Conceptual models of nearshore reefs in the Adelaide and Mount Lofty Ranges region

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Department for Environment and Water
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1 Background

Nearshore subtidal reefs provide fundamental ecological and socio-economic services for South Australia and represent one of the five key marine habitats that are used to assess the condition of the State’s marine ecosystems. Management of these resources, with particular reference to the relationships between catchment and marine, estuarine and wetland environments remains a requirement under South Australia’s Natural Resources Management Act (NRM Act, 2004). This also includes providing information on state and condition of natural resources, and any environmental, social, economic and practical considerations relating to the use, management, conservation, protection, improvement or their rehabilitation. Such information underpins guiding targets 10, 12 and 13 of South Australia’s NRM Plan (2007-2017) and respective regional NRM Plans.

The Adelaide and Mount Lofty Ranges (AMLR) Natural Resources Management (NRM) region encompasses approximately 50% terrestrial landscapes and 50% marine waters. Marine waters in the region are largely characterized by two main water bodies; Gulf St Vincent and Backstairs Passage, which the former comprises a heterogeneous habitat matrix consisting of seagrass, reef and sand. Less protected waters of Backstairs Passage on the Southern Fleurieu Peninsula comprise largely reef and sand (Figure 1.1). Nearshore subtidal reefs are particularly valuable assets in the AMLR region because of their proximity to greater Adelaide and capacity to provide ecological and socio-economic services (such as fishing and diving). Reefs in the AMLR region support iconic species and species of conservation concern including blue groper and harlequin fish, and provide critical structural and breeding habitat that underpin the life-cycles for a wide range of commercially and recreationally fished and non-fished species.

Understanding how individual or comparable types of reefs function across the region, or identifying changes in state or condition, requires long-term knowledge of drivers, pressures and threats, but also environmental responses (or resilience) of species within those systems. This is a key requirement and outcome of the AMLR NRM Plan, which aims to understand the temporal resilience of ecosystems and identify the potential factors that induce negative change (e.g. system degradation).

Over the years there have been a number of reef monitoring programs established across the AMLR region (e.g. Reef Health, Reef Life Survey (Brock et al. 2017). Given the importance of these ecosystems the AMLR Board engaged the Department for Environment and Water (DEW) Science and Information Group to review the existing suite of monitoring sites and their associated data, and to provide recommendations on the sites and indicators used to assess the condition of nearshore reef systems within the AMLR region (Brock et al. 2017). An overarching AMLR Reef Condition Assessment project has been established to implement the recommendations of Brock et al. (2017), with one key recommendation being to develop conceptual models to capture information on the drivers, pressures and threats that impact reef condition in the AMLR region.

Conceptual models are a valuable element of many ecological monitoring and management programs. They may be used as a basis for discussion and planning, to help identify gaps in knowledge, or to prioritise areas that require further research or monitoring (Roman and Barrett 1999). Conceptual models provide a representation of the current knowledge of an asset or resource, in this case reef ecosystems, and should integrate current understanding of system dynamics with important processes and functions (Gross 2003). Fundamentally they are working hypotheses about ecosystem form and function, resting on clearly-stated assumptions that are open to review, and should facilitate transparency of thought processes and assumptions around the functioning of the system of interest (Wilkinson et al. 2007).

Conceptual models are also important communication tools, as they can show how ecosystem components relate to one another in a spatial context, without the need for lengthy descriptive text (Wiebkin 2014). Conceptual diagrams can be communicated to stakeholders in an engaging way and can also guide natural resource managers to choose indicators that track the condition of the system and the impacts of key threats. These indicators can form the basis for on-going monitoring and reporting (Wiebkin 2014).
Figure 1.1: Established monitoring sites for various reef programs within the AMLR region and mapped extent of known reefs. Source: Reef Life Survey (2016), Collings et al. (2008), Brook and Bryars (2014), DEWNR unpublished data, DEWNR (2016a, b) (mhw = mean high water). Map taken from Brock et al. 2017.
1.1 Project Objectives

The overarching objective of this project was to develop conceptual models of nearshore AMLR reef ecosystems characterised in Brock et al. (2017) to provide a framework and context for assessing temperate reef condition in the region. Development of reef conceptual models for the AMLR region will contribute to the broader AMLR Reef Condition Assessment project and provide a basis for future work to characterise, monitor and manage reefs in the AMLR region. The models should build on and integrate with existing conceptual models for the AMLR region, including the regional marine health conceptual model (available at: http://www.naturalresources.sa.gov.au/adelaidemtloftyranges/about-us/our-regions-plan/conceptual-models/marine-health)

More detailed objectives of the project include to:

- Capture our current understanding of the drivers and function of reef systems in the AMLR region providing technical inputs that can be simplified and understood by a non-technical audience
- Identify, where possible, key pressures and threats of reef condition in the AMLR region and how they may impact on reef function
- Identify, where possible, the ecological and socio-economic values of reefs in the AMLR region
- Identify knowledge gaps
- Develop associated information to support the conceptual models including an evidence library.
2 Methodology

The conceptual models were developed through a number of steps detailed in Figure 2.1, which involved the synthesis of best available knowledge and data (see evidence library for references) as well as capturing expert opinion through two facilitated workshops.

