the Exmouth Gulf area, including islands (Kendrick 1993; DEC 2010; DBCA 2020a). Some of these species may be vagrant species. Coastal mangroves provide important habitat to specialist species such as: the north-western free-tailed bat (*Ozimops coburginanus*) and the Arnhem long-eared bat (*Nyctophilus arhnemensis*), which have been recorded from near Simpson and Doole Islands; and the northern mastiff bat (*Chaerophon jobensis*) from near Tent Island (DBCA 2020a). Fringing mangrove habitats around the gulf potentially support habitat for the locally extinct water rat (Baynes and Jones 1993).

Introduced mammals account for 24% of the mammal fauna of the Exmouth Peninsula, and include: predators such as wild dogs, feral cats and foxes; and feral herbivores including rabbits, goats, donkeys and cattle; and the house mouse and black rat (e.g., DEC 2010). Foxes have been observed crossing mudflats at low tide to Burnside, Tent, Sandalwood and Hope Point Islands (Abbott and Wills 2011), which may have implications for conservation significant taxa and other small mammal fauna on the islands. Conversely, densities of the euro (*Osphranter robustus erubescens*) appear to have increased due to adaptation to modified human environments, such as around caravan parks, which may lead to overgrazing and environmental degrading effects on the values of the Cape Range National Park (DEC 2010).

Potential impacts from human activity include disturbance to mammals on islands and mangroves from tourists and fishing industries, and in terrestrial environments from camping, caving, rock-climbing, especially around areas where rock wallabies are present. Development, including mining and infrastructure, may directly impact mammals through the removal of habitat and mortality from collisions with vehicles, and indirectly through increased light and noise, and ground-water drawdown leading to reduced water and vegetation availability.

Given the high proportion of mammal fauna extinctions in the area since European settlement, climate change is likely to exacerbate existing impacts to mammal fauna and potentially lead to further local extinctions. The species of highest risk are the critical weight range mammals (those in the 35 to 4200g weight range) including the echidna (*Tachyglossus aculeatus*), and golden-backed tree rat due to the risk from decreased rainfall; black-flanked rock-wallaby from loss of permeant water sources (Burbidge and McKenzie 1989; DBCA 2017); and those inhabiting islands such as the pale field rat (*Rattus tunneyi*), and mangrove and coastal habitats due to the risk from sea level rise and increasing storm events.

8.2.4. Terrestrial Environmental Quality

8.2.4.1. Soil Quality

8.2.4.1.1. Pilbara Region

The Pilbara region is characterised by shallow stony soils on hills and ranges as well as sandplains (Van Vreeswyk et al. 2004). In the south, soils are mainly red earth over hardpan on level to gently inclined plains. Lower flood plains have cracking and non-cracking clay soils. Duplex (texture-contrast) soils occur in localised areas on saline alluvial plains. These soils support grazing and are susceptible to erosion.

Concentrations of arsenic, nickel and chromium in sediments of the nearshore Pilbara region have caused concerns to regulators for many years (Stoddart et al. 2019). A meta-analysis of data collected over many years across hundreds of kilometres of coastline, shows that chromium and nickel (and arsenic more rarely), occur at concentrations above the screening trigger thresholds outlined in national guidelines. Past dredging activity is the most likely contributor. Stoddart et al. (2019) concluded that levels of these heavy metals were little threat to biota.

8.2.4.1.2. Exmouth Region

Surface sediments of the Exmouth Gulf are largely quartz and calcite sand which is high in phosphorus, carbonate and iron (Brunskill et al. 2001). Barium, lithium, lead, and copper vary in direct proportion to the abundance of the aluminosilicate fraction. The Tantabiddi Terrace forms the major part of the West Cape Range coastal plain (Hesp and Morrissey 1984; Kolkovski and Machin 2004). Large volumes of alluvial sediments of variable depths cover much of the plain where the salinity is high (19 parts per thousand), alluvial (cover) sediments are thin to non-existent. The coral bound stone and calcarenite forms a relatively uniform, very hard sheet (Hesp and Morrissey, 1984). Along the western coastline of Exmouth Gulf, the plains consist of brownish sands to a depth of 60-100cm over limestone (Kolkovski and Machin 2004). The coastal dunes and beaches consist of calcareous sands. Non-cracking clays, ≤55cm deep with ~pH 8.5, also occur in the area.

The Holocene Yanrey Delta, located on the eastern shore of Exmouth Gulf, is a unique arid-zone delta of international significance (Semeniuk and Brocx 2020). The Yanrey River interacted with the dune field to form a unique arid-zone dune complex. The complex consists of deltaic deposits of sand and mud with inter-dune swales filled with floodplain red mud in isolated lenses. The delta and regional winds have transformed originally coarsely-spaced dunes to more finely-spaced dunes. The 2002 Biodiversity Audit for W.A. concluded that large reserves, extensive sandplains and dune fields had not been degraded by stock and feral herbivores and were mostly in good condition (McKenzie et al. 2002).

Giralia Bay mangroves (Photo: Wendy Thompson)

Holocene coastal landforms flank the dunes from South Wapet Creek to the Sandalwood peninsula (Kolkovski and Machin 2004). Limestone platforms and coral outcrops occur infrequently along the eastern shore. The eastern hinterland is lower lying, sloping gently westward to the embayment. The southern shores of Exmouth Gulf comprise extensive mud and sandflats. The western shore is mostly narrow coarse-grained pebble beach abutting low intertidal limestone.

The Giralia Province is based on Cretaceous and Tertiary marine sediments, mainly consisting of calcarenite, other limestones and bentonitic siltstone (Mitchell et al. 1988). Close to half of Giralia Station consists of sandplain, dunes or swales with thin sand cover and uniform textured, red or reddish-brown soil with minor accumulations of clay. Soils are generally alkaline (except shallow loams over the hardpan) and low in salinity (except near the coastal fringe). Where Giralia Station meets Exmouth Gulf, mudflats are subject to tidal inundation and have highly saline soils (> 0.5% salt). Saline loams and duplex soils are common on slopes, plains and drainage floors.

Eliot et al. (2011) described the soils of the Exmouth area in detail. The plateau and steep slopes of the Cape Range, Giralia and Rough Ranges are characterised by calcareous lithosols. Soils are 10 to 40cm deep and are usually dark reddish brown with ~pH 8.5 (Kolkovski and Machin 2004).

The Exmouth Gulf islands are ringed by narrow beaches and fringing shallow subtidal to intertidal limestone platforms and coral outcrops (Kolkovski and Machin 2004). The soil of inshore islands is alluvial with shoreline and aeolian deposits that are vulnerable to erosion, particularly if surface vegetation is removed (e.g., fire, cyclones, trampling by visitors, vehicles, excavation) (DBCA 2020a).

8.2.4.1.3. Pastoral Land

Van Vreeswyk et al. (2004) found ~77% of 12,445 visual traverse assessments of Pilbara pastoral land, indicated ‘good’ or ‘very good’ vegetation condition, 11% indicated fair condition and 12% indicated poor or very poor condition. Poor or degraded soils with loss of litter layers and minerals have been identified in pastoral land of the Carnarvon Bioregion (Payne et al. 1987). The continental stress class (a measure of landscape health) of the Carnarvon Bioregion is three (medium). It would be rated worse except for a significant knowledge gap; the loss of native vegetation and soil have not been measured (McKenzie et al. 2002).

8.2.5. Landforms

8.2.5.1. Key Landforms

The physical geography of the Exmouth Gulf area is characterised by limestone ranges, a fringing coral reef, sand plains and dunes, a shallow coastal embayment and large saline lake (Russell 2004).

Exmouth Gulf is defined by three geomorphic provinces: western hinterland, eastern hinterland and North West Shelf (Brown 1988). The Cape Range (up to 300m above sea level), Rough Range and Giralia anticlines (~100m above sea level) dominate the western hinterland. These features are flanked by ridges up to ~50m above sea level.

Features of Exmouth Gulf’s physical geography reflect processes that have taken place over 150 million years including tectonic and sedimentary activity, the separation of the Gondwanan supercontinent and changes in climate and sea levels (Russell 2004).

The broad scale geomorphology of the Cape Range region, including regional-scale morphotectonics, ages of terraces, fossil evidence, carbonate terrain and coastal margins, was reviewed by Wyrwoll et al. (1993).

The DBCA Cape Range National Park Management Plan 2010 details the landforms of the National Park (DEC 2010). The landforms are described as relatively unspoilt. The Landscape Character Type is classified as 'high scenic quality' based on criteria including diversity, uniqueness, prominence and naturalness. Areas of the Cape Range National Park with particularly high scenic quality include the canyons, slopes, ridges, rocky outcrops, rock walls, hills, blowouts, dune formations and ocean shoreline including headlands, sandy points and tidal flats.

Short (2005) provides descriptions of the western beaches within the Cape Range National Park, and along the Exmouth Gulf coastline and islands. Short (2020) discusses the climate, geology and coastal and biological processes of the semi-arid North West from Exmouth Gulf to King Sound.

A closer examination of the Bay of Rest and Heron Point area at the south-western end of Exmouth Gulf identified 13 geomorphic units, reflective of climate and sea level changes (Fitzpatrick et al. 2019).

Hamilton-Smith et al. (1998) reviewed the scientific literature on the Cape Range Karst Province and management implications. The Cape Range Karst Province is described as highly important with a range of unique values associated with its archaeological, geomorphic and subterranean attributes. Limestone from the Cape Range contain *Lepidocyclina* and other foraminifera (Chapman 1927).

The Cape Range's rich variety of landforms have a significant geo-evolutionary history (Hamilton-Smith et al. 1998). Pelagic biogenic carbonates deposited during the mid-Cretaceous are now exposed as the limestone karst of the Cape Range (Russell 2004). Twiggs and Collins (2010) produced a chronology of the Holocene development of the eastern Ningaloo Reef within Exmouth Gulf embayment.

In addition to their geomorphological importance, the landforms of Cape Range underpin the area's biodiversity and have biogeographical and ecological significance. For example, Humphreys (2006) discusses the association between the Bundera Sinkhole, groundwater ecosystems and vegetation. It is likely that the separation of bird populations is related to distinct landforms and vegetation of the Cape Range peninsula (Kendrick 1993).

Since the uplift of the Cape Range in the late Miocene/early Pliocene Epoch, the area has been subject to ongoing coastal marine and terrestrial geomorphic processes that maintain the area's unique and globally significant habitats and biodiversity (Russell 2004). Since the uplift, and through the Tertiary period the dissolution of limestone has produced the karstic environment important to maintaining the stygofauna and troglofauna ecosystems.

The tsunami hypothesis proposes that prehistoric tsunamis were larger than historic ones (Nott 2004). The W.A. coast is prime territory for investigating the tsunami hypothesis because four of the most powerful tropical cyclones anywhere in the world occurred here between 1999 and 2002. Mapping by the Geological Survey of Western Australia and others has identified a multitude of debris deposits along the W.A. coastline that are indicative of paleo-tsunamis. Coral, shell and wave eroded channels on top of a headland in north Western Australia (Bryant and Nott 2001) indicate a run-up height of at least 30m (Nott 1997). Young et al. (1997) demonstrated that the long-term frequency of tsunami impacts on the coast of Australia is as high as the frequency of tsunamis in the Ryukyu Islands, one of the most tsunami-prone locations in the world. The only difference between this location and Australia is that a substantial tsunami has not struck an urban centre in Australia since European settlement over the last 230 years.

Numerous threats to the Cape Range landforms have been identified (Wood 2003). Threats to the dune systems include waste and fishing (e.g., launching boats from beaches thus affecting primary dunes and beaches). Coastal landforms can have low stability resulting in susceptibility to natural or human disturbances (DEC 2010). Cape Range landforms are also susceptible to degradation and erosion because low annual rainfall results in slow plant growth.

To support strategic planning and facilitate risk assessments, a report by Damara W.A. Pty. Ltd and the Geological Survey of W.A. provides information regarding landform vulnerability along the Gascoyne coast (Eliot et al. 2011).

An analysis of the platform and geomorphic attributes of several northwest Australian islands was used to assess their potential vulnerability to future erosion (Bonesso et al. 2020). In Exmouth Gulf, Y Island recorded an increase in island volume and average elevation whilst Eva Island (also known as Victor Island) recorded a decrease in land area, volume and elevation, potentially suggesting erosion.

During the 1995 Consultative Environmental Review of the Proposed Special Residential Development, Exmouth (Lyndon Locations: 222 and 223), two sensitive geological formations were deemed not suitable for housing development (W.G. Martinick and Associates Pty. Ltd. 1995). These included the Holocene coastal deposits (coastal dunes) and Quaternary alluvial sediments associated with creeks.

8.2.5.2. Geomorphology and Geochemistry

A collaborative project between Geoscience Australia and the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA), included a literature review on the sedimentology and geomorphology of the North West Marine Region (NWMR) and nominated area of the North Marine Region (NMR) (Baker et al. 2008). The North West Shelf extends from Exmouth Gulf to Darwin and includes four major Phanerozoic (550 million years ago) sedimentary basins of ≤15km deep: Bonaparte, Browse, offshore Canning and Carnarvon Basin. The Carnarvon Basin encompasses the Cape Range peninsula, extending inland ~160km (WG Martinick and Associates 1995).

Hocking (1988) describes the regional geology of the Northern Carnarvon Basin including Exmouth, Barrow and Dampier sub-basins. Using new basin-wide broadband 3D seismic data, the extrusive volcanics of a late Jurassic pulse of igneous activity was mapped in the Exmouth sub-basin (O'Halloran et al. 2019). Features mapped included cone-shaped vents up to 8km in diameter and >250m high.

Wyrwoll et al. (2000) reported on the geological, geomorphological and soil of 63 terrestrial quadrats in the Carnarvon Basin region and identify links between the biota and physical environment. Brooke et al. (2009) reviewed research activities on the Carnarvon Shelf. They aimed to identify a range of physical environmental parameters of the southern Carnarvon Shelf as surrogates of patterns of benthic biodiversity.

8.3. Water

8.3.1. Inland Waters

8.3.1.1. Groundwater Systems

Groundwater is a highly significant environmental value because throughout the Exmouth Gulf area, as there is a limited supply of freshwater, and it is critical to the survival of biota and human settlement. Exmouth's only source of freshwater is an unconfined karstic limestone aquifer (karstic aquifer system) present within saturate solution cavities and voids of the Trealla and Tulki Limestone of the Cape Range Peninsula (Boulton et al. 2003; Lee 2008). The karstic aquifer overlies the less permeable Mandu Limestone / marl (Allen 1993; EPA 1997a). Near the coast, the water table approaches sea level at 0m AHD (EPA 1997a).

The storage volume of the Cape Range unconfined karstic aquifer is estimated to range between 200 to 500 million m^3 of groundwater as calculated from a surface area of 1 x 109m^2 (above 100m surface elevation), a saturated depth of 100m and a 5% porosity. Restricting factors include the ridge line (drainage divide, east and west), presence of the Tulki /Trealla Limestone characteristics, dependent ecosystems, abstraction drawdown boundaries, groundwater recharge patterns and effects of saline intrusion. The Cape Range Peninsula (Water Reserve 34055) is designated by DWER as a Priority 1 Groundwater supply area (EPA 1997a). For management purposes, the Exmouth groundwater area is divided into groundwater management subareas that reflect groundwater availability and accessibility (Figure 7). In 2006, the Cape Range aquifer resource was split into its fresh and saline components (pers. comm DWER). The 'saline resource' category was introduced to account for near-beach saline groundwater where the aquifer is being used essentially to filter seawater through 'beach wells' for use in aquaculture, marine research and Reverse Osmosis desalination purposes. Confined groundwater is present within the Birdrong Siltstone Formation which is present about 1000 to 1500m below ground level and extends in an easterly direction underlying the Carnarvon Basin to the contact with the Yilgarn Craton. There is currently no groundwater use or allocation component for the deeper, confined Birdrong Sandstone aquifer due to development costs and the lack of demand. The aquifer has been documented to provide large quantities of saline water of between 1,000 to 4,000mS/m (8000 – 30,000mg/L TDS) across the Carnarvon Basin.

The Exmouth unconfined karstic limestone aquifer system is present as saturated voids and cavity in the Trealla and Tulki Limestone units with the "fresh" groundwater extending >100m below sea level relative to the Ghijben Herzberg ratio as measured from the Cape Range Limestone ridge crest (pers. comm. DWER). The "fresh" groundwater horizon grades downward into a brackish transition zone that overlies saline groundwater associated with the marine environment. The depth of groundwater development is generally restricted to the karstic limestone of the Trealla and Tulki with limited groundwater availability in the underlying Mandu Limestone due to the lack of karstic features.

The capacity for development is a function of the catchment size from the ridge crest to the bore site, limestone characteristics and karstic conditions and spatial orientation (pers. comm. DWER). Abstraction volumes are limited due to interference and risks of saline groundwater upconing (vertical upward movement of saline groundwater) and landward movement of the saline wedge. Groundwater storage and recharge capabilities represent restricting conditions for groundwater abstraction. The unique characteristics of each location must be considered in the determination of groundwater availability and abstraction rates.

The aquifer consists of a freshwater layer which overlies a transition zone of brackish water resting on the seawater wedge (EPA 1997a, 1999; Kolkovski and Machin 2004). The freshwater/saltwater transition is ~5km from the coast and the zone of diffusion is approximately 20-30m deep (EPA 1997a). Due to the interaction between seawater and groundwater, water drawn from the aquifer (e.g., via bores on pastoral stations) may have high salinity (depending on the depth of the bore). For animal or human consumption, much of the groundwater requires treatment including desalination, cooling, softening and removal of iron (W.A. Planning Commission 2004).

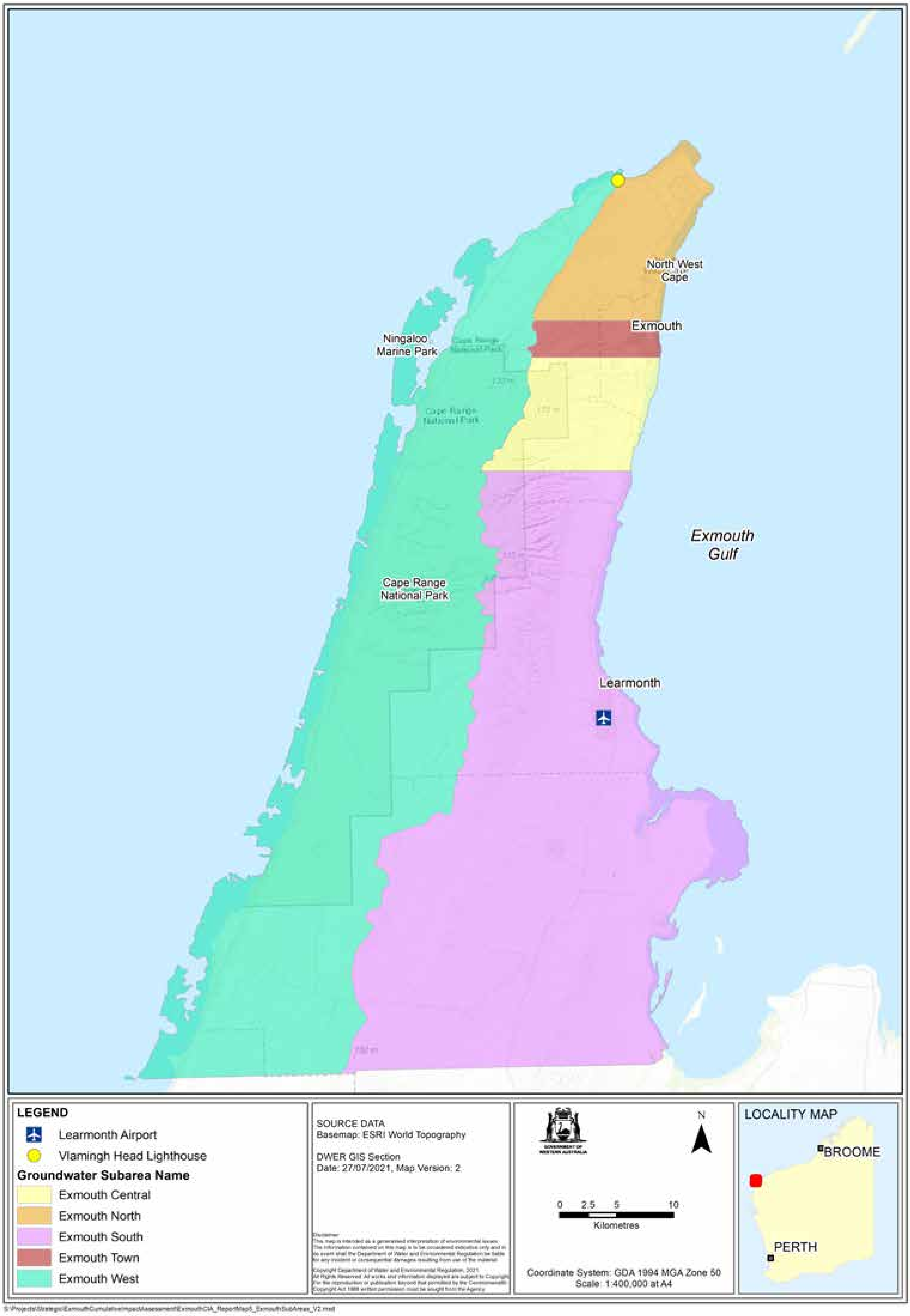


Figure 7: Groundwater subareas of the Exmouth Groundwater Area.

The freshwater groundwater lens is recharged by storm runoff and direct surface infiltration through permeable river beds, ephemeral streams and limestone outcrops across Cape Range (EPA 1997a, 1997b; Kolkovski and Machin 2004). Thinning of the freshwater lens and increasing groundwater salinity in the past has been attributed to periods of low rainfall, tidal influences and groundwater abstraction (Lee 2008). The groundwater will move down gradient towards the coast with discharge into the marine environment. Recharging of the groundwater system occurs rapidly after heavy rainfall (Kolkovski and Machin 2004). Groundwater loss will occur through evapotranspiration from coastal vegetation near Exmouth and evaporation from pools along Yardie Creek and Qualing Pool. Ephemeral springs are also reported as well as a large perennial freshwater spring at Tulki and Mandu limestones contact at a tributary of Shothole Canyon (Allen 1993).

The spatial scope for this review also includes part of the Ashburton River Catchment and part of the Carnarvon Basin (Van Vreeswyk et al. 2004). The Carnarvon Basin is underlain by the Birdrong Aquifer (saturated Birdrong Sandstone) that is under artesian pressure with temperatures ranging from 40 to 70˚C.

The geology, geomorphology and groundwater environment is markedly different for the Ashburton River Catchment, which includes two major aquifer systems: the Yarraloola Conglomerate aquifer and the Lyons Group aquifer. The Yarraloola Conglomerate aquifer is considered poor, with bore yields generally <100m^3/day. Groundwater recharge occurs mostly by leakage from the alluvial aquifers. Salinities at depth range from 6000 to 40,000 mg/L total dissolved solids (TDS), increasing with depth and along the flow. The Lyons Group aquifer is large (average bore yields >1,000m^3/day) and saline (mostly >20,000mg/L TDS) suggesting relatively low rates of recharge. The Lyons Group aquifer with flow rates up to 5000m^3/day, is a potential supply of saline groundwater from depths >100m (Van Vreeswyk et al. 2004).

Exmouth's groundwater systems constitute unique groundwater dependent ecosystems (GDE) that support high levels of biodiversity and endemism (Kløve et al. 2014). The Exmouth Cape Range is the only Australian example of Tertiary (65 thousand – 1.8 million years ago) orogenic karst where environmental conditions have remained relatively stable facilitating the survival of unique biota (Humphreys 2006) such that the GDE's represent a high priority refugia in a changing climate (Davis et al. 2013). The Bundera Sinkhole on the coastal plain of the Cape Range peninsula is the only known deep continental anchialine system in the southern hemisphere. The Sinkhole contains many extremely vulnerable relicts and short-range endemics (which are discussed under 'marine environmental values') (Boulton et al. 2003; Davis et al. 2013).

At risk groundwater ecosystems include ephemeral creeks and permanent soaks (McKenzie et al. 2002). Processes which threaten groundwater ecosystems include groundwater development, pollution, grazing, salinity, weeds, mining, inappropriate tourism, urbanisation and climate change.

Abstraction of groundwater and localised groundwater drawdowns have been recognised as risks since Exmouth was established in the 1960s (Allen 1993; Boulton et al. 2003). In 1997, the EPA reported abstraction levels were 100ML/km/year (EPA 1997a). In 1998, concerns were raised that projected population and tourism growth over the next decade means *"the availability of groundwater on a sustainable basis is questionable"* (W.A. Planning Commission 1998). Options for other water sources, namely the establishment of a desalination plant, poses significant questions surrounding sustainability (Bradley 2012).

In 1997, potential risks of the proposed expansion of Exmouth Marina included effects on groundwater (impact of drawdown), enhanced landward movement of the saline wedge and surface water (impact of high flow events). The EPA identified that the proposed expansion would cause temporary effects on water levels and salinity of groundwater during dewatering for construction of the marina and canals. The EPA also noted that the development would cause permanent changes in salinity of the aquifer due to seawater moving into the marina and canals. However, the EPA concluded that the groundwater concerns could be managed such as with the inclusion of detention basins and culverts (EPA 1997b).

Contamination of Exmouth's limited groundwater resource is an ongoing concern. The Exmouth Water Reserve Water Source Protection Plan 2000 describes how Exmouth Town Water Supply is vulnerable to contamination from inappropriate land uses in its recharge area (Water and Rivers Commission 2000). The Plan highlighted potential point sources of contamination including: the Department of Transport quarry, Whitecrest limestone mine, Exmouth Quarries, Qualing Scape waste disposal site and the Airfield. Several recommendations were made to minimise the risk of contamination including limiting vehicle access, ceasing the discarding of oil at the tip site, opposing future mining leases within the Water Reserve and consideration of groundwater protection in the Cape Range National Management Plan.

Mining operations within Exmouth Gulf present a potential pollution risk (Kolkovski and Machin 2004). In 1998, Sun Resources NL, proposed to drill a land-based petroleum exploration well (White Opal-1) on Commonwealth (Navy) land near Point Murat on the tip of the Cape Range peninsula to a total depth of 2600m. Concerns included contamination of unconfined (EPA 1998).

Kløve et al. (2014), in their review on the effects of climate change on GDE, found that climate change can affect water quantity, quality, flow, pH and the hydrological conditions of soil (Kløve et al. 2014).

8.3.1.2. Waste Water

Water Corporation secured a 99-year lease on the proposed Exmouth North Waste Water Treatment Plant (WWTP) located on Commonwealth Government land (McLean 2018). The WWTP consists of three ponds: a 'smart pond' containing an anaerobic pot, a maturation pond and a winter storage dam. Three 350kL storage tanks are located in town near the irrigation sites. The WWTP provides recycled water to the Shire of Exmouth for the Exmouth Recycling Scheme, which includes the irrigation of Public Open Space and the golf course. Water Corporation intend to relocate and upgrade the WWTP, however substantial works are yet to commence.

8.3.1.3. Surface Water Systems

Surface water includes rivers, streams, creeks, lakes and above-ground reservoirs including drinking water (Water Education Foundation 2021). Six main creeks with a total catchment area of 45.4km^2 flow in an easterly direction from the Cape Range ridge crest to discharge into the Exmouth Gulf (Van Vreeswyk et al. 2004). The largest of these is the LIA (Light Industrial Area) Creek catchment (13.4km^2) and the Market Street catchment (18.6km^2). The eastern part of the Cape Range has a well-developed drainage net with well-defined channels (Kolkovski and Machin 2004). The highest central part of the Giralia Province trends in a north northeast direction and drainage occurs via a series of short parallel flow lines fanning out northwest and east over the lower outwash plains (Mitchell et al. 1988). It is expected that a similar number of drainages are present on the western slope of Cape Range within the Cape Range National Park which drain into the Indian Ocean.

Hydrological assessment conducted as part of the proposed Subsea 7 Learmonth Pipeline Fabrication Facility (2019), found that the floodplain has very few defined flow paths based on aerial imagery and topographical data. It was difficult to determine surface water catchment boundaries, but the most prospective groundwater supply area was identified in the area west of the Minilya-Exmouth Road towards the base of the Cape Range and proximate to creek outflows near Little Bore. Groundwater quality assessments identified hypersaline groundwater in bores and fresh to slightly brackish groundwater in the western area (Subsea 7 Australia Contracting Pty Ltd 2019).

Qualing Pool (Photo: Wendy Thompson).

Risks to Exmouth surface waters include those for groundwater mentioned above. Some main river channels in the region have also been reported to be blocked with sand (McKenzie et al. 2002).

PFAS have been detected in the backwater lagoon, east of the Harold E. Holt Naval Communication Base (DoD 2019). PFAS concentrations exceeded the ecological screening criterion. The Commonwealth Department of Defence (DoD) concluded that PFAS contamination most likely occurred through surface water runoff. The lagoon is periodically connected to Exmouth Gulf via a narrow channel at its northern end. During heavy or prolonged rainfall, the lagoon can overflow into Exmouth Gulf. According to DoD, this scenario would involve high levels of dilution. Estimated PFAS concentrations for fish nearshore in Exmouth Gulf marginally exceeded the mammalian wildlife dietary guidelines in the National Environmental Management Plan. However, DoD concluded that PFAS poses a *"low risk"* to lower trophic level terrestrial and marine aquatic organisms, avian food chains, marine mammals and marine turtles.

8.3.1.4. Wetlands

The entire east coast of Exmouth Gulf is included in the Directory of Important Wetlands (Exmouth Gulf East Wetland - WA007) (EPA 2008). The wetlands therein include all salt flats and inshore waters from Giralia Bay to Urala Creek, Locker Point and parts of the Tent, Burnside, Simpson, Whitmore, Roberts and Doole Islands. This area includes temporary wetlands that form around 58% of Tent Island during spring high tide. These temporary wetlands are important habitat for resident and migratory birds (DBCA 2020a).

The mangroves of Bay of Rest near Whitmore Island are recognised as a wetland of regional significance in the 2002 Biodiversity Audit for W.A. (McKenzie et al. 2002). At a national level, these wetlands are listed as wetlands of national importance in the Directory of Important Wetlands in Australia (DBCA, 2020a). In 2008, the EPA recommended against the Yannarie Solar Salt project proposal proceeding as it was deemed environmentally unacceptable to locate a 17,765 hectare salt field within a wetland of national importance (EPA, 2008). At an international level, the east coast wetlands were considered for inclusion in the Ningaloo Coast World Heritage Area and are recognised as a Key Biodiversity Area (KBA 23) (EPA 2008; Key Biodiversity Areas Partnership 2020; DBCA 2020a).

Threats to wetlands in general include changes in water regimes, habitat modification, land reclamation, invasion by exotic species, resource exploitation, changes in hydrology, eutrophication, pollution and climate change (Finlayson and Rea 1999; Junk et al. 2013). Ecological information for northern (tropical) Australian wetlands, including in the Exmouth/Pilbara area, is reviewed by Finlayson and von Oertzen (1993). Mangroves have been considered in more detail under Section 8.1.1.4.

Aerial of Exmouth Gulf east (Photo: Wendy Thompson).

8.3.1.5. Flooding

No official record of flood history is available for the Shire of Exmouth but the town is located on a floodplain where runoff naturally accumulates (Przywolnik 2002; May et al. 2015). The area often experiences tropical cyclones and flooding. On March 22 1999, one of the most powerful cyclones in Australia's historical record, category five TC Vance made landfall in Exmouth and the township experienced the most significant flooding since its establishment in the 1960's. A total of 150mm of rain fell and the wind speed (up to 267km/hour) was the highest ever recorded on mainland Australia. A combination of storm surge and stormwater runoff resulted in the peak flood level reaching 4.5m. In January 1999, prior to the flood events, a bushfire destroyed large areas of vegetation on Cape Range, thus reducing vegetation that would otherwise slow flow. This fire is considered to have been a major contributor to high runoff rates.

A flood management strategy for Exmouth has been developed to provide 100-year flood protection to existing and proposed future development areas via the continued use and maintenance of existing floodways and natural flow paths to three existing ocean outlets (Martens et al. 2000). However, modelling by Roberts (2012), indicates that construction of the Exmouth marina and 'the squeeze' between development and the shoreline has caused loss of essential disaster-mitigating ecosystem functions, increased risk to previously unaffected areas of Exmouth township and reduced adaptability to climate change.

8.4. Air

8.4.1. Air Quality

There appears to be little to no published information available on air quality specific to the Exmouth area. The Air Quality Index (AQI) is not measured in or near Exmouth town site. The northernmost location for which publicly available AQI are recorded is Geraldton.

8.4.2. Greenhouse Gas Emissions

There is limited information readily available on the level of greenhouse gas emissions generated in Exmouth. Increased greenhouse gas emissions from human activities are responsible for climate change and warming of the terrestrial and marine environments, which is a global crisis (Oreskes 2004; Ripple et al. 2019). Climate change impacts on Exmouth Gulf are discussed in Section 7 and are interspersed throughout Sections 8.

Byrnes and Warnken (2006) estimated the overall and per capita greenhouse gas (GHG) emissions associated with tour boat operations in Australia (including information collected from Exmouth and Broome) at 70,000 tons CO_2-e or 0.1% of the transport sector in Australia. This was the fastest growing sector in terms of GHG emissions. On average, this represented an extra 27kg CO_2-e (petrol) to 61kg CO_2-e (diesel) per tourist – the equivalent of driving 140km or 300km in a standard passenger vehicle.

An analysis of GHG emissions from W.A. finfish supply chains found that electricity consumption was the largest contributor followed by refrigeration gas leakage and disposal of unused fish (Denham et al. 2016).

8.5. People

8.5.1. Social Surroundings

8.5.1.1. Examples of Documented Indigenous Heritage

It must be noted that the information in this section was prepared by non-Indigenous authors and only pertains to published literature. As a result, the following section should be considered precursory. It by no means reflects the extent of the area's Aboriginal cultural and spiritual significance.

Terra Rosa Cultural Resource Management in consultation with the Yamatji Marlpa Aboriginal Corporation (YMAC) as agents of the Gnulli Traditional Owners Group, prepared a desktop report of known Aboriginal (and European) heritage places and values within the Shire of Exmouth (Chisholm 2013). Baiyungu and Inggarda (Yinggarda) were described as coastal dwelling societies with sophisticated methods employed in a marine focused economy. A total of 81 registered Aboriginal heritage places and 28 registered reports were found in the Shire of Exmouth including middens and artefact scatter. Middens (n=39), including the Mandu Mandu Creek Rock-shelter in the Cape Range National Park, are characterised by the archaeological remains of marine fauna. Artefact scatter (n=19) are the archaeological remains of camps. The report concluded that, *"there is considered to be a high potential for any development on the Exmouth peninsula to have a significant impact upon heritage places both known and unknown"*.

Prior to the Chisholm (2013) report, several authors detailed registered sites within the scope area, including 14 registered sites of Aboriginal heritage significance on the Ningaloo Coast coastline (Mason and Moore 1998), which emphasised the importance of the marine environment to Aboriginal people in the area. This is also supported by numerous documented shell middens along the northwest W.A. coast, including Exmouth (O'Connor 1996). Numerous shell middens can be found throughout the Cape Range (Morse 1996; Meissner 2011), as well as rock shelters, such as at Mandu Mandu Creek, Pilgonaman Creek, Yardie Well (Morse 1993a). The limestone of the Cape Range preserves organic materials such as shell and bone (Morse 1993a; Morse 1993b; Morse 1993c), and this archaeological evidence, including rock-shelters, coastal shell middens, rock art and open sites, provides the earliest unequivocal evidence for the use of coastal resources and human occupation going back at least 35,000 years. These sites indicate that there was a distinctive regional economy where goods were transported many hundreds of kilometres. It should be noted that these analyses provide insights into the archaeological significance of sites and objects but not their spiritual meaning (Mason and Moore 1998).

In a review of the Unallocated Crown Land (UCL) of the Cape Range peninsula, Meissner (2011), provides a broadscale map of nine registered sites on the W.A. Aboriginal Sites Register including: Winpikayna (Site ID 756), Padjari Cave (11885), Yardie Creek Caravan Burial (6017), Pap Hill 1 (6119), Pap Hill 2 grinding patches (6120), Yardie Station engraving (11400), 5 Mile Well Cape Range (11401), Pap Hill Ochre (17447) and Chugori Rockhole (17448).

Language is a vital cultural value. It has been suggested that there were eleven to twelve Aboriginal languages originally spoken in the Gascoyne-Ashburton region: Maya, Yingkarta, Thalaynyji, Purduna, Pinikura, Tharrkari, Warriyangka, Thiin, Jiwarli, Jurruru and Wajarri (Austin 1988). In the 1980s, it was reported that only older people (>65 years), based in Carnarvon and Onslow, were fluent in language but attempts were being made to teach younger generations in schools.

The DBCA Draft Management Plan for the Pilbara Inshore Islands Nature Reserves and Proposed Additions 2020, explains that the Aboriginal cultural heritage values of the islands are not well known and collaboration with Traditional Owners is needed (DBCA 2020a).

8.5.1.2. Anglocentric Heritage

The DBCA Draft Joint Management Plan for Nyinggulu (Ningaloo) Coastal Reserves 2019, reports a rich European heritage associated with early exploration, pastoralism, cameleers, traders, shipping, pearling and the hunting of whales, turtles and lobster (DBCA 2019a).

The 1825 journal of a Captain Phillip P. King documents an exploration of the W.A. coast including Cape Range and Exmouth Gulf (King 1825). Europeans first ventured into the Gascoyne area in 1839. The 2013 Terra Rosa Cultural Resource Management report lists European heritage places and values within the Shire of Exmouth (Chisholm 2013). Anglocentric heritage sites in the general scope area include the Vlamingh Head Lighthouse Group, Yardie Creek Homestead, Bundegi-Cape Well, Cape Range oil wells, the 'Lonely Grave', Giralia Station, Operation Potshot site and Point Murat Pier. Three commemorative river gumtrees were planted in Exmouth in the 1960s as markers of the relationship between the Australian and American governments.

A total of 39 shipwrecks have been identified in coastal waters surrounding the Exmouth area (Chisholm 2013; DBCA 2020a, 2019a). Within the scope area, three wrecks are documented around Point Murat and include the Fairy Queen (1875), Mildura (1166) and Emlyn Castle (1960).

The first recorded contact between Europeans and local Aboriginal people in the Exmouth area was in October 1875 when The Stefano wrecked south of the Cape (Petkovic 2007; Chisholm 2013). Two survivors from the Stefano, Miho Baccich and Ivan Jurich, were said to have been 'adopted' by a group of Aboriginal people and were, *"impressed with their innumerable acts of kindness, gentle ways and harmony with nature"* (Rathe 1992).

In the context of Australia's history, it is essential to acknowledge the northwest of W.A., including the Gascoyne area, saw systematic persecution of Aboriginal Australians at the hands of European settlers (Austin 1988).

Aboriginal people were hunted, kidnapped and forced to work on pearling boats and pastoral stations (Austin 1988). Large numbers died from the introduction of European diseases. Strong and historically significant Aboriginal resistance was mounted particularly in the 1880s but Jones et al. (2016) wrote that the Yinikutira people of the Exmouth area perished in "an unknown event" within twenty years of European pastoralism. Mason and Moore (1998) wrote that Aboriginal heritage site registration is hampered in the area because, *"the original Aboriginal custodians of the Ningaloo sites were killed"*.

The introduction of the *Aborigines Act of 1905* gave the 'Chief Protector' and police the power to forcibly remove children from their families (in what we now recognise as 'The Stolen

Generation') (Austin 1988). Many Aboriginal children in the Gascoyne and Ashburton regions were removed from their families and taken to reserves.

8.5.1.3. National Heritage

The Cape Range was given interim listing on the Register of the National Estate by the Australian Heritage Commission (AHC) due to the paleo-historical values of the karst, subterranean environments and endemic troglobitic (underground cave) fauna (EPA 1999).

Hamilton-Smith et al. (1998) reviewed the unique values of the Cape Range peninsula. They noted the scientific importance and increasing national and international recognition of the fringing coral reefs, archaeology, geomorphology and subterranean fauna of the area. They recommended that the Cape Range peninsula be nominated as a site of World Heritage significance. In 2011, the Ningaloo Coast including marine (71%) and terrestrial (29%) features was declared a World Heritage site due to exceptional natural beauty, biodiversity and endemism (IUCN 2011).

There are varied reports about the attitudes of local residents to the World Heritage listing. Interviews with 23 locals indicated overall support for World Heritage listing with some concerns about the listing process. The total number of interviewees is unclear but interviews with local residents by Jones and Shaw (2012) revealed some opposition to World Heritage listing by people who feared rapid social and economic change. While results may have been biased by strong but non-representative views, Ingram (2008) found that local residents' (n=132) perception of Ningaloo Marine Park management was influenced by processes and decisions about recreational fishing access. The World Heritage nomination process mainly involved experts and state officials but in a move toward participatory governance, the local community is increasingly involved (Hughes et al. 2016).

8.5.1.4. Amenity

An exercise conducted by Boschetti et al. (2014) in four locations (Melbourne, Canberra, Hobart and Exmouth) explored Australians' perceived visions of the potential future of the country in 2050. Feared futures involved economic growth at the expense of the environment and quality of life. Desired futures focused on local, inclusive, peaceful and equitable environments. These desired futures are reflected in the Strategic Community Plan Exmouth 2030, which states that the local community's vision is, *"To be a prosperous and sustainable community living in harmony with our natural environment"* (Shire of Exmouth 2018).

The Exmouth Local Planning Strategy 2015-2025 described how the Shire of Exmouth is experiencing economic growth driven in part by tourism, lifestyle, industrial and regional development (Barnett 2016). In preparing the Shire of Exmouth Strategic Community Plan (2011), the community expressed its support for progress but not at the expense of the natural environment, their relaxed lifestyle or small-town values. The Strategy aimed to achieve balanced growth while maintaining small-town values and a positive community spirit, increasing the town centre's commercial and retail opportunities and protecting and enhancing the natural environment.

Roberts et al. (2014) explored the vulnerability of the Exmouth township to cyclonic storm surge, property buyers' risk perception, insurance and risk mitigation. Analysis of property sales data 1988 to 2013, indicated that buyers valued amenity so highly that neither flood or cyclone risk affected property prices or sales in Exmouth township (Roberts et al. 2015). Reardon et al. (1999) described the structural impact TC Vance had on Exmouth township. The impact on approximately 75% of houses was negligible with the houses originally built for the United States Navy least affected and transportable homes the worst affected. After TC Vance in 1999, buildings in Exmouth township were constructed or repaired to withstand cyclone strength winds

(Arthur and Gray 2019). This housing pool in Exmouth township, an essential amenity value for residents and visitors, is reported to be in a severe shortage in 2021 (www.abc.net.au/news/2021-02-15/exmouth-housing-shortage-due-to-border-closures,-tourist-season/13150896)

The amenity value of the area to visitors has been described qualitatively (Tonge et al. 2013). Visitors demonstrate high site fidelity to the Ningaloo coastline. Visitors (n=30) to remote coastal campsites along the Ningaloo Marine Park valued the opportunity to escape into isolation in warm, beautiful, natural, expansive surroundings. They reported feeling a sense of community as they bonded with family and like-minded people. Visitors valued sharing rewarding experiences, including land and marine-based recreation, that brought them and the people around them happiness. The amenity value of the area to visitors has also been described quantitatively. Hailu et al. (2011) estimated the value visitors to Ningaloo Marine Park place on recreational activities at specific sites. Recreational site choice was found to be influenced by cost of access, suitability of the site for various activities and water sports.

A survey of 125 local residents indicated that there is strong local support for scientific research in the Ningaloo Marine Park. The local community values scientific research as important for the management of the park and to enhance trust in local managers (Cvitanovic et al. 2018).

Ease and safety of movement to and within the region is challenging for both residents and visitors (Shire of Exmouth 2018). An extensive network (totally 1256km) of vehicle tracks facilitates public access along the Ningaloo Marine Park coast (Kobryn et al. 2017). Conservation areas had the least extensive vehicle track network while pastoral stations had the most tracks. Along the Ningaloo Marine Park, Waayers et al. (2009) found the highest density of vehicle tracks at Bateman's Bay, Bundegi, Jane's Bay and Coral Bay, mostly in the critical nesting area for turtles.

Fulton et al. (2011) undertook modelling of the entire Ningaloo/Exmouth system to outline potential futures associated with various development and management possibilities. Under a wide range of scenarios, the modelling took into account aspects of industry, the biophysical environment and socio-economic factors. A diverse range of futures were foreseen. Particular management interventions were identified that steer towards desirable outcomes. Influential drivers included fishing regulations, housing plans, marketing and catering for specific tourist types, and infrastructure development.

8.5.1.4.1. Land and Marine-Based Recreation

A snapshot of the land and marine-based recreational activities occurring, or previously occurring in Exmouth Gulf is given in Table 17. More literature was documented for marine-based activities, which does not mean land-based activities are not frequently occurring. Some land and marine-based activities may also not have been captured in the literature sourced.

Table 17: Snapshot of the literature pertaining to the various recreational activities in the Exmouth area. Most of the literature sourced relates to marine-based activities.

Activities	Location(s)	Comments/concerns	Reference(s)
Camping, fishing, diving, whale-watching and boating	Serrurier Island Nature Reserve, South Muiron Island, Thevenard Island	Concerns include campfires, rubbish, pets, disturbance to nesting birds, lights, toileting. Some activities may not be compatible with the reserves' purpose	DBCA (2020a)
Fishing, snorkelling	Ningaloo Marine Park, Cape Range National Park	Recreation varies with adjacent land tenure type. For example, there were lower levels of recreational fishing and higher levels of snorkelling where sanctuary ('no-take') zones were adjacent to Cape Range National Park	Smallwood and Beckley (2012) Smallwood et al. (2013)
Recreational fishing	Managed fishing zones in W.A., including the Gascoyne region, and within that, Exmouth Gulf	Recreational fishing catch rates are significantly influenced by fish stocks, effort, bait use and if the fish is the targeted species	Raguragavan et al. (2013)
Recreational fishing	W.A.	52% of 906 surveyed fishers had experienced ≥1 shark encounter but the majority were still satisfied despite these encounters	Ryan et al. (2019)
Recreational fishing	Ningaloo Marine Park	Modelling the ecological and economic impact of recreational fishing on the coral reef system in Ningaloo Marine Park	Gao and Hailu (2011)
Snorkelling, visiting beaches, fishing, swimming with whale sharks	Gascoyne region including Exmouth	A 2003 Gascoyne Coast visitor survey (n=336) found the most important reasons for visiting included snorkelling/diving (26.5%), Ningaloo Marine Park (22%) and nature (17.6%)	Carlsen and Wood (2004)
Whale shark watching	Ningaloo Marine Park	Whale sharks may respond to vessels by changing direction more frequently	Raudino et al. (2016)
Wide variety of land and marine-based recreation	Ningaloo Marine Park	This report lists human uses of the Marine Park, estimated numbers of people engaged in these activities and key locations	Cary et al. (2000)

8.5.1.4.2. Economic

In 2004, on behalf of the Sustainable Tourism Cooperative Research Centre, the then Department of Conservation and Land Management (CALM) and W.A. Tourism Commission, made the first attempt to estimate the recreation and tourism value of W.A. national parks, marine parks and forests (Carlsen and Wood 2004). An estimated 272,000 domestic and international tourists visited the Gascoyne region in 2002, contributing an estimated $149 million to the economy.

Wood and Glasson (2005) analysed six years of longitudinal data from 1997 to 2003 and estimated the direct spend of tourists to the Ningaloo Coast at $138 million, with >$80 million annually in Exmouth township alone. Annual visitor spend attributable to the natural environment was roughly estimated at $124 million, that is 90% of the total $138 million spend.

More recently, Deloitte Access Economics estimated the economic contribution of the Ningaloo region to the W.A. state economy 2018 to 2019 at $110 million, 90% of which is attributed to reef oriented tourism, supporting more than 1000 full-time jobs (Deloitte Access Economics 2020). This estimate included four economic sectors: tourism, commercial fishing, recreation (residents), and management and research.

8.5.1.4.2.1. Commercial Fishing

Annual reports on the status of all W.A. fisheries are produced by DPIRD (Gaughan and Santoro 2019; Gaughan and Santoro 2020). The primary fishery operating in Exmouth Gulf is the Exmouth Gulf Prawn Managed Fishery (Gaughan and Santoro 2020; Kangas et al. 2015). Approximately 29% (335nm^2) of Exmouth Gulf is trawled, and trawling is prohibited in the nursery area (344nm^2) in the southern and eastern section of the Gulf.

Brown tiger, western king and blue endeavour prawns are the primary target of the fishery, though bycatch landings of blue swimmer crab, squid, bugs (*Thenus orientalis*), coral prawns, cuttlefish and mantis shrimp are also caught. A 2009 case study on the Fishery, assessed its management as a template for other fisheries, identified legislative amendment imperatives, and assessed the case for progressing co-management and Marine Stewardship Council certification of the fishery (Rogers 2009). The Exmouth Gulf Prawn Fishery Ecologically Sustainable Development Reports provide extensive information on the status and management of the Fishery (Kangas et al. 2015). In October 2015, the fishery was granted Marine Stewardship Council (MSC) certification, and Kangas et al. (2015) provides a comprehensive description of the Fishery, including details of the environment, methods, gear, historical catch, target species biology, external influences and management systems.

Kailis (2000) and Kailis et al. (2010) discussed the pros and cons of the sole ownership of the Exmouth Gulf Prawn Managed Fishery and made comparisons to other Australian fisheries. Kailis et al. (2010), asserted that the Fishery is managed in a more sustainable way than a multiple-owner competitive example but also outlined other multiple-owner strategies that could lead to sustainability. Kailis (2000) posited that traditional fishery strategies have poor economic performance due to inter-fisher competition. In contrast, they praised co-operative management, which utilises research and innovation to improve efficiency and sustainability.

Penn and Caputi (1986) investigated the cause of severely reduced recruitment of tiger prawns (*Penaeus esculentus*) in Exmouth Gulf in 1980. They evaluated spawning stock levels, environmental factors, fishing effort and recruitment. Findings indicated a direct correlation between fishing effort, autumn recruitment and spring spawning stock. These results suggested that recruitment equilibrium would decrease with increased fishing effort. Harman (2001) found a full moon was associated with poorer catch in the Fishery.

Large-scale prawn stock enhancement programs have only been implemented in Japan and China (Loneragan et al. 2006) but stock enhancement policies are being considered in W.A. (Loneragan et al. 2013). Loneragan et al. (2013) synthesised information on marine and estuarine release programs in Australia and identified potential opportunities for stock enhancement ranging from releases of tens of thousands (e.g., abalone), hundreds of thousands (e.g., tiger prawns) and millions (e.g., eastern king prawns) of individuals. Loneragan et al. (2000) discussed the viability and ecological implications of releasing juvenile brown tiger prawns in wild nursery grounds in Exmouth Gulf. Further research was recommended to develop an optimal release strategy including high-density production techniques, development of genetic markers to understand the population, identifying juvenile release habitats, and bioeconomic modelling to understand trends (Loneragan et al. 2003). Subsequent bioeconomic modelling predicted that the release of 21 million 1g prawns would produce an enhanced catch of 100 tonnes with a 66.5% chance of making a profit. The greatest uncertainty was post release mortality (Ye et al. 2005). Loneragan et al. (2006) investigated the feasibility and bioeconomics of releasing hatchery-reared juvenile tiger prawns for stock enhancement in Exmouth Gulf.

A small beach seining fishery operates in Exmouth Gulf (Exmouth Gulf Beach Seine and Mesh Net Managed Fishery), and the Gulf is also included in the zoning for more widespread fisheries, such as the Pearl Oyster Managed Fishery, W.A. Sea Cucumber Fishery, and the Marine Aquarium Fish Managed Fishery and Specimen Shell Managed Fishery (Smith et al. 2010; DPIRD 2018a; DPIRD 2018b; Gaughan and Santoro 2020).

The 2004 Draft Aquaculture Plan for Exmouth Gulf (Fisheries Management Paper No.172) aimed to provide an ecologically sustainable strategy for future aquaculture ventures in Exmouth Gulf. Public consultation was undertaken together with a review of physical, biological and social environmental characteristics. Constraints such as conflicting resources and lack of infrastructure were highlighted while 13 species of finfish and eight shellfish were identified as viable targets (DoF 2004). Fifty-six sites were initially identified in the state, which may be suitable for land-based aquaculture operations. This was further refined to 10 sites, six of which were in Exmouth Gulf though there were concerns about cyclone risk. Several economic analyses investigating the feasibility of oyster and finfish aquaculture on the Pilbara-Gascoyne coast have determined that they would not be viable (Australian Venture Consultants Pty Ltd 2016). Challenges have been identified including high upfront cost with long payback periods, high ongoing operational costs, adverse environmental conditions and competitive markets that are difficult to break into (DoF 2016b). The Gascoyne Development Commission produced a 2009 investment profile on fishing and aquaculture operations and opportunities in the Gascoyne region, which at the time, talked about development of aquaculture ventures such as prawn, tropical rock lobster, squid and live coral (Gascoyne Development Commission 2009).

Proposed aquaculture developments in the area include the 2011 Marine Farms Ltd. aquaculture development to produce mahi-mahi at the site of the gravel pit just south of the town boundary and north of Mowbowra creek (Marine Farms Limited 2011). More recently, Seafarms proposed to breed wild caught prawns at a Founder Stock Centre and Quarantine Centre in Exmouth. 'Project Sea Dragon' is in the development stage but has been deemed a Major Project by the Commonwealth, Northern Territory and Western Australian governments (Seafarms 2021).

In addition to the economic value of fishing and aquaculture in Exmouth, the costs of these industries (e.g., damage to reefs, bycatch, GHG emissions), must also be considered. For example, Kangas et al. (2007) evaluated the impact of trawl fisheries on biodiversity in Exmouth Gulf and Shark Bay. While no major detrimental ecological impacts were identified, there was some evidence that high trawl effort sites in Exmouth Gulf had lower abundance of fauna and several small areas within current trawl grounds contain sensitive habitats. Kangas and Thomson (2004) investigated the effectiveness of bycatch reduction devices in the Exmouth Gulf and Shark Bay. Devices were fully implemented by 2002, and were reported to reduce catch of turtles, larger sharks and rays by 95 to 100%. A more recent management plan (2014 to 2019) outlines strategies to further reduce bycatch in the Exmouth Gulf Prawn Managed Fishery (DoF 2014).

Humphrey et al. (1998) described the occurrence, prevalence and distribution of infectious agents in *P. maxima* farmed in W.A. A mortality event, attributed to an unidentified disease agent, occurred in *P. maxima* farmed in Exmouth Gulf in October 2006 (Jones et al. 2010).

Many attempts were made to exploit green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) turtles commercially from the mid-1800s, potentially contributing to a decline in their numbers (Halkyard 2009). Archival and oral history evidence reveal that up to 69,000 green and 55,125 hawksbill turtles were potentially harvested from W.A. waters prior to the closure of the industry in 1973.

8.5.1.4.2.2. Tourism

Tourism planning is a relatively recent planning policy development that has emerged, in part, due to the need to redress inappropriate development of the past four decades (Wood et al. 2012). Tourism planning now forms an integral part of The Shire of Exmouth's overall strategic planning (Shire of Exmouth 2018).

The Shire of Exmouth recognises tourism is a significant source of economic stimulus but also a challenge to Exmouth's natural environment, 'small-town personality' and limited resources (Barnett 2016). Surveys of a random sample of >1200 residents and tourists in 1990 and 1991 revealed that both groups viewed tourism as environmentally harmful but more environmentally compatible than other commercial activities in the area such as pastoralism, fishing and mining (Dowling 1993). Mason and Moore (1998) identified 31 possible effects of ecotourism at Ningaloo Reef and Legendre Island (Dampier Archipelago), 28 of which were more negative than positive.

Community consultation is essential to any planned development to gauge and possibly change the attitudes of stakeholders (Fulton et al. 2013). The Ningaloo Coast has been a case study for Learning Tourism Destination, a methodology to improve sustainable tourism decision making through stakeholder collaboration (Schianetz et al. 2009). It is increasingly acknowledged that development, especially where it interacts with social systems and nature, can involve complex issues (Jones and Wood 2008). Sustainable development requires common understanding, collaboration, pragmatic problem solving and use of different disciplines to address problems (Jones et al. 2011).

Key sites for day visits to the Exmouth area include Bundegi Beach, Surfers Beach and Tantabiddi for the boat launching facilities (Cary et al. 2000). A 1997 survey found that visitors to the Cape Range National Park utilised camping sites and visited sites including Mangrove Bay, Turquoise Bay, Oyster Stacks, Sandy Bay and Yardie Creek.

In 2003, ~73% of visitors stayed in campgrounds, 28.2% in backpacker hostels, 16.5% in motels/hotels and 13.1% in caravan parks (Wood and Glasson 2005) (note that these statistics may have changed significantly post COVID-19 and with the addition of other accommodation options). In 2003, visitors mainly engaged in activities including snorkelling from the shore (29.7%), swimming with whale sharks (18.6%), diving from a boat (10.2%) and snorkelling from a boat (5.9%).

DBCA has historically not granted licences for commercial tourism on the Pilbara inshore islands except South Muiron Island (six marine charters, 15 whale shark operators) (DBCA 2020a).

Using ten years of participant data and questionnaires administered in 2006, Catlin et al. (2009) estimated the monetary value of whale shark tourism to the Ningaloo region at $894 per trip or $6 million in total with $2.4 to $4.6 million lost if whale shark tourism did not exist. Mau (2008) explored the effectiveness of whale shark conservation management at Ningaloo. They found that the whale shark industry had grown by 150% since 1995 yet had had limited ecological and biological management. A Whale Shark Management plan has since been endorsed and implemented, which places a particular focus on Ningaloo Marine Park (DPAW 2013). Past surveys of whale shark-tour participants showed they were willing to pay a transparent 'access fee' towards the cost of sustainable management (Davis and Tisdell 1999). Huveneers et al. (2017) surveyed 711 tourist divers across Australia, including Ningaloo and Exmouth, and estimated the economic value of shark diving tourism across the country at $25.5 million annually.

Understanding the behaviour of visitors once they reach their destination is essential for protected area planning and resource allocation. In 2007, Smallwood undertook 1208 interviews with visitors to the Ningaloo Marine Park. Visitation was found to be highly dependent on the road network. While some international visitors travelled long distances for recreation, more than a third of visitors did not travel any further to participate in recreation once they reached their accommodation (Smallwood 2009). The 300km of Ningaloo coast has several land tenure types offering a range of recreational opportunities to visitors (Smallwood et al. 2013). Visitor use of the adjacent marine park varies depending on land tenure type. For example, visitors to pastoral leases had longer lengths of stay compared to other tenure types possibly due to the time taken to access remote sites, visitor characteristics or familiarity with the destination.

Whale watching tours have been operating in Exmouth Gulf and Ningaloo for many years (DBCA 2020b). While results did not achieve statistical significance, Sprogis et al. (2017) found that humpback whales changed their behaviour in response to whale watching vessels including taking fewer breaths and making shorter dives. The researchers observed that some protocols were not followed, such as vessels approaching too near to whales and placing swimmers in the water with calves. Trials of swim-with humpback whale tours in the state Ningaloo Marine Park and Muiron Islands Management Area Exmouth started in 2016 and will continue to 2023 before transitioning to a licensed industry (Figure 8). Sprogis et al. (2020) recommended that swim-with whale tour vessels avoid in-path approaches and avoid placing swimmers in the water with animals displaying agonistic behaviours and/or with young-of-year calves. In 2020, three swimmers in the space of a week were injured by humpback whales during snorkelling tours in Exmouth (www.watoday.com.au/national/western-australia/third-swimmer-in-one-week-injured-by-humpback-whales-while-swimming-off-exmouth-20200807-p55jr1.html). Interactions with humpback whales are managed in accordance with the *Management Program for humpback whale interactions along the Ningaloo Coast 2020* (DBCA 2020b).

Human-turtle interactions are also a consideration in the Ningaloo Marine Park and Waayers et al. (2009) highlighted that 17% of beaches in the Park were impacted by off-road vehicle tracks, mostly located in the critical turtle nesting area on beaches.

8.5.1.4.2.3. Defence Services

The Commonwealth DoD has several facilities in Exmouth, including Naval Communication Station Harold E. Holt (including Areas A, B and C, and the Space Surveillance Telescope), RAAF Base Learmonth (combined RAAF Air Base/civilian airport), Learmonth Air Weapons Range and Learmonth Solar Observatory (Shire of Exmouth 2018). The Naval Communication Station Harold E Holt base was built during World War II and served as an important Very

Humpback whale breaching just south of Exmouth Marina (Photo: Kate Sprogis).

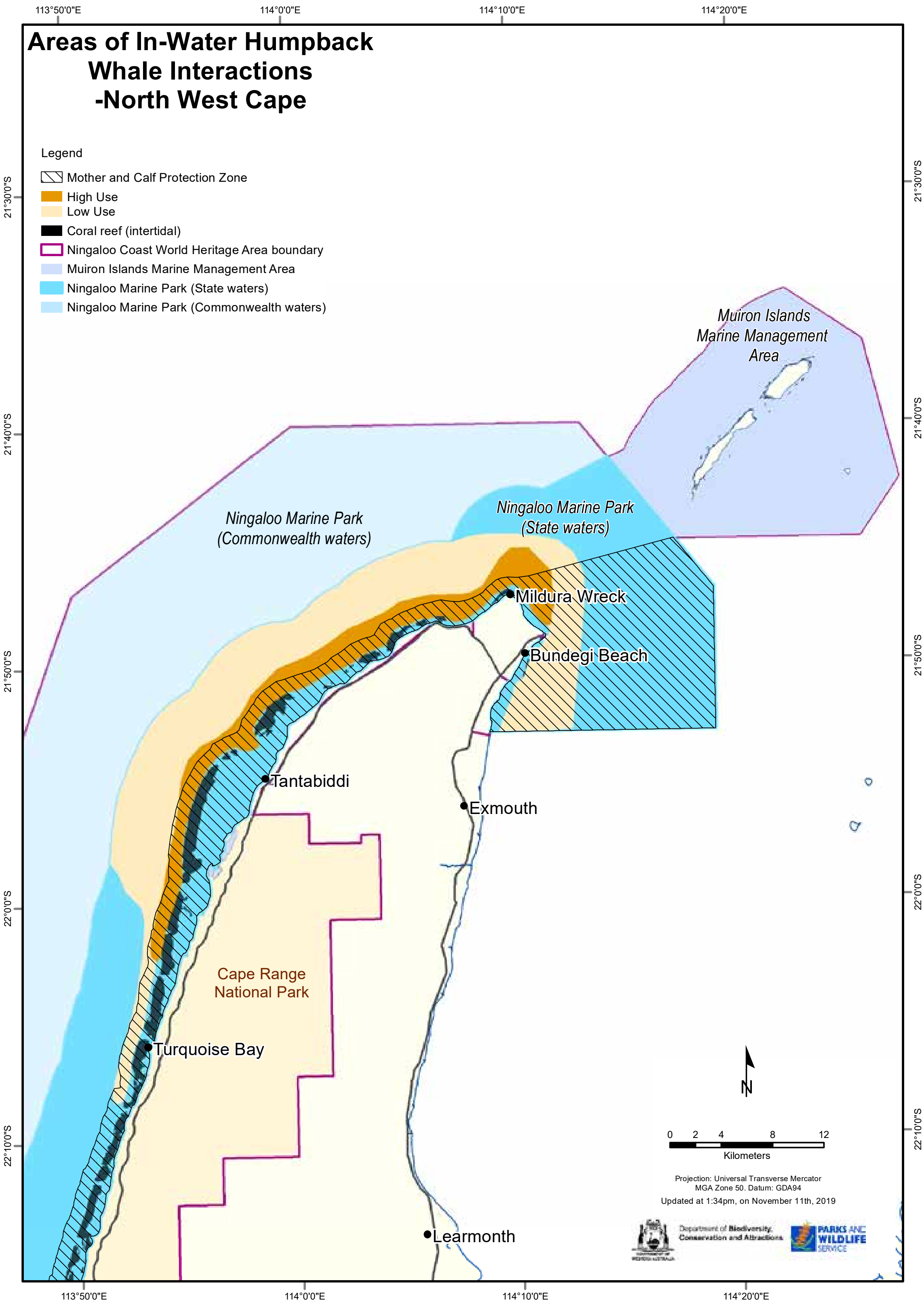


Figure 8: Areas of high and low use by commercial operators from 2016-2019 for in-water humpback whale interactions around the North West Cape. Sourced from DBCA (2020b).

Low Frequency station during the Vietnam War (DBCA, 2019a). The Naval Communication Station Harold E Holt, RAAF Base Learmonth, and Learmonth Air Weapons Range are included on the Commonwealth Heritage List. Exmouth township was originally established to support the Station (Barker and Ondaatje 2015). Detailed accounts of Anglocentric history include a description of Operation Potshot and the establishment of the Learmonth base during World War II (Smith 2003).

The Navy Pier at Point Murat is leased to commercial dive operators.

8.5.1.4.2.4. Resource Extraction

There are current and proposed resource extraction industries based in the Exmouth area including limestone and industrial salt facilities. Past and current activities are listed in Figure 9, and details of past and current proposals can be viewed on the EPA website (www.epa.wa.gov.au).

A 1995 Public Environmental Review details the proposed Whitecrest Enterprises Pty. Ltd. and Swan Portland Cement Ltd. limestone mine and quicklime production facility near Exmouth (Limestone Mine, Quicklime Plant and Shiploading Facility Exmouth, W.A.: Public Environmental Review 1995). The Review outlines the proposed use of the existing Point Murat port to load limestone and quicklime with storage facilities adjacent to the jetty.

In 1953, oil was discovered at Rough Range No. 1, the W.A. Petroleum Company's first exploration bore. This represented the first significant flow of oil in Australia (Condon 1954). Protective of their sensitive local environment and tourism industry, public mistrust of extractive industries such as oil and gas has been described in the local Exmouth community (Stejskal 1995). The Hadson Carnarvon Pty Ltd (Hadson) well drilling project (permits EP342 and TP/9) located at the northern end of Exmouth Gulf, was used as a case study to understand the importance of community consultation and communication between proponents and stakeholders. Extensive local community education and consultation, an impact assessment study and a commitment to statutory and voluntary environmental guidelines, were said to contribute to the success of the management strategy. In July 1994, the W.A. State Government announced that petroleum exploration within the Ningaloo Marine Park would no longer be permitted (Stejskal 1995).

Annually, over 10 million tonnes of high-grade solar salt are exported from a number of large solar salt fields on the northwest coast of W.A. Mottershead and Davidson (2009) considered technical findings and concluded that the Straits Salt Yannarie Solar Salt Mine proposed for the eastern Exmouth Gulf margin should be approved. Tuckwell (2012) explores the bitter dispute between conservationists and developers over the proposed solar salt field. A report commissioned by Straits Resources Ltd., stated that, *"the total and cumulative impacts of the proposal should be considered by the EPA"* (Oceanica 2006). In 2008, the EPA recommended that the Yannarie Solar industrial salt facility proposal should not be permitted to proceed, as it did not believe that the proposal could be made environmentally acceptable. Concerns were raised, including that the proposal lay within the State Government's World Heritage Consultative Committee preferred boundary and would involve the destruction and division of the Yannarie delta, which is of global geo-heritage significance (EPA 2008). Hobbs (2011) examined the polarisation of pro-conservation versus pro-development views on the proposed Straits Salt Mine and the impact on the decision-making process. Discussion of the merits of the salt mine proposal was overshadowed because, *"conservationists and developers continuously disputed their oppositions' knowledge of the area from increasingly polarised positions"* and the author suggests that communication of the risks and rewards of development to the public is integral for decision making, yet often neglected.

8.5.1.4.2.5. Pastoralism

Pastoral leases afford the lessee the right to graze livestock on Crown Land, under part 7 of W.A.'s *Land Administration Act 1997* (LAA). The Exmouth area has a history of pastoralism dating back to the 1880s (Austin 1988). The DBCA 'Draft Joint Management Plan for Nyinggulu (Ningaloo) Coastal Reserves 2019' cites the establishment of Minilya Station in 1876 as the beginning of European pastoralism in the area (DBCA 2019a). The Plan recommends that strips of coastal land from the pastoral leases and the entire Ningaloo Station be incorporated into the reserve system. The process of incorporating part of the Ningaloo coastal area for conservation begun during the 2015 pastoral lease renewal process, where some pastoral land (portions and entire leases) was not renewed under the LAA. More recent pastoral changes are summarised in the Shire of Exmouth Local Planning Scheme Number 4 and Local Planning Strategy Number 1 (Shire of Exmouth 2016). Pastoral leases around the Exmouth Gulf are listed in Table 18.

Table 18: Pastoral leases around Exmouth Gulf. Note Giralia and Ningaloo are technically ex-pastoral leases and are UCL until Indigenous Land Use Agreements (ILUAs) are established to pave the way for incorporation into the conservation estate.

Station	Lease no.	Type	Authorised Permit Activity
Exmouth Gulf	N050424		Pastoral-Based Tourism
Giralia	N/A	Sheep	Ex pastoral lease. Acquired by CALM in 2002
Ningaloo	N/A	Sheep	Ex pastoral lease. Acquired by DEC in 2008
Bullara	N050158	Cattle	Pastoral-Based Tourism
Yanrey	N050196	Cattle	Pastoral-Based Tourism
Koordarrie	N050082	Cattle	
Urala	N049393	Cattle	
Minderoo	N049514	Cattle	Agriculture

Source: (www.parliament.wa.gov.au/publications/tabledpapers.nsf/displaypaper/4012495c7c33d42993f9582f482583c300069e8b/$file/ tp-2495.pdf).

Remote sensing (e.g., Land Monitor and STVI-1) has been used to distinguish and assess the condition of rangeland pastoral leases in the Pilbara and Kimberley regions (Robinson et al. 2012). An experimental study by Holm and Allen (1988) investigated whether the nutritional quality of spinifex (*Triodia* spp.) pasture is improved by burning (through the indirect effect of increasing growth of other grasses). They found that no species tested was more nutritious or palatable than soft spinifex.

There is a growing tourism industry on pastoral stations along the northern Gascoyne coast from Quobba Station to Exmouth (Wood 2003). A longitudinal survey of visitors and hosts identified negative impacts of tourism on coastal stations, attributed to the absence of appropriate management and plans (Wood and Hughes 2006). Analyses have found that visitors who use unmanaged remote camping contribute the least to the economy and incurred greatest environmental impact.

8.5.2. Human Health

A Consultative Environmental Review (1995) for the Exmouth borefield extension concluded that population growth was resulting in increased demand for water and that supply and infrastructure were inadequate. While borefield extension would spread the impact over a larger area, risks to stygofauna were highlighted (Water Authority 1995). The 'Water and Rivers Commission Exmouth Water Reserve Water Source Protection Plan for the Town of Exmouth' includes a description of the bore and wellfield, groundwater pollution risks, subterranean fauna, natural vegetation and ecosystem maintenance (Water and Rivers Commission 2000). More recently, Gilgallon and McGivern (2018), investigated options to improve borefield production at Exmouth using aerial electromagnetic surveys, 3D hydrogeological modelling and pumping tests. They mapped saline water distribution and identified lower salinity and higher flow rate bores with substantial additional sustainable production.

A W.A. wide survey of Aboriginal child health focused on how key health and wellbeing are associated with aspects of the communities in which they live (Sven et al. 2006). The survey report discusses the role of economic wellbeing, family and stress.

Following the 1992 Ross River Virus outbreaks, Lindsay et al. (1993) undertook field collections and laboratory analysis of mosquitos collected from Exmouth and Marble Bar. They provided the first report of Ross River Virus in five species of mosquitos and isolated the virus from three other species.

Between 2016 and 2017, there were nine envenomation incidents around Exmouth town and Ningaloo coast involving Irukandji jellyfish (*Keesingia gigas*) (Keesing et al. 2020). Many *K. gigas* have been observed and collected in the area and their abundance appears to be determined by prevailing winds, waves and currents driving them south March to May.

A questionnaire administered to 29 Exmouth residents suggested that recreational fishing may have health and wellbeing benefits but a greater sample size is required to verify these findings (McManus et al. 2011).

Natural disasters, such as tropical cyclones, have the potential to affect human physical and mental health (Pooley et al. 2013). A survey of 512 residents of four cyclone-prone communities in northern W.A., found that disaster stress is often accompanied by disaster growth. Community resilience, which reduces stress from disasters, relies on competence and a sense of community (Pooley 2004).

9. Nganhurra Thanardi Garrbu Values and Concerns

Qualing Pool (Photo: Wendy Thompson)

9.1. Background

Ningaloo and Exmouth Gulf area is the traditional land and sea country of the Baiyungu, Yinikurtira and Thalanyji (also known as Jinigudira) people. Native Title was granted to the Gnulli Native Title claimants (Yinggarda, Baiyungu and Thalanyji People) on 17 December 2019 and includes ~71,354km^2 across the Shires of Ashburton, Carnarvon, Exmouth, Murchison and Upper Gascoyne. The Nganhurra Thanardi Garrbu Aboriginal Corporation (NTGAC) and Yinggarda Aboriginal Corporation and are responsible for the Native Title across this region, with the NTGAC being responsible for the Baiyungu and Thalanyji area that includes Ningaloo and Exmouth Gulf.

The proposed Nyinggulu (Ningaloo) coastal reserves is the first Indigenous Land Use Agreement (ILUA) registered under the W.A. State Government's Plan for our Parks initiative. The ILUA was made with the NTGAC, and together with DBCA, the Nyinggulu (Ningaloo) coastal reserves draft joint management plan 2019 was developed to provide direction for joint management of the Nyinggulu (Ningaloo) Coast over a period of 10 years. The Nyinggulu (Ningaloo) coastal reserves include:

- the terrestrial portion of Ningaloo Marine Park, an existing reserve 40 metres landward of the high water mark north of Amherst Point
- land not renewed in the 2015 pastoral lease renewal process from Red Bluff in the south to Winderabandi in the north
- other portions of unallocated Crown land

9.2. Exmouth Workshop Process

On the 13 May 2021, a workshop was held between WAMSI, EPA and the NTGAC at the Gwoonwardu Mia, Gascoyne Aboriginal Heritage and Cultural Centre, Carnarvon, to help inform this report and the strategic advice the EPA will be providing to the W.A. Minister for Environment (Appendix 3).

It is acknowledged that this workshop alone was not able to deliver an adequate understanding of all the values and concerns of the NTGAC. We are, however, grateful for the expert knowledge, considered input, frank discussions and time given by the NTGAC participants and look forward to a future collaborative partnership to better understand the values and main issues for Nyinggulu area.

Workshop with WAMSI, EPA and the NTGAC in Carnarvon (13 May 2021).

In keeping with the EPA themes of Sea, Land, Water, Air and People, WAMSI, EPA and the NTGAC discussed the most important animals and plants in the Gulf, their location, condition and any impacts.

Three main questions helped to structure the workshop and included:

1. For a healthy country, what are the most important:
   a. Places
   b. Plants, and
   c. Animals
2. What condition are they in? (Condition: Very good, Good, Poor, Very Poor, Don't know)
3. What are the threats now and in the future?

More specifically:

For the animals in a healthy country, we are interested in animals in the marine area (Gulf), fresh water and on land.

- Although all interconnected, what animals are most valued?
- What are their names and their uses?
- Where do they live, now and in ancient times?
- What condition are they in?
- What are the threats and likely impacts: now and in the future?

For the plants in a healthy country, we are interested in plants in the marine area (Gulf), fresh water and on land.

- Although all interconnected, what plants are most valued?
- What are their names and their uses?
- Where do they live, now and in ancient times?
- What condition are they in?
- What are the threats and likely impacts: now and in the future?

For the special places on Country

- Where are they on a map?
- What are their names- Traditional and in English if possible?
- If possible; any special purpose that can be shared?
- What condition are they in (now and in past)?
- What are the threats and likely impacts: now and in the future?

9.3. Exmouth Workshop Findings

9.3.1. Marine Animals and Plants

It was not possible for workshop attendees to prioritise marine animals or plants of the Exmouth Gulf region and identify one important animal or plant over another, as all are interconnected. Each of the animals are important for different seasons and ceremonies. The marine animals and plants (and other benthic habitats) discussed by workshop attendees are provided in Table 19.

During discussions on marine animals, plants and habitats, the following points were raised:

- 60,000 years ago, it was a shallow walk from the top of Exmouth Gulf to the Muiron Islands, as evidenced by middens
- Ancestors were driven by a cycle of food and ceremonies, within the seasons
- Everything is linked and everything is important
- Exmouth Gulf is an important nursery area
- Boat scars, fuel spillage and vehicle tracks have a deleterious impact on reefs and shore plants
- The quality of water is not as good now e.g., boats in the marina
- There are a lot of caravans, boats and tourists and they take a lot of fish – indiscriminate fishing
- See more people 'wobblies' (people with caravans/trailers) and boats now

- Fish are not as plentiful as they once were and it is not as easy to get a feed
- There is recreational overfishing
- Tourism is unsustainable
- The climate is changing and the water temperature is increasing
- Boat numbers are increasing and boat strikes on animals are more likely with increased boat numbers
- The Marina has changed fishing
- There is more fuel in the water
- Where boat access is tricky, boat scars result from hulls and propellers
- There are more big ships than ever before
- Noise from boats as well as from platforms is an issue
- Artificial reefs – seems to have attracted more fish than there was previously. There wasn't a consensus about having artificial reef with/on existing reef

Table 19: Marine animals, plants and habitats discussed during the May 2021 workshop in Exmouth.

Marine animals	Traditional name	Location	Condition / impacts	Comments
Turtles	Majun		4WDs damaging the coast, they are crushing the turtle nests and hatchlings. Ningaloo station has fenced off parts of the coast to protect the turtle hatchlings.	2021 = good year for hatchlings
Turtles - Hawksbill		Islands		
Turtles - Loggerhead		Islands		
Turtles - Green turtles		West side of the Gulf and Ningaloo side		
Sea snakes - banded	Warnaangura			
Sea snakes - yellow				
Dugong	Yarayara	Males and females	Boat strike an issue as die soon after	Tagging project – understand links between Shark Bay, Exmouth Gulf and Broome
Humpback whales	Jumuwardu buniji			
Whale sharks and babies		Whale shark babies in the northeast end of the Gulf, a natural basin with a lot of nutrients. Babies left there to grow up and mothers go off.		
Dolphins				
Oysters				

Marine animals	Traditional name	Location	Condition / impacts	Comments
Molluscs: Bailer Shells			See very few but still there	Ancestors would walk along and if see something – would eat it. Still see in middens
Molluscs: Cone shells			Don't see many	
Molluscs: Clams				
Molluscs: Oysters		Important food source – on every midden		
Molluscs:				
Octopus				
Molluscs: Squid	Wuruwurugaja			
Prawns (many species) Kings, coral, tiger, banana			Commercial prawn fishers are controlled and managed, prefer them to other recreational fishers	
Mangrove crabs/ mud crabs		Exmouth Station and up the east coast, the mangrove system, especially important for the mangrove crab habitat, - must be preserved. Intertidal areas, south/eastern mud flats area (Giralia Bay and Bullara Station). Nanutarra river mouth down, very rich in food sources.		
Crayfish				
Crabs				
Manta rays	Yambarna		Declining	Still some there but declined. Some of the older ones have died.
Shark	Nhuga		Catching sharks seems to be a relatively recent phenomenon. Now when fishing, hook into sharks –never have before	

Marine animals	Traditional name	Location	Condition / impacts	Comments
Fish: Blue bone or baldchin groper*		Near Qualing Pool	Declining	
Fish: Parrot fish			Declining, but not as much as bluebone	
Fish: Coral trout Banded emperor Snapper Mullet Rock cods			All fish harder to get, less plentiful. Under pressure. Tourists take a lot of fish = indiscriminate fishing The marina interrupted a lot of natural fishing, caused a sandbar that prevented natural fish movements. The fishing bag limit needs to be reduced.	
Fish: Aquarium species Clown Fish (nemos) Surgeon fish (dories) Sea horses				
Marine plants/ habitats	**Traditional name**	**Location**	**Condition / impacts**	**Comments**
Seagrass				
Mangroves		Eastern and southern gulf		Very important
Corals				
Algal mats			Good condition	
Salt flats			Good condition	
Samphire		Medicinal use and sauces		
Pigface		Medicinal use and sauces		

9.3.2. Terrestrial Animals and Plants

It was not possible for workshop attendees to prioritise terrestrial animals or plants of the Exmouth Gulf region and identify one important animal or plant over another. The terrestrial animals and plants discussed by workshop attendees are provided in Table 20.

During discussions on terrestrial plants and animals, the following points were raised:

- The main impacts are from people
- There are also impacts from some vehicles
- There are impacts from land development
- There are impacts from reduced rain – climate changing and rainfall decreasing
- Less bush tucker can be found now
- Plants are impacted by vehicles and development
- Wildlife and traditional animals are impacted by poison baits
- Goats really damage the country - cattle numbers are manageable, but goats are a problem, but not as many as pre-Tropical Cyclone Vance
- Pastoralists are pretty good custodians of the land these days
- Karara (tree) seems to be impacted by less and less water. You can see trees that were green and now they are dying and going grey. There is no way they can come back. You often see one green tree in a grove of grey trees
- Traditional fire management is important for management of grasses but more especially germination of many plants. When there were no fires, didn't get seed regeneration
- If a bush fire is too hot and burns everything, it is a real hazard
- Changed to mosaic/spot burning and seems to be working
- Main impacts: development, trapping, vehicles, goats, all stock but particularly goats
- Traditional Owners want DBCA to understand the difference between wax and ordinary spinifex because the former creates a very hot fire, spark and run, and this should be clearly understood and managed accordingly

Table 20: Terrestrial animals and plants discussed during the May 2021 workshop in Exmouth.

Terrestrial animals	**Traditional name**	**Location / Use**	**Condition / impacts**	**Comments**
Rock wallaby - stripes and blackfoot		Leave alone		
Other wallaby – euros		Good drought food		
Bardi grubs	Gulyu			Bardi (Acacia + Eucalyptus) trees
Termite mounds		Don't eat but important shade for animals, they attract bush turkeys, kangaroos & echidna		
Echidna	Irrabuddi			
Kangaroo			Increased over the past few years	
Bush turkey		Eat		
Goanna		Goannas (NTT only eat yellow, not black, goannas)		
Emu		Seasonal. They nest on south part of Exmouth Station (near where Subsea 7 had their development).		That area needs to be preserved
Terrestrial plants	**Traditional name**	**Location**	**Condition / impacts**	**Comments**
Yams (sweet potato)	Gulyu	Very important, rich in vitamins		After rain when ground soft
Acacia	Thambali	Very important food tree Bardi grab found on roots. Also use seeds for crushing and cooking. Use gum / toffee		
Quandongs (Santalum)				
Big tree, no leaves		Milky sap used for medicinal purposes		
Karara tree	Karara	Seeds are ground for damper		

Terrestrial plants	Traditional name	Location	Condition / impacts	Comments
Long bean with white stripes, white flower	Wanyu	Pop seeds out and eat. Also, cockatoos eat		Pop seeds out
Spinifex (*Triodia*): plain and wax. Ants use the wax inside the termite mound.	Waranbary	Ants use the wax inside the termite mound. Use to burn as incense. Use wax to make spears		2 types Resinous/waxy spinifex – likely *Triodia schinzii*; hard/non-waxy – possibly T*riodia basedowii* or *T. wiseana*
Rock Fig tree (Ficus)				
Gum trees (*Eucalyptus*)		Bardi also associated		
Little tree with black seed		Burn seed use as medicine		
Large milky tree, long spines		Cape Range		
Wattles (Acacia)		Eat seeds like peanuts		
Bush banana				Good after rains

9.3.3. Special Places on Country

Exmouth Gulf was like a highway with Clans gathering on Giralia. Claypans can be found on the southern side of Exmouth Gulf and many stone tools are present. Exmouth Gulf is a nursery that provides much food. According to Peter Veth (Professor of Archaeology, The University of Western Australia), in the old times, there was no water in Exmouth Gulf. Middens can now be found on the islands and you can still visit them.

Although there are numerous Registered Sites in the scope area listed on the W.A. Department of Planning, Lands and Heritage's (DPLH) Aboriginal Heritage Inquiry System (AHIS), there are other areas that are culturally significant and not officially listed, such as burial grounds, meeting places, dreaming locations and freshwater soaks. The special locations discussed by workshop attendees is provided in Table 21.

During discussions on special places on Country, the following points were raised:

- The clan that inhabits the area on the western side of the Gulf are Yinnigurrura
- The clan that inhabits the southern end of the Gulf are the Jardulya
- The clan that inhabits the area on the northern side of the Cape (north and east side of the Cape) are the Yardi
- The number of people on Country and their impact are the biggest threat. Impacts on cultural, marine and terrestrial values are potentially at a tipping point, especially since COVID-19 has pushed more and more people into the region (Bali tourists).
- Potable water is under stress
- The amount of sewage being generated is a concern
- The town is probably not capable of doubling its population – sewage and potable water will probably limit population growth

Table 21: Special places discussed during the May 2021 workshop in Exmouth.

Terrestrial animals	Traditional name	Location / Use	Condition / impacts	Comments
NE end of the Gulf, a natural basin with a lot of nutrients. Whale shark babies left there to grow up and mothers go off.				
Qualing Pool				
Exmouth Station and up the east coast, the mangrove system, especially important for the mangrove crab habitat - must be preserved.				
Middens in the blow outs on the coast, near freshwater (evidenced by bailer shells, although they are declining on the beach)				
Jiralia has the freshwater soak – very important source of water		*(Not sure if that is the spelling of different places or the same e.g., Jiralia and Giralia)*		
Giralia Bay was a traditional meeting place (a highway stop over for traditional people). A lot of stone tools				Large gathering place
Quailing pool and creek are very important				
The islands Tent Island (north-east) Doole and Roberts Island (southern Gulf)		Were all connected Found skeletons and artefacts		
The eastern side of the gulf are burial grounds in the dunes behind the intertidal area				
The top end of the Cape is important for freshwater sources (soaks), a lot of middens				

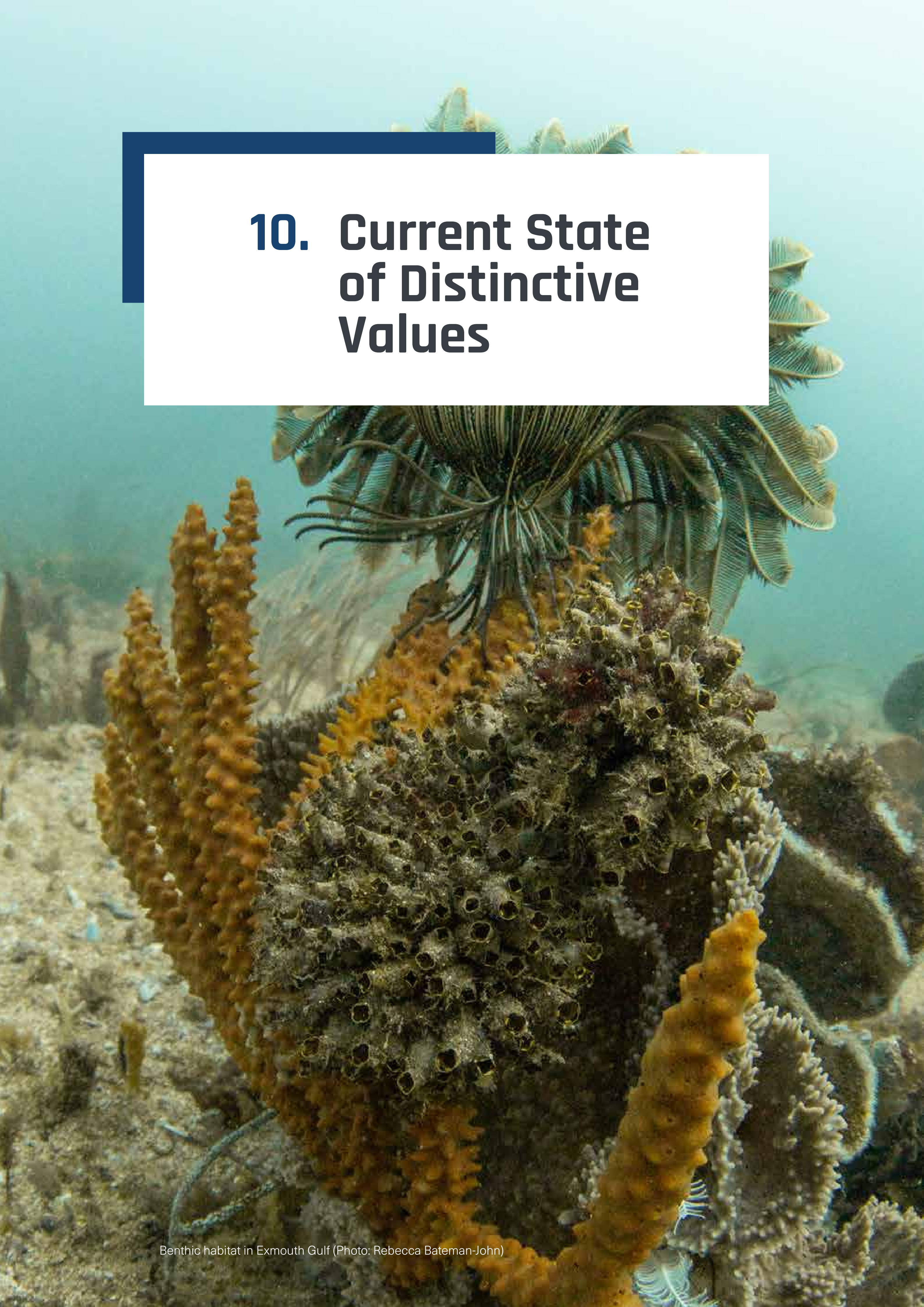
Terrestrial animals	Traditional name	Location / Use	Condition / impacts	Comments
Cape Range down to Giralia Station is a traditional dreaming site				
The gulf area is a traditional dreaming place				
Caves in the Cape Range are vulnerable. An important fresh water system.				
Southern part of Exmouth Station (near where SubSea 7 had their proposal).		Emu nesting sites		

9.3.4. Impacts of Most Concern

When asked what impacts are of most concern, the workshop participants responded with:

- As COVID-19 impacts have increased, the number of people in Exmouth has increased.
- Although DBCA is trying to minimise the impact, the number of boats has increased and the fishing bag limits are too high.
- On Country and on water, the commercial needs are dictating what happens, as there is a push for increased numbers of people. A mass of people puts huge pressure on Country. The campsites and caravan parks are all overflowing. This adds pressure to the sewage and the water.
- There is an impact on Country and water. Questioned whether the water use is sustainable?
- The town could increase a little but the Shire wants to double (2x) the size – this is too much
- Over capacity now and it has created huge impacts. This is also challenging to small Business owners.
- There is concern about the cave system (Karst system) and impact from water use.
- Desalination plants are very expensive and salt by-product has to go somewhere.

10. Current State of Distinctive Values



Benthic habitat in Exmouth Gulf (Photo: Rebecca Bateman-John)

The current state of Distinctive Values was assessed based on the available literature and should be viewed as a preliminary assessment only. In assigning scores from 'Very Good' to 'Very Poor' (Table 22) (see score definitions in Table 4), the assessment of the Distinctive Values ranged across all categories except 'Very Poor'. The majority of Distinctive Values in Exmouth Gulf were graded as 'Good' or 'Very Good'. The confidence for most of these gradings is low to medium. Corals, sea snakes, turtles, dugongs, seabirds/shorebirds, coastal dunes, groundwater and surface water systems were graded as 'Poor' No Distinctive Values were graded as 'Very Poor'. A lack of current knowledge precluded the grading of fishes, shovelnose rays, sawfish, coastal dolphins, threatened/priority flora, terrestrial fauna, karsts systems and subterranean communities, topsoil and the economics of pastoralism. An expert working group and stakeholder consultation process is recommended to refine this preliminary grading.

Table 22: Current state of Distinctive Values in Exmouth Gulf.

Very good	Good	Poor	Very poor	Unknown

Distinctive Values	Current state	Conf.	Justification
SEA			
Benthic Communities and Habitats			
Macroalgae and turf algae	Good	M	Algae has recovered well from past disturbances e.g., Cyclone Vance (Loneragan et al. 2013). Exmouth Gulf wide mapping has not occurred for benthic habitats so confidence is not high. Uncertainty around impacts of marine heatwaves on macroalgae.
Seagrass	Good	M	Natural variability in abundance and cover across seasons for different species is evident (Vanderklift et al. 2016). Seagrass showed recovery after Cyclone Vance (Loneragan et al. 2013). *Halophila ovalis* populations considered to be genetically resilient. Exmouth Gulf wide mapping has not occurred for benthic habitats so confidence is not high.
Coral	Poor	M	Bleaching of corals has occurred after past marine heat stress events (Moore et al. 2012; Depczynski et al. 2013; Clarke et al. 2019). Currently anecdotal evidence of bleaching for corals along eastern margin following warming earlier in 2021. Coral rubble is a widespread habitat indicating that corals have been continually impacted over time (Loneragan et al. 2003, Day et al. 2013). Gulf wide mapping has not occurred for benthic habitats thus confidence is not high. DBCA considers the decreasing trend in coral cover, coral recruitment and changing community composition to be having a negative effect on coral communities of the Ningaloo Marine Park (with med-high confidence) (DBCA 2017d).
Sponges and filter feeders	Very good	L	Diverse communities are present, particularly between North West Cape and Muiron Islands (RPS Bowman Bishaw Gorham 2004; Hooper et al. 2002; Hooper and Ekins 2004; Kangas et al. 2007). Cyclone Vance did cause some damage to sponges (Loneragan et al. 2003). Exmouth Gulf wide mapping has not occurred for benthic habitats thus confidence is not high. No recent information on communities within the Gulf and if this has changed since 2000s.

Distinctive Values	Current state	Conf.	Justification
Sand and mud		L	Sandy habitats are continually trawled for prawns, so would expect that infaunal and epifaunal communities have been impacted somewhat. A comparison of trawled versus untrawled areas for prawns in Exmouth Gulf found some evidence that high trawl effort sites had lower faunal abundance (Kangas et al. 2006). Sand and mud habitat is extensive across Exmouth Gulf, however knowledge of infaunal communities is not well known.
Mangroves		M	Tropical Cyclone Vance caused the loss of 44% of cover along eastern margin (Paling et al. 2008). Uncertain if this has fully recovered. Mangroves been impacted to some extent by fluctuating sea levels (e.g., La Niña vs El Niño years) (Reef and Lovelock 2019) and rare locust swarms (Reef et al. 2012).
Samphire		L	Occur extensively along the eastern margin of Exmouth Gulf and also southern and western margin and around tidal creeks (Keighery and Gibson 1993; Oceanica 2006). Large Defence communication towers sit on samphire saltmarshes. No known significant impacts to extensive samphire along eastern margin. Limited literature on samphire in Exmouth Gulf. No widespread losses have been recorded.
Blue-green algal mats		M	Occur extensively along the eastern margin of Exmouth Gulf (Humphreys et al. 2005; Straits Salt Pty Ltd 2006; EPA 2008; Straits Salt Pty Ltd 2009). No known obvious damage is evident to mats. Considered one of the last intact extensive salt flat ecosystems in W.A. Mats need room to migrate landward and seaward with fluctuating sea levels.
Reef flats and oyster beds		L-M	Productive rocky intertidal and subtidal areas occur at all the creek mouths along the western shoreline (pers. comm. DWER). These creek mouths are numerous and prone to high levels of visitation and occasional severe disturbance from flood runoff. Extent of any damage is uncertain. Extensive coastal/intertidal mapping has not been carried out. Low relief subtidal reef is extensive around Bundegi and North West Cape across to Muiron Islands, and likely occur around many of the islands (Bancroft and Sheridan 2000; Beckley and Lombard 2012; van Keulen and Langdon 2011; Dee et al. 2020).
Salt flats		L	Considered one of the last intact extensive salt flat ecosystems in W.A (EPA 2008). No known obvious damage is evident to flats. Limited literature on salt flats in Exmouth Gulf.
Marine Fauna			
Crustaceans - prawns		H	Commercially fished so have been impacted for a long time, though considered sustainable by DPIRD and MSC. Cyclone Vance resulted in an immediate significant loss in critical prawn nursery habitat, seagrass and macroalgae, which resulted in a decrease in prawn landings two years after the cyclone (Loneragan et al. 2013). Landings increased as macroalgae and seagrass recovered.
Crustaceans - mud crabs		L	Fishing pressure would be having an impact. Limited available information on mud crab populations in Exmouth Gulf.
Teleost - whiting		M	Fishing pressure would be having an impact. A widespread species. Limited available information on populations in Exmouth Gulf, though stocks are generally considered sustainable-adequate for the Gascoyne region (Gaughan et al. 2019).
Teleost - mangrove jack			Fishing pressure would be having an impact. Limited knowledge available on mangrove jack population in Exmouth Gulf.

Distinctive Values	Current state	Conf.	Justification
Teleost - trevally			Fishing pressure would be having an impact. Limited knowledge available on trevally population in Exmouth Gulf. Widespread species.
Teleost - coral trout			Fishing pressure would be having an impact. Limited knowledge available on coral trout population in Exmouth Gulf.
Teleost - red emperor			Fishing pressure would be having an impact. Limited knowledge available on red emperor population in Exmouth Gulf.
Teleost - tuskfish			Fishing pressure would be having an impact. Limited knowledge available on red emperor population in Exmouth Gulf
Elasmobranchs - rays (shovelnose)			Uncertainty around current state. Current research underway. Fin Focus has been collecting citizen science data and has a catalogue of photos.
Elasmobranchs - rays (manta)		M-H	Tourism may be having an impact for a portion of the population. Mantas have had focused research effort. McGregor et al. 2019 provides *'indirect evidence for potential increased vessel strikes on manta rays within the Ningaloo Coast World Heritage Area'*. Armstrong et al. 2020b – *'With an exceptionally low maximum population growth rate (Dulvy et al., 2014), M. alfredi is particularly susceptible to human impacts and is classified as "Vulnerable" on the International Union for the Conservation of Nature Red List of Threatened Species....For example, recent studies conducted in the Ningaloo Coast WHA have reported short-term behavioural changes in M. alfredi in up to a third of tourism interactions (Venables et al., 2016)'.*
Elasmobranchs - sawfish			Uncertainty around current state. Current research underway.
Elasmobranchs - sharks		M	No evidence of long-term impacts of tourism on the whale sharks at Ningaloo has been found (e.g. Sanzogni et al. 2015; Lester et al. 2019). Less is known about other shark species (e.g., reef, grey nurse, white pointer), though some work has focused on depredation by sharks in the region (Mitchell et al. 2018, 2019, 2020), which has caused concern.
Marine reptiles – sea snakes		L-M	In a declining state elsewhere across the NW of Australia. Caught as by-catch in the Exmouth Prawn Trawl Fishery. It is believed improved reporting practices are responsible for the increased number of sea snakes recorded as bycatch (Gaughan and Santoro 2019), and that those sea snakes found alive are typically returned alive (Kangas et al 2015). Some species have small home ranges, so would be more susceptible to impacts. AIMS website: *'Global sea snake populations have declined in recent years, including those in the Great Barrier Reef, Western Australia and New Caledonia. Declines in native sea snake populations at the remote offshore Ashmore reef, NW Australia, have made this species a focus for conservation and long-term monitoring. While the reasons for decline are not well understood, one key concern in Australian waters is that they are frequently caught as by-catch in trawl fisheries.'*

Distinctive Values	Current state	Conf.	Justification
Marine reptiles - turtles		M-H	Area well used by turtle for foraging, and nesting occurs on islands just north of Exmouth Gulf (Thums et al. 2018; Rob et al. 2019; Fossette et al. 2021). All marine turtles are EBPC Act listed threatened species and there is a recovery plan for marine turtles in Australia. Turtles face threats outside of Australian waters given they are migratory. Since the implementation of exclusion devices in prawn trawl fisheries in Exmouth Gulf, an estimated drop of 95% of large animals, including turtles, sharks and rays, was observed (Kangas and Thomson 2004). Exmouth Gulf was an exploited fishing ground for turtles up until the industry closed in 1973 (Halkyard 2009). Historical records show upwards of 55,000 green turtles, and 15,000-32,000 hawksbill turtles were harvested in W.A.. Observable declines in marine turtles resulted from commercial harvesting. Prince at al. (2012) reported unusual numbers of sick and dying turtles on a number of occasions between 1990-98 in the Exmouth area, though no obvious cause was identified.
Marine mammals - whales (humpback)		H	Exmouth Gulf has long been a recognised resting and nursery area for humpback whales (Chittleborough 1953; Jenner et al. 2001). Humpback whale population numbers have continued to increase at a rate of ~11% per year (last assessment done in 2016). Some evidence that whales are being harassed by silver gulls in Exmouth Gulf (Harkness and Sprogis 2020). Humpback whales are migratory and impacts to food availability in Antarctica will impact humpback whales.
Marine mammals - dolphins (coastal)			Uncertainty around current state as species level data is not available for most of Exmouth Gulf. Current boat-based research about to begin. Aerial surveys have been conducted previously, however, surveys are focused on whales and dugongs, so different dolphin species were not always separated (e.g., Jenner and Jenner 2005; Irvine and Salgado Kent 2019). Aerial surveys in 2018 sighted 556 dolphins from 179 pods, including 10 calves; dolphins had a broad distribution across Exmouth.
Marine mammals - dugongs		M-H	Penrose (2005) details a range of impacts and potential impacts to dugongs, in relation to the Straits Salt proposal, but concludes 'the current knowledge of dugongs in Exmouth Gulf is inadequate to assess the potential threats of the Straits Salt proposal and thus to effectively plan for their management'. Some knowledge has been gathered since then, with several aerial flights surveying dugongs (e.g., Irvine and Salgado Kent 2019). A decline in dugongs occurred following Cyclone Vance in 1999 and the removal of seagrass Gales et al. (2004). More recent assessment of dugong population trends is needed. A study by Hodgson et al. (2008) found no real change across years. Is a listed threatened species on the W.A. Threatened and Priority Fauna list.
Seabirds and shorebirds		L-M	Exmouth Gulf Mangroves is designated as an Important Bird Area, and also qualifies as a Key Biodiversity Area based on this (Biodiversity Areas Partnership 2020). It has national and international significance and many that are critically endangered, endangered, vulnerable etc. 4WD activity has likely caused some damage to burrows/nests. Trampling on islands (seabird nests and burrows and physical disturbance) and pets (i.e. dogs) are also greatest disturbance risks (pers. comm. DBCA). Storm surges can inundate islands and destroy nesting sites. Difficult to assess such a diverse group of species, but based many being listed species, a 'poor' score is given.

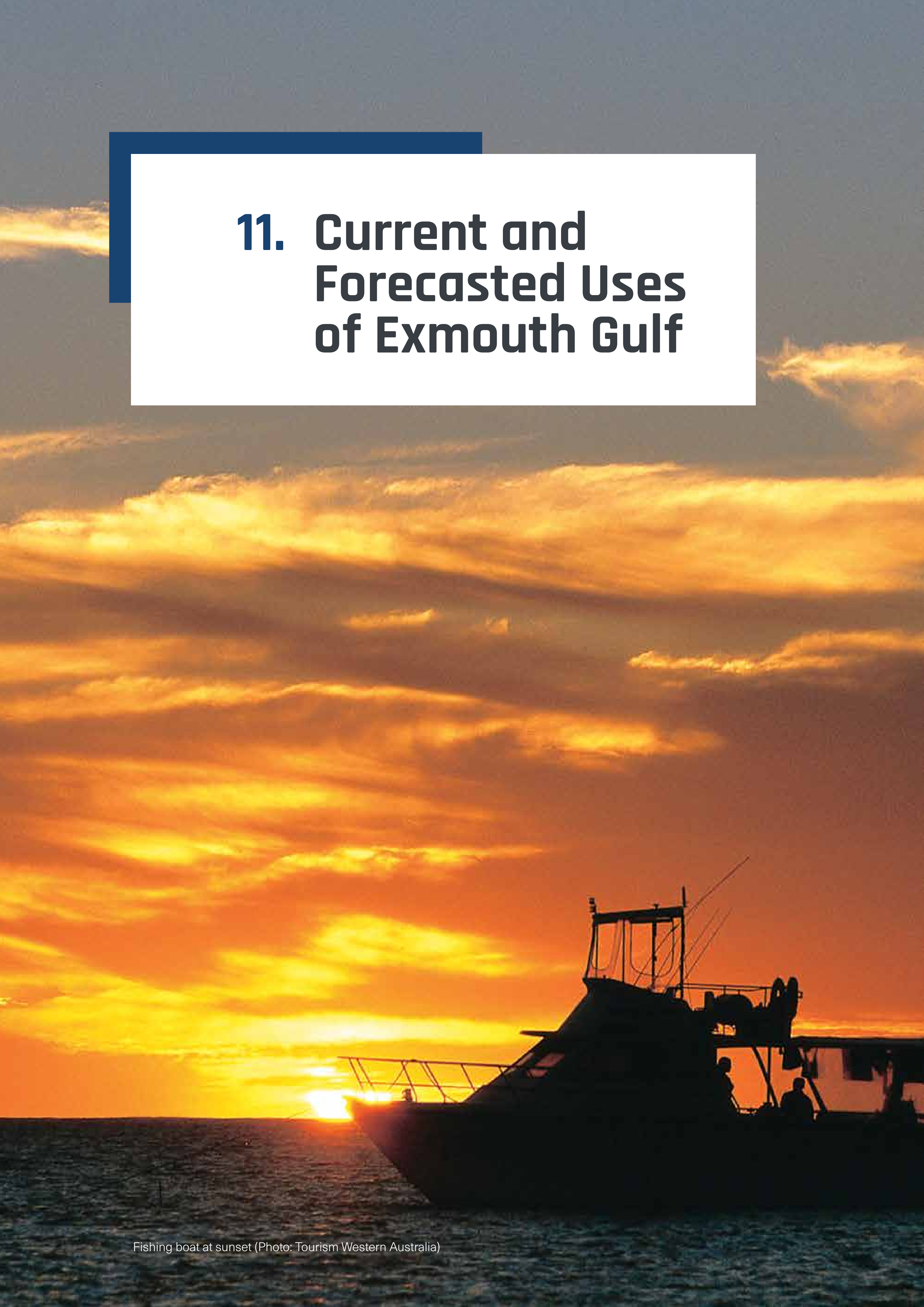
Distinctive Values	Current state	Conf.	Justification
Marine Environmental Quality			
Water quality		L-M	Exmouth is a naturally turbid environment. Widespread water quality issues are not evident in Exmouth Gulf, though widespread continual monitoring is not carried out. Microplastic pollution is evident in Exmouth Gulf. Water temperature is typically considered under water quality. DBCA considers the increasing trend in seawater temperature as having a negative effect with high confidence for water quality of the Ningaloo Marine Park (DBCA 2017d).
Sediment quality		L-M	Exmouth sites had highest concentrations of Cobalt, Lead and Vanadium and were thought to be related to the region's geology (DEC 2006). Widespread sediment quality issues are not evident in Exmouth Gulf, though widespread continual monitoring is not carried out.
Coastal Processes			
Geophysical processes		M	Geophysical processes are influenced by tropical cyclones e.g., large washover fans occur at Point Lefroy, and sandy ridges at Giralia Bay and Heron Point (Brill et al. 2016; May et al. 2018; Fitzpatrick et al. 2019). Cyclones have also caused erosion (Nott and Hubbert 2005).
Hydrodynamic processes		M	No evidence of significant impact. The hydrological environment remains relatively stable given freshwater sources from rainfall and runoff are very low (Penn and Caputi 1986). Tides can contribute to the turbidity of Exmouth Gulf (Dufois et al. 2017).
Nutrient flow		L-M	No evidence of significant impacts apart from natural disturbances. The Gulf is considered relatively productive. All sources of nutrients into Exmouth Gulf are yet to be 100% determined, though largely thought to be influenced by salt flats and blue-green algal mats (McKinnon and Ayukai 1996; Ayukai and Miller 1998; Lovelock et al. 2009; Penrose 2011).
LAND			
Flora and Vegetation			
Coastal plains		L-M	Development has removed vegetation. There is no fine scale vegetation mapping that covers the whole of the project area. As of 2019, a total of 21 plant species are identified as endemic to the Cape Range peninsula (Keighery and Lilburn 2019). 22 species from the Peninsula are priority taxa - species of conservation significance (DBCA 2019b). In some pastoral areas, native grasses have been replaced by annual pastures. Buffel grass has spread extensively throughout the region, including the national park (Meissner 2010). Selective overgrazing by sheep, goats and cattle has also exposed areas to wind and erosion (W.A. Planning Commission 1996). Trampling of vegetation and compaction of the earth are also issues particularly around watering points.
Limestone cliffs & gullies		L-M	Possibly less disturbed than coastal plains and dunes due to access? Selective overgrazing and trampling by introduced herbivores may remove some species (W.A. Planning Commission 1996). Weed invasion can displace native species and change fire regimes (especially buffel grass). Basic raw material extraction or groundwater drawdown may have also resulted in vegetation decline, however, the extent of loss of vegetation is not well known.

Distinctive Values	Current state	Conf.	Justification
Coastal dunes		M	Twelve taxa are found exclusively within the northern red sand dunes within the UCL on the Cape Range peninsula (Meissner 2011; Metcalf and Bamford 2005). Camping and 4WD has caused extensive damage across dune vegetation (pers. comms.; Kobryn et al. 2017).
Threatened/ priority flora			Uncertainty around current state. Surveys needed.
Terrestrial fauna			
Reptiles			The Exmouth Gulf area is the northern extent of distribution of at least six species' ranges. Six endemic reptile species are known from the North West Cape. Five species of conservation significance are listed in the W.A. Threatened and Priority Fauna list (DBCA 2019). Off-roading likely to have caused some damage to habitats but uncertain of extent. Overgrazing by livestock, weed invasion and predation from pests/feral animals has likely had the biggest impact to reptiles (pers. comm. DBCA). Baseline information missing for reptiles around Exmouth so uncertain as to current status.
Mammals			At least half of the original mammals in the Cape Range area have become extinct since European colonisation (Baynes and Jones, 1993; McKenzie et al. 2002). Increasing use of the islands (e.g., by tourists, fishermen and shell collectors) has been a long standing concern. Bandicoots have been translocated onto Doole Island – all nesting sites are below storm surge level as based off Olwen surge level, so they are at risk from storm surge (pers. comm.). Current status unknown due to lack of detailed surveys and baseline data.
Birds			The terrestrial birdlife of the North West Cape is typical of the Pilbara and Carnarvon Basin regions and has a diverse assemblage with over 240 terrestrial bird species recorded within the cape and surrounds (within a 50km search area, ALA 2021; W.A. Museum 2021b). Off-roading likely to have caused damage to habitats, nests and burrows. Bird surveys are undertaken by volunteers (e.g. Birdlife Australia). However, uncertainty around the current status of birds in the area.
Short-range endemic invertebrates			The short-range endemic (SRE) invertebrate fauna of Cape Range are data deficient.
Amphibians			Limited studies on amphibians, but endemic species are found e.g. Douglas' toad (*Pseudophryne douglasi*). Off-roading likely to have caused some damage to habitats but uncertain of extent. Uncertainty around the current status of birds in the area.
Landforms			
Karst systems			Dumping of rubbish and rocks occurs (pers. comm.). Sedimentation during heavy rains and floods can occur. There is currently uncontrolled access to some caves e.g., Camerons Cave and Bundera Sinkhole. Disturbances, such as diving and swimming can cause alteration of chemico-physical attributes of the waterbody in Bundera Sinkhole. Unknown how past variations in water chemistry has impacted fauna living in systems. Uncertain around the connectivity between karst systems.

Distinctive Values	Current state	Conf.	Justification
Islands		M	Inundation of some island has occurred in the past with storm surge e.g., Tropical Cyclone Olwyn. Currently receiving research focus. An analysis of the platform and geomorphic attributes of several northwest Australian islands was used to assess their potential vulnerability to future erosion (Bonesso et al. 2020). In Exmouth Gulf, Y Island recorded an increase in island volume and average elevation whilst Eva Island (also known as Victor Island) recorded a decrease in land area, volume and elevation, potentially suggesting erosion.
Subterranean Fauna			
Troglofauna			Communities are vulnerable as they may only be known from single sites. Uncertainty around the connectivity between karst systems and thus faunal communities. Current impacts to karst systems would likely be impacting communities. Many species listed as endangered, vulnerable and critical on the Threatened or Priority Species list. Groundwater drawdown will impact humidity. Past declines of troglobitic fauna in a single-chambered cave on the Cape Range peninsula (C-118) has been noted (Humphreys 1991).
Stygofauna			Communities are vulnerable as they may only be known from single sites. Uncertainty around the connectivity between karst systems and thus faunal communities. Current impacts to karst systems would likely be impacting communities. Many species listed as endangered, vulnerable and critical on the Threatened or Priority Species list. Groundwater drawdown will impact water chemistry.
Terrestrial Environmental Quality			
Topsoil			Overgrazing is likely to have had some impact on erosion of topsoil, and runoff for some areas of Exmouth. Van Vreeswyk et al. (2004) found ~77% of 12,445 visual traverse assessments of Pilbara pastoral land, indicated 'good' or 'very good' vegetation condition, 11% indicated fair condition and 12% indicated poor or very poor condition. Uncertainty around current quality and state of topsoil.
WATER			
Inland waters			
Groundwater systems		H	Groundwater resources on the Exmouth peninsula are limited due to the relatively small size of the peninsula and low rainfall. Exmouth's only source of freshwater is an unconfined karstic limestone aquifer of the Cape Range Peninsula (Boulton et al. 2003; Lee 2008). Thinning of the freshwater lens and increasing groundwater salinity in the past has been attributed to periods of low rainfall, tidal influences and groundwater abstraction (Lee 2008). At risk groundwater ecosystems include ephemeral creeks and permanent soaks. Abstraction of groundwater and localised groundwater drawdowns have been recognised as risks since Exmouth was established in the 1960s.
Surface water systems		M	Impacts have already occurred to surface water systems - many no longer in a 'natural' or 'pristine' state. PFAS have been detected in the backwater lagoon, east of the Harold E. Holt Naval Communication Base (DoD 2019). Some main river channels in the region have also been reported to be blocked with sand (McKenzie et al. 2002).

Distinctive Values	Current state	Conf.	Justification
AIR			
Air quality		H	No issues with air quality given the relatively small population and infrastructure.
PEOPLE			
Social surroundings			
Aboriginal heritage & culture			Not scored – Indigenous input required.
National heritage		M	Ningaloo Coast World Heritage Area has had some impacts to its Outstanding Value e.g., coral bleaching.
Amenity - land-based recreation		H	Many land-based recreational activities are currently occurring.
Amenity – marine-based recreation		H	Many marine-based recreational activities are currently occurring.
Amenity - intrinsic/ wilderness aesthetic		H	Exmouth is a major attraction for those people wanting the intrinsic/ wilderness aesthetic. Some concerns over increased uses of Exmouth Gulf. Oil platforms/flares seen from lighthouse and current industrial activities impact the sense of wilderness. COVID-19 saw increased numbers of tourists to Exmouth which impacted upon aesthetic (pers. comm. workshop)
Amenity - noise, dust, odour, light		H	All at relatively good levels. Exmouth is internationally known for it's 'dark skies' and has a number of telescopes and events that rely on the maintenance of this important value.
Economic - tourism		H	Tourism is significant source of economic stimulus (Shire of Exmouth 2018).
Economic - commercial fishing		H	Prawn trawling has been impacted by past extreme events but has recovered (Loneragan et al. 2013). Managed by DPIRD and considered sustainable.
Economic - pastoralism			Uncertainty around current state. Pastoral stations are now offering accommodation and experiences to tourists.
Economic - science and research		H	Has and is still being used as a key location for research. Currently, accommodation issues are inhibiting full research capacity. Minderoo Foundation Exmouth Research Laboratory is up and running to accommodate research.
Human health			
Potable water		H	Shire is confident that enough potable water will be available for human use. The Shire commented that supplies were able to handle the influx of people during COVID-19 tourist influx. There are strong concerns over potable water availability and groundwater drawdown (pers. comm. workshop).

11. Current and Forecasted Uses of Exmouth Gulf



Fishing boat at sunset (Photo: Tourism Western Australia)

11.1. Current and Forecasted Uses within Scope

Part of the scope of this report was to identify the current and forecasted uses of Exmouth Gulf, including but not limited to fisheries/aquaculture, tourism, transport and logistics, industry and pastoralism/agriculture. Current and forecasted uses of Exmouth Gulf were compiled from EPA proposals or EPA knowledge of potential proposals, Perspectives Group knowledge, input from the Department

Past EPA proposals	Current activities	Potential future activities - 5-10yrs	Potential future activities - 20+years
Fisheries/aquaculture -Mariculture *not implemented[1] -Prawn farm Heron Point *not implemented[1] **Transport & logistics** - Exmouth Boat Harbour[1] **Development** -Marina Resort & Residential Development[1] -Special Residential Development, Lyndon locations *not implemented[1] -Water Supply Borefield extension[1] -Industrial Subdivision[1] **Mining & petroleum** -Limestone Mine[1] -Exmouth Limestone Project Barge Loading Facility *not implemented[1] -Oil exploration[1] -Melanie-1 Petroleum Exploration *not implemented[1] -Yannarie Solar Salt *not implemented[1]	**Fisheries/aquaculture** -Oyster Growth Trials (Bay of Rest) -Prawn Hatchery (Seafarms Project Sea Dragon) -Kailis prawn fishing activities **Tourism** -Recreational Fishing -Commercial Charter Fishing (including catch/release & fly fishing) -Lighthouse Caravan Park upgrade -Recreational use of islands (camping) -Applications for gulf coastal campgrounds -Fishing & marine tours **Transport & logistics** -Servicing offshore oil & gas from Exmouth marina -Tantabiddi boat ramp redevelopment[2] -Servicing offshore oil & gas needs **Development** -Residential and commercial upgrades & maintenance[3] -Local Planning Scheme 4 Amendment 1[1] -Redevelopment of health campus[4] **Pastoral/agriculture** -Camping leases **Renewable energy production** -Battery Energy Storage System ($7.8 million) **Mining & petroleum** -Subsea 7 *not implemented[1] -Marine support from Exmouth Marina for oil & gas	**Fisheries/aquaculture** -Finfish & shellfish[2,6,7] -Aquaculture sites (sea cucumber harvesting) **Tourism** -Cruise ships[4] -Trek Ningaloo (walking tours) -Mountain Bike trails development *-NOTE: Mixed eco & citizen science tourism industry concept to develop further.* **Transport & logistics** -Gascoyne Gateway Single Jetty Deep Water Port and Renewable Hub[8] -Expansion to facilitate cruise ships & cargo[9] **Development** -Workforce accommodation -Residential land release(s) -Lighthouse Resort development[1] -Aged Care facility investigation currently underway by Shire *-NOTE: Lack of workforce accommodation is a contentious issue in the community and a priority for development in Exmouth* **Pastoral/ agriculture** -Camping leases *-NOTE: Potential use of pastoral land for environmental offsets/carbon capture* **Renewable energy production** -Horizon Power energy PPA expires 2024, HP investigating renewable options -Gascoyne Gateway Ltd (Solar powered municipal power supply/augmentation) **Mining & petroleum** -Limestone expansion[1] -Salt farm K&S Salt[1] -Potash[10] **National interests** -Space Fence (Harold E Holt base) -RAAF Base Learmonth upgrades	**Development** -Satellite aged care facility[4] -Research innovation facilities -Education facilities[4] -Maternity Unit[4] **Renewable energy production** -100% renewable energy aspiration **Mining & petroleum** -Marine support for oil & gas[4] **National interests** -Expansion of operations[4]

Figure 9: Previous, current and potential future activities relating to Exmouth Gulf. Where possible, further detail and source of information is provided. [1]Environmental Protection Authority, [2]NationalMap, [3]Shire of Exmouth tenders, [4]Gascoyne Regional Investment Blueprint – Gascoyne Development Commission, [5]W.A. Labor Plan for NW Central, [6]Draft aquaculture plan for Exmouth Gulf 2004, [7]Aquaculture Development Plan for Western Australia , [8]Gascoyne Gateway Limited , [9]ACIL Allen Consulting 2019 - Economic benefits assessment of Exmouth Marine Infrastructure Project Final Report, [10]Whalebone Wyloo Metals.

of Jobs, Tourism, Science and Innovation, Gascoyne Development Commission, the Exmouth Shire, and associated state plans and strategies (Figure 9). A search of NationalMap datasets relating to coastal plans, tenements and licences was also undertaken. Some of the activities listed in Figure 9 helped to inform the risk assessment process.

The activities listed for the next 5-10 years may also be possibilities in 20+ years' time, though it is difficult to predict with certainty. There was also less information suggesting future uses for 20+ years' time.

11.2. Marine Vessels in Exmouth Gulf

Some of the proposed activities for Exmouth Gulf will result in an increase in the number of vessels using Exmouth Gulf to some extent. An increase in the number of vessels will then lead to increased underwater noise and possibly vessel strikes with marine fauna. In order to better understand the future cumulative impacts of increased vessels using Exmouth Gulf, it is useful to have an understanding of the current use. The main types of vessels using Exmouth Gulf are for recreational, commercial fishing (including charters), tourism, industrial and defence purposes.

The information consolidated in the section was sourced from DBCA, DPIRD and the Australian Maritime Safety Authority (AMSA). It should be noted that the information presented below should be viewed as the minimum of the number of vessels using Exmouth Gulf, as consistent surveys have not been carried out for all vessel types across all points in time.

11.2.1. Commercial Fishing

The Exmouth Gulf Prawn Trawl Fishery is the primary fishery operating in Exmouth Gulf. MG Kailis owns and operates 100% of the available licences in the Exmouth Gulf Prawn Fishery. Six trawling vessels are currently in operation during the peak fishing season, and have been since 2012. From 1963 to 1989, there were up to 23 vessels operating in the fleet (pers. comm. DPIRD). Though the number of vessels in the fleet has decreased over time, it is important to note that net configuration has also changed. Smaller quad nets were found to be a more efficient gear configuration and were also economically efficient and, as such, towing of quad nets was fully introduced in 2000. Overtime, the number of vessels continued to decrease as fleets were restructured. The current fleet of six vessels includes four of these towing 10.97m (6ftm nets) and two larger boats towing 14.6m (8ftm nets) in quad gear configuration, giving a total headrope capacity of 292.6m (160ftm nets). This is 25% less headrope towed than permitted and, overall, there is significantly less net on the bottom today than the 80's.

MG Kailis also operates two demersal fish trawlers that target the Pilbara Interim Managed Fish Trawl fishery. While these vessels may exit through Exmouth Gulf to reach fishing grounds, they do not operate inside the Gulf.

11.2.2. Recreational Vessels

DPIRD conducts recreational fishing surveys statewide and the latest report was produced in 2019 (Ryan et al. 2019a). While information provided is on recreational catch, fishing effort and the number of boat licenses for recreational fishing, this is broken into regional boundaries, e.g. Gascoyne, and the resolution of data currently available is too course for the purposes of this report.

DBCA have been conducting aerial surveys of recreational boat trailers and vehicles at Exmouth Marina during school holiday periods every year since 2007 (December - January, April, July, September - October). Though surveys are scheduled every year, including multiple days during each school holiday period, it is highly weather dependant. The data collected can provide single daily snapshots across each school holiday period, and the temporal extent of the data would allow for trends to be observed over time. The number of empty boat trailers observed at Exmouth Marina on a given day appear to be higher during the July and September - October school holidays, compared to April and December - January school holidays (Figure 10). On one day in July 2020, 50 empty boat trailers were counted at the marina. The maximum number of empty boat trailers recorded across the dataset was 84 trailers in July 2008 (Figure 11). This data gives

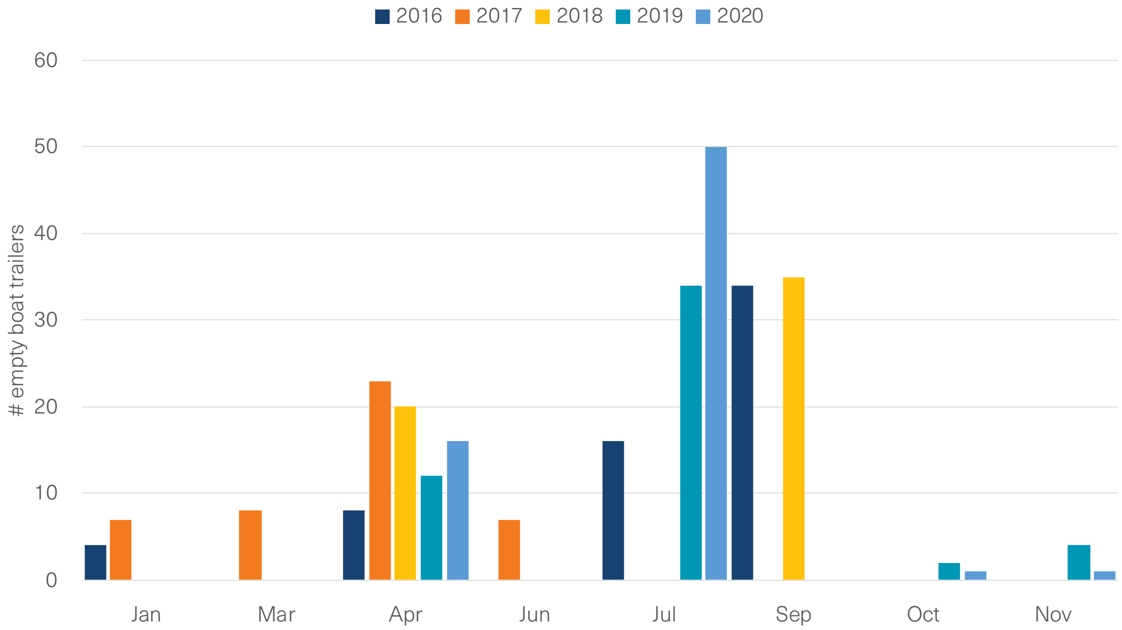


Figure 10: Indicative representation only of the number of boat trailers with no boats observed at Exmouth Marina on one day in each month surveyed. Data supplied by DBCA, May 2021. Unsurveyed months are not shown.

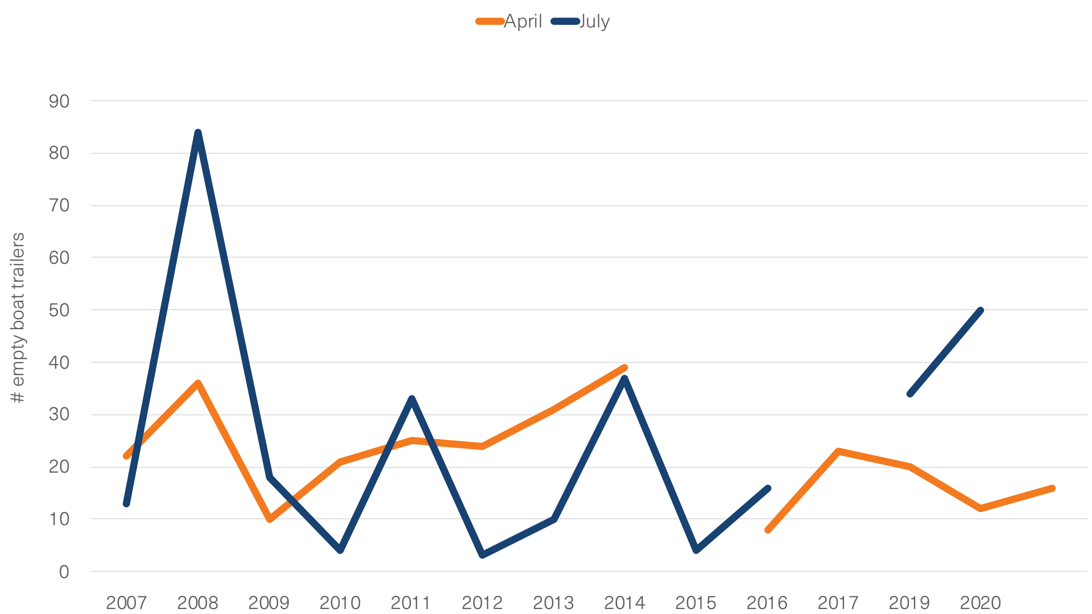


Figure 11: Indicative representation only of the maximum number of boat trailers with no boats observed at Exmouth Marina on the days sampled during April and July across years. The two months presented were surveyed most consistently every year. Data supplied by DBCA, May 2021.

an indication only of the minimum number of recreational vessels launching from the marina at the surveyed points in time. More vessels would be launched from Bundegi Boat Ramp and other vessels may enter Exmouth Gulf from outside areas. It cannot be assumed that all vessels leaving Exmouth Marina are remaining in Exmouth Gulf for the duration of their trip.

DBCA also collects data from a vehicle counter set up at the Bundegi Boat Ramp. The counter collects information on the types of vehicles that visit the boat ramp. Car and buses are included in Table 23 as it is very unlikely that motorbikes would be towing a boat. Buses are included as they may have been dropping customers off to tourism-related vessels waiting at the ramp, or they could have been mobile accommodation buses and caravans. A major caveat for including the data for the purposes of this section is that not all cars and buses would have been towing or using a vessel at the boat ramp. Some people may have travelled to the area for other purposes, such as fishing, swimming and snorkelling. It should also be noted that the same vehicle may have visited the boat ramp multiple times a day or month. The attached data is the best available at time of reporting, but it is acknowledged that future reported figures are subject to change due to the nature of coming from a live database that may be corrected over time as errors are identified.

The highest number of car visits to Bundegi Boat Ramp was 39,625 vehicles in 2016-17 (Table 23). The number of car visits remained relatively stable between 2015-2019, and there was a clear decrease in the number of vehicles at the start of January, most probably in response to COVID-19 restrictions. Interestingly, the number of buses increased significantly across the 2019-2020 year. This may have reflected continual visits by the same people if they were restricted from travelling out of the region.

It is not possible to determine what percentage of car and bus visits engaged in vessel activity from the boat ramp.

Table 23: Bundegi Boat Ramp vehicles 2015-16 to 2019-20. Data supplied by DBCA, May 2021. Order of months follows the financial year. Greyed months indicate school holiday periods.

	2015-2016		2016-2017		2017-2018		2018-2019		2019-2020	
	Cars	Buses	Cars	Buses	Cars	Buses	Cars	Buses	Cars	Buses
Jul	3887	119	4218	160	4218	160	4735	249	*	*
Aug	3988	125	4278	210	4574	228	1100	71	*	*
Sep	3476	106	4024	163	4228	209	4236	201	4168	527
Oct	3717	99	3626	116	3751	159	3751	159	4133	489
Nov	2637	77	2678	86	5154	212	5154	212	2253	255
Dec	2862	68	3111	87	2885	92	2885	92	2776	253
Jan	2687	74	2956	57	3242	135	3229	143	2531	205
Feb	2172	63	1921	53	1808	61	1800	69	1822	203
Mar	3447	95	2479	80	3000	91	1871	176	2329	256
Apr	3775	123	4292	146	1373	59	2958	277	1868	195
May	3398	105	3002	91	826	58	1960	195	1559	108
Jun	3152	104	3040	129	3689	221	1896	260	3047	404
SUM	**39,198**	**1158**	**39,625**	**1378**	**38,748**	**1685**	**35,575**	**2104**	**26,486**	**2895**

* hardware issues - no data collected.

11.2.3. Vessels Tracked and Recorded by AMSA

Spatial data on vessel traffic is available via the Spatial@AMSA website (www.operations.amsa.gov.au/Spatial/DataServices/DigitalData). The data presented in Table 24 and 25 are based on Automatic Identification System (AIS) data extracted from the AMSA Craft Tracking System database. The AIS data is available for each month spanning back to 1999 and covers the extent of Australia's Search and Rescue Region. Only vessels that have AIS fitted/switched on will have been recorded and, as such, many recreational vessels will not have been captured. Some vessels may have only been passing by or through Exmouth Gulf, rather than operating in the Gulf e.g., those vessel types labelled as fishing. No data on vessel ownership or ship identification was provided.

The information collected on vessel type and other vessel features are more detailed than those categories presented in Table 24 and 25. Only a broad indication of vessel type, size, draught and speed in Exmouth Gulf is provided in this report. A similar number of vessels with AIS were detected in Exmouth Gulf across 2018 (581 vessels) and 2020 (565). These years were chosen to reflect pre-COVID-19 and COVID-19 conditions. Aside From the ‘other’ category, cargo (37) and tug/towing (31) vessels were the most common vessel type in 2018, whereas pleasure crafts (37), fishing (32) and tug/towing (32) vessels were most common in 2020. The highest number of vessels were detected during November (65) in 2018, and during September (68) in 2020. The largest vessels with AIS recorded were tankers (238 ± 6.2m in length) with an average draught of 8.7 ± 0.3 m. Passenger ships and pilot vessels were detected travelling at an average speed of 12-13 knots in 2018, and up to 14.6 ± 4 knots for pilot vessels in 2020. Most other vessel types were detected at an average speed of less than 10 knots.

Other includes vessels listed as ‘other’ in the AIS data set as well as any ambiguously labelled vessels e.g. ‘reserved', 'Local 57’, and ‘ship (according to RR Resolution No. 18 (Mob-83)’.

Table 24: The main vessel types, fitted with an Automatic Identification System, detected within Exmouth Gulf (spatial scope of this report) across 2018 and 2020. Data supplied by DBCA, May 2021.

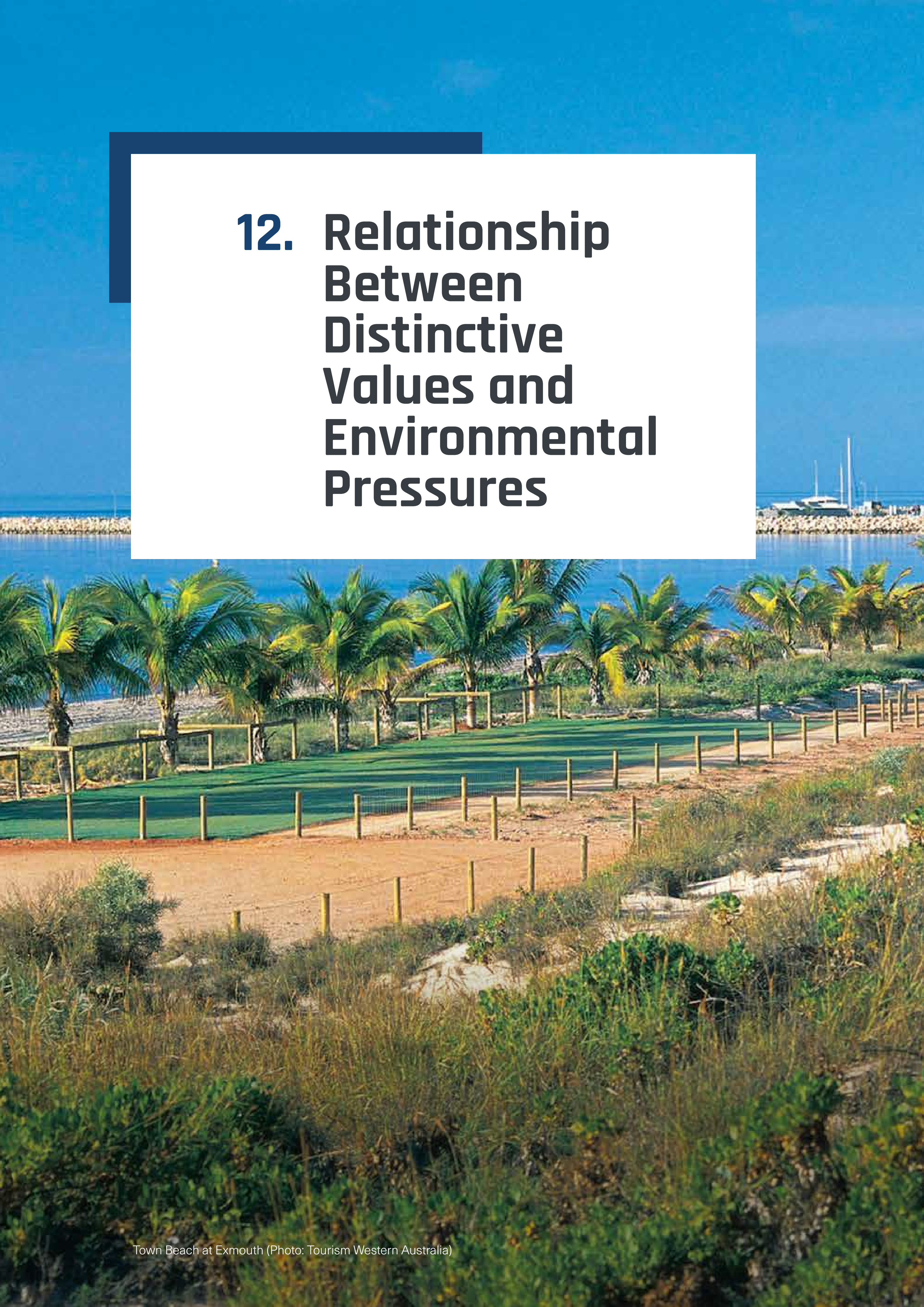
2018													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Cargo	1	3	3	6	4	1	4	3	1	2	5	4	**37**
Fishing	0	0	0	1	0	0	0	0	0	0	0	0	**1**
Law enforcement	1	1	0	1	0	0	0	0	0	0	0	1	**4**
Other*	22	29	36	37	38	42	38	29	47	46	47	41	**452**
Pleasure craft	0	0	0	0	1	2	1	0	1	1	2	2	**10**
Port tender	1	1	1	1	1	1	1	1	1	1	1	1	**12**
Tanker	4	2	1	2	1	0	0	2	1	1	4	1	**19**
Tug/towing	2	4	1	2	3	4	1	1	2	3	5	3	**31**
Passenger ship	1	4	1	1	0	0	0	0	0	1	0	2	**10**
Pilot vessel	0	0	1	0	0	0	0	0	1	1	1	0	**4**
Diving operations	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Total	**32**	**44**	**44**	**51**	**48**	**50**	**45**	**36**	**54**	**56**	**65**	**56**	**581**
2020													
Cargo	1	6	2	1	1	0	0	3	1	2	1	4	**22**
Fishing	0	0	0	0	0	0	0	1	5	10	10	6	**32**
Law enforcement	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Other*	21	32	39	34	29	34	34	47	48	12	15	11	**356**
Pleasure craft	0	0	2	1	0	2	1	2	5	16	4	4	**37**
Port tender	0	1	1	1	1	1	1	1	2	3	5	5	**22**
Tanker	2	1	2	3	0	1	2	0	2	2	3	3	**21**
Tug/towing	4	4	4	4	1	0	3	2	2	1	4	3	**32**
Passenger ship	0	2	2	0	0	0	1	1	1	1	5	0	**13**
Pilot vessel	1	1	0	0	0	1	0	0	0	2	1	1	**7**
Sailing	0	0	0	0	0	1	2	3	2	6	4	4	**22**
Total	**29**	**47**	**53**	**44**	**32**	**40**	**44**	**60**	**68**	**55**	**52**	**41**	**565**

* Other includes vessels listed as 'other' in the AIS data set as well as any ambiguously labelled vessels e.g. 'reserved', 'Local 57', and 'ship (according to RR Resolution No. 18 (Mob-83)'.

Table 25: Average length, draught and speed of main vessel types, fitted with an Automatic Identification System, detected within Exmouth Gulf (spatial scope of this report) across 2018 and 2020. Standard errors are provided. Data supplied by DBCA, May 2021.

	Ave length (m)		Ave draught (m)		Ave speed (knots)	
Vessel type	2018	2020	2018	2020	2018	2020
Cargo	98 ± 6.0	80 ± 11.4	5.9 ± 0.2	5.1 ± 0.3	7.3 ± 0.9	7.7 ± 0.7
Fishing	20	22 ± 0.6	0	0	6.3	6.9 ± 0.7
Law enforcement	59	8	2.9 ± 0.3	0	11.9 ± 0.2	0
Other*	65 ± 4.3	45 ± 2.6	4.5 ± 0.2	3.9 ± 0.2	8.3 ± 0.3	8.4 ± 0.3
Pleasure craft	34.3 ± 5.4	22 ± 2.0	2.5 ± 0.2	2.3	8.2 ± 1.0	7.3 ± 1.5
Port tender	34	26 ± 1.6	2.6	2.6	6.4 ± 3.1	12.1 ± 2.5
Tanker	233 ± 8.3	238 ± 6.2	8.5 ± 0.3	8.7 ± 0.3	6.1 ± 0.9	5.0 ± 0.9
Tug/towing	67 ± 3.8	43 ± 4.0	5.6 ± 0.3	5.7 ± 0.2	8.6 ± 0.7	8.8 ± 0.5
Passenger ship	174 ± 19.3	67 ± 19.9	5.8 ± 0.6	4.1 ± 0.9	12.0 ± 1.5	9.4 ± 1.3
Pilot vessel	18 ± 0.3	27 ± 10.1	1.9 ± 0.03	4.8 ± 2.8	12.9 ± 5.5	14.6 ± 4.0
Diving operations	112	0	6.5	0	3.2	0
Sailing	0	12.9 ± 0.5	0	0	0	4.6 ± 0.8

* Other includes vessels listed as ‘other’ in the AIS data set as well as any ambiguously labelled vessels e.g. ‘reserved’, 'Local 57’, and ‘ship (according to RR Resolution No. 18 (Mob-83)’.



12. Relationship Between Distinctive Values and Environmental Pressures

Town Beach at Exmouth (Photo: Tourism Western Australia)

12.1. Exmouth Gulf Risk Assessment

A total of 61 Distinctive Values were scored during the qualitative risk assessment process for Exmouth Gulf; 33 belonging to the EPA theme Sea, 14 to Land, two for Water, one for Air, and 11 for People. Considering all combinations of pressures x Distinctive Values (remembering not all pressures were relevant to all Distinctive Values), 849 individual risk scores were derived during risk assessment workshops and post-workshop efforts (Appendix 5). If a definite risk score was not arrived at, e.g., 6-8, this was recorded in Appendix 5, but a conservative approach was taken and the highest score was used throughout the report and the assessment of cumulative pressures.

Before the results of the risk assessment are interpreted, it is important to acknowledge the following caveats and considerations:

- Not all risk scores were assigned during the two single-day workshops because of time constraints. Scoring of some themes and value x pressure combinations were required after the workshop and involved scoring by one, or multiple people. While these scores were distributed for review by workshops attendees (incl. subject matter experts) before finalisation, it is recognised that some scores and justifications did not benefit from the extensive workshop discussions as other scores did.
- More input from experts on the risk scores, either during or post-workshop, was made for the Sea theme and Land theme. This is likely reflective of the level of knowledge and expertise of workshop attendees, rather than a lack of significance or importance.
- Different participants in different workshops may have resulted in some themes being scored at a level higher than others e.g., Land over Sea theme. Familiarity with risk assessment processes may have been uneven for participants across workshops
- In all cases, the exact footprints and design details of developments in and out of the water were not available for the risk assessment process. Risks were assigned on rough spatial extents and conceptual designs.
- In many cases, the level of knowledge was low for the impacts on pressures on Distinctive Values, and even for general knowledge of the Distinctive Values.
- There were a number of constraints on the project including: limited time, limited resources and COVID-19 restrictions. This reduced the notification time for workshops, the number of workshops that could be held and the number of people who could physically attend each workshop.
- This is a qualitative process enabling an assessment of risk in data poor situations. It cannot be transferred to a quantitative process or interpretation.
- There was a lack of Indigenous voices in the development of the processes used and the scoring of the risks. This was noted and as a result the 'Aboriginal heritage and culture' value was not scored. A special meeting was convened with the NTGAC and results of the workshop were incorporated into Section 9.
- As many of the values and pressures were consolidated, caution must be applied when interpreting the results in some of the tables. For example, Fishing is an activity which includes commercial trawling, commercial fishing and recreational fishing. The risk on the species (e.g. Table 26) comes from recreational fishing not commercial fishing and this can only be understood when going back to the risk scores (Appendix 5).

- The assignment of consequence and likelihood scores considered current and future pressures. The scores do not reflect any mitigation of risks, though some 'typical' mitigation measures were noted in the justification for awareness. While cumulative impact considerations would apply to most, if not all, Distinctive Values, these were not reflected in the scores. If cumulative impacts were specifically mentioned for a value and pressure combination, this was noted in the justification, again, for awareness.
- For the development activity, it was difficult to split up the proportion of impact coming from residential, industrial and tourism pressures. For example, light pollution impacting on dark skies was given the same high-risk score (12) across residential, industrial and tourism-related light pollution. Similarly, residential groundwater drawdown and industrial groundwater drawdown were scored as having the same risk to stygofauna and troglofauna.

12.1.1. Sea

Over half of the 33 Distinctive Values under the Sea theme were categorised as high risk from at least one pressure (Figure 12). High risks were spread across all four factors under the Theme Sea: Benthic Communities and Habitats, Marine Fauna, Marine Environmental Quality and Coastal Processes. All remaining Distinctive Values received a medium risk at least once, except for hydrodynamic processes, which was low.

Those Distinctive Values with the greatest number of high risks included seabirds/shorebirds (four high risks) (Photo: Rebecca Bateman-John).

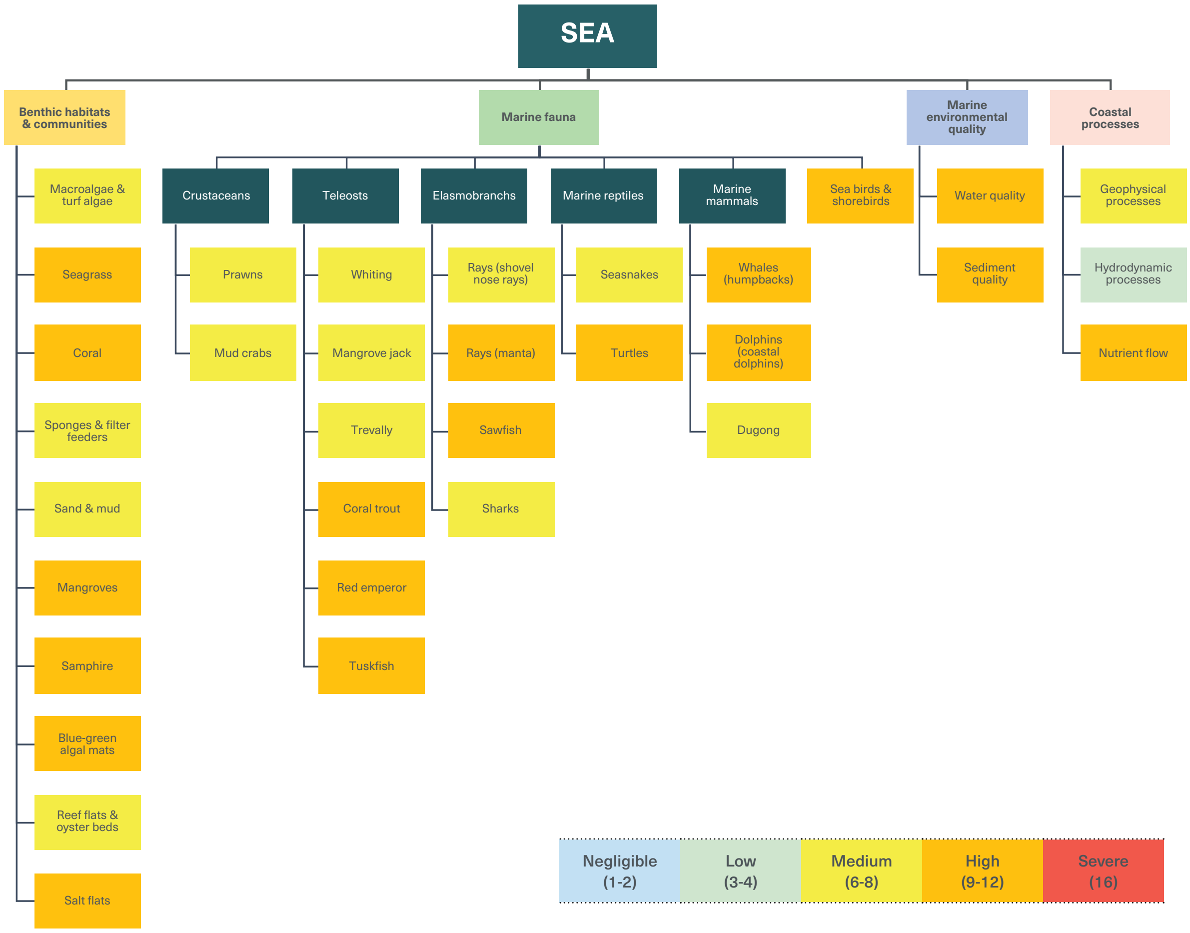


Figure 12: A summary of the risks to Distinctive Values under the EPA Sea theme. The highest risk scored across all five activities assessed is shown, rather than an average.

Those Distinctive Values with the greatest number of high risks were seabirds/shorebirds (four high risks) and marine turtles (3 high risks). For seabirds/shorebirds, pollution relating to Shipping (light and oil/fuel spills), and direct physical disturbance and rubbish relating to Tourism/Visitation were the pressures most impacting upon this value. Light pollution and rubbish were high risk for marine turtles, in addition to tropical storms and cyclones that could erode suitable nesting beaches.

Seagrasses, coral trout, humpback whales and dolphins all received two high risks each, which were not all caused by the same pressures and activities (Table 26).

Climate Change pressures, notably marine heatwaves and tropical storms and cyclones, posed the greatest number of high risks, overall, to Distinctive Values under the Sea theme (4 high risks). Pollution (oil, fuel, antifoul) from Shipping activity, recreational fishing and pollution from Tourism/Visitation all impacted three separate Distinctive Values. Recreational fishing was also highlighted as a concern by Traditional Owners during the workshop with the Nganhurra Thanardi Garrbu Aboriginal Corporation (Section 9).

Of note, is the almost consistent scoring of medium risks for Distinctive Values facing the pressures of introduced marine pests (Shipping), suspended sediments from dredging (Shipping), oil and gas seismic surveys (Mining) (Table 27).

Light pollution and rubbish were high risk for marine turtles, in addition to tropical storms and cyclones that could erode suitable nesting beaches. (Photo: Rebecca Bateman-John).

12.1.2. Land

More than half of the 14 Distinctive Values under the Land theme were at high risk from at least one pressure (Figure 13). High risks were spread across four factors: Flora and Vegetation, Terrestrial Fauna, Landforms and Subterranean Fauna. All remaining Distinctive Values received a medium risk at least once.

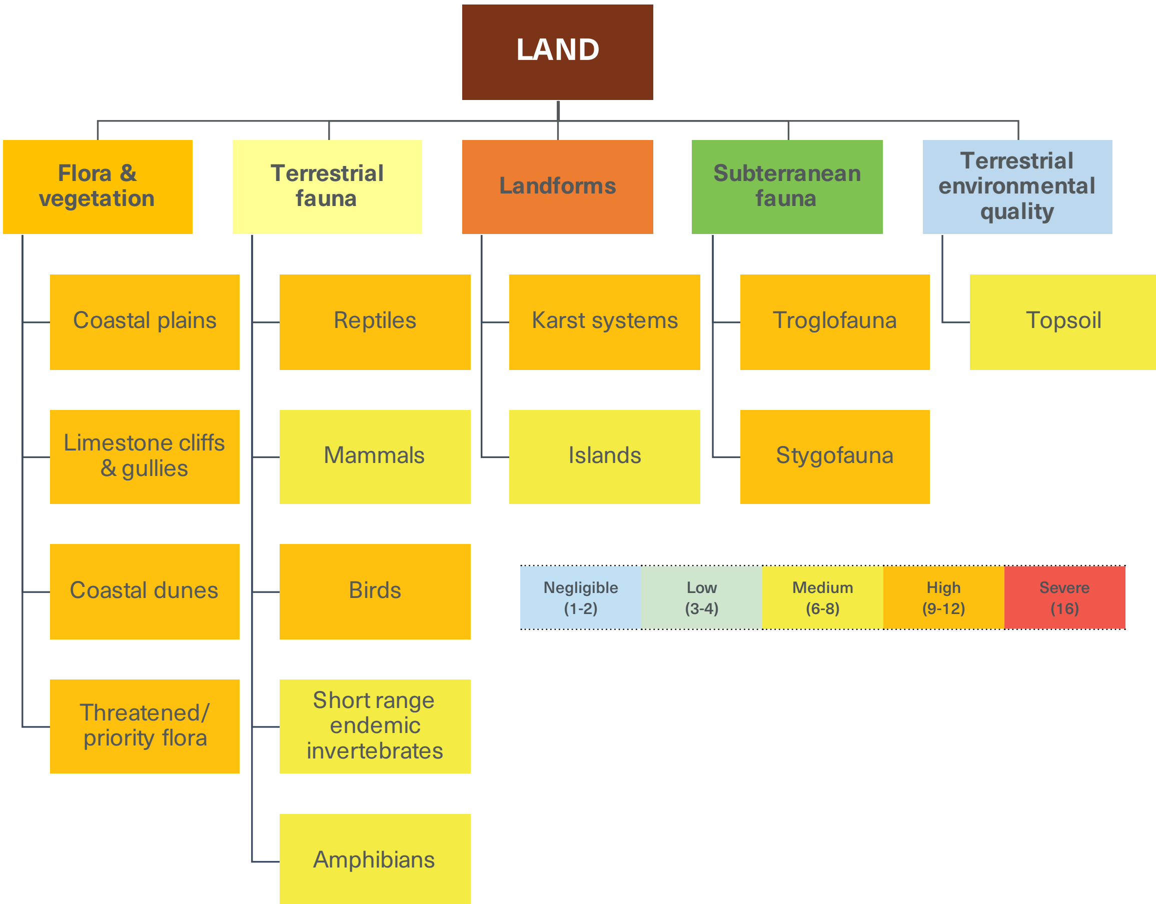


Figure 13: A summary of the risks to Distinctive Values under the EPA Land theme. The highest risk scored across all six activities assessed is applied, rather than an average.

The Distinctive Value with the greatest number of high risks were threatened/priority flora (seven high risks). These high risks related to Climate Change, Development, Pastoralism and Tourism/Visitation pressures (Table 26). The Flora and Vegetation Factor overall accounted for 14 out of 24 high risks given to Distinctive Values under the Land Theme.

Given karst systems, stygofauna and troglofauna communities are all linked, values received high risks in relation to groundwater drawdown associated with residential, industrial and tourism Development. Water use was also highlighted as a concern by Traditional Owners during the workshop with the Nganhurra Thanardi Garrbu Aboriginal Corporation (Section 9).

Overall, pressures associated with the activity Development posed the greatest number of high risks to Distinctive Values under the Land theme (16 high risks). Tourism and industrial footprints accounted for three high risks each (on Flora and Vegetation). Off-road driving associated with Tourism/Visitation posed high risks to three Flora and Vegetation values, while overgrazing (Pastoralism) accounted for two high risks on Flora and Vegetation.

Physical footprint, light pollution and noise pollution from residential, industrial and tourism development were consistently rated as having a medium risk on all terrestrial fauna (Table 27).

Off-road driving associated with Tourism/Visitation posed high risks to three Flora and Vegetation values. (Photo: Rebecca Bateman-John).

12.1.3. Water

Both ground water systems and surface water systems received a high risk from at least one pressure (Table 26). For groundwater systems, the high risks came from potable water use in relation to Tourism/Visitation and potential contamination (by PFAS). Similarly, contamination also rated as a high risk for surface water systems. Most of the remaining pressures were scored as low risk to the two Distinctive Values, though some medium risks to these values were associated with Mining and Development (Table 27).

12.1.4. Air

Air quality was the only Distinctive Value assessed under the Air theme, and negligible to low risks were assigned to emissions from Mining (industrial salt, potash and limestone operations) and Development pressures (residential and industrial), as well as the potential increase and intensity of fires associated with Climate Change.

12.1.5. People

Out of the 10 Distinctive Values assessed under the People theme, two values received a high risk rating from at least one pressure: intrinsic/wilderness aesthetic amenity (Social Surroundings) and potable water (Human Health) (Figure 14). All other Distinctive Values received a medium risk at least once, except for science and research, which had low risks.

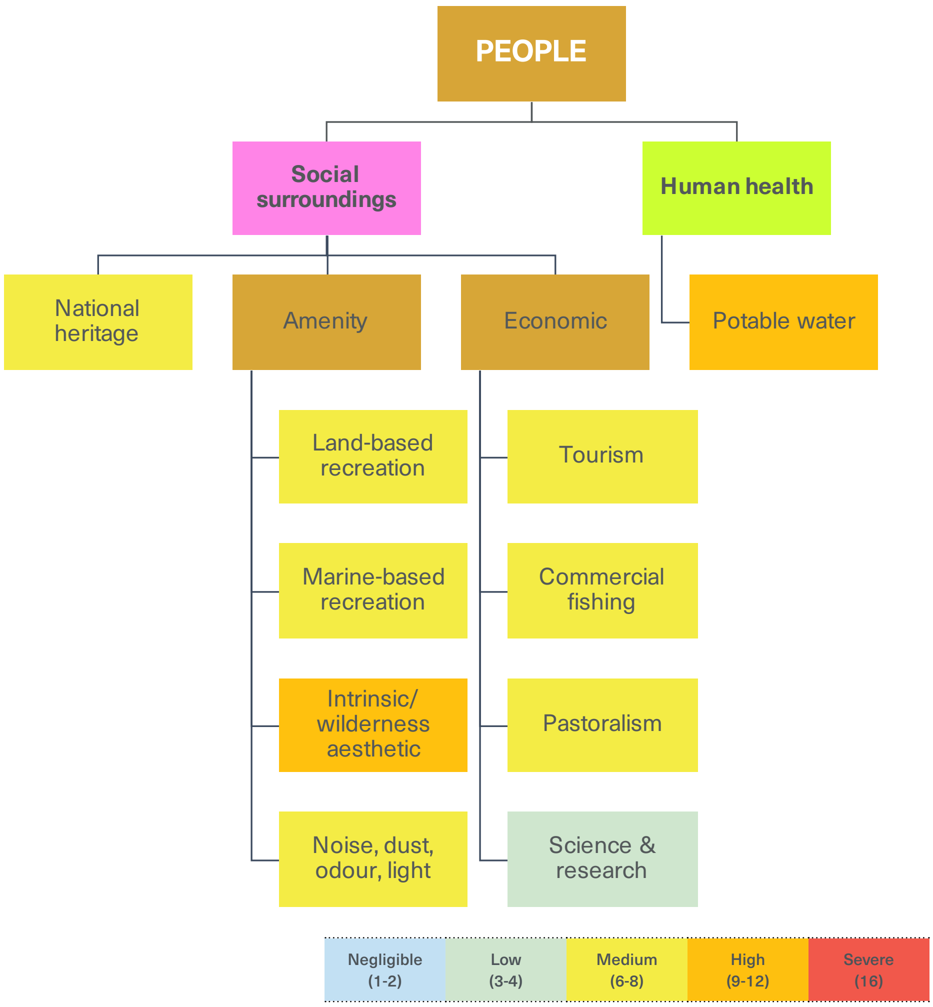


Figure 14: A summary of the risks to Distinctive Values under the EPA People theme. The highest risk scored across all six activities assessed is applied, rather than an average.

The intrinsic/wilderness aesthetic of Exmouth Gulf received four high risks. Three of these related to light pollution from residential, industrial and tourism development, which would impact upon the internationally important 'dark skies' value of the region. Dark skies are important for solar observations and astronomy. Off-road driving in relation to Tourism/Visitation also posed a high risk to the intrinsic/wilderness aesthetic.

Potable water use in relation to Tourism/Visitation was, unsurprisingly, the pressure posing a high risk to the Distinctive Value of potable water.

All pressures from Mining activity consistently posed medium risks to amenity, economy and potable water, as did fire in relation to Climate Change. Industrial footprint in relation to Development was a medium risk for land and marine-based recreation, intrinsic/wilderness aesthetic and tourism (in terms of economy), whereas the noise generated from tourist-related developments posed a medium risk to amenity and national heritage.

12.1.6. Impact of Pressures and Activities Overall

Out of all activities assessed, pressures associated with Tourism/Visitation posed high risks to all themes, except Air (Table 26). Climate Change posed high risks to the Distinctive Values under the Sea and Land theme, and Development posed high risks to Distinctive Values under the Land and People themes (noting Development was not assessed for the Sea theme).

This is not to say that those activities assessed for a single theme, e.g., Shipping and Fishing for the Sea theme, should be of less concern than more widespread pressures and activities, particularly given that not all possible pressures from all activities were assessed for all Distinctive Values.

Mining, and its associated pressures, was the only activity posing medium risks to all EPA themes, except Air (Table 27). This was followed closely by Tourism/Visitation and Climate Change pressures, which posed medium risks to Distinctive Values of Sea, Land and People, and Development, which posed medium risks to Distinctive Values of Land, Water and People.

Qualing Pool (Photo: Wendy Thompson).

Table 26: A summary of the high risks (9-12) associated with each major activity for each EPA theme. Those Distinctive Values for which the high risks relate are indicated.

	Factors	Shipping	Mining	Fishing	Tourism/ Visitation	Climate Change	Development	Pastoralism	Defence
SEA	Benthic habitats and communities		• Blue-green algal mats • Salt flats			• Seagrass • Mangroves • Coral • Samphire			
	Marine fauna	• Turtles • Humpback whales • Dolphins • Seabirds and shorebirds		• Coral trout • Red emperor • Tuskfish	• Manta rays • Turtles • Humpback whales • Seabirds and shorebirds	• Coral trout • Sawfish • Turtles			
	Marine environmental quality	• Water quality • Sediment quality							
	Coastal processes		• Nutrient flow						
LAND	Flora and vegetation				• Coastal plains • Coastal dunes • Threatened/ priority flora	• Threatened/ priority flora	• All Distinctive Values	• Limestone cliffs and gullies • Threatened/ priority flora	
	Terrestrial fauna					• Birds	• Reptiles	• Reptiles	
	Landforms						• Karst systems		
	Subterranean fauna						• Troglofauna • Stygofauna		
WATER	Inland waters				• Groundwater systems				• Groundwater systems • Surface water systems
PEOPLE	Social surroundings				• Amenity - intrinsic/ wilderness aesthetic		• Amenity - intrinsic/ wilderness aesthetic		
	Human health				• Potable water				

Table 27: A summary of the medium risks (6-8) associated with each major activity for each EPA theme. Those Distinctive Values for which the medium risks relate are indicated.

	Factors	Shipping	Mining	Fishing	Tourism/ Visitation	Climate Change	Development	Pastoralism	Defence
SEA	Benthic habitats and communities	• All Distinctive Values except blue-green algae mats and salt flats	• Mangroves • Samphire	• Sponges and filter feeders	• Coral	• All Distinctive Values except seagrass and salt flats			
	Marine fauna	• All Distinctive Values	• All Distinctive Values except prawns and mud crabs	• Prawns • Mud crabs • Whiting • Mangrove jack • Trevally • Shovelnose ray • Sawfish • Sharks • Sea snakes	• All Distinctive Values	• All Distinctive Values except whiting, mangrove jack, trevally, and red emperor			
	Marine environmental quality	• Water quality				• Water quality			
	Coastal processes					• Geophysical processes • Nutrient flow			
LAND	Flora and vegetation				• All Distinctive Values	• All Distinctive Values except threatened/ priority flora	• All Distinctive Values	• All Distinctive Values except threatened/ priority flora	• Threatened/ priority flora
	Terrestrial fauna		• Reptiles • Short range endemics		• All Distinctive Values except amphibians	• Reptiles • Mammals • Short range endemics	• All Distinctive Values	• Mammals • Amphibians	• Birds • Amphibians
	Landforms		• Karst systems		• Karst systems	• Karst systems • Islands	• Karst systems		• Karst systems
	Subterranean fauna		• Troglofauna • Stygofauna		• Troglofauna • Stygofauna	• Troglofauna • Stygofauna	• Troglofauna • Stygofauna		• Troglofauna • Stygofauna
	Terrestrial environmental quality							• Topsoil	• Topsoil

(Continued)

	Factors	Shipping	Mining	Fishing	Tourism/ Visitation	Climate Change	Development	Pastoralism	Defence
WATER	Inland waters		• Groundwater systems • Surface water systems				• Groundwater systems		
PEOPLE	Social surroundings		• Land-based recreation • Amenity - intrinsic/ wilderness aesthetic • Amenity – noise, dust, odour, light • Economic – tourism • Economic – commercial fishing		• Amenity - intrinsic/ wilderness aesthetic • Economic - tourism	• All Distinctive Values except national heritage, economic – commercial fishing and economic – science and research	• All Distinctive Values except economic – commercial fishing, economic – pastoralism and economic – science and research	• Amenity - intrinsic/ wilderness aesthetic	
	Human health		• Potable water				• Potable water		• Potable water

12.2. Exmouth Gulf Cumulative Pressures

The methodology for assessing cumulative pressures of Distinctive Values and activities is explained in Section 5.7 and 5.8. The individual risk scores that were used in this cumulative process are provided in Appendix 5. The ordering of activities based on cumulative pressures is indicative and qualitative only and should serve as a guide to help inform high-level strategic advice, rather than a definitive guide for proponents. It is important to reiterate that while activities are presented on an ordinal scale based on cumulative scores, the difference between 1 and 2 is not necessarily the same difference as between 2 and 3, or 3 and 4.

Certain activities will also have varying levels of pressure on Distinctive Values, and this variability is not accounted for in this process. For example, a small change in Climate Change pressures may result in an exponential growth in interactive impacts on Distinctive Values, whereas a small change in Mining, may have a more linear or less variable impact on Distinctive Values

Mining and Climate Change had some level of impact on the Distinctive Values for all five EPA themes of Sea, Land, Water, Air and People (Table 28). Tourism/Visitation and Development impacted upon four themes, Pastoralism and Defence activities upon three themes, and Fishing and Shipping upon the Sea theme. It should be reiterated that not all activities were assessed for each theme, e.g., Fishing was not assessed for the Land theme, though relationships would exist here. The ordering of activities based on cumulative pressures are therefore only relevant for the major activities that were included in the assessment, and it is recognised that if all possible pressures from all activities were accumulated for Distinctive Values, then this may change the outcome of ordered activities.

For Distinctive Values of the Sea theme, there are more pressures, or pressures with a higher risk score, associated with Shipping (Table 28). Pressures associated with Climate Change and Mining were having a greater impact from a cumulative pressures perspective on Distinctive Values than Tourism/Visitation and Fishing pressures.

Development had the greatest impact on Distinctive Values under the Land theme from a cumulative pressures perspective (Table 28). Mining, Tourism/Visitation and Climate Change had a greater impact on Distinctive Values than Pastoralism and Defence pressures.

Mining was the most concerning activity for inland waters under the Water theme, followed by Development, Tourism/Visitation and Climate Change (Table 28). Pastoralism and Defence pressures had a lesser impact on Distinctive Values under the Water theme.

Out of the three activities assessed for the Air theme, and for the only Distinctive Value of air quality, Mining had more cumulative pressures, or pressures with a higher risk score, impacting on air quality than Development or Climate Change (Table 28).

For Distinctive Values of the People theme, there are more pressures, or pressures with a higher risk score, associated with Development (Table 28). Pressures associated with Mining, Tourism/Visitation and Climate Change were, once again, having a greater impact on Distinctive Values than Pastoralism and Defence pressures.

All Distinctive Values under all EPA themes are facing cumulative pressures by most, if not all, major activities (Table 29, 30, 31, 32).

Table 28: Ordering of major activities relevant to each EPA theme based on cumulative pressure scores.

Sea	Land	Water	Air	People
1 Shipping	1 Development	1 Mining	1 Mining	1 Development
2 Climate Change	2 Mining	2 Development	2 Development	2 Mining
3 Mining	3 Tourism/ Visitation	3 Tourism/ Visitation	3 Climate Change	3 Tourism/ Visitation
4 Tourism/ Visitation	4 Climate Change	4 Climate Change		4 Climate Change
5 Fishing	5 Pastoralism	5 Defence		5 Pastoralism
	6 Defence	6 Pastoralism		6 Defence

Table 29: Cumulative pressures facing Distinctive Values under the EPA Sea theme.

SEA	SHIPPING	MINING	FISHING	TOURISM/ VISITATION	CLIMATE CHANGE
Blue-green algal mats					
Coral					
Crustaceans					
Elasmobranchs					
Geophysical processes					
Hydrodynamic processes					
Macroalgae and turf algae					
Mangroves					
Marine mammals					
Marine reptiles					
Nutrient flow					
Reef flats and oyster beds					
Salt flats					
Samphire					
Sand and mud					
Seabirds and shorebirds					
Seagrass					
Sediment quality					
Sponges and filter feeders					
Teleosts					
Water quality					

Table 30: Cumulative pressures facing Distinctive Values under the EPA Land theme. F&V = Flora and Vegetation.

LAND	MINING	TOURISM/ VISITATION	CLIMATE CHANGE	DEVELOPMENT	PASTORALISM	DEFENCE
Amphibians	■	■	■	■	■	■
Birds	■	■	■	■	■	■
Coastal dunes (F&V)		■	■	■	■	■
Coastal plains (F&V)	■	■	■	■	■	■
Islands		■	■	■		
Karst systems	■	■	■	■		■
Limestone cliffs & gullies (F&V)	■	■	■	■	■	■
Mammals	■	■	■	■	■	■
Reptiles	■	■	■	■	■	■
Short-range endemic invertebrates	■	■	■	■	■	■
Stygofauna	■	■	■	■		■
Threatened/priority flora	■	■	■	■	■	■
Topsoil	■	■	■	■	■	■
Troglofauna	■	■	■	■		■

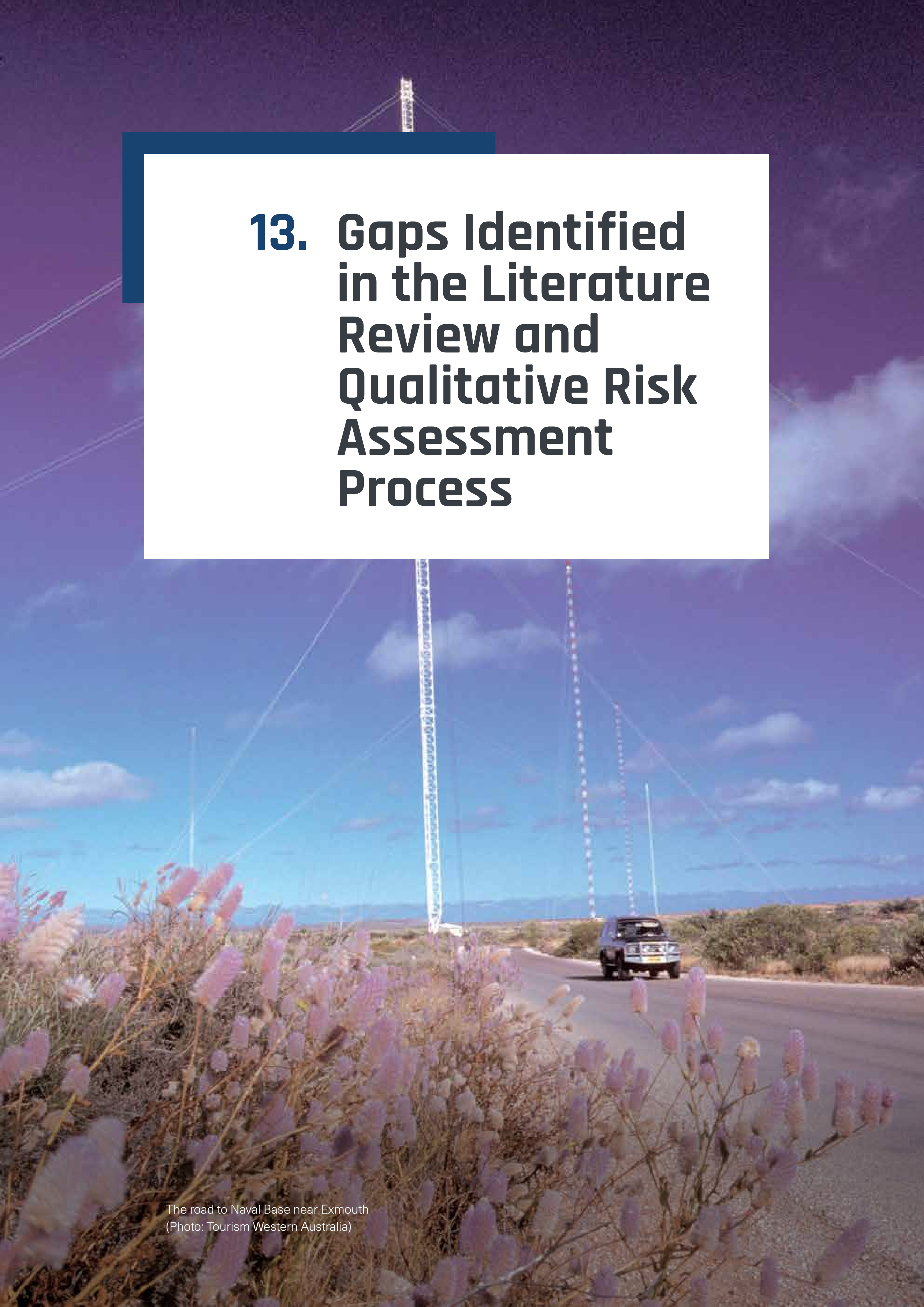
Table 31: Cumulative pressures facing Distinctive Values under the EPA Water theme.

LAND	MINING	TOURISM/ VISITATION	CLIMATE CHANGE	DEVELOPMENT	PASTORALISM	DEFENCE
Groundwater systems	■	■	■	■		■
Surface water systems	■	■	■	■	■	■

Table 32: Cumulative pressures facing Distinctive Values under the EPA People theme.

LAND	MINING	TOURISM/ VISITATION	CLIMATE CHANGE	DEVELOPMENT	PASTORALISM	DEFENCE
Amenity - intrinsic/wilderness aesthetic	■	■	■	■	■	■
Amenity – land-based recreation	■	■	■	■		■
Amenity – marine-based recreation		■	■	■		■
Amenity – noise, dust, odour, light	■	■	■	■	■	
Economic – commercial fishing	■		■			■
Economic - pastoralism		■	■			■
Economic – science and research		■	■	■		
Economic - tourism	■	■	■	■	■	■
National heritage		■		■		
Potable water	■	■	■	■		■

13. Gaps Identified in the Literature Review and Qualitative Risk Assessment Process



The road to Naval Base near Exmouth
(Photo: Tourism Western Australia)

The knowledge gaps listed below have not undergone a prioritisation process involving stakeholders. More importantly, the knowledge gaps have not benefited from thorough Traditional Owner input, nor do they represent all the knowledge gaps of the Traditional Owners. Future efforts to address knowledge gaps in Exmouth Gulf should be done so in partnership with Traditional Owners.

13.1. Gaps and Research Recommendations Evident from the Literature Review

The literature review has highlighted the current western science knowledge of Exmouth Gulf and surrounding lands, and also revealed where more knowledge is needed. The below gaps in knowledge are by no means extensive, but they provide guidance on key areas that will enhance our understanding of marine and terrestrial ecological functioning, and will also aid better decision making around future developments facing Exmouth Gulf. The gaps are ordered under the same EPA themes of Sea, Land, Water, Air and People.

SEA

- Comprehensive intertidal and benthic habitat mapping across the whole of Exmouth Gulf.
- Understand the current marine soundscape of Exmouth Gulf, the future soundscape based on modelled development activities, and how underwater noise is impacting key taxa and the ecological function of Exmouth Gulf.
- More specific climate change projections for Exmouth Gulf, and likely impacts to key marine and terrestrial ecosystems and taxa.
- Better understanding of connectivity across the land/sea interface and between Exmouth Gulf and surrounds, such as Ningaloo Reef (including but not limited to: nutrient sources and flows, biogeochemical dynamics, seed banks, recruitment, larval dispersal, nursery areas).
- Current understanding of water and sediment quality.
- Better understanding of samphire communities and the reliance on them by other species e.g., the role of samphire for shore birds (in particular migratory birds).
- Sand and mud flat communities and their role in sediment health.
- Better understanding of the elasmobranch species using Exmouth Gulf, particularly listed species such as sawfish, and species that may be relying on the extensive mangrove habitat, such as shovelnose rays.
- Home ranges and habitat use of sea snakes in Exmouth Gulf.
- Diversity of coastal dolphin species using Exmouth Gulf and whether populations are resident, migratory or a mix of both.
- Exmouth Gulf food webs.

LAND

- Comprehensive and fine scale mapping of vegetation complexes.
- Baseline flora and fauna surveys, with a particular focus on threatened and priority species.
- Habitat use by key fauna and the likely impacts of habitat loss and fragmentation.
- Information on the pathogens (bacteria, fungi, yeast, viruses) and parasites of flora and fauna of the region.
- Detailed and comprehensive climate change risk assessment for the area.
- Impact of enigmatic anthropogenic disturbances such as light, noise, dust, vibrations, and visual disturbances on fauna.
- Knowledge of the basic biology of most species of subterranean fauna and karst systems. The full distribution of many species and systems is unknown. It is likely that there remain undescribed genera and families of subterranean fauna in the Cape Range.
- Extent of connectivity of karst systems.

AIR

- Air Quality Index measurements specific to Exmouth Gulf.

WATER

- Extent and locations of groundwater intrusion into Exmouth Gulf.
- Carrying capacity of groundwater and projected sustainability with increasing development.

PEOPLE

- Better understanding and documentation of culturally important sites.

13.2. Gaps Evident from the Risk Assessment Process

Gaps arising from the risk assessment process comes from two avenues: risks assigned with a low to medium data confidence and direct mention of knowledge gaps by workshop participants and post-workshop experts. A data confidence score in this instance relates to whether there was a low, medium or high degree of confidence in the assigned risk score (Appendix 5), which differs to the data confidence applied to the current state of values in Section 10.

During the risk assessment process, 29 Distinctive Values received a high-risk rating (9-12) at least once in relation to a certain pressure (see Table 26). The level of data confidence for many of these high-risk scores was rated as low to medium. The high-risk scores will be used to derive recommendations for the EPA strategic advice, and the next steps beyond this advice would benefit from focused research effort to better understand those high-risk Distinctive Values with low to medium data confidence.

The Distinctive Values and pressures with a low to medium data confidence in the assigned high-risk score include:

SEA

- Samphire and the impact of tropical storms and cyclones (Climate Change).
- Coral trout and the impact of marine heatwaves (Climate Change) and recreational fishing (Fishing).
- Red emperor and the impact of recreational fishing (Fishing).
- Tuskfish and the impact of recreational fishing (Fishing).
- Sawfish and the impact of marine heatwaves (Climate Change).
- Manta rays and the impact of rubbish (Tourism/Visitation).
- Turtles and the impact of tropical storms and cyclones (Climate Change) and rubbish (Tourism/Visitation).
- Dolphins and the impact of a port infrastructure footprint (including channel) (Shipping).
- Humpback whales and the impact of disturbance (e.g., vessel strikes and harassment) (Tourism/Visitation).
- Seabirds/shorebirds and the impact of oil and fuel spills and antifoul (Shipping), disturbance (e.g., vessel strikes and 4WD) (Tourism/Visitation), and rubbish (Tourism/Visitation).
- Nutrient flow and the impact of an industrial salt production facility footprint (Mining).
- Sediment quality and the impact of pollution from oil and fuel spills and antifoul (Shipping).
- Water quality and the impact of pollution from oil and fuel spills and antifoul (Shipping).

LAND

- Coastal plains vegetation and the impact of industrial and tourism footprints (Development).
- Coastal dunes vegetation and the impact of tourism footprints (Development).
- Threatened/priority flora and the impact of tropical storms, cyclones and fire (Climate Change), industrial and tourism footprints (Development), overgrazing and pest/feral animals (Pastoralism), and off-road driving (Tourism/Visitation).
- Limestone cliffs and gullies vegetation and the impact of industrial and tourism footprints (Development), and overgrazing (Pastoralism).

PEOPLE

- Intrinsic/wilderness aesthetic and the impact of off-road driving (Tourism/Visitation).

During the risk assessment workshops, any knowledge gaps directly mentioned by participants were also recorded. These include:

SEA

- Better understanding of the impacts of underwater noise on crustaceans, fishes, elasmobranchs and marine mammals.
- Better understanding of the impacts of seismic activity on crustaceans, fishes, elasmobranchs and marine mammals.
- Impacts of copper-based contaminants.
- Comprehensive gulf-wide habitat mapping, including species-specific mapping and density estimates.
- Better understanding of the types of sediments in Exmouth Gulf e.g., grain size, muddy or sandy.
- Impacts of potential introduced marine pests and diseases with international shipping on marine fauna and habitats, including coral diseases.
- Extent of vessel strikes occurring to marine fauna currently.
- Soft sediment communities, including at depth e.g., 5-10m.
- Impacts of light pollution on marine fauna (not just turtles).
- Impacts of bitterns discharge on marine fauna, flora and water quality, including spatial and temporal modelling specific to Exmouth Gulf.
- More certainty around the impacts of seawater intake for use by industrial salt facilities.
- Identification of nursery locations for threatened fauna e.g., sea snakes, sawfishes, shovelnose rays.
- Comprehensive understanding of all nutrient sources into Exmouth Gulf.
- Better understanding of the impact of marine heatwaves on benthic communities and marine fauna.
- Direct and indirect impacts of increased storms and sea level rise on marine flora and fauna.

LAND

- Understand the carrying capacity of people in Exmouth Gulf and the impacts of overcapacity on the surrounding environment.
- Flooding and sewage systems and how this can impact the surrounding environment.
- Comprehensive surveys and mapping of threatened and priority flora.
- Comprehensive flora and vegetation surveys.
- Comprehensive surveys of short-range endemic invertebrates.
- Connectedness of karst systems across the Cape Range.
- Impact of groundwater drawdown on karst systems and subterranean fauna.
- Resolution and knowledge on genetic structure for a lot of subterranean populations.
- Impacts of tourist related activities on karst systems.
- Use of salt flats and blue-green algal mats by terrestrial fauna.

WATER

- Extent of PFAS contamination in groundwater and surface water systems.

PEOPLE

- Carrying capacity of potable water sources given projected high visitation rates, including extremely high visitation for the solar eclipse event in 2022.

14. Discussion and Next Steps

Emu near Exmouth
(Photo: Tourism Western Australia).

Exmouth Gulf is an area of high ecological importance and community value. This report has undertaken three areas of investigation to highlight a number of gaps in our understanding of the Distinctive Values and the pressures on them. The extensive review of the literature uncovered over 600 references and provided a snapshot of research over nine decades. It has highlighted the extent of western science knowledge and has also identified significant gaps in knowledge for a number of values. Importantly, there is limited data and understanding of the connectivity between the values, the impact of increased activities in the area and the linkages or flow-on affects between values.

14.1. Qualitative Risk Assessment and Cumulative Pressures

Alongside the literature review, the assessment of risks and cumulative pressures has provided a better understanding of both existing knowledge and the gaps in knowledge in Exmouth Gulf. The qualitative risk assessment process provided a mechanism for identification of the Distinctive Values that are at the greatest risk from pressures and activities (Table 26 and 27; Figure 12, 13 and 14). It is noteworthy that no value was rated as 'Severe' in this process (Appendix 5. Exmouth Gulf Risk Assessment). The cumulative pressures process highlights how Distinctive Values are clearly being impacted from a cumulative perspective across multiple pressures. These multiple pressures can 'add' up to pose higher risk to a value which may, normally, not be an issue if one activity was assessed in isolation.

Assessing the impact of one pressure on one or more values is a similar approach to traditional Environmental Impact Assessment (EIA). While this report went one step further to highlight cumulative pressures by 'adding up' multiple pressures, it did so without a full understanding of the potential amplifying relationships

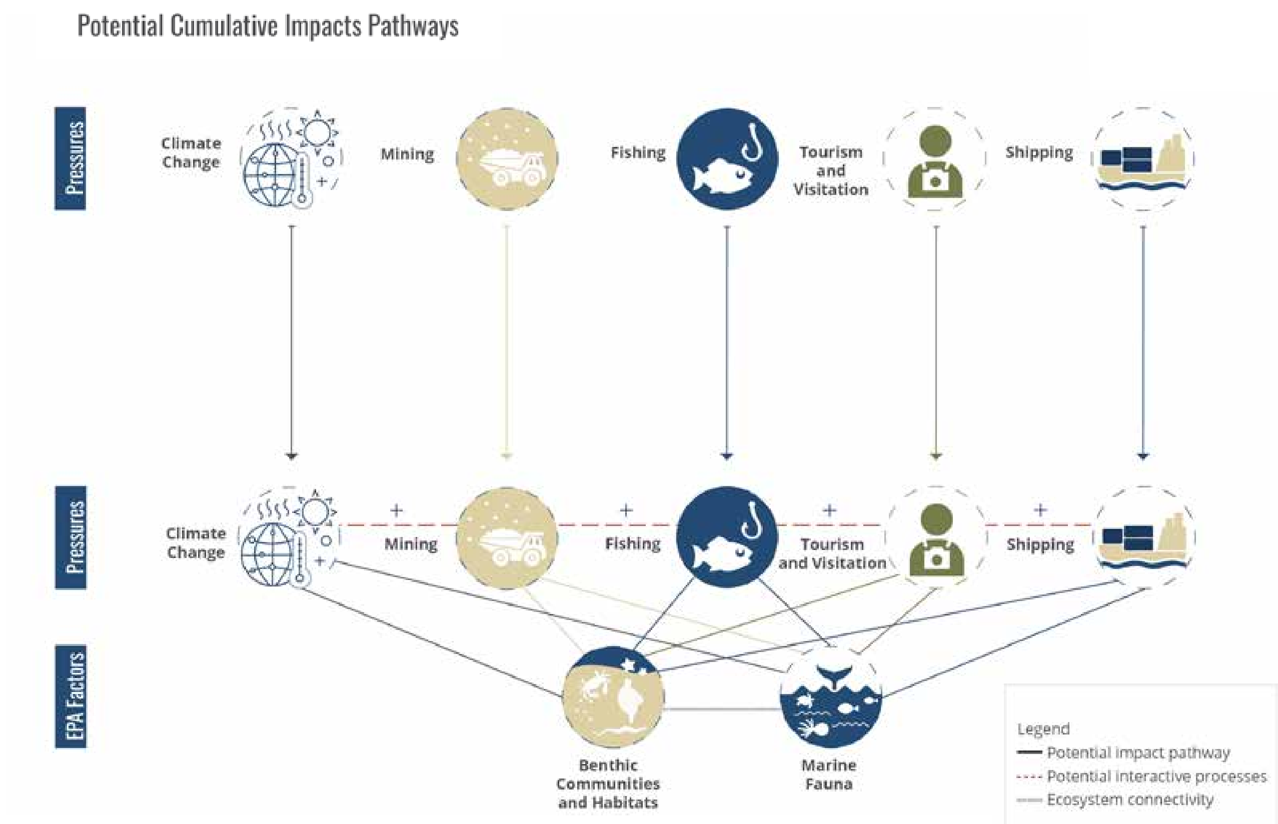


Figure 15: Potential Cumulative Impacts pathways for Exmouth Gulf. The EPA Factors in the conceptual diagram should be read as surrogate for all the distinct values beneath (i.e., keeping the figure high-level rather than complex in the absence of spatial/temporal information).

between pressures from the same activity and between pressures across different activities (Figure 15). This process would be more robust and offer more certainty with the appropriate spatial and temporal context of a proposal or several proposals in an EIA process. The cumulative pressures assessment also did not account for the natural relationships that occur between Distinctive Values and factors, and how an impact to one Distinctive Value from a pressure could cause an impact on another. Understanding the connectivity between both pressures and Distinctive Values are necessary for robust and realistic Cumulative Impact Assessment, and typically, the additive/ synergistic relationship between pressures is poorly addressed or recognised when considering the environment.

Within the context of the EPA, it is also important to understand the connectivity between EPA themes and factors, to better inform assessment, decision making and strategic advice. For example, the simplistic connectivity pathway provided in Figure 16 for Exmouth Gulf shows how a decrease in blue-green algal mats might eventually lead to a decrease in groundwater use, an increase in the health of karst systems, better air quality and increased intrinsic wilderness/natural amenity. This one simplistic example, which is not necessarily accurate, has impacts across all five EPA themes. Again, consideration of such interactions and connectivity between Distinctive Values may have resulted in a different outcome to what is presented in Section 12.2. Connectivity amongst Distinctive Values, as well as other values, is essential for a healthy functioning marine and terrestrial ecosystem, and these relationships have the potential to exacerbate or somewhat alleviate cumulative impacts. This connectivity was also highlighted by Traditional Owners who weren't able to prioritise the most at risk Distinctive Values in Exmouth Gulf because they are all connected and are all important for a healthy country.

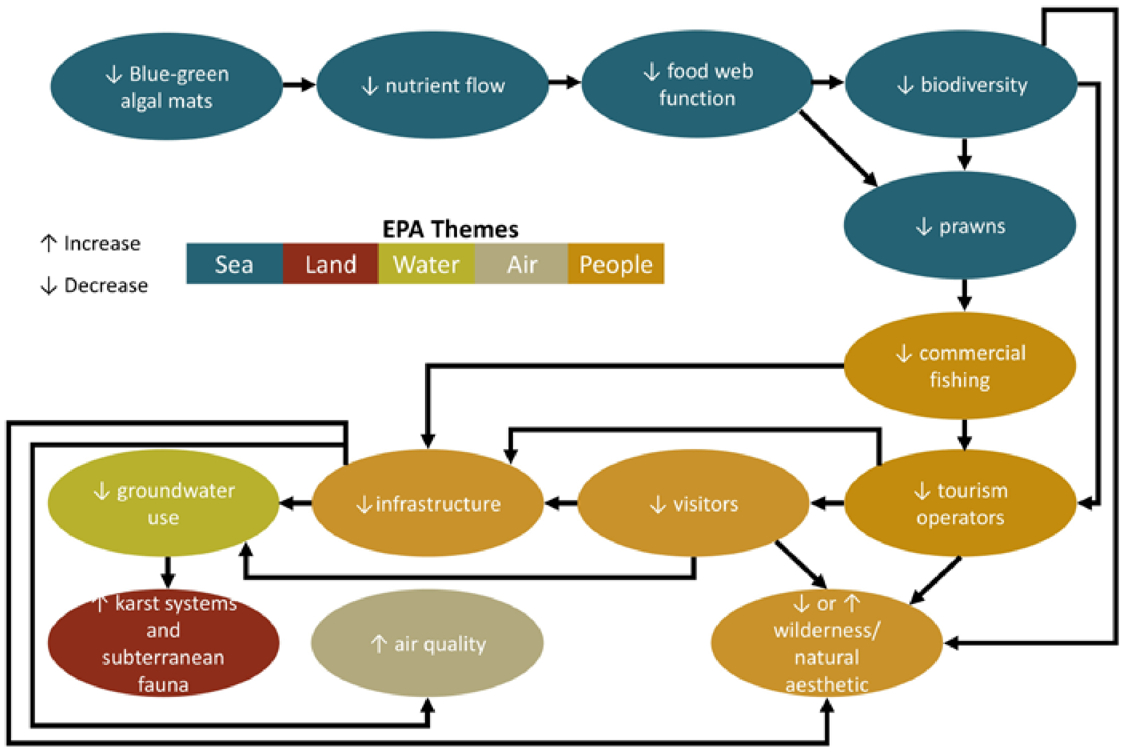


Figure 16: A simplistic example of a pathway that illustrates the potential connectivity between the EPA Themes and Factors.

The assessment of risk and cumulative pressures only accounts for the major activities currently or potentially facing Exmouth Gulf: Shipping, Mining, Fishing, Development, Climate Change, Tourism/Visitation, Pastoralism and Defence. Consideration of the full suite of minor to major activities, along with all possible pressures from each activity, may result in a different outcome to what is presented in Section 12.2. However, due to a lack of knowledge the undertaking of this task is unrealistic in most circumstances, and the decision to focus on main activities and pressures is, at least in this case, the most efficient and reasonable way to consider cumulative pressures on Exmouth Gulf. The outcomes of the risk assessment and cumulative process could be viewed as a baseline for the minimum amount of pressures facing Exmouth Gulf in the foreseeable future, despite the conservative approaches taken throughout the risk assessment and cumulative processes.

Though the full extent of Climate Change pressures was not assessed (i.e., past a 5-10-year timeframe), they are pressures that are undeniable for Exmouth Gulf, which will continue to increasingly ‘tick along in the background’ alongside more visible anthropogenic impacts.

The main pressures assessed were of most concern to the community of Exmouth Gulf, based on submissions, and also reflected some of the major proposals facing the Gulf. This report was able to provide an assessment on whether those activities are compatible with Exmouth Gulf. Based on an assessment of the current state of Distinctive Values, not all values were rated as ‘very good’, and no values were rated as ‘very poor’. Along with guidance from the literature, the current level of anthropogenic activity in Exmouth Gulf is likely sustainable for many of these Distinctive Values. Some of the future proposed activities, and expansion of current activities, assessed during the risk assessment and cumulative process posed high and medium risks to Distinctive Values, which have the potential to degrade the current state of Distinctive Values.

14.2. Next Steps- A Shared Analytic Framework for the Environment (SAFE)

This report has established the Distinctive Values and undertaken a review of the recognised pressures on those values in the Exmouth Region. Through a risk assessment and prioritisation process it has also provided an understanding of the activities impacting on the values within the EPA themes. This, in addition to a review of the available literature on Exmouth Gulf has resulted in a better understanding of the existing knowledge gaps and where new knowledge is required to provide greater confidence in decision making around the pressures/values.

Other assessments, such as the Cockburn Sound-Drivers-Pressures-State-Impacts-Responses (DPSIR) Assessment (BMT 2018), have been undertaken to elucidate the links between anthropogenic and environmental stressors, and in turn, ecosystem condition.

Applying the DPSIR process to the context of Exmouth Gulf, the work described in this report has provided a clearer understanding of the drivers and pressures on Exmouth Gulf, but still needed is a better understanding of the state of the environment, the impacts to the ecosystem and the responses by the various ecosystem components to the distinctive pressures. This DPSIR analysis is important in helping to understand the impact of cumulative pressures on a region over time. However, it presents only a snapshot of understanding based on the availability of information at the time of compiling the report.

Underlying the DPSIR process is the historical environmental data, which is used for assessment of new development proposals. Currently environmental data is not well managed, not readily shared, owned by many, and is often difficult to acquire. Further, environmental data are collected using a variety of non-standardised methods, which often makes it difficult to compare different data sets.

A culture shift is needed to integrate the DPSIR process with a shared data and analytical capability, which would collect, curate, integrate, analyse and use environmental data, to effectively make the whole process dynamic. New data collected through routine monitoring or specific projects could be fed back to continuously improve and grow our understanding of values/pressures in the region.

Consultation with State Government, industry and the research community have indicated support for the development of a Shared Analytic Framework for the Environment (SAFE) to enable efficient, robust, repeatable and transparent environmental information and analysis underpinning regional environmental assessment, planning, assurance and reporting. In partnership, WAMSI and WABSI have developed a rationale, background, and approach to establishing a SAFE for a given region (Appendix 6). Specifically, the logic considers how to routinely characterise and forecast the cumulative impact of pressures on values across regions (Figure 17). This approach is required to meet future challenges (i.e. Act reform, single touch approval, shareholder and community expectations).

Applied to Exmouth Gulf, a shared analytic framework framework could deliver the ability to cooperatively use information and decision-support tools earlier in the environmental assessment process (Figure 18). With data and analysis tools shared between proponents and regulators, there would be more certainty in the process resulting in improved efficiency for all parties. Efficiency gains would be magnified by reusing the data and analysis tools across other projects in the same region. This capacity has equivalent benefits to environmental reporting, accounting and planning.

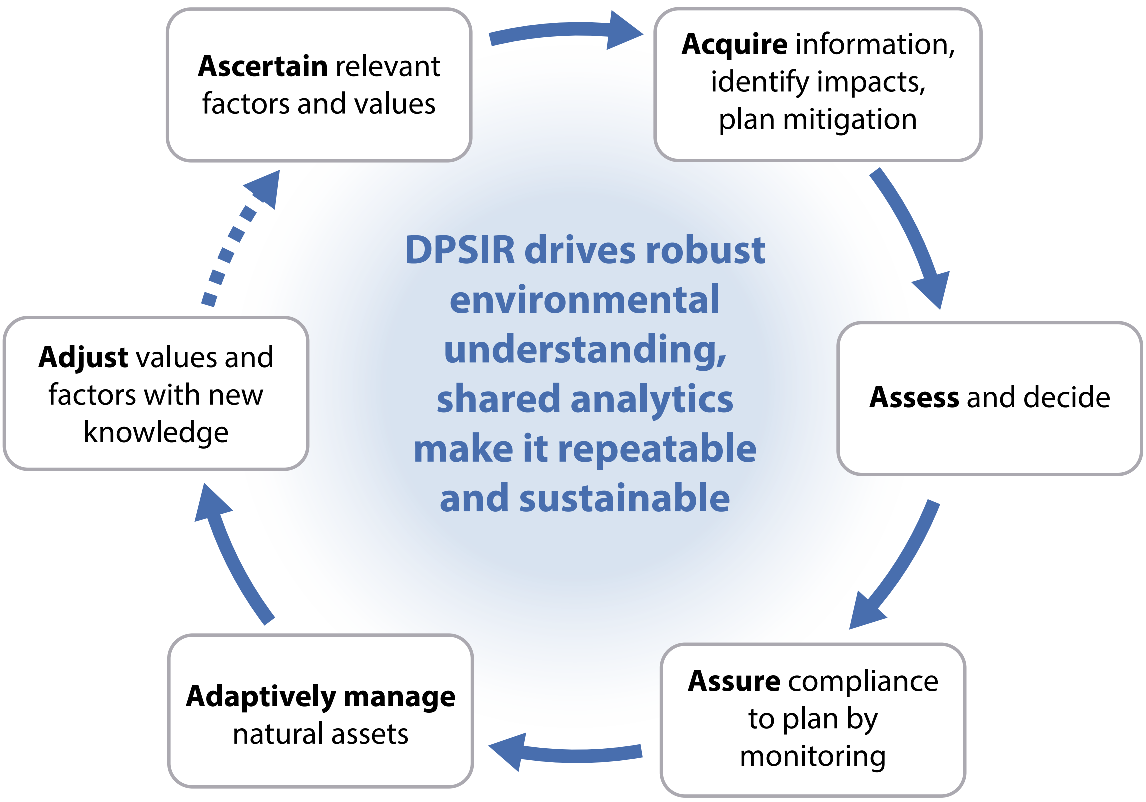


Figure 17: Shared Analytic Framework for considering cumulative impacts on a region or area.

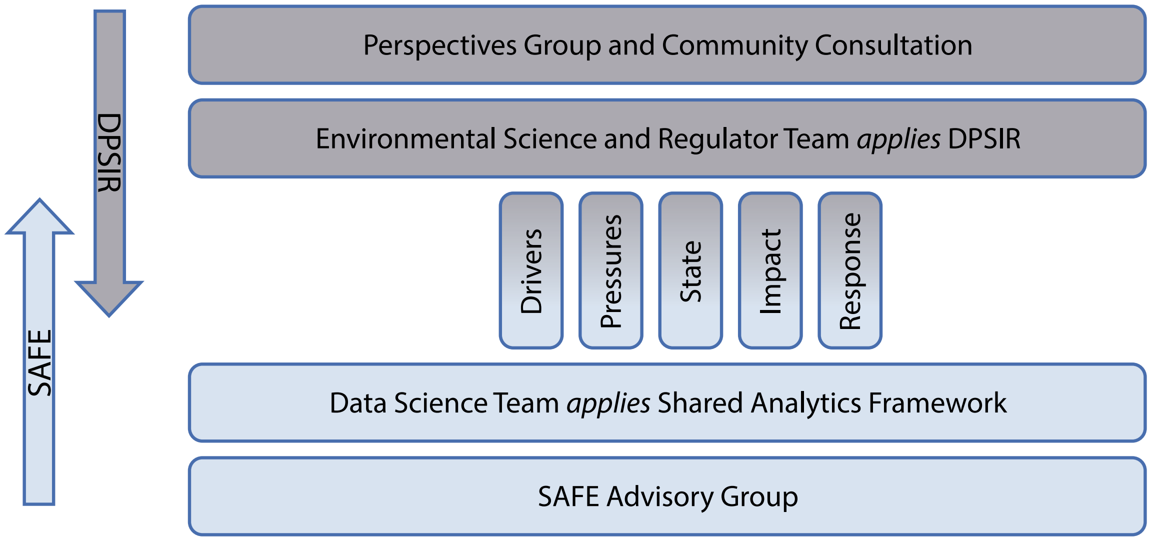


Figure 18: Integration of DPSIR and SAFE.

The work undertaken by WAMSI with the EPA described in this report has provided a significant step forward in defining the unique values of Exmouth Gulf for a wide range of stakeholders, and to identify the present and emerging pressures on those values. This has helped to fulfil two steps of the framework above (Figure 18):

Ascertain relevant factors and values – The Distinctive Values have been identified under each EPA Theme and Factor. See Section 6, Figure 3, 4, 5, and 6.

Acquire information, identify impacts – The drivers and pressures have been identified (Section 5.3) and rolled up into the main activities described for Exmouth Gulf.

Further, the prioritisation process has identified the highest risk pressure/value relationships and has outlined gaps of scientific knowledge where they exist (Section 13). Gap analysis is critical to understand how to assess and decide where the monitoring and scientific effort should focus.

Assess and decide - we have a better understanding of the science gaps and the priorities for filling those gaps, which need to be filled to manage pressures on values or make decisions (for instance, on approvals). At this stage of the framework, regulators/stakeholders decide on where to focus attention to assist decision making.

In the context of Exmouth Gulf where several values were considered to be at high risk from current and projected pressures, the next steps of the framework should be considered for future monitoring or targeted programs to support decision making.

Assure monitoring of predicted impacts - develop monitoring program or science discovery programs to provide missing information and fill priority gaps in understanding. The prioritisation process described in this report (Section 12) provides a method to systematically work through the list of priorities. Monitoring programs for predicted impacts will provide information to feedback into the analytical tools (such as a conceptual model), which will lead to continuous improvement.

Adaptively manage natural assets - as above, use new information to manage or make better decisions.

Adjust values and factors with new knowledge - continuous assessment and improvement will help to understand emerging trends on the values and pressures, which can then be understood and managed appropriately.

Through a shared understanding of the value/pressure relationships in Exmouth Gulf and a vision for continuously acquiring ecosystem information through systematic data collection, curation, integration, analysis and use, SAFE will improve our collective ability to enable environmental protection and support ecologically sustainable development and cumulative assessment.

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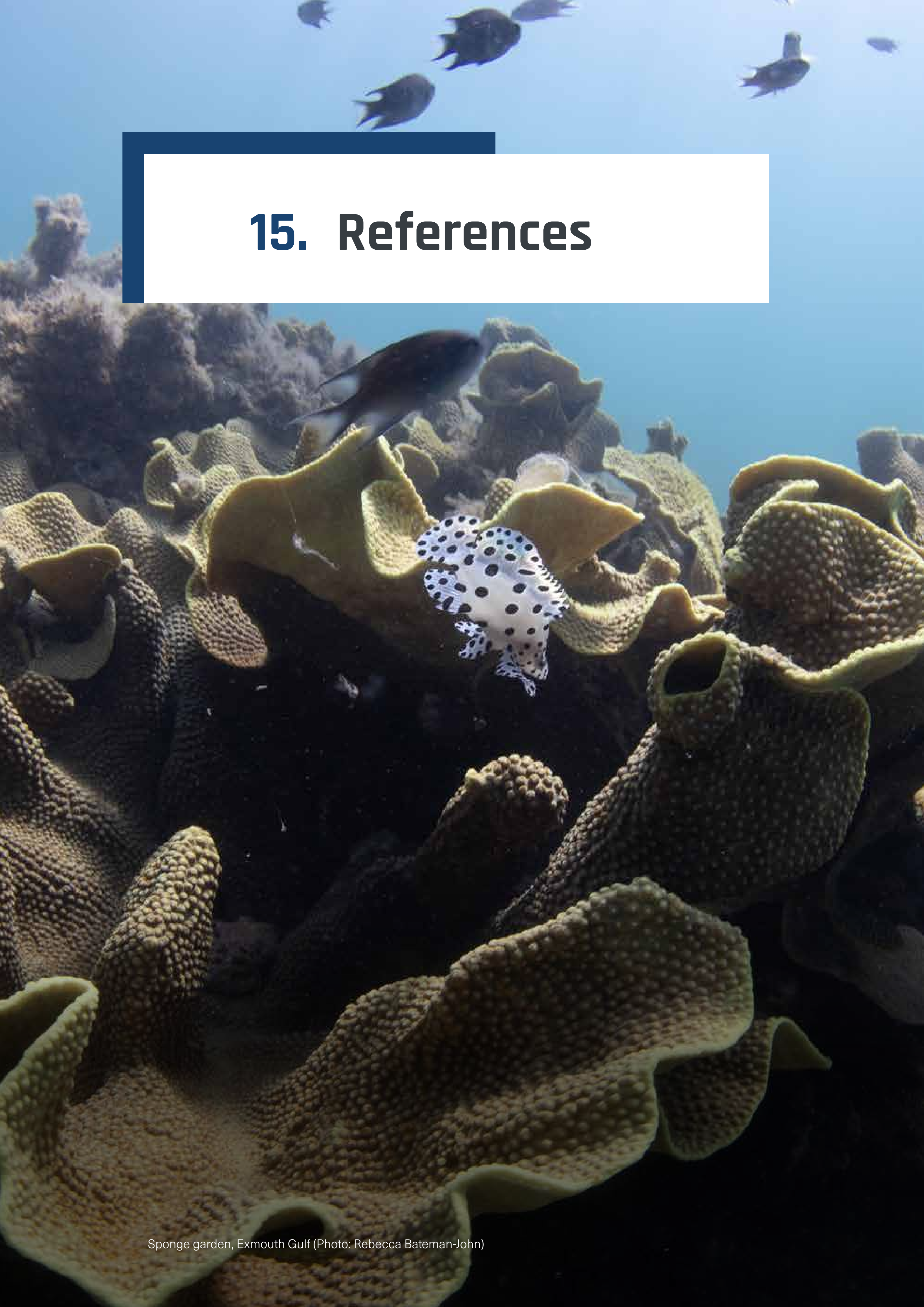

Sponge garden, Exmouth Gulf (Photo: Rebecca Bateman-John)

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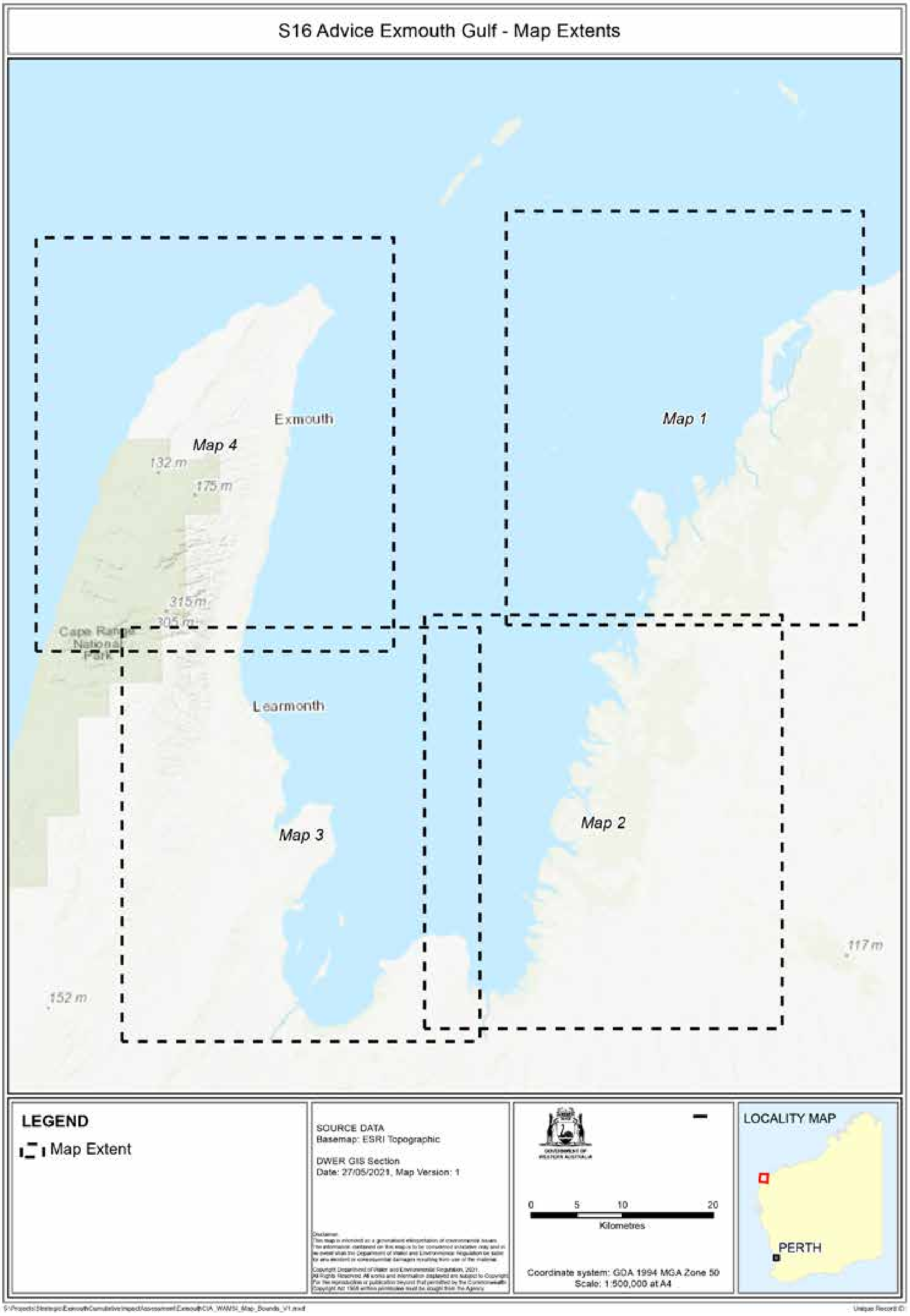
Zinke, J., Hoell, A., Lough, J. M., Feng, M., Kuret, A. J., Clarke, H., Ricca, V., Rankenburg, K., and McCulloch, M. T. (2015). Coral record of southeast Indian Ocean marine heatwaves with intensified Western Pacific temperature gradient. Nature Communications 6, 8562. https://doi.org/10.1038/ncomms9562.

16. Appendices

Leopard shark, Exmouth (Photo: Rebecca Bateman-John)

Appendix 1 – Locations and Features of Exmouth Gulf and Surrounds




Exmouth Gulf Features - Map 1
Observation Island
Locker Point
Fly Island
Tubridgi Point
Urala Creek North
Tubridgi Reef
Rocky Island
Brown Island
Urala Creek South
Eva Island
North Creek
Y Island
Naughton Creek
Sommerville Island
Toms Creek
Tent Point
Tent Island
Talandji
Burnside Island
Simpson Island
LEGEND
Exmouth Point of Interest
Major Road
SOURCE DATA
Basemap: Vivid 2 Satellite Imagery
DWER GIS Section
Date: 27/05/2021, Map Version: 1
0 2 4 8
Kilometres
Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:200,000 at A4
LOCALITY MAP


Exmouth Gulf Features - Map 2
Simpson Island
Hope Point
Hope Island
Yanrey Point
Whalebone Island
Hope Creek
Main Island
Islam Islets
Scotts Creek
Yannerie River North
Deans Creek
Yankagee Claypan
Yannerie River South
South Creek
Yannarie River
Sandalwood Peninsula
Giralia Bay
LEGEND
Exmouth Point of Interest
Major Road
SOURCE DATA
Basemap: Vivid 2 Satellite Imagery
DWER GIS Section
Date: 27/05/2021, Map Version: 1
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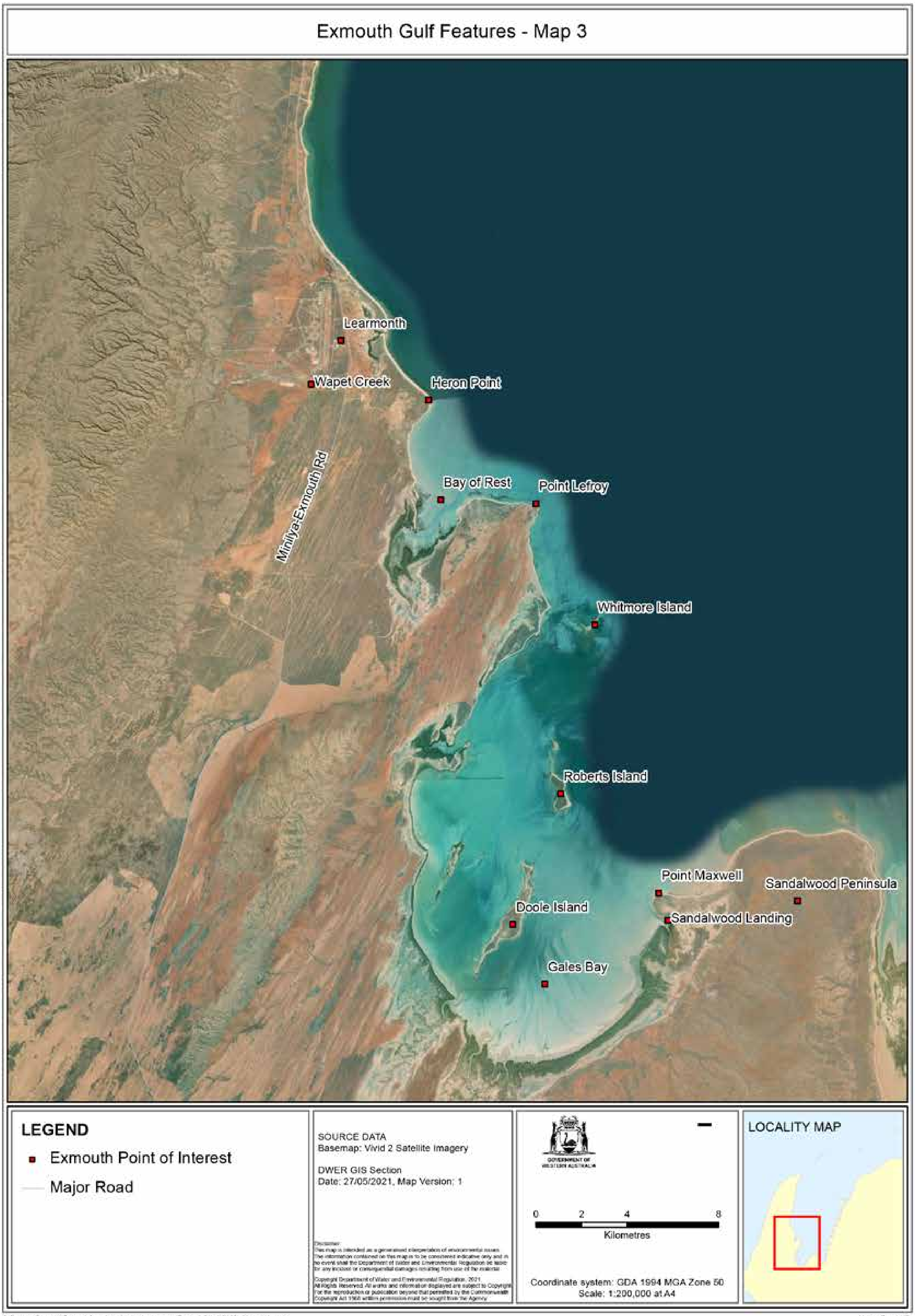
Kilometres
Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:200,000 at A4
LOCALITY MAP


Exmouth Gulf Features - Map 3
Learmonth
Wapet Creek
Heron Point
Minilya-Exmouth Rd
Bay of Rest
Point Lefroy
Whitmore Island
Roberts Island
Point Maxwell
Sandalwood Peninsula
Doole Island
Sandalwood Landing
Gales Bay
LEGEND
Exmouth Point of Interest
Major Road
SOURCE DATA
Basemap: Vivid 2 Satellite Imagery
DWER GIS Section
Date: 27/05/2021, Map Version: 1
0 2 4 8
Kilometres
Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:200,000 at A4
LOCALITY MAP


Exmouth Gulf Features - Map 4
North West Cape
Vlamingh Head Lighthouse
Naval Communication Station Harold E. Holt
Jurabi Coastal Park
Bundegi Coastal Park
King Reef (artificial reef)
Tantabiddi Boat Ramp
Exmouth
Exmouth Boat Harbour
Mangrove Bay
Mowbowra Creek
Cooper Shoal
Bennet Shoal
Turquoise Bay
Cape Range
Minilya-Exmouth Rd
LEGEND
Exmouth Point of Interest
Major Road
SOURCE DATA
Basemap: Vivid 2 Satellite Imagery
DWER GIS Section
Date: 27/05/2021, Map Version: 1
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Kilometres
Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:200,000 at A4
LOCALITY MAP

Appendix 2 – Project Teams and Perspective Group Members

DWER Project Team

Matthew Tonts	EPA Chair
Anthony Sutton	Executive Director EPA Services, DWER
Jenny Pope	EPA Member - Chair of the Perspectives Group
Shaun Meredith	Manager Strategy and Guidance, EPA Services
Wendy Thompson	Principal Environmental Officer, Project Manager Section 16(e) Exmouth Gulf, EPA Services
Elle Purdue	A/Senior Environmental Officer, EPA Services
Naomi Rakela	Executive Officer - Business Support, EPA Services
Fiona Webster	Senior Environmental Officer, Marine Ecosystems Branch, Science and Planning
TEB Team	Terrestrial Ecosystems Branch, Science and Planning, DWER

WAMSI Project Team

Luke Twomey	CEO
Jenny Shaw	Research Director
Alicia Sutton	Carijoa
Aleta Johnston	Communications Manager
Trish Wells	Executive Assistant

Perspectives Group Members

Matthew Tonts	EPA Chair
Jenny Pope	EPA Member, Chair of the Perspectives Group
Fiona McKenzie	EPA Member
Glen McLeod	EPA Member
Anthony Sutton	Executive Director EPA Services, DWER
Christopher Cottam	Executive Director Strategic Projects Resources & Project Facilitation, JTSI
Peter Sharp	Executive Director Parks and Visitor Services, DBCA
Paul Gamblin	Director, Protect Ningaloo
Brett Molony	A/Deputy Director-Science Director, Oceans & Atmosphere, CSIRO
Cameron Woods/ Matthew Bird	CEO, Shire of Exmouth
Rachael Cooyou	NTGAC Board Chairperson

Appendix 3 – Workshop Participants and Consultations

Nganhurra Thanardi Garrbu Aboriginal Corporation (NTGAC) stakeholders and workshop participants

Site visit 21.03.21

Rachael Cooyou	NTGAC Chairperson
Ailsa Johnstone	NTGAC Board Director

Special meeting Carnarvon 13.05.21

Jenny Shaw	WAMSI Research Director (Facilitator)
*Rachael Cooyou	NTGAC Board Director and Chairperson
Paul Baron	NTGAC Board Director
Ailsa Johnstone	NTGAC Board Director
Hazal Walgar	NTGAC Board Director
Gwen Peck	NTGAC Board Director
Charles Baron	NTGAC Board Director
Kirsty Anderson	YMAC Director of Projects
Jenny Pope	EPA Board
Fiona McKenzie	EPA Board
Wendy Thompson	EPA Services, DWER

*Apologies: Rachael Cooyou

Risk Assessment Workshop 1: 19.02.21

Invitees and attendees

Jenny Shaw	WAMSI Research Director (Facilitator)
Alicia Sutton	WAMSI/ Carijoa
Luke Twomey	WAMSI CEO
Matthew Tonts	EPA Chair
Fiona McKenzie	EPA Member
Jenny Pope	EPA Member - Chair of the Perspectives Group
Elle Purdue	A/Senior Environmental Officer, EPA Services

Shaun Meredith	Manager Strategy and Guidance, EPA Services	
Fiona Webster	Senior Environmental Officer, DWER	
Kevin McAlpine	Manager, Marine Ecosystems Branch, Science and Planning Directorate, DWER	
Ben Fitzpatrick	Ecologist / Director OceanWise	
Brett Molony	A/Deputy Director-Science Director, Oceans & Atmosphere, CSIRO	
Christopher Cottam	Executive Director Strategic Projects Resources & Project Facilitation, JTSI	
Paul Gamblin	Director, Protect Ningaloo	
Peter Barnes	Marine Park Coordinator, Exmouth, DBCA	Marine/Management
Catherine Lovelock	Professor of Biological Sciences, UQ	Benthic Habitat/Mangroves
Daniel Gaughan	Director of Fisheries Science and Resource Assessment, DPIRD	Commercial Fishing
Kathryn McMahon	Associate Professor, School of Science & Centre for Marine Ecosystems Research, ECU	Seagrass/Climate change
Kate Sprogis	Marine mammal scientist, Murdoch University	Humpbacks and Noise
Kelly Waples	Principal Research Scientist. Marine Science Program, DBCA	Marine Mammals
Kimberly Onton	Divisional Leader Regional Services, DBCA	Seabirds
Chari Pattiaratchi	Professor of Coastal Oceanography. UWA / Facility Leader, IMOS Ocean Gliders	Climate Change/Coastal Processes
Mick O'Leary	Climate Geoscientist, UWA	Coastal Processes
Christophe Cleguer	Postdoctoral Researcher, Murdoch University	Marine Megafauna
Ben Ansell	DBCA	Wetlands
Tegan Gourley	Ningaloo World Heritage Advisory Committee Program Manager	
Jaqueline Hine	Ningaloo World Heritage Advisory Committee Member	
Russell Babcock	Marine Ecologist	
Leah Pearson	Exmouth District Manager, DBCA	

*Additional experts, government and community stakeholders, and Traditional Owners were contacted for input but were not available to respond within the timeframe.

Risk Assessment Workshop 2: 24.02.21

Invitees and attendees

Jenny Shaw	WAMSI Research Director (Facilitator)	
Alicia Sutton	WAMSI/ Carijoa	
Luke Twomey	WAMSI CEO	
Jenny Pope	EPA Member - Chair of the Perspectives Group	
Fiona McKenzie	EPA Member	
Fiona Webster	Senior Environmental Officer, DWER	
Elle Purdue	A/Senior Environmental Officer, EPA Services	
Stephanie Hing	The Write Up	Terrestrial Values
Ben Fitzpatrick	Ecologist / Director OceanWise	
Catherine Lovelock	Professor of Biological Sciences, UQ	Mangroves
Mervi Kangas	Principal Research Scientist, DPIRD	Invertebrates
Christopher Cottam	Executive Director Strategic Projects Resources & Project Facilitation, JTSI	
Peter Barnes	Marine Park Coordinator, DBCA	
Kathy McInnes	CSIRO	Sea level/Atmospheric
Paul Gamblin	Director, Protect Ningaloo	
Matthew Tonts	EPA Chair	
Shaun Meredith	Manager, Strategy and Guidance, EPA Services	
Peter Sharp	Executive Director Parks and Visitor Services, DBCA	
Brett Molony	A/Deputy Director-Science Director, Oceans & Atmosphere, CSIRO	
Regina Flugge	Chair Ningaloo Coast World Heritage Committee	
Lucy Clausen	Principal Technical Officer, Exmouth, DBCA	
Kathleen McInnes	Sea level rise and coasts team, CSIRO Marine and Atmospheric Research	Sea level/Atmospheric
David Pickles	Environmental Officer – Conservation and Development Management, Pilbara Region, DBCA	
Brooke Halkyard	Environmental Officer – Conservation and Development Management, Pilbara Region, DBCA	

*Additional experts, government and community stakeholders, and Traditional Owners were contacted for input but were not available to respond within the timeframe.

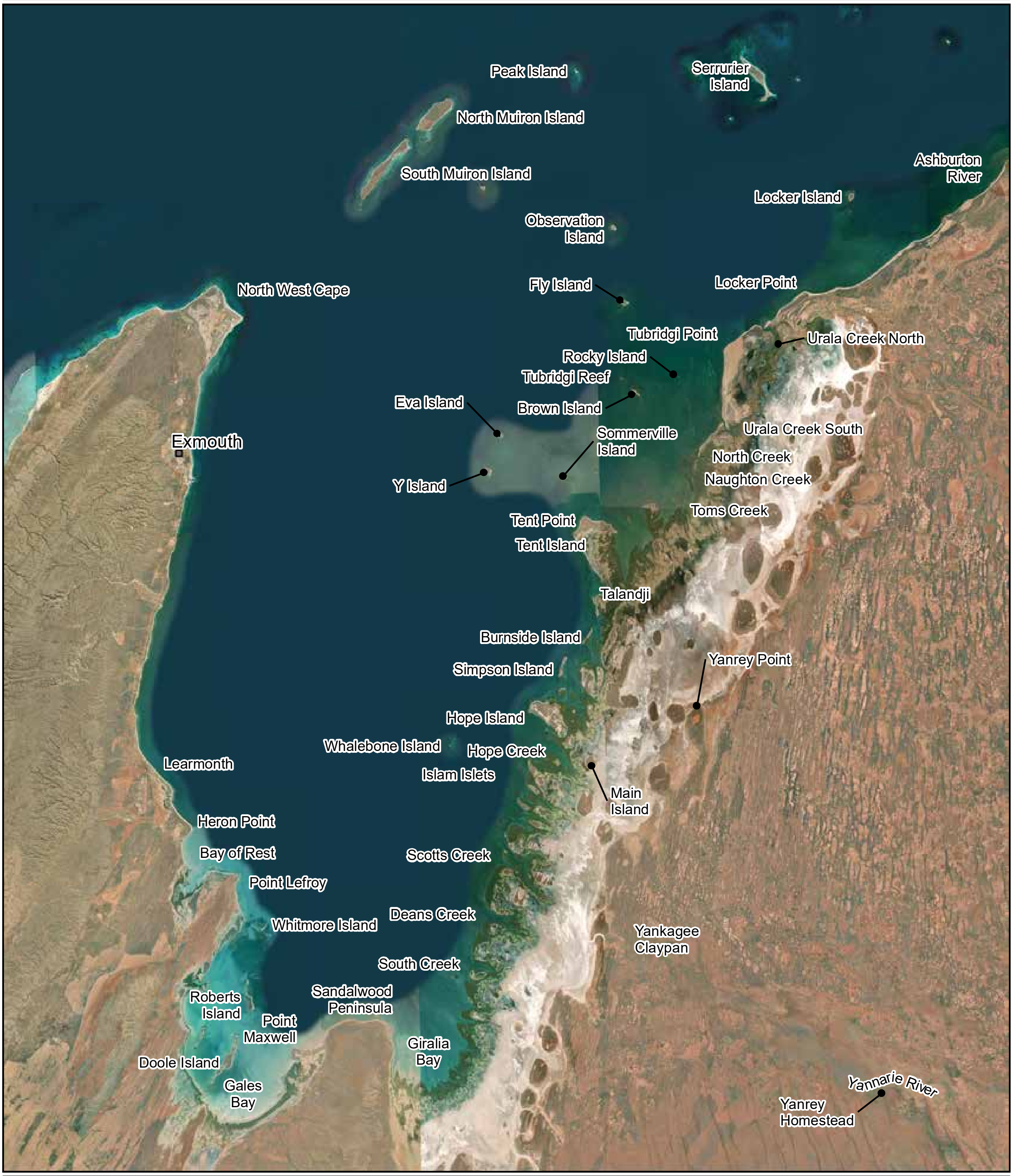
Additional Subject Matter Experts, Consulted During the Project

Mick O'Leary	Climate Geoscientist, UWA
Nicola Browne	Curtin University
Heather Barnes	DBCA / Ningaloo World Heritage Advisory Committee
Kathleen McInnes	Group Leader, Climate Extremes & Projections, CSIRO
Terrestrial Ecosystem Branch	DWER
Mark Cowan	DBCA
Rachel Meissner	Flora and vegetation
Andrew Heyward	AIMS

Appendix 4 – Resources Used in Risk Assessment Workshops

1. Features of the Exmouth Gulf (W.A. Department of Water and Environmental Regulation)
2. Exmouth Gulf Regional Map (W.A. Department of Mines, industry, Regulation and Safety)
3. S16 Advice – Exmouth Gulf Locations (W.A. Department of Water and Environmental Regulation)
4. Exmouth Gulf Habitat Map (Lyne et al. 2008)
5. Habitat Map in Exmouth Gulf Prawn Managed Fishery and Habitat Map in Exmouth Gulf Prawn Managed Nursery (W.A. Department of Primary Industries and Regional Development)
6. Petroleum Permits (W.A. Department of Water and Environmental Regulation)
7. Exmouth Town Zoning Map (W.A. Department of Planning, Lands and Heritage)
8. BlackFlanked Rock Wallaby presence/'absence' surveys & incidental observations 2005-2019 (W.A. Department of Biodiversity, Conservation and Attractions)
9. S16 Advice - Exmouth Gulf Wetlands (W.A. Department of Water and Environmental Regulation)
10. S16 Advice - Exmouth Gulf Land-Based Values (W.A. Department of Water and Environmental Regulation)

Features of the Exmouth Gulf



LEGEND

- Towns

SOURCE DATA
Basemap: Vivid 2 Imagery

DWER GIS Section
Date: 27/05/2021, Map Version: 1

Disclaimer:
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GOVERNMENT OF WESTERN AUSTRALIA

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Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:500,000 at A4

LOCALITY MAP

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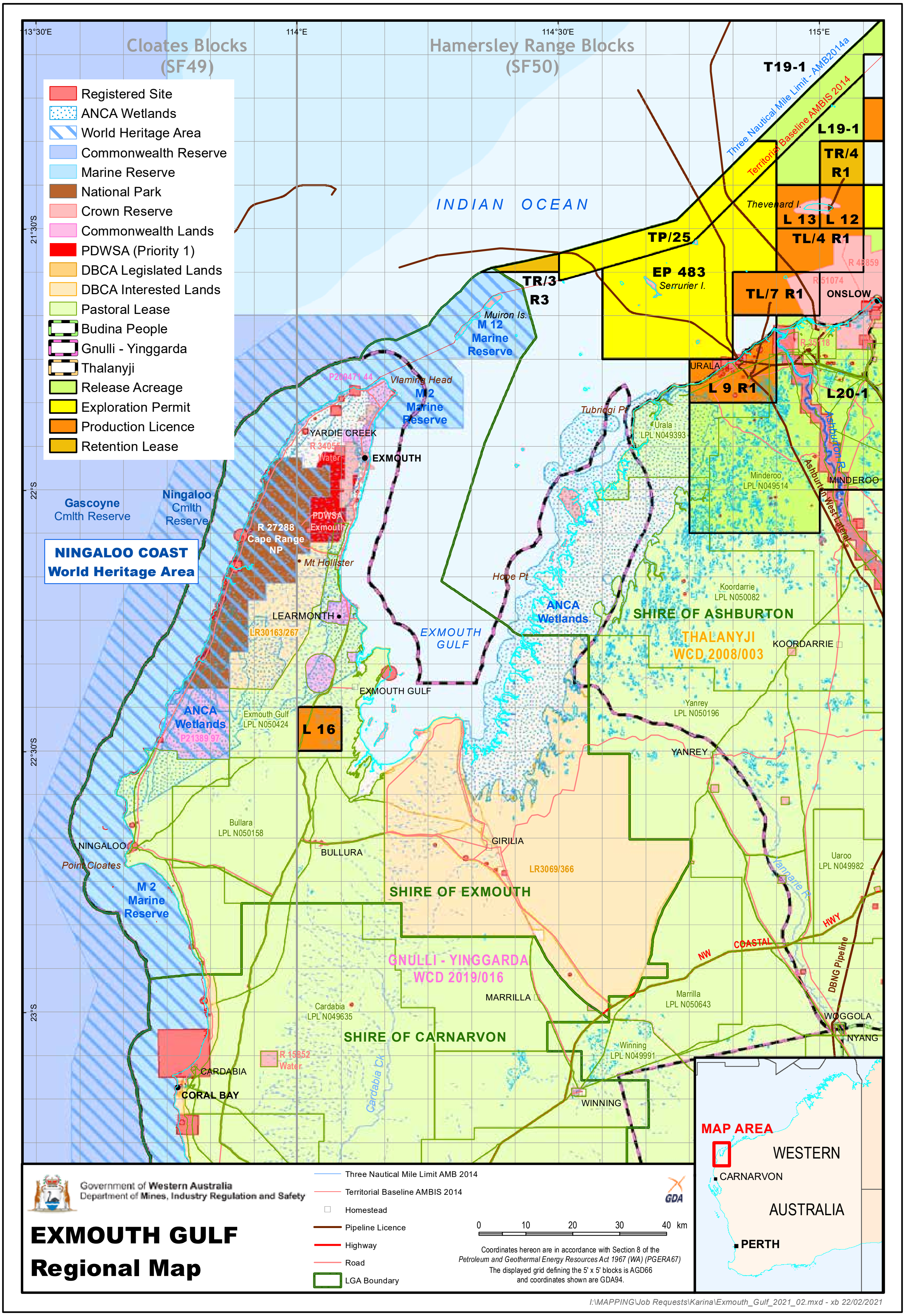
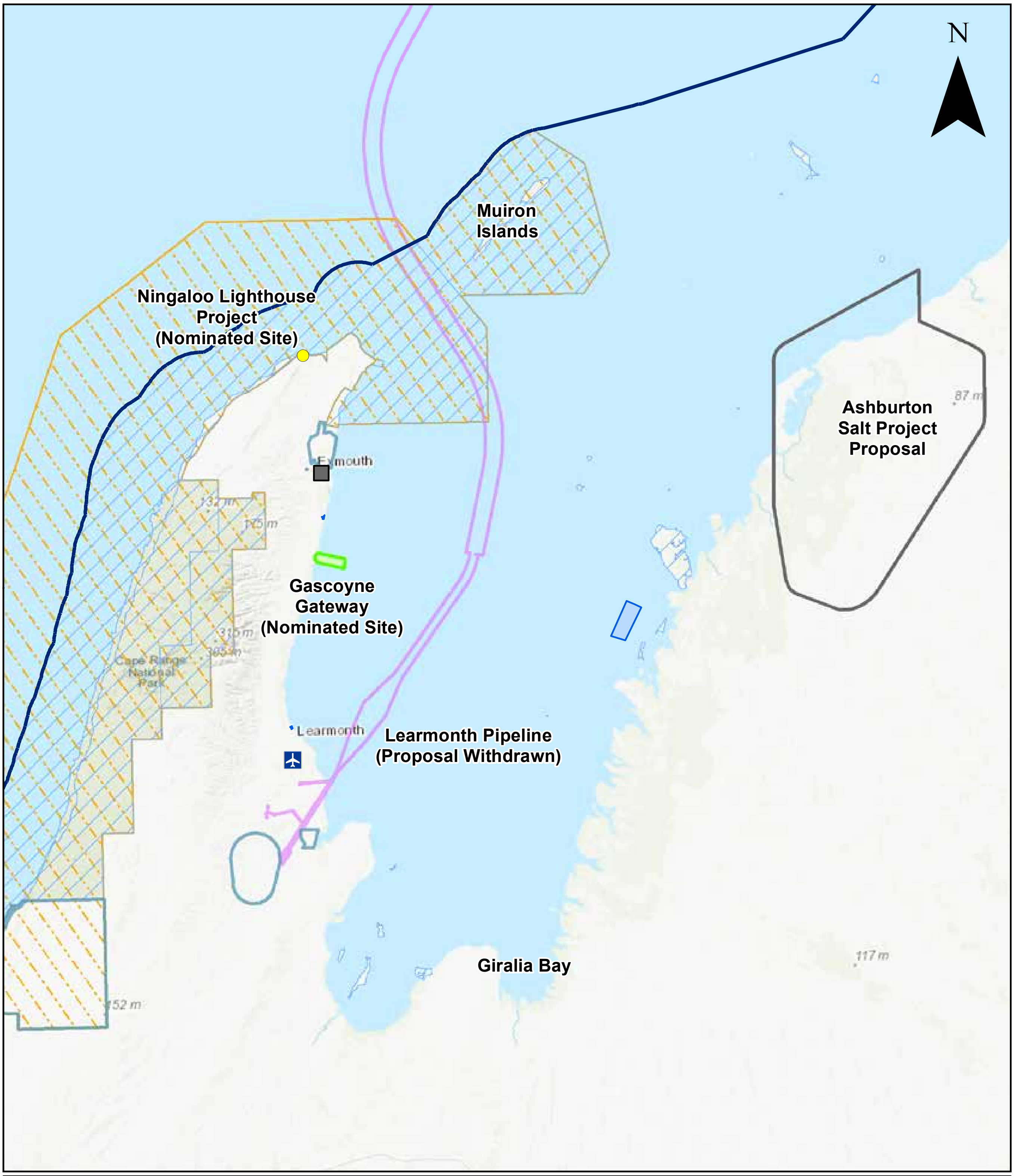


Cloates Blocks (SF49)
Hamersley Range Blocks (SF50)
Registered Site
ANCA Wetlands
World Heritage Area
Commonwealth Reserve
Marine Reserve
National Park
Crown Reserve
Commonwealth Lands
PDWSA (Priority 1)
DBCA Legislated Lands
DBCA Interested Lands
Pastoral Lease
Budina People
Gnulli - Yinggarda
Thalanyji
Release Acreage
Exploration Permit
Production Licence
Retention Lease
INDIAN OCEAN
NINGALOO COAST World Heritage Area
Gascoyne Cmlth Reserve
Ningaloo Cmlth Reserve
EXMOUTH GULF
SHIRE OF ASHBURTON
SHIRE OF EXMOUTH
SHIRE OF CARNARVON
THALANYJI WCD 2008/003
GNULLI - YINGGARDA WCD 2019/016
EXMOUTH
ONSLOW
CORAL BAY
Three Nautical Mile Limit AMB 2014
Territorial Baseline AMBIS 2014
Homestead
Pipeline Licence
Highway
Road
LGA Boundary
MAP AREA
WESTERN AUSTRALIA
CARNARVON
PERTH
Government of Western Australia
Department of Mines, Industry Regulation and Safety
EXMOUTH GULF Regional Map
Coordinates hereon are in accordance with Section 8 of the Petroleum and Geothermal Energy Resources Act 1967 (WA) (PGERA67)
The displayed grid defining the 5' x 5' blocks is AGD66 and coordinates shown are GDA94.
I:\MAPPING\Job Requests\Karina\Exmouth_Gulf_2021_02.mxd - xb 22/02/2021

S16 Advice - Exmouth Gulf Locations



Basemap: ESRI
DWER GIS Section
Date: 17/02/2021, Map Version: 1

Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:600,000 at A4

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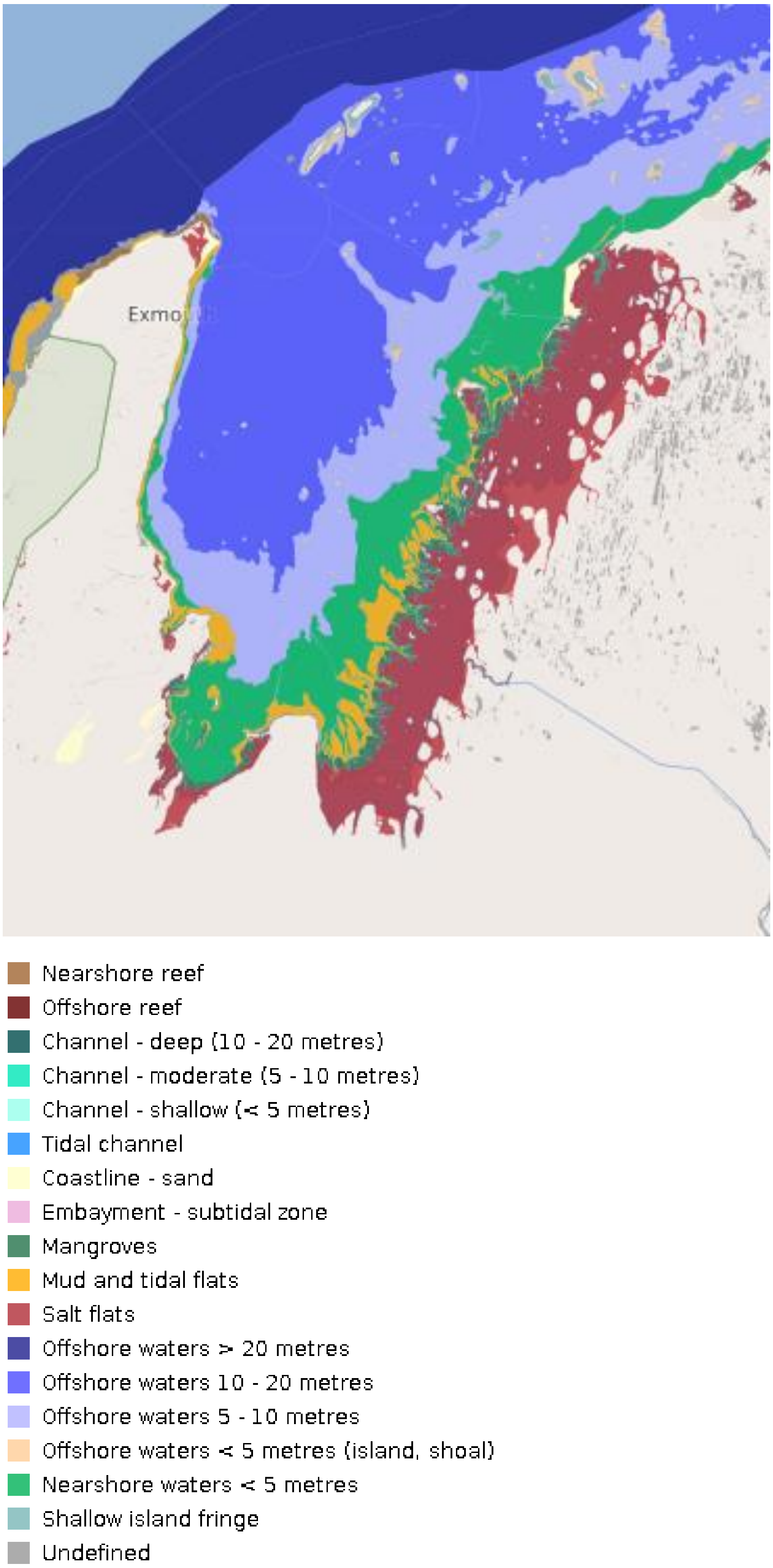
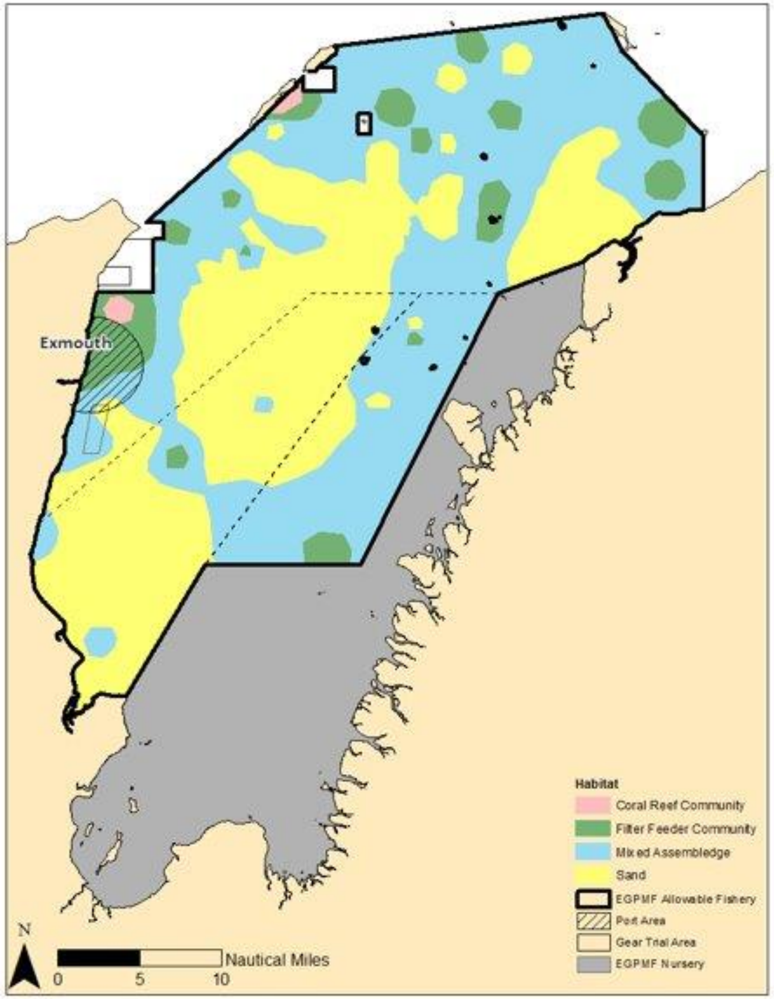
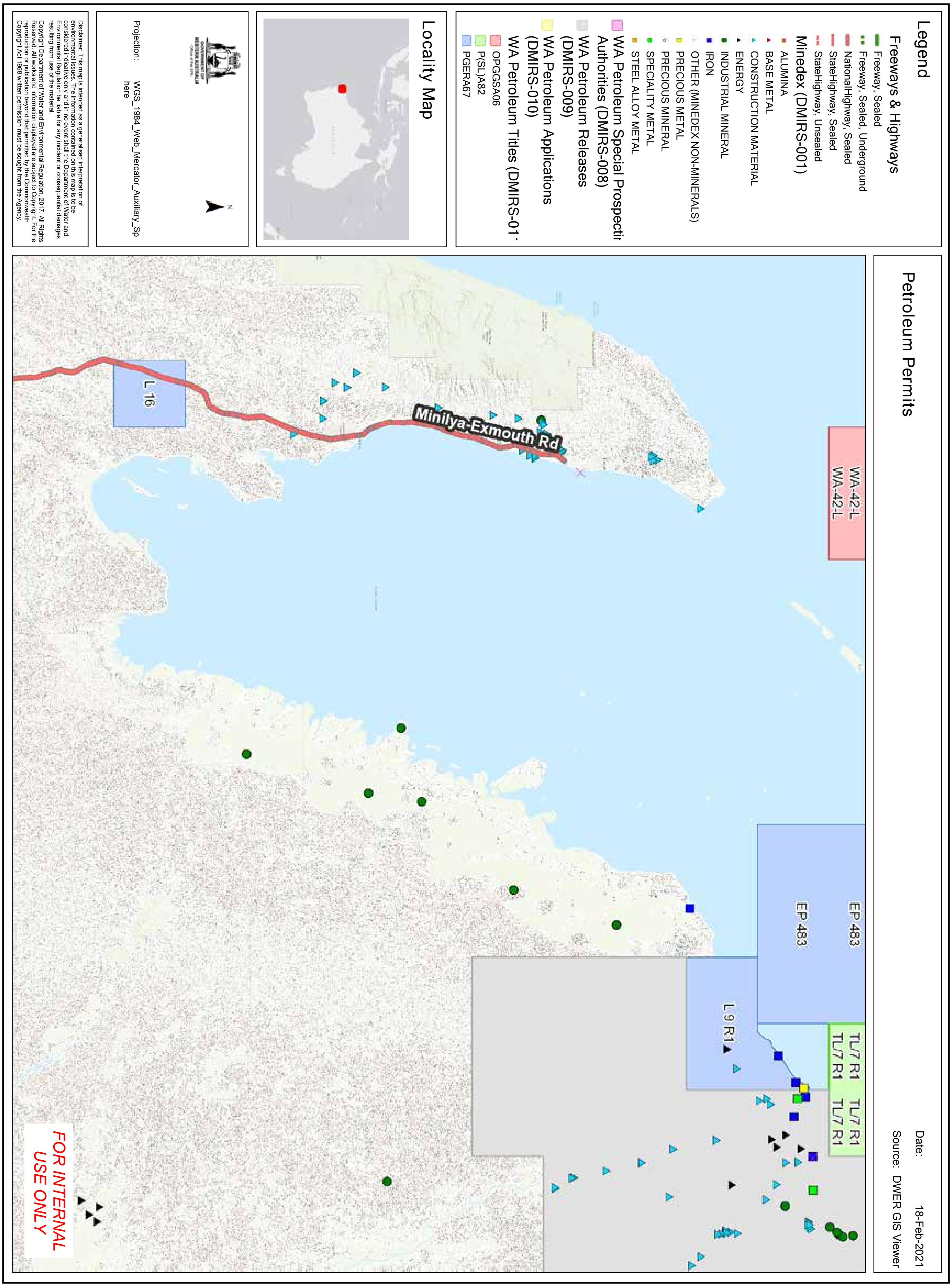
Unique Record ID:

Exmouth Gulf Habitat Map



Lyne V, Fuller M, Last P, Butler A, Martin M, Scott R (2008). Ecosystem characterisation of Australia's North West Shelf. NSWJEMS through CSIRO. Data accessed at http://metadata.imas.utas.edu.au/geonetwork/srv/en/metadata.show?uuid=516811d7-cd33-207a-e0440003ba8c79dd on (access date).

	
2018 Habitat Map in Exmouth Gulf Prawn Managed Fishery **Taken from** DPIRD 2020. WA Marine Stewardship Council Report Series No. 17: Ecological Risk Assessment of the Exmouth Gulf Prawn Managed Fishery. DPIRD, Western Australia.	**Habitat map in Exmouth Gulf Prawn Managed Fishery Nursery**


Petroleum Permits
Date: 18-Feb-2021
Source: DWER GIS Viewer
Legend
Freeways & Highways
Freeway, Sealed
Freeway, Sealed, Underground
NationalHighway, Sealed
StateHighway, Unsealed
Minedex (DMIRS-001)
ALUMINA
BASE METAL
CONSTRUCTION MATERIAL
ENERGY
INDUSTRIAL MINERAL
IRON
OTHER (MINEDEX NON-MINERALS)
PRECIOUS METAL
PRECIOUS MINERAL
SPECIALITY METAL
STEEL ALLOY METAL
WA Petroleum Special Prospecti Authorities (DMIRS-008)
WA Petroleum Releases (DMIRS-009)
WA Petroleum Applications (DMIRS-010)
WA Petroleum Titles (DMIRS-01
OPGGSA06
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PGERA67
Locality Map
Projection: WGS_1984_Web_Mercator_Auxiliary_Sphere
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WA-42-L
WA-42-L
L 16
Minilya-Exmouth Rd
EP 483
EP 483
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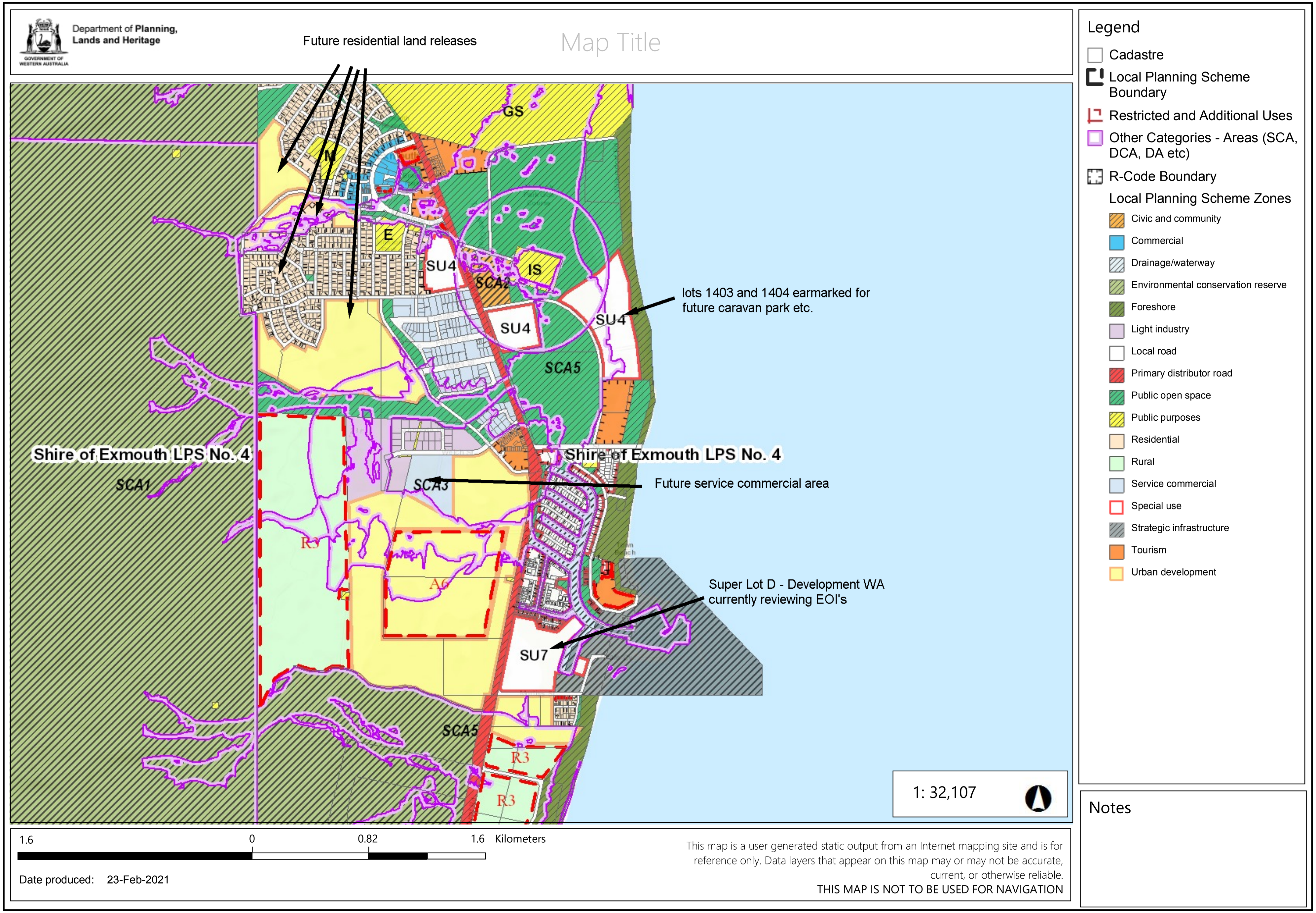
TL/7 R1
FOR INTERNAL USE ONLY


Department of Planning, Lands and Heritage
GOVERNMENT OF WESTERN AUSTRALIA
Future residential land releases
Map Title
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E
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IS
SCA2
SU4
SU4
SCA5
lots 1403 and 1404 earmarked for future caravan park etc.
Shire of Exmouth LPS No. 4
SCA1
Shire of Exmouth LPS No. 4
SCA3
Future service commercial area
R3
A6
Super Lot D - Development WA currently reviewing EOI's
SU7
SCA5
R3
R3
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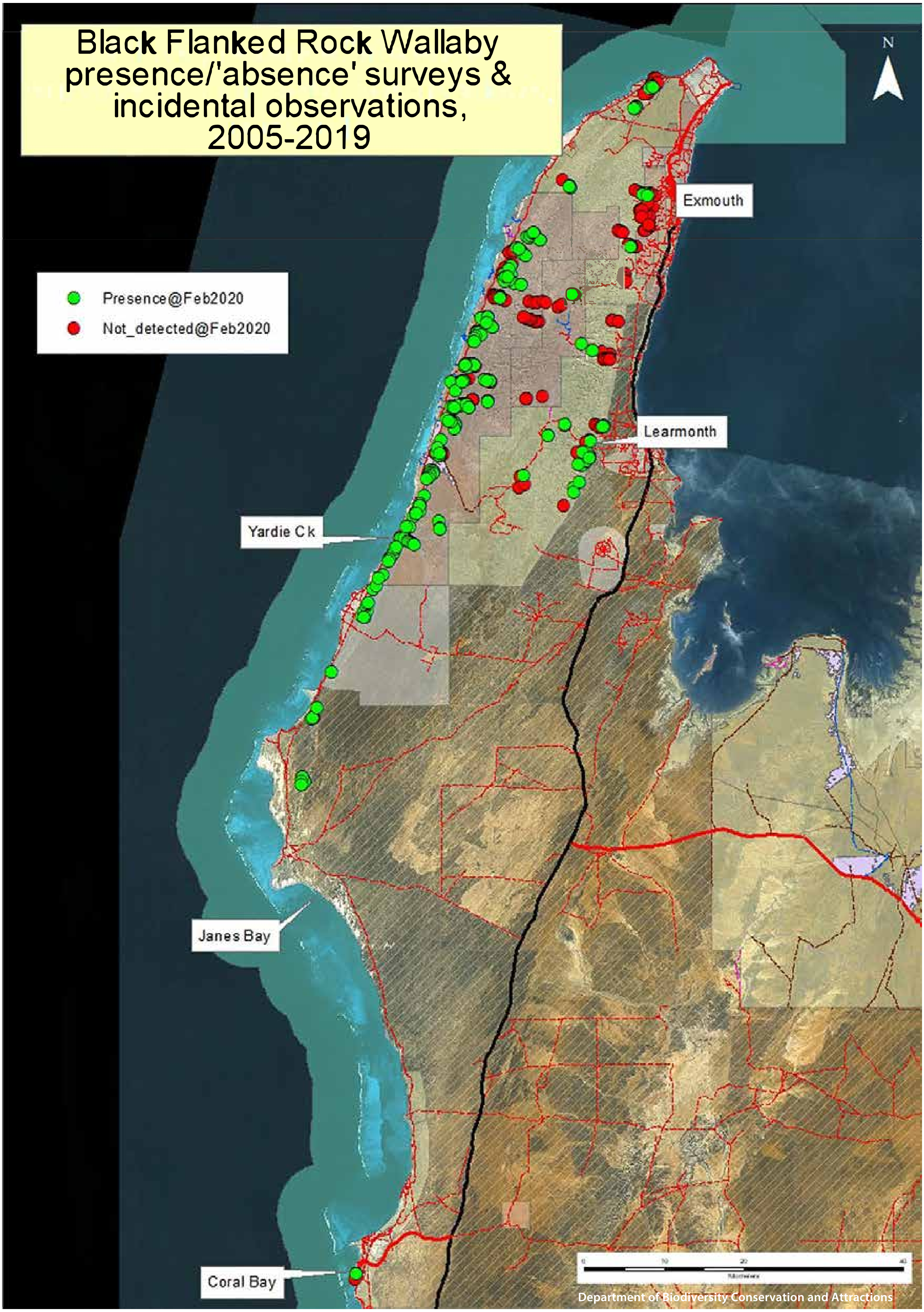
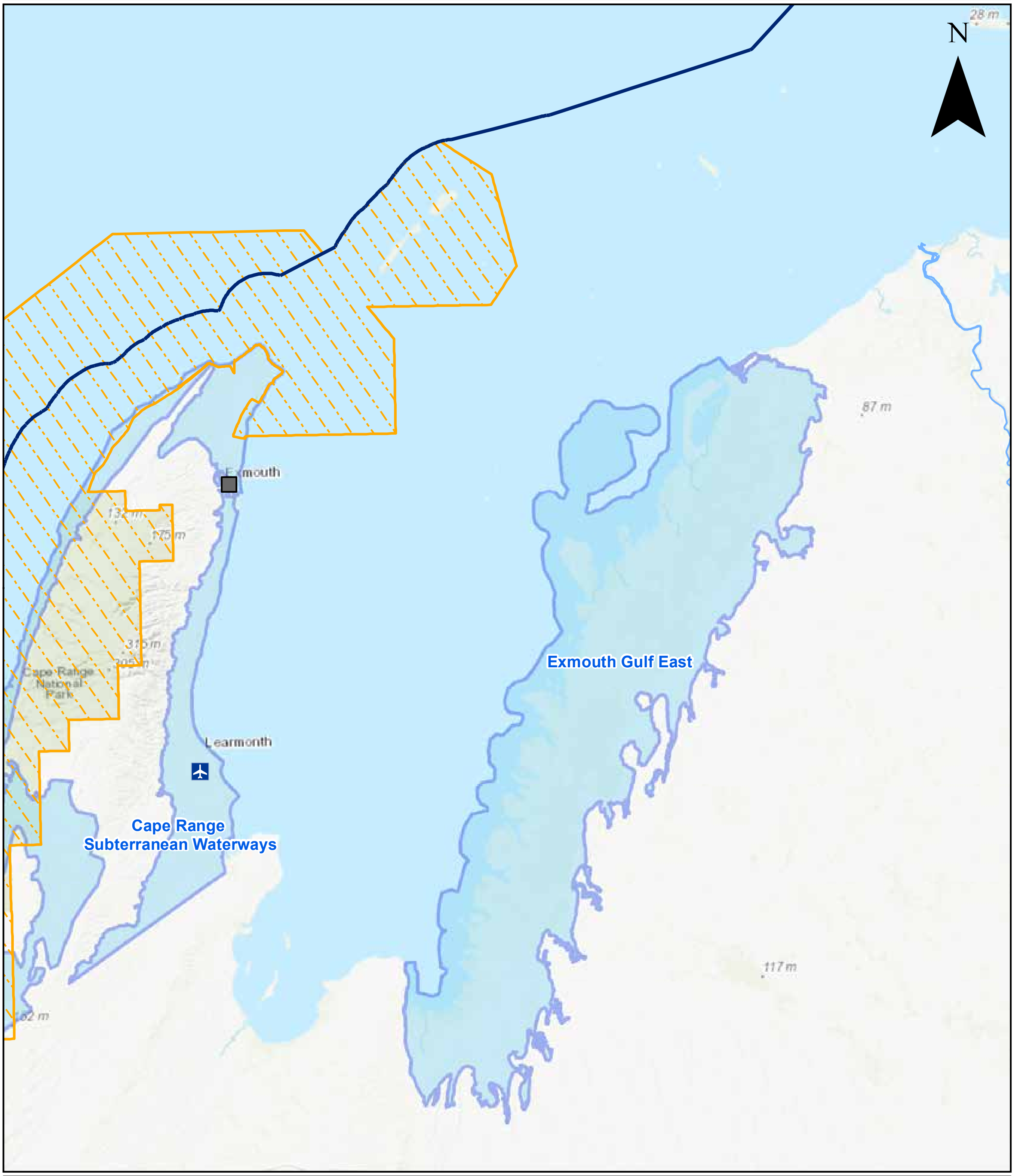
Kilometers
Date produced: 23-Feb-2021
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.
THIS MAP IS NOT TO BE USED FOR NAVIGATION
Legend
Cadastre
Local Planning Scheme Boundary
Restricted and Additional Uses
Other Categories - Areas (SCA, DCA, DA etc)
R-Code Boundary
Local Planning Scheme Zones
Civic and community
Commercial
Drainage/waterway
Environmental conservation reserve
Foreshore
Light industry
Local road
Primary distributor road
Public open space
Public purposes
Residential
Rural
Service commercial
Special use
Strategic infrastructure
Tourism
Urban development
Notes


Black Flanked Rock Wallaby presence/'absence' surveys & incidental observations, 2005-2019
Presence@Feb2020
Not_detected@Feb2020
N
Exmouth
Learmonth
Yardie Ck
Janes Bay
Coral Bay
Department of Biodiversity Conservation and Attractions

S16 Advice - Exmouth Gulf Wetlands



GOVERNMENT OF WESTERN AUSTRALIA

Basemap: ESRI
DWER GIS Section
Date: 17/02/2021, Map Version: 1

Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:600,000 at A4

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LEGEND

- Learmonth Airport
- Exmouth Townsite
- State Coastal Waters Limit
- Ashburton River
- World Heritage Areas
- Directory of Important Wetlands

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Kilometres

LOCALITY MAP

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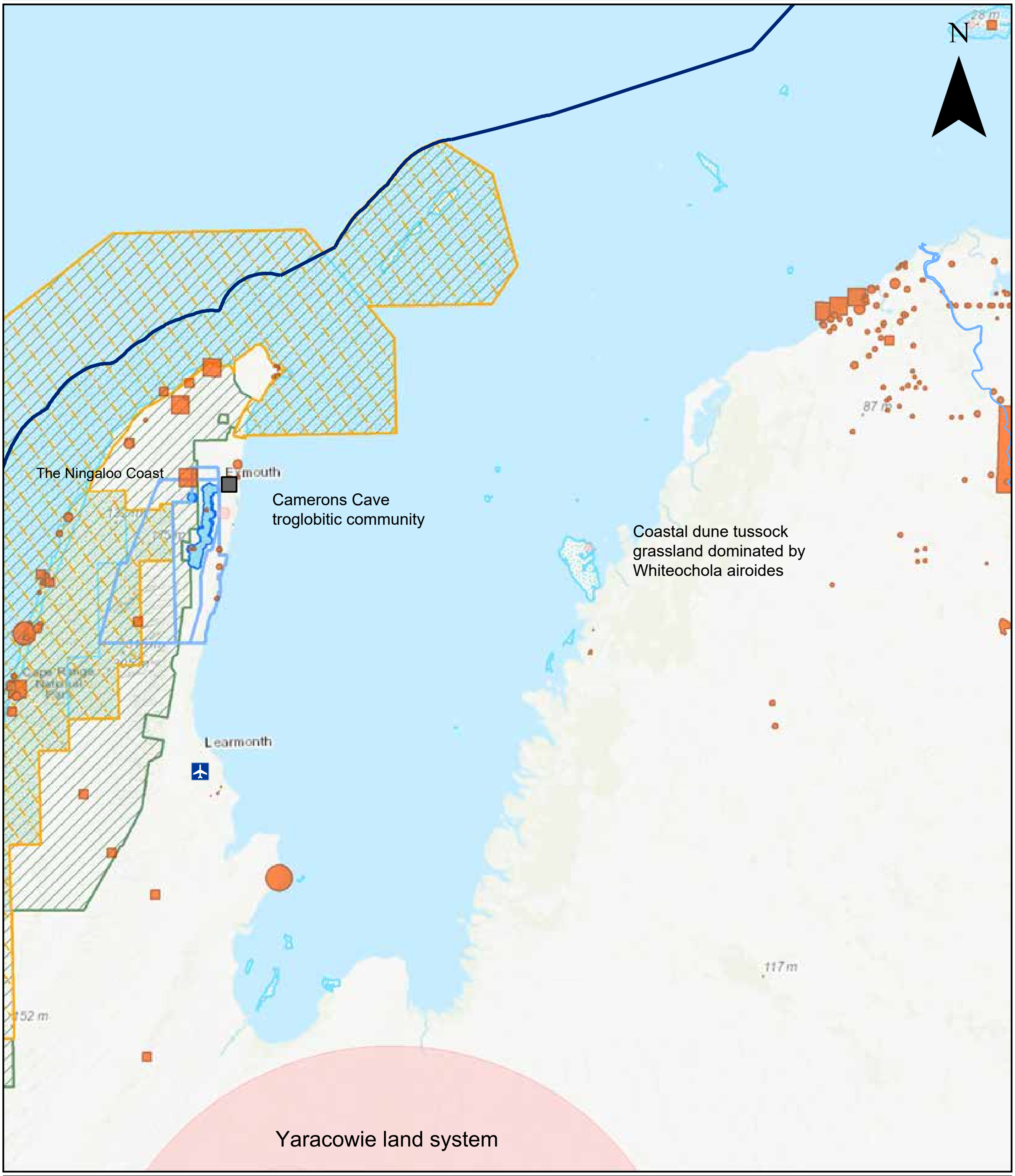
S16 Advice - Exmouth Gulf Land Based Values



Basemap: ESRI
DWER GIS Section
Date: 18/02/2021, Map Version: 1

Coordinate system: GDA 1994 MGA Zone 50
Scale: 1:600,000 at A4

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LEGEND

- Learmonth Airport
- Exmouth Townsite
- State Coastal Waters Limit
- Ashburton River
- Aboriginal Places Register
- Threatened Ecological Communities (buffered)
- Public Drinking Water Source Areas
- Public Drinking Water Supply Protection Zones
- Ningaloo World Heritage Site
- National Heritage List
- DBCA Managed Lands and Waters

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Kilometres

LOCALITY MAP

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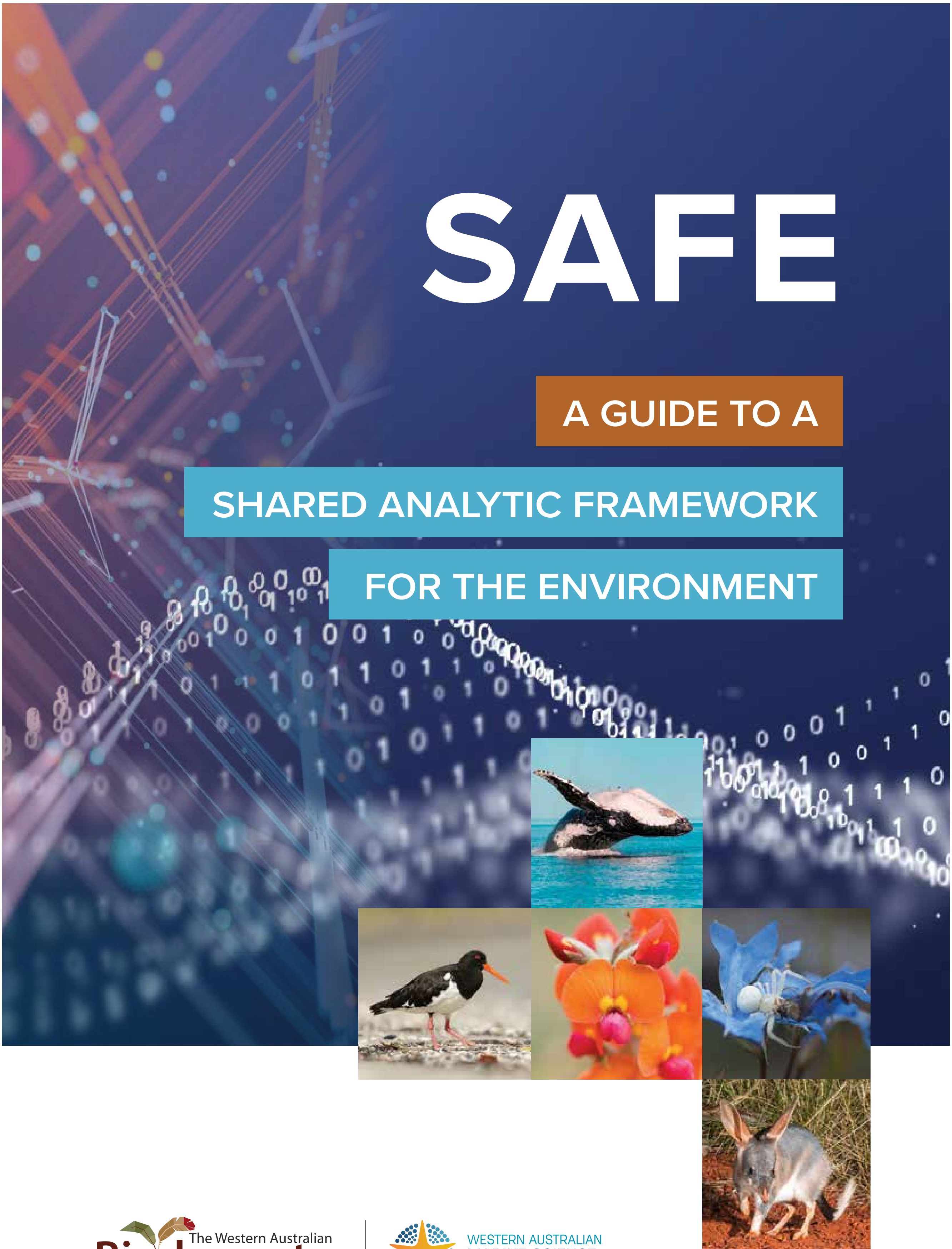
Appendix 5 – Exmouth Gulf Risk Assessment

See separate attachment for Appendix 5 (357 pages).

Appendix 6 – SAFE A Guide to the Shared Analytic Framework for the Environment WAMSI 2021



SAFE

A GUIDE TO A SHARED ANALYTIC FRAMEWORK FOR THE ENVIRONMENT

The Western Australian Biodiversity Science Institute

Western Australian Marine Science Institution

The Western Australian Biodiversity Science Institute

ACKNOWLEDGEMENTS:

We acknowledge our many partners across industry, government and research for their ongoing contribution and support. Our thanks to Dr Greg Terrill, Rob Freeth and Chris Gentle in the development of the framework highlighted in this guide.

Prepared by The Western Australian Biodiversity Science Institute:

ISBN 978-0-646-83607-2

Images courtesy: DBCA and Lochman Transparencies (inset)
Cover images courtesy: WAMSI, Megan Hele and Lochman Transparencies

CONTENTS

Images above courtesy: Megan Hele

BACKGROUND AND AIM

The Western Australian Biodiversity Science Institute (WABSI) and the Western Australian Marine Science Institution (WAMSI) have been working together to enhance access, aggregation, interpretation and management of biodiversity information collected in Western Australia.

In 2019, in conjunction with a working group and advisory committee, WABSI and WAMSI published the report *Digitally Transforming Environmental Assessment: Leveraging information to streamline environmental assessment and approvals*,[1] which made the following recommendation:

> ***"A shared analytic framework for the environment: Develop digital analytic tools to assist environmental impact assessment, including identifying trends and predicting impacts of multiple activities in a region over time, to improve confidence in decisions made and to reduce the need to rely on the precautionary principle."***

WABSI and WAMSI are now developing a strategy to implement this recommendation and this guide has been developed as a basis for discussion and collaborative refinement. It outlines the rationale for and approach to a shared analytic framework for the environment. The next stage will include the presentation of case studies and a roadmap to be published in a second report, Dynamically Transforming Environmental Assessments, due for release in 2021.

We welcome your feedback on this guide. Please contact: chris.gentle@wabsi.org.au

[1] Refer to the report *Digitally Transforming Environmental Assessment*. ISBN 978-0-646-81505-3.

Image courtesy: Andrew Halsall, WA Museum

WHAT IS SAFE?

A shared analytic framework for the environment (SAFE) depicts the capabilities – the building blocks – which work together across the information and analytic supply chain to provide input decision-support and reporting tools for environmental assessments. It is a management tool, providing a framework and language to:

- Facilitate a consistent view of the capabilities and their interdependencies;
- Help align effort and prioritise investment across these capabilities.

SAFE has been developed to accelerate the move to devolved robust, repeatable and transparent decision making for environmental assessments. This will:

- Reduce risk for investors, as they will be better able to understand the impact of, and to develop mitigation strategies for, activities that they propose to undertake;
- Remove duplication between regulators at different levels of government;
- Provide public reassurance about the quality of decisions.

SAFE can help individual projects determine the capabilities that they need, as well as help prioritise effort across the information and analytic supply chain that supports national decision making.

SAFE has been developed by WABSI, WAMSI and many others. It is based upon the Global Biodiversity Information (GBIO) Outlook[2].

[2] Based on the report *Delivering Biodiversity Knowledge in the Information Age.* Available at: https://doi.org/10.15468/6jxa-yb44.

ENVIRONMENTAL ASSESSMENTS: A VISION

A major review of national environmental legislation, the *Report of the Independent Review of the EPBC Act*[3], has proposed a vision of improved environmental outcomes, combined with transparency around faster and lower-cost decisions. Elements include:

- **Single-touch environmental approvals**
  - Underpinned by legally enforceable National Environmental Standards and subject to rigorous, transparent oversight (Recommendation 14).
- **National Environmental Standards**
  - National Environmental Standards that would be legally enforceable, and evolve (Recommendations 3, 4).
  - Including "A Standard for Data and Information to set clear requirements for providing best available evidence" (Recommendation 31).
- **National supply chain of information**
  - "A national supply chain of information will deliver the right information at the right time to those who need it. This supply chain should be an easily accessible, authoritative source that the public, proponents and governments can rely on. A clear strategy to deliver an efficient supply chain is needed so that each investment made contributes to building and improving the system" (Recommendation 32, p22).
- **Improvements to the environmental information system**, including:
  - An interim supply chain Custodian to oversee the improvements to information and data;
  - A set of national environment information assets to ensure essential information streams are available; and
  - Expanding existing work with jurisdictions on the digital transformation of environmental assessments and ensuring it is aligned with implementation of the national environmental information supply chain.

Proponents, regulators, the technical community and the broader public do not generally have an agreed touchstone of information and analyses informing a given proposal. This can become the basis of appeal or challenge, and under any realisation of delegated approvals, becomes crucial to Commonwealth assurance of state decisions.

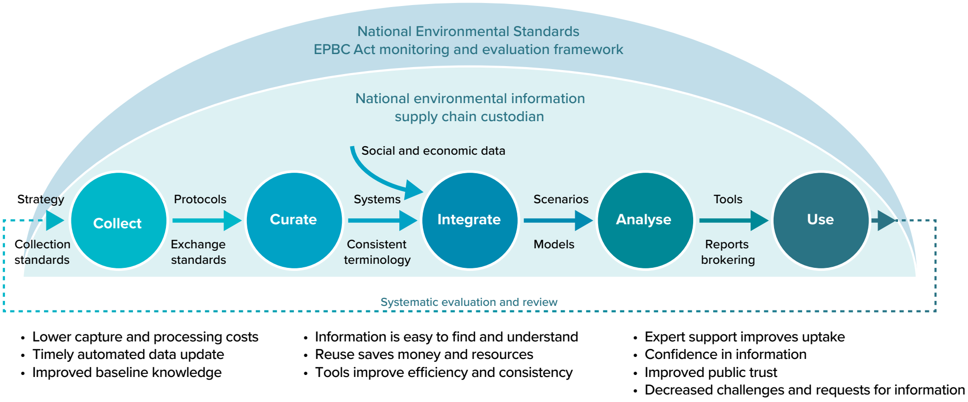
SAFE can help overcome fragmentation and deliver the information infrastructure needed to enable transparent, trusted and devolved decision making. It does this by providing a framework and language to facilitate a consistent view of the capabilities and their interdependencies, and to help align effort and prioritise investment across these capabilities.

[3] Samuel, G 2020, *Independent Review of the EPBC Act—Final Report*, Department of Agriculture, Water and the Environment, Canberra, October 2020. CC BY 4.0

The value of having a shared analytic framework includes:

- **Flexibility:** different organisations and researchers can work within their own area of expertise while contributing to a larger effort to support information and analytic supply chain.
  - The current approach includes many independent actors providing solutions that do not readily integrate and with low collective improvement.
- **Reuse:** Analytics tools developed for one purpose can readily be re-used.
  - Tools developed for decision support can often be reused for reporting or to guide environmental management.
- **Progressive improvement:** once solutions are in place, they can be incrementally improved through a consistent and managed framework as new knowledge and methods become available.

The value of SAFE is illustrated by the future state depiction contained in the *Final Independent Review Report*.



Future state of the national environmental information supply chain[3]

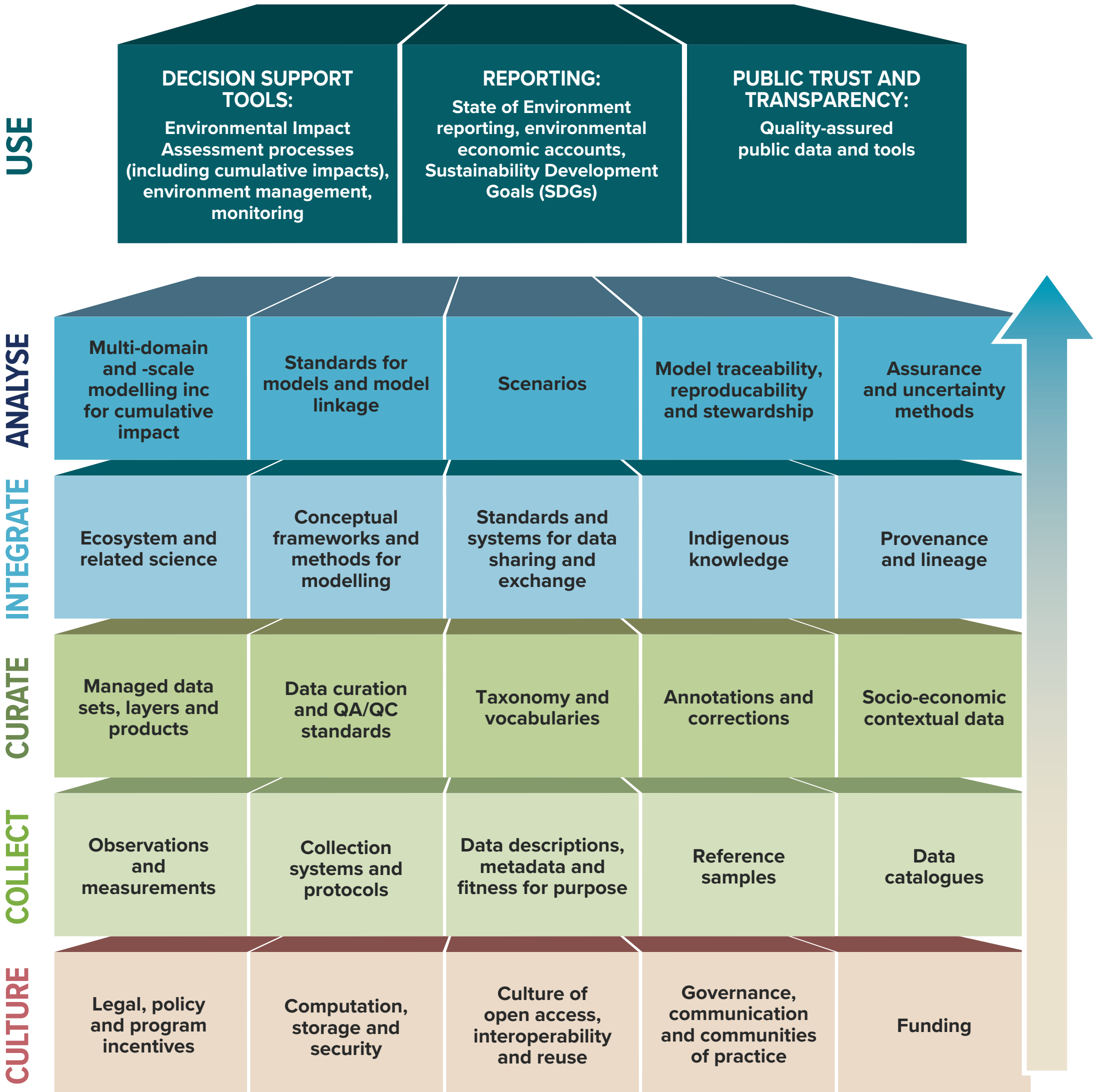
Aligned capabilities could support, for any region in Australia, a collection of knowledge products supporting environmental decision-making and reporting. The knowledge products would take cumulative impacts and offsets into account, and be linked across regions to enable:

- Rapid assessment of the current state of the regional environment and likely future states under various stressors and scenarios;
  - Automated or digitally assisted preliminary assessment of proposals presenting low environmental risk;
- Faster assessment of impacts of an activity on a region, taking into account cumulative impacts, identification of offsets, monitoring and reporting;
- Easier and more consistent reporting of the state of the environment, environmental economic accounts, sustainable development goals, and more;
- Improved public trust and transparency through public visibility of the above tools; and
- Collective learning and continuous improvement.

SAFE ENVISIONED

SAFE has five tiers, each of which describes key capabilities that support decision-making and reporting for environmental assessments. Each tier has several core components, and all tiers interconnect and add value to each other. The tiers and components are conceptual, and in many cases a particular organisation may provide services across more than one tier. At this stage organisations are not individually identified in the framework, although illustrative examples are provided later in the document.

The diagram illustrates the framework, showing the tiers and the capabilities within each tier:



SAFE
EXPLORED

The following section outlines each layer and capability in more detail, providing some illustrative institutional examples.

CULTURE

The Culture tier comprises the fundamental approaches and capabilities needed to enable all elements of SAFE to interact effectively.

LEGAL, POLICY AND PROGRAM INCENTIVES

Australia has some world-leading institutions for data collection and curation, for integration and for modelling. While sharing is frequent and widespread, a culture of sharing is not universal. There remain concerns that sharing data may lead to unwelcome scrutiny, lack of data control and confidentiality breaches. Policy, legislative and financial frameworks often include requirements to share, although these do not fully align across an institutional landscape with many players.

Public policies, legislation and funding initiatives need to reinforce open access, interoperability and reuse of data and knowledge products, as well as the application of standards to support interoperability and reuse. This applies to the system, as well as within individual programs, capabilities and projects. The challenges extend beyond legal frameworks to include culture.

COMPUTATION, STORAGE AND SECURITY

Security is a challenge with large scale federated systems. Ensuring that data which need to be kept secure remains so is a critical requirement to support decision-making and reporting for environmental assessments.

Long term storage for assurance and reuse is a common problem with data and data products developed by shorter term activities (eg surveys for environmental assessments, or research projects), or where incentives are weak. Too often, data and model resources disappear, go offline or change protocols, making any systems built on them unreliable and costly to maintain. Australia has national environmental data repositories, but they are not capable of storing all of the large data streams now available. There are not yet comparable national repositories for model code and outputs, though private and open source options exist.

CULTURE OF OPEN ACCESS, INTEROPERABILITY AND REUSE

One commonly used framework for data is the FAIR principles – data should be Findable, Accessible, Interoperable and Reusable. Data are often expensive to collect and curate, and this cost should be incurred only once, while the benefits are derived many times.

Open access is best practice, with some limited exceptions to protect sensitive data or knowledge products. Licencing arrangements, attribution protocols and authentication controls, which enable tracing of what a user has viewed, altered or copied, can reduce the risks associated with open access.

Interoperability requires participants to adopt agreed approaches and standards so that data, models or knowledge products can readily be used by other systems and people. This is particularly important when integrating elements from a range of sources, as is necessary in Australia's current fragmented information landscape.

Reuse is a transparency and efficiency principle. Ensuring that reuse can occur is both cultural and technical, and dependent upon clear standards and frameworks at all levels.

GOVERNANCE, COMMUNICATION AND COMMUNITIES OF PRACTICE

SAFE encompasses a large range of capabilities and institutions, both public and private. No single governance approach exists to cover all aspects; a network of governance approaches is therefore needed. Governance, as a supporting capability, will apply within each tier of SAFE (eg various naming standards and definitions related to data), and across the SAFE tiers (eg routine means for data and data products to link to models, as well as for models to link to each other). Governance needs to incorporate ethics, privacy and consent considerations.

Communication is a dimension of almost all components. From the user's perspective, it is critical to have confidence in the knowledge products being used to support decisions. This involves communication about the data, assumptions and methods used to generate a result, as well as the uncertainty that surrounds it. This involves communication products, as well as provenance and assurance processes.

Communities of practice exist within individual capabilities and tiers, as well as across tiers. Some communities are mature (eg for many data capabilities), while others are evolving (eg to assure decision support tools, or multi domain model development and integration).

FUNDING

While there are many existing funding sources for individual elements of SAFE, it will be necessary to work together to achieve the overall potential of the system. A key argument for SAFE is that it should be possible to gain significantly greater benefit from existing funding using shared approaches.

FURTHER SOURCES: CULTURE

LEGAL, POLICY AND PROGRAM INCENTIVES:

EPBC Act – www.environment.gov.au/epbc

National Collaborative Research Infrastructure Strategy – www.education.gov.au/national-collaborative-research-infrastructure-strategy-ncris

National Environmental Science Program – www.environment.gov.au/science/nesp

COMPUTATION, STORAGE AND SECURITY:

National Computational Infrastructure – nci.org.au

Pawsey Supercomputing Centre – pawsey.org.au

Australian Signals Directorate – www.cyber.gov.au/acsc/view-all-content/ism

CULTURE OF OPEN ACCESS, INTEROPERABILITY AND REUSE:

FAIR principles – ardc.edu.au/resources/working-with-data/fair-data/

National Data Commissioner – www.datacommissioner.gov.au

Digital Transformation Agency – www.dta.gov.au

Australian Research Data Commons – www.ardc.edu.au

GOVERNANCE AND COMMUNITIES OF PRACTICE:

Australian Research Council – www.arc.gov.au/policies-strategies/strategy/research-data-management

Data Governance Australia – www.datagovernanceaus.com.au

Data Management Association Australia – www.dama.org.au

Maiam nayri Wingara Aboriginal and Torres Strait Islander Data Sovereignty Collective – www.maiamnayriwingara.org

Image courtesy: Bayden Smith, Greening Australia

COLLECT

The Collect tier includes the capabilities to generate multiple types of data, from existing sources to new fieldwork observations and automated sensors.

OBSERVATIONS AND MEASUREMENTS

This capability includes the primary data from observations made on the physical world. Often these are outputs from the many providers of ecosystem data, including:

- Marine and coastal
- Geospatial, satellite, drone and other remote earth observation technologies
- Soil and geomorphology
- Hydrology
- Atmospheric, including meteorological and climate
- Landscape and terrestrial, including ecology, biology, and genetics, through samples and sensors.

Many of these observations and measurements are made in Australia. Some will be sourced internationally. There are rapidly emerging technologies for more automatic collection and recognition of environmental characteristics, including environmental DNA sampling, automated species recognition software, and environmental sensors.

COLLECTION SYSTEMS AND PROTOCOLS

Data collection is often expensive and there are many ways to collect data, including traditional ecological field assessments, as well as newer technology involving field assessment mobile apps, remote capture through cameras and other sensors. Systems are rapidly evolving but the need to collect and curate data remains common – including interoperability across collection platforms. Even if sensors or methods change, they may be measuring the same phenomenon, and so ways to ensure comparability need to be continually updated.

There are often trade-offs between survey methods, survey detail, and the range of subsequent uses. Different approaches and solutions to these trade-offs may cause a lack of comparability among data sets, in particular in relation to national and regional data sets. In addition, it can be difficult to compare data collected at site level with that at larger scales.

Data sets sometimes extend beyond offering evidence that a species was present at a given location and date, also making it possible to assess community composition for broader taxonomic groups or the abundance of species at multiple times and places. These quantitative or sampling-event data sets typically derive from standard protocols for measuring and monitoring biodiversity such as vegetation transects, animal or bird censuses and freshwater or marine sampling. Through indicating the methods, events and relative abundance of species recorded in a sample, these data sets improve comparisons with data collected using the same protocols at different times and places.

DATA DESCRIPTIONS, METADATA AND FITNESS FOR PURPOSE

Data quality refers to data being fit for purpose. In the case of environmental assessments, the purposes for which data contributes relate to investment planning, regulatory decisions and public trust, and these impose high requirements for data quality.

There is no simple agreed definition of data quality, and it differs depending upon whether the data are from samples, observations and measurements, or is statistical or derived from modelling. Data quality starts at the point of creation. This applies to the data itself, as well as the metadata used to describe it. Clear information about data quality enables decisions to be made about how different forms of uncertainty can be propagated through analytics to provide the end user with overall estimates of uncertainty.

Metadata is an essential component of data quality and is important to enable decisions regarding fitness for further use. There are many metadata schemas, or structures for metadata about particular domains. Metadata schemas specify a set of metadata concepts or terms, as well as their definitions and relationships. They also clarify how the data were created, scale of the data, the areas of interest, any cleaning or validation processes and whether there are any restrictions that apply to the data. Reference data is a form of metadata, used to classify or categorize other data, e.g. in relation to units of measurement or calendar structures, and typically changes only slowly over time.

Image courtesy: Brooke Gibbens, UWA/CSIRO

REFERENCE SAMPLES

Reference specimens maintained in biological collections include the material samples on which new species are described – the type specimens – and also additional specimens that represent the variety and variability that support species identification. Collections are essential for taxonomic and systematic research, identification and naming.

Reference samples may be housed in physical collections, such as museums, herbaria and other collection institutions.

DATA CATALOGUES

There are a number of international and Australian biodiversity and ecosystem data catalogues. The Catalogue of Life is the most comprehensive and authoritative global index of species, holding information on the names, relationships and distributions of over 1.8 million species.

The longevity of access to data sources is an issue. The Biodiversity Information Projects of the World (BIPW) attempted to organise the web's biodiversity databases into an indexed list. A recent investigation found that of 600 databases from BIPW, only half were accessible in early 2020.[4] Many of the other databases remain available, but are difficult to access because of broken web links, etc, putting the information they contain in danger of being lost.

In Australia, there are policies requiring data created using public funds to be made public. While this is often the case, and there are some excellent national and state level data aggregators, much research data is at best difficult to find.

[4] Blair J, Gwiazdowski R, Borrelli A, Hotchkiss M, Park C, Perrett G, Hanner R (2020) Towards a catalogue of biodiversity databases: An ontological case study. *Biodiversity Data Journal* 8: e32765. https://doi.org/10.3897/BDJ.8.e32765

Image courtesy: WAMSI

FURTHER SOURCES: COLLECT

OBSERVATIONS AND MEASUREMENTS:

Geoscience Australia – www.ga.gov.au

Bureau of Meteorology – www.bom.gov.au

Atlas of Living Australia (ALA) – ala.org.au

Terrestrial Ecosystem Research Network (TERN) – www.tern.org.au

Integrated Marine Observing System (IMOS) – www.imos.org.au

CSIRO – www.csiro.org.au, adaptnrm.csiro.au/biodiversity-options/ (and much more)

Global Biodiversity Information Facility (GBIF) – www.gbif.org

Australian Government national authority on measurement – www.industry.gov.au/policies-and-initiatives/national-measurement-institute

COLLECTION SYSTEMS AND PROTOCOLS:

Terrestrial Ecosystem Research Network (TERN) – www.tern.org.au

Index of Biodiversity Surveys for Assessments (IBSA) – www.wa.gov.au/service/environment/environmental-impact-assessment/program-index-of-biodiversity-surveys-assessments

Index of Marine Surveys for Assessments (IMSA) – www.epa.wa.gov.au/forms-templates/instructions-for-preparing-data-packages-for-the-index-of-marine-surveys-for-assessments-imsa

DATA DESCRIPTIONS, METADATA AND FITNESS FOR PURPOSE:

ARDC – ardc.edu.au/resources/working-with-data/metadata/

Bureau of Meteorology – www.bom.gov.au (including National Environmental Information Infrastructure)

Geoscience Australia – www.ga.gov.au/about/facilities/geophysical-network/data-quality-control-data-availability-and-statistics

Terrestrial Ecosystem Research Network – www.tern.org.au

National Vegetation Information System – via: www.environment.gov.au

Australian Bureau of Statistics – www.abs.gov.au/websitedbs/D3310114.nsf/home/Quality:+The+ABS+Data+Quality+Framework

5* Open Data – 5stardata.info/en/

REFERENCE SAMPLES:

Australasian Virtual Herbarium – avh.chah.org.au

Geoscience Australia – www.ga.gov.au

National soil archive – www.csiro.au/en/Do-business/Services/Enviro/Soil-archive and www.asris.csiro.au

DATA CATALOGUES:

Data.gov.au – www.data.gov.au

CSIRO Knowledge Network – via: www.csiro.org.au

Global Biodiversity Information Facility – www.gbif.org

Catalogue of Life – www.catalogueoflife.org

CURATE

Managed data sets, layers and products	Data curation and QA/QC standards	Taxonomy and vocabularies	Annotations and corrections	Socio-economic contextual data

Curate level is the engine room where data are processed to make it fit for purpose, complete and interoperable. Data curation is an active and ongoing process that covers the full data lifecycle.

The result is often a dataset that differs in structure and form from the original data. Organizing data in forms that can support analysis and modelling should increasingly take place through automated processing, based upon naming frameworks, structures and standards.

There are varying views of 'big data'. For some types of data there are powerful means emerging to automate curation, ingesting large amounts of data of different types, and enabling it to be used even if poorly structured or defined. Other types of data, including species observations data, have to date proved less amenable to such treatment and require manual, often expert, curation. Both can contribute. In some circumstances, standardised, long term data sets are critical to validating and calibrating approaches that use large, unstructured data sets; and large unstructured data sets can sometimes extend conclusions that might be drawn from standardised, longer term data sets.

MANAGED DATA SETS, LAYERS AND PRODUCTS

Managed data sets, layers and products are primary inputs for further analysis. The quality and the accuracy of the records in the data are an integral part in both the selection of the data and in preparing it for subsequent analysis. Some data may need filtering before it is fit for use. The method of analysis to be undertaken will determine the degree to which the data may need filtering. Data may not always cover the areas of concern and some form of modelling may be required to extrapolate into those areas where the data are inadequate. There is often an extensive process involved in preparing data sets, layers and products for further use.

DATA CURATION AND QA/QC STANDARDS

Data quality management is a process where protocols and methods are employed to ensure that data are properly collected, handled, processed, used, and maintained at all stages of the data lifecycle.

It is critical that the approaches used to transform raw data into managed data sets, layers and products is transparent.

The increasing availability of digitized biodiversity data, provided by an increasing number of institutions and researchers, and the growing use of those data for a variety of purposes have raised concerns related to the "fitness for use" of such data and the impact of data quality on the outcomes of analyses, reports, and decisions. A consistent approach to assess and manage data quality is currently critical for biodiversity data users. However, achieving this goal has been particularly challenging because of idiosyncrasies inherent in the concept of quality.

TAXONOMY AND VOCABULARIES

A vocabulary sets out the common language a discipline has agreed to use to refer to concepts of interest. One of the current challenges for biodiversity data is that while there are broadly shared vocabularies, there are many exceptions. There are also important gaps, for example in relation to descriptions of pressures or threats to the environment.

Vocabularies, taxonomies and other knowledge organisation systems ensure that both machines and humans can interpret and use data arising from multiple sources. Agreed vocabularies are important to enable efficient collaboration to occur.

ANNOTATIONS AND CORRECTIONS

Data quality can be improved through annotations and corrections, using human and automated tools to correct and annotate individual data elements, so that annotations become visible to researchers who subsequently access the data. Annotations often take the form of metadata, whereas corrections modify the original data record. Annotations should be tied to the original data.

Annotations need to be transparent, and their provenance traceable. Tools have now been developed for online annotations and corrections to be associated with digital records.

SOCIO-ECONOMIC CONTEXTUAL DATA

Decision support tools may need information beyond that of the biophysical world. Data about social and economic factors need to be capable of being integrated with biophysical data. There are many rich sources of social and economic data, often highly structured and readily accessed.

FURTHER SOURCES: CURATE

MANAGED DATA SETS, LAYERS AND PRODUCTS:

Geoscience Australia – www.ga.gov.au

Bureau of Meteorology – www.bom.gov.au

Atlas of Living Australia – ala.org.au

Terrestrial Ecosystem Research Network – www.tern.org.au

Integrated Marine Observing System – www.imos.org.au

ABARES – www.agriculture.gov.au/abares

CSIRO – www.csiro.org.au, adaptnrm.csiro.au/biodiversity-options/ (and much more)

Global Biodiversity Information Facility (GBIF) – www.gbif.org

DATA CURATION AND QA/QC STANDARDS:

Australian National Data Service (now subsumed into ARDC) **–** www.ands.org.au/guides/curation-continuum

Australian Bureau of Statistics – www.abs.gov.au/websitedbs/D3310114.nsf/home/Quality:+The+ABS+Data+Quality+Framework

National Archives of Australia – www.naa.gov.au/information-management/building-interoperability/interoperability-development-phases/data-governance-and-management/data-quality

TAXONOMY AND VOCABULARIES:

Australian Biological Resources Study (ABRS) – www.environment.gov.au/science/abrs

Taxonomy Australia – www.taxonomyaustralia.org.au/about-taxonomy-australia

Australian Research Data Commons – ardc.edu.au/services/research-vocabularies-australia/

National Environmental Information Infrastructure – www.neii.gov.au

ANNOTATIONS AND CORRECTIONS:

Atlas of Living Australia – www.ala.org.au/blogs-news/annotations-alerts-about-new-annotations-and-annotations-of-interest/

SOCIO-ECONOMIC CONTEXTUAL DATA:

Numerous sources, including:

ABS – www.abs.gov.au

data.gov.au – www.data.gov.au

INTEGRATE

The Integration tier takes data and curated data products and links them to other data products in preparation for being used in analytic and modelling tools. It also identifies the key characteristics necessary to ensure their continued integrity, and the scientific basis for their integration.

ECOSYSTEM AND RELATED SCIENCE

The Convention on Biological Diversity defines an ecosystem as a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.[6] Some aspects of ecosystems, such as individual species distributions and community-level modelling of species, have good data streams and modelling tools, and the challenges are well known. How different species interact and communities and ecosystems function is less understood.

CONCEPTUAL FRAMEWORKS AND METHODS FOR MODELLING

Conceptual models of the environment – from the molecular level to whole ecosystems – remain immature overall. There is considerable scientific work needed to build conceptual models to improve understanding of biological systems and integrate that knowledge into other models, from geology to economics.

One commonly applied classification of regions is the Interim Biogeographic Regionalisation for Australia. IBRA classifies Australia's landscapes into 89 large geographically distinct bioregions based on common climate, geology, landform, native vegetation and species information. The 89 bioregions are further refined to form 419 subregions which are more localised and homogenous geomorphological units in each bioregion. IBRA is a more detailed subset of the global ecoregions defined by WWF.

One conceptual approach, the Australian Ecosystem Models Framework, captures knowledge of ecosystem dynamics in a set of dynamic ecosystem models which describe the dynamic characteristics and drivers of Australian ecosystems. The models have the potential to provide an architecture for natural resource management prioritisation, including environmental assessments, as well as monitoring and evaluation.

Causal networks or causal pathways provide an approach to estimating cumulative impacts, through identifying pressures, and assessing links between pressures and endpoints. Risks to ecological or other values are assigned by likelihood and severity, and protection and management processes that might avoid or mitigate potential impacts can be considered. Causal networks can offer a transparent logic linking pressures, states and responses, common factors included in environmental assessments.

[6] https://www.cbd.int/convention/articles/?a=cbd-02

STANDARDS AND SYSTEMS FOR DATA SHARING AND EXCHANGE

Standards for data exchange ensure that information carries consistent meaning across various transformations and as it is fed into analytic and modelling systems. Standards achieve this by using a dictionary of agreed terms, definitions, relationships and formats regardless of how the information is stored. These standards are built into APIs, and may enable provision of data as a service (DaaS). DaaS takes observation and derived data and makes it model-ready in relation to format, structure, temporal and spatial up/downscaling, translation, harmonisation, quality control and uncertainties.

Data sharing often takes place according to legal agreements between a custodian and a recipient. These can be effective means to manage the risk of unwanted release, though may also be time-consuming to finalise. Systems to track data lineage, covered below, can also help mitigate risk.

INDIGENOUS KNOWLEDGE

Irreplaceable knowledge is held, and continually developed, by Aboriginal and Torres Strait Islander people. Where appropriate, some of this has been integrated into management practice, for instance through Indigenous ranger and Caring for Country programs. Best practice has Indigenous engagement and knowledge built into management approaches, based upon a clear sense of value to the Indigenous people involved, as well as long term ongoing engagement.

Indigenous people will often have both direct interests and deep expertise that will benefit decision making. Engagement with traditional owners and Indigenous communities is needed to ensure culturally appropriate governance processes, supply and use of traditional knowledge, and engagement with data, data products, model structures and modelled outputs. Engagement involves Indigenous people being involved in decision making at all levels.

PROVENANCE AND LINEAGE

The ability to track unit level data from the point of creation through curation and to integration into data products and systems for exchange, to be analysed and modelled, is critical to building confidence in decision-support tools. This is often referred to as recording provenance or lineage. It facilitates data sharing through providing reassurance to the data custodian; it also helps tracks intellectual property. It can aid analysis of results based upon dependencies upon particular data or other inputs, as well as error-detection, auditing and compliance investigation. Capturing provenance and lineage may require considerable metadata documentation, including of data transformations. It is often challenging to track which data or data products contributed to model results.

Assurance of integration processes is needed to ensure that the inputs to be analysed and modelled are fit for purpose. Persistent identifiers are important to ensure the longer term stability of references to particular data or knowledge products or model versions. Digital object identifiers (DOIs) are commonly used unique identifiers.

Image courtesy: Monique Grol

FURTHER SOURCES:

ECOSYSTEM AND RELATED SCIENCE:

Many sources, including:

Ecosystem Science Council – ecosystemscience.org.au

Ecological Society of Australia – www.ecolsoc.org.au

CONCEPTUAL FRAMEWORKS AND METHODS FOR MODELLING:

Australia Ecosystem Model Frameworks – research.csiro.au/biodiversity-knowledge/projects/models-framework/

Australian bioregions – www.environment.gov.au/land/nrs/science/ibra

Pressure state response model – www.epa.wa.gov.au/state-environment-reporting

Causal pathways – www.bioregionalassessments.gov.au/methods/developing-conceptual-model-causal-pathways

STANDARDS AND SYSTEMS FOR DATA SHARING AND EXCHANGE:

Australian Research Data Commons – ardc.edu.au/services/research-data-australia/

National Archives of Australia – www.naa.gov.au/information-management/building-interoperability/interoperability-development-phases/implementation/data-exchange

National Data Commissioner – www.datacommissioner.gov.au/resources/draft-data-sharing-agreement-template

INDIGENOUS KNOWLEDGE:

National Indigenous Australians Agency – www.niaa.gov.au/indigenous-affairs/environment

AIATSIS – aiatsis.gov.au

IP Australia – www.ipaustralia.gov.au/understanding-ip/getting-started-ip/indigenous-knowledge

CSIRO – www.csiro.au/en/Research/LWF/Areas/Pathways/Sustainable-Indigenous/Our-Knowledge-Our-Way

Bureau of Meteorology – www.bom.gov.au/iwk/

CSIRO – www.csiro.au/en/Indigenous-engagement/Indigenous-engagement

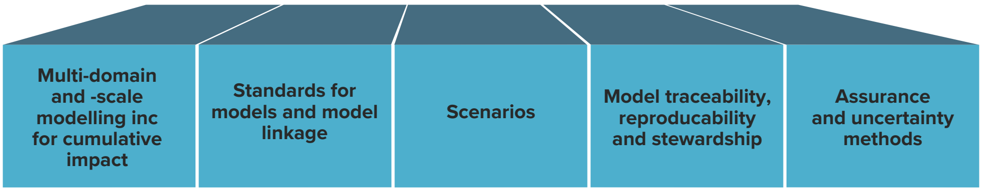
Australian Institute of Health and Welfare – www.aihw.gov.au/reports/indigenous-australians/engagement-with-indigenous-communities-in-key-sect/contents/table-of-contents

PROVENANCE AND LINEAGE:

Digital object identifier system – www.doi.org

Australian National Data Service – www.ands.org.au/working-with-data/publishing-and-reusing-data/data-provenance

ANALYSE



The Analysis tier identifies the analytic and modelling capabilities that underpin decision support tools.

MULTI-DOMAIN AND MULTI-SCALE MODELS, INCLUDING FOR CUMULATIVE IMPACT

Domain specific models are available for environmental characteristics including climate, land surface, species, hydrology and habitat extent and condition. There are several such models available, peer reviewed and curated, often with reliable data sources, though particularly at local scales data may need to be supplemented.

Cross-domain modelling can take place through the loose coupling of specialised models. This has the advantage that the specific strengths of each model are retained, though limited information is generally exchanged between coupled models, and often in only one direction, with an accompanying lack of feedback between the modelled components. There is also the risk of inconsistencies in representations of the same phenomenon in the different models.

Scale refers to the extent and resolution of models. Ecological patterns and processes change at different scales. Ecosystems have different features and structures that influence inter-relationships between interacting species. The scale-dependence of these relationships is not always apparent because of variations in methodological reliability as well as data availability and accuracy.

Integrated assessment models embed different model representations of the system in a consistent manner. The inclusion of feedback and interaction between the different modules is generally stronger and there is more likely to be consistent representation of variables across the different modules. Such models have inherent complexity, which reduces the applicability and transparency of the models.

A challenge is to make models dynamic, able to readily update based on new flows of data.

Simple models of ecosystems have been developed using Bayesian or causal networks to organise disparate information in a consistent framework and incorporate some of the uncertainties inherent in natural systems. Causal networks have potential to contribute more significantly to environmental impact assessment, as they can concisely document cause-and-effect relationships. These models can be attractive due to their high transparency, the possibility to combine empirical data with expert knowledge and their explicit treatment of uncertainties. Sensitivity analysis tools allow characterisation of uncertainties so that key causal factors and knowledge gaps can be identified. Such models tend not to represent dynamic processes, as continuous probability distributions require conversion into discrete figures for calculation.

Cumulative impact remains a challenge, as it is often not additive but multi-factorial with feedback loops and relationships between different factors that are not always well understood.

STANDARDS FOR MODELS AND MODEL LINKAGE

Standards for models and model linkage can help assess the reliability of model results, ensure transparency and consistency in the translation of scientific results into decision support tools, and focus on where improvements might be most needed in the underlying science.

There are no overall standards for ecosystem models. There are however means to select models and tools for analysis, and standardised QA/QC procedures for risk characterisation and peer review.

SCENARIOS

Scenarios are representations of possible futures for one or more components of a system, particularly for pressures or drivers of change. They often incorporate alternative intervention, policy or management options. They offer a key opportunity for end user engagement and interaction with the modelling system and a component of communication and education to understand the basis of the system being modelled.

Scenarios and models play complementary roles, with scenarios describing possible futures for drivers of change or policy interventions and models translating those scenarios into projected consequences for nature.

Some decision support tools – especially at more local levels of decision making – will require consideration of intervention options that are not necessarily known in advance, but arise dynamically. Analysis and modelling in such situations requires the modification of intervention scenarios informed by feedback on the modelled consequences of these options.

The spatial extent and resolution of scenarios and models needs to be aligned with the scale of interest. Temporal scales – ranging from changes made over a few years, through to those focused on achieving longer-term change over several decades – have implications for any scenarios and models.

MODEL TRACEABILITY, REPRODUCIBILITY AND STEWARDSHIP

How models are specified can have considerable impact upon the results that they produce. It can be difficult to gain visibility of model parameters, or the impact of any choices and changes. Platforms are available that offer models with default parameters, which can be altered while creating an auditable record of change.

Stewardship is a concept commonly applied to the activities that preserve and improve the information content, accessibility, and usability of data and metadata. The same concept is important for models. Stewardship activities are a critical support for assurance and reuse, as well as long-term preservation.

A recent survey by the scientific journal *Nature* found that "more than 70% of researchers were unable to reproduce research by others, and 50% were not even able to reproduce their own results."[5] Metadata standards are one response to this, as are standardised data sets, models and model parameters (together with customisation and DOIs) such as offered by EcoCommons for species distribution and other modelling. The ability to reproduce modelled results is central to public trust and assurance of any decision-support tools.

ASSURANCE AND UNCERTAINTY METHODS

Assurance includes setting standards for best practices, using model-data and model-model inter-comparisons to provide robust and transparent evaluations of uncertainty and encouraging new research into methods of measuring and communicating uncertainty and its impact on decision-making. It includes QA/QC approaches.

Uncertainty in scenarios and models arises from a variety of sources, including insufficient or erroneous data used to construct and test models; lack of understanding or inadequate representation of underlying processes; and low predictability or random behaviour in a system. Biodiversity and ecosystem models currently available provide a range of options to assist policymakers in understanding relationships between drivers and impacts, and in evaluating interventions.

For knowledge products to be used by proponents to shape investment proposals, for regulators to make decisions, and for public trust, models must be both of high standards and known to be so.

An example of model assurance in practice is through the scientific oversight built into EcoCommons. An expert committee provides assurance over 100s of curated data sets, 17+ peer reviewed species models, default model parameters and more. While users can introduce new data and vary parameters, DOIs can be minted for all analytic results creating a permanent record of all data, model parameters, etc, and offering an audit and reproducibility trail.

[5] Feng, X., Park, D.S., Walker, C. et al. 'A checklist for maximizing reproducibility of ecological niche models'. Nat Ecol Evol 3, 1382–1395 (2019). https://doi.org/10.1038/s41559-019-0972-5

FURTHER SOURCES: ANALYSE

MULTI-DOMAIN AND -SCALE MODELLING, INCLUDING FOR CUMULATIVE IMPACT:

CSIRO bushfire modelling – research.csiro.au/spark/

CSIRO – www.csiro.org.au

Habitat Condition Assessment System – research.csiro.au/biodiversity-knowledge/projects/hcas/

Australian Urban Research Infrastructure Network (AURIN) – aurin.org.au

STANDARDS FOR MODELS AND MODEL LINKAGE:

National Environmental Information Infrastructure [BOM] – www.neii.gov.au/about

Foundation Spatial Data Framework – fsdf.org.au

SCENARIOS:

Intergenerational Report – treasury.gov.au/intergenerational-report

CSIRO Australian National Outlook – via: www.csiro.au

Intergovernmental Panel on Climate Change emissions scenarios – via: www.ipcc.ch

Nature Futures Scenarios – ipbes.net/scenarios-models

MODEL TRACEABILITY, REPRODUCIBILITY AND STEWARDSHIP:

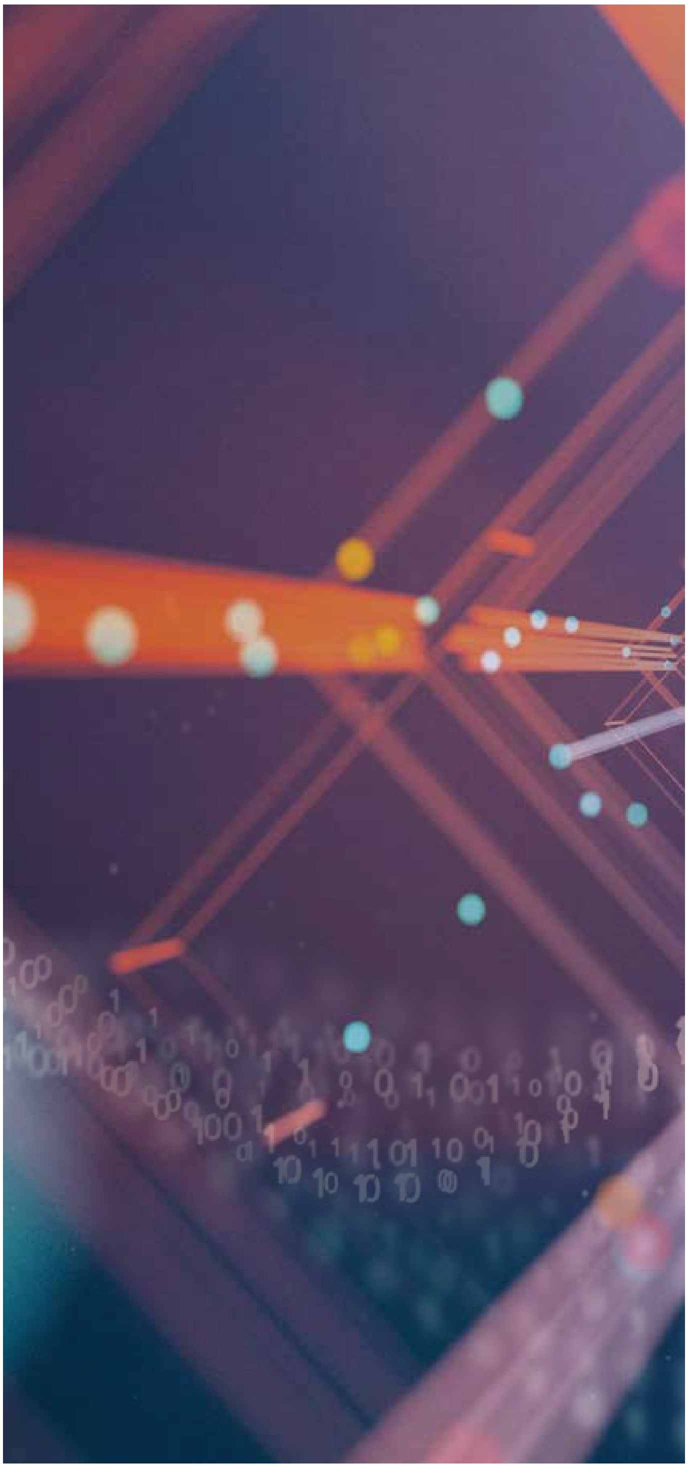
EcoCommons – ecocommons.org.au

Model reproducibility standard – Feng, X., Park, D.S., Walker, C. et al. 'A checklist for maximizing reproducibility of ecological niche models'. Nat Ecol Evol 3, 1382–1395 (2019). doi.org/10.1038/s41559-019-0972-5

ASSURANCE AND UNCERTAINTY METHODS

EcoCommons – ardc.edu.au/project/ecocommons-australia/

A number of reports discuss approaches to uncertainty in their field, eg. ***Great Barrier Reef Outlook Report 2019*** – www.gbrmpa.gov.au/our-work/outlook-report-2019



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WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION

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WABSI and WAMSI are supported by the State Government of Western Australia, through the Department of Jobs, Tourism, Science and Innovation

Mangroves, Exmouth Gulf (Photo: Rebecca Bateman-John)

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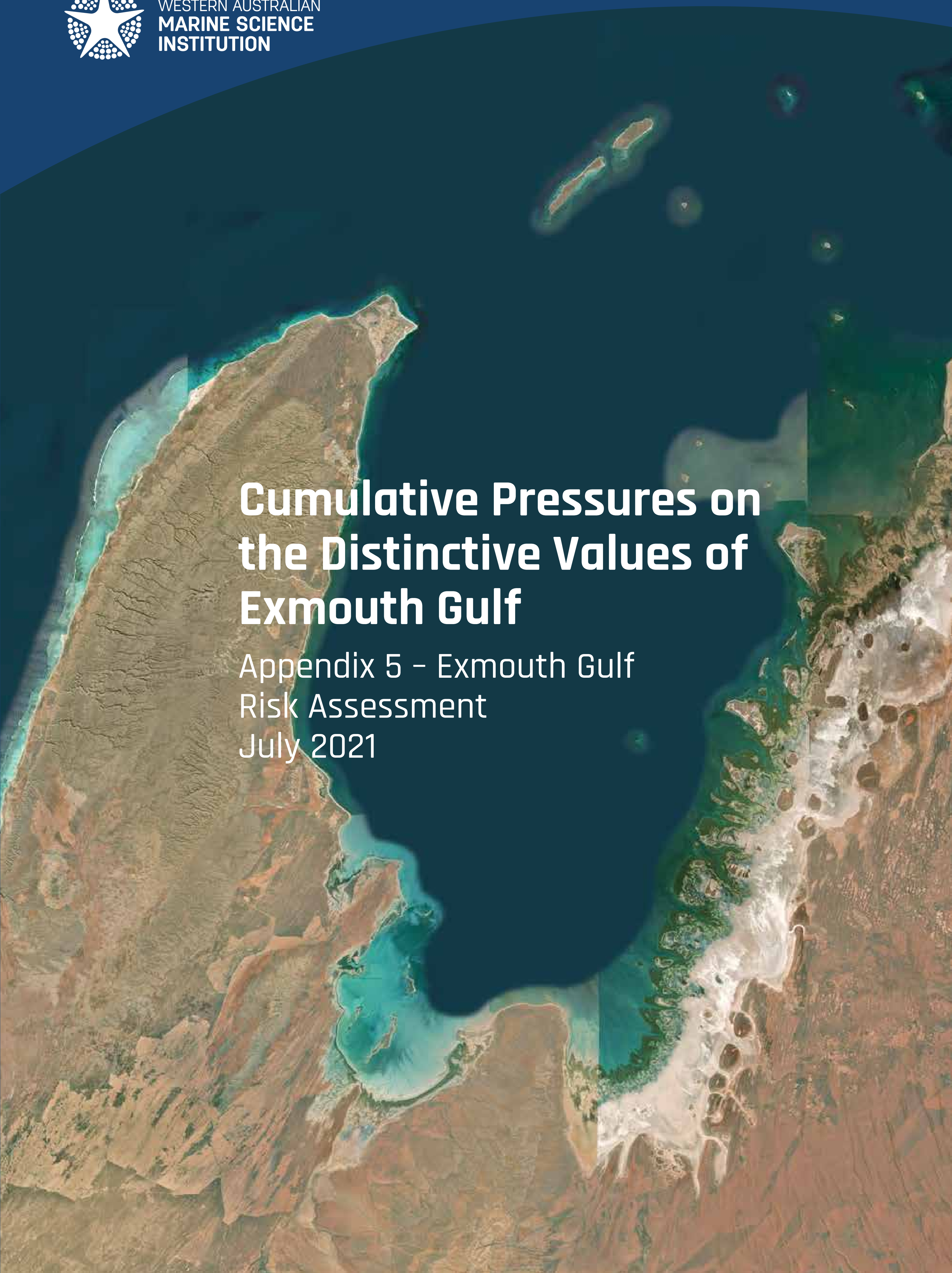
INSTITUTION

Cumulative Pressures on the Distinctive Values of Exmouth Gulf

Appendix 5 – Exmouth Gulf Risk Assessment

July 2021



Contents

EPA SEA THEME

Negligible	Low	Medium	High	Severe
1-2	3-4	6-8	9-12	16

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						

General statements to consider for all values

As a point of comparison, Shark Bay is quite shallow - water flows in and has a harder time flowing back out. Exmouth Gulf is a bit deeper, has big tides, more mixing and water comes in and out much quicker. In Exmouth Gulf, warm water mixes and dissipates quicker. The Gulf, however, still has captured water compared to coastal areas with no embayments.

During a heatwave, warm water will come in and out with the tide every day, and solar radiation is added on top (this can happen for weeks/months).

There can be strong temperature and salinity gradients along the Exmouth Gulf from north to south. So perhaps we cannot assume mixing is happening all the time, or at least throughout the whole Gulf?

During some events, like La Niña years, we are going to experience warmer periods and an increase in the frequency of heatwaves and storms.

Many of Exmouth Gulf's habitats and the biodiversity they support are existing at their physiological extremes and biogeographical limits. This means they are susceptible to stress and perturbations from anthropogenic impacts, such as industrialisation and climate change. The Gulf's prevailing environmental conditions such as aridity, sporadic intense rainfall, salinity and other factors mean that habitats, such as mangroves, are likely to respond more acutely to climate change effects.

Another component of heatwaves is wind. During La Niña periods, winds decrease and become more easterly. Winds can dilute the warm water coming into Exmouth Gulf. Currently (Feb 2021), the cold water is not present to modulate temperatures.

Kathleen McInnes meeting - 4 March 2021 - comments made generally, not specific to Exmouth Gulf

- There is already natural variability. It is hard to predict the influence of climate change drivers on the Exmouth Gulf marine environment over a short 5-10 year time frame
- A 3.5mm sea level rise per year is predicted - but this is strongly influenced by the El Niño-Southern Oscillation (ENSO)
- Marine heatwave frequency is projected using longer time scales
- Over 5-10 years you are mainly looking at ENSO cycles and how that covaries with rainfall in Exmouth Gulf. There are different predictions for each region. Climate change will be less of an issue over this time frame, but it would still be going on in the background and will amplify other impacts.
- Typically, we look at 20-100 years when looking at projections.

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						

- For projections for 2030, the values are small in comparison with natural variability. We do not start to see a separation in values/patterns until about 2040 and beyond.
- The last time national projections were rolled out for Western Australia they focused on Natural Resource Management (NRM) regions - The Rangelands North sub-cluster comprises NRM regions in four States and the Northern Territory, extending from the Indian Ocean to northwestern New South Wales. Climate projections are on the national climate change website (www.climatechangeinaustralia.gov.au/en/projections-tools/regional-climate-change-explorer/sub-clusters/?current=RLNC&tooltip=true&popup=true)
- Work on marine heatwave projections out to 2100 (not specific to Exmouth Gulf), show permanent hot conditions e.g., current heatwave conditions, but permanent.
- Drying climate, lack of rainfall and increase in air temperature of 1.3 degrees by 2030
- 34 days over 35 degrees by 2030 (increase of 7 days since 1981), and an increase of 4 days over 40 degrees.
- There has been some Shark Bay CSIRO work on climate change
- Under high emission scenarios, marine heatwaves as intense as 2011 off the coast of W.A. could change from a one-in-80-year event to an annual event
- 4-7 years cycle for ENSO - The Bureau of Meteorology does seasonal forecast outlooks. El Niño conditions are usually characterised by drought conditions, low sea levels and low rainfall.
- La Niña has a tendency towards warmer ocean temps, higher rainfall, rapid transpiration, more rainfall, more floods, more tropical cyclones
- Tidal movements could be impacted by climate change, but it would need modelling work done to determine the extent. Still expect the same tidal regime but low tides are getting higher, and high tides are getting higher, and the shoreline is incrementally becoming more submerged.

Climate Change in Australia website: Rangelands North (incl. Exmouth Gulf) - **On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human-induced trend, particularly in the next 20 years and for rainfall.**

Factor: Benthic habitats and communities						
Value: Macroalgae and turf algae						
Y	Marine heatwaves	2	4	8	M	There has been impacts on macroalgae from the 2011 marine heatwave but not sure to what degree - **more knowledge needed - low data confidence** The supply of propagules into the Exmouth Gulf system may not be as good as elsewhere We have a better understanding for corals from long-term data sets. Impacts to species would also depend on their distribution in the Gulf **Consider cumulative impacts here:** • *Marine heatwave projections are increased frequency and longer duration* • *If there are two every ten years, this may be too much for a system to handle*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *Under high emissions scenarios, there could be a marine heatwave similar in intensity to 2011 occurring almost every year* When thinking of climate change impacts and projections, are we considering ecosystem services provided by macroalgae or specific species? The amount of light reaching the bottom is usually lower in summer. As temperature increases, primary producers need more light to photosynthesise. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that marine heatwaves can negatively impact algae* • *Low confidence of how marine heatwaves have impacted algae in Exmouth Gulf*
Y	Tropical storms and cyclones	2	3	6	H	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence. With medium confidence, fewer but more intense tropical cyclones are projected - *Climate Change in Australia website* Influx of freshwater, sediments, nutrients and direct removal of holdfasts are considerations here. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can dislodge algae* • *High confidence that past cyclones have caused the loss of significant macroalgae beds - see Loneragan et al 2013*
Y	Sea level rise	1	3	3	M	For Rangelands North, which includes Exmouth Gulf, mean sea level will continue to rise, and the height of extreme sea-level events will also increase (very high confidence) - Climate Change in Australia website A rise in sea level could permanently inundate macroalgae adapted to intertidal areas, but algae grows quickly and could shift distribution. This may not be realised in the 5-10 year timeframe. Unlikely to have a significant impact *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact subtidal and intertidal macroalgae in Exmouth Gulf*
Value: Seagrass						
Y	Marine heatwaves	3	4	12	H	Prawn stocks declined after the 2011 heatwave; impacts were seen on seagrass loss. The amount of light reaching the bottom is usually lower in summer. As temperature increases, primary producers need more light to photosynthesise. There were large-scale losses observed for seagrass in Shark Bay following 2011 marine heatwave *Data confidence* • High confidence that marine heatwaves will increase as predicted • *High confidence that marine heatwaves can negatively impact seagrass (e.g. Shark Bay)* • *High confidence in how past marine heatwaves have impacted seagrass in Exmouth Gulf*
Y	Tropical storms and cyclones	3	3	9	H	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Flooding was noted to have contributed to the loss of seagrass in Shark Bay coupled with the marine heatwave. Freshwater influx, nutrient runoff and direct removal of seagrasses are considerations here. Note that projected marine heatwave events can be mitigated by tropical cyclone events, so the two risks are inter-related. Cumulative impacts are not always 'cumulative' *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can dislodge seagrass* • *High confidence that past cyclones have caused the loss of seagrass beds - see Loneragan et al 2013*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Y	Sea level rise	1	3	3		For Rangelands North, which includes Exmouth Gulf, mean sea level will continue to rise, and the height of extreme sea-level events will also increase (very high confidence) - Climate Change in Australia website Could cause a shift in distribution but may not be realised in the 5-10 year timeframe. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact seagrasses in Exmouth Gulf*
Value: Coral						
Y	Marine heatwaves	4	3	12	H	Bleaching currently occuring for corals in the Gulf e.g., along the eastern margin. It is well known that increased temperatures cause bleaching and the subsequent death of corals. There are cumulative considerations here if algal growth on deteriorating corals cannot be controlled by herbivores. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that marine heatwaves can negatively impact corals* • *High confidence that warmer waters have caused bleaching of corals in Exmouth Gulf (as recently occurred over the summer months 2020-2021) see Moore et al. 2012 and Depczynski et al. 2013*
Y	Tropical storms and cyclones	2	4	8	H	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Storm/cyclone events can cause direct damage to corals. Freshwater influxes may stress corals at points of freshwater entry. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can cause damage to corals* • *High confidence that past cyclones have caused the loss of corals in the Gulf, e.g., lots of coral rubble is still evident at Bundegi - see Loneragan et al 2003 and Day et al 2013*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Y	Sea level rise	3	2	6	M	Corals may be at risk if growth cannot keep up with sea level rise, but it is unlikely that the impact of this would be realised in the 5-10 year timeframe. *Data confidence* • *High confidence in sea level rise predictions* • *Medium confidence on how sea level rise can impact seagrasses in general* • *Low confidence in how sea level rise will impact seagrasses in Exmouth Gulf*
Value: Sponges and filter feeders						
Y	Marine heatwaves	2	3	6	L-M	Not as much is known about the impacts to sponges and filter feeders, though we would expect there to be some impact depending on the physiological tolerance limits of species. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence around the impact of marine heatwaves on sponges and filter feeders, and how they will be impacted in Exmouth Gulf*
Y	Tropical storms and cyclones	2	3	6	H	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Storm events could directly dislodge sponges and filter feeders. It is uncertain how freshwater influxes may impact growth. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can cause damage to sponges and filter feeders* • *High confidence that past cyclones have caused the loss of sponges in the Gulf, e.g., sponges were found uprooted following Cyclone Vance - see Loneragan et al. 2003*
Y	Sea level rise	1	3	3	L-M	For Rangelands North, which includes Exmouth Gulf, mean sea level will continue to rise, and height of extreme sea-level events will also increase (very high confidence) - Climate Change in Australia website

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						It could cause a shift in distribution, but this may not be realised in the 5-10 year timeframe. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact sponges and filter feeders, and how they will be impacted in Exmouth Gulf*
Value: Sand and mud						
Y	Marine heatwaves	2	3	6	L-M	Infauna communities may be impacted by increased temperatures. **More knowledge needed.** If decaying material is increased due to death of seagrasses, macroalgae etc. following a heatwave, then the increased organic load may have positive and negative consequences. Infauna is relatively fast growing, so it could recover after disturbances. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence around the impact of marine heatwaves on sand and mud habitat and communities, and how they will be impacted in Exmouth Gulf*
Y	Tropical storms and cyclones	1	4	4	M	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Some impact may be felt at the benthic level with mixing of water but could be similar to above. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones would cause some disturbance to sand and mud habitats and communities* • *Low confidence in the knowledge of sand and mud habitats and communities, and the extent to which they would be impacted in the Gulf*
Y	Sea level rise	1	2	2	L-M	Uncertain whether there would be many/any negative effects

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						Data confidence • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact sand and mud habitats and communities, and how they will be impacted in Exmouth Gulf*
Value: Mangroves						
Y	Marine heatwaves	2	4	8	M	Air temps and heatwaves - mangroves can be stressed by periods of lower-than-average sea level combined with a lack of rainfall. This has caused some dieback in the Gulf of Carpentaria. Root systems dried out. 1000km coastline impacted with dieback. Given position on landscape, mangroves will experience some inundation of roots with warm waters, but possibly not complete inundation? *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence around the impact of marine heatwaves on mangroves* • *High confidence that past warming events in the Gulf have not resulted in significant die off*
Y	Tropical storms and cyclones	3	3	9	H	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Rainfall and dry root systems leads to mangrove death. Erosion will impact growth and stability and movement of sediments can release carbon buried among roots. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can cause damage to mangroves* • *High confidence that past cyclones have caused significant loss of mangroves in the Gulf, e.g., see Paling et al. 2008*
Y	Sea level rise	4	2	8	H	Mangroves can migrate shoreward if room is available. If the land is developed however, coastal squeeze could reduce the extent of mangroves.

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						Tidal regimes require modelling for the localised area and the effect of La Niña needs to be considered as well. In general, the effect of climate change on tides tends to be small, and we would expect roughly the same tidal regime with rising sea levels, but low tides are getting higher, and high tides are getting higher. Incrementally mangroves are becoming more submerged. The extent of landward migration and coastal squeeze is not likely to be realised in a 5-10 timeframe. If consideration was given to 20+ years, then we would expect a higher likelihood of a high or severe consequence. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence in how sea level rise will impact mangroves, and how they will be impacted in Exmouth Gulf - see Reef and Lovelock 2019*
Value: Samphire						
Y	Marine heatwaves	2	2	4	L-M	Tidal regimes may mean samphire is exposed to warmer water temperatures; however, it has already adapted to living in a hot environment. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence around the impact of marine heatwaves on samphire, and how they will be impacted in Exmouth Gulf*
Y	Tropical storms and cyclones	3	3	9	M	Similar concerns as for mangroves *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can cause damage to samphire* • *Low confidence that past storms/cyclones have caused significant loss of samphire in the Gulf*
Y	Sea level rise	4	2	8	M-H	Same reasons as for mangroves *Data confidence* • *High confidence in sea level rise predictions*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence in how sea level rise will impact samphire, and how they will be impacted in Exmouth Gulf, though no specific studies in the area*
Value: Blue green algal mats						
Y	Marine heatwaves	2	2	4	L-M	May have some influence due to periodic inundation, but have already adapted to a hot, harsh environment. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence around the impact of marine heatwaves on blue green algal mats, and the impact specifically within the Gulf*
Y	Tropical storms and cyclones	1	4	4	M	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Winds could cause disturbance to mats and prolonged flooding may cause death or lack of activity if tolerances are low. Grows quickly so it can recover. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can cause damage to blue green algal mats* • *Low confidence that past storms/cyclones have caused significant loss of blue green algal mats in the Gulf*
Y	Sea level rise	4	2	8	M-H	Same reasons as for mangroves *Data confidence* • *High confidence in sea level rise predictions* • *High confidence in how sea level rise will impact on blue green algal mats, and how they will be impacted specifically in Exmouth Gulf, though no specific studies in the area*
Value: Reef flats and oyster beds						
Y	Marine heatwaves	1	2	2	M	Unlikely to have much of an impact as oysters are adapted for harsh, hot conditions.

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						Reef flats (excluding biota growing on flats, which is covered above) would not be impacted. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence around the impact of marine heatwaves on blue green algal mats* • *Low confidence on impact of warmer water on oysters*
Y	Tropical storms and cyclones	1	2	2	M-H	Minimal impact. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones will not cause significant damage to solid reefs flats and oyster beds* • *High confidence that past storms/cyclones have not caused significant loss of reef flats and oyster beds in the Gulf, though no specific studies have examined this*
Y	Sea level rise	3	2	6	M-H	Oyster beds would need to grow in height at a speed that matches sea level rise, but likely not realised in the 5-10 year time frame. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence in how sea level rise will impact on reef flats and oyster beds, and how they will be impacted specifically in Exmouth Gulf, though no specific studies in the area*
Value: Salt flats						
N	Marine heatwaves					
Y	Tropical storms and cyclones	1	4	4	M	Erosion and winds would disturb flats. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that storms/cyclones can cause damage to salt flats*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *Low confidence that past storms/cyclones have caused significant loss of salt slats in the Gulf*
Y	Sea level rise	1	3	3	M-H	If considering a longer timeframe, then sea level rise would have more of an impact. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence in how sea level rise will impact on salt flats, and how they will be impacted specifically in Exmouth Gulf, though no specific studies in the area*
Factor: Marine fauna						
Value: Crustaceans - prawns						
Y	Marine heatwaves	2	4	8	H	The heatwave had a marked indirect effect on brown tiger prawns in Exmouth Gulf due to loss of seagrass habitat. The heatwave also resulted in a decline in western king prawn recruitment. Recovery of prawns occurred as macroalgae and seagrass recovered, several years after the cyclone. Scored based off a one-in-10 -year event. Prawns recovered from the 2011 within ~ five years, but western king prawns appear to be slowly declining, which may be related to warming temperatures. **Consequence would increase if heatwaves were more frequent** See Fisheries research report for more information on the climate change risks to invertebrates and fishes. - *Management implications of climate change effect on fisheries in Western Australia Part 1: Environmental change and risk assessment* *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence in the impact of marine heatwaves on prawns* • *High confidence in the impact of marine heatwaves on prawns in Exmouth Gulf*
Y	Tropical storms and cyclones	2	4	8	H	Cyclone Vance in 1999 caused a decline in prawn abundance two years after the cyclone event, due to loss of macroalgae and seagrass habitat. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence that storms/cyclones can negatively impact prawns in Exmouth Gulf see Loneragan et al 2013*
Y	Sea level rise	1	4	4	L-M	Uncertainty around the effects of sea level rise on prawns. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact on prawns, and how they will be impacted specifically in Exmouth Gulf*
Value: Crustaceans - mud crabs						
Y	Marine heatwaves	2	4	8	L-M	Similar reasons as above but less certainty around impacts to mud crabs. Ranked as medium risk in Fisheries research report. - *Management implications of climate change effect on fisheries in Western Australia Part 1: Environmental change and risk assessment* *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in the impact of marine heatwaves on mud crabs, and the impact specifically in Exmouth Gulf*
Y	Tropical storms and cyclones	2	4	8	L-M	Similar reasons as above but less certainty around impacts to mud crabs. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence that storms/cyclones can negatively impact mud crabs, and the impact specifically in Exmouth Gulf*
Y	Sea level rise	1	4	4	L-M	Similar reasons as above but less certainty around impacts to mud crabs. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact on mud crabs, and how they will be impacted specifically in Exmouth Gulf*
Value: Teleost - whiting						

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Y	Marine heatwaves	1	3	3	M	Warm temperatures from the 2011 heatwave were noted as providing favourable conditions for spawning by whiting in the West Coast Bioregion. - *Fisheries fact sheet for yellowfin whiting* **More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Medium confidence in the impact of marine heatwaves on whiting in general* • *Low confidence of the impact specifically in Exmouth Gulf*
Y	Tropical storms and cyclones	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence that storms/cyclones can negatively impact whiting, and the impact specifically in Exmouth Gulf*
?	Sea level rise	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact whiting, and how they will be impacted specifically in Exmouth Gulf*
Value: Teleost - mangrove jack						
Y	Marine heatwaves	1	3	3	M-H	Warm waters during La Niña years correlated with higher growth rates of mangrove jack. There may be growth implications during El Niño years. **More knowledge needed** - *Ong et al 2015 - Contrasting environmental drivers of adult and juvenile growth in a marine fish: implications for the effects of climate change.* *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Medium confidence of the impact specifically in Exmouth Gulf - see Ong et al 2015*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Y	Tropical storms and cyclones	1	3	3	M-H	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Some evidence that the growth of juveniles responds positively to increased rainfall. This was not similarly observed for adults - *Ong et al 2015 - Contrasting environmental drivers of adult and juvenile growth in a marine fish: implications for the effects of climate change.* *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Medium confidence that storms/cyclones may have some positive impacts to mangrove jack juveniles in Exmouth Gulf - see Ong et al 2015*
Y	Sea level rise	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact mangrove jack, and how they will be impacted specifically in Exmouth Gulf*
Value: Teleost - trevally						
Y	Marine heatwaves	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. Wide ranging species. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in the impact of marine heatwaves on trevally in general, and in Exmouth Gulf*
Y	Tropical storms and cyclones	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. Wide ranging species *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence that storms/cyclones can negatively impact trevally, and the impact specifically in Exmouth Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Y	Sea level rise	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. Wide ranging species. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact trevally, and how they will be impacted specifically in Exmouth Gulf*
Value: Teleost - coral trout						
Y	Marine heatwaves	4	3	12	M	Coral trout are associated with coral habitats, which are threatened by marine heatwaves. Experiments on *Plectropomus leopardus* off the east coast of Australia (Great Barrier Reef) showed that growth and survival of larvae were impacted by increased temperatures. *Pratchett et al 2010 - Effects of climate change on reproduction, larval development, and adult health of coral trout (Plectropomus* spp.*)* *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence in the impact of marine heatwaves on coral trout in general* • *Low confidence of the impact to coral trout specifically in the Gulf*
Y	Tropical storms and cyclones	2	3	6	M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Medium confidence that storms/cyclones can negatively impact coral trout due to impacts to coral - e.g., lots of coral rubble is still evident at Bundegi - see Loneragan et al 2003 and Day et al 2013*
Y	Sea level rise	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in how sea level rise will impact coral trout, and how they will be impacted specifically in Exmouth Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Value: Teleost - red emperor						
Y	Marine heatwaves	1	3	3	M	Fisheries report includes red emperors in a low risk group for climate change - Caputi et al 2015. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence in the impact of climate change on red emperor in general* • *Low confidence of the impact of marine heatwaves to red emperor specifically in the Gulf*
Y	Tropical storms and cyclones	1	3	3	M	Fisheries report includes red emperors in a low risk group for climate change - Caputi et al 2015. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence in the impact of climate change on red emperor in general* • *Low confidence of the impact of extreme rainfall events and cyclones to red emperor specifically in the Gulf*
Y	Sea level rise	1	3	3	M	Fisheries report includes red emperors in a low risk group for climate change - Caputi et al 2015. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence in the impact of climate change on red emperor in general* • *Low confidence in how sea level rise will impact red emperor specifically in Exmouth Gulf*
Value: Teleost - tuskfish						
Y	Marine heatwaves	2	3	6	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence that marine heatwaves will increase as predicted*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *Low confidence in the impact of marine heatwaves on tuskfish in general, and specifically in the Gulf*
Y	Tropical storms and cyclones	2	3	6	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence in the impact of extreme rainfall events and cyclones on tuskfish in general, and specifically in the Gulf*
Y	Sea level rise	1	3	3	L-M	**More knowledge needed** on the direct and indirect impacts to different fish species. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in the impact of sea level rise on tuskfish in general, and specifically in the Gulf*
Value: Elasmobranchs - rays (shovelnose)						
Y	Marine heatwaves	2	3	6	L-M	Could impact on food sources for shovelnose rays, and increased temperatures could cause temporary shifts in distribution of both prey and rays. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in the impact of marine heatwaves on shovelnose rays in general, and specifically in the Gulf*
Y	Tropical storms and cyclones	1	3	3	L-M	Uncertainty around impact - **more knowledge needed.** *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence in the impact of extreme rainfall events and cyclones* • *on shovelnose rays in general, and specifically in the Gulf*
Y	Sea level rise	1	2	2	L-M	Uncertainty around impact - **more knowledge needed.**

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						Data confidence • *High confidence in sea level rise predictions* • *Low confidence in the impact of sea level rise on shovelnose rays in general, and specifically in the Gulf*
Value: Elasmobranchs - rays (manta) ***EPBC Act - Migratory, Marine listed***						
Y	Marine heatwaves	2	4	8	L-M	Could impact on food sources for manta rays, and increased temperatures could cause temporary shifts in distribution of both prey and mantas. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in the impact of marine heatwaves on manta rays in general, and specifically in the Gulf*
Y	Tropical storms and cyclones	1	3	3	L-M	Uncertainty around impact - **more knowledge needed.** *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence in the impact of extreme rainfall events and cyclones on manta rays in general, and specifically in the Gulf*
Y	Sea level rise	1	2	2	L-M	Uncertainty around impact - **more knowledge needed.** *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence in the impact of sea level rise on manta rays in general, and specifically in the Gulf*
Value: Elasmobranchs - sawfish						
Y	Marine heatwaves	3	3	9	M	Sawfishes (Great Barrier Reef) were found to be highly vulnerable to climate change - *A Vulnerability Assessment for the Great Barrier Reef* Uncertainty around climate change impacts to WA populations. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence that marine heatwaves will increase as predicted* • *High confidence that climate change impacts sawfishes* • *Low confidence in the impact of marine heatwaves on sawfishes in the Gulf*
Y	Tropical storms and cyclones	2	3	6	M	As above *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that climate change impacts sawfishes* • *Low confidence in the impact of extreme rainfall events and cyclones on sawfishes in the Gulf*
Y	Sea level rise	1	2	2	M	Uncertainty around impact - **more knowledge needed.** Likely will not impact within 5-10 years. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that climate change impacts sawfishes* • *Low confidence in the impact of sea level rise on sawfishes in the Gulf*
Value: Elasmobranchs - sharks						
Y	Marine heatwaves	2	3	6	M	Wide ranging. Could impact prey (plankton) of whale sharks (EPBC Act - Vulnerable, Migratory). Some work at the Great Barrier Reef show epaulette sharks are being born smaller, exhausted and undernourished. Warmer temperatures may impact on migration, food availability, brain development etc. If heatwaves become a more common occurrence, then impacts may be more obvious. Scored based on likelihood within 5-10 years. **More knowledge needed** *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that marine heatwaves can impact sharks* • *Low confidence in the impact of marine heatwaves on sharks in the Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Y	Tropical storms and cyclones	1	3	3	L-M	Uncertainty around impact - **more knowledge needed.** Sharks can swim deeper to avoid surface impacts of storms. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence that extreme rainfall events and cyclones impact sharks, and specifically impacts them in the Gulf*
Y	Sea level rise	1	2	2	L-M	Uncertainty around impact - **more knowledge needed.** Likely will not impact sharks within 5-10 years. *Data confidence* • *High confidence in sea level rise predictions* • *Low confidence that sea level rise impacts sharks, and specifically impacts them in the Gulf*
Value: Marine reptiles - sea snakes						
Y	Marine heatwaves	2	3	6	L-M	Several species are EPBC conservation listed, including Critically Endangered. Research underway but not a lot known regarding climate change. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in how marine heatwaves can impact sea snakes, and what impacts those will be specifically in the Gulf*
Y	Tropical storms and cyclones	2	3	6	L-M	Research underway but not a lot known regarding climate change. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence that extreme rainfall events and cyclones can impact sea snakes, and specifically impact them in the Gulf*
Y	Sea level rise	1	2	2	L-M	Likely will not impact sharks within 5-10 years. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence in sea level rise predictions* • *Low confidence in whether sea level rise impacts sea snakes, and specifically impacts them in the Gulf*
Value: Marine reptiles - turtles *(EPBC Act - all species are Vulnerable or Endangered)*						
Y	Marine heatwaves	2	3	6	L-M	Likely impacted through changes in prey. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in how marine heatwaves will impact marine turtles, and what impacts those will be specifically in the Gulf*
Y	Tropical storms and cyclones	3	3	9	M	Winds, floods could erode suitable nesting beaches. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones can impact marine turtle nesting beaches* • *Low confidence how marine turtles and beaches will be specifically impacted in the Gulf*
Y	Sea level rise	3	2	6	M	Will cause erosion of nesting beaches. Probably not too much in the 5-10 year timeframe *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that sea level rise can impact marine turtle nesting beaches* • *Low confidence in how sea level rise will impact marine turtles in the Gulf*
Y	Air temperatures	4	2	8	H	Temperature of the nests influence what sex hatchlings will be. Warming temperatures may cause an unbalanced proportion of males and females and have severe reproductive repercussions. Temperature of nests will depend on the depth eggs are buried at. May not be realised in 5-10 year timeframe. *Data confidence* • *High confidence in air temperature predictions*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence that rising air temperatures can impact marine turtles due to temperature dependant sex determination, and how turtles will be impacted in the Gulf - see Bentley et al 2020, Stubbs and Mitchell 2018, Stubbs et al 2019*
Value: Marine mammals - whales (humpback) ***(EPBC Act - Vulnerable, Migratory, Cetacean listed species)***						
Y	Marine heatwaves	2	3	6	L-M	If occurs during the time whales are in the Gulf (Aug-Oct), then may affect whether they would use Gulf as normally would. Any impacts to mothers and calves could impact population growth that year. May be too hot for mothers and calves to stay for too long. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in how marine heatwaves will impact humpback whales, and what impacts those will be specifically in the Gulf*
Y	Tropical storms and cyclones	2	3	6	L-M	Any disturbance on mothers and calves could have reproductive impacts *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence in whether extreme rainfall events and cyclones can impact humpback whales, specifically in the Gulf*
Y	Sea level rise					Linked to melting of sea ice. This will impact Antarctic krill, the food source for humpback whales in Antarctica. Not assessed here.
Value: Marine mammals - dolphins (coastal)						
Y	Marine heatwaves	2	3	6	M	Coastal dolphins are EPBC Act listed as Cetacean and/or Migratory species. Changes in prey could have impacts, and reproductive outputs could be impacted by warm temperatures. Dolphins were impacted due to the loss of seagrass in Shark Bay following the 2011 marine heatwave. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that marine heatwaves can impact dolphins due to impacts to prey*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *Low confidence in how marine heatwaves will impact dolphins specifically in the Gulf*
Y	Tropical storms and cyclones	2	3	6	L-M	Could disturb resident populations, particularly if prey and prey habitat are disturbed or damaged. It is Unknown whether dolphins move away or die during a cyclone. Cyclones can alter the distribution of the population. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence in how extreme rainfall events and cyclones can impact dolphins and to what extent, specifically in the Gulf*
Y	Sea level rise					
Value: Marine mammals - dugongs *(EPBC Act - Migratory, Marine listed species)*						
Y	Marine heatwaves	2	4	8	M-H	Seagrass loss will directly impact dugong feeding. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that marine heatwaves can impact the food source of dugongs* • *Medium confidence in how past losses of seagrass have resulted in dugongs moving out of the Gulf - see Gales et al 2004. Losses were associated with a tropical cyclone, but losses could also occur due to a marine heatwave*
Y	Tropical storms and cyclones	2	3	6	L-M	Could disturb resident populations. It is unknown whether dugongs move away or die during a cyclone. Cyclones can alter the abundance of populations, particularly if seagrass habitat is lost. Dugongs may move out of an area until the seagrass has recovered, which has been recorded for the Gulf. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *Low confidence in how extreme rainfall events and cyclones can impact dugongs and to what extent, specifically in the Gulf*
Y	Sea level rise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
Value: Seabirds and shorebirds						
Y	Marine heatwaves	2	3	6	M	Some species are EPBC Act listed species, including Critically Endangered. Could impact reproduction and growth of birds through changes to prey density and distribution. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that marine heatwaves can impact the food source of seabirds and shorebirds* • *Low confidence in how past marine heatwaves have impacted seabirds and shorebirds in the Gulf*
Y	Tropical storms and cyclones	2	4	8	M	Can inundate shorelines and islands where birds are nesting. Could cause direct destruction of nests and populations themselves Scores would be different for migratory vs resident bird populations. Shearwaters nest on islands, among other species. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones can erode nesting beaches* • *Low confidence in how nesting beaches have been impacted in the Gulf*
Y	Sea level rise	4	2	8	M	Can inundate shorelines and islands where birds are nesting. May not occur within 5-10 year timeframe. Shearwaters nest on islands, among other species. Birdlife Australia 2020 - 'Exmouth Gulf is one of the largest embayments on Australia's west coast, providing over 200 kilometres of coast with wide intertidal flats and supratidal salt flats, mangroves and islands; it has only recently been recognised as important for shorebirds'. *Data confidence* • *High confidence in sea level rise predictions*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *High confidence that sea level rise can impact seabird and shorebird nesting beaches* • *Low confidence in how seabirds and shorebirds may be impacted in the Gulf*
Factor: Marine environmental quality						
Value: Water quality						
Y	Marine heatwaves	2	3	6	M	Water quality has been influenced by ENSO events. An examination of 25 years of satellite imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's Terra satellite shows that during La Niña there has been a reduction of water quality due to increased sediment in the water column. So, if increased sediments coincides with warmer waters, then the system will get a double hit (Paula Cartwright). *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that increased temperatures can impact water quality* • *Low confidence in how past marine heatwaves have impacted water quality in the Gulf*
Y	Tropical storms and cyclones	2	3	6	M	For Rangelands North, which includes Exmouth Gulf, increased intensity of extreme rainfall events is projected, with high confidence - Climate Change in Australia website Influxes of freshwater, sediments and nutrients will lessen water quality. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones can impact water quality* • *Low confidence in the extent to which water quality is impacted in the Gulf*
Y	Sea level rise	1	3	3	M	Erosion would result in more sediments in the water. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that sea level rise can impact water quality*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *Low confidence in how water quality will be impacted in the Gulf*
Value: Sediment quality						
Y	Marine heatwaves	1	3	3	M	Could impact on organic matter in sediments. *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *High confidence that increased temperatures can impact sediment quality* • *Low confidence in how past marine heatwaves have impacted sediment quality in the Gulf*
Y	Tropical storms and cyclones	1	3	3	M	Sediments would get stirred up and resuspended - not sure if it would impact sediment quality. May impact water quality if resuspends contaminants. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones can impact sediment quality* • *Low confidence in the extent to which sediment quality is impacted in the Gulf*
Y	Sea level rise	1	3	3	M	Erosion would result in more sediments in water. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that sea level rise can impact sediment quality* • *Low confidence in how sediment quality will be impacted in the Gulf*
Factor: Coastal processes						
Value: Geophysical processes						
N	Marine heatwaves					
Y	Tropical storms and cyclones	2	3	6	H	May cause significant shifts in coastal sediments and cause erosion and accretion at certain locations. Resilience of coral reef islands, such as the Exmouth Gulf islands, relies on the balance between the import and export of sediment

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						Data confidence • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones can cause erosion* • *High confidence in the extent to which geophysical processes will be impacted in the Gulf e.g., see Eliot et al 2011, Perry et al 2011, Brill et al 2016, Callow et al 2018, May et al 2018*
Y	Sea level rise	2	3	6	H	Will impact on coastline formations e.g., erosion. Resilience of coral reef islands, such as the Exmouth Gulf islands, relies on the balance between the import and export of sediment *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that sea level rise can impact coastline formations* • *High confidence in how geophysical processes will be impacted in the Gulf e.g., see Cuttler et al 2020, Bonesso et al 2020*
Value: Hydrodynamic processes						
N	Marine heatwaves					
Y	Tropical storms and cyclones	1	3	3	M	Would have short-term localised impacts. Not sustained. Tropical cyclones can impact salinity. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones can impact hydrodynamic processes* • *Low confidence in the extent to which hydrodynamic processes will be impacted in the Gulf*
Y	Sea level rise	2	2	4	L-M	Would likely have changes to hydrodynamics but probably not realised in 5-10 years. *Data confidence* • *High confidence in sea level rise predictions*

Score?	Drivers / Pressures	Cons	Like	Risk	Data conf HML	Justification
Climate change						
						• *Low confidence in how much sea level rise will impact hydrodynamic processes, particularly in the Gulf*
Value: Nutrient flow						
Y	Marine heatwaves	1	3	3	L-M	May impact on organic matter in water column, but perhaps not nutrient flow from land into water as much? *Data confidence* • *High confidence that marine heatwaves will increase as predicted* • *Low confidence in how marine heatwaves will impact nutrient flow, particularly in the Gulf*
Y	Tropical storms and cyclones	1	4	4	H	Flooding and run off would increase nutrient input into waters. This could have positive or negative flow on effects. *Data confidence* • *High confidence for increased intensity of extreme rainfall events and cyclones* • *High confidence that extreme rainfall events and cyclones impact nutrient flow* • *High confidence that extreme rainfall events and cyclones will impact nutrient flow in the Gulf e.g., see Lovelock et al 2011*
Y	Sea level rise	2	3	6	H	Higher sea level would likely increase flow of nutrients into the water but possibly not realised within 5-10 years. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that sea level rise will impact nutrient flow, including in the Gulf, though not specific studies have been done*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
Factor: Benthic habitats and communities						
Value: Macroalgae and turf algae						
Y	Commercial - physical trawling	1z	2	2	H	It is uncommon for macroalgae to be captured in the trawl nets. Communities are usually attached to some type of solid substrate e.g., limestone. Trawling avoids these areas and typically is over sand / mud bottom. Macroalgae recovers quickly (unlike sponge and coral). Marine Stewardship Council (MSC) - prawns DPIRD (2020): Between 2012 and 2016, very small overlap of fishing on mixed habitat assemblages. *Data confidence* • *High confidence that trawling predominantly occurs over sandy habitat*
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Seagrass						
Y	Commercial - physical trawling	1	1	1	H	Seagrass is sparse and tends to occur in shallow areas, not in deeper trawl grounds. Areas of more abundant seagrass are protected in closed prawn nursery area. DPIRD (2020) - MSC prawns: Between 2012 and 2016, less than 5% of fishing occurred on seagrass habitat. There is a suggestion there may be a high abundance of seagrass in depths <6m on high tide, where trawling occurs at depths >7m (confirmation subject to review of recent research). *Data confidence* • *High confidence that trawling predominantly occurs over sandy habitat*
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Coral						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
Y	Commercial - physical trawling	1	2	2	H	There are no obvious large coral communities abundant in the trawl grounds. Trawlers avoid these areas to avoid damage to nets. There is anecdotal evidence that 'duffing', or the removal of large objects using boats and chains, may have occurred prior to prawn trawling (Shaw 2000). DPIRD (2020) - MSC prawns: Between 2012 and 2016, only about 0.1% of fishing occurred on coral reefs. Evidence shows that the trawler fleet avoids coral to prevent damage to trawl gear. *Data confidence* • *High confidence that trawling predominantly occurs over sandy habitat*
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Sponges and filter feeders						
Y	Commercial - physical trawling	2	4	8	H	See above, likely that habitat previously modified, recovery of sponges slower and less net damage. Kangas et al. (2007) pg95: 'It is likely that the faunal assemblages, biodiversity and habitats in the trawled areas of Shark Bay, Exmouth Gulf and Onslow have changed significantly since trawling began but have now reached a new 'balance' compatible with trawling. Comparisons of biodiversity and abundance measures are difficult to make since there are no equivalent soft sediment untrawled regions similar to Shark Bay or Exmouth Gulf in Western Australia.' DPIRD (2020) - MSC prawns: Between 2012 and 2016, about 5-8% of fishing occurred on mapped filter feeder communities within the managed fishery area of Exmouth Gulf. The extent of damage to filter feeding communities depends on the frequency of trawling. Rationale for scoring likelihood could not be agreed by the participants between unlikely and possible, and the likelihood of 'possible' was recorded, subject to further review of existing data. *Data confidence* • *High confidence that trawling predominantly occurs over sandy habitat, but can overlap with filter feeding communities*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Sand and mud						
Y	Commercial - physical trawling	1	4	4	H	DPIRD (2020) - MSC prawns: Between 2012 and 2016, the majority (~72%) of fishing occurred on mapped sand habitats. Recognition of World Heritage Area boundary should be included in habitat mapping. *Data confidence* • *High confidence that trawling predominantly occurs over sandy habitat*
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Mangroves						
N	Commercial - physical trawling					NA
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Samphire						
N	Commercial - physical trawling					
N	Commercial - catch					
N	Recreational - catch					
Value: Blue green algal mats						
N	Commercial - physical trawling					
N	Commercial - catch					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
N	Recreational - catch					
Value: Reef flats and oyster beds						
Y	Commercial - physical trawling					NA Intertidal - no trawling occurs
N	Commercial - catch					NA
N	Recreational - catch					NA
Value: Salt flats						
Y	Commercial - physical trawling					NA Intertidal - no trawling occurs
N	Commercial - catch					NA
N	Recreational - catch					NA
Factor: Marine fauna						
Value: Crustaceans - prawns						
Y	Commercial - physical trawling	1	4	4	H	Of low concern. Large nursery areas are protected and closed. Trawl method uses a tickle chain (1cm diameter), designed to skim over sand and not dig into the sea floor. DPIRD (2020) - MSC prawns pg. 10 *Data confidence* • *High confidence - regular reporting by Fisheries - DPIRD*
Y	Commercial - catch	2	4	8	H	Indicator species: brown tiger, western king and blue endeavour prawns are fished within their catch range with breeding stocks above target levels. Gaughan and Santoro (2020). MSC Certification 2015., EPBC Accreditation 2015-2025. DPIRD (2020) - MSC prawns. *Data confidence* • *High confidence - regular reporting by Fisheries - DPIRD*
N	Recreational - catch					NA
Value: Crustaceans - mud crabs						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
N	Commercial - physical trawling					NA in shallower intertidal waters and mangrove habitat
N	Commercial - catch					NA- Worth noting DPIRD (2020) - MSC prawns: blue swimmer crabs *Portunus armatus* represent 0.5% of the total catch. Extensive refuge in the permanently closed nursery areas. Minimum legal size (127mm carapace length) is larger than size at maturity. DoF scored Minor Possible Risk = Low
Y	Recreational - catch	2	3	6	L	Recreational fishing likely to have increased in eastern part of gulf, of which mud crabs are the likely target. *Data confidence* • *Low confidence in catch of mud crabs by recreational fishers in Exmouth Gulf*
Value: Teleost - whiting						
Y	Commercial - physical trawling	1	1	1	H	Likely to move out of the way. May also escape through bycatch reduction devices (BRDs). *Data confidence* • *High confidence that physical trawling has minimal impact on whiting due to regular reporting by Fisheries DPIRD*
Y	Commercial - catch	1	2	2	H	DPIRD (2020) - MSC prawns. If caught in a trawl net, whiting is retained. Fishery independent survey shots recorded a Sillago spp. catch as 3.1% of total catch. Used to be commercial fisher beach seining along western edge of gulf. No longer operating. When considering bycatch from trawling, survival rates from being returned alive are a consideration. *Data confidence* • *High confidence in catch of whiting - regular reporting by Fisheries DPIRD see - Kangas and Thompson (2004)*
Y	Recreational - catch	2	3	6	L	Target whiting - don’t know catch. Recreational fishing likely to have increased in Exmouth Gulf, and whiting are a likely target. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
						• *Low confidence in catch of whiting by recreational fishers in Exmouth Gulf*
Value: Teleost - mangrove jack						
Y	Commercial - physical trawling	1	2	2	M	Habitat likely in nearshore waters. Potential impacts to juveniles? Unlikely to be major trawling impacts unless sponge gardens trawled. Same for trevally, coral trout and red emperor. Likely risk is about right - rarely captured in low numbers. *Data confidence* • *Medium confidence in the extent physical trawling impacts the habitat of mangrove jack given most trawling occurs over sandy habitats*
Y	Commercial - catch	1	2	2	H	The majority of bycatch species are not targeted by other fisheries in the region - DPIRD (2020) - MSC prawns *Data confidence* • *High confidence in catch of mangrove jack - regular reporting by Fisheries DPIRD see - Kangas and Thompson (2004)*
Y	Recreational - catch	2	3	6	L	Targeted species, increasing number of recreational fishers and fishing effort. *Data confidence* • *Low confidence in catch of mangrove jack by recreational fishers in Exmouth Gulf*
Value: Teleost - trevally						
Y	Commercial - physical trawling	1	2	2	M	Unlikely to be major trawling impacts unless sponge gardens trawled. *Data confidence* • *Medium confidence in the extent physical trawling impacts the habitat of trevally given most trawling occurs over sandy habitats*
Y	Commercial - catch	1	2	2	H	Trevally make up 0.9% of total trawl catch. The majority of bycatch species are not targeted by other fisheries in the region - DPIRD (2020) - MSC prawns. *Data confidence* • *High confidence in catch of trevally - regular reporting by Fisheries DPIRD see - Kangas and Thompson (2004), DPIRD (2020)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
Y	Recreational - catch	1/2	3	6	L	Targeted species, increasing number of recreational fishers and fishing effort *Data confidence* • *Low confidence in catch of trevally by recreational fishers in Exmouth Gulf*
Value: Teleost - coral trout						
Y	Commercial - physical trawling	1	2	2	M	Unlikely to be major trawling impacts unless sponge gardens trawled. *Data confidence* • *Medium confidence in the extent physical trawling impacts the habitat of coral trout given most trawling occurs over sandy habitats*
Y	Commercial - catch	1	2	2	H	Not caught in trawl nets, not targeted commercially. *Data confidence* • *High confidence in catch of coral trout - regular reporting by Fisheries DPIRD see - Kangas and Thompson 2004, DPIRD (2020) - MSC prawns*
Y	Recreational - catch	3	4	12	L	Targeted species, increasing number of recreational fishers and fishing effort. Small home range. Easy to spear and catch. *Data confidence* • *Low confidence in catch of coral trout by recreational fishers in Exmouth Gulf*
Value: Teleost - red emperor						
Y	Commercial - physical trawling	2	2	4	M	Unlikely to be major trawling impacts unless sponge gardens trawled. Possible impacts on juvenile red emperor which are less mobile than adults and which do recruit into the Gulf. *Data confidence* • *Medium confidence in the extent physical trawling impacts the habitat of red emperor given most trawling occurs over sandy habitats*
Y	Commercial - catch	1	2	2	H	Red emperor make up 0.4% of total trawl catch. The majority of bycatch species are not targeted by other fisheries in the region, with the exception of minor catches of demersal finfish such as emperors - DPIRD (2020) - MSC prawns. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
						• *High confidence in catch of coral trout - regular reporting by Fisheries DPIRD see - Kangas and Thompson (2004), DPIRD (2020) - MSC prawns*
Y	Recreational - catch	3	4	12	L	Targeted species, increasing number of recreational fishers and fishing effort. *Data confidence* • *Low confidence in catch of red emperor by recreational fishers in Exmouth Gulf*
Value: Teleost - tuskfish						
Y	Commercial - physical trawling	1	2	2	M	Major impacts unlikely for most species. *Data confidence* • *Medium confidence in the extent physical trawling impacts the habitat of tuskfish given most trawling occurs over sandy habitats*
Y	Commercial - catch	1	2	2	H	DPIRD (2020) - MSC prawns - red emperor make up 0.4% of total trawl catch. The majority of bycatch species are not targeted by other fisheries in the region, with the exception of minor catches of demersal finfish such as emperors. *Data confidence* • *High confidence in catch of tuskfish - regular reporting by Fisheries DPIRD see - Kangas and Thompson (2004), DPIRD (2020) - MSC prawns*
Y	Recreational - catch	3	4	12	L	Targeted species, increasing number of recreational fishers and fishing effort. Blackspot Tuskfish (*Choerodon schoenleinii*) is one of three most commonly caught fish at Nanga, Shark Bay. Tuskfish are significant contributors to sand production in the Gulf. *Data confidence* • *Low confidence in catch of red emperor by recreational fishers in Exmouth Gulf*
Value: Elasmobranchs - rays (shovel nose rays)						
N	Commercial - physical trawling					NA
Y	Commercial - catch	2	3	6	M	A significant portion of nearshore waters are closed to trawling. There is compliance with national recovery plan. Reduction in stock (very low numbers of small animals captured

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
						and released). Captured in very low numbers. Given the short duration of the trawl, post-release survival is likely to be moderate to high. *Data confidence* • *Medium confidence in catch of shovelnose rays - regular reporting by Fisheries DPIRD, though post release survival in more uncertain*
N	Recreational - catch					NA
Value: Elasmobranchs - rays (manta) ***EPBC Act - Migratory, Marine listed***						
Y	Commercial - physical trawling	1	1	1	H	Mainly north of the Gulf. More surface water feeders *Data confidence* • *High confidence that physical trawling does not significantly impact manta rays*
Y	Commercial - catch	1	1	1	H	Bycatch reduction devices in place, which free any catches of large fish. *Data confidence* • *High confidence that bycatch does not significantly impact manta rays - regular reporting by Fisheries DPIRD*
N	Recreational - catch					NA
Value: Elasmobranchs - sawfish						
N	Commercial - physical trawling					NA
Y	Commercial - catch	2	3	6	M	Statutory reporting of all endangered, threatened and protected species (ETP) species. A significant portion of nearshore waters are closed to trawling. Compliance with national recovery plan. Reduction in stock (very low numbers of small animals captured and released). Captured in very low numbers. Post-release survival is likely to be low - DPIRD (2020) - MSC prawns. *Data confidence* • *Medium confidence that bycatch does not significantly impact sawfish - regular reporting by Fisheries DPIRD, though post release survival in more uncertain*
N	Recreational - catch					NA

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
Value: Elasmobranchs - sharks						
N	Commercial - physical trawling					NA
Y	Commercial - catch	1	1	1	M	DPIRD (2020) - MSC prawns. Very low numbers of small animals captured and released. Significant portion of nearshore waters are closed to trawling. Bycatch reduction devices on trawl gear. *Data confidence* • *Medium confidence that bycatch does not significantly impact sharks - regular reporting by Fisheries DPIRD, though post release survival in more uncertain*
Y	Recreational - catch	2	3	6	L-M	Shark depredation - may be more incidental as well as targeted recreational catch. *Data confidence* • *Medium confidence in rates of depredation* • *Low confidence on catch of sharks in Exmouth Gulf*
Value: Marine reptiles - sea snakes						
Y	Commercial - physical trawling	2	3	6	L	Several species are EPBC conservation listed, including Critically Endangered. Possible that physical trawling may disturb habitat or sea snakes. Small home ranges to consider *Data confidence* • *Low confidence in the impact of trawling on sea snakes and their habitat*
Y	Commercial - catch	2	4	8	H	DPIRD (2020) - MSC prawns - Regularly captured in prawn trawl gear but majority are returned alive. Listed conservation status of short-nose sea snake is a source of public concern and is under review to relax status based on abundance and distribution. Trawl fishery observes about 25% of this species being caught in trawl gear and released. Further research in progress to determine current conservation status. Increasing public interest may occur based on public perception. Review risk if capture trends change significantly or if a public campaign eventuates to generate interest in perceived risk. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
						• *High confidence that bycatch significantly impacts sea snakes - regular reporting by Fisheries DPIRD*
Y	Recreational - catch	1	4	4	L	It is common for sea snakes to be caught incidentally by recreational fishers. *Data confidence* • *Low confidence in catch of sea snakes by recreational fishers in Exmouth Gulf*
Value: Marine reptiles - turtles *(EPBC Act - all species are Vulnerable or Endangered)*						
Y	Commercial - physical trawling	1	2	2	M	Bycatch reduction devices in all nets. Long trawl time in this fishery likely to exceed breath hold times for most turtles. *Data confidence* • *Medium confidence in the impact of trawling on marine turtles*
Y	Commercial - catch	1	2	2	M	DPIRD (2020) - MSC prawns - Low numbers mostly captured in prawn try gear, but almost all returned alive. Capture in trawl gear and returned to sea. Bycatch reduction devices in all nets. *Data confidence* • *Medium confidence in the bycatch impact on turtles - regular reporting by Fisheries DPIRD, though post release survival in more uncertain*
N	Recreational - catch					
Value: Marine mammals - whales (humpback) *(EPBC Act - Vulnerable, Migratory, Cetacean listed species)*						
Y	Commercial - physical trawling	1	1	1	H	DPIRD (2020) - MSC prawns. Potential vessel strike with cetaceans resulting in injury /fatality. Unlikely given low speed of trawl vessels and engine when underway. *Data confidence* • *High confidence in the impact of trawling on whales*
N	Commercial - catch					Fishing gear entanglement included under Tourism/Visitation
N	Recreational - catch					
Value: Marine mammals - dolphins (coastal)						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
Y	Commercial - physical trawling	1	1	1	H	Coastal dolphins are EPBC Act listed as Cetacean and/or Migratory species. DPIRD (2020) - MSC prawns - Vessel strikes unlikely because of low speed of trawl vessels and engine noise when underway. *Data confidence* • *High confidence in the impact of trawling on dolphins*
Y	Commercial - catch	1	1	1	H	DPIRD (2020) - MSC prawns - Potential injury or mortality from vessel strike unlikely because of low speed of trawl vessels and engine noise when underway. Prawn nets are small and low profile (quad nets) and close to the bottom compared to other nets and midwater trawls. *Data confidence* • *High confidence in the impact of trawling on dolphins - regular reporting by Fisheries DPIRD*
Y	Recreational - catch	1	1	1	L	Most dolphins could avoid recreational boat traffic. Entanglement in fishing gear considered under Tourism/Visitation. *Data confidence* • *Low confidence in the impact of recreational fishing on dolphins*
3Value: Marine mammals - dugongs *(EPBC Act - Migratory, Marine listed species)*						
Y	Commercial - physical trawling	1	1	1	H	DPIRD (2020) - MSC prawns - Potential injury or mortality from boat strike unlikely. Low speed of trawl vessels and noise when underway. Kathryn McMahon: Dugongs mainly in the eastern Gulf where there is a trawling exclusion zone. *Data confidence* • *High confidence in the impact of trawling on dugongs*
Y	Commercial - catch	1	1	1	H	DPIRD (2020) - MSC prawns - vessel strikes with dugongs and cetaceans. Potential injury or mortality. Low speed of trawl vessels and engine noise when underway. Prawn nets are small and low profile (quad nets) and close to the bottom compared to other nets and midwater trawls. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
						• *High confidence in the impact of trawling on dugongs - regular reporting by Fisheries DPIRD*
Y	Recreational - catch	1	1	1	L	Dugongs likely to move out of the way. Disturbance likely to be an issue. Will move and graze elsewhere. *Data confidence* • *Low confidence in the impact of recreational fishing on dolphins*
Value: Seabirds and shorebirds						
N	Commercial - physical trawling					NA
	Commercial - catch	1	2	2	H	Some species are EPBC Act listed species, including Critically Endangered. State of Fisheries reports do not list seabirds as a bycatch species. Not as common for Exmouth Gulf as for other locations e.g., south coast. Low potential for diving birds to be caught up in trawl netting. Birds are attracted to fishing vessels for a source of food. Interactions with seabirds can happen when boats are trawling, and the bird comes into contact with the wires used to drag the net along. - AFMA website. *Data confidence* • *High confidence in the impact of trawling on dugongs - regular reporting by Fisheries DPIRD*
N	Recreational - catch					NA
Factor: Marine environmental quality						
Value: Water quality						
Y	Commercial - physical trawling	1	4	4	M	DPIRD (2020) - MSC prawns - Turbidity. Deployment of benthic trawl gear from six vessels. Disturbance of sediments likely from trawling. Short-lived phenomenon. Tides and currents disperse turbidity rapidly. Strong currents and tides in Exmouth Gulf dominate potential sources of turbidity. The contribution from trawling would unlikely be measurable. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
						• *Medium confidence in the impact of trawling on water quality - gear would stir up sediments, but no specific studies done in the Gulf*
N	Commercial - catch					
N	Recreational - catch					
Value: Sediment quality						
Y	Commercial - physical trawling	1	1	1	M	Contamination associated with chains is negligible. Any oil & fuel waste likely to be surface pollution *Data confidence* • *Medium confidence in the impact of trawling on sediment quality - gear would stir up sediments, but no specific studies done in the Gulf*
N	Commercial - catch					
N	Recreational - catch					
Factor: Coastal processes						
Value: Geophysical processes						
N	Commercial - physical trawling					
N	Commercial - catch					
N	Recreational - catch					
Value: Hydrodynamic processes						
N	Commercial - physical trawling					
N	Commercial - catch					
N	Recreational - catch					
Value: Nutrient flow						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Fishing						
N	Commercial - physical trawling					NA
N	Commercial - catch					NA
N	Recreational - catch					NA

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
Factor: Benthic habitats and communities						
Value: Macroalgae and turf algae						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Bitterns would be localised. The risk would increase if bitterns discharge went unmanaged. Exmouth Gulf is already hypersaline, bitterns could add more stress. Bitterns are very dense when released but mixing of the bittern plume would happen straight away. There will be a core of influence where all values will be impacted, but probably would not translate to a population or system-wide impact. No other contaminants are introduced to bitterns. In Nickol Bay, Dampier, mangroves and seagrasses have been lost. This has been (inconclusively) related to continuous bittern discharge. The loss could also be from the ponds' saline groundwater being pushed sideways into mangroves. Modelling of the spread of bitterns was ~4-5km^2. *Assumptions: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised. Currently three proposals ~20km length. Exmouth Gulf is already hypersaline.* Depends on how it is regulated - *scoring does not consider potential controls/management.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Seagrass						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Bitterns would be localised. The risk would increase if bitterns discharge is unmanaged. *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Coral						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Bitterns would be localised. The risk would increase if bitterns discharge is unmanaged. There are many patches of corals/bommies on the east side of the Gulf and quite a bit of soft coral on east side.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						The impact of bittern discharge on corals would depend on the location of discharge, and there is enough reef on the east side to be aware of where you would place a discharge pipe. Coral will take longer to recover than algae or seagrass, so the consequences would be higher, but still considered a local impact. *Assumption: Risk score is based on the assumption that discharge is from one point and there will be diffusion. There are currently three proposals ~20km length. Assumes that the discharge location will be into the Gulf from the eastern margin.* ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Sponges and filter feeders						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Bitterns would be localised. The risk would increase if bittern discharge is unmanaged. *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Sand and mud						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Bitterns would be localised. The risk would increase if bittern discharge is unmanaged. *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Mangroves						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
Y	Mining - industrial salt production facility - footprint	2	4	8	M-H	Footprint would have an impact on hydrology, surface runoff, and subsurface water flow. Consequences for mangroves could possibly result. Mangroves live in saline condition most of the time. The likelihood of coastal squeeze in the future should be considered. Sea level rise limits the ability for mangroves to retreat landward. Total mortality of mangroves could occur within the area if coastal squeeze is realised. A small increase in sea level can lead to a large horizontal displacement. Keep 5-10 years in mind when thinking about sea level rise and squeeze. If there are many La Niña years, this would increase the water level a lot more than the mean sea level rise. Think about connectivity as well. Potential flow-on effects to fish or prawns. - *fish and prawns assessed separately* One industrial salt production facility is unlikely to lead to local extinction. *Assumption: Risk score is based on the assumption of one industrial salt production facility-20km length.* ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised. There are also proposals throughout the Pilbara area that could impact mangroves.* If there is divergence in scores, this may indicate we do not know enough - **more knowledge needed** *Data confidence* • *High confidence that coastal squeeze can impact mangroves, and salt facility is proposed adjacent to mangrove habitat* • *Medium confidence in the extent of impact on mangroves given exact footprint is not known*
Y	Mining - industrial salt production facility - bitterns discharge	2	3	6	L	In Nickol Bay, Dampier, mangroves and seagrass has been lost. This has been (inconclusively) linked to continuous bitterns discharge. It could also be from the ponds' saline groundwater being pushed sideways into mangroves. Modelling of the spread of bitterns was ~4-5km^2. In Adelaide, there has been damage to mangroves due to leakage of highly saline water.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						The impact to the composition of species depends on how much discharge there will be and where. *Assumptions: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised. Currently three proposals ~20km length. There are also proposals throughout the Pilbara area that could impact mangroves* *Data confidence* • *Medium confidence around the impact of bitterns discharge on mangroves* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Samphire						
Y	Mining - industrial salt production facility - footprint	2	4	8	M-H	Samphire might be more impacted than mangroves because salt ponds tend to be built on top of those habitats. Not just the immediate footprint to think about but the influence of other related industrial salt production facility infrastructure. *Assumption: Risk score is based on the assumption of one industrial salt production facility (20km length), one discharge point and that diffusion will occur.* ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised. There is the Wyloo Potash project also to consider.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Data confidence • *High confidence that footprint will directly impact samphire* • *Medium confidence in the extent of impact given exact footprint is not known*
N	Mining - industrial salt production facility - bitterns discharge					Samphire occurs high on the intertidal zone, so it is likely not impacted
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Blue green algal mats						
Y	Mining - industrial salt production facility - footprint	3	4	12	M-H	Algal mats could be quite severely affected by an industrial salt production facility. Algal mats migrate seaward and landward depending on the sea level e.g., during La Niña years, the mats migrate landward. When the sea level drops, they migrate seaward. The footprint of an industrial salt production facility could prevent this movement. Algal mats occupy a very narrow tidal inundation regime and are sensitive to changes e.g., sea level rise. Blue green algae are quick to grow so they can be resilient *IF* the industrial salt production facility and/or walls are removed. The Straits Salt proposal suggested a seaward wall just behind the mats assuming that the mats were static - but they are not. Eastern Gulf salt flats is one of the largest and last intact examples of salt flat ecosystems in WA (which are not well represented in conservation reserves). The area was listed in the Directory of Important Wetlands for its regionally and internationally significant mangroves (included by World Heritage Committee as grounds for recommending the inclusion of Exmouth Gulf for World Heritage listing, given ecological links with Ningaloo). *Assumption: Risk score is based on the assumption of one industrial salt production facility (20km length), one discharge point and that diffusion will occur.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Cumulative impact considerations *Consequences will increase if more than one industrial salt production facility is realised. Removal of intertidal areas like blue green algal mats and, in turn, productivity, are going to have a trophic impact on the system, including for fishes. The link with hydrodynamics and nutrient flows needs to be considered. There is the Wyloo Potash project also to consider* *Data confidence* • *High confidence that footprint will directly impact mats* • *Medium confidence in the extent of impact given exact footprint is not known*
N	Mining - industrial salt production facility - bitterns discharge					
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Reef flats and oyster beds						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Oyster beds occur in the southwest margin of the Gulf, so they may not be impacted as much by bitterns discharge. *Assumption: the bitterns discharge locations would not be in the southern end of the Gulf near oyster beds.* Significant reef flats occur around Tubridgi and near Ashburton. There is uncertainty around how bitterns would impact these reef flats, but the outfall location could avoid these reef flats.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Assumption: Risk score is based on the assumption of one industrial salt production facility (20km length), one discharge point and that diffusion will occur. ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Salt flats						
Y	Mining - industrial salt production facility - footprint	3	4	12	M-H	Salt flats are very much the footprint of an industrial salt production facility. Materials that accumulate on salt flats will not get delivered to the nearshore zone if an industrial salt production facility is in the way. Eastern Gulf salt flats is one of the largest and last intact examples of salt flat ecosystems in WA (which are not well represented in conservation reserves). This area was listed in the Directory of Important Wetlands, for its regionally and internationally significant mangroves (included by World Heritage Committee as grounds for recommending the inclusion of Exmouth Gulf for World Heritage listing, given ecological links with Ningaloo). Salt flats can look unvegetated, but they can have microbial communities growing on them. With sea level rise, mangroves and blue green algal mats can migrate over salt flats. *Assumption: Risk score is based on the assumption of one industrial salt production facility (20km length), one discharge point and that diffusion will occur.* ***Cumulative impact considerations*** *Consequences will increase if more than one industrial salt production facility is realised.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Data confidence • *High confidence that footprint will directly impact salt flats* • *Medium confidence in the extent of impact given exact footprint is not known*
N	Mining - industrial salt production facility - bitterns discharge					
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Factor: Marine fauna						
Value: Crustaceans - prawns						
N	Mining - industrial salt production facility - footprint					Check back to coastal processes as impacts to run off impacts prawn productivity.
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Magnesium chloride has an impact on invertebrates. Two main prawn species use the nursery area. The impact on them from bitterns will depend on scale - how much, how long and where. In the overall scheme of things e.g., that the extent of the nursery is large, bitterns will probably have a low and localised impact. When there is a lot of rainfall, nutrient runoff on to the flat helps to stimulate the prawn nursery. If you change the hydrology of the water coming off the land, this will have an impact on the nursery. *Assumptions: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Cumulative impact considerations *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Prawns spawn down east coast of Gulf, so the impact would depend on where the intake pipe is placed and the volume of seawater that goes into the facility. There could be possible active recruitment taken into intake pipes. Marine life can get drawn in as evidenced by intake pipes in other locations. For example, Cargill salt ponds have 50mm intake grids and have had mangroves propagules enter as well as mud crabs and fish growing inside ponds. Dampier Salt is exposed to a huge tidal range and has high volumes coming in through the intake pipe. Species do grow in ponds, but these species are occuring outside - so overall is it a minor consequence? The industrial salt production facility at Mardie can pull in the volume of the creek system in a day. *Assumption: the intake pipe would be in the Gulf along the eastern margin.* *Caveats: There are temporal and spatial scales to consider, and data confidence is low.* ***So, assume minor consequence. More knowledge needed.*** *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to prawns in the Gulf*
Y	Mining - O&G - seismic surveys	1	3	3	L-M	The prawn fishery is still productive so are seismic survey activities occuring outside of the Gulf having that much of an impact? The impact will depend on the proximity of seismic activity to prawns. Work by Rob McCauley from Curtin University looked at the impacts of seismic activity on zooplankton, which would include larval stages of species such as prawns. McCauley et al.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						(1998a and 1998b) also tested seismic activity responses of a suite of taxa, from squid to whales. *Caveat: scored on very limited knowledge.* ***More knowledge needed.*** *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)* • *Low confidence around impacts to prawns specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Crustaceans - mud crabs						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Same as above for prawns. *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same as above for prawns. *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to mud crabs in the Gulf*
Y	Mining - O&G - seismic surveys	1	3	3	L-M	Same as above for prawns. *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)* • *Low confidence around impacts to mud crabs specifically*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Teleost - whiting						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1/2	4	4-8	L	There is a lot of whiting occuring all through Exmouth Gulf. They could move away from a bitterns discharge area. **More knowledge needed** on the migratory route of whiting down the eastern side of Gulf. The discharge location could occur within their pathway. The Gulf is already a saline environment, so will bitterns discharge be outside tolerance limits of whiting? There was no knowledge of fish kills being linked to bitterns discharge, but there could be sublethal effects. The level of risk would depend on whether the habitat impacted by bitters is critical for whiting. - **more knowledge needed** It is standard practice for salt discharge to go through a diffuser. - *mitigation measures are not considered when scoring* *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. There are currently three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same reasonings as prawns and mud crabs. Any impact, if there was an impact, would be localised. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to whiting in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	The impact depends on the proximity to seismic activity. It is unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially, by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefor higher likelihood. -* ***More knowledge needed*** *Data confidence* • *High confidence that seismic surveys can impact fishes - see McCauley et al. (1998a)* • *Low confidence around impacts to whiting specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Teleost - mangrove jack						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Mangrove Jacks are more likely to occur in coastal waters adjacent to industrial salt production facility. They live in schools around mudflats and creeks. It is unlikely that discharge will occur in creeks. It is still a localised impact. *Assumption: the discharge pipe would be in the Gulf along the eastern margin, not in creeks that mangrove jacks use. Risk score is based on the assumption that discharge is from one point and diffuse. It assumes that the discharge location will be into the Gulf from*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything. ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. There are currently three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same reasons as above for whiting *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to mangrove jacks in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	The impact depends on proximity to seismic activity. It is unlikely that such mobile species could move far enough and fast enough to avoid any impacts. Essentially, by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore a higher likelihood -* ***More knowledge needed.*** *Data confidence* • *High confidence that seismic surveys can impact fishes - see McCauley et al. (1998a)* • *Low confidence around impacts to mangrove jack specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*

Value: Teleost - trevally

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Move around a lot and can avoid discharge locations. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. It assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same reasons as above for whiting *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to trevally in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Data confidence* • *High confidence that seismic surveys can impact fishes - see McCauley et al. (1998a)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *Low confidence around impacts to trevally specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Teleost - coral trout						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1/2	4	4-8	L	Some juveniles use areas around subtidal reef. Perhaps coral trout are more at risk due to their association with a particular habitat - e.g., corals/reefs. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same reasons as above for whiting *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to coral trout in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore a higher likelihood. -* ***More knowledge needed.*** *Data confidence* • *High confidence that seismic surveys can impact fishes - see McCauley et al. (1998a)* • *Low confidence around impacts to coral trout specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Teleost - red emperor						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Juveniles typically use deeper areas but may make use of macroalgal habitats like other emperors do. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same reasons as above for whiting *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to red emperor in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Data confidence* • *High confidence that seismic surveys can impact fishes - see McCauley et al. (1998a)* • *Low confidence around impacts to red emperor specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Teleost - Tuskfish						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	2	4	8	L	A lot of sediment has been found in the stomachs of tuskfish in the Gulf. They may play quite significant roles for sediment production and may be responsible for island sediments. So perhaps there is more than just a local impact to consider if bitterns discharge affects tuskfish. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Cumulative considerations: *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Same reasons as above for whiting *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to tuskfish in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. The role of tuskfish in sediment production would increase the consequence. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed.*** *Data confidence* • *High confidence that seismic surveys can impact fishes - see McCauley et al. (1998a)* • *Low confidence around impacts to tuskfish specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*

Value: Elasmobranchs - rays (shovel nose rays)

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Juveniles derive nutrients from nearshore habitats that could be affected by bitterns discharge. There is a high abundance of juveniles in the creeks. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore a higher likelihood. -* ***More knowledge needed*** *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *Low confidence around impacts to shovel nose rays specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Elasmobranchs - rays (manta) ***EPBC Act - Migratory, Marine listed***						
N	Mining - industrial salt production facility - footprint					
N	Mining - industrial salt production facility - bitterns discharge					Mantas occur more along the west and south of the Gulf. Large aggregations are seen on western coast.
N	Mining - industrial salt production facility - seawater intake					
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore a higher likelihood. -* ***More knowledge needed.*** *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)* • *Low confidence around impacts to manta rays specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
Value: Elasmobranchs - sawfish						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	2	4	8	L	Ashburton River is a pupping site in general - not just for supplying the Gulf. The river is one of the few pupping locations identified in the state. Sawfish have a spatially restricted habitat. No dedicated sawfish surveys have been carried out in the Gulf. There is uncertainty around the impacts of bitterns discharge on sawfish, but if there is any impact, it would be a higher consequence than other rays given the spatially restricted habitat. • *Caveat: Scored with low confidence in sawfish data in the Gulf. -* ***More knowledge needed*** *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge* • *Low confidence around sawfish population in the Gulf*
N	Mining - industrial salt production facility - seawater intake					Too large for grids
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore a higher likelihood. -* ***More knowledge needed*** *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)* • *Low confidence around impacts to sawfish specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Elasmobranchs - sharks						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Sharks can move out of the way of discharge locations. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					Too large for grids

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (2017) - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore a higher likelihood -* ***More knowledge needed.*** *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)* • *Low confidence around impacts to sharks specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Marine reptiles - sea snakes						
N	Mining - industrial salt production facility - footprint					Footprint - some snakes may come up to areas that may be impacted by footprint
Y	Mining - industrial salt production facility - bitterns discharge	2	3	6	L	Several species are EPBC conservation listed, including Critically Endangered. Endemic species of sea snakes, Critically Endangered short-nosed sea snake, occurs in the Gulf. The importance of this habitat (Exmouth Gulf) to this species needs to be ascertained before making a confident risk assessment. • *They may swim away from a bitterns discharge location unless the location is in a nursery area -* ***More knowledge needed*** *on nursery locations. Low confidence in data. Some prawn trawl bycatch data.* Environment Protection and Biodiversity Conservation listed species.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Some? species have small home ranges (e.g., ~100m) and are susceptible to localised impacts. Some individuals might be impacted if they occur around outflow. Small home ranges could probably justify a consequence of 2. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge* • *Low confidence around sea snake populations in the Gulf*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	Any impact, if there was an impact, would be localised. *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to sea snakes in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	L-M	Impact depends on proximity to seismic activity. Unlikely that such mobile species could move far enough and fast enough to prevent any impacts. Essentially by the time they hear it, it would be too late. The Australian Institute of Marine Science is currently doing research in this space. Different seismic activities affect different species in different ways and *Carroll et al. (20170 - A critical review of the potential impacts of marine seismic surveys on fish & invertebrates* warns about generalising when there is a lack of knowledge. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed*** *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a)* • *Low confidence around impacts to sea snakes specifically* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Marine reptiles - turtles *(EPBC Act - all species are Vulnerable or Endangered)*						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1/2	4	4-8	L	No turtle nesting sites have been identified within the Gulf, but the Gulf is used as feeding habitat during inter-nesting periods (time between egg laying). This can occur around mangrove creeks. Juvenile green turtles feed on vegetation around mangrove areas and do not move very far. Marine turtles are already threatened species. They could move away from discharge location, but there is uncertainty about any indirect effects. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L-M	The seawater intake should be slow enough for a juvenile fish to swim away, so it should be ok for juvenile sea turtles. May not need to score at all.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Data confidence • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to turtles in the Gulf*
Y	Mining - O&G - seismic surveys	2	3	6	M	'Possible ramifications for turtles include: exclusion from critical habitats, damage to hearing and entanglement in seismic survey equipment' - Nelms et al. (2016) Impact depends on proximity to seismic activity. *Caveat: Scored on very limited knowledge, therefore a higher likelihood. - **More knowledge needed*** *Data confidence* • *High confidence that seismic surveys can impact marine turtles - see McCauley et al. (1998a)* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Marine mammals - whales (humpback) *(EPBC Act - Vulnerable, Migratory, Cetacean listed species)*						
N	Mining - industrial salt production facility - footprint					
N	Mining - industrial salt production facility - bitterns discharge					
N	Mining - industrial salt production facility - seawater intake					
Y	Mining - O&G - seismic surveys	2	3	6	M	Seismic surveys in the Gulf would be "a horrible idea" due to the shallow embayment and sound propagation from any seismic activity. There have been previous seismic programs proposed well within the scope and the Federal government stepped in to stop one in particular.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Seismic activity currently occurs within and adjacent to the scope area (northern area of scope/outer Gulf) at certain times throughout the year. Jaquelin Hines - can speak more on this. Past study by *McCauley et al. (1998b)* looked at seismic impacts to humpback whales. The study area was 50 km northeast of North West Cape, Exmouth, Western Australia. Migratory species need to be considered when carrying out seismic activities. e.g., Humpbacks are in the Gulf for ~4 months of the year. If seismic activity happens on their migratory route while travelling, the whales will respond differently to if they are resting in the Gulf. The impacts to whales during resting periods would be greater. There is a need to consider the migratory route itself - they are more vulnerable if they are in a restricted migratory corridor (such as the narrow continental shelf on the west side of the cape) but they also exit the Gulf in the narrow corridor between the mainland and the Muiron Islands. If migratory species are seen, seismic activities must stop, so management actions could reduce the consequence. C*ontrols are not considered in scoring.* **More knowledge needed** What are the long-term impacts of seismic? What is the likely distance from seismic activity? *Data confidence* • *High confidence that seismic surveys can impact humpback whales - see McCauley et al. (1998b)* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Marine mammals - dolphins (coastal)						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Coastal dolphins are EPBC Act listed as Cetacean and/or Migratory species.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						There are known sites where dolphins feed on mullet and it is not known if foraging activities will be affected by localised discharge. Dolphins will follow prey, so if their prey is impacted by bitterns, then dolphins will be too. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
Y	Mining - O&G - seismic surveys	1/2	3	3-6	L-M	Hearing and vocals are the main form of communication between dolphins. Noise/seismic impacts could mask communications. It is unlikely that such a mobile species could move far enough and fast enough to avoid any impacts. Essentially, by the time they hear it, it would be too late. *Caveat: scored with uncertainty on how dolphins are using the different areas of the Gulf.* *Assumption: seismic activity is occurring close to the Gulf.* *Data confidence* • *High confidence that seismic surveys can impact cetaceans - see McCauley et al. (1998b)* • *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf* • *Low confidence around the extent dolphins are using Exmouth Gulf*

Value: Marine mammals - dugongs *(EPBC Act - Migratory, Marine listed species)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	Bitterns discharge may impact on seagrass, which is a food source for dugongs. Dugongs can move away from a discharge location. *Caveat: knowledge of local use by dugongs is low -* ***more knowledge needed.*** *They are most likely feeding but we do not know how important that is on a larger scale. There are also connectivity considerations.* *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
Y	Mining - O&G - seismic surveys	2	3	6	L-M	*Dugongs do not see well, but they can hear well. So, noise is likely to have an impact on them.* *Dugongs can relocate temporarily* *Assumption: seismic activity is occurring close to the gulf.* *Data confidence* • *High confidence that seismic surveys can impact marine life - see McCauley et al. (1998a and 1998b)* • *Low confidence around the impact to dugongs specifically*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						• *Low confidence around the seismic activities that will occur in vicinity to Exmouth Gulf*
Value: Seabirds and shorebirds						
Y	Mining - industrial salt production facility - footprint	2	3	6	M	Some species are EPBC Act listed species, including Critically Endangered. It could impact on foraging opportunities along salt flats and may impact on nearby nesting, if that is occurring? Salt flats beyond the mangroves on the eastern (and to a lesser extent southern) side of Exmouth Gulf are used extensively by shorebirds when inundated (as foraging habitat). They are vast. Salt ponds (from saltworks) have also provided alternative feeding habitats at Port Hedland and Dampier (often accessed at high tide when the natural intertidal foraging habitat is inundated). *Data confidence* • *Medium confidence that footprint will impact foraging opportunities for seabirds and shorebirds* • *Medium confidence in the extent of impact given exact footprint is not known*
Y	Mining - industrial salt production facility - bitterns discharge	2	3	6	L	More knowledge is needed. It could impact prey species and cause more energy expenditure to hunt further away. That would depend on the outflow location. If benthic invertebrates prey are impacted, then shorebirds will be affected. *Data confidence* • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
Factor: Marine environmental quality						
Value: Water quality						
N	Mining - industrial salt production facility - footprint					
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	M	Localised impact that will recover quickly *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:** Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.* *Data confidence* • *High confidence around the impact of bitterns discharge on water quality* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L	Continual removal of water and associated nutrients and salt. Uncertainty on whether this would be an issue. *Data confidence* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to water quality in the Gulf*
N	Mining - O&G - seismic surveys					
Value: Sediment quality						
Y	Mining - industrial salt production facility - footprint	1	4	4	M	Construction of an industrial salt production facility would disrupt sediments. There is likely to be some erosion of walls initially during construction. A wall would increase the mean water level. Putting a pipeline on the seabed will involve some dredging.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Satellite evidence after high storm surges show a big resuspension of sediments that are flushed out during ebb tides. Ponds may impact the level of flush off during flooding and impact nutrient flow. There could be a reduction in the transfer of intertidal sediments to the subtidal environment due to the salt pond footprint. *Data confidence* • *Medium confidence that footprint will impact sediment quality* • *Medium confidence in the extent of impact given exact footprint is not known*
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	M	Still localised. Will redissolve over time. Any stratification of layers may have a greater impact. *Data confidence* • *High confidence around the impact of bitterns discharge on sediment quality* • *Low confidence around the location of bitterns discharge*
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Factor: Coastal processes						
Value: Geophysical processes						
Y	Mining - industrial salt production facility - footprint	1	4	4	M	Localised movements may be impacted somewhat. *Data confidence* • *Medium confidence that footprint will impact geophysical processes* • *Medium confidence in the extent of impact given exact footprint is not known*
N	Mining - industrial salt production facility - bitterns discharge					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
N	Mining - industrial salt production facility - seawater intake					
N	Mining - O&G - seismic surveys					
Value: Hydrodynamic processes						
N	Mining - industrial salt production facility - footprint					Disagreement on whether this pressure should be scored for hydrodynamic processes. One viewpoint - tides flood salt flats and the footprint will impact tides. Second viewpoint - if there is a wall, this can change the habitat but not the hydrodynamics. How can an industrial salt production facility be considered localised? The DBCA Plan for our Parks proposed boundary means that Yannarie Solar Salt, or a similar project, cannot be reactivated in the same area. The northern proposed boundary of the park is yet to be confirmed is waiting for the K+S Salt proposal assessment and the boundary associated with that.
N	Mining - industrial salt production facility - bitterns discharge					
Y	Mining - industrial salt production facility - seawater intake	1	4	4	L	Localised impact. Mixing zone is in proximity of assumed intake pipe. *Data confidence* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to hydrodynamic processes*
N	Mining - O&G - seismic surveys					
Value: Nutrient flow						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
Y	Mining - industrial salt production facility - footprint	3	4	12	M	If there is a change in habitat, then there will be a change in nutrient flow. Salt flats have a lot of organic debris, which could no longer be reached by high tides at the location of the footprint. This organic debris is a food sources for inshore animals. The EPA's recommendation against the proposed Yannarie solar salt project included potential impacts on nutrient inputs and high levels of uncertainty about this, as well as commentary that there is limited capacity for management remediation of these impacts. Large events, like cyclones, in the Gulf are followed by a spike in productivity of mangrove and seagrass communities. The K+S Salt proposal encompasses ~ 15-20% of the salt marsh area and could affect the nutrient runoff that contributes to the spike in productivity. We do not have a complete understanding on sources of productivity/nutrients in the Gulf. Nutrients could come from a number of sources. Blue green algal mats are considered a major contributor. Another suggestion was the soldier crabs bioturbating the large intertidal flats every tidal cycle. Low data confidence of nutrient sources - **more knowledge needed** *Data confidence* • *High confidence that footprint will impact nutrient flow* • *Medium confidence in the extent of impact given exact footprint is not known* • *Low to medium data confidence around all sources of nutrients into the Gulf*
Y	Mining - industrial salt production facility - bitterns discharge	1	4	4	L	The composition of bitterns discharge is not changed, therefore may not impact nutrient flow highly. *Assumption: Risk score is based on the assumption that discharge is from one point and diffuse. Assumes that the discharge location will be into the Gulf from the eastern margin. Any chemicals lining the outflow pipe would be neutralised/wiped out by the concentration of the bitterns - it would kill everything.* ***Cumulative considerations:*** *Removal of intertidal areas like blue green algal mats and, in turn, productivity, are going to have a trophic impact on the system, including for fishes. The link with hydrodynamics and nutrient flows needs to be considered. Consequences will increase if more than one industrial salt production facility is realised. Currently there are three proposals ~20km length.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
Mining						
						Data confidence • *Low confidence around the impact of bitterns discharge* • *Low confidence around the location of bitterns discharge*
Y	Mining - industrial salt production facility - seawater intake	1	4	4		*Caveat: Not a lot of confidence on how intake of water will impact nutrient flow -* ***more knowledge needed*** *Data confidence* • *High confidence around marine life being drawn into intake pipes* • *Low confidence around location of intake pipe* • *Low confidence around direct impact to prawns in the Gulf*
N	Mining - O&G - seismic surveys					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Factor: Benthic habitats and communities						
Value: Macroalgae and turf algae						
Y	Shipping - port infrastructure footprint (incl channel)	2	4	8	M	Could estimate a footprint of ~10 hectares. Plus associated marine offloading facilities and hardstands, and channel ~1km out to 12.5m deep. Turn around area potentially 2km out from shore (or Gulf?) to get required depth. Is 12.5m enough depth for large vessels? Moderately large dredging operation possible. Will probably utilise natural channel. Exmouth marina was built on a pre-existing channel. It gets flooded often. Houses are raised up to avoid flooding impacts. A proposed port would probably require some raising up. Consequences are not likely to be minimal. There will be direct removal of macroalgae. The southerly flow and alongshore drift of sediments will be changed, which may impact on sediment build up and cover over nearshore algal limestone pavements. *Some overlap of knowledge/score with coastal processes.* What is the distribution of platform reefs along the western margin? Are they broken or continuous? - **More knowledge needed.** Would need to be consideration of spatial extent of habitats (~40km of limestone pavement). Forecasting done for Westport about the future of ship designs shows that ships are only going to get bigger - but this consideration may be beyond the 5-10 year timeframe. Coal terminal channels are going to be 19m deep. Allows for tidal regime and 1m below *Caveats: We do not know the final port footprint.* *Data confidence* • *Medium confidence in the extent of macroalgae along western margin of Gulf - e.g., Lyne et al. (2006), Cassata and Collins (2004); Cassata and Collins (2008); van Keulen and Langdon (2011)* • *Medium confidence around final footprint extent*
N	Shipping - vessel strike					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L	Tributyltin biocide (TBT) is no longer used for small and large vessels, which is considered an improvement. However, copper-based coatings are being used and impact of copper and contemporary contaminants is unknown. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants*
Y	Shipping - pests	2	3	6	M	Pests likely would not come from ballast water discharge, which is prohibited, but they could come from hull fouling. Shipping and ship movement in and out of Gulf already exists. No biosecurity monitoring by DPIRD is taking place. Potential for pests (including bacteria, viruses, pathogens, and fungi) to smother or consume algae. However, algae is expansive and quick to reproduce. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Assumptions: Tourist, industrial vessels and international vessels need to be considered, given the type of port and exact uses of the port are unknown. Would prefer to see only small cargo ships use a port if it were to go into Exmouth Gulf. Submarines could potentially enter the Exmouth Gulf, as well as other local, national and foreign naval vessels.* *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018). Subsea 7 Learmonth Bundle Site - Invasive Marine Species and Pathogen Desktop Risk Assessment. Report for Subsea 7 Australia Contracting Pty Ltd. Report Reference BFS1551; Version 4.0.*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how macroalgae would be impacted specifically*
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	H	The types of dredging that can produce suspended sediments include capital and maintenance dredging. Stirring up of sediments from ships should also be considered. The Gulf is a shallow body of water and thus more susceptible to resuspension of sediments. Platforms along the western Gulf that macroalgae grow on are 3-4m deep. These would be locally impacted if resuspension is continuous. Considerations: Dredging for port will be short term and near platforms. Dredging plume from ships would likely be offshore, and not around platforms? Easterly winds may blow plume inshore. Trawling for prawns results in high levels of resuspended sediments and decreases water quality along the western margin of the Gulf. Divers often will not dive at certain locations during trawling season (Apr-Dec). Suspended sediments are more significant for coral. There can be controls put in place to manage suspended sediments and how to handle dredge spoil. Less controls are needed with shipping plumes than with dredging plumes. *Scoring does not consider potential controls/management.* ***Cumulative impact considerations*** *The Gulf is already a very turbid environment - strong tides influence greater movement of sediments (2.5m tidal range). Trawling adds to turbidity. Future shipping and volume of ships could then add to this. However, ships move on high tide.* *Caveats* ***More knowledge needed** on the type of sediments in the Gulf. Need to know grain size, muddy or sandy.* *Subsea 7 should have some info here - reports mentions ‘pretty fine’ sediments.* *The dredging process generates fine sediments.*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Some discussion around whether a 3 or 4 was needed for Likelihood. Settled on 4 after considering the above caveat. *Data confidence* • *High confidence that algae occur in the area that would be exposed to suspended sediments* • *High confidence that suspended sediments can impact benthic habitats such as macroalgae beds - see WAMSI Dredging Node reports* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Seagrass						
Y	Shipping - port infrastructure footprint (incl channel)	2	4	8	L-M	There are significant patches of seagrass north and south of proposed Gascoyne Gateway port footprint on the western Gulf. If this is a smaller spatial extent compared to seagrass meadows on the east side, does that make it more important to protect? Dugongs have been observed feeding on the western margin of Gulf, around proposed Gascoyne Gateway area, and feeding scars are visible along the stretch of the western margin. *Caveats* ***More knowledge needed.*** *There is uncertainty around the species present on the western margin. Some of the seagrass species in the Gulf form permanent meadows and some ephemeral.* *Data confidence* • *Low - medium confidence in the extent of seagrass along western margin of Gulf e.g., Lyne et al. (2006)* • *Medium confidence around final footprint extent*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L	TBT biocide is no longer used for small and large vessels, which is considered an improvement. However, copper-based coatings are being used and the impact of copper and contemporary contaminants is unknown. *Caveat: scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants*
Y	Shipping - pests	2	3	6	M	Pests likely would not come from ballast water discharge, which is prohibited, but they could come from hull fouling. Shipping and ship movement in and out of Gulf already exists. No biosecurity monitoring by DPIRD is taking place. There is a potential for pests to smother or consume seagrass. Seagrass slower to recover than algae. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Assumptions: Tourist, industrial vessels and international vessels need to be considered, given the type of port and exact uses of the port are unknown. Would prefer to see only small cargo ships use a port if it were to go into Exmouth Gulf. Submarines could potentially enter the Exmouth Gulf, as well as other local, national and foreign naval vessels.* *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how seagrass would be impacted specifically*
N	Shipping - light pollution					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	H	The types of dredging that can produce suspended sediments include capital and maintenance dredging. Stirring up of sediments from ships should also be considered. The Gulf is a shallow body of water and thus more susceptible to resuspension of sediments. Seagrass occurring along western margin. These would be locally impacted if resuspension is continuous. Considerations: Dredging for port will be short term and near platforms. Dredging plume from ships would likely be offshore, and not around platforms? Easterly winds may blow plume inshore. Trawling for prawns results in a high level of resuspended sediments and decreases water quality along the western margin of the Gulf. Divers often will not dive at certain locations during trawling season (Apr-Dec). Suspended sediments are more significant for coral. There can be controls put in place to manage suspended sediments and how to handle dredge spoil. Less controls are needed with shipping plumes than with dredging plumes. *Scoring does not consider potential controls/management.* ***Cumulative impact considerations*** *The Gulf is already a very turbid environment - strong tides influence greater movement of sediments (2.5m tidal range). Trawling adds to turbidity. Future shipping and volume of ships could then add to this. However, ships move on high tide.* *Caveats* ***More knowledge needed** on the type of sediments in the Gulf i.e., grain size, muddy or sandy.* *Subsea 7 should have some info here - reports mentions 'pretty fine' sediments.* *The dredging process generates fine sediments.* There was some discussion around whether a 3 or 4 was needed for Likelihood. Settled on 4 after considering the above caveat. *Data confidence* • *High confidence that seagrass occurs in the area that would be exposed to suspended sediments*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *High confidence that suspended sediments can impact benthic habitats such as seagrasses - see WAMSI Dredging Node reports* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Coral						
Y	Shipping - port infrastructure footprint (incl channel)	2	4	8	M	Some bommies may be impacted. These are known to occur in the area of the proposed footprint (dependent on the port concept). *Data confidence* • *Medium confidence in the extent of corals along western margin of Gulf e.g., Lyne et al. (2006), Twiggs and Collins (2010)* • *Medium confidence around final footprint extent*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L	TBT is no longer used for small and large vessels, which is considered an improvement. However, copper-based coatings are being used and impact of copper and contemporary contaminants is unknown. *Caveat: scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants*
Y	Shipping - pests	2	3	6	M	Pests/diseases likely would not come from ballast water discharge, which is prohibited, but they could come from hull fouling. Shipping and ship movement in and out of Gulf already exists. No biosecurity monitoring by DPIRD is taking place.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						There is uncertainty around what pests would impact corals, though coral disease has occurred on Ningaloo Reef. Need to check whether these are introduced diseases or naturally occurring in the region. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Assumptions: Tourist, industrial vessels and international vessels need to be considered, given the type of port and exact uses of the port are unknown. Would prefer to see only small cargo ships use a port if it were to go into Exmouth Gulf. Submarines could potentially enter the Exmouth Gulf, as well as other local, national and foreign naval vessels.* *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how corals would be impacted specifically*
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	H	The types of dredging that can produce suspended sediments include capital and maintenance dredging. Stirring up of sediments from ships should also be considered. The Gulf is a shallow body of water and thus more susceptible to resuspension of sediments. Coral bommies occur along the western margin. These would be locally impacted if resuspension is continuous. Considerations: Dredging for port will be short term and near platforms. Dredging plume from ships would likely be offshore, and not around platforms? Easterly winds may blow plume inshore. Trawling for prawns results in high levels of resuspended sediments and decreases water quality along the western margin of the Gulf. Divers often will not dive at certain locations during trawling season (Apr-Dec).

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Suspended sediments are more significant for coral than seagrass or algae. There can be controls put in place to manage suspended sediments and how to handle dredge spoil. Less controls are needed with shipping plumes than with dredging plumes. *Scoring does not consider potential controls/management.* ***Cumulative impact considerations*** *The Gulf is already a very turbid environment - strong tides influence greater movement of sediments (2.5m tidal range). Trawling adds to turbidity. Future shipping and volume of ships could then add to this. However, ships move on high tide.* *Caveats* ***More knowledge needed** on the type of sediments in the Gulf i.e., grain size, muddy or sandy.* *Subsea 7 should have some info here - reports mentions 'pretty fine' sediments.* *The dredging process generates fine sediments.* Some discussion around whether a 3 or 4 was needed for Likelihood. Settled on 4 after considering the above caveat. *Data confidence* • *High confidence that coral occurs in the area that would be exposed to suspended sediments* • *High confidence that suspended sediments can impact benthic habitats such as corals - see WAMSI Dredging Node reports* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Sponges and filter feeders						
Y	Shipping - port infrastructure footprint (incl channel)	2	4	8	L-M	Likely some occurrences of sponges and filter feeders along the western margin. **More knowledge needed** about the density of occurrence *Data confidence* • *Low confidence in the extent of sponges and filter feeders along the western margin of Gulf. Most extensive area known is between North West Cape and the Muiron Islands e.g., RPS Bowman Bishaw Gorham (2004)*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around final footprint extent*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L	TBT is no longer used for small and large vessels, which is considered an improvement. However, copper-based coatings are being used and impact of copper and contemporary contaminants is unknown. *Caveat: scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants*
Y	Shipping - pests	2	3	6	M	Pests/diseases likely would not come from ballast water discharge, which is prohibited, but they could come from hull fouling. Shipping and ship movement in and out of Gulf already exists. No biosecurity monitoring by DPIRD is taking place. Uncertainty around what pests would impact sponges/ascidians. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Assumptions: Tourist, industrial vessels and international vessels need to be considered, given the type of port and exact uses of the port are unknown. Would prefer to see only small cargo ships use a port if it were to go into Exmouth Gulf. Submarines could potentially enter the Exmouth Gulf, as well as other local, national and foreign naval vessels.* *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how sponges and filter feeders would be impacted specifically - the only known pest record in the Gulf in a colonial ascidian which appears to be confined to artificial structures. Could increase competition for resources, though this report considered sea bottom sponges and filter feeders rather than communities occuring on artificial structures.*
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M	Impacted more than macroalgae and seagrass. Impacted similar to coral. As above. *Data confidence* • *Medium confidence that sponges and filter feeders occur in the area that would be exposed to suspended sediments* • *High confidence that suspended sediments can impact benthic habitats such as sponges and filter feeders - see WAMSI Dredging Node reports* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Sand and mud						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	M-H	Sediments and infauna communities will definitely be impacted by the footprint. Growth of infauna species is quicker than other marine life. Typically, widespread - prevalent. Not likely to be wiping out a small, localised patch of endemics as they will occur nearby. Sub-sediment communities would be occurring at 10-15m, where a channel could be and ships anchor. These soft sediment communities need more investigation. Unsure about their ecological importance - **More knowledge needed.** Not sure what footprint will look like. *Data confidence*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *High confidence that sand and mud communities will be disturbed as they are the most extensive habitat throughout the Gulf - e.g., BMT (2020); Lyne et al. (2006); MBS Environmental (2018)* • *Medium confidence around final footprint extent*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L	TBT is no longer used for small and large vessels, which is considered an improvement. However, copper-based coatings are being used and impact of copper and contemporary contaminants is unknown. *Caveat: scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants*
Y	Shipping - pests	2	3	6	M	Pests/diseases likely would not come from ballast water discharge, which is prohibited, but they could come from hull fouling. Shipping and ship movement in and out of Gulf already exists. No biosecurity monitoring by DPIRD is taking place. There is uncertainty around what pests would impact infauna. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Assumptions: Tourist, industrial vessels and international vessels need to be considered, given the type of port and exact uses of the port are unknown. Would prefer to see only small cargo ships use a port if it were to go into Exmouth Gulf. Submarines could potentially enter the Exmouth Gulf, as well as other local, national and foreign naval vessels.*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how sand and mud communities would be impacted specifically*
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	1/2	3	3-6	M	Infauna live in sediments, so continual resuspension will disturb communities. Same reasonings as above. *Data confidence* • *High confidence that sand and mud (and associated communities) occur in the area that would be exposed to suspended sediments* • *High confidence that suspended sediments can impact benthic habitats - see WAMSI Dredging Node reports - but low confidence in how sand and mud communities would specifically be impacted* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Mangroves						
Y	Shipping - port infrastructure footprint (incl channel)	1	3	3	M	Shipping needs to be considered for any industrial salt facility established on the eastern margin of the Gulf. *Assumption: Low barges would be needed to make transfers to a deeper water port around Serrurier Island.* If K+S Salt's Ashburton Salt proposal goes ahead, it will most likely be shipping off the northern most end of the scope area. The footprint for this would likely be less than the Gascoyne Gateway proposal and there would be less accompanying dredging activities. It is likely a cut would need to be made through the mangroves to reach the barge. Localised impact. Unsure if there will be a cut, so a 'possible'. Mangroves occurring along the western and southern margins of the Gulf are not in close proximity to the proposed Gascoyne Gateway footprint

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *High confidence that mangrove occurs along eastern margin and would be impacted by shipping infrastructure in relation to salt facility* • *Low confidence around footprint extent related to salt facilities*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	2	4	8	M	Oil and fuel spills will impact mangroves as the spill would inundate intertidal areas. Roots and stems can get smothered. Bay of Rest and Giralia Bay to Yanrey Flats are identified as Regionally Significant areas for mangroves. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence that oil and fuel spills can impact mangroves* • *Medium confidence that wetlands along eastern margin in Exmouth Gulf are at 'low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	1	3	3	M	Similar reasons as above for sand and mud. *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how mangroves would be impacted specifically*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - light pollution					
N	Shipping - suspended sediments (dredging and prop wash)					
Value: Samphire						
Y	Shipping - port infrastructure footprint (including channel)	1	3	3	L-M	Shipping needs to be considered if an industrial salt facility is established on the eastern margin of the Gulf. *Assumption: Low barges would be needed to make transfers to a deeper water port around Serrurier Island.* If K+S Salt's Ashburton Salt proposal goes ahead, it will most likely be shipping off the northern most end of the scope area. The footprint for this would likely be less than the Gascoyne Gateway proposal (less accompanying dredging activities). It is likely that a cut would need to be made through the samphire to reach the barge. Localised impact. Unsure if there will be a cut so a 'possible'. Some samphire may occur along the western margin. The Gascoyne Gateway footprint will not be over samphire. *Data confidence* • *High confidence that samphire occurs along eastern margin and would be impacted by shipping infrastructure in relation to salt facility* • *Low confidence around footprint extent related to salt facilities* • *Low confidence around the occurrence of samphire in area of proposed Gascoyne Gateway footprint, but is known to occur elsewhere along western margin*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - pollution (oil, fuel, antifoul)	1/2	4	4-8	M	Oil and fuel spills will impact samphire as the spill will inundate intertidal areas. Roots and stems can get smothered. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence that oil and fuel spills can impact samphire* • *Medium confidence that wetlands along eastern margin in Exmouth Gulf at 'low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	1	3	3	M	Similar reasons as above for sand and mud. *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how samphire would be impacted specifically*
N	Shipping - light pollution					
N	Shipping - suspended sediments (dredging and prop wash)					
Value: Blue green algal mats						
N	Shipping - port infrastructure footprint (incl channel)					Shipping infrastructure should not impact algal mats. Industrial salt facility footprint already considered and scored. N/A
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	3	3	L-M	Most spills would likely accumulate around stems of mangroves and saltmarshes and may not reach the algal mats. However, the algal mats may still get submerged depending on the tides and whether the waters were carrying an oil and fuel spill. It is unlikely that a huge spill will occur and reach the upper intertidal areas of the eastern gulf - but not impossible. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Medium confidence that oil and fuel spills can impact blue green algae mats* • *Medium confidence that wetlands along eastern margin in Exmouth Gulf at 'low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	1	2	2	L-M	There is uncertainty as to whether there would be marine and or terrestrial pests that could grow over algal mats. Algal mats are at the interface between both environments, so require marine and terrestrial pest considerations. Marine pests would need to survive the extreme environment of the intertidal zone and exposure to sun - hypersaline environment. *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of terrestrial pests that could impact mats* • *Low confidence in the types of marine pests that could impact mats*
N	Shipping - light pollution					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - suspended sediments (dredging and prop wash)					
Value: Reef flats and oyster beds						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	M	Limestone flats are present in the area of the proposed Gascoyne Gateway footprint. Oyster beds are towards south. Infrastructure would remove the physical hard structures of reefs. *Data confidence* • *High confidence that reef flats occur along western margin and in vicinity of proposed port area* • *Medium confidence around footprint extent of port facility on western margin*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	M	Oil and fuel can smother surfaces of reef flats and oyster beds *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence that oil and fuel spills can impact reef flats and oyster beds* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Similar reasons as above for sand and mud. *Data confidence*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in how reef flats and oyster beds would be impacted specifically. 'The only known pathogen documented to date in the Exmouth Gulf is an unknown species of infectious intracellular ciliate which was found in the digestive glands of cultured oysters (Pinctada maxima) in the Exmouth Gulf in 2006, and appears to have caused oyster oedema disease and severe mortality' - see Biofouling Solutions (2018)*
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M	Not really an issue for reef flats but could be a serious issue for oysters as they are filter feeders. *Data confidence* • *High confidence that reef flats occur in the in the area that would be exposed to suspended sediments* • *High confidence that suspended sediments can impact filter feeders* • *Low confidence whether dredge plumes would reach oyster stacks in the southern end* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Salt flats						
N	Shipping - port infrastructure footprint (incl channel)					N/A - as above
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	1	3	3	L-M	Most spills would likely accumulate around stems of mangroves and saltmarshes and may not reach the salt flats. However, salt flats still may get submerged depending on the tides and whether the waters were carrying oil and fuel spill. It is unlikely that a huge spill will occur and reach the upper intertidal areas of the eastern gulf - but not impossible. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Medium confidence that oil and fuel spills can impact blue green algae mats* • *Medium confidence that wetlands along eastern margin in Exmouth Gulf at 'low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	1	2	2	L-M	There is uncertainty around whether there would be marine and or terrestrial pests that could row over salt flats. Salt flats are at the interface between both environments, so have marine and terrestrial pest considerations. Marine pests would need to survive the extreme environment of the intertidal zone and exposure to sun - hypersaline environment. *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of terrestrial pests that could impact mats* • *Low confidence in the types of marine pests that could impact mats*
N	Shipping - light pollution					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - suspended sediments (dredging and prop wash)					NA
Factor: Marine fauna						
Value: Crustaceans - prawns						
Y	Shipping - port infrastructure footprint (incl channel)	1	3/4	3-4	M	A shipping channel may have some impacts, though this would just be deepening the sandy habitat that prawns inhabit. *Data confidence* • *High confidence that prawns would occur in area of port footprint* • *Medium confidence around footprint extent of port* • *Low confidence around direct impacts to prawns in the Gulf*
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Limited knowledge on noise impacts on prawns. Some shipping traffic already exists and there is still a productive prawn fishery. Cumulative impacts to consider: How much noise is too much? There is already noise to consider, let alone future noises. *Data confidence* • *Low confidence around the impact of anthropogenic noises on prawns* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Limited knowledge on noise impacts on prawns. Some shipping traffic already exists and there is still a productive prawn fishery. Cumulative impacts to consider: How much noise is too much? There is already noise to consider, let alone future noises. *Data confidence* • *Low confidence around the impact of anthropogenic noises on prawns*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L-M	Unless oil and fuel sinks to bottom, prawns may be relatively unaffected. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impact prawns* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	2/3	4-6	M-H	There is a biosecurity risk for prawns - white spot disease. There is no evidence to suggest this has come from shipping, and it is more likely the use of raw products as bait by recreational fishers could be the cause. Addressed by the Australian Quarantine and Inspection Service and bait imports. Currently, the majority of Exmouth Gulf users (industrial and recreational), are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Medium confidence in the types of marine pests and pathogens that could impact prawns*
Y	Shipping - light pollution	1	3	3	M	Prawns come out at night. There is uncertainty as to how they are impacted by light above the surface. It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor - light reaching the bottom and disturbing prawns is unlikely due to turbidity?

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts prawns*
Y	Shipping - suspended sediments (dredging and prop wash)	1	4	4	M	Prawns live and feed on soft-bottom environments, and suspended sediments may impact on foraging and other behaviours. Cumulative impacts to consider: The Gulf is already a turbid environment. *Data confidence* • *High confidence that prawns occur in the in the area that would be exposed to suspended sediments* • *Low confidence that suspended sediments can impact prawns* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Crustaceans - mud crabs						
Y	Shipping - port infrastructure footprint (incl channel)	1	3/4	3-4	M	As above for prawns. *Data confidence* • *High confidence that mud crabs would not occur in area of port footprint on western margin* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility, which would impact on mud crabs*
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	As above for prawns. *Data confidence* • *Low confidence around the impact of anthropogenic noises on mud crabs* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	As above for prawns.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *Low confidence around the impact of anthropogenic noises on mud crabs* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	1	4	4	L-M	As above for prawns. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impact mud crabs* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	2/3	4-6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Caveat: scored with limited data - **more knowledge needed.*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact mud crabs*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts mud crabs*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - suspended sediments (dredging and prop wash)	1	4	4	M	As above for prawns. *Data confidence* • *High confidence that mud crabs probably do not occur in the area that would be exposed to suspended sediments* • *Low confidence that suspended sediments can impact mud crabs* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Teleost - whiting						
N	Shipping - port infrastructure footprint (incl channel)					Not likely to influence whiting as they can move to more favourable waters. Wide ranging. N/A
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Possible effects but unknown. Whiting can move away from a noise source. *Caveat: Scored on very limited knowledge, therefore higher likelihood.* ***More knowledge needed.*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on whiting* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Possible effects but unknown. Whiting can move away from a noise source. *Caveat: Scored on very limited knowledge, therefore higher likelihood.* ***More knowledge needed.*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on whiting* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Whiting can swim away from oil spills, though they could come into contact with pollutants which could impact their gills. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Caveat: scored with no knowledge on impacts of copper-based contaminants. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to whiting* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this consequence changed to a 2. *Caveat: scored with limited data -* ***more knowledge needed.*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact fishes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts fishes*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that whiting occur in the area that would be exposed to suspended sediments*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Teleost - mangrove jack						
Y	Shipping - port infrastructure footprint (incl channel)	1	3	3	L-M	Shipping needs to be considered for any industrial salt facility established on the eastern margin of the Gulf. Uncertain whether mangrove jacks would use the western margin much, but typically mangrove, river dwelling. *Data confidence* • *Low confidence around mangrove jacks occurring in area of port footprint on western margin* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility*
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Perhaps more territorial and may not move away from noise? Mangrove jacks are found in mangroves. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on mangrove jack* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Perhaps more territorial and may not move away from noise? Mangrove jacks are found in mangroves.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Caveat: Scored on very limited knowledge, therefore higher likelihood. - ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on mangrove jack* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Mangrove jacks can swim away from spills, though they could come into contact and impact gills. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to mangrove jack* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	There is uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: scored with limited data -* ***more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact fishes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts fishes*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that mangrove jack probably do not occur in the area that would be exposed to suspended sediments - but suspended sediments could spread to mangrove areas* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Teleost - trevally						
N	Shipping - port infrastructure footprint (incl channel)					Not likely to influence trevally as they can move to more favourable waters. Wide ranging. N/A
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Possible effects but unknown. Trevally can move away from noise source. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on trevally* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Possible effects but unknown. Trevally can move away from noise source. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on trevally* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Trevally can swim away from spills, though could come into contact and impact their gills. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to trevally* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: Scored with limited data -* ***more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact fishes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts fishes*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that trevally occur in the area that would be exposed to suspended sediments* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Teleost - coral trout						
Y	Shipping - port infrastructure footprint (incl channel)	1	3	3	M	Coral trout would likely be occurring along the western margin in the vicinity of a port footprint. Benthic dwelling and infrastructure could remove some suitable habitat *Data confidence* • *Medium confidence coral trout are occurring in area of port footprint on western margin* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility*
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Perhaps more territorial and may not move away? Found around corals/reef. Would depend on proximity to seismic activity. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed***

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *Low confidence around the impact of anthropogenic noises on coral trout* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Perhaps more territorial and may not move away? Found around corals/reef. *Caveat: scored on very limited knowledge, therefore higher likelihood. - **More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on coral trout* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Can swim away from spills, though could come into contact and impact gills. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to coral trout* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: scored with limited data. - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact fishes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts fishes*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that coral trout occur in the area that would be exposed to suspended sediments* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Teleost - red emperor						
Y	Shipping - port infrastructure footprint (incl channel)	1	3	3	M	Red emperor is a demersal and reef-associated species that inhabit hard bottom areas and areas of vertical relief and/or large epibenthos. Shipping infrastructure on eastern and western margins could remove suitable habitat *Data confidence* • *Medium confidence red emperor is occurring in area of port footprint on western margin* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Possible effects but unknown. Can move away from noise source *Caveat: scored on very limited knowledge, therefore higher likelihood.* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on red emperor* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Possible effects but unknown. Can move away from noise source *Caveat: scored on very limited knowledge, therefore higher likelihood.* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on red emperor* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Can swim away from spills, though could come into contact and impact gills. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to red emperor* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: scored with limited data - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact fishes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts fishes*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that red emperor occurs in the area that would be exposed to suspended sediments* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*

Value: Teleost - Tuskfish

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - port infrastructure footprint (incl channel)	1	3	3	M	Tuskfish can be associated with a range of habitats including sand, rubble, seagrass, algae, rock and coral substrates. Shipping infrastructure on eastern and western margins could remove suitable habitat *Data confidence* • *Medium confidence tuskfish are occurring in area of port footprint on western margin* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility*
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	2	3	6	L-M	A lot of sediment has been found in the stomachs of tuskfish in the gulf. They may play quite significant roles for sediment production and may be responsible for island sediments. So perhaps more than just a local impact to consider if noise impacts tuskfish. Mobile animals can move away from the sound. Role in sediment production would increase consequence. *Caveat: scored on very limited knowledge, therefore higher likelihood.* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on tuskfish* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	2	3	6	L	As above *Data confidence* • *Low confidence around the impact of anthropogenic noises on tuskfish* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Can swim away from spills, though could come into contact and impact gills. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Caveat: Scored with no knowledge on impacts of copper-based contaminants. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to tuskfish* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: scored with limited data - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact fishes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts fishes*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that tuskfish occur in the area that would be exposed to suspended sediments*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Elasmobranchs - rays (shovelnose)						
Y	Shipping - port infrastructure footprint (incl channel)	2	3	6	L-M	Potentially impacts rays more than fish, as rays use the benthic environment for resting and feeding. A port footprint can remove available space. *Data confidence* • *Low confidence around the use of the western margin by rays* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility, which could also impact on rays*
N	Shipping - vessel strike					Not likely as bottom dwelling. N/A
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Shovelnose rays can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood - **More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on rays* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Shovelnose rays can move away from noise. The role the rays play in sediment production would increase consequence. *Caveat: Scored on very limited knowledge, therefore higher likelihood - **More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on rays*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	2	4	L-M	Shovelnose rays can swim away from spills. As they are bottom dwelling, it is less likely for their gills to come into contact with oil/fuel. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to rays* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases and parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk- based on this consequence changed to a 2. *Caveat: Scored with limited data - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact rays*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts rays*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *Low confidence that shovel nose rays occur in the area that would be exposed to suspended sediments, though suspended sediments could spread* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Elasmobranchs - rays (manta) ***EPBC Act - Migratory, Marine listed***						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	M-H	Manta rays exist in the water column, they are not bottom dwelling. The proposed port may remove a small area that would otherwise we available for feeding. *Data confidence* • *High confidence around the use of the western margin by rays - see Irvine & Salgado-Kent (2019), Jenner and Jenner (2005), Hodgson (2007)* • *Medium confidence around footprint extent of port on western margin*
Y	Shipping - vessel strike	1	2	2	L	Vessel strike is possible as mantas occur in the water column and on the surface. However, ships would be moving slowly. Vessel strike would be more of an issue for recreational boats - SEE TOURISM *Data confidence* • *Low confidence around the incidence of ship strike on manta rays in the Gulf*
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Mantas can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on rays* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Mantas can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood. - **More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on rays* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Mantas can swim away from spills, though contact is possible which could impact their gills. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to rays* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: Scored with limited data. - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact rays*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts rays*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *High confidence that manta rays occur in the area that would be exposed to suspended sediments - see Irvine & Salgado-Kent (2019), Jenner and Jenner (2005), Hodgson (2007)* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Elasmobranchs - sawfish						
Y	Shipping - port infrastructure footprint (incl channel)	2	3	6	L-M	Potentially impacts rays more than fish, as rays use the benthic environment for resting and feeding. A port footprint could remove available space. *Data confidence* • *Low confidence around the use of the western margin by sawfish* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of some infrastructure on eastern margin in relation to salt facility, which could also impact on sawfish*
Y	Shipping - vessel strike	1	2	2	L	Sawfish are mainly bottom dwelling, but there is some possibility of vessel strike. It is more of an issue for recreational boats - SEE TOURISM *Data confidence* • *Low confidence around the incidence of ship strike on sawfish in the Gulf*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Sawfish can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on sawfish* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Sawfish can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on sawfish* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	2	4	L-M	Sawfish can swim away from spills. They are bottom dwelling and less likely to come into contact with oil/fuel. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to sawfish* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: Scored with limited data -* ***more knowledge needed.***

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact sawfish*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts sawfish*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *Low confidence that sawfish occur in the area that would be exposed to suspended sediments, though suspended sediments could spread* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Elasmobranchs - sharks						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	M	Sharks use the water column. The proposed port area might remove a small area that would otherwise be available for feeding. *Data confidence* • *Medium confidence around the use of the western margin by sharks (whale sharks do not usually occur, but other sharks likely would)* • *Medium confidence around footprint extent of port on western margin*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - vessel strike	1/2	3	3-6	L	Sharks inhabit the water column and can come to the surface. However, ships are moving slowly. However, whale sharks (EPBC Act - Vulnerable, Migratory) move slowly, are less agile than other sharks and are more likely to be at the surface. Vessel strike could be more of an issue for recreational boats? - SEE TOURISM *Data confidence* • *Low confidence around the incidence of ship strike on sharks in the Gulf*
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Sharks can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on sharks* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Sharks can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on sharks* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Sharks can swim away from spills, though contact is possible which could impact their gills. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to sharks*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: Scored with limited data - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact sharks*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development* • *Low confidence around how light pollution impacts sharks*
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M	Fine sediments can irritate gills and affect the respiratory system. *Data confidence* • *Medium confidence that sharks occur in the area that would be exposed to suspended sediments, though suspended sediments could spread* • *Medium confidence that suspended sediments can impact fishes e.g., Partridge, G.J., and Michael, R.J. (2010) Direct and indirect effects of simulated calcareous dredge material on eggs and larvae of pink snapper Pagrus auratus. J Fish Biol 77(1), 227-40.*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the exact port footprint and extent of dredging*
Value: Marine reptiles - sea snakes						
Y	Shipping - port infrastructure footprint (incl channel)	2	3	6	M	Several species are EPBC conservation listed, including Critically Endangered. Some species have a small home range, and the port may impact on this home range. It might also remove some foraging area. A small home range suggests a higher consequence. *Data confidence* • *Medium confidence around the use of the western margin by sea snakes (based on catch in trawl nets)* • *Medium confidence around footprint extent of port on western margin*
Y	Shipping - vessel strike	1/2	2	2-4	L	Strikes could relate more to entanglement in propellors? There is uncertainty around the occurrence of snakes and vessel strikes. This is more of an issue for recreational boats - SEE TOURISM *Caveat: Scored with very limited data - **more knowledge needed*** *Data confidence* • *Low confidence around the incidence of ship strike on sea snakes in the Gulf*
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Sea snakes can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood - **More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on sea snakes* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Sea snakes can move away from noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood - **More knowledge needed*** *Data confidence*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Low confidence around the impact of anthropogenic noises on sea snakes* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	L-M	Sea snakes can swim away from spills, though contact is possible which, as air breathers, could impact their respiratory system. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impacts to sea snakes* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	Uncertainty around diseases, parasites. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Caveat: Scored with limited data - **more knowledge needed*** *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)* • *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact sea snakes*
Y	Shipping - light pollution	1	3	3	M	It is expected the Gascoyne Gateway proposal would produce a lot of light. Light interacting with turbidity is a factor i.e., less light reaching through the water column. *Data confidence* • *High confidence that light pollution will increase with port development*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Low confidence around how light pollution impacts sea snakes*
Y	Shipping - suspended sediments (dredging and prop wash)	1	4	4	M	Fine sediments could irritate snakes in some way, but not gills as in fish. *Data confidence* • *Medium confidence that sea snakes occur in the area (based on capture in trawl nets) that would be exposed to suspended sediments, though suspended sediments could spread* • *Low confidence that suspended sediments can impact sea snakes* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Marine reptiles - turtles *(EPBC Act - all species are Vulnerable or Endangered)*						
Y	Shipping - port infrastructure footprint (incl channel)	2	3	6	M-H	Turtles do not nest within the proposed Gascoyne Gateway footprint. However, there is evidence of use of the Qualing Pool area for foraging/mating etc. *Data confidence* • *High confidence around the use of the western margin by turtles - see Irvine & Salgado-Kent (2019), Jenner and Jenner (2005), Hodgson (2007)* • *Medium confidence around footprint extent of port on western margin*
Y	Shipping - vessel strike	1	3	3	L	Vessel strike can occur as turtles come to the surface to breath. However, large vessels move slowly. Vessel strike is more of an issue for recreational boats. - SEE TOURISM *Data confidence* • *Low confidence around the incidence of ship strike on turtles in the Gulf*
Y	Shipping - noise pollution (vessel)	1	3	3	L-M	Turtles can move away from noise. Nelms et al. 2016 mentions that it is possible there can be damage to hearing from seismic activity, so perhaps there is some disturbance also caused from vessel noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood - **More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on turtles*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	3	L	Turtles can move away from noise. Nelms et al. (2016) mentions that it is possible there can be damage to hearing from seismic, so perhaps there is also some disturbance caused from vessel noise. *Caveat: Scored on very limited knowledge, therefore higher likelihood. -* ***More knowledge needed*** *Data confidence* • *Low confidence around the impact of anthropogenic noises on turtles* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	3	6	M	Turtles can swim away from spills, though contact is possible which, as air breathers, could impact their respiratory system. Turtles can get coated in oil causing skin irritation and suffocation. There is uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Caveat: Scored with no knowledge on impacts of copper-based contaminants.* *Data confidence* • *Low confidence around the impact of copper-based contaminants* *Med confidence around oil and fuel spills impacts to turtles* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
Y	Shipping - pests	2	3	6	M	There is uncertainty around diseases and parasites for turtles. Tumour disease occurs in Shark Bay. There are also some naturally occurring diseases. Currently, the majority of Exmouth Gulf users (industrial and recreational) are from domestic waters. A port targeting international ships would change the risk - based on this, consequence changed to a 2. *Data confidence* • *High confidence that vessels entering Exmouth Gulf increase the risk of introduced marine pests - see Biofouling Solutions (2018)*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the types of vessels entering the Gulf if a port was developed* • *Low confidence in the types of marine pests that could impact turtles*
Y	Shipping - light pollution	3	4	12	H	Light pollution poses a major impact on turtle hatchlings. The proposed Gascoyne Gateway infrastructure would have lighting and markers in the water, but greater impacts are likely from the lights on land as hatchlings will be attracted landward, whereas lights out in water on port infrastructure would at least lead hatchlings out to the water. Light pollution could also lead to increased predation of turtle hatchlings. Light pollution may also disorient females returning to their nesting beach. *Data confidence* • *High confidence that light pollution will increase with port development* • *High confidence around how light pollution impacts marine turtles*
Y	Shipping - suspended sediments (dredging and prop wash)	1	4	4	M	Fine sediments could irritate turtles in some way, but not gills as in fish *Data confidence* • *High confidence that turtles occur in the area that would be exposed to suspended sediments* • *Low confidence that suspended sediments can impact turtles* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Marine mammals - whales (humpback) ***(EPBC Act - Vulnerable, Migratory, Cetacean listed species)***						

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - port infrastructure footprint (incl channel)	1/2	3/4	3-8	H	Port infrastructure would have a lower impact on humpbacks compared to shipping and underwater noise. However, the footprint of the proposed Gascoyne Gateway port is in humpback whale waters. Humpback whales occur throughout most of the Gulf, and many will use shallow waters, particularly the 10m depth contour (mainly the central-western side of the Gulf), for migrating out of the Gulf. There is the potential for whale contact if vessels are moored and moving around this contour. The highest density area of whales overlaps with the preferred industry anchoring sites. More vessels/infrastructure will impact on the space available for nursing females and their calves. Killer whales will cause humpbacks to hug the coastline to avoid predation. Other considerations: Is it a small spatial area when you are thinking about the entire stock of Humpback whales? Not all stock enters Exmouth on their southern migration, but large numbers do. It is an important resting area. Marine mammals are protected through other legislation. Exmouth region has now been designated as an Important Marine Mammal Area (IMMA) - although it remains to be seen if this does/changes anything. The IMMA acknowledges that this is an important area for cetaceans. The Gulf is a resting and nursing habitat, and neonate humpback whales can use the Gulf as well. Note: the calving ground located on the west side of Ningaloo Reef increases the chances of very young whales in the vicinity. *Data confidence* • *High confidence around the use of the western margin by humpback whales - see Irvine & Salgado-Kent (2019), Jenner and Jenner (2005), Hodgson (2007)* • *Medium confidence around footprint extent of port on western margin, however given the area humpbacks use, it would overlap with port placement anywhere along the western margin*
Y	Shipping - vessel strike	2	3/4	6-8	M	Vessel strike is a bigger issue than the port/dredge channel footprint. Increased shipping is likely to increase the risk/number of strikes. A new port would increase the shipping

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						movement into the Gulf, and potentially deeper into the Gulf. Shipping movement at night would increase the risk of strike due to lower chance of visuals on whales. Humpback whale mothers can rest just below the surface, or on the surface, and are hard to see, which increases their chances of vessel strike. Calves can surface randomly in front of boats. During the peak whale season, the risk increases. South of the proposed GG footprint is an important resting area, so a lot of attention is required by vessels in that area. Anecdotally, there are ship strikes on humpback whales. There is uncertainty around the responsibility of vessel skippers to report strikes, although there are small boat/humpback whale strike signs at the boat ramps around Exmouth. You do not generally see a dead whale and they do not all die from boat strikes. Around 20% of whale sharks (EPBC Act - Vulnerable, Migratory) have boat scars. There is a higher chance of ship strike in the southern end of Gulf as it is a high density area for whales to rest on the surface and just below the surface e.g., 3-5m depth. *Data confidence* • *High confidence around cetaceans and ships strikes* • *Low confidence around the incidence of ship strike on whales in the Gulf*
Y	Shipping - noise pollution (vessel)	3	4	12	M-H	Louder vessels will disturb whales and they will swim away. The Gulf is a shallow water environment, which makes it noisier. More vessels mean more noise, and more disturbance, such as short-term behavioural responses. Communication is very quiet/silent between mothers and calves, so increased shipping/noise can mask these communications. The use of dynamic positioning in lieu of anchoring also needs to be considered. There is a study in the Gulf showing humpbacks avoid ships on dynamic positioning. Whales use hearing as their primary sense. If noise disturbs important behaviours, like nursing and resting, then there may be an impact on reproductive output, which in turn will have population level impacts (as mothers cannot replenish their energy stores lost due to disturbance from humans). Noise travels five-times faster in water than in air, so underwater noise is important to consider. *Cumulative impact of noises is a consideration*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Ambient noise is relatively high already as it is a shallow embayment - snapping shrimp and wave action contribute to this. *Increased noise may jeopardise the Gulf as a resting area.* *Ships currently operate in the Gulf but an increasing in shipping activity, would increase the risk to humpback whales.* *Data confidence to consider -* ***more knowledge needed*** *on noise impacts to whales.* *Data confidence* • *High confidence that vessel noise can impact humpbacks in general - e.g., Dunlop RA. 2019 The effects of vessel noise on the communication network of humpback whales. R. Soc. open sci. 6: 190967. http://dx.doi.org/10.1098/rsos.190967* • *Medium confidence around the impact of anthropogenic noises on humpback whales in the Gulf - see Sprogis et al. (2020)* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	2	2/3	4-6	L-M	Noise from pile driving and dredging is spatially and temporarily constrained. However, the noise is loud and acute. Noise travels five-times faster in water than in air. If these activities and noise occurred during whale season, the noise would impact the behaviour of whales. However, this would not be an ongoing disturbance. It is suggested that if one breeding season was missed due to construction disturbance in the Gulf, this would not have an impact on population. However, if dredging of potential shipping lanes and mooring stations was to occur (e.g., to allow for large ships), then the noise would disturb whales in the vicinity - **more knowledge needed here.** There would be a recommendation that these activities do not happen during whale season at all. Whales arrive in the Gulf in late August and leave between the end of October and early November, depending on the timing of the migration that year. The peak whale season is around mid-end September. Juvenile whales arrive first, then competitive breeding adults, and lastly mother-calf pairs. There are controls that exist to mitigate the risk to whales. If these were in place, the consequence would be lower. *Control measures not considered in scoring.* *Data confidence*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the impact of anthropogenic noises on humpback whales in the Gulf - see Sprogis et al. (2020)* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	2	2	4	M-H	Probably small and localised if no major oil spills occur. If a large oil spill/pollution occurs during the breeding season, then this will have a larger impact on the whales. *Data confidence* • *High confidence around oil and fuel spills impacts to whales if they are resting in the Gulf* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
N	Shipping - pests					NA
N	Shipping - light pollution					NA
N	Shipping - suspended sediments (dredging and prop wash)					NA
Value: Marine mammals - dolphins (coastal)						
Y	Shipping - port infrastructure footprint (incl channel)	3	3	9	M	Coastal dolphins are EPBC Act listed as Cetacean and/or Migratory species. Construction will remove benthic habitat used by Indo-Pacific bottlenose dolphins, and Australian humpback dolphins. These two species frequent Exmouth Gulf, using shallow, coastal waters. The different habitat types, of reef, seagrass and sand/mud are likely to be important feeding habitats for the dolphins. Australian humpback dolphins are listed as Vulnerable, and Indo-Pacific bottlenose dolphins are listed as Near Threatened on the International Union Conservation Nature Red List. Australian snubfin dolphins are also sighted in the Gulf, but mostly in the southern and eastern portion. Australian snubfin dolphins are listed as Vulnerable. No dedicated boat-based surveys have been conducted on dolphins south of Exmouth Marina, thus there is no data on habitat use and abundance of the different species of dolphins in Exmouth Gulf.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *Medium confidence around the use of the western margin by different dolphin species* • *Medium confidence around footprint extent of port on western margin*
Y	Shipping - vessel strike	2	2	4	M	Ship strike on dolphins does occur, but more so from fast moving vessels like jet skis and small recreational vessels. Dolphins have more time to move away from larger slower moving vessels. If a dolphin is hit by a boat or jet ski, then death can occur, or large wounds can occur that heal. This risk is higher for larger, slower moving whales like humpback whales (especially as they rest on and near the surface), and slower moving dugongs. SEE TOURISM for scoring of recreational boats *Data confidence* • *High confidence around cetaceans and ships strikes* • *Low confidence around the incidence of ship strike on dolphins in the Gulf*
Y	Shipping - noise pollution (vessel)	3	3	9	M-H	Underwater noise from vessels disturbs cetaceans in general, as this is their primary sensory modality. They use sound for communication, finding prey and sensing predators. Thus, the more noise pollution the more chance there is for masking of communication whistles and foraging echolocation. Shipping is generally a low frequency noise but does have high level transients which dolphins can hear. The noise from shipping is more in the auditory range of baleen whales; however, it can still affect dolphins. For example, masking of whistles between mother and calves can, for example, mean that the calf is separated from its mother which leaves it vulnerable to predation from sharks and/or humans (boat strike) etc. Thus, managing underwater noise levels in a shallow water embayment is important as resident dolphins will decline in abundance if there is too much pressure on the system. This has been shown in Shark Bay, when there were two whale-watch vessels, the number of bottlenose dolphins declined from that area. It has also occurred in Fjords in New Zealand, when the dolphins leave the area because there is too much boat noise in the Fjords. It needs to be managed correctly, for these resident, shallow water dolphins. *Data confidence*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *High confidence around the impact of anthropogenic noises on dolphins, though no specific studies in Exmouth Gulf* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	2	3	6	M	Coastal dolphins are resident to an area and have restricted home ranges. If construction occurs in an area, then particular individuals will be impacted where the noise and construction occur. Dolphins cannot necessarily just leave an area. They reside in a range, and some dolphins have small ranges (i.e., 20km^2). These individuals are sensitive to disturbance. Dolphins are also sensitive to construction and underwater noise, depending on the time of the year e.g., the breeding or calving season. Construction is recommended to only take place outside of calving season. This is a seasonal trend across around three months. The peak dolphin birthing time in Exmouth Gulf is unknown, however it is suspected to occur over Spring-Summer. Generally, when construction occurs, a Marine Mammal Observer is required to ensure construction is not taking place when dolphins come within a certain distance. - *control measures are not considered in the score* *Data confidence* • *High confidence around the impact of anthropogenic noises on dolphins, though no specific studies in Exmouth Gulf* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	3	2	6	M	If there is a big oil spill (e.g., the 2010 Deep Water Horizon oil spill event in the Gulf of Mexico), then a range of problems will occur, including respiratory illnesses from inhaling oil on the surface of the water. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence around oil and fuel spill impacts to dolphins* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - pests					NA
N	Shipping - light pollution					NA
Y	Shipping - suspended sediments (dredging and prop wash)	1	1	1	M	Exmouth Gulf is already a highly turbid environment. However, some dolphins may specialise on certain prey, e.g., fish that live in the seagrass. Thus, if the seagrass is affected by sediment and that has an impact on the fish, then dolphins with a specialised diet will be affected. However, the diet of the dolphins in Exmouth Gulf is unknown and it can only be inferred from other similar locations where diet isotope studies have been done. *Data confidence* • *Medium confidence that dolphins occur in the area that would be exposed to suspended sediments* • *Low confidence that suspended sediments can impact dolphins* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Marine mammals - dugongs ***(EPBC Act - Migratory, Marine listed species)***						
Y	Shipping - port infrastructure footprint (incl channel)	2	4	8	M-H	Dugongs use the Gulf year-round and can occur throughout the Gulf. They also migrate, so the population can fluctuate. There are seagrass beds along the western margin - which does not look to be shown in benthic habitat maps for Gascoyne Gateway proposal. Dugongs consume seagrass, so there may be some impacts on dugongs, but it may not impact whole population. There is evidence of dugong feeding trails along the western margin, including in the area of the port proposal footprint. This is considered a 'prime' area for dugongs. Mother and calves are also seen close to shore along the western margin. A few population surveys have been done using aerial surveys, which shows a high concentration of dugongs in the eastern Gulf. Their general distribution in the Gulf is known based off coarse surveys. A fine-scale monitoring program is needed to understand dugong uses of the Gulf. *Data confidence*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *High confidence around the use of the western margin by dugongs, see Irvine & Salgado-Kent (2019), Jenner and Jenner (2005), Hodgson (2007)* • *Medium confidence around footprint extent of port on western margin*
Y	Shipping - vessel strike	1	4	4	M	Dugongs are sometimes hit by large vessels, but it is rare, because the large ships are slow moving and the dugongs have more time to respond and swim away. As soon as a mother is hit, they are separated from their calf. In Moreton Bay, there is a higher strike risk due to more vessels. There has been a significant decline in the dugong population, which is attributed to boat strikes. The impact of vessel strikes does vary between locations. New Caledonia has high vessel activity, but dugongs remain there. This is not the case in Moreton Bay and there is evidence of learned behaviour from boats and hunting. Dugongs may move away, at least temporarily, and there is evidence of this. They will come back when the noise is gone. Anecdotally, necropsies show that dugongs appear to be hit by small vessels, like jet skis. Is it just boat strike - or also boating activity frightening them? Cumulative impacts to consider: more vessels increases the risk. *Data confidence* • *High confidence around dugongs and ships strikes* • *Low confidence around the incidence of ship strike on dugongs in the Gulf*
Y	Shipping - noise pollution (vessel)	2	4	8	L-M	Dugongs do not see well, but they can hear well. So, noise is likely to have an impact on them. Dugongs can relocate temporarily. Dugong behaviour and distribution patterns can change in response to vessel noise and movements (i.e., their natural behaviours are altered). *Data confidence* • *Low confidence around the impact of anthropogenic noises on dugongs* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - noise pollution (pile driving & dredging)	1	4	4	L	In New Caledonia, dugongs showed shifts in local populations during dredging, but they came back after the work. Given the scale, it is probably a minor consequence. *Data confidence* • *Low confidence around the impact of anthropogenic noises on dugongs* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	3	2	6	M	Indirect pollution - If there is pollution that affects seagrass then it can be ingested by dugongs. Dugong respiration should be a consideration, as it is for dolphins. If there are oil slicks, and if the dugongs are residents, then they may breathe in air that is contaminated causing respiratory problems. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence around oil and fuel spill impacts to dugongs* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
N	Shipping - pests					N/A
N	Shipping - light pollution					N/A
N	Shipping - suspended sediments (dredging and prop wash)					Suspended sediments will affect dugongs if the seagrass is impacted. Dugongs only feed on seagrass thus rely on it. Effects to seagrass have been considered above.
Value: Seabirds and shorebirds						
Y	Shipping - port infrastructure footprint (incl channel)	2	3	6	M	Some species are EPBC Act listed species, including Critically Endangered. Existing or future habitat for nesting could be removed. Nesting locations can be unpredictable, and in the face of rising sea levels, there needs to be as much suitable nesting habitat available as possible. Exmouth Gulf mangroves are listed as an Important Bird Area for migratory shorebirds - Dutson et al. (2009)

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Data confidence • *Low - Medium confidence around the use of the western margin by seabirds and shorebirds* • *Medium confidence around footprint extent of port on western margin* • *High confidence that shipping infrastructure on the eastern margin relating to salt facility would impact on the recognised Important Bird Area* • *Low confidence around possibility of shipping infrastructure on eastern margin*
N	Shipping - vessel strike					
Y	Shipping - noise pollution (vessel)	1	4	4	L-M	Noise may mask communications between birds on land. Underwater, they may largely rely on vision to find prey. *Data confidence* • *Low confidence around the impact of anthropogenic noises on seabirds and shorebirds* • *Medium confidence around the types of vessels that will be using the gulf in relation to port development, and the noise they will emit*
Y	Shipping - noise pollution (pile driving & dredging)	1	3	4	L	Noise may mask communications between birds on land. Underwater, they may largely rely on vision to find prey. *Data confidence* • *Low confidence around the impact of anthropogenic noises on seabirds and shorebirds* • *Low confidence around the frequency of pile driving and dredging activity*
Y	Shipping - pollution (oil, fuel, antifoul)	3	3	9	M	Shorebirds and seabirds are vulnerable to oil spills and fuel slicks because they use surface waters and nest on shorelines. The risks would likely be the same for migratory and resident bird populations, though the impacts would be different (i.e., could affect nesting habitat for residents, whereas non-nesting birds will have roost and foraging habitat impacted). *Data confidence* • *Low confidence around the impact of copper-based contaminants*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *High confidence around oil and fuel spill impacts to seabirds and shorebirds* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
N	Shipping - pests					
N	Shipping - light pollution	3	3	9	H	Light pollution could interrupt the birds' natural light cycles and have flow-on effects for population biology. The impact of light disorientation is well known for seabirds - *see National Light Pollution Guidelines for Wildlife* - "lights can disorient flying birds, particularly during migration, and cause them to divert from efficient migratory routes or collide with infrastructure". Birds may starve when artificial lighting disrupts foraging, and fledgling seabirds may not be able to take their first flight if their nesting habitat never becomes dark. Migratory shorebirds may use less preferable roosting sites to avoid lights and may be exposed to increased predation where lighting makes them visible at night." Lighting, alongside oil pollution, is the most significant known threat to shorebirds/seabirds from shipping. *Data confidence* • *High confidence that light pollution will increase with port development* • *High confidence around how light pollution impacts seabirds and shorebirds*
N	Shipping - suspended sediments (dredging and prop wash)	2	3	6	M	Effectiveness at catching prey may be affected if birds are fishing in turbid waters. *Data confidence* • *High confidence that seabirds would use the area that would be exposed to suspended sediments* • *Low confidence that suspended sediments can impact seabirds* • *Medium confidence around the exact port footprint and extent of dredging*
Factor: Marine environmental quality						
Value: Water quality						

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	M	Assuming that the port is an open port, the water quality is probably not a big issue, though Gascoyne Gateway Limited mentioned plans to rezone the entire Exmouth Gulf as a 'port'. How will this impact on the water quality currently assigned to Exmouth Gulf? Are there any water quality issues in the existing marina, given marinas generally have water quality issues? Anchoring and dynamic positioning occurs all through the Gulf, e.g., with service vessels. Offshore platform supply vessels (120m) are a common fixture in the Gulf at certain times of the year, anchored around the 10-15m isobar. *Data confidence* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of shipping infrastructure on eastern margin* • *High confidence that ports can reduce water quality in general* • *Low confidence in how water quality will be impacted in the Gulf*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	2/3	3	6-9	M	Nearby oil spill response equipment does not guarantee containment. Antifoulants and contaminants from the washing of ship decks would enter the water column. Exmouth marina is closed and therefore easier to contain an oil spill. Whereas the proposed Gascoyne Gateway port would be open, so pollutants could spread across Gulf. Marine offshore facilities in deeper water are also a consideration. Big storm events flush out the marina. If porous materials are under the marina/port, then water circulation is less inhibited. The marina has been built on an old waste tip.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Four trawlers were turned over during a flood in Exmouth marina. Contaminants could get pushed out into Gulf this way. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence around oil and fuel spill impacts to water quality* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
N	Shipping - pests					
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	2	4	8	M-H	Dredging and ship movements could continually resuspend contaminants into the water column, which will cause increased turbidity. Cumulative impacts to consider: It is already a turbid environment. *Data confidence* • *High confidence that water quality is impacted by suspended sediments* • *Medium confidence around the exact port footprint and extent of dredging*
Value: Sediment quality						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	M	Construction may leach chemicals into sediments. This would have an initial disturbance to sediments. Infrastructure could restrict some water flow which could prevent turnover and flushing of sediments. *Data confidence* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of shipping infrastructure on eastern margin* • *High confidence that ports can reduce sediment quality in general* • *Low confidence in how sediment quality will be impacted in the Gulf*
N	Shipping - vessel strike					

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
Y	Shipping - pollution (oil, fuel, antifoul)	2/3	3	6-9	M	The concentration of vessels in a small area could cause a build-up of chemicals and contaminants in sediments. Sediments can then be distributed across the Gulf from winds and storms etc. *Comment: "it is not helpful to include risks from shipping due to antifoul and minor refuelling spillages into the same category as potentially major accidents resulting from shipwrecks (e.g., large amounts of bunker oil). The possibility of even larger spills from production accidents, pipeline issues etc. is not even mentioned. The consequences of these two types of pressures/drivers are not in the same end of the spectrum. Consequently, it is difficult to provide meaningful assessments for the various taxonomic groups."* We understand this is a valid point, but separate assessments were not done due to time constraints. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence around oil and fuel spill impacts to sediment quality* • *Medium confidence around much of Exmouth Gulf being rated as 'very low to low risk' to oil spills - see Navigatus Consulting (2018). Medium because oil spill exposure and risk was modelled for the Pilbara region, not specifically the Gulf*
N	Shipping - pests					
N	Shipping - light pollution					
Y	Shipping - suspended sediments (dredging and prop wash)	1	4	4	M-H	Dredging and ship movements could continually resuspend contaminants into the water column. These activities could continually change and/or interrupt sediment composition. Probably not a significant impact. *Data confidence* • *High confidence that sediment quality is impacted by suspended sediments*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Medium confidence around the exact port footprint and extent of dredging*
Factor: Coastal processes						
Value: Geophysical processes						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	L-M	If a marine offshore facility happens, then there will be localised coastal change to the adjacent shoreline. *Data confidence* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of shipping infrastructure on eastern margin* • *Low confidence in how geophysical processes will be impacted in the Gulf*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
N	Shipping - pollution (oil, fuel, antifoul)					
N	Shipping - pests					
N	Shipping - light pollution					
N	Shipping - suspended sediments (dredging and prop wash)					
Value: Hydrodynamic processes						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	L-M	If the Gascoyne Gateway port is a floating platform, then the impact to hydrodynamic processes is likely to be minimal. If it is not a floating platform, and there was a 1km long structure, then the flow would go around it. Some sediment build up could be expected, as the port footprint will be on sandy beaches.

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						Generally southward travelling sediments in the Gulf - the tide out is strong. *Data confidence* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of shipping infrastructure on eastern margin* • *Low confidence in how geophysical processes will be impacted in the Gulf*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
N	Shipping - pollution (oil, fuel, antifoul)					
N	Shipping - pests					
N	Shipping - light pollution					
N	Shipping - suspended sediments (dredging and prop wash)					
Value: Nutrient flow						
Y	Shipping - port infrastructure footprint (incl channel)	1	4	4	L-M	May be localised impacts to nutrient flows. If a marine offshore facility is built, how much guano build-up will occur, and how much would this influence nutrients? A low barge transfer to a ship loader is a possibility for an industrial salt facility. A jetty jutting out could potentially impact on some of the nutrient flow. *Data confidence* • *Medium confidence around footprint extent of port on western margin* • *Low confidence around possibility of shipping infrastructure on eastern margin*

Score?	Drivers / Pressures	Cons.	Like.	Risk	Data conf HML	Justification
Shipping						
						• *Low confidence in how nutrient flow will be impacted in the Gulf*
N	Shipping - vessel strike					
N	Shipping - noise pollution (vessel)					
N	Shipping - noise pollution (pile driving & dredging)					
N	Shipping - pollution (oil, fuel, antifoul)					
N	Shipping - pests					
N	Shipping - light pollution					
N	Shipping - suspended sediments (dredging and prop wash)					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Factor: Benthic habitats and communities						
Value: Macroalgae and turf algae						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Some damage is possible from trampling and anchor damage. Algae grows relatively quickly so it could be likely to recover easily. *Data confidence* • *High confidence that anchors can damage algae beds* • *Low confidence around the extent of damage to algae in Exmouth Gulf* • *Medium confidence around the full extent of algal beds in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	The impacts and likelihood of an oil and fuel spill from recreational vessels is probably low. Potentially there are some considerations around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L	Rubbish can smother and prevent the growth of algae if lodged. Entanglements of fishing gear are sometimes hard to remove from algae clumps and may impact on fauna of not removed. Community underwater clean-ups occur semi-regularly. *Data confidence* • *Low confidence around the extent of rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting algae in the Gulf*
Value: Seagrass						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Some damage is possible from trampling and anchor damage. Continual disturbance may prevent regrowth. Seagrass grows slower than algae. *Data confidence* • *High confidence that anchors can damage seagrass beds* • *Low confidence around the extent of damage to seagrass in Exmouth Gulf* • *Medium confidence around the full extent of seagrass beds in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially there are some considerations around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L	Rubbish can smother and block light for photosynthesis if lodged. Entanglements of fishing gear are sometimes hard to remove from clumps and may impact on fauna of not removed. Community underwater clean-ups occur semi-regularly. *Data confidence* • *Low confidence around the extent of rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting seagrass in the Gulf*
Value: Coral						
N	Disturbance - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Y	Disturbance - damage (anchoring/diving)	2	3	6	M	Some damage is possible from trampling/fin kicks and anchor damage. Bundegi is advertised as a snorkelling spot so would expect people to be swimming near/over coral. Some corals grow faster than others. Increased tourism and water use would increase the risk of damage. *Data confidence* • *High confidence that anchors and diving can damage corals* • *Low confidence around the extent of damage to corals in Exmouth Gulf* • *Medium confidence around the full extent of corals in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially there are some considerations around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L-M	Rubbish can smother and block light for photosynthesis if lodged. Entanglements of fishing gear are sometimes hard to remove and may impact on fauna of not removed. Community underwater clean-ups occur semi-regularly. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting coral in the Gulf*
Value: Sponges and filter feeders						
N	Disturbance - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Some damage possible from trampling and anchor damage. *Data confidence* • *High confidence that anchors and diving can damage sponges and filter feeders* • *Low confidence around the extent of damage to sponges and filter feeders in Exmouth Gulf* • *Medium confidence around the full extent of sponges and filter feeders in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L-M	Rubbish can smother and block water flow if lodged. Entanglements of fishing gear are sometimes hard to remove from clumps and may impact on fauna of not removed. Community underwater clean-ups occur semi-regularly. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting sponges and filter feeders in the Gulf*
Value: Sand and mud						
N	Disturbance - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
N	Disturbance - damage (anchoring/diving)					NA
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
N	Pollution - rubbish					NA
Value: Mangroves						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Damage may occur to mangrove roots from trampling. 4WD tracks? Increased tourism could increase the risk if tourists and use of areas are not properly regulated. *Data confidence* • *High confidence that mangroves can be directly damaged from human activity such as trampling and 4WD* • *Low confidence around the extent of damage to mangroves in Exmouth Gulf, and if it is even occurring* • *High confidence around the full extent of mangroves in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Data confidence • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L	Rubbish could smother pneumatophores. Community clean-ups occur semi-regularly *Data confidence* • *Low confidence around the extent of rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting mangroves in the Gulf*
Value: Samphire						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Damage may occur to shrubs from trampling. 4WD tracks? Increased tourism could increase risk if tourists and use of areas are not properly regulated. *Data confidence* • *High confidence that samphire can be directly damaged from human activity such as trampling and 4WD* • *Low confidence around the extent of damage to samphire in Exmouth Gulf, and if it is even occurring* • *Medium confidence around the full extent of samphire in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L	Rubbish could smother plants are prevent photosynthesis. Community clean-ups occur semi-regularly *Data confidence* • *Low confidence around the extent of rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting samphire in the Gulf*
Value: Blue green algal mats						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Damage may occur to algal mats from trampling. 4WD tracks? Increased tourism could increase risk if tourists and use of areas are not properly regulated. *Data confidence* • *High confidence that mats can be directly damaged from human activity such as trampling and 4WD* • *Low confidence around the extent of damage to mats in Exmouth Gulf, and if it is even occurring* • *High confidence around the full extent of mats in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
N	Pollution - rubbish					N/A
Value: Reef flats and oyster beds						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Damage may occur to oyster beds from trampling. Increased tourism could increase risk if tourists and use of areas are not properly regulated. *Data confidence* • *High confidence that anchors and trampling can damage reef flats and oyster beds* • *Low confidence around the extent of damage in Exmouth Gulf* • *Medium confidence around the full extent of reef flats in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	1	2	2	L	Rubbish can smother and block filter feeding of oysters if lodged. Entanglements of fishing gear are sometimes hard to remove from clumps and may impact on fauna of not removed. Community underwater clean-ups occur semi-regularly. *Data confidence* • *Low confidence around the extent of rubbish in the Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around the extent to which rubbish is impacting reef flats and oyster beds in the Gulf*
Value: Salt flats						
N	Disturbance - noise					
Y	Disturbance - damage (anchoring/diving)	1	4	4	M	Damage may occur to flats from trampling. 4WD tracks? Increased tourism could increase risk if tourists and use of areas are not properly regulated. *Data confidence* • *High confidence that salt flats can be directly damaged from human activity such as trampling and 4WD* • *Low confidence around the extent of damage to salt flats in Exmouth Gulf, and if it is even occurring* • *High confidence around the full extent of salt flats in Exmouth Gulf*
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around impacts of copper-based contaminants* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
N	Pollution - rubbish					N/A
Factor: Marine fauna						
Value: Crustaceans - prawns						
Y	Disturbance - noise	1	3	3	L-M	Limited knowledge on noise impacts

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Still productive prawn fishery - is it having that much of an impact? Cumulative impacts to consider in terms of how much noise is too much. *Data confidence* • *Low confidence around the impact of anthropogenic noises on prawns* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impact prawns* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Breakdown products of rubbish (e.g., microplastics) could make their way into sediments and accumulate in prawns. Evidence elsewhere of microplastics being ingested by smaller invertebrates such as coral polyps and zooplankton. Researchers are still understanding the impact of microplastics on marine life at all scales. Microplastic fibres occur in beach samples 4-5 pieces per 25g samples. Microplastics <5mm are present in surface waters of Exmouth Gulf. Would expect microplastic pollution to increase over time - local sources and oceanographic influences need to be considered. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting prawns in the Gulf*
Value: Crustaceans - mud crabs						
Y	Disturbance - noise	1	3	3	L-M	Limited knowledge on noise impacts. Cumulative impacts to consider in terms of how much noise is too much. *Data confidence* • *Low confidence around the impact of anthropogenic noises on mud crabs* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	1	4	4	L	Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Potentially some consideration around the use of copper-based antifoul - similar to shipping relating vessels. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spills impact mud crabs* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting mud crabs in the Gulf*
Value: Teleost - whiting						
Y	Disturbance - noise	1	3	3	L-M	Possible effects but unknown. Can move away from noise source. *Data confidence* • *Low confidence around the impact of anthropogenic noises on whiting* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to fishes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting fishes in the Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Value: Teleost - mangrove jack						
Y	Disturbance - noise	1	3	3	L-M	Possible effects but unknown. Can move away from noise source. *Data confidence* • *Low confidence around the impact of anthropogenic noises on mangrove jack* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to fishes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting fishes in the Gulf*
Value: Teleost - trevally						
Y	Disturbance - noise	1	3	3	L-M	Possible effects but unknown. Can move away from noise source.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Data confidence • *Low confidence around the impact of anthropogenic noises on trevally* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to fishes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting fishes in the Gulf*
Value: Teleost - coral trout						
Y	Disturbance - noise	1	3	3	L-M	Possible effects but unknown. Can move away from noise source. *Data confidence* • *Low confidence around the impact of anthropogenic noises on coral trout*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to fishes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting fishes in the Gulf*
Value: Teleost - red emperor						
Y	Disturbance - noise	1	3	3	L-M	Possible effects but unknown. Can move away from noise source. *Data confidence* • *Low confidence around the impact of anthropogenic noises on red emperor* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminants. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to fishes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting fishes in the Gulf*
Value: Teleost - tuskfish						
Y	Disturbance - noise	1	3	3	L-M	Possible effects but unknown. Can move away from noise source. *Data confidence* • *Low confidence around the impact of anthropogenic noises on tuskfish* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving)					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to fishes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting fishes in the Gulf*
Value: Elasmobranchs - rays (shovelnose)						
Y	Disturbance - noise	1	3	3	L-M	Mobile animals - can move. Do not know what the impacts would be - **more knowledge needed**, therefore higher likelihood. *Data confidence* • *Low confidence around the impact of anthropogenic noises on rays* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving) - incl. vessel strikes					Bottom dwelling may not be an issue?

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to rays* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Similar as for prawns. Fishing gear entanglement a consideration as well. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low confidence around the extent to which rubbish is impacting rays in the Gulf*
Value: Elasmobranchs - rays (manta) ***EPBC Act - Migratory, Marine listed***						
Y	Disturbance - noise	2	3	6	L-M	Manta rays are disturbed by tourism - this is the case for mantas off Coral Bay (Venables et al. 2016). Whether the driver of disturbance is noise is unknown. Manta rays occur in the Gulf almost year-round, with occurrences higher between August - November. There is potential for disturbance to the manta rays from tourism, ship strike, jet ski harassment etc. Recreational and tourism vessels are more of a concern than shipping vessels as manta rays are actively targeted and there are no proximity or duration rules/limits as there are for whales/whale sharks etc. Would expect an increase in recreational vessels and tourism over time. Do not know what the impacts would be - **more knowledge needed**, therefore higher likelihood. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around the impact of anthropogenic noises on rays* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (anchoring/diving) - incl. vessel strikes	2	3	6	M-H	Fast moving vessels can strike mantas using the surface waters. Increased recreational vessels in the Gulf increases the risk of strike. *Data confidence* • *High confidence that vessels strike manta rays* • *Medium confidence around the frequency of vessel strikes in the gulf- see McGregor et al. (2020)* • *Medium confidence around the volume of recreational vessels using the gulf*
Y	Pollution - oil/fuel	2	2	4	L	Minimal, however if there are oil or fuel slicks when the mantas are feeding then they will also ingest this fuel. Potential to impact/irritate gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminants. Contaminants can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to rays* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	3	3	9	L-M	Manta rays are filter feeders and feed in the tide lines. There are huge tide lines that occur along the 5-10m depth contour off the Exmouth Marina and north along the coast to Bundegi. The manta rays feed in these tide lines, especially from August. The manta rays arrive in the Gulf at this time in large numbers. As they are feeding, they will take in plastics and rubbish that is floating on and near the surface as they barrel roll and skim feed. Any rubbish in the ocean is no good for filter feeders like manta rays and whale sharks (EPBC Act - Vulnerable, Migratory).

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Researchers are still understanding the impact of microplastics on marine life at all scales. Microplastic fibres occur in beach samples 4-5 pieces per 25g samples. Microplastics <5mm are present in surface waters of Exmouth Gulf and occur where manta rays feed. Would expect microplastic pollution to increase over time - local sources and oceanographic influences need to be considered. Fishing gear entanglement a consideration as well. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish in the Gulf* • *Low to Medium confidence around the extent to which rubbish is impacting manta rays in the Gulf - see King (2019)*
Value: Elasmobranchs - sawfish						
Y	Disturbance - noise	1	3	3	L-M	Mobile animals - can move. Do not know what the impacts would be - **more knowledge needed**, therefor higher likelihood. *Data confidence* • *Low confidence around the impact of anthropogenic noises on sawfish* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
N	Disturbance - damage (anchoring/diving) - incl. vessel strikes					Bottom dwelling may not be an issue?
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Data confidence • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to sawfish* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Breakdown products of rubbish (e.g., microplastics) occur in the water column and accumulate in animals. Evidence elsewhere of microplastics being ingested by smaller invertebrates such as coral polyps and zooplankton through to mobile vertebrates. Researchers are still understanding the impact of microplastics on marine life at all scales. Microplastic fibres occur in beach samples 4-5 pieces per 25g samples. Microplastics <5mm are present in surface waters of Exmouth Gulf. Would expect microplastic pollution to increase over time - local sources and oceanographic influences need to be considered. Fishing gear entanglement a consideration as well. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting sawfish in the Gulf*
Value: Elasmobranchs - sharks						
Y	Disturbance - noise	2	2	4	L-M	Sharks can be disturbed by vessels approaching them and when swimmers are placed in the water- this is the case for whale sharks (EPBC Act - Vulnerable, Migratory) (Raudino et al. 2016). Whether the driver of the disturbance is noise is yet to be determined.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Sharks are not that heavily targeted in Exmouth Gulf due to the high turbidity and fewer whale sharks compared to the Ningaloo Reef. This is the same for tiger sharks, that are targeted off Coral Bay and not in Exmouth Gulf due to the turbidity. Recreational and tourism vessels are more of a concern than shipping vessels for sharks other than whale sharks as can be actively targeted and there are no proximity or duration rules/limits as there are for whales/whale sharks etc. *Data confidence* • *Low confidence around the impact of anthropogenic noises on whiting* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (anchoring/diving) - incl. vessel strikes	2	3	6	M	Fast moving vessels can strike whale sharks. Increased recreational vessels in the Gulf increases the risk of strike. *Data confidence* • *High confidence that vessels have hit whale sharks in the Ningaloo area - see recent incident May 2021* • *Low confidence around the frequency of vessel strikes* • *Medium confidence around the volume of recreational vessels using the gulf*
Y	Pollution - oil/fuel	2	1	2	L	Minimal- unless a filter feeder like whale sharks. However, there are minimal whale sharks in the Gulf compared to Ningaloo Reef side. Can swim away from spills, though could come into contact and impact gills. Impacts and likelihood of oil and fuel spill from recreational vessels is probably low. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to sharks*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	3	2	6	L-M	Higher risk to filter feeding whale sharks than non-filter feeders. However, there are minimal whale sharks in the Gulf compared to Ningaloo Reef side. Breakdown products of rubbish (e.g., microplastics) occur in the water column and accumulate in animals. Evidence elsewhere of microplastics being ingested by smaller invertebrates such as coral polyps and zooplankton through to mobile vertebrates. Researchers are still understanding the impact of microplastics on marine life at all scales. Microplastic fibres occur in beach samples 4-5 pieces per 25g samples. Microplastics <5mm are present in surface waters of Exmouth Gulf. Would expect microplastic pollution to increase over time - local sources and oceanographic influences need to be considered. Fishing gear entanglement a consideration as well. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting sharks in the Gulf*
Value: Marine reptiles - sea snakes						
Y	Disturbance - noise	1	3	3	L-M	Several species are EPBC conservation listed, including Critically Endangered. Mobile animals - can move. Do not know what the impacts would be - **more knowledge needed**, therefor higher likelihood. *Data confidence* • *Low confidence around the impact of anthropogenic noises on sea snakes*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (anchoring/diving) - incl. vessel strikes	1	4	4	L-M	Fast moving vessels can strike snakes, or snakes may get tangled in propellors. Increased recreational vessels in the Gulf increases the risk of strike. *Data confidence* • *Low confidence around the frequency of vessel strikes in the gulf* • *Medium confidence around the volume of recreational vessels using the gulf*
Y	Pollution - oil/fuel	2	2	4	L	Can swim away from spills, though could come into contact and impact respiratory as air breathers. Spills from recreational vessels unlikely. Uncertainty around copper-based contaminates. Contaminants can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Low confidence around oil and fuel spill impacts to sea snakes* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	3	6	L-M	Breakdown products of rubbish (e.g., microplastics) occur in the water column and accumulate in animals. Evidence elsewhere of microplastics being ingested by smaller invertebrates such as coral polyps and zooplankton through to mobile vertebrates. Researchers are still understanding the impact of microplastics on marine life at all scales. Microplastic fibres occur in beach samples 4-5 pieces per 25g samples. Microplastics <5mm are present in surface waters of Exmouth Gulf. Would expect microplastic pollution to increase over time - local sources and oceanographic influences need to be considered. Fishing gear entanglement a consideration as well. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting sea snakes in the Gulf*
Value: Marine reptiles - turtles ***(EPBC Act - all species are Vulnerable or Endangered)***						
Y	Disturbance - noise	2	3	6	L-M	Turtles come to breed and nest around the North West Cape. There are turtles in Exmouth Gulf and when nesting on the beaches people can disturb the breeding mothers coming up the beach to lay their eggs. Mating turtles in the shallows can be disturbed by vessels, jet skis, and people. Whether the driver of disturbance is noise needs to be determined. Turtles are present in the Gulf year-round, but different species may be occurring at different times of the year. Observations of greens and hawksbill turtles arriving in the Gulf around August have been made, when the water increases in temperature. Recreational and tourism vessels are more of a concern than shipping vessels for turtles as they can be actively targeted and there are no proximity or duration rules/limits as there are for whales/whale sharks etc. Can expect tourism and vessel use to increase. *Data confidence* • *Low confidence around the impact of anthropogenic noises on turtles* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (anchoring/diving) - incl. vessel strikes	2	3	6	L-M	Fast moving vessels can strike turtles. Increased recreational vessels, including greater incidence of jet ski use, in the Gulf increases the risk of strike. *Data confidence* • *Low confidence around the frequency of vessel strikes in the gulf* • *Medium confidence around the volume of recreational vessels using the gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Y	Pollution - oil/fuel	2	2	4	L-M	Can swim away from spills, though could come into contact and impact respiratory as air breathers. Spills from rec vessels unlikely. Uncertainty around copper-based contaminates. Contaminates can bioaccumulate in higher order consumers. *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *Medium confidence around oil and fuel spill impacts to turtles* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	3	2/3	6-9	L-M	Plastic bags and look like floating jellyfish etc. and thus turtles ingest the plastics and rubbish. Turtles can't digest the rubbish and they become 'floaters', preventing them from diving to feed and causing death from starvation. Floaters are more easily predated upon by tiger sharks or are more easily hit by vessels and jet skis, which can also cause death or their shells to crack. Fishing gear entanglement a consideration as well. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting turtles in the Gulf*
Value: Marine mammals - whales (humpback) ***(EPBC Act - Vulnerable, Migratory, Cetacean listed species)***						
Y	Disturbance - noise	2	4	8	M	Humpback whales are targeted for the whale-watching industry- which is focused on the north western side of the Gulf. Tours are done for several hours for sunset tours. Whales in this area range from juvenile, adults and mother-calves. They are all targeted to 100 m distance which is the Australian National Guidelines. At 100 m if the vessel is a quiet vessel underwater, then the whales may not be disturbed. However, if the vessel is loud (e.g., over 160dB re 1 µpa source level) then the whales will be disturbed and will swim away. Operators are to adhere to the Australian National Whale-Watching Guidelines in regard to approach angles, distance and speed. There are however currently no guidelines on the

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						limits of vessel noise, and this research has been conducted in Exmouth Gulf on humpback whales (Sprogis et al. 2020b). There is also the swim-with-humpback whale industry which began in the Ningaloo Marine Park in 2016 and occurs in the northwestern portion of the Gulf when the water is clearer. The vessels target whales up to 75m and place swimmers in the water (noise source closer to whales). Some vessels will do an in-path approach by moving in front of the whales and place swimmers in the water in the hope that the whales swim under the swimmers, however this is an invasive approach and causes behavioural disturbance to the whales. This approach is known globally and not recommended. Also, mother and calves are swum-with, which is also not best practice. These older calves may only be 3-4 months old. This is not best-practice, and behavioural responses have been published off the Ningaloo Marine Park (Sprogis et al. 2020a). At this stage, the swim-with industry is likely more invasive than whale-watching due to the in-path approaches allowed (which places the noise source in front of the whales), the closer distances allowed to approach whales (noise is more abrupt at closer distances), and that calves are still allowed to be swum with (mother-calves are the most sensitive to disturbance). *Data confidence* • *Medium confidence around the impact of anthropogenic noises on humpback whales in the Gulf - see Sprogis et al. (2020)* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (e.g., anchoring/diving) - incl. vessel strikes and harassment	2/3	3	6-9	M	Gulls have been shown to change the behaviour of resting humpback whales in the Gulf. Off Argentina, gulls have had a significant negative impact on humpback whales as the rubbish tip is close to the coastline. Gulls tear off skin and blubber from the backs of the whales and disturb both mothers and calves. This harassment has happened over decades and behaviours and physiology of the whales has been altered permanently due to the gull. There is concern this could start to happen in the Gulf if not managed well. Anecdotal evidence that there has been an explosion of silver gull numbers in Exmouth over the past 10 years.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Fast moving vessels can strike resting whales in the Gulf. However, this is likely not reported. *Data confidence* • *High confidence that vessel strikes do occur in the gulf* • *Low confidence around the frequency of vessel strikes in the gulf* • *Medium confidence around the volume of recreational vessels using the gulf* • *Medium confidence around the disturbance to whales from gulls*
N	Pollution - oil/fuel					N/A
Y	Pollution - rubbish	1	2	2	L	Entanglement in fishing gear can be an issue for humpback whales. Unsure about the extent of gear in the Gulf that would lead to this. *Data confidence* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting whales in the Gulf*
Value: Marine mammals - dolphins (coastal)						
Y	Disturbance - noise	2	3	6	M-H	Coastal dolphins are EPBC Act listed as Cetacean and/or Migratory species. There is limited tourism with dolphins in Exmouth Gulf. The tours generally target humpback whales and see dolphins as a bonus. There is an eco-tour which incorporates dolphins, but it does not focus on them. Generally, the Australian humpback dolphins are shyer than the Indo-Pacific bottlenose dolphins, and the humpback dolphins will swim away from any approaching vessels. The bottlenose dolphins may bow ride but can move away from the area unless being harassed. Recreational users such as jet skis and water skiing have fast and unpredictable movements of which this noise disturbance can change the natural behaviour of the dolphins i.e., moving away. *Data confidence* • *High confidence around the impact of anthropogenic noises on dolphins, though no specific studies in Exmouth Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (anchoring/diving) - incl. vessel strikes	2	3	6	L-M	Fast moving vessels can strike dolphins. Increased recreational vessels in the Gulf increases the risk of strike. *Data confidence* • *Low confidence that vessel strikes do occur in the gulf* • *Low confidence around the frequency of vessel strikes in the gulf* • *Medium confidence around the volume of recreational vessels using the gulf*
N	Pollution - oil/fuel					N/A
Y	Pollution - rubbish	2	2	4	L-M	Bioaccumulation of microplastics may occur through ingestion of prey, but likely less of a risk that direct feeding by filter feeders and turtles. Entanglement in marine debris (e.g., discarded fishing line) is also an issue. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting dolphins in the Gulf*
Value: Marine mammals - dugongs ***(EPBC Act - Migratory, Marine listed species)***						
Y	Disturbance - noise	2	3	6	L-M	There is an eco-tour company in the Gulf, however it does not target dugongs. There are dugongs around Bundegi and the Navy Pier where the Eco-tour transits, however the vessel is generally slow moving and the dugongs would not be highly disturbed. This is not the case for jet skis. There would be high disturbance from the harassment and noise from jet skis. Also, water skiing activities occur in the region e.g., along Town Beach. Possibly an operator with a license to use underwater scooters. Uncertainty on the license restrictions around this but this should not be allowed to occur around animals. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *Low confidence around the impact of anthropogenic noises on dugongs* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*
Y	Disturbance - damage (e.g., anchoring/diving - includes vessel strikes	2	3	6	L-M	Usually happens with small high-speed boats and jet skis - As dugongs need time to pinpoint the noise source and react, and if it is shallow water, then there is a high chance of being hit by fast moving vessels. *Data confidence* • *Low confidence around the frequency of vessel strikes in the gulf* • *Medium confidence around the volume of recreational vessels using the gulf*
N	Pollution - oil/fuel					N/A
Y	Pollution - rubbish	2	1	2	L-M	Less likely that bioaccumulation would occur as microplastics do not attach to seagrass leave, but some ingestion of contaminated sediments may occur? *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting dugongs in the Gulf*
Value: Seabirds and shorebirds						
Y	Disturbance - noise	2	3	6	L-M	Some species are EPBC Act listed species, including Critically Endangered. Could disturb foraging birds and nesting activities on land *Data confidence* • *Low confidence around the impact of anthropogenic noises on seabirds and shorebirds* • *Medium confidence around the volume of recreational vessels using the gulf and the noise they emit*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Y	Disturbance - damage (anchoring/diving) - incl. vessel strikes and 4WD	3	4	12	L	More likely to get hit by fast moving recreational vessels than slow moving ships, though the risk and consequence at a population level would be very low. Disturbance here also includes potential impacts by 4WD to nesting and roosting seabirds and shorebirds, both through nest destruction and disturbance causing energy expenditure and potentially abandoning sites. If this can capture seabirds and shorebirds, suggest the consequence is increased to 3, making the overall risk 12. Trampling on islands (seabird nests and burrows and physical disturbance) and pets (i.e., dogs) are also greatest disturbance risks. *Data confidence* • *Low confidence around the frequency of vessel strikes in the gulf* • *Medium confidence around the volume of recreational vessels using the gulf* • *Low confidence around the disturbance to seabirds and shorebirds from 4WDs* • *Low confidence around the disturbance to seabirds and shorebirds from people and dogs*
Y	Pollution - oil/fuel	2	3	6	M	Are vulnerable to oil spills and fuel slicks due to use of surface waters and shorelines *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence around oil and fuel spill impacts to seabirds and shorebirds* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	3	3	9	L-M	Can get tangled in rubbish and fishing line. May ingest plastics and feed to young. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf* • *Low confidence around the extent to which rubbish is impacting seabirds and shorebirds in the Gulf*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Factor: Marine environmental quality						
Value: Water quality						
N	Disturbance - noise					
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L-M	Spills from recreational/tourism vessels less likely. Antifoulants entering into water column *Data confidence* • *Low confidence around the impact of copper-based contaminants* • *High confidence around oil and fuel spill impacts to water quality* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	2	4	M	Breakdown of rubbish could increase particles in the water column and microplastics can carry accumulated contaminants. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf*
Value: Sediment quality						
N	Disturbance - noise					
N	Disturbance - damage (anchoring/diving)					
Y	Pollution - oil/fuel	2	2	4	L-M	Spills from recreational/tourism vessels less likely. Antifoulants entering into water column and sediments *Data confidence* • *Low confidence around the impact of copper-based contaminants*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *High confidence around oil and fuel spill impacts to sediment quality* • *Low confidence around the frequency of occurrence of oil and fuel spills in the Gulf or in general*
Y	Pollution - rubbish	2	2	4	L-M	Breakdown of rubbish could increase particles in the sediments and microplastics can carry accumulated contaminants. *Data confidence* • *High confidence that microplastics occur in the water column of Exmouth Gulf - see King (2019)* • *Low confidence around the extent of hard rubbish/fishing gear in the Gulf, and in sediments*
Factor: Coastal processes						
Value: Geophysical processes						
N	Disturbance - noise					
N	Disturbance - damage (anchoring/diving)					
N	Pollution - oil/fuel					
N	Pollution - rubbish					
Value: Hydrodynamic processes						
N	Disturbance - noise					
N	Disturbance - damage (anchoring/diving)					
N	Pollution - oil/fuel					
N	Pollution - rubbish					
Value: Nutrient flow						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
N	Disturbance - noise					
N	Disturbance - damage (anchoring/diving)					
N	Pollution - oil/fuel					
N	Pollution - rubbish					

EPA LAND THEME

Negligible	Low	Medium	High	Severe
1-2	3-4	6-8	9-12	16

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Factor: Flora & vegetation						
Value: Coastal plains						
N	Sea level rise					
Y	Tropical storms/cyclones	2	3	6	M	Within 10 years, likely to increase frequency and extent in some way which may impact flora and vegetation communities. *Data confidence* • *High confidence about cyclone predictions* • *High confidence that changes in cyclones will impact the area as multiple reports and papers over many years detail the impact of cyclones on the Exmouth area* • *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*
Y	Fire	2	3	6	M	As above *Data confidence* • *High confidence about fire predictions as robust data on the increased risk of fire and altered fire regimes in a changing climate* • *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*
N	Atmospheric temperatures					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Value: Limestone cliffs & gullies						
N	Sea level rise					
Y	Tropical storms/cyclones	2	3	6	M	As above *Data confidence* • *High confidence about cyclone predictions* • *High confidence that changes in cyclones will impact the area as multiple reports and papers over many years detail the impact of cyclones on the Exmouth area* • *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*
Y	Fire	2	3	6	M	As above *Data confidence* • *High confidence about fire predictions as robust data on the increased risk of fire and altered fire regimes in a changing climate* • *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*
N	Atmospheric temperatures					
Value: Coastal dunes						
Y	Sea level rise	1	3	3	M-H	We will see some localised sea level rise in 10 years. *Data confidence* • *High confidence in sea level rise predictions*
Y	Tropical storms/cyclones	2	3	6	M	As above *Data confidence* • *High confidence about cyclone predictions* • *High confidence that changes in cyclones will impact the area as multiple reports and papers over many years detail the impact of cyclones on the Exmouth area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*
Y	Fire	2	3	6	M	As above *Data confidence* • *High confidence about fire predictions as robust data on the increased risk of fire and altered fire regimes in a changing climate* • *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*
N	Atmospheric temperatures					
Value: Threatened/priority flora						
N	Sea level rise					Endemic threatened/priority flora on dunes & coastal plains may be at risk with sea level rise.
Y	Tropical storms/cyclones	3	3	9	M	• *Frequency and extent could increase and cause population level impacts. Low confidence in baseline data.* *Data confidence* • *High confidence about cyclone predictions* • *High confidence that changes in cyclones will impact the area as multiple reports and papers over many years detail the impact of cyclones on the Exmouth area* • *Low confidence around the extent of threatened/priority flora*
Y	Fire	3	3	9	M	As above *Data confidence* • *High confidence about fire predictions as robust data on the increased risk of fire and altered fire regimes in a changing climate* • *Lower confidence about how exactly this will impact which types of flora and the extent & timeframe of those effects*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
N	Atmospheric temperatures					
Factor: Terrestrial fauna						
Value: Reptiles						
Y	Sea level rise	1	2	2	L-M	Low lying islands and coastal fringes will eventually experience some level of inundation and erosion, which would impact on fauna, but probably not to a large extent within 5-10 years Uncertainty exists as to which species would be affected due to an overall lack of survey in the area and lack of detail around community structure for reptiles. *Data confidence* • *High confidence in sea level rise predictions and likely impact on reptiles in the longer term* • *Low confidence around risk of seal level rise on reptiles in the area* • *Low confidence around the distribution of species in the area*
Y	Tropical storms/cyclones	2	3	6	L-M	Storm surges have potential to inundate islands, which have reptile communities, although reptiles in general have higher resilience to short term perturbations than do mammals. There is a lack of survey on islands. *Data confidence* • *High confidence in cyclone predictions and likely impact on reptiles in general* • *Low confidence around risk of cyclones on reptiles in the area* • *Low confidence around the distribution of species in the area*
Y	Fire	2	3	6	M	In the case of large extent and hot fire there could be medium term effects on species and assemblages. The effects can be exacerbated by dry conditions post fire, increased grazing and/or weed invasion/predation. A combination of these may have longer term impacts on species persistence and species community structure. Frequent fire could have cumulative impacts through lack of population recovery in intervening periods. Conversely, in some cases lack of managed fire can also have negative impacts through senescence of vegetation resulting in structural change of habitat.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						Data confidence • *High confidence in fire predictions and impact on reptiles in general* • *Low confidence around risk of fire on reptiles in the area.*
Y	Atmospheric temperatures	1	2	2	M	As reptiles are ectothermic, they rely on behavioural patterns to regulate body temperature and in the short term it is doubtful shifts in temperature would have a significant negative effect. Temperatures changes could potentially impact on development of eggs. *Data confidence* • *High confidence in atmospheric temperature predictions and impact on reptiles in general* • *Low confidence around risk of atmospheric temperatures on reptiles in the area.*
Value: mammals						
Y	Sea level rise	2	2	4	M	Low lying islands will eventually experience some level of inundation and erosion, which would impact fauna, but possibly not to a large extent within 5-10 years. *Data confidence* • *High confidence in sea level rise predictions and likely impact on mammals in general* • *Low confidence around risk of seal level rise on mammals in the area*
Y	Tropical storms/cyclones	2	4	8	M	Doole Islands- potential for inundation to storm surges - most of the islands go under water. Bandicoots have been translocated onto Doole Island - all nesting sites are below storm surge level as based off Olwen surge level. *Data confidence* • *High confidence in cyclone predictions and likely impact on mammals in general* • *Low confidence around risk of cyclones on mammals in the area.*
Y	Fire	2	3	6	M	As above for reptiles *Data confidence* • *High confidence in cyclone predictions and impact on mammals in general*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *Low confidence around risk of fire on mammals in the area.*
Y	Atmospheric temperatures	1	3	3	M	Some species may not be able to tolerate warming temperature, although effects of this on species may not be seen within 5-10 years. *Data confidence* • *High confidence in atmospheric temperature predictions and impact on mammals in general* • *Low confidence around risk of atmospheric temperatures on mammals in the area.*
Value: birds						
Y	Sea level rise	1	3	3	M	Nesting habitat may be impacted. *Data confidence* • *High confidence in sea level rise predictions and impact on terrestrial birds in general* • *Low confidence around risk of sea level rise on terrestrial birds in the area.*
Y	Tropical storms/cyclones	1	3	3	M	As above for mammals *Data confidence* • *High confidence in cyclone predictions and likely impact on terrestrial birds in general* • *Low confidence around risk of cyclones on terrestrial birds in the area.*
Y	Fire	1	3	3	M	As above for reptiles *Data confidence* • *High confidence in fire predictions and impact on terrestrial birds in general* • *Low confidence around risk of fire on terrestrial birds in the area.*
Y	Atmospheric temperatures	3	3	9	M-H	Some species may not be able to tolerate warming temperature & mass avian mortalities & range shifts have occurred in WA. However more information is required to assess the risk of atmospheric temperatures on birds in the area. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *High confidence in atmospheric temperature predictions* • *High confidence that heatwaves can cause mass mortalities - see McKechnie et al. (2012), McKechnie and Wolf (2010)* • *Low confidence around whether birds in the Exmouth region have been impacted*
Value: short range endemic invertebrates						
N	Sea level rise					
Y	Tropical storms/cyclones	2	3	6	L-M	Storm surges have the potential to inundate islands, which may have short-range endemic communities. *Data confidence* • *High confidence in cyclone predictions* • *Low confidence around the diversity and distribution of SREs in the Exmouth area* • *Low confidence around risk to terrestrial invertebrates from storms in the Exmouth area*
Y	Fire	2	3	6	L-M	In the case of a catastrophic fire. *Data confidence* • *High confidence in fire predictions* • *Low confidence around the diversity and distribution of SREs in the Exmouth area* • *Low confidence around risk to terrestrial invertebrates from fire in the Exmouth area*
Y	Atmospheric temperatures	1	3	3	L-M	Some species may not be able to tolerate warming temperature, although effects of this on species may not be seen within 5-10 years. *Data confidence* • *High confidence in atmospheric temperature predictions* • *Low confidence around the diversity and distribution of SREs in the Exmouth area* • *Low confidence around risk to terrestrial invertebrates from rising temperatures in the Exmouth area*
Value: amphibians						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
N	Sea level rise					
Y	Tropical storms/cyclones	1	3	3	L-M	For islands there are likely few if any amphibians. Storm surges have the potential to inundate ephemeral freshwater systems adjacent to the gulf, in which case breeding success in these areas could be compromised. *Data confidence* • *High confidence in cyclone predictions and likely impact on amphibians in general* • *Low confidence around the distribution of amphibians in the Exmouth area* • *Low confidence around risk to amphibians from cyclones in the Exmouth area*
Y	Fire	1	3	3	L-M	Most amphibians that would occur around the periphery of the gulf cocoon below ground or bury themselves in dry conditions so are unlikely to feel direct effects from fire. It is the following indirect effects that have greater potential for negative impacts such as changes to hydrology and/or landscape changes as a result of grazing pressure and/or weeds. *Data confidence* • *High confidence in fire predictions and likely impact on amphibians in general* • *Low confidence around the distribution of amphibians in the Exmouth area* • *Low confidence around risk to amphibians from fires in the Exmouth area*
Y	Atmospheric temperature	2	2	4	L-M	Amphibians typically need moist environments, or access to water during life cycles, however species found around the gulf are arid adapted and can deal with fairly long durations (generally multiple years) of low rainfall. *Data confidence* • *High confidence in atmospheric temperature predictions and the impact on amphibians in general* • *Low confidence around the distribution of amphibians in the Exmouth area* • *Low confidence around risk to amphibians from rising temperatures in the Exmouth area*

Factor: Landforms

Value: islands

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Y	Sea level rise	4	2	8	M-H	Low-lying islands will eventually experience some level of inundation and erosion, but possibly not to a large extent within 5-10 years. *Data confidence* • *High confidence in sea level rise predictions and impact on islands in general* • *Medium confidence around risk of sea level rise to islands around Exmouth Gulf - see Cuttler et al. (2020) and Bonesso et al. (2020)*
Y	Tropical storms/cyclones	2	4	8	M-H	Doole Islands- potential for inundation to storm surges - most of the islands go under water. Bandicoots have been translocated onto Doole Island - all nesting sites are below storm surge level as based off Olwen surge level. Sandy covered rock islands are more sensitive to changes. If sand is eroded by winds cyclones or rainfall, then that habitat is removed for fauna, including birds. Island would still exist though. *Data confidence* • *High confidence in storm and cyclone predictions and impact on islands in general* • *Medium confidence around risk to islands around Exmouth Gulf*
N	Fire					
N	Atmospheric temperatures					
Value: karst systems						
Y	Sea level rise	3	2	6	M	Sea level rise will impact on chemistry and hydrology of karst systems *Data confidence* • *High confidence in sea level rise predictions* • *High confidence around impact of changes in seawater intrusion on karst systems* • *Low confidence around assessing the likelihood or timeframe for the impact of sea level rise on Karst systems*
Y	Tropical storms/cyclones	1	3	3	M	Potentially impacted by the frequency of the volume of water falling on and draining off the landscape. Could impact sedimentation of cave systems. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *High confidence in cyclone predictions* • *High confidence around impact of flooding/inundation on karst systems* • *Low confidence around assessing the likelihood or timeframe for the impact of cyclones on Karst systems*
N	Fire					
Y	Atmospheric temperatures	2	3	6	M	Hot, drying climate could change humidity of karst systems. *Data confidence* • *High confidence in temperature predictions* • *High confidence around impact of drying/changing humidity on karst systems* • *Low confidence around assessing the likelihood or timeframe for the impact of atmospheric changes on Karst systems.*
Factor: Subterranean fauna						
Value: troglofauna						
Y	Sea level rise	4	1	4	M	Sea level rise will impact on chemistry and hydrology of karst systems, and the space available for troglofauna, but this may not be realised within 5-10yr timeframe. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence around potential impact of changes in seawater intrusion on troglofauna* • *Low confidence around assessing the likelihood or timeframe for the impact of sea level rise on troglofauna.*
Y	Tropical storms/cyclones	1	3	3	M	As above for karst systems *Data confidence* • *High confidence in cyclone predictions* • *High confidence around potential impact of the potential impact of flooding/ inundation on troglofauna*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *Low confidence around assessing the likelihood or timeframe for the impact of cyclones on troglofauna.*
N	Fire					
Y	Atmospheric temperatures	2	3	6	M	Troglofauna are sensitive in changes to humidity in underground cave systems. *Data confidence* • *High confidence in both atmospheric temperature and precipitation predictions* • *High confidence that troglofauna are sensitive to changes to humidity* • *Low confidence around assessing the likelihood or timeframe for the impact of atmospheric changes on troglofauna*
Value: stygofauna						
Y	Sea level rise	4	2	8	M	Sea level rise will impact on chemistry and hydrology of karst systems, and thus stygofauna, but this may not be realised within 5-10yr timeframe. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that any changes in salinity will significantly impact stygofauna* • *Low confidence around the information available to assess the likelihood or timeframe for the impact*
Y	Tropical storms/cyclones	1	3	3	M	As above. • *High confidence in cyclone predictions* • *High confidence around potential impact of the potential impact of flooding/ inundation on stygofauna* • *Low confidence around assessing the likelihood or timeframe for the impact of cyclones on troglofauna*
N	Fire					
Y	Atmospheric temperatures	1/2	3	3-6	M	Uncertainty whether stygofauna are as affected as troglofauna by changes to air temperature/humidity.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						Data confidence • *High confidence in both atmospheric temperature and precipitation predictions* • *High confidence that stygofauna will be impacted by a drying climate* • *Low confidence around assessing the likelihood or timeframe for the impact of atmospheric changes on stygofauna*
Factor: Terrestrial environmental quality						
Value: topsoil						
N	Sea level rise					
Y	Tropical storms/cyclones	1	4	4	M	Cyclone winds can erode soil, and flood waters could transport and accumulate soils in certain locations. *Data confidence* • *High confidence in cyclone predictions and likely impact on topsoil in general.* • *Low confidence around impact of cyclones on topsoil in the Exmouth area*
Y	Fire	1	4	4	M	Fires can significantly affect soil properties as organic matter is combusted, which then has flow on effects to chemical, physical, and microbiological properties. *Data confidence* • *High confidence in fire predictions* • *Low confidence around extent of impact to topsoil in Exmouth area*
N	Atmospheric temperatures					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Factor: Flora & vegetation						
Value: Coastal plains						
Y	Contamination	1	3	3	M	Assuming there is low level legacy contamination, however it is difficult to score with certainty, as military exercises are ongoing. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *Low confidence around the effects on flora & vegetation in the Exmouth area*
Value: Limestone cliffs & gullies						
Y	Contamination	1	3	3	M	As above. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *Low confidence around the effects on flora & vegetation in the Exmouth area*
Value: Coastal dunes						
Y	Contamination	1	3	3	M	As above. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *Low confidence around the effects on flora & vegetation in the Exmouth area*
Value: Threatened/priority flora						
Y	Contamination	2	3	6	L-M	Slightly higher consequence, just by virtue of flora being threatened/priority. Not a high confidence in baseline data. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
						• *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the effects on flora & vegetation in the Exmouth area* • *Low confidence around the distribution of threatened and priority flora in the Exmouth area*
Factor: Terrestrial fauna						
Value: Reptiles						
Y	Contamination	1	3	3	M	Likely to be localised as there is legacy contamination. Providing contamination is localised and not widespread then impacts should not be large. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the effects on fauna in the Exmouth area*
Value: mammals						
Y	Contamination	1	3	3	M	As above. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the effects on fauna in the Exmouth area*
Value: birds						
Y	Contamination	2	3	6	M	Birds rely on specific freshwater sources, and migratory birds may be impacted.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
						Data confidence • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the effects on fauna in the Exmouth area*
Value: short range endemic invertebrates						
Y	Contamination	1	3	3	M	As above. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the effects on fauna in the Exmouth area*
Value: amphibians						
Y	Contamination	2	3	6	M	Providing contamination is localised and not widespread then impacts should not be large. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the effects on fauna in the Exmouth area*
Factor: Landforms						
Value: islands						
N	Contamination					
Value: karst systems						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Y	Contamination	1/2	3	3-6	M	Localised contamination could seep into karst systems. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *Low confidence around the extent that run-off containing PFAS is entering karst systems*
Factor: Subterranean fauna						
Value: troglofauna						
Y	Contamination	1/2	3	3-6	M	Same as Karst above. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the extent that run-off containing PFAS is entering karst systems*
Value: stygofauna						
Y	Contamination	1/2	3	3-6	M	As above. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)* • *High confidence that PFAS can accumulate and have toxic implications for flora and fauna in general* • *Low confidence around the extent that run-off containing PFAS is entering karst systems*
Factor: Terrestrial environmental quality						
Value: topsoil						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Y	Contamination	1/2	3	3-6	H	Same as flora and vegetation. *Data confidence* • *High confidence in data indicating contamination has occurred/is occurring - see DoD (2019)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Factor: Flora & vegetation						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						

- What has been the total loss of quality and function of the peninsula?
- A map would be useful to see where vegetation types are. Then we can have a more adequate assessment of the risk.
- There are unknowns around light industrial opportunities - do not know what might pop up.
- Impact not just confined to the development e.g., introduced weeds and plant pathogens could impact other areas.
- Relatively few waterways in the area. On western side of Exmouth Gulf - half a dozen waterways that drain into Gulf - probably two or three have been radically altered e.g., one that leads into marina, Wappet Creek, Mowbowra, Qualing Pool. Associated vegetation complexes have likely been impacted for three or four of the waterways. The waterway near the VLF transmitter masts is no longer there, and at Harold E. Holt Base, the waterway has radically altered.
- Fragmentation of vegetation complexes near town.
- Goats were a major problem in the past and were wide roaming. Goats not such a large issue anymore, at least not in the last five years. Annual camera surveys have been conducted and goats have been under control (Department of Biodiversity, Conservation and Attractions (DBCA) - aerial shoots). Camera surveys have been done on Defence, DBCA and Watercorp land. Goats have been picked up on camera on Exmouth Gulf pastoral lease behind Learmonth area.
- Permanent waterholes occur around Badjirrajirra Creek and there are ‘rainforest’ pockets around this creek. In the past they were overrun by goats.
- Surface water changes will be assessed under WATER factor.
- Some stations derive most of income from grazing animals - no fences - goats used to roam through hinterland around town.
- In the past, goats were impacting more than pastoral areas. ‘Mobs’ of goats were found behind the town.

Value: Coastal plains						
Y	Residential - footprint	1	3	3	M	Shire has informed that future residential development will be to infill areas (mostly in the main town), rather than develop whole new areas. There is **currently** no identified major residential development in Exmouth within the next 5-10 years, as far as the Shire is aware. The main footprint of town is ~3-4km long by ~2km wide. There is a housing shortage so there would be pressures from increased residential builds, which may/may not happen within 5-10 years. What is the vegetation within infill areas? **Knowledge needed.** Vegetation has faced impacts of destructive activities around town - motorbike use etc. Need to understand what the baseline is for coastal vegetation, then can assess the incremental risks better. Some info exists, **but a better understanding is needed, particularly for unique flora.** Subspecies of flora exist in Cape Range.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						DBCA did a lot of vegetation work through area which included defining the spatial area of some vegetation complexes - course level data. Coastal plain vegetation includes samphire, which are extensive throughout region. Big Defence towers sit on saltmarshes. Coastal saltmarshes are an Environment Protection and Biodiversity Conservation listed community. Dunes adjacent to town have all been impacted by people. *Data confidence* • *High confidence that increased infill will lead to further damage & fragmentation of coastal vegetation* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be*
Y	Residential - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	2/3	4	8-12	L-M	Shire planning maps do not show major industrial development in next 5-10 years. Gascoyne Gateway (GG) - tourism (cruise ships) will be less than 10 visitations a year (Department of Jobs, Tourism, Science and Innovation), industrial port activities will occur on a regular basis. What is land based footprint? Substantial ~100 hectares??? Solar arrays to consider - west of development. **Score based on assumption of 100 hectares for Gascoyne Gateway (GG) if proposing a multi-user jetty facility goes ahead.**

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Probably a combination of hard stand and cleared area, not all concrete - but either way NOT vegetation. Could be limestone in parts. Cumulative impacts to consider along west edge of Gulf - starting to look like a considerable impact if development continues. Existing development further up the cape already adds to cumulative development and impacts. At least a moderate consequence if considering cumulative impacts. Exmouth Gulf Marina - filled in base of catchment - infill has influenced the impacts felt from cyclones and floods. **Data confidence is not high for scoring impacts of industrial development.** *Data confidence* • *High confidence that increased development will lead to further damage & fragmentation of coastal vegetation* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be* • *Low confidence around details and extent of proposed developments*
Y	Industrial - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
Y	Industrial - solid waste	1/2	4	4-8	M	Based on numerous anecdotal reports and satellite imagery, illegal dumping occurs (~500 mounds of dumped materials, including fill and demolition rubbish) at a location between the town and the industrial area (between the main road and coastline). Unsure if this is contaminated. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the extent of impacts on coastal plain vegetation*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint (inc. road)	2/3	4	8-12	L-M	Two areas are earmarked for future caravan parks in the town Not sure of the quality of the land of the proposed areas. Is it already degraded?) Lighthouse redevelopment project is a major consideration. Not a lot of information about the project - so will need to speculate. Road at lighthouse is proposed to be moved behind the existing development so that there is access to the beach - this would go through pristine vegetation. Scoring of this pressure/activity includes ROADS. Lighthouse could be an improvement- but the road is a major impact. Increased tourism will have a significant impact on groundwater draw down - how will this impact vegetation? All three tourism developments will result in cumulative issues - and this needs to be considered. Caravan park, if properly managed, could be a good thing, otherwise the area at the moment is degraded (if the locations believed to be earmarked are correct). Camping occurs on pastoral lands and future proposals are likely. Data confidence is not high for scoring impacts of tourism development. *Data confidence* • *High confidence that increased development will lead to further damage & fragmentation of coastal vegetation* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be* • *Low confidence around details and extent of proposed developments*
Y	Tourism - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Limestone cliffs & gullies						
Y	Residential - footprint	1	3	3	L-M	Similar justification to above. Along the dry creek beds are Eucalyptus and Acacia species. Qualing Pool - has limestone cliff and gullies, old fossil coral ridges plus four vegetation types in vicinity of GG and Qualing Pool area How do the vegetation complexes in the residential areas compare with other vegetation complexes? **Botanical surveys needed to capture detail.** *Data confidence* • *Medium confidence that increased infill will lead to further damage & fragmentation of vegetation on limestone cliffs & gullies* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be*
Y	Residential - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
Y	Residential - solid waste	1	4	4	L-M	Quite a lot of illegal dumping occurs around Mowbowra area (old fridges and car bodies). Vegetation has already been impacted. Anecdotal reports of illegal dumping but no empirical data on extent, type or impact on limestone cliff & gully vegetation.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Data confidence • *High confidence that illegal dumping is occurring* • *Low confidence around the full extent and types of rubbish that is dumped* • *Low confidence around the impact of illegal dumping and rubbish tip on flora and vegetation*
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	3	4	12	M	GG port - concerns from public submissions around Qualing Pool and freshwater expression. Given the values of Qualing Pool, the consequence is likely to be high. There is a light industrial area just north of Qualing Pool already - so an impact already. Cumulative impacts to consider. *Data confidence* • *High confidence that increased development will lead to further damage & fragmentation of vegetation* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be* • *Low confidence around details and extent of proposed developments*
Y	Industrial - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Tourism - footprint	3	4	12	L-M	Proposed lighthouse and caravan parks. Vlamingh Head - limestone. Future developments will increase consequence - cumulative impacts. *Data confidence* • *High confidence that increased development will lead to further damage & fragmentation of vegetation of cliffs and gullies* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be* • *Low confidence around details and extent of proposed developments*
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Coastal dunes						
Y	Residential - footprint	1	3	3	M	Coastal dunes: soft spinifex covers the front and back of dunes. Plains: *Triodia*- spikey spinifex and other shrubs. Most residential development is away from dunes. *Data confidence* • *High confidence that increased infill will lead to further damage & fragmentation of vegetation on dunes.* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be*
Y	Residential - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	1	4	4	M	Main industrial areas in town are not an issue but GG will be. It will probably cut through dunes for access. Due to different versions of the GG footprint, we do not know the GG footprint so can only speculate. GG might cut through and not overlay dunes. If the footprint does back on to the dunes, rather than cut through the dunes, then the consequence score would be different. Different conceptual designs will impact the consequence score. Trying to do a conceptual assessment - not actually assessing GG or lighthouse specifically - these developments are concepts only. For the existing industrial footprint, the consequence would be minor, but proposals/concept plans increase the consequence. *Data confidence* • *High confidence that increased development will lead to further damage & fragmentation of dune vegetation* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be* • *Low confidence around details and extent of proposed developments*
Y	Industrial - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	3	3	9	L-M	Coastal plains and dunes are probably most impacted by the road. Would still have access to surfing and dive spots. Track out to Mildura wreck would probably stay. Two carparks in between coast and lighthouse would probably stay. Some locals concerned about limited access. Turtles in coastal dunes - degraded vegetation on dunes would cause secondary impacts to turtle nesting. Minor consequence with current developments, but future proposed developments would increase this consequence, largely because of the road, to a moderate/high consequence. Do not know where the road will go. One possible road option - Base of Vlamingh head and in behind existing lighthouse?? Can only speculate. All we can say is that there will be impacts from a road on flora and fauna. Score for the worst case scenario - if the road went through the dune system. Access from old caravan park to lighthouse bay, along the old creek bed, has some implications on pedestrian access. Lighthouse Bay regularly monitored for turtle nesting - lighting an issue here, as is access to people looking at nesting turtles. Also, a significant Aboriginal site - shell middens are found through the dunes. Osprey also nest in the area. SCORE LIGHT POLLUTION AND TURTLES UNDER FAUNA *Data confidence* • *High confidence that increased development will lead to further damage & fragmentation of vegetation of dunes* • *Low confidence around the plant species and community composition that may be affected and how severe those effects will be* • *Low confidence around details and extent of proposed developments*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Tourism - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Threatened/priority flora						
Y	Residential - footprint	1	3	3	L	Do not have expertise in the room. Limited baseline information Priority 3 species: *Tecticornia (samphire - considered under SEA)* *Tephrosia* DBCA mapping shows no 'threatened' flora species within scope - but it does not mean they are not there. Surveys for flora are required in a separate Environmental Impact Assessment. Much of peninsula was an island for a long time - so speciesism and endemism are likely. Harold E. Holt base possibly impacted by road realignment. What was there or lost before the roads went in? Subsea 7 did some targeted vegetation surveys - but not sure if representative of entire area. Impacts on vegetation behind salt flats is considered under MINING *Data confidence* • *Low confidence around whether threatened/priority flora are located at infill sites and if so, the extent to which they would be affected by developments*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Residential - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	3	3	9	L	If there is an impact, consequence would be high because threatened species unlikely to be covering vast distances. **More knowledge needed** on the presence and distribution of species. *Data confidence* • *Low confidence around whether threatened/priority flora are located at sites proposed for industrial development and, if so, the extent to which they would be impacted*
Y	Industrial - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Tourism - footprint	3	3	9	L	Minor consequence with current developments, but future proposed developments would increase this consequence, largely because of the lighthouse road, to a moderate/high consequence. Do not know where the road will go. All we can say is that there will be impacts from a road on flora and fauna. *Data confidence* • *Low confidence around whether threatened/priority flora are located at development sites and if so, the extent to which they would be affected by developments*
Y	Tourism - groundwater drawdown	2/3	2	6	M	Groundwater drawdown has the potential to impact flora and vegetation through lack of water *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation* • *Low confidence around how much flora and vegetation has been/or will be impacted in the Exmouth area*
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Factor: Terrestrial fauna						
Value: Reptiles						
Y	Residential - footprint	1	4	4	L-M	Due to localised extent and footprint being infill in existing urban landscapes, the overall consequence is minor as species occurring within the Exmouth precinct are likely to have substantial distributions outside of the townsite. Shire has informed that future residential development will be to infill areas - mostly in the main town - rather than develop whole new areas. Some clearing of habitat would occur with infilling. Development/urban sprawl in general can push fauna out. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that increased infill will remove habitat for reptiles occuring in residential footprints* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which reptiles would be impacted*
Y	Residential - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Residential - solid waste	1	3	3	M	Rubbish and contamination leached from rubbish may accumulate in food webs/fauna over time but perhaps will not be realised within the timeframe of 5-10 years. *Data confidence* • *High confidence that illegal dumping is occurring* • *Low confidence around the full extent and types of rubbish that is dumped* • *High confidence that native reptiles will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Residential - light	2	3	6	M	Increased light pollution impacts on natural light cycles which reptiles have evolved with. Impacts of light on many terrestrial fauna species not well studied. There may be impacts to behaviour and/or physiology, reducing survivorship or reproductive output. - *Perry et al. 2008 - Effects of night lights on urban reptiles and amphibians* and *DEE 2020 - National Light Pollution Guidelines for Wildlife.* It is unlikely that light will affect species outside a residential footprint and as disturbance will have already occurred from development, species that are tolerant of such change will likely persist. If only assessing the risk to terrestrial reptiles, then the consequence and likelihood would be 1 and 3, respectively. However, marine turtle hatchlings are significantly impacted by light from land development, which can disorient hatchlings inland rather than out to sea. Note that marine turtles are part of the EPA's marine fauna factor, however, because light pollution

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						from Development was not assessed under the Sea theme (only light pollution from Shipping is), it is assessed here. The score reflects both terrestrial reptiles and marine turtles. An assessment of light pollution across Australia identified the North West Shelf of Australia (including Cape Range) as one of two sites facing the highest potential risk from light pollution. Altered light horizons are associated with oil and gas facilities on islands outside of Exmouth Gulf (Limpus 2007). *Data confidence* • *Medium confidence in the effect of light pollution on terrestrial reptiles in general* • *High confidence in the effect of light pollution on marine turtles - see Kamrowski et al. (2012)* • *Low confidence in the impact of light pollution on terrestrial and marine reptiles specifically in Exmouth*
Y	Residential - noise	1	3	3	L-M	It is unlikely that noise will affect species outside a residential footprint and as disturbance will have already occurred from development, species that are tolerant of such change will likely persist. Overall, the consequence would likely be only minor to moderate for terrestrial reptiles. Some species of reptiles are also vocal and vocalisations (and mating behaviours) may be impacted by anthropogenic noise - knowledge about the effects of anthropogenic noise on reptile social behaviours are severely lacking. - *Simmons and Narins 2018 - Effects of Anthropogenic Noise on Amphibians and Reptiles* *Data confidence* • *High confidence that noise is generated from residential developments* • *Low confidence in the diversity of reptiles in residential areas* • *Low confidence in the impact of noise on reptiles*
Y	Industrial - footprint	2	4	8	L-M	Due to the likelihood of industrial footprints being larger than residential and affecting areas outside of the townsite through land clearing and habitat loss, the consequence could be considered moderate. Particularly in that there is a lack of detail around species distributions and assemblage structures associated with different environments. There are

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						also several priority species recorded in the general area for which we have little knowledge on habitat requirements. More development results in less natural areas available for habitation. Development in general can push fauna out. *Data confidence* • *High confidence that increased industrial development will remove habitat for reptiles* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which reptiles would be impacted*
Y	Industrial - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Industrial - solid waste	1	3	3	M	Rubbish and contamination leached from rubbish may accumulate in food webs/fauna over time but perhaps will not be realised within the timeframe of 5-10 years. *Data confidence* • *High confidence that industrial solid waste is present in the area* • *Low confidence around the full extent and types of waste* • *High confidence that native reptiles will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Industrial - light	2	3	6	M	As for residential. *Data confidence* • *Medium confidence in the effect of light pollution on terrestrial reptiles in general* • *High confidence in the effect of light pollution on marine turtles - see Kamrowski et al. (2012)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence in the impact of light pollution on terrestrial and marine reptiles specifically in Exmouth*
Y	Industrial - noise	1	3	3	L-M	As for residential. *Data confidence* • *High confidence that noise is generated from industrial developments* • *Low confidence in the diversity of reptiles in industrial areas* • *Low confidence in the impact of noise on reptiles*
Y	Tourism - footprint	2	4	8	L-M	More development results in less natural areas available for habitation. Similar to industrial, depending on where developments and land usage occurs. A lack of detail on species distributions and assemblage structures elevates risks over that of urban development. *Data confidence* • *High confidence that increased tourism development will remove habitat for reptiles* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which reptiles would be impacted*
Y	Tourism - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
N	Tourism - solid waste					Considered under TOURISM/VISITATION.
Y	Tourism - light	3	3	9	M	As above for residential, however, given lighthouse redevelopment project is close to the coast and turtles nesting beaches, the impacts would be greater. *Data confidence* • *Medium confidence in the effect of light pollution on terrestrial reptiles in general*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence in the effect of light pollution on marine turtles - see Kamrowski et al. (2012)* • *Low confidence in the impact of light pollution on terrestrial and marine reptiles specifically in Exmouth*
Y	Tourism - noise	1	3	3	L-M	As above for residential. *Data confidence* • *High confidence that noise is generated from tourism developments* • *Low confidence in the diversity of reptiles in residential areas* • *Low confidence in the impact of noise on reptiles*
Value: mammals						
Y	Residential - footprint	2	4	8	L-M	Similar reasons to above. *Data confidence* • *High confidence that increased infill will remove habitat for mammals occuring in residential footprints* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which mammals would be impacted*
Y	Residential - groundwater drawdown	3	2	6		Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands
Y	Residential - solid waste	1	3	3	M	Similar reasons to above. *Data confidence* • *High confidence that residential solid waste is present in the area and illegal dumping occurs* • *Low confidence around the full extent and types of waste* • *High confidence that native mammals will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Residential - light	2	3	6	L-M	Similar reasons to above.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Data confidence • *Medium confidence in the effect of light pollution on mammals in general* • *Low confidence in the impact of light pollution on mammals specifically in Exmouth*
Y	Residential - noise	2	3	6	M	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from residential developments* • *High confidence in the impact of noise on mammals e.g., Slabbekoorn et al. (2018) Effects of Man-Made Sound on Terrestrial Mammals. In Effects of Anthropogenic Noise on Animals (eds. Slabbekoorn, H., Dooling, R. J., Popper, A. N. & Fay, R. R.) 243-276 (Springer, 2018). doi:10.1007/978-1-4939-8574-6_9.* • *Low confidence in the diversity of mammals in residential areas* • *Low confidence in the impact of noise on mammals in Exmouth specifically*
Y	Industrial - footprint	2	4	8	L-M	Similar reasons to above. *Data confidence* • *High confidence that increased industrial development will remove habitat for mammals* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which mammals would be impacted*
Y	Industrial - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Industrial - solid waste	1	3	3	M	Similar reasons to above. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that industrial solid waste is present in the area* • *Low confidence around the full extent and types of waste* • *High confidence that native mammals will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Industrial - light	2	3	6	L-M	Similar reasons to above. *Data confidence* • *Medium confidence in the effect of light pollution on mammals in general* • *Low confidence in the impact of light pollution on mammals specifically in Exmouth*
Y	Industrial - noise	2	3	6	M	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from industrial developments* • *High confidence in the impact of noise on mammals e.g., Slabbekoorn et al. (2018) Effects of Man-Made Sound on Terrestrial Mammals. In Effects of Anthropogenic Noise on Animals (eds. Slabbekoorn, H., Dooling, R. J., Popper, A. N. & Fay, R. R.) 243-276 (Springer, 2018). doi:10.1007/978-1-4939-8574-6_9.* • *Low confidence in the diversity of mammals in industrial areas* • *Low confidence in the impact of noise on mammals in Exmouth specifically*
Y	Tourism - footprint	2	4	8	L-M	Similar reasons to above. *Data confidence* • *High confidence that increased tourism development will remove habitat for mammals* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which mammals would be impacted*
Y	Tourism - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Data confidence • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
N	Tourism - solid waste					Considered under TOURIMS/VISITATION.
Y	Tourism - light	2	3	6	L-M	Similar reasons to above. *Data confidence* • *Medium confidence in the effect of light pollution on mammals in general* • *Low confidence in the impact of light pollution on mammals specifically in Exmouth*
Y	Tourism - noise	2	3	6	M	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from tourism developments* • *High confidence in the impact of noise on mammals e.g., Slabbekoorn et al. (2018) Effects of Man-Made Sound on Terrestrial Mammals. In Effects of Anthropogenic Noise on Animals (eds. Slabbekoorn, H., Dooling, R. J., Popper, A. N. & Fay, R. R.) 243-276 (Springer, 2018). doi:10.1007/978-1-4939-8574-6_9.* • *Low confidence in the diversity of mammals in tourism areas* • *Low confidence in the impact of noise on mammals in Exmouth specifically*
Value: birds						
Y	Residential - footprint	2	4	8	L-M	Similar reasons to above. *Data confidence* • *High confidence that increased infill will remove habitat for birds occuring in residential footprints* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which birds would be impacted*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Residential - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Residential - solid waste	1	3	3	M	Similar reasons to above. *Data confidence* • *High confidence that residential solid waste is present in the area and illegal dumping occurs* • *Low confidence around the full extent and types of waste* • *High confidence that native birds will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Residential - light	2	3	6	L-M	Similar reasons to above. *Data confidence* • *Medium confidence in the effect of light pollution on birds in general* • *Low confidence in the impact of light pollution on birds specifically in Exmouth*
Y	Residential - noise	2	3	6	L-M	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from residential developments* • *Low confidence in the diversity of birds in residential areas* • *Low confidence in the impact of noise on birds*
Y	Industrial - footprint	2	4	8	L-M	Similar reasons to above. *Data confidence* • *High confidence that increased industrial development will remove habitat for birds* • *Low confidence around species diversity, community assemblages*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence around the extent to which birds would be impacted*
Y	Industrial - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Industrial - solid waste	1	3	3	M	Similar reasons to above. *Data confidence* • *High confidence that industrial solid waste is present in the area* • *Low confidence around the full extent and types of waste* • *High confidence that native birds will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Industrial - light	2	3	6	L-M	Similar reasons to above. *Data confidence* • *Medium confidence in the effect of light pollution on birds in general* • *Low confidence in the impact of light pollution on birds specifically in Exmouth*
Y	Industrial - noise	2	3	6	L-M	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from industrial developments* • *Low confidence in the diversity of birds in industrial areas* • *Low confidence in the impact of noise on birds*
Y	Tourism - footprint	2	4	8	L-M	Similar reasons to above. *Data confidence* • *High confidence that increased tourism development will remove habitat for birds* • *Low confidence around species diversity, community assemblages*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence around the extent to which birds would be impacted*
Y	Tourism - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
N	Tourism - solid waste					Considered under TOURIMS/VISITATION.
Y	Tourism - light	2	3	6	L-M	Similar reasons to above. *Data confidence* • *Medium confidence in the effect of light pollution on birds in general* • *Low confidence in the impact of light pollution on birds specifically in Exmouth*
Y	Tourism - noise	2	3	6	L-M	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from tourism developments* • *Low confidence in the diversity of birds in tourism areas* • *Low confidence in the impact of noise on birds*
Value: short range endemic invertebrates						
Y	Residential - footprint	2	4	8	L	Similar reasons to above. *Data confidence* • *Low confidence around the occurrence of short range endemics in residential footprints* • *Low confidence around the extent to which short range endemics would be impacted*
Y	Residential - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Data confidence • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Residential - solid waste	1	3	3	L	Similar reasons to above. *Data confidence* • *High confidence that residential solid waste is present in the area and illegal dumping occurs* • *Low confidence around the full extent and types of waste* • *Low confidence that short range endemics will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Residential - light	2	3	6	L	Similar reasons to above. *Data confidence* • *Low confidence around the occurrence of short range endemics in residential areas* • *Low confidence in the effect of light pollution on short range endemics in general or in Exmouth*
Y	Residential - noise	2	3	6	L	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from residential developments* • *Low confidence around the occurrence of short range endemics in residential areas* • *Low confidence in the impact of noise on short range endemics in general or in Exmouth*
Y	Industrial - footprint	2	4	8	L	Similar reasons to above. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence around the occurrence of short range endemics in industrial footprints* • *Low confidence around the extent to which short range endemics would be impacted*
Y	Industrial - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Industrial - solid waste	1	3	3	L	Similar reasons to above. *Data confidence* • *High confidence that industrial solid waste is present in the area* • *Low confidence around the full extent and types of waste* • *Low confidence that short range endemics will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Industrial - light	2	3	6	L	Similar reasons to above. *Data confidence* • *Low confidence around the occurrence of short range endemics in industrial areas* • *Low confidence in the effect of light pollution on short range endemics in general or in Exmouth*
Y	Industrial - noise	2	3	6	L	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from industrial developments* • *Low confidence around the occurrence of short range endemics in industrial areas*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence in the impact of noise on short range endemics in general or in Exmouth*
Y	Tourism - footprint	2	4	8	L	Similar reasons to above. *Data confidence* • *Low confidence around the occurrence of short range endemics in tourism footprints* • *Low confidence around the extent to which short range endemics would be impacted*
Y	Tourism - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
N	Tourism - solid waste					Considered under TOURIMS/VISITATION.
Y	Tourism - light	2	3	6	L	Similar reasons to above. *Data confidence* • *Low confidence around the occurrence of short range endemics in tourism development areas* • *Low confidence in the effect of light pollution on short range endemics in general or in Exmouth*
Y	Tourism - noise	2	3	6	L	Similar reasons to above. *Data confidence* • *High confidence that noise is generated from tourism developments* • *Low confidence around the occurrence of short range endemics in tourism areas* • *Low confidence in the impact of noise on short range endemics in general or in Exmouth*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Value: amphibians						
Y	Residential - footprint	1	4	4	L-M	Town site unlikely to broadly represent significant habitat for most species. If urban landscape support wetlands or areas that are episodically inundated and form breeding habitat there may be medium consequence but likely to be at the local scale only. *Data confidence* • *Medium confidence that increased infill will remove habitat for amphibians occuring in residential footprints* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which amphibians would be impacted*
Y	Residential - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Residential - solid waste	1	3	3	M	Similar reasons to reptiles above. *Data confidence* • *High confidence that residential solid waste is present in the area and illegal dumping occurs* • *Low confidence around the full extent and types of waste* • *Medium confidence that amphibians will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*
Y	Residential - light	1	3	3	L-M	Similar reasons to reptiles above. *Data confidence* • *Medium confidence in the effect of light pollution on amphibians in general*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence in the impact of light pollution on amphibians specifically in Exmouth*
Y	Residential - noise	1	3	3	L-M	Similar reasons to reptiles above. *Data confidence* • *High confidence that noise is generated from residential developments* • *Low confidence in the diversity of amphibians in residential areas* • *Low confidence in the impact of noise on amphibians*
Y	Industrial - footprint	2	4	8	L-M	Similar reasons to above. Similar as for reptiles albeit that there is significantly less diversity in the frog community. Greatest risks are associated with habitat clearing and changes to drainage or areas of episodic flooding. *Data confidence* • *Medium confidence that increased industrial developments will remove habitat for amphibians* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which amphibians would be impacted*
Y	Industrial - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
Y	Industrial - solid waste	1	3	3	M	Similar reasons to reptiles above *Data confidence* • *High confidence that industrial solid waste is present in the area* • *Low confidence around the full extent and types of waste* • *Medium confidence that amphibians will be present at sites affected by solid waste* • *Low confidence around the impact of waste on fauna in the area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Industrial - light	1	3	3	L-M	Similar reasons to reptiles above. *Data confidence* • *Medium confidence in the effect of light pollution on amphibians in general* • *Low confidence in the impact of light pollution on amphibians specifically in Exmouth*
Y	Industrial - noise	1	3	3	L-M	Similar reasons to reptiles above *Data confidence* • *High confidence that noise is generated from industrial developments* • *Low confidence in the diversity of amphibians in industrial areas* • *Low confidence in the impact of noise on amphibians*
Y	Tourism - footprint	2	4	8	L-M	Similar reasons to reptiles above *Data confidence* • *Medium confidence that increased tourism developments will remove habitat for amphibians* • *Low confidence around species diversity, community assemblages* • *Low confidence around the extent to which amphibians would be impacted*
y	Tourism - groundwater drawdown	3	2	6	M	Groundwater drawdown has the potential to indirectly impact terrestrial fauna habitat e.g., vegetation and wetlands *Data confidence* • *High confidence that groundwater drawdown can impact flora and vegetation and, in turn, fauna* • *Low confidence around how fauna have or will be impacted in the Exmouth area*
N	Tourism - solid waste					Considered under TOURIMS/VISITATION.
Y	Tourism - light	1	3	3	L-M	Similar reasons to reptiles above *Data confidence* • *Medium confidence in the effect of light pollution on amphibians in general*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence in the impact of light pollution on amphibians specifically in Exmouth*
Y	Tourism - noise	1	3	3	L-M	Similar reasons to reptiles above *Data confidence* • *High confidence that noise is generated from tourism developments* • *Low confidence in the diversity of amphibians in tourism areas* • *Low confidence in the impact of noise on amphibians*
Factor: Landforms						
Value: islands						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
N	Industrial - footprint					
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	1	4	4	H	A couple of islands have accommodation. Uncertain whether island accommodation and activities will increase, but unlikely. *Data confidence* • *High confidence about locations and extent of the tourism footprint on the islands*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					Assessed under TOURISM/VISITATION.
N	Tourism - light					
N	Tourism - noise					
Value: karst systems						
Y	Residential - footprint	1	3	3	M	There is not a good understanding of the linkages between karsts systems and how connected they are. Impacts of gardening, fertiliser, runoff, household waste should be considered. There have been changes in the way stormwater is managed - it runs off quickly rather than soaking into the landscape. Hardening of surfaces changes storm water runoff e.g., concrete, bitumen, roofs. *Data confidence* • *High confidence about current and future residential footprint* • *Medium confidence about extent of karst systems close to the residential area*
Y	Residential - groundwater drawdown	3/4	3	9-12	H	There has been a measurable drawdown of water table in Watercorp bore field. This has the potential to impact upon larger areas of the karst system than it currently does - particularly with new subdivisions, increased tourism and the need to populate out the light industrial area. Groundwater resources on the Exmouth peninsula are limited due to the relatively small size of the peninsula and low rainfall. The Exmouth Town Water Supply (TWS) bore field is located immediately west of town in the Town and Central sub-areas. The bore field extends about 7km southwards along the eastern flank of Cape Range, and consists of 34 Production bores, 10 of which were drilled in 2007/08, solar panels to power these bores were installed in June 2017. The bore field also contains 22 monitoring bores consisting of saltwater interface monitoring bores (SWIM) and stygofauna habitat monitoring bores (SHM). The production bores abstract

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						fresh to brackish groundwater from the unconfined Cape Range aquifer between 30m and 200m below ground level. Groundwater resources are subdivided into five regions in the Exmouth area, each with varying levels of groundwater available. As well as the main Exmouth town water supply, there are other backyard bores and the navy also contributes to the drawdown of groundwater. The navy has a desalination plant and can create fresh water on site. Water stress: impact on subterranean waterways is likely. Stress can occur through drying up of freshwater lens that supports stygofauna and can also change the humidity in the caves which is important for troglofauna. Troglofauna need humidity to exist. Spatial extent of the impact of the drawdown of fresh water is uncertain in terms of how it will impact on overall karst system and values. Some gaps in knowledge on distribution of species along Exmouth side of Cape Range. Organisms are genetically distinct from western side of Cape Range. Water drawdown will have an impact on eastern fauna - so knowledge of the spatial extent of impact from drawdown is important. Karst management Considerations for the Cape Range Karst Province, Western Australia” (Hamilton-Smith et al. 1998). This report is a key reference that outlines a number of threats (EPA). *Data confidence* • *High confidence about current and future residential footprint* • *High confidence that expanded residential footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Residential - solid waste (litter, pollution) - includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	Potential for pollutants for get down into karst systems, e.g., has happened diesel spills from flooding events, Per- and polyfluoroalkyl substances (PFAS) contamination from firefighting foams, sewage treatment, pre-existing and historical rubbish tips. Each waste source has potential to leach contaminants. People throw litter down holes e.g., cans/beer bottles. People throw rocks (big boulders) down holes. Some rubbish types would have a local impact, and some would have a larger impact. Darren Brooks (does expedition into holes and has mapped most of karst features in Cape Range). Pollution, and dumping of rubbish or toxic waste was listed as a potential threat to Camerons Cave in *the Camerons Cave troglobitic community, Camerons Cave millipede and Camerons Cave pseudoscorpion Interim Recovery Plan 2012-2017* as well as for Bundera Sinkhole - *Cape Range remipede community (Bundera Sinkhole) and Cape Range remipede Interim Recovery Plan 2000-2003* (EPA). *Data confidence* • *High confidence that expanded residential footprint will result in more residential solid waste* • *High confidence that karst systems would be very sensitive to any increase in solid waste entering the systems* • *Low confidence around the full extent of waste impacting karsts systems*
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	1	3	3	M	Can cause changes to run-off which can impact runoff into karst systems - hardening of surfaces, concrete, bitumen, roofs *Data confidence* • *Medium confidence about future industrial footprint* • *Medium confidence about extent of karst systems close to the industrial area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Industrial - groundwater drawdown	3/4	3	9-12	M-H	See 'residential groundwater' - hard to separate out residential, industrial and tourism drawdown of groundwater as coming from same sources. Do not know the proportion each takes. *Data confidence* • *Medium confidence about future industrial footprint* • *High confidence that expanded industrial footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems*
Y	Industrial - solid waste - includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	Similar waste issues to above. *Data confidence* • *High confidence that expanded industrial footprint will result in more industrial solid waste* • *High confidence that karst systems would be very sensitive to any increase in solid waste entering the systems* • *Low confidence around the full extent of waste impacting karsts systems*
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	1	3	3	M	Similar considerations to residential and industrial *Data confidence* • *Medium confidence about future tourism footprint* • *Medium confidence about extent of karst systems close to the tourism area*
Y	Tourism - groundwater drawdown	3/4	3	9-12	M-H	See 'residential groundwater' - Hard to separate out residential, industrial and tourism drawdown of groundwater as coming from same sources. Do not know the proportions each takes. *Data confidence* • *Medium confidence about future tourism footprint*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that expanded tourism footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems*
N	Tourism - solid waste - includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants					Scored under TOURISM/VISITATION
N	Tourism - light					
N	Tourism - noise					
Y	Sedimentation	2	4	8	M	Sedimentation - some systems/holes been filled in by sediments due to changes in hydrology. Changes in storm water runoff regimes has led to exposure of holes to water flow, which has then led to dumping of sediments into the holes. *Data confidence* • *High confidence that any changes or increases in sedimentation would negatively impact karst systems* • *Low confidence in the quantifiable impacts of sedimentation to karst systems so far*
Factor: Subterranean fauna						
Value: troglofauna						
Y	Residential - footprint	1	3	3	M-H	For reasons given above regarding impacts to karst systems, could expect scores to fauna, which depend on the systems, to be similar. *Data confidence* • *High confidence about current and future residential footprint* • *Medium confidence about the occurrence of troglofauna near residential area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Residential - groundwater drawdown	3	3	9	H	Water stress: impact on subterranean waterways is likely. Stress can occur through drying up of freshwater lens that supports stygofauna and can also change the humidity in the caves which is important for the troglofauna. Depends on humid conditions and changes to this, and on the amount of water that comes into karst systems. Groundwater drawdown can reduce humidity. EPA - From the Cameron's Cave Interim Recovery Plan "Water levels in the Exmouth borefield bores fell between 1981 and 1991, apparently due to low rainfall (Lee 2008) and, concurrently, salinity has increased across many bores in the borefield. The freshwater lens has thinned and there has been more mixing with seawater in the northern half of the borefield presumably because of a longer history of excessive abstraction relative to recharge, and due to higher conductivities in the Upper Tulki Karst Aquifer (Lee 2008). Increasing groundwater salinity was also noted in periods of lower rainfall (Lee 2008). The lens has thinned considerably with seawater intrusion mainly due to historical groundwater abstraction, long term below average rainfall and tidal influences (Lee 2008). The sustainability of the aquifer will be dependent on ensuring that drawdown does not cause seawater to encroach into the aquifer, as this kind of damage to aquifers is not reversible (Lee 2008). A lot of subterranean fauna have limited distributions of 500 m radius. There is a lack of resolution and knowledge on genetic structure for a lot of populations. *Data confidence* • *High confidence about current and future residential footprint* • *High confidence that expanded residential footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems and, in turn, troglofauna*
Y	Residential - solid waste includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	As above for karst systems *Data confidence* • *High confidence that expanded residential footprint will result in more residential solid waste*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that karst systems and, in turn, troglofauna, would be very sensitive to any increase in solid waste entering the systems* • *Low confidence around the full extent of waste impacting troglofauna*
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	1	3	3	M	As above for karst systems *Data confidence* • *Medium confidence about future industrial footprints* • *Medium confidence about the occurrence of troglofauna near industrial areas*
Y	Industrial - groundwater drawdown	3	3	9	M-H	As above for karst systems *Data confidence* • *Medium confidence about future industrial footprint* • *High confidence that expanded industrial footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems and, in turn, troglofauna*
Y	Industrial - solid waste includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	As above for karst systems *Data confidence* • *High confidence that expanded industrial footprint will result in more industrial solid waste* • *High confidence that karst systems and, in turn, troglofauna, would be very sensitive to any increase in solid waste entering the systems* • *Low confidence around the full extent of waste impacting troglofauna*
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	1	3	3	M	As above for karst systems

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Data confidence • *Medium confidence about future tourism footprints* • *Medium confidence about the occurrence of troglofauna near tourism areas*
Y	Tourism - groundwater drawdown	3	3	9	M-H	As above for karst systems *Data confidence* • *Medium confidence about future tourism footprint* • *High confidence that expanded tourism footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems and, in turn, troglofauna*
N	Tourism - solid waste					Scored under TOURISM/VISITATION.
N	Tourism - light					
N	Tourism - noise					
Y	Sedimentation	2	4	8	M	As above for karst systems. *Data confidence* • *High confidence that any changes or increases in sedimentation would negatively impact karst systems and, in turn, troglofauna* • *Low confidence in the quantifiable impacts of sedimentation to troglofauna so far*
Value: stygofauna						
Y	Residential - footprint	1	3	3	M-H	As above for karst systems *Data confidence* • *High confidence about current and future residential footprint* • *Medium confidence about the occurrence of stygofauna near residential area*
Y	Residential - groundwater drawdown	3	3	9	H	Highly stratified groundwater feature, freshwater lens and different physiochemical properties for different strata result if different species exist within each stratum. Some may only exist in certain strata and others can span across multiple.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Increased groundwater drawdown could cause increased salinity from seawater intrusion, which can also impact the karst and stygofauna. There are distinct gradients of salinity in the anchialine systems in Cape Range and different fauna species inhabit different layers, and some are sensitive to the mixing of the water layers and cannot tolerate changed water chemistry (EPA). Also, water drawdown leads to loss of stygofauna habitat. A lot of subterranean fauna have limited distributions of 500 m radius. There is a lack of resolution and knowledge on genetic structure for a lot of populations. Cape Range remipedes: one species has now been divided up into three. One occurs in the south of Cape Range and two in north. Distinct barrier between populations. Need to investigate further. *Kumonga exleyi* (Cape Range remipede) is currently considered critically endangered. 10 other species are also Listed species - either endangered, threatened or Priority 4. *Data confidence* • *High confidence about current and future residential footprint* • *High confidence that expanded residential footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems and, in turn, stygofauna*
Y	Residential - solid waste includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	As above for karst systems *Data confidence* • *High confidence that expanded residential footprint will result in more residential solid waste* • *High confidence that karst systems and, in turn, stygofauna, would be very sensitive to any increase in solid waste entering the systems* • *Low confidence around the full extent of waste impacting stygofauna*
N	Residential - light					
N	Residential - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Industrial - footprint	1	3	3	M	As above for karst systems *Data confidence* • *Medium confidence about future industrial footprints* • *Medium confidence about the occurrence of stygofauna near industrial areas*
Y	Industrial - groundwater drawdown	3	3	9	M-H	As above for karst systems *Data confidence* • *Medium confidence about future industrial footprint* • *High confidence that expanded industrial footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems and, in turn, stygofauna*
Y	Industrial - solid waste includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	As above for karst systems *Data confidence* • *High confidence that expanded industrial footprint will result in more industrial solid waste* • *High confidence that karst systems and, in turn, stygofauna, would be very sensitive to any increase in solid waste entering the systems* • *Low confidence around the full extent of waste impacting stygofauna*
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	1	3	3	M	As above for karst systems *Data confidence* • *Medium confidence about future tourism footprints* • *Medium confidence about the occurrence of stygofauna near tourism areas*
Y	Tourism - groundwater drawdown	3	3	9	M-H	As above for karst systems *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Medium confidence about future tourism footprint* • *High confidence that expanded tourism footprint will result in higher groundwater drawdown* • *High confidence that higher groundwater drawdown will affect karst systems and, in turn, stygofauna*
N	Tourism - solid waste					Scored under TOURISM/VISITATION.
N	Tourism - light					
N	Tourism - noise					
Y	Sedimentation	2	4	8	M	As above for karst systems *Data confidence* • *High confidence that any changes or increases in sedimentation would negatively impact karst systems and, in turn, stygofauna* • *Low confidence in the quantifiable impacts of sedimentation to stygofauna so far*
Factor: Terrestrial environmental quality						
Value: topsoil						
Y	Residential - footprint	1	4	4	H	Topsoil would be removed, and the ground covered in concrete with additional development. *Data confidence* • *High confidence about plans for future expansion of residential footprint* • *High confidence that damage, disturbance, removal of topsoil will occur with any terrestrial development*
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Y	Industrial - footprint	1	4	4	M-H	Topsoil would be removed, and the ground covered in concrete with additional development. *Data confidence* • *Medium confidence about future expansion of industrial footprint* • *High confidence that damage, disturbance, removal of topsoil will occur with any terrestrial development*
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	1	4	4	H	Topsoil would be removed, and the ground covered in concrete with additional development. *Data confidence* • *Medium confidence about future expansion of tourism footprint* • *High confidence that damage, disturbance, removal of topsoil will occur with any terrestrial development*
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
Factor: Flora & vegetation						
Value: Coastal plains						
Y	Limestone - footprint	1	4	4	M	Limestone mining already existing and the footprint has caused/is causing damage to flora and vegetation of the coastal plains. Expansions of footprint may remove surrounding vegetation. Uncertainty as to whether land for expansion is already cleared? *Data confidence* • *High confidence that expanded operations will remove flora and vegetation* • *Low confidence in the species and complexes that would be impacted*
N	Limestone - operation					
N	Limestone - groundwater drawdown					Groundwater considered under WATER theme
Y	Industrial salt facility - footprint	1	4	4	M	Vegetation inland of saltmarshes and mangroves needs to be considered here. Footprint could directly remove vegetation or disrupt localised connectivity patterns. Probably not as much as mangroves and saltmarshes? Flow on impacts on hydrology, surface runoff, and subsurface water flow needs to be considered. *Data confidence* • *High confidence that some vegetation will be impacted by an industrial salt farm footprint* • *Medium confidence around the details and extent of industrial salt farm footprint* • *Low confidence in the species and complexes that would be impacted specifically along the eastern margin*
Y	Potash - footprint	1	3	4	M	Uncertainty on how large the potash footprint would be. Vegetation inland of saltmarshes and mangroves needs to be considered here.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						Footprint could directly remove vegetation or disrupt localised connectivity patterns. e.g., impact on hydrology, surface runoff, and subsurface water flow. *Data confidence* • *High confidence that some vegetation will be impacted by potash footprint* • *Medium confidence around the details and extent of potash footprint* • *Low confidence in the species and complexes that would be impacted specifically*
N	Potash - abstraction of brine					
Value: Limestone cliffs & gullies						
Y	Limestone - footprint	1	4	4	M	Expansion could result in removal of vegetation at a localised scale. *Data confidence* • *Medium confidence that expanded operations will remove flora and vegetation* • *Low confidence in the species and complexes that would be impacted*
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: Coastal dunes						
N	Limestone - footprint					
N	Limestone - operation					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: Threatened/priority flora						
Y	Limestone - footprint	1	3	3	L-M	Uncertainty around the distribution and abundance of priority flora. Some impact possible. *Data confidence* • *Low confidence that expanded operations will remove threatened and priority flora due to unknown extent of flora* • *Medium confidence in the species occuring on the Cape Range Peninsula - 22 priority species (DBCA 2019b; Meissner 2011)*
N	Limestone - operation					
N	Limestone - groundwater drawdown					Groundwater considered under WATER theme.
Y	Industrial salt facility - footprint	1	4	4	L-M	Vegetation inland of saltmarshes and mangroves needs to be considered here. Footprint could directly remove vegetation or disrupt localised connectivity patterns. Probably not as much as mangroves and saltmarshes? e.g., impact on hydrology, surface runoff, and subsurface water flow. *Data confidence* • *Low confidence that threatened and priority flora occur in the footprint and will be impacted by industrial salt farm footprint - EPA (2008) reported nine priority flora species were possibly present at the proposed Yannarie Salt Mine site but were not found in surveys.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *Medium confidence around the details and extent of industrial salt farm operations*
Y	Potash - footprint	1	3	4	L-M	Vegetation inland of saltmarshes and mangroves need to be considered here. Footprint could directly remove vegetation or disrupt localised connectivity patterns. e.g., impact on hydrology, surface runoff, and subsurface water flow. Uncertainty on how large potash footprint would be. *Data confidence* • *Low confidence that threatened and priority flora occur in the footprint and will be impacted by potash footprint* • *Medium confidence around the details and extent of footprint operations*
N	Potash - abstraction of brine					
Factor: Terrestrial fauna						
Value: Reptiles						
Y	Limestone - footprint	2	4	8	M	Similar to industrial development, depending on size of footprint and where mining occurs. Lack of detail around species distributions and faunal assemblages associated with habitat. Priority listed species exist in the area more broadly and taxonomic work continues to reveal new species across Cape Range. *Data confidence* • *High confidence that expanded footprint will impact reptiles, and likely endemic species - see DEC (2010)* • *Medium confidence in the details and extent of proposed footprint* • *Low confidence in reptile abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining on those reptiles*
Y	Limestone - operation	1	4	4	M	Vibrations from machinery and blasting would be a consideration. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *High confidence that expanded operations will impact reptiles, and likely endemic species - see DEC (2010)* • *Medium confidence in the details and extent of proposed operations* • *Low confidence in reptile abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining on those reptiles*
N	Limestone - groundwater drawdown					Groundwater considered under WATER theme.
Y	Industrial salt facility - footprint	2	3	6	M-H	Lack of detail around species distributions and faunal assemblages associated with habitat. Priority listed species exist in the area more broadly and taxonomic work continues to reveal new species across Cape Range. Potentially a large displacement of animals due to destruction of habitat. Uncertainty on the diversity and distribution across salt flats, as well as the use of salt flats for foraging etc. Reptiles can often be found in harsh conditions. *Data confidence* • *High confidence that footprint will impact reptiles* • *Medium confidence in the details and extent of proposed footprint* • *Medium confidence that native reptile species are present at proposed salt mining sites e.g., 58 native reptile species were recorded during surveys of the proposed Yannarie Salt Mine site (EPA 2008).*
Y	Potash - footprint	2	3	6	M-H	Lack of detail around species distributions and faunal assemblages associated with habitat. Priority listed species exist in the area more broadly and taxonomic work continues to reveal new species across Cape Range. *Data confidence* • *High confidence that footprint will impact reptiles* • *Medium confidence in the details and extent of proposed footprint* • *Medium confidence that native reptile species are present at proposed pot ash mining sites e.g., 58 native reptile species were recorded during surveys of the proposed Yannarie Salt Mine site (EPA 2008).*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Potash - abstraction of brine					
Value: mammals						
Y	Limestone - footprint	1	4	4	M	Expanded footprints are likely to remove habitat, as well as displace (push out) fauna. Already a cleared and impacted area. *Data confidence* • *High confidence that expanded footprint will impact mammals - see DEC (2010)* • *Medium confidence in the details and extent of proposed footprint* • *Low confidence in mammal abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining on those mammals*
Y	Limestone - operation	1	4	4	M	Vibrations from machinery and blasting would be a consideration. *Data confidence* • *High confidence that expanded operations will impact mammals - see DEC (2010)* • *Medium confidence in the details and extent of proposed operations* • *Low confidence in mammal abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining on those mammals*
N	Limestone - groundwater drawdown					Groundwater considered under WATER theme.
Y	Industrial salt facility - footprint	1	2	2	L-M	**More knowledge needed** about likelihood, extent, severity, timeframe of how industrial salt facility would affect mammals. Macropods occasionally take advantage of low tides to visit the inshore islands (DBCA 2020) and the red fox has been able to cross flats at low tide to Burnside, Tent, Sandalwood and Hope Point islands (Abbott and Wills 2011) *Data confidence* • *Medium confidence that footprint will impact mammals which transiently use the area* • *Medium confidence in the details and extent of proposed footprint*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *Low confidence in the diversity of mammals and the extent of impact*
Y	Potash - footprint	1	2	2	L-M	As above. *Data confidence* • *Medium confidence that footprint will impact mammals which transiently use the area* • *Medium confidence in the details and extent of proposed footprint* • *Low confidence in the diversity of mammals and the extent of impact*
N	Potash - abstraction of brine					
Value: birds						
Y	Limestone - footprint	1	4	4	M-H	Expanded footprints are likely to remove habitat, as well as displace (push out) fauna. Already a cleared and impacted area. *Data confidence* • *High confidence that expanded footprint will impact birds* • *Medium confidence in the details and extent of proposed footprint* • *Medium confidence round the diversity of birds in the area, but not abundance and distribution e.g., Peregrine falcon (Falco peregrinus), listed as Schedule 4 (Specially Protected), and new subspecies of rufous grasswren (Amytornis whitei) discovered in 2020 on the limestone plateau - see Black et al. (2020)*
Y	Limestone - operation	1	4	4	M-H	Vibrations from machinery and blasting would be a consideration. *Data confidence* • *High confidence that expanded operations will impact birds* • *Medium confidence in the details and extent of proposed operations* • *Medium confidence round the diversity of birds in the area, but not abundance and distribution e.g., Peregrine falcon (Falco peregrinus), listed as Schedule 4 (Specially Protected), and new subspecies of rufous grasswren (Amytornis whitei) discovered in 2020 on the limestone plateau - see Black et al. (2020)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Limestone - groundwater drawdown					Groundwater considered under WATER theme.
Y	Industrial salt facility - footprint	1	3	3	M-H	Could reduce prey options for birds on salt flats. Uncertain whether birds use the salt flats extensively. *Data confidence* • *High confidence that footprint will impact birds which use the area* • *Medium confidence in the details and extent of proposed footprint* • *High confidence that many bird species are present within proposed salt facility sites e.g., 57 bird species were recorded during surveys of the Yannarie Solar Salt site - EPA (2008)*
Y	Potash - footprint	1	3	3	M-H	Could reduce prey options for birds on salt flats. Uncertain whether birds use the salt flats extensively. *Data confidence* • *High confidence that footprint will impact birds which use the area* • *Medium confidence in the details and extent of proposed footprint* • *High confidence that many bird species are present within proposed salt facility sites e.g., 57 bird species were recorded during surveys of the Yannarie Solar Salt site - EPA (2008)*
N	Potash - abstraction of brine					
Value: short range endemic invertebrates						
Y	Limestone - footprint	1	4	4	L	Several species of endemic Camnaeid land snails are specialised to rock-face habitat and are only known from single gorges. Expanded footprints are likely to remove habitat, as well as displace (push out) fauna. Already a cleared and impacted area. *Data confidence* • *Low confidence that expanded footprint will impact short range endemics*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *Medium confidence in the details and extent of proposed footprint* • *Low confidence in short range endemics abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining on those short range endemics*
Y	Limestone - operation	1	4	4	L	Vibrations from machinery and blasting would be a consideration. *Data confidence* • *Low confidence that expanded operations will impact short range endemics* • *Medium confidence in the details and extent of proposed operation* • *Low confidence in short range endemics abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining on those short range endemics*
N	Limestone - groundwater drawdown					Groundwater considered under WATER theme.
Y	Industrial salt facility - footprint	2	3	6	L	**More knowledge needed** on whether short range endemics are occurring along the salt flats. *Data confidence* • *Low confidence in short range endemics abundance and distribution along the eastern margin and in the footprint area* • *Medium confidence in the details and extent of proposed footprint*
Y	Potash - footprint	2	3	6	L	As above. *Data confidence* • *Low confidence in short range endemics abundance and distribution along the eastern margin and in the footprint area* • *Medium confidence in the details and extent of proposed footprint*
N	Potash - abstraction of brine					

Value: amphibians

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
Y	Limestone - footprint	1	4	4	L	Expanded footprints are likely to remove habitat, as well as displace (push out) fauna. Already a cleared and impacted area. Probably lower consequence than for reptiles unless alteration of breeding habitat occurs. *Data confidence* • *Low confidence that expanded footprint will impact amphibians* • *Low confidence in amphibian abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining*
Y	Limestone - operation	1	4	4	L	Vibrations from machinery and blasting would be a consideration. As above. *Data confidence* • *Low confidence that expanded operations will impact amphibians* • *Low confidence in amphibian abundance and distribution in the limestone area & extent, severity, timeframe of impact of limestone mining*
N	Limestone - groundwater drawdown					
Y	Industrial salt facility - footprint	1	2	2	M-H	Some amphibians would be occurring along salt flats. Five native amphibians have been recorded during surveys of the Yannarie Solar Salt site (EPA 2008). *Data confidence* • *High confidence that footprint will impact amphibian which use the area* • *Medium confidence in the details and extent of proposed footprint* • *High confidence that amphibian species are present within proposed salt facility sites - EPA (2008)*
Y	Potash - footprint	1	2	2	M-H	Some amphibians would be occurring along salt flats. Five native amphibians have been recorded during surveys of the Yannarie Solar Salt site (EPA 2008). *Data confidence* • *High confidence that footprint will impact amphibian which use the area* • *Medium confidence in the details and extent of proposed footprint*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *High confidence that amphibian species are present within proposed salt facility sites - EPA (2008)*
N	Potash - abstraction of brine					
MINING						
Factor: Landforms						
Value: islands						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Salt farm - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: karst systems						
Y	Limestone - footprint	2	3/4	6-8	M	Production of limestone is proposed to increase significantly. Uncertainty around how much water is used for limestone mining. Anecdotally some sub-feature opened up due to mining and organisms have been found. Highly desirable product for metallurgy. Hard to score as definition does not really apply to geological features. We do not know how connected the systems are. There will not be a recovery of the landform removed, but can it be sacrificed because there are more of them nearby? **More knowledge needed.** *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *High confidence that karst features have been found in the vicinity of limestone quarry areas* • *Medium confidence in details and extent of proposed limestone footprint* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems*
Y	Limestone - operation	1	4	4	M	Vibrations from machinery and blasting would be a consideration. Not a lot of understanding here. • *High confidence that karst features have been found in the vicinity of limestone quarry areas* • *Medium confidence in details and extent of proposed limestone operations* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems*
Y	Limestone - groundwater drawdown	2	4	8	M	Production of limestone is proposed to increase significantly. Not enough knowledge. Is dewatering needed? Are they draining nearby water from karsts systems? *Data confidence* • *High confidence that limestone quarrying affects groundwater chemistry & physical properties generally (e.g. Marzouk, S.H. (2018). Influences of limestone stone quarries on groundwater quality. Int. J. Hum. Capital Urban Manage., 3(4): 315-324, Autumn 2018* • *Medium confidence in details and extent of proposed limestone operations* • *High confidence that higher groundwater drawdown will affect karst systems* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems*
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
Factor: Subterranean fauna						
Value: troglofauna						
Y	Limestone - footprint	2	3/4	6-8	M	For reasons given above regarding the karst system, which supports subterranean fauna, scoring would likely be the same. *Data confidence* • *High confidence that karst features have been found in the vicinity of limestone quarry areas* • *Medium confidence in details and extent of proposed limestone footprint* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems and troglofauna*
Y	Limestone - operation	1	4	4	M	Vibrations from machinery and blasting would be a consideration. *Data confidence* • *High confidence that karst features have been found in the vicinity of limestone quarry areas* • *Medium confidence in details and extent of proposed limestone operations* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems and troglofauna*
Y	Limestone - groundwater drawdown	2	4	8	M	Production of limestone is proposed to increase significantly. Not enough knowledge. Is dewatering needed? Are they draining nearby water from karsts systems? Troglofauna will be impacted if humidity conditions change *Data confidence* • *High confidence that higher groundwater drawdown will affect karst systems and the humid conditions for troglofaunal* • *Medium confidence in details and extent of proposed limestone operations* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems and troglofauna*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: stygofauna						
Y	Limestone - footprint	2	3/4	6-8	M	For reasons given above regarding the karst system, which supports subterranean fauna, scoring would likely be the same. *Data confidence* • *High confidence that karst features have been found in the vicinity of limestone quarry areas* • *Medium confidence in details and extent of proposed limestone footprint* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems and stygofauna*
Y	Limestone - operation	1	4	4	M	Vibrations from machinery and blasting would be a consideration. *Data confidence* • *High confidence that karst features have been found in the vicinity of limestone quarry areas* • *Medium confidence in details and extent of proposed limestone operations* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems and stygofauna*
Y	Limestone - groundwater drawdown	2	4	8	M-H	Possible effects: loss of habitat for unique, endemic subterranean fauna (including listed species) and changes to water chemistry and salinity from drawdown. *Data confidence* • *High confidence that limestone quarrying affects groundwater chemistry & physical properties generally (e.g. Marzouk, S.H. (2018). Influences of limestone*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						stone quarries on groundwater quality. Int. J. Hum. Capital Urban Manage., 3(4): 315-324, Autumn 2018 • *High confidence that higher groundwater drawdown will affect karst systems and the water chemistry conditions for stygofauna* • *Medium confidence in details and extent of proposed limestone operations* • *Low confidence about extent, severity, timeframe of effects of future expanded limestone quarrying on karst systems and stygofauna*
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Factor: Terrestrial environmental quality						
Value: topsoil						
Y	Limestone - footprint	1	3	3	M-H	Removal of topsoil would likely occur for expansion of the quarry. *Data confidence* • *Medium confidence in details and extent of proposed limestone footprint* • *High confidence expanded footprint would remove topsoil*
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
Factor: Flora & vegetation						
Value: Coastal plains						
Y	Overgrazing	2	3	6	M	Note that runoff/contamination is a by-product of overgrazing. This rating really depends on the continued cooperation of responsible pastoral land managers to ensure stocking rates are appropriate. It is possible that future land activities on pastoral land presents a risk to the coastal plain, particularly as the majority of pastoral tenure is within the coastal plains area. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area* • *Low confidence around up to date data on the current extent and impacts of overgrazing on coastal plain vegetation*
Y	Pests/feral animals	2	4	8	M-H	Land managers are responsible for managing the spread of weeds and controlling feral species on pastoral lands. Pest species are an ongoing threat that requires constant management over large areas of land. The majority of pastoral tenure is within the coastal plains area. *Data confidence* • *High confidence that feral animals are present in the area* • *High confidence that feral herbivores have significant impact on coastal plain flora* • *Low confidence around up to date data about the abundance & distribution of feral herbivores & the effects they are having on native flora in Exmouth*
Value: Limestone cliffs & gullies						
Y	Overgrazing	2/3	3	6-9	M	Gullies are more relevant in the pastoral land space than cliffs. Cattle and other pastoral animals are attracted to and gather at water source areas such as gullies. The congregation of species at these locations leads to degradation of landscapes and habitats for native species. Overgrazing may lead to changes in water quality in ephemeral gully systems and movement of soil into the ocean.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						Data confidence • *High confidence that overgrazing has occurred/is occurring in the area* • *Low confidence around up to date data on the current extent and impacts of overgrazing on limestone and gully vegetation*
Y	Pests/feral animals	2	4	8	M-H	Large feral herbivores such as goats, donkeys and camels are attracted to areas with water such as gullies. Weeds can also infest areas with permanent water sources. Feral animals and weeds can change gully landscapes. *Data confidence* • *High confidence that feral animals are present in the area* • *High confidence that feral herbivores have significant impact on flora and vegetation* • *Low confidence around up to date data about the abundance & distribution of feral herbivores & the effects they are having on native flora in Exmouth*
Value: Coastal dunes						
Y	Overgrazing	2	3	6	M	Note that runoff/contamination is a by-product of over-grazing. Runoff and trampling of vegetation from overgrazing may impact on some coastal dune systems, depending on the how close pastoral land is to the Exmouth Gulf and whether appropriate containment/fencing is available to ensure stock do not venture into coastal systems. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area* • *Low confidence around up to date data on the current extent and impacts of overgrazing on coastal dune vegetation*
Y	Pests/feral animals	2	4	8	M-H	As above *Data confidence* • *High confidence that feral animals are present in the area* • *High confidence that feral herbivores have significant impact on vegetation and flora*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						• *Low confidence around up to date data about the abundance & distribution of feral herbivores & the effects they are having on native flora in Exmouth*
Value: Threatened/priority flora						
Y	Overgrazing	3	3	9	L-M	It is assumed that there are some threatened or priority species on pastoral lands, even though the baseline data is weak. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area* • *Low confidence around up to date data on the current extent and impacts of overgrazing on coastal dune vegetation* • *Low confidence in the distribution of threatened and priority flora*
Y	Pests/ feral animals	3	3	9	L-M	As above *Data confidence* • *High confidence that feral animals are present in the area* • *Low confidence around up to date data about the abundance & distribution of feral herbivores & the effects they are having on threatened and priority flora in Exmouth* • *Low confidence in the distribution of threatened and priority flora*
Factor: Terrestrial fauna						
Value: Reptiles						
Y	Overgrazing	3	4	12	M-H	Habitat degradation/loss through intensive trampling of foraging and denning areas. Because of the scale of pastoral activity and the continuing alteration of habitat this activity probably poses the greatest risk to individual species and the maintenance of species community structure. Issues are confounded through lack of detailed knowledge around patterns of distribution for reptile fauna around the periphery of the gulf. Interactions between grazing, weed invasion, soil compaction and or loss, fire and predator activity can have compounding and long-term detrimental impacts *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						• *High confidence that overgrazing has occurred/is occurring in the area* • *High confidence that overgrazing impacts reptiles generally* • *Low confidence around reptile assemblage(s) in the area and the extent, severity, timeframe of any effects*
Y	Pests/ feral animals	3	4	12	M-H	Feral animals can compete with native animals for habitat and food. Feral animals also predate native animals. Weeds can degrade habitat and cause changes in landscapes. Weed invasion is capable of permanently altering landscapes at large scales, generally with a resulting loss in species diversity. Predation may be detrimental to a number of species but particularly to larger less abundant species. Grazing by feral animals may have similar impacts to those of pastoralism more generally. Complexities between interactions of all these elements at landscape scales elevate the risks. Lack of knowledge around species distributional patterns inject uncertainty into what has occurred and what may continue to occur (same for all of the broader land usage and altering Note: Cane toads may be present in the Gulf within 10 years. If this does occur, then the risk would be much higher, particularly regarding reptiles. However, this is not necessarily a pastoral-only related pressure. *Data confidence* • *High confidence that feral animals are present* • *High confidence that feral animals affect reptiles generally* • *Low confidence about reptile assemblages in the Exmouth area and the extent and severity of any effects*
Value: mammals						
Y	Overgrazing	1/2	3	3-6	M-H	Small mammals are more likely to be affected with cattle likely to trample foraging and denning habitats. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area* • *High confidence that overgrazing impacts mammals generally* • *Low confidence around mammal assemblage(s) in the area and the extent, severity, timeframe of any effects*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
Y	Pests/ feral animals	1	3	3	M-H	Feral herbivores (goats, donkeys, camels etc.) and other feral animals compete for food, water and habitat. Feral animals also predate native animals. *Data confidence* • *High confidence that feral animals are present* • *High confidence that feral animals affect mammals generally* • *Low confidence about mammals assemblages in the Exmouth area and the extent and severity of any effects*
Value: birds						
Y	Overgrazing	1	3	3	M-H	Degradation/loss of bird habitats is likely from intensive trampling of foraging and nesting areas. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area* • *High confidence that overgrazing impacts birds generally* • *Medium confidence around bird assemblage(s) in the Exmouth area and the extent, severity, timeframe of any effects*
Y	Pests/ feral animals	1	3	3	M-H	Feral animals can compete with native animals for habitat and food. Feral animals also predate native animals. *Data confidence* • *High confidence that feral animals are present* • *High confidence that feral animals affect birds generally* • *Medium confidence about bird assemblages in the Exmouth area and the extent and severity of any effects*
Value: short range endemic invertebrates						
Y	Overgrazing	1	3	3	M	Habitat degradation/loss through intensive trampling of mosaic vegetation. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						• *Low confidence around short range endemic assemblage(s) in the Exmouth area and the extent and severity of any effects*
Y	Pests/ feral animals	1	3	3	M	Pests/feral animals could completely change the mosaic habitats needed for short-range endemic fauna. *Data confidence* • *High confidence that feral animals are present* • *Low confidence around short range endemic assemblage(s) in the Exmouth area and the extent and severity of any effects*
Value: amphibians						
Y	Overgrazing	2	4	8	M-H	Habitat degradation/loss through intensive trampling of foraging and breeding areas. Amphibians rely on water bodies to reproduce and live, which could be impacted through loss of water quality from runoff and contamination. Same reasoning as for reptiles but due to lower diversity perhaps marginally lower consequence *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area* • *High confidence that overgrazing impacts amphibians generally* • *Low confidence around amphibian assemblages in the Exmouth area and the extent, severity, timeframe of any effects*
Y	Pests/ feral animals	2	4	8	M-H	Feral animals can compete with native amphibians for habitat and food or become a food source for invasive predators. Weeds can degrade habitat and cause changes in landscapes. Same reasoning as for reptiles but due to lower diversity perhaps marginally lower consequence. *Data confidence* • *High confidence that feral animals are present* • *High confidence that feral animals affect amphibians generally*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						• *Low confidence about amphibians assemblages in the Exmouth area and the extent and severity of any effects*
Factor: Landforms						
Value: islands						
N	Overgrazing					
N	Pests/ feral animals					
Value: karst systems						
N	Overgrazing					
N	Pests/ feral animals					
Factor: Subterranean fauna						
Value: troglofaunal						
N	Overgrazing					
N	Pests/ feral animals					
Value: stygofauna						
N	Overgrazing					
N	Pests/ feral animals					
Factor: Terrestrial environmental quality						
Value: topsoil						
Y	Overgrazing	2	3	6	M-H	Terrestrial environmental quality could be impacted through overgrazing by changes to the chemical, physical and aesthetic characteristics of soils. Overgrazing can lead to erosion of topsoil and runoff. Severe erosion leads to poor soil structure in the remaining soil, reduced water infiltration and general loss of soil health. *Data confidence* • *High confidence that overgrazing has occurred/is occurring in the area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						• *High confidence that overgrazing impacts topsoil* • *Low confidence around up to date data on extent of impact to topsoil in Exmouth*
N	Pests/ feral animals					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
Factor: Flora & vegetation						
Value: Coastal plains						
N	Potable water use					Groundwater drawdown addresses this
Y	Rubbish	1	3	4	L-M	Dumped rubbish is often contaminated with seeds (weeds/pests). Weeds are probably more likely to come from tourism/visitation/transport from other areas. Site specific. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to vegetation* • *Low confidence about the vegetation assemblages occuring in the Exmouth area*
Y	Human waste	1	4	4	M	The Shire has said they have no major problem with sewage, and they can accommodate peak periods but what will a peak period look like in 10 years? The carrying capacity is for the Gulf is unknown. Free camping waste is more of an issue. People are not using sewage facilities. Risk could change with increased tourism **More knowledge needed** on sewage systems - becomes an issue when there are floods Assessments of water quality have not been done for Exmouth marina. *Data confidence* • *High confidence that human waste will increase in the area* • *Medium confidence around capacity for future peak periods* • *Low confidence round impacts on coastal plains vegetation*
Y	Camping	2	4	8	M	Ample anecdotal data but little empirical evidence. People camp all the way along the west side of the Exmouth Gulf, on plains and dunes, but mainly dunes. Camping is poorly regulated on some pastoral stations.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						In April 2023 there is a solar eclipse event, and a big tourism influx is expected of between 50-70,000 people. The whole of the Gulf up to Onslow is the ideal location for viewing the event due to lack of light pollution. There have been more visitors in last 12 months due to COVID-19 - so we are not working off the normal baseline figures. *Data confidence* • *High confidence that camping occurs in areas where coastal plain vegetation occurs* • *Low confidence around the extent of impacts to vegetation*
Y	Off-road driving	3	4	12	H	Ample anecdotal and some empirical evidence Four-wheel-drive (4WD) tracks cover the plains and dunes at the back of town. There is no real limitation on where people can go. The Dunes and beaches have uncontrolled 4WD access. Where there is not access, they come up into dunes then back down to beach. Weeds are probably brought from other areas by tourism, visitation and transport. There is not much 4WD access along the east coast of Gulf. Some 'Islands' of vegetation are scattered throughout salt flats and should be considered. Kobryn et al. 2017 paper showed 1200km of vehicle tracks from aerial remote sensing along the Ningaloo marine park coastline. Likely to be the same around Exmouth Gulf? One fisherman's comment was that tracks are causing a danger to their vehicles. Dunes get blown out. Tracks can be quite deep. Tracks through dunes open them up to erosion. *Data confidence* • *High confidence that 4wd tracks occur across coastal plains, which is evident in the Cape Range and adjacent to Ningaloo Reef - see Kobryn et al. (2017)* • *High confidence that 4wd tracks have had an impact to coastal plain vegetation*
Value: Limestone cliffs & gullies						
N	Potable water use					Groundwater drawdown addresses this.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
Y	Rubbish	1	3	3	L-M	Probably not a big issue compared to coastal plains. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to vegetation* • *Low confidence about the vegetation assemblages occuring in the Exmouth area*
Y	Human waste	1	4	4	M	As above for Coastal plains. *Data confidence* • *High confidence that human waste will increase in the area* • *Medium confidence around capacity for future peak periods* • *Low confidence round impacts on limestone and gully vegetation*
Y	Camping	2	4	8	L-M	Less information available about camping on limestone cliffs & gullies compared to dunes & coastal plains *Data confidence* • *Medium confidence that camping occurs in areas where limestone cliffs & gully vegetation occurs* • *Low confidence around the extent of impacts to vegetation*
Y	Off-road driving	1	3	3	M	Not as much driving would occur here given there are cliffs and gullies. *Data confidence* • *High confidence that 4wd tracks occur extensively in the Exmouth area* • *Low confidence around the extent of impact to vegetation of cliffs and gullies*
Value: Coastal dunes						
N	Potable water use					Groundwater drawdown addresses this.
Y	Rubbish	1	4	4	L-M	Probably not a big issue compared to coastal plains. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to vegetation*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						• *Low confidence about the vegetation assemblages occuring in the Exmouth area*
Y	Human waste	1	4	4	M-H	People use the dunes as toilets. Toilet paper is evident in the dunes from overnight campers. Coastal dunes are probably the most at risk and this is where you would get the most threatened species. *Data confidence* • *High confidence that human waste will increase in the area* • *Medium confidence around capacity for future peak periods* • *Medium confidence round impacts on coastal plains vegetation*
Y	Camping	2	4	8	M-H	Ample anecdotal and some empirical evidence As above for Coastal plains. Coastal dunes are probably the most at risk and where you would get the most threatened species. *Data confidence* • *High confidence that camping occurs in areas where coastal dune vegetation occurs* • *Medium confidence around the extent of impacts to vegetation*
Y	Off-road driving	3	4	12	H	Ample anecdotal and empirical evidence As above or Coastal plains. Coastal dunes are probably the most at risk and where you would get the most threatened species. Residents and tourists use off-road driving tracks. *Data confidence* • *High confidence that 4wd tracks occur across coastal dunes* • *High confidence that 4wd tracks have had an impact to coastal dune vegetation*
Value: Threatened/priority flora						
	Potable water use					
	Rubbish					
	Human waste					
	Camping	2	3	6	L	As above for Coastal plains. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						• *Low confidence that camping occurs in areas where threatened and priority flora occurs* • *Low confidence around the extent of impacts to threatened and priority flora occurs*
	Off-road driving	3	3	9	M	As above or Coastal plains, but the occurrence and extent of threatened and priority flora is not well known. Off-road driving is less contained that camping thus the consequence is higher. Coastal dunes are probably the most at risk and where you would get the most threatened species. *Data confidence* • *High confidence that 4wd tracks occur extensively around the Exmouth area* • *Low confidence around the extent of impact on threatened and priority flora*
Factor: Terrestrial fauna						
Value: Reptiles						
	Potable water use					
	Rubbish	1	3	3	L-M	Rubbish could be ingested or could impact suitability of habitat. Unlikely to be much of an issue although individuals of some species do get their heads stuck in bottle or cans *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to fauna* • *Low confidence about the reptile assemblages occuring in the Exmouth area*
	Human waste					
	Camping	1	3	3	L-M	Camping could cause some displacement of reptiles and/or dependence on campers for food. Noise considerations. *Data confidence* • *High confidence that camping occurs in areas where reptiles inhabit* • *Low confidence around the extent of impacts to reptiles* • *Low confidence about the reptile assemblages occuring in the Exmouth area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
	Off-road driving	2	4	8	M	Some empirical data on extent of off-road tracks Off-road driving could directly cause harm, loss of life and/or impact on habitat. Tracks cover large distances and could impact large stretches of habitat used by reptiles. Road kill is a significant impact during high tourism periods but this is mostly for road vehicles. *Data confidence* • *High confidence that off road driving occurs extensively in the Exmouth area* • *Low confidence around the impacts of 4WD on reptiles*
Value: mammals						
	Potable water use					
	Rubbish	1	3	3	L-M	As above for reptiles. Pearson (2013) lists pollution as likely to affect endangered rock wallabies but more information required about extent, severity etc. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to fauna* • *Low confidence about the mammal assemblages occuring in the Exmouth area*
	Human waste					
	Camping	1	3	3	L-M	In the Cape Range NP Management Plan 2010, DEC acknowledged camping as a threat to endangered black-flanked rock wallabies, but more information required about extent, severity etc. *Data confidence* • *High confidence that camping occurs in areas where mammals inhabit* • *Low confidence around the extent of impacts to mammals* Low confidence about the mammals assemblages occuring in the Exmouth area
	Off-road driving	2	4	8	M	As above for reptiles. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						• *High confidence that off road driving occurs extensively in the Exmouth area* • *Low confidence around the impacts of 4WD on mammals*
Value: birds						
	Potable water use					
	Rubbish	1	3	3	M	As above for reptiles. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to fauna* • *Medium confidence about the bird assemblages occuring in the Exmouth area*
	Human waste					
	Camping	1	3	3	M	As above for reptiles. *Data confidence* • *High confidence that camping occurs in areas where birds inhabit* • *Low confidence around the extent of impacts to birds* • *Medium confidence about the bird assemblages occuring in the Exmouth area*
	Off-road driving	2	4	8	M	Burrowing birds can be impacted by off-road vehicle use. Consideration of seabirds and shorebirds is given under sea theme. *Data confidence* • *High confidence that off road driving occurs extensively in the Exmouth area* • *Low confidence around the impacts of 4WD on birds*
Value: short range endemic invertebrates						
	Potable water use					
	Rubbish	1	3	3	L-M	As above for reptiles. *Data confidence* • *High confidence that rubbish and illegal dumping occurs*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						• *Low confidence around the nature and severity of impacts to fauna* • *Low confidence about the short range endemic assemblages occuring in the Exmouth area*
	Human waste					
	Camping	2	3	6	L	Given their short range, impacts to habitat would be more significant compared to species that can travel further away from a disturbance. Uncertainty on the number and extent of short range endemics. *Data confidence* • *Low confidence that camping occurs in areas where short range endemics inhabit* • *Low confidence around the extent of impacts to short range endemics* • *Low confidence about the short range endemics assemblages occuring in the Exmouth area*
	Off-road driving	2	3	6	L-M	Given their short range, impacts to habitat would be more significant compared to species that can travel further away from a disturbance. Uncertainty on the number and extent of short range endemics. *Data confidence* • *High confidence that off road driving occurs extensively in the Exmouth area* • *Low confidence around the impacts of 4WD on short range endemics* • *Low confidence about the short range endemics assemblages occuring in the Exmouth area*
Value: amphibians						
	Potable water use					
	Rubbish	1	3	3	L-M	Potential contamination of breeding sites. *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to fauna* • *Low confidence about the amphibian assemblages occuring in the Exmouth area*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
	Human waste					
	Camping	1	3	3	L-M	Camping near water sources may impact on frogs that breed in temporary water bodies after major rains - probably only through contamination? *Data confidence* • *High confidence that camping occurs in areas where amphibians inhabit* • *Low confidence around the extent of impacts to amphibians* • *Low confidence about the amphibian assemblages occuring in the Exmouth area*
	Off-road driving	1	3	3	M	Impacts to vegetation and soil close to a water source may impact frogs. Tracks may not be as likely to occur very close to water bodies. Tracks can alter surface flow and redirect water away from pooling or change overall structure of pools, possibly making some unsuitable for breeding. *Data confidence* • *High confidence that off road driving occurs extensively in the Exmouth area* • *Low confidence around the impacts of 4WD on amphibians*
Factor: Landforms						
Value: islands						
N	Potable water use					
Y	Rubbish	1	4	4	M	Rubbish left on islands has been documented in reports and management plans *Data confidence* • *High confidence that rubbish and illegal dumping occurs* • *Low confidence around the nature and severity of impacts to islands*
Y	Human waste	1	2	2	L	Probably not a big issue as day trekking on many islands is not allowed. *Data confidence* • *Low data confidence around impacts of human waste to islands*
Y	Camping					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
Y	Off-road driving					
Value: karst systems						
	Potable water use					Already considered under development in terms of tourism groundwater drawdown
	Rubbish - includes anything 'foreign' to karsts systems including hard rubbish, rocks, contaminants	2	4	8	M	Ample anecdotal evidence for increased rubbish generation into landfill. Contaminants from landfill could leach into karst systems. Hard rubbish and rock throwing into karst system holes occurs. *Data confidence* • *High confidence that rubbish and illegal dumping occurs in karst systems* • *Low confidence around the nature and severity of impacts to karst systems*
	Human waste	2	3	6	M	Increased tourism contributes to increased sewage waste. The Shire said they had the capacity to deal with sewage/water during peak times. Broader implications may occur if there are instances with a high volume of sewage waste combined with a flooding event. *Data confidence* • *High confidence that human waste will increase in the area* • *Medium confidence around capacity for future peak periods* • *Low data confidence around impacts of human waste to karst systems*
	Camping	1	4	4	M	Ample anecdotal evidence about risks of increased human activities near karst systems but little empirical data Camping and off-road driving go hand-in-hand for some karst locations. *Data confidence* • *High confidence that camping occurs in vicinity to karst systems* • *Low confidence around the extent of impacts to karst systems*
	Off-road driving	1	4	4	M	People are exploring more obscure tracks. There is increasing visitation to less visited areas that can include karst systems. For example, Bulldozer Cave is a hole that was created when a bulldozer fell through. People can drive in there now and get to the water, and with that comes the introduction of sediments and rubbish (rubbish scored elsewhere and not considered here).

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						More knowledge needed on the impacts of tourist related activities. *Data confidence* • *High confidence that off road driving occurs in vicinity to karst systems* • *Low confidence around the impacts of 4WD on karst systems*
Factor: Subterranean fauna						
Value: troglofauna						
	Potable water use					
	Rubbish	2	4	8	M	See reasonings above. Impacts to karsts systems would impact subterranean fauna. Ample anecdotal evidence for increased rubbish *Data confidence* • *High confidence that rubbish and illegal dumping occurs in karst systems* • *Low confidence around the nature and severity of impacts to troglofauna*
	Human waste	2	3	6	M	As above. *Data confidence* • *High confidence that human waste will increase in the area* • *Medium confidence around capacity for future peak periods* • *Low data confidence around impacts of human waste to karst systems and troglofauna*
	Camping	1	4	4	M	As above. *Data confidence* • *High confidence that camping occurs in vicinity to karst systems* • *Low confidence around the extent of impacts to karst systems and troglofauna*
	Off-road driving	1	4	4	M	As above. Anecdotal evidence about risks of increased human activities near karst systems containing troglofauna but little empirical data *Data confidence* • *High confidence that off road driving occurs in vicinity to karst systems*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
						• *Low confidence around the impacts of 4WD on karst systems and troglofauna*
Value: stygofauna						
	Potable water use					
	Rubbish	2	4	8	M	As above. *Data confidence* • *High confidence that rubbish and illegal dumping occurs in karst systems* • *Low confidence around the nature and severity of impacts to stygofauna*
	Human waste	2	3	6	M	As above *Data confidence* • *High confidence that human waste will increase in the area* • *Medium confidence around capacity for future peak periods* • *Low data confidence around impacts of human waste to karst systems and stygofauna*
	Camping	1	4	4	M	As above *Data confidence* • *High confidence that camping occurs in vicinity to karst systems* • *Low confidence around the extent of impacts to karst systems and stygofauna*
	Off-road driving	1	4	4	M	As above *Data confidence* • *High confidence that off road driving occurs in vicinity to karst systems* • *Low confidence around the impacts of 4WD on karst systems and stygofauna*
Factor: Terrestrial environmental quality						
Value: topsoil						
	Potable water use					
	Rubbish					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION- Visitation includes local impacts as well						
	Human waste					
	Camping					
	Off-road driving	1	4	4	M-H	Soils from tracks are expected to deteriorate and constantly be disturbed. Soil can be transported elsewhere in tyres. *Data confidence* • *High confidence that 4WD will disturb and impact soils* • *Medium confidence in the extent of impact*

EPA WATER THEME

Negligible	Low	Medium	High	Severe
1-2	3-4	6-8	9-12	16

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Factor: Inland waters						
Value: Groundwater systems						
Y	Sea level rise	1	3	3	H	The WA Planning Commission is allowing for 0.38 m sea level rise per year over the next 100 years. It is likely that some sea level change will occur, however the extent within a 10-year period would be localised. Within the scope of 10 years, it is more the frequency and extent of fire/storms/atmospheric temperatures that will be impacted. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that there is interaction between seawater and groundwater and that sea level rise, to a certain extent, will impact on the groundwater aquifer*
Y	Tropical storms/cyclones	1	3	3	H	It is likely that some change to tropical storms and cyclones will occur, however the extent within a 10-year period would be localised. Within the scope of 10 years, it is more the frequency and extent of fire/storms/atmospheric temperatures that will be impacted. *Data confidence* • *High confidence in cyclone predictions* • *High confidence that cyclones will bring heavy rainfall* • *High confidence that heavy rainfall will contribute to high inflow into groundwater aquifer*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
N	Fire					
N	Atmospheric temperatures					
Value: Surface water systems						
Y	Sea level rise	1	3	3	M-H	As above for groundwater systems. *Data confidence* • *High confidence in sea level rise predictions* • *High confidence that sea level rise, to a certain extent, will impact on surface water systems* • *Low confidence about how sea level rise will impact on groundwater systems of Exmouth within the timeframe*
Y	Tropical storms/cyclones	1	3	3	H	As above for groundwater systems *Data confidence* • *High confidence in cyclone predictions* • *High confidence that cyclones will bring heavy rainfall* • *High confidence that heavy rainfall will contribute to high inflow into surface water systems*
Y	Fire	1	3	3	M	Within the scope of 10 years, it is more the frequency and extent of fire/storms/atmospheric temperatures that will be impacted. *Data confidence* • *High confidence in fire predictions* • *Low confidence around impacts to surface water systems*
Y	Atmospheric temperatures	1	3	3	H	Within the scope of 10 years, it is more the frequency and extent of fire/storms/atmospheric temperatures that will be impacted. *Data confidence* • *High confidence in atmospheric temperature predictions*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *High confidence that increased temperatures and altered precipitation patterns will affect surface water systems*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Factor: Inland waters						
Value: Groundwater systems						
Y	Contamination	3	3	9	H	Per- and polyfluoroalkyl substances (PFAS) from firefighting foam can contaminate groundwater. Uncertain as to the extent of PFAS contamination. Contaminated groundwater can leach into the marine environment and karst systems. *Data confidence* • *High confidence that PFAS contamination is present at Harold Holt base - see DoD 2019*
Value: Surface water systems						
Y	Contamination	3	3	9	H	PFAS from firefighting foam can contaminate surface water. Uncertain as to the extent of PFAS contamination. *Data confidence* • *High confidence that PFAS in concentrations exceeding the ecological screening criterion is present in the backwater lagoon on the base. It most likely occurred through surface water runoff - see DoD 2019*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Factor: Inland waters						
Value: Groundwater systems						
N	Residential - footprint					
Y	Residential - groundwater use	2	3	6	M-H	The town draws water from the aquifer, this continual drawdown may impact on karst system. WaterCorp is aware of concerns and is looking at options. The Shire has no concerns about current usage of potable water - it can handle peak periods (thinking about supply). In 1995, a warning was expressed of expansion of the bore field in Exmouth Gulf, and how impacts of the bore field are too great for a bore field extensions. There would be impacts to stygofauna. This was when visitation was lower than current days. Impacts to waterways and extraction of water can compound quite rapidly. Intense rainfall events recharge fresh water lens and the dynamic is changing due to climate change. The extraction of the freshwater lens is leading to infiltration of more saline waters into areas where extraction is occurring. The impacts on stygofauna are unknown. What would happen if tourism increased and more potable water was extracted - what are the impacts on stygofauna? What are the current proportions of groundwater water from domestic, industrial and tourism uses? Work was done in 2004 documenting the variation in freshwater and saltwater and composition of bores - from around and including Cape Range. Currently at a critical point in terms of water supply. But do not have expertise to comment and score. Expertise is not in the room. Low certainty of reliable data. Outdated reports WaterCorp need to be involved in discussions (and Department of Water and Environmental Regulation (DWER)). Kathy McInnes (CSIRO / UTAS) - climate change projections and groundwater is a complex one to entangle.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Consequence is likely to be high if groundwater drawdown impacts on stygofauna. There have been historical falls of civilisation due to lack of water. Stygofauna are short range endemics. Blind cave fish has a 50 km limit in cave systems in the southern end of the study site. Blind cave fish can be in sea water through to fresh. For other stygofauna species, we do not know enough about their physiology to understand impacts - if we are impacting on biogeochemical processes and water sources. Humid caves are needed for stygofauna species. Dry caves may impact on some species. Taken from publications via DWER (still awaiting data from Water Licensing Team at DWER): Exmouth drinking water comes from 34 bores located on eastern side of Cape Range Peninsula. Bore field is located west and south of the town and extends over distance of 7km. Water is extracted from unconfined limestone aquifers within karst formations. Risks to towns drinking water supply is contamination via pathogens and nutrients and hydrocarbons from vehicles via spills and leaks of fuel. Department supports all existing, approved land uses and activities, and encourages land owners and managers to adopt best practices. Via the Exmouth Water Reserve Water Source Protection Plan (2000), reviewed in 2011: Water reserve is managed as a Priority 1 source protection, therefore development in water reserve is limited. Heavy, light, general industry and urban development activities are incompatible with a P1 water reserve. Extractive industries and mining are conditionally compatible. Tourism development is incompatible in the water reserve area. According to the *Carnarvon Artesian Basin water management plan*: Allocation limit for the entire region is 30,000,000 kL/year. Licensed allocations are 7,429,560 kL/year. Available supply is 22,570,440 kL/year. However, this is at a regional scale. Contacted: Erin Maher (DWER) provided info on 26/03/21: Groundwater resources on the Exmouth peninsula are limited due to the relatively small size of the peninsula and low rainfall. The town water supply uses production bores to abstract fresh to brackish groundwater between 30m to 200m below ground level. Abstraction for town water supply has been close to the licenced entitlement for a number of years (peaking in 2019/2020 at 1,010,394 kL of the 1,032,000 kL licensed

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						allocation). DWER will not allow town water supply to draw more than the allocation. Water Corp is investigating future sources (new bore field or desalination option). Residents used 482,658 kL of allocation in 2019/2020. Water Corp can maintain current water use, however not likely to be able to significantly expand water use for Town Supply. Tried to contact Water Corp without response. *Data confidence* • *High confidence around the volume of water used by residents* • *Medium confidence around the future use of water by residents and expanded residential developments*
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
N	Industrial - footprint					
Y	Industrial - groundwater use	2	2	4	M-H	Commercial water licences used 330,000 kL of allocation in 2019/2020. DWER is unable to licence naval, communication and air bases as this is Commonwealth land. Approximately 200ML is used by Department of Defence and this is considered in DWER allocation planning. MG Kailis Group and Main Roads also have licences for water extraction, however this source is different to town supply and water availability from this source is ok. *Data confidence* • *High confidence around the volume of water used by industry* • *Medium confidence around the future use of water by industry and expanded industrial developments*
N	Industrial - solid waste					
N	Industrial - light					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Industrial - noise					
N	Tourism - footprint					
Y	Tourism - groundwater use	2	3	6	M-H	Lighthouse Caravan park and Ningaloo Marine Research Facility both requested water licences, which recently underwent assessment by DWER (72 ML/year and 400 ML/year respectively). Assessments found low risk of impacting other users and the environment. The golf club, Department of Education, Caravan parks and Shire hold water licences in the area. Water Corp can maintain current water use, however not likely to be able to significantly expand water use for additional tourism use. *Data confidence* • *High confidence around the volume of water used by tourists/tourism* • *Medium confidence around the future use of water by tourists and the tourism industry*
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Surface water systems						
Y	Residential - footprint	1	1	1	M-H	Only infill is planned for residential development within Exmouth town in next 10 years due to restriction of available land, expansion of the town is unlikely, unless the Shire can secure land to the south of the existing town (Defence to the north, Water Reserve area, and crown land). *Data confidence* • *High confidence about planned residential infill and that this will not directly infill surface water bodies* • *High confidence that changes to run-off pathways will impact surface water systems*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence around the extent to which residential development will impact run-off pathways*
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	1	1	1	L-M	According to the Local Planning Scheme, there are several sites zoned for light industry, service commercial and general industry use that already exist. The Shire has indicated that there are currently no plans to extend these areas. *Data confidence* • *Low confidence about planned industrial development* • *High confidence that changes to run-off pathways will impact surface water systems* • *Low confidence around the extent to which industrial development will impact run-off pathways*
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
Y	Tourism - footprint	1	2	2	L-M	The unknown here is the plans for lighthouse redevelopment. Not enough information is yet known about the proposal to say with certainty whether diversions to creek beds/channels or surface water flows will be required as part of this proposal or not. If needed, these changes are likely to be localised. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence about planned tourism development* • *High confidence that changes to run-off pathways will impact surface water systems* • *Low confidence around the extent to which tourism development will impact run-off pathways*
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
Factor: Inland waters						
Value: Groundwater systems						
N	Limestone - footprint					
N	Limestone - operation					
Y	Limestone - groundwater drawdown	1/2	3	3-6	L	Groundwater supply is required for water use. However, it is unlikely to require a significant additional allocation. Groundwater contamination is unlikely. However, it requires appropriate management. Limestone quarries are already operational. However, there is a possibility that expansion of operations may increase water supply requirements in the foreseeable future. *Data confidence* • *Low confidence around the volumes of groundwater needed for current and future limestone operations*
Y	Industrial salt facility - footprint	1	4	4	L-M	Seepage and mounding from concentration and crystalliser ponds are expected and would need appropriate management. Changes in the groundwater regime are likely. However, they are expected to be localised around pond walls. *Data confidence* • *Medium confidence around the details and extent of footprint* • *Low confidence around the impact to groundwater systems*
Y	Industrial salt facility - groundwater drawdown	1	2	2	L	Some groundwater drawdown is expected to facilitate potable water use at the industrial salt facility. *Data confidence* • *Low confidence around the volumes of groundwater needed for future salt operations*
Y	Potash - footprint	1/2	4	4-8	L-M	Changes in groundwater regimes due to abstraction of brine are likely. The extent is unknown due to a lack of information regarding the Whalebone/Wyloo resources proposal.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						Data confidence • *Medium confidence around the details and extent of footprint* • *Low confidence around the impact to groundwater systems*
N	Potash - brine extraction					
Value: Surface water systems						
Y	Limestone - footprint	1/2	3	3-6	L	Limestone quarries are already active. However, expansion of operations is possible. Any additional diversion or disturbance of creek beds/channels or drainage lines may impact water surface flows. *Data confidence* • *Low confidence around the details and extent of future footprint* • *Low confidence around the impact to surface water systems*
N	Limestone - operation					
N	Limestone - groundwater drawdown					
Y	Industrial salt facility - footprint	1	3	3	L-M	Any diversion or disturbance of creek beds/channels or drainage lines may impact water surface flows. Brine leaks and spills are a consideration. Erosion and sediment loss are also a consideration. *Data confidence* • *Medium confidence around the details and extent of footprint* • *Low confidence around the impact to surface water systems*
N	Industrial salt facility - groundwater drawdown					
Y	Potash - footprint	1	3	3	L-M	As above for industrial salt facility. *Data confidence* • *Medium confidence around the details and extent of footprint*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *Low confidence around the impact to surface water systems*
N	Potash - brine extraction					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
Factor: Inland waters						
Value: Groundwater systems						
N	Overgrazing					
N	Pests/feral animals					
Value: Surface water systems						
Y	Overgrazing	1	3	3	M	Includes contamination and runoff. Overgrazing can result in increases in stream turbidity, salinity and water quality degradation. Overgrazing removes vegetation cover and compacts exposed soil, removing topsoil. The obligations of pastoral leaseholders include methods of best pastoral and environmental management practices for the management of stock, conservation and regeneration of pasture for grazing. *Data confidence* • *High confidence that overgrazing impacts on surface waters in general* • *Low confidence around how surface water systems have been impacted locally*
Y	Pests/feral animals	1	3	3	M	Feral herbivores include such animals as goats, camels, donkeys. Pest plants include such species as mesquite (*Prosopis* spp.), kapok bush (*Aerva javanica*), lantana (*Lantana camara*), ruby dock (*Rumex vesicarius*), Tamarix (*Tamarix aphylla*). Control of declared pest animals and invasive plants on pastoral land is an obligation on leaseholders under the *Biosecurity and Agriculture Management Act 2007 (BAM Act).* Pest plants can become prolific in surface water channels due to the presence of ephemeral water. If not appropriately managed, this is likely to be localised. Feral animals are also attracted to surface water locations and can impact waterways through destruction of habitat and degradation of water quality. *Data confidence* • *High confidence that pests/ferals impact on surface waters in general*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						• *Low confidence around how surface water systems have been impacted locally*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Factor: Inland waters						
Value: Groundwater systems						
Y	Potable water use	2/3	3	6-9	H	The town draws on aquifer for potable water use. Via the Exmouth Water Reserve Water Source Protection Plan (2000), reviewed in 2011: Water reserve is managed as Priority 1 source protection, therefore development in water reserve is limited. Heavy, light, general industry and urban development activities are incompatible with a P1 water reserve. Extractive industries and mining are conditionally compatible. Tourism development is incompatible in the water reserve area. According to the *Carnarvon Artesian Basin water management plan*: Allocation limit for the entire region is 30,000,000 kL/year. Licensed allocations are 7,429,560 kL/year. Available supply is 22,570,440 kL/year. However, this is at a regional scale. Contacted: Erin Maher (Department of Water and Environmental Regulation (DWER)) provided information on 26/03/21: Groundwater resources on the Exmouth peninsula are limited due to the relatively small size of the peninsula and low rainfall. The town water supply uses production bores to abstract fresh to brackish groundwater between 30m to 200m below ground level. Abstraction for town water supply has been close to the licenced entitlement for a number of years (peaking in 2019/2020 at 1,010,394 kL of the 1,032,000 kL licensed allocation). DWER will not allow town water supply to draw more than the allocation. Water Corp is investigating future sources (new borefield or desalination option). Residents used 482,658 kL of allocation in 2019/2020. Water Corp can maintain current water use, however it is not likely to be able to significantly expand water use for Town Supply. Unable to contact Water Corp for comment. *Data confidence* • *High confidence around potable water uses and capacity*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
N	Rubbish					
N	Human waste					
N	Camping					
N	Off-road driving					
Value: Surface water systems						
N	Potable water use					
Y	Rubbish	1	2	2	M	Rubbish is unlikely to change surface water flows or quality in Exmouth Gulf, although it should be managed appropriately. Anecdotal reports of rubbish but little empirical data *Data confidence* • *High confidence that rubbish occurs in the area* • *Low confidence around how rubbish is impacting surface water systems specifically in Exmouth*
Y	Human waste	1	2	2	M	Human waste is unlikely to significantly alter surface water flows or quality in Exmouth Gulf, although it should be managed appropriately. *Data confidence* • *High confidence that human waste occurs in the area* • *Low confidence around how human waste is impacting surface water systems specifically in Exmouth*
N	Camping					
Y	Off-road driving	1	3	3	M	Some erosion and changes to creek beds are expected, particularly near beach areas. However, significant alteration is unlikely. *Data confidence* • *High confidence that off-road driving extensive in the area and occurs near surface water systems* • *Low confidence around how much surface water systems have been impacted by off-road driving*

EPA AIR THEME

Negligible	Low	Medium	High	Severe
1-2	3-4	6-8	9-12	16

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Factor: Air quality						
N	Sea level rise					
N	Tropical storms/cyclones					
Y	Fire	1	3	3	H	Frequency and extent likely to be influenced by climate change within 10 years, however difficult to say with any certainty the degree of influence. As we saw on east coast of Australia last year - impacts to air quality could be from particulate matter, smoke and volatile organic compounds. *Data confidence* • *High confidence in fire predictions* • *High confidence that fire affects air quality in WA - see Borchers Arriagada et al. (2020) Exceedances of national air quality standards for particulate matter in Western Australia: sources and health-related impacts. Med J Aust 2020; 213 (6): 280-281. || doi: 10.5694/mja2.5054*
N	Atmospheric temperatures					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Factor: Air quality						
N	Contamination					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Factor: Air quality						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Residential - emissions	1	2	2	M	Air emissions from residential development may increase slightly due to population growth (heating, lighting, cooling of buildings, construction emissions, transport emissions including greenhouse gas emissions and particulates). However, due to population growth predictions and the current state of the Exmouth Gulf, airshed is unlikely to dramatically change within 5-10 years. Should note: fluctuations in air quality and pollution changes in Exmouth Gulf can impact Defence activities and infrastructure in the Gulf. *Data confidence* • *High confidence that increased residential infill will result in increased emissions* • *Low confidence around the rate of increase and when this would start to impact air quality in Exmouth*
N	Industrial - footprint					
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
Y	Industrial - emissions	1	2	2	M	Light industry and service industry are the main industrial profile within Exmouth Gulf in its current state. No heavy industry is currently planned for development in Exmouth Gulf,

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						however, some additional shipping in the Gulf, as well as natural growth of the light industrial businesses can be expected, leading to minor additional emissions in the Gulf. *Data confidence* • *High confidence that increased industrial development will result in increased emissions* • *Low confidence around the rate of increase and when this would start to impact air quality in Exmouth*
N	Industrial - noise					
N	Tourism - footprint					
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
Factor: Air quality						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
Y	Limestone - emissions	1	3	3	M	Rock quarrying can produce fine and coarse particulate matter, which can be carried by winds. Current limestone operations are expected to continue and potentially expand within the next 5/10 years, however any potential increases in particulate matter from operations are expected to be small and localised. Typically, this is managed appropriately through buffer zones, dust suppression and adjusting operations during unfavourable meteorological conditions. *Data confidence* • *High confidence that increased limestone operations will result in increased particulate matter* • *Low confidence around the rate of increase and when this would start to impact air quality in Exmouth*
N	Salt farm - footprint					
Y	Salt farm - emissions	1	3	3	M	Really depends on the type of operation proposed. Yannarie industrial salt facility as proposed was set to produce approx. 43,500 tpa CO_2-e, which is not likely to be significant. *Data confidence* • *High confidence that industrial salt operations will result in increased emissions* • *Low confidence around the rate of increase and when this would start to impact air quality in Exmouth*
N	Potash - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Potash - abstraction of brine					
Y	Potash - emissions	1	3	3	M	Really depends on the type of operation proposed. Based on recent Lake Way project assessed by EPA, potash production is not likely to produce significant greenhouse gas emissions. *Data confidence* • *High confidence that industrial salt operations will result in increased emissions* • *Low confidence around the rate of increase and when this would start to impact air quality in Exmouth*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
Factor: Air quality						
N	Overgrazing					
N	Runoff/contamination					
N	Pests/ferals					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Factor: Air quality						
N	Potable water use					
N	Rubbish					
N	Human waste					
N	Camping					
N	Off-road driving					

EPA PEOPLE THEME

Negligible	Low	Medium	High	Severe
1-2	3-4	6-8	9-12	16

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Factor: Social surroundings						
Value: Aboriginal heritage & culture - not scoring						
N	Sea level rise					
N	Tropical storms/cyclones					
N	Fire					
N	Atmospheric temperatures					
Value: National heritage - Ningaloo Coast World Heritage Area						
N	Sea level rise					
N	Tropical storms/cyclones					
N	Fire					
N	Atmospheric temperatures					
Value: Amenity - land based recreation						
N	Sea level rise					
Y	Tropical storms/cyclones	2	3	6	H	Recreation activities around the Gulf may not have the same access if the frequency and extent of storms increases over a 10-year period.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						Data confidence • *High confidence in cyclone/storm predictions* • *High confidence from past events in the Exmouth area that winds, rainfall & flooding associated with cyclones/storms results in impacted amenity*
Y	Fire	2	3	6	H	As above. *Data confidence* • *High confidence in fire predictions* • *High confidence that fire will impact amenity based on past events in the Exmouth area - see https://www.midwesttimes.com.au/news/midwest-times/firefighters-battling-to-contain-exmouth-blaze-ng-b88766600z*
Y	Atmospheric temperatures	2	2	4	H	Rising temperatures will impact on people's ability or desire to recreate outside, though this may not be too much of an issue within the next 5-10yrs. *Data confidence* • *High confidence around air temperature predictions* • *High confidence that increasing temperature will impact land based recreation in the Exmouth region*
Value: Amenity - marine based recreation						
N	Sea level rise	1	4	4	H	Would have localised impacts at swimming beaches. *Data confidence* • *High confidence in sea level predictions* • *High confidence that sea level rise will affect amenity of beaches & islands & other coastal areas*
Y	Tropical storms/cyclones	2	3	6	H	Recreation activities around the Gulf may not have the same access if the frequency and extent of storms increases over a 10-year period. *Data confidence* • *High confidence in cyclone/storm predictions*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *High confidence from past events in the Exmouth area that winds, rainfall & flooding associated with cyclones/storms results in impacted amenity*
N	Fire					
N	Atmospheric temperatures					
Value: Amenity - intrinsic/wilderness aesthetic						
Y	Sea level rise	1	3	3	H	Localised. *Data confidence* • *High confidence in sea level predictions* • *High confidence that sea level rise will affect amenity of beaches & islands & other coastal areas*
Y	Tropical storms/cyclones	1	3	3	H	Localised damage likely. *Data confidence* • *High confidence in cyclone/storm predictions* • *High confidence from past events in the Exmouth area that winds, rainfall & flooding associated with cyclones/storms results in impacted amenity*
Y	Fire	2	3	6	H	Fire intensity and frequency may wipe out wilderness areas. *Data confidence* • *High confidence in fire predictions* • *High confidence that fire will impact amenity based on past events in the Exmouth area - see https://www.midwesttimes.com.au/news/midwest-times/firefighters-battling-to-contain-exmouth-blaze-ng-b88766600z*
Y	Atmospheric temperatures	1	3	3	H	May impact the natural biota people come to see. *Data confidence* • *High confidence around air temperature predictions* • *High confidence that increasing temperature will impact the natural wilderness*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Value: Amenity - noise, dust, odour, light						
N	Sea level rise					
N	Tropical storms/cyclones					
Y	Fire	2	3	6	H	Particulate matter and smoke would change - dust, odour and potentially light if catastrophic event occurs. *Data confidence* • *High confidence in fire predictions* • *High confidence that fire will impact amenity based on past events in the Exmouth area - see https://www.midwesttimes.com.au/news/midwest-times/firefighters-battling-to-contain-exmouth-blaze-ng-b88766600z*
N	Atmospheric temperatures					
Value: Economic - tourism						
Y	Sea level rise	1	3	3	M	Localised, and tourism operators can avoid eroded/inaccessible areas. *Data confidence* • *High confidence in sea level predictions* • *Low confidence about the economic effect of sea level rise on tourism in the area*
Y	Tropical storms/cyclones	2	3	6	H	Potential visitors may stay away from Exmouth Gulf if frequency and extent of storms increases within 10 years. *Data confidence* • *High confidence in cyclone/storm predictions* • *High confidence that cyclones/storms result in significant economic losses to the tourism industry based on past events in the area*
Y	Fire	2	3	6	H	Particulate matter and smoke would change - dust, odour and potentially light if catastrophic event occurs. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *High confidence in fire predictions* • *High confidence that fire result in significant economic losses to the tourism industry*
Y	Atmospheric temperatures	1	3	3	H	Potential visitors may stay away from Exmouth Gulf if it becomes too hot, but unlikely in 5-10 years. *Data confidence* • *High confidence around air temperature predictions* • *High confidence that temperature impacts amenity values that draw in tourists*
Value: Economic - commercial fishing						
Y	Sea level rise	1	3	3	M	Localised, and operators can avoid eroded/inaccessible areas. *Data confidence* • *High confidence in sea level predictions* • *Low confidence about the effect of sea level rise on commercial fishing in the area and this flow on to impact economics*
Y	Tropical storms/cyclones	1	3	3	H	Some data to suggest increased nutrient flow after storms fuels the invertebrates (prawns) in Gulf. *Data confidence* • *High confidence in cyclone/storm predictions* • *High confidence that cyclone/storms result in significant economic losses to the commercial fishing industry based on past events in the area - see Loneragan et al. (2013)*
N	Fire					
N	Atmospheric temperatures					Marine heatwaves already scored under marine factors
Value: Economic - pastoralism						
N	Sea level rise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
Y	Tropical storms/cyclones	2	3	6	M-H	Changes in frequency and extent of storms could lead to degradation of road infrastructure and access to pastoral lands. *Data confidence* • *High confidence in cyclone/storm predictions* • *High confidence that cyclones/storms can result in flooding of pastoral lands* • *Low confidence around the impact cyclones/storms have had on pastoral lands in Exmouth to date*
Y	Fire	2	3	6	H	Particulate matter and smoke would change - dust, odour and potentially light if catastrophic event occurs. *Data confidence* • *High confidence in fire predictions* • *High confidence that fire result in significant economic losses to the pastoralism industry*
Y	Atmospheric temperatures	1	3	3	M-H	An official ABARES report in 2019 estimated that changes in climate since 2000 reduced cropping revenue by $1.1billion/year Could impact farming choices - e.g., crops and livestock, but likely not within 5-10 years. *Data confidence* • *High confidence around air temperature predictions* • *High confidence in data indicating significant economic costs of atmospheric temperature and precipitation changes on pastoralism in general* • *Low confidence around the impacts to pastoral lands specifically in Exmouth*
Value: Economic - science and research						
Y	Sea level rise	1	3	3	M	Some impacts could occur to study sites. *Data confidence* • *High confidence in sea level predictions* • *Low confidence about the extent of impact to scientific and research activities*
Y	Tropical storms/cyclones	1	3	3	H	Some impacts could occur to study sites.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						Data confidence • *High confidence in cyclone/storm predictions* • *High confidence that cyclones/storms can impact scientific and research activities*
Y	Fire	1	3	3	H	Some impacts could occur to study sites. Can assume fire would interfere with many scientific and research activities *Data confidence* • *High confidence in fire predictions* • *High confidence that fire would have some impact on scientific and research activities*
Y	Atmospheric temperatures	1	3	3	H	Some impacts could occur to study sites. *Data confidence* • *High confidence around air temperature predictions* • *High confidence that increasing atmospheric temperatures would impact on scientific and research activities*
Factor: Human health						
Value: potable water						
N	Sea level rise					
Y	Tropical storms/cyclones	1	3	3	M	Increased frequency and intensity of storms could cause changes in water supply depending on seepage rate, rain catchment, inundation etc. *Data confidence* • *High confidence in cyclone/storm predictions* • *Low confidence around the extent of impact to potable water*
N						
Y	Atmospheric temperatures	1	3	3	H	Hot, drying climate may result in higher water evaporation and changes to seepage and rain catchment areas. However, extent unknown within 10-year timeframe. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
CLIMATE CHANGE						
						• *High confidence around air temperature and precipitation predictions* • *High confidence that changes in temperature and precipitation will affect Exmouth's limited potable water supply as the WA government has recognised that "In the north of Western Australia, climate change has caused increased variability in weather patterns and rainfall is less predictable which impacts upon water security" (https://www.mediastatements.wa.gov.au/Pages/McGowan/2020/09/Exmouth-residents-to-receive-water-saving-support.aspx)*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Factor: Social surroundings						
Value: Aboriginal heritage & culture						
N	Contamination					
Value: National heritage - Ningaloo Coast World Heritage Area						
N	Contamination					
Value: Amenity - land based recreation						
Y	Contamination	1	2	2	H	Assume localised contamination could be appropriately managed. The Department of Defence (Defence) has undertaken detailed environmental investigations regarding contamination of its sites in the Exmouth region, including investigations of Per- and polyfluoroalkyl substances (PFAS). As long as it continues to be monitored and managed appropriately, it is unlikely to present a serious risk to the community, including recreation activities. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination can cause risk to people if left unmanaged*
Value: Amenity - marine based recreation						
Y	Contamination	1	2	2	H	Assume localised contamination could be appropriately managed. PFAS was detected in seepage water at the coast but poses a low risk to ecological health of the marine environment. As long as it continues to be monitored and managed appropriately, it is unlikely to present a serious risk to the community, including recreation activities. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination can cause risk to people if left unmanaged*
Value: Amenity - intrinsic/wilderness aesthetic						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Y	Contamination	1	2	2	H	Assume localised contamination could be appropriately managed. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination can cause risk to flora and fauna if left unmanaged, which would impact amenity*
Value: Amenity - noise, dust, odour, light						
N	Contamination					
Value: Economic - tourism						
Y	Contamination	1	2	2	H	Assume localised contamination could be appropriately managed. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination can cause risk to people and likely tourist activities if left unmanaged*
Value: Economic - commercial fishing						
Y	Contamination	1	2	2	H	Assume localised contamination could be appropriately managed. As part of the investigations undertaken by Defence, marine life including fish and crustaceans were sampled at Wapet Creek and the in Exmouth Gulf and found that seafood did not present a contamination pathway, at this time. A detailed management plan is now in place to monitor and manage any future detection of PFAS. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination has not caused loss of commercial fishing revenue due to contamination of prawns or other targeted species*
Value: Economic - pastoralism						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEFENCE						
Y	Contamination	1	2	2	H	Assume localised contamination could be appropriately managed. Soil samples collected in pastoral or pastoral-adjacent land found PFAS levels were below human health and ecological criteria. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination has not impacted pastoralism*
Value: Economic - science and research						
N	Contamination					
Factor: Human health						
Value: potable water						
Y	Contamination	1/2	3	3-6	H	Assume localised contamination could be appropriately managed and would not impact deep aquifer potable water source. Investigations undertaken by Defence found that drinking water supplies are safe to drink. Water Corporation testing confirmed no PFAS was detected in the town water supply bores. *Data confidence* • *High confidence that contamination has taken/is taking place - see DoD (2019)* • *High confidence that contamination has not contaminated drinking water*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
Factor: Social surroundings						
Value: Aboriginal heritage & culture - not scoring						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
N	Industrial - footprint					Significant Aboriginal heritage sites all through waterways Kate Morse, W.A., Museum - has done surveys in area, and Peter Veth, UWA
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
N	Tourism - footprint					
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: National heritage - Ningaloo Coast World Heritage Area						

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Residential - footprint					NA - based on consideration of the Ningaloo World Heritage boundaries
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					NA - based on consideration of the Ningaloo World Heritage boundaries
N	Residential - noise					NA - based on consideration of the Ningaloo World Heritage boundaries
Y	Industrial - footprint	1	3	3	L-M	Not much capacity for industrial development occurring in the gulf to impact Ningaloo World Heritage Area. *Data confidence* • *Low confidence around the details of future industrial developments* • *High confidence that industrial developments will not occur within the Ningaloo Coast World Heritage Area (NCWHA)* • *Low confidence about industrial developments outside the NCWHA impacting the Outstanding Value of the NCWHA*
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
Y	Industrial - light	2	3	6	L-M	Light from shipping/shipping lanes, which could impact turtles and nesting beaches, which are a feature of the Ningaloo World Heritage Area. Moderate consequence. Dark sky impact. Likely to be shipping in the Gulf. Probably have low impact because of regulation around the turtle beaches. Downward focus lighting would be useful. Hopefully not generic street lighting to minimise any impacts. However, mitigation is not considered in the score. *Data confidence* • *Low confidence around the details of future industrial developments* • *High confidence that light from industrial developments can impact terrestrial and marine values*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence about light from industrial developments impacting values within the NCWHA*
Y	Industrial - noise	2	3	6	L-M	Shipping noise from Gascoyne Gateway (GG). Shipping is likely to cross World Heritage boundaries and potentially impact species that are sensitive to noise. *Data confidence* • *Low confidence around the details of future industrial developments* • *High confidence that noise from industrial developments can impact terrestrial and marine values* • *Low confidence about noise from industrial developments impacting values within the NCWHA*
Y	Tourism - footprint	1	3	3	L-M	Lighthouse development is within current land remit. More boat based concerns than physical footprint. *Data confidence* • *Low confidence around the details of future tourism developments* • *High confidence that proposed tourism developments will impact the Ningaloo Coast World Heritage Area (NCWHA)* • *Low confidence about tourism developments outside the NCWHA impacting the Outstanding Value of the NCWHA*
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
Y	Tourism - light	2	3	6	M	Potentially more light pollution from lighthouse development and accommodation. Also, tourist vessel light emissions, e.g., cruise ships, are a consideration. Lights from vehicles driving around potential realigned road. Could impact turtles and nesting beaches, which are a feature of the Ningaloo World Heritage Area. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Low confidence around the details of future tourism developments* • *High confidence that light from tourism developments can impact terrestrial and marine values* • *Medium confidence about light from tourism developments impacting values within the NCWHA*
Y	Tourism - noise	2	3	6	L-M	Noise from increased recreational boats and cruise chips. As well as tour boats targeting marine megafauna. *Data confidence* • *Low confidence around the details of future tourism developments* • *High confidence that noise from tourism developments can impact terrestrial and marine values* • *Low confidence about noise from tourism developments impacting values within the NCWHA*
Value: Amenity - land based recreation						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					See Amenity - intrinsic/wilderness aesthetic for scoring of dark skies value
N	Residential - noise					
Y	Industrial - footprint	2	3	6	L-M	Proposed GG, K+S Salt footprints. Salt is probably not going to impact land-based recreational activities. GG footprint could impact people's access to camping and other land-based activities. *Data confidence* • *Low confidence around the details of future industrial developments* • *Medium confidence that industrial developments will impact land based recreation*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					See Amenity - intrinsic/wilderness aesthetic for scoring of dark skies value.
Y	Industrial - noise	2	3	6	L	Salt is probably not going to impact land-based recreation. GG noise may impact wildlife in immediate area and bird watching activities (and other wildlife activities). *Data confidence* • *Low confidence around the details of future industrial developments* • *Low confidence that industrial noise will impact land based recreation*
Y	Tourism - footprint	2	3	6	L-M	As above. Lighthouse and road realignment could impact access and use of the land. *Data confidence* • *Low confidence around the details of future tourism developments* • *Medium confidence that tourism developments will impact land based recreation*
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					See Amenity - intrinsic/wilderness aesthetic for scoring of dark skies value.
Y	Tourism - noise	2	3	6	L	Increased noise from people and vehicles, generators, off-roading vehicles, with increased tourism, which could impact enjoyment of land-based activities, wildlife and noise free environments. *Data confidence* • *Low confidence around the details of future tourism developments* • *Low confidence that tourism noise will impact land based recreation*

Value: Amenity - marine based recreation

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	2	3	6	L-M	GG, K+S salt footprint. Salt is probably not going to impact marine-based recreational activity. GG footprint could impact people's access to the coast, fishing spots, swimming spots. *Data confidence* • *Low confidence around the details of future industrial developments* • *Medium confidence that industrial developments will impact marine based recreation*
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
Y	Industrial - noise	2	3	6	L-M	Salt is probably not going to impact marine-based recreational. GG noise may impact wildlife in immediate area and people's marine wildlife viewing opportunities. But could still carry out the actual recreational activity itself. The experience may not be the same, which overlaps with wilderness aesthetic value. *Data confidence* • *Low confidence around the details of future industrial developments* • *Low confidence that industrial noise will impact marine based recreation*
N	Tourism - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
Y	Tourism - noise	2	3	6	L	Increased noise from people and vessels with increased tourism, could impact enjoyment of marine based activities, wildlife and noise free environments. *Data confidence* • *Low confidence around the details of future tourism developments* • *Low confidence that tourism noise will impact marine based recreation*
Value: Amenity - intrinsic/wilderness aesthetic						
Y	Residential - footprint	1	4	4	M-H	More infilled areas could 'appear' to look like urban sprawl. *Data confidence* • *High confidence around the details of future residential developments* • *Medium confidence that residential developments will impact intrinsic/wilderness aesthetic*
N	Residential - groundwater drawdown					
Y	Residential - solid waste	1	4	4	H	Visually seeing waste will take away from the natural look and feel. *Data confidence* • *High confidence that solid waste exists and illegal dumping occurs* • *High confidence that solid waste impacts on intrinsic/wilderness aesthetic*
Y	Residential - light	3	4	12	M-H	Can impact dark sky/star gazing. Controlling and managing light pollution is an emerging priority for national heritage and attractions, especially for the eclipse in 2023. Department of Defence highlighted the need for dark skies to continue their deep space astro-activities, particularly the tracking of space junk. Western Australian Planning Commission (WAPC) Draft Position Statement: Dark Skies and Astrotourism document acknowledges that controlling and managing light pollution is an emerging

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						priority for regional economic development and tourism businesses in more remote parts of Western Australia. *Data confidence* • *High confidence that an increase in residential developments will increase light emissions* • *Medium confidence that increased light emission from residential developments will impact on a sense of intrinsic/wilderness aesthetic*
Y	Residential - noise	1	4	4	M-H	Artificial noise can detract from wilderness aesthetic. *Data confidence* • *High confidence that an increase in residential developments will increase noise* • *Medium confidence that increased noise from residential developments will impact on a sense of intrinsic/wilderness aesthetic*
Y	Industrial - footprint	2	3	6	M	Could start to give the impression of an industrial town. *Data confidence* • *Low confidence around the details of future industrial developments* • *High confidence that industrial developments will impact intrinsic/wilderness aesthetic*
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
Y	Industrial - light	3	4	12	M-H	Can impact dark sky/star gazing. Controlling and managing light pollution is an emerging priority for national heritage and attractions, especially for the eclipse in 2023. Department of Defence highlighted the need for dark skies to continue their deep space astro-activities, particularly the tracking of space junk. Western Australian Planning Commission (WAPC) Draft Position Statement: Dark Skies and Astrotourism document acknowledges that controlling and managing light pollution is an emerging

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						priority for regional economic development and tourism businesses in more remote parts of Western Australia. *Data confidence* • *High confidence that an increase in industrial developments will increase light emissions* • *Medium confidence that increased light emission from industrial developments will impact on a sense of intrinsic/wilderness aesthetic*
Y	Industrial - noise	1	4	4	M-H	Artificial noise can detract from wilderness aesthetic. *Data confidence* • *High confidence that an increase in industrial developments will increase noise* • *Medium confidence that increased noise from industrial developments will impact on a sense of intrinsic/wilderness aesthetic*
Y	Tourism - footprint	1	4	4	M	Development of lighthouse will be very visual to people and could detract from wilderness aesthetic. *Data confidence* • *Low confidence around the details of future tourism developments* • *High confidence that tourism developments will impact intrinsic/wilderness aesthetic*
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
Y	Tourism - light	3	4	12	M-H	Can impact dark sky/star gazing. Controlling and managing light pollution is an emerging priority for national heritage and attractions, especially for the eclipse in 2023. Department of Defence highlighted the need for dark skies to continue their deep space astro-activities, particularly the tracking of space junk. Western Australian Planning Commission (WAPC) Draft Position Statement: Dark Skies and Astrotourism document acknowledges that controlling and managing light pollution is an emerging priority for regional economic development and tourism businesses in more remote

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						parts of Western Australia. WAPC have stated that areas around identified astrotourism sites, including observatories, should be protected and adequate infrastructure for tourists provided, that do not contribute to light or noise pollution. Lighthouse redevelopment and road realignment behind the lighthouse has consequences for light. *Data confidence* • *High confidence that an increase in tourism developments will increase light emissions* • *Medium confidence that increased light emission from tourism developments will impact on a sense of intrinsic/wilderness aesthetic*
Y	Tourism - noise	1	4	4	M-H	Artificial noise can detract was wilderness aesthetic. *Data confidence* • *High confidence that an increase in tourism developments will increase noise* • *Medium confidence that increased noise from tourism developments will impact on a sense of intrinsic/wilderness aesthetic*
Value: Amenity - noise, dust, odour, light						
N	Residential - footprint					
N	Residential - groundwater drawdown					
Y	Residential - solid waste	1	4	4	M	Increased population leads to increased waste, which could increase odour in some locations. *Data confidence* • *High confidence that solid waste exists and illegal dumping occurs* • *Low confidence that solid waste is having an impact on noise, dust, odour or light*
Y	Residential - light	1	4	4	H	Will likely increase. See Amenity - intrinsic/wilderness aesthetic for scoring of dark skies value.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						Data confidence • *High confidence that an increase in residential developments will increase light emissions*
Y	Residential - noise	3	2	6	H	Will likely increase. The Department of Defence submission emphasised the importance of radio silence for much of the area surrounding Exmouth townsite and most especially around their infrastructure at the top of the Cape. *Data confidence* • *High confidence that an increase in residential developments will increase noise*
N	Industrial - footprint					
N	Industrial - groundwater drawdown					
Y	Industrial - solid waste	1	4	4	M-H	Increased development leads to increased waste, which could increase odour in some locations. *Data confidence* • *High confidence that solid waste exists* • *Medium confidence that solid waste would impact on dust and odour*
Y	Industrial - light	1	4	4	H	Will likely increase. See Amenity - intrinsic/wilderness aesthetic for scoring of dark skies value. *Data confidence* • *High confidence that an increase in industrial developments will increase light emissions*
Y	Industrial - noise	1	4	4	H	Will likely increase. *Data confidence* • *High confidence that an increase in industrial developments will increase noise*
N	Tourism - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					Assessed under TOURISM/VISITATION.
Y	Tourism - light	1	4	4	H	Will likely increase. See Amenity - intrinsic/wilderness aesthetic for scoring of dark skies value. *Data confidence* • *High confidence that an increase in tourism developments will increase light emissions*
Y	Tourism - noise	3	2	6	H	Will increase. The Department of Defence submission emphasised the importance of radio silence for much of the area surrounding Exmouth townsite and most especially around their infrastructure at the top of the Cape. *Data confidence* • *High confidence that an increase in tourism developments will increase noise*
Value: Economic - tourism						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
Y	Industrial - footprint	1/2	4	4-8	L	GG port could be a positive for tourism due to access for cruise ships. But need to look at negative impacts as well. GG port noise would impact fauna, which in turn would impact tourism. Some of the operations/activities which industrial development could impact include: Whale watching, charter fishing, manta ray tours, scenic flights, recreational boating

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						fly fishing - half a dozen operations, net fishers on western/southern end of the Gulf (father/daughter team), aquarium fish collectors Bird watchers also come to the proposed GG port site to see migratory species. Permit fisherman - some concern that there would be impacts to these businesses from GG port. Permit fishing is a high-end tourism product - can cost $10k to come from states to catch a permit fish (a type of dart fish) in a wilderness setting. Depending on where structures are built, may restrict some access on some days to certain locations (weather dependant?). Economic paper (Deloitte 2020) just released on tourism value of Ningaloo region. Exmouth Gulf is part of study. ~$110m contribution to economy from tourism for Ningaloo region/system. People cross over from Ningaloo to Gulf. Navy pier diving is a consideration. Some tourist operators worry about the impact of mass tourism and how it will be managed e.g., cruise ships in the Gulf and what it means for the whole image/brand of the Gulf. GG port footprint may not destroy tourism operations but may cause displacement form key locations. Some activities would be minor, some would be moderate. If people stop booking tours because animals are not coming into Gulf, then this has a big impact on economics. *Data confidence* • *Low confidence around the details of future industrial developments* • *Low confidence around how tourism will be impacted by future industrial developments*
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
Y	Industrial - light	1	4	4	M	Could result in less tourism income if natural and wilderness aesthetic is degraded. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that an increase in industrial developments will increase light emissions* • *Low confidence around how tourism will be impacted by increased light from industrial developments*
Y	Industrial - noise	1	4	4	M	Could result in less tourism income if natural and wilderness aesthetic is degraded. *Data confidence* • *High confidence that an increase in industrial developments will increase noise* • *Low confidence around how tourism will be impacted by increased noise from industrial developments*
N	Tourism - footprint					
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Economic - commercial fishing						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
N	Industrial - footprint					
N	Industrial - groundwater drawdown					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
N	Tourism - footprint					
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Economic - pastoralism						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
N	Industrial - footprint					
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
N	Tourism - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					
Value: Economic - science and research						
N	Residential - footprint					
N	Residential - groundwater drawdown					
N	Residential - solid waste					
Y	Residential - light	1	3	3	M	Increased residential light may impact on research that relies on dark skies but local data is required to measure light outputs and impacts on science and research Could impact on studies and/or experiments on biota. Science and research is adaptable. *Data confidence* • *High confidence that an increase in residential developments will increase light emissions* • *Low confidence that increased light will impact on science and research*
Y	Residential - noise	1	3	3	M	Little data available to measure how residential noise may impact on science and research. Science and research is adaptable. Could impact on studies and/or experiments on biota. *Data confidence* • *High confidence that an increase in residential developments will increase noise* • *Low confidence that increased noise will impact on science and research*
N	Industrial - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
N	Industrial - groundwater drawdown					
N	Industrial - solid waste					
Y	Industrial - light	1	3	3	M	Increased industrial light may impact on research that relies on dark skies but local data is required to measure light outputs and impact on science and research Could impact on studies and/or experiments on biota. Science and research is adaptable. *Data confidence* • *High confidence that an increase in industrial developments will increase light emissions* • *Low confidence that increased light will impact on science and research*
Y	Industrial - noise	1	3	3	M	Little data available to measure how industrial noise may impact on science & research. Science and research is adaptable. Could impact on studies and/or experiments on biota. *Data confidence* • *High confidence that an increase in industrial developments will increase noise* • *Low confidence that increased noise will impact on science and research*
N	Tourism - footprint					
N	Tourism - groundwater drawdown					
N	Tourism - solid waste					
Y	Tourism - light	1	3	3	M	Increased light from tourist developments may impact on research that relies on dark skies but local data is required to measure light outputs and impacts on science and research Could impact on studies and/or experiments on biota. Science and research is adaptable. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *High confidence that an increase in tourism developments will increase light emissions* • *Low confidence that increased light will impact on science and research*
Y	Tourism - noise	1	3	3	M	Little data available to measure how tourism development noise may impact on science & research. Science and research is adaptable. Could impact on studies and/or experiments on biota. *Data confidence* • *High confidence that an increase in tourism developments will increase noise* • *Low confidence that increased noise will impact on science and research*
Factor: Human health						
Value: potable water						
N	Residential - footprint					
Y	Residential - groundwater drawdown	3	2	6	H	Shire is confident that enough potable water will be available for human use. Future projected uses would need to be carefully considered. *Data confidence* • *High confidence around available potable water and capacity* • *High confidence around future residential developments and thus groundwater drawdown*
N	Residential - solid waste					
N	Residential - light					
N	Residential - noise					
N	Industrial - footprint					
Y	Industrial - groundwater drawdown	3	2	6	M-H	Shire is confident that enough potable water will be available for human use. Future projected uses would need to be carefully considered. *Data confidence* • *High confidence around available potable water and capacity*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
DEVELOPMENT						
						• *Medium confidence around the future use of water by industry and expanded industrial developments*
N	Industrial - solid waste					
N	Industrial - light					
N	Industrial - noise					
N	Tourism - footprint					
Y	Tourism - groundwater drawdown	3	2	6	M-H	Shire is confident that enough potable water will be available for human use. Future projected uses would need to be carefully considered. *Data confidence* • *High confidence around available potable water and capacity* • *Medium confidence around the future use of water by tourism development*
N	Tourism - solid waste					
N	Tourism - light					
N	Tourism - noise					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
Factor: Social surroundings						
Value: Aboriginal heritage & culture - Not scoring						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: National heritage - Ningaloo Coast World Heritage Area						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: Amenity - land based recreation						
N	Limestone - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Limestone - operation					
N	Limestone - groundwater drawdown					
Y	Industrial salt facility - footprint	2	4	8	M	Possibly restricted access to intertidal areas. Locals may think they can do what other visitors cannot, so to them, new restrictions would have a bigger consequence than to visitors who had not experienced areas before restrictions were in place. Some anecdotal suppositions but little available data. *Data confidence* • *Medium confidence around the details and extent of industrial salt farm footprint* • *Medium confidence around land based recreation on the eastern margin of the Gulf*
Y	Potash - footprint	2	3	6	M	As above but uncertainty around the scale of the potash development and how it would affect land-based recreation *Data confidence* • *Medium confidence around the details and extent of pot ash footprint* • *Medium confidence around land based recreation on the eastern margin of the Gulf*
N	Potash - abstraction of brine					
Value: Amenity - marine based recreation						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: Amenity - intrinsic/wilderness aesthetic						
Y	Limestone - footprint	2	3	6	M-H	Potential future development is likely. What would impact amenity more than current development? Will have a visual impact if it occurs close to town and near Wapet Creek, where people visit. Aerial tourism, light aircraft, would get another view of development. The consequence and risk would be different depending on where you are and who you are. *Data confidence* • *Medium confidence in the details and extent of proposed footprint* • *High confidence around the intrinsic/wilderness aesthetic being impacted by limestone setup and operations*
Y	Limestone - operation	1	4	4	M-H	More trucks operating and noise could impact people's enjoyment of nearby places e.g., Wapet Creek, and in general if slow moving bulky loads are commonly seen on main roads. Could give the feeling of an industrial town more so than a natural/wild/pristine location. Though operations should not be as visible or seen around large parts of the cape where tourists visit. *Data confidence* • *Medium confidence in the details and extent of proposed footprint and operations* • *High confidence around the intrinsic/wilderness aesthetic being impacted by limestone setup and operations*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Limestone - groundwater drawdown					
Y	Industrial salt facility - footprint	2	4	8	M	Potential future development is likely. What would impact amenity more than current development? Will have a visual impact. Aerial tourism, light aircraft, would get another view of development - some operators fly over the Gulf due to visual amenity. The consequence and risk would be different depending on where you are and who you are. Not likely to impact the aesthetics of the whole Gulf, just the eastern margin, but it could give the feeling of an industrial town more so than a natural/wild/ pristine location. *Data confidence* • *Medium confidence around the details and extent of industrial salt farm footprint* • *Medium confidence around intrinsic/wilderness aesthetic being impacted*
Y	Potash - footprint	2	3	6	M	As above but uncertainty around the scale of the potash development. *Data confidence* • *Medium confidence around the details and extent of pot ash footprint* • *Medium confidence around intrinsic/wilderness aesthetic being impacted*
N	Potash - abstraction of brine					
Value: Amenity - noise, dust, odour, light						
N	Limestone - footprint					
Y	Limestone - operation	2	4	8	M	Dust and noise would increase from increased limestone operations. Do operations occur at night time? If so, light emissions would also be a consideration. *Data confidence* • *Medium confidence in the details and extent of proposed footprint and operations*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *Medium confidence around dust and noise increasing with increasing operations*
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: Economic - tourism						
Y	Limestone - footprint	2	3	6	L-M	Aerial tourism may be impacted by the less pristine visuals. Could give the feeling of an industrial town more so than a natural/wild/pristine location. *Data confidence* • *Medium confidence in the details and extent of proposed footprint* • *Low confidence around the impact to tourism*
Y	Limestone - operation	2	3	6	L-M	Could give the feeling of an industrial town more so than a natural/wild/pristine location. *Data confidence* • *Medium confidence in the details and extent of proposed footprint and operations* • *Low confidence around the impact to tourism*
N	Limestone - groundwater drawdown					
Y	Industrial salt facility - footprint	2	3	6	L-M	Aerial tourism may be impacted by the less pristine visuals. Could give the feeling of an industrial town more so than a natural/wild/pristine location. *Data confidence* • *Medium confidence around the details and extent of industrial salt farm footprint* • *Low confidence around tourism being impacted*
Y	Potash - footprint	2	3	6	L-M	As above.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						Data confidence • *Medium confidence around the details and extent of potash footprint* • *Low confidence around tourism being impacted*
N	Potash - abstraction of brine					
Value: Economic - commercial fishing						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
Y	Industrial salt facility - footprint	2	4	8	L-M	Some concerns for potential changes in hydrodynamics e.g., will taking water from a hypersaline environment have an impact on long-term productivity? Will it impact inshore habitats and juveniles/nursery areas? Will discharge of toxins impact prawns and the areas they use and their productivity? When the proposal for an industrial salt facility was to be more extensive than currently proposed, there was potentially a major impact. The revised footprint and scale have lessened this impact. *Data confidence* • *Medium confidence around the details and extent of industrial salt farm footprint* • *Low confidence around commercial fisheries being impacted by footprint*
Y	Potash - footprint	2	3	6	L-M	As above but uncertainty around scope of potash footprint. *Data confidence* • *Medium confidence around the details and extent of potash footprint* • *Low confidence around commercial fisheries being impacted by footprint*
Y	Potash - abstraction of brine	2	3	6	L-M	As above but uncertainty around scope of potash footprint. *Data confidence* • *Medium confidence around the details and extent of potash footprint*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
						• *Low confidence around commercial fisheries being impacted by brine abstraction*
Value: Economic - pastoralism						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Value: Economic - science and research						
N	Limestone - footprint					
N	Limestone - operation					
N	Limestone - groundwater drawdown					
N	Industrial salt facility - footprint					
N	Potash - footprint					
N	Potash - abstraction of brine					
Factor: Human health						
Value: potable water						
N	Limestone - footprint					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
MINING						
N	Limestone - operation					
Y	Limestone - groundwater drawdown	1/2	3	3-6	M	Cumulative impacts to consider with increasing tourism and reaching capacity. Groundwater supply is used but it is unlikely to require significant additional allocation. Groundwater contamination is unlikely but requires appropriate management. Limestone quarries are already operational, however, there is a possibility that an expansion of operations may increase water supply requirements in foreseeable future. *Data confidence* • *Low confidence around the volumes of groundwater needed for current and future limestone operations* • *High confidence around available potable water and capacity*
N	Industrial salt facility - footprint					
Y	Industrial salt facility - groundwater drawdown	1	2	2	M	Some groundwater drawdown expected to facilitate potable water use at the industrial salt facility. *Data confidence* • *Low confidence around the volumes of groundwater needed for future salt operations* • *High confidence around available potable water and capacity*
N	Potash - footprint					
N	Potash - abstraction of brine					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
Factor: Social surroundings						
Value: Aboriginal heritage & culture						
N	Overgrazing					
N	Pests/feral animals					
Value: National heritage - Ningaloo Coast World Heritage Area						
N	Overgrazing					
N	Pests/feral animals					
Value: Amenity - land based recreation						
N	Overgrazing					
N	Pests/feral animals					
Value: Amenity - marine based recreation						
N	Overgrazing					
N	Pests/feral animals					
Value: Amenity - intrinsic/wilderness aesthetic						
Y	Overgrazing	1	3	3	M	It is possible that overgrazing could impact on amenity values and aesthetics because of a degrading landscape. The consequence is likely to be localised. *Data confidence* • *High confidence that overgrazing can damage landscapes* • *Low confidence about the extent to which overgrazing has impacted landscapes of Exmouth*
Y	Pests/ feral animals	2	3	6	M	Higher consequence as a particularly unmanaged pest/feral problem could impact on aesthetics and change the look and shape of landscapes, for example, unmanaged infestations of weeds can compete with native vegetation, which can lead to changes in

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						the landscape. Effects of weeds and feral animals on landscape aesthetics are well documented elsewhere. *Data confidence* • *High confidence that pest/ferals can impact landscapes* • *Low confidence about the extent to which pest/ferals have impacted landscapes of Exmouth*
Value: Amenity - noise, dust, odour, light						
Y	Overgrazing	1	3	3	M	Possible localised impacts of overgrazing could generate dust, noise and odour that would cause degradation of the amenity of the area. *Data confidence* • *High confidence that overgrazing can generate dust, noise and odour* • *Low confidence about the extent to which overgrazing has impacted dust, noise and odour in Exmouth*
Y	Pests/ feral animals	1	3	3	M	For feral animals specifically - not plants/weeds etc. Uncontrolled/unmanaged feral animals, such as goats, could cause localised odour and noise impacts that leads to degraded amenity. *Data confidence* • *High confidence that pest/feral animals can cause odour and noise* • *Low confidence about the extent to which pest/ferals have impacted odour and noise specifically in Exmouth*
Value: Economic - tourism						
Y	Overgrazing	1	3	3	M	Possible negative effect on tourism - for the reasons above. *Data confidence* • *High confidence that overgrazing can generate dust, noise and odour* • *Low confidence about the extent to which overgrazing has impacted tourism in Exmouth*
Y	Pests/ feral animals	1	3	3	M	Possible negative effect on tourism - for the reasons above.

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
PASTORALISM						
						Data confidence • *High confidence that pest/feral animals can cause odour and noise* • *Low confidence about the extent to which pest/ferals have impacted tourism in Exmouth*
Value: Economic - commercial fishing						
N	Overgrazing					
N	Pests/ feral animals					
Value: Economic - pastoralism						
N	Overgrazing					
N	Pests/ feral animals					
Value: Economic - science and research						
N	Overgrazing					
N	Pests/ feral animals					
Factor: Human health						
Value: potable water						
N	Overgrazing					
N	Pests/ feral animals					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Factor: Social surroundings						
Value: Aboriginal heritage & culture - Not scoring						
N	Potable water use					
N	Rubbish					
N	Human waste					
N	Camping					
N	Off-road driving					
Value: National heritage - Ningaloo Coast World Heritage Area						
N	Potable water use					
Y	Rubbish	1	2	2	M	People create rubbish. Rubbish is still left on land and in the water. Only scant anecdotal information. Needs more robust assessment of how rubbish may affect National heritage values. *Data confidence* • *High confidence that rubbish is left by tourists/visitors in Exmouth area* • *Low confidence around the impact on Ningaloo Coast World Heritage Area (NCWHA)*
N	Human waste					
N	Camping					
Y	Off-road driving	1	3	3	M	Some clear tracks within the World Heritage boundaries but not as much as on the eastern side of Cape Range and Exmouth town - see (Kobryn et al. 2017). More details required to specifically assess damage to national heritage values. *Data confidence* • *High confidence that off road driving occurs within the NCWHA* • *Low confidence around the flow on impacts to NCWHA values*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
Value: Amenity - land-based recreation						
N	Potable water use					
Y	Rubbish	1	3	3	M	May impact where recreation occurs. New areas could be used if rubbish is prevalent in commonly used areas. Only scant anecdotal information. Needs more robust assessment of how rubbish may affect land-based recreation. *Data confidence* • *High confidence that rubbish is left by tourists/visitors in Exmouth area* • *Low confidence around the impact on land based recreation*
N	Human waste					
N	Camping					
Y	Off-road driving	1	4	4	M	May disturb camping, recreating due to sight and noise of constant 4WDs. Will impact some people more than others. The activity itself is also a land-based recreational activity. *Data confidence* • *High confidence that off road driving occurs within the area* • *Low confidence around the impacts to land based recreation*
Value: Amenity - marine-based recreation						
N	Potable water use					
Y	Rubbish	1	3	3	M	May impact where recreation occurs. New areas could be used if rubbish is prevalent in commonly used areas. Published literature on marine plastic pollution (King 2019) but more information required about how this may impact marine-based recreation. *Data confidence* • *High confidence microplastics and larger rubbish occur in the water* • *Low confidence around the impact on marine based recreation*
N	Human waste					
N	Camping					

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
N	Off-road driving					
Value: Amenity - intrinsic/wilderness aesthetic						
N	Potable water use					
Y	Rubbish	2	4	8	M	Some coastal rubbish issues. Illegal dumping occurs near Mowbowra Creek. Foredune rubbish accumulation is evident. People will dump rubbish outside the tip area if the tip is closed. Rubbish degrades natural vistas. Fish frames are scattered around the place. Particular places would have a higher consequence and be more unpleasant e.g., Mowbowra Caves. Bay of Rest also has rubbish. Corroborating anecdotal reports and satellite imagery. Increased number of people will increase the impact of waste. Cumulative considerations. *Data confidence* • *High confidence that rubbish is left by tourists/visitors in Exmouth area* • *Low confidence around the impact on intrinsic/wilderness aesthetic*
N	Human waste					
N	Camping					
Y	Off-road driving	3	4	12	M	Poorly managed in the gulf. Big impact on surrounding. Brooke (workshop attendee; Exmouth Gulf local for 15yrs) - would score 2020 as having moderate to severe impact due to COVID-19. Increased visitation to the area meant that it was hard to get away from vehicle traffic, and the damage was evident in the dunes. A different demographic of people are also visiting e.g., people who would normally go to Bali, went to Exmouth Gulf because of COVID-19 restrictions. There was high visitation March - November 2020, then a demographic change again in December /January as people from inland visited the coast. Cumulative impact of more people and a perceived shift in the demographic type to consider. *NOTE: 'Pristine' in this context means public opinion/perception, not scientifically 'pristine'.*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						Data confidence • *High confidence that off road driving occurs within the area* • *Low confidence around the impacts to intrinsic/wilderness aesthetic*
Value: Amenity - noise, dust, odour, light						
N	Potable water use					
N	Rubbish					
Y	Human waste	1	2	2	M	Volume of human waste not there to be an issue for odour. Unregulated camping causes some issues and is a growing problem. Town Beach has more dog poo issues. Toilet paper is evident from overnight campers, but odour has not been raised as an issue. *Data confidence* • *High confidence that managed and unmanaged human waste occurs* • *Low confidence around unmanaged waste impacting on Amenity - noise, dust, odour, light*
N	Camping					
Y	Off-road driving	1	3	3	M	Noise would impact people's ability to enjoy peaceful surroundings. Dust may also be a factor if stirred up constantly from 4WDs. *Data confidence* • *High confidence that off road driving occurs within the area* • *Low confidence around the impacts to Amenity - noise, dust, odour, light*
Value: Economic - tourism						
N	Potable water use					
Y	Rubbish	1	3	3	M	People create rubbish. Rubbish is still left on land and in the water. Tourist operators would likely avoid areas with rubbish. Toilet paper evident from overnight campers. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *High confidence that rubbish is left by tourists/visitors in Exmouth area* • *Low confidence around the impact on tourism*
N	Human waste					
N	Camping					
Y	Off-road driving	2	3	6	M	Tracks everywhere. May not appear pristine for tourists. Also a tourist activity itself. *Data confidence* • *High confidence that off road driving occurs within the area* • *Low confidence around the impacts to tourism*
Value: Economic - commercial fishing						
N	Potable water use					
N	Rubbish					
N	Human waste					
N	Camping					
N	Off-road driving					
Value: Economic - pastoralism						
N	Potable water use					
N	Rubbish					
N	Human waste					
N	Camping					
Y	Off-road driving	1	3	3	M	Some stations may experience people driving through properties but it's unclear to what extent. *Data confidence*

Score?	Drivers / Pressures	Cons	Like	Risk	Data Conf HML	Justification
TOURISM/VISITATION						
						• *High data confidence that pastoral stations have the longest cumulative length of off-road tracks compared to other land-use types along the western margin of the cape (Kobryn et al. 2017)* • *Low confidence around the impacts to economics of pastoralism*
Value: Economic - science and research						
N	Potable water use					
N	Rubbish					
N	Human waste					
N	Camping					
Y	Off-road driving	1	3	3	M	Probably not a major impact but could also be used for the research. *Data confidence* • *High data confidence that off road driving occurs in the area* • *Low confidence around the impacts to science and research*
Factor: Human health						
Value: potable water						
Y	Potable water use	4	3	12	H	Exmouth and Exmouth Gulf was at capacity in 2020 supporting up to 20,000 people during the holiday season (DWER). The visitation rate has been unprecedented. It is difficult to know if this trend is going to continue. *Data confidence* • *High confidence around potable was use and capacity*
N	Rubbish					
N	Human waste					
N	Camping					
N	Off-road driving					

WESTERN AUSTRALIAN
MARINE SCIENCE
INSTITUTION

Better science **Better decisions**

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