To determine the content and format of the conceptual models the following elements were defined:

- Audience
- Purpose
- Scope and format
- Stakeholders and experts
- Key messages/stories for models

It was also necessary to determine whether suitable conceptual models already existed that could fulfil the needs of the project, and whether workshops would be needed in order to develop the models.

![Figure 2.1. The steps taken to develop conceptual models as part of the current project (indicated in blue) along with suggested future work (indicated in green).](image)

2.1 Workshops

Workshop one was a scoping workshop with the aim of:

- Confirming the types of models to be developed and discussing whether the scale will be adequate to capture key information and differences.
- Exploring how to define baseline condition for the models and what changes we are interested in capturing
- Discussing the key messages and questions for each model
- Discussing key data sources and references (including existing models)

Workshop two was held to further develop the conceptual models, with the specific aims of:

- Producing diagrammatic conceptual models for each agreed model type
- Identifying the key drivers, pressures and threats for each model type
- Identifying key indicators and metrics for each model type
• Documenting fundamental assumptions and knowledge gaps for each model type

Outcomes of the workshops are presented in Appendix one (workshop one) and Appendix two (workshop two) and have been incorporated into the conceptual model project outputs or recommendations where appropriate. It is important to note that these Appendices are records of discussions that occurred during the workshops and are not verified facts or the views of DEW but are direct records of statements and key points made in the workshops.

During workshop one it was decided that the conceptual models should be focused on the function of reef systems, with the understanding that state (or condition) should reflect function. A table was developed by the workshop participants to document what were considered to be the key functions and drivers of reef systems in the AMLR region (Table 2.1).

Table 2.1. Function and driver table for nearshore reefs in the AMLR region as developed by participants during project workshop one. Abiotic drivers are those non-living components of the ecosystem, whilst biotic drivers are living components of the ecosystem.

<table>
<thead>
<tr>
<th>Function</th>
<th>Abiotic</th>
<th>Biotic</th>
<th>Drivers (presented in no particular order)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-economic values</td>
<td>X</td>
<td>X</td>
<td>• Iconic species</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Political context and status</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fisheries and other extractive pressures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Tourism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Regulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Recreation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water quality (aesthetics)</td>
</tr>
<tr>
<td>Habitat provision</td>
<td>X</td>
<td>X</td>
<td>• Hydrodynamics (wave energy, currents)</td>
</tr>
<tr>
<td>(physical structure of macroalgae and rock)</td>
<td></td>
<td></td>
<td>• Depth</td>
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<td></td>
<td></td>
<td></td>
<td>• Light availability</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Nutrient availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Geomorphology (sediment/rock structure)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• pH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Physical disturbance</td>
</tr>
<tr>
<td>Nutrient cycling and detrital pathways</td>
<td>X</td>
<td>X</td>
<td>• Inorganic and organics nutrient loads (N+P)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Light availability</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Reef topography</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Carbon fixation rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water column saturation of bicarbonate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water circulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Microbial and invertebrate community</td>
</tr>
<tr>
<td>Primary and secondary production</td>
<td>X</td>
<td></td>
<td>• Toxicants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Topography</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Carbon fixation rates</td>
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<td></td>
<td></td>
<td></td>
<td>• Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Nutrient and light availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Pests</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Biodiversity and community composition</td>
</tr>
</tbody>
</table>
### Function Table

<table>
<thead>
<tr>
<th>Function</th>
<th>Abiotic</th>
<th>Biotic</th>
<th>Drivers (presented in no particular order)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fishing pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Recruitment structures and ability to recruit</td>
</tr>
<tr>
<td>Food web structure</td>
<td></td>
<td>X</td>
<td>↓ <strong>Builds on primary and secondary production.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Community composition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Functional diversity and redundancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Timing</td>
</tr>
<tr>
<td>Wave attenuation and hydrodynamics</td>
<td>X</td>
<td>X</td>
<td>↔ <strong>Direct link to and feedback with habitat provision</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Climate change</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bottom structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Depth</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Geomorphology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Biological structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Climate</td>
</tr>
<tr>
<td>Connectivity</td>
<td>X</td>
<td>X</td>
<td>• Hydrodynamics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Proximity (source of recruits) and adjacent habitat</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Biological structures (life history and directionality)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Community composition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Trophic processes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Behavioural traits</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Timing (e.g. temporal scales of tides, ocean currents, reproduction)</td>
</tr>
</tbody>
</table>

#### 2.2 Conceptual model framework

The function table (Table 2.1) provided the basis for the development of a framework for the conceptual models project (illustrated in Figure 2.2) which describes how the conceptual models and supporting information are related. This framework was designed so that information is captured at different resolutions to cater for the differing purposes and audiences. The components of the framework are described in Table 2.2.

Table 2.2. **Components of the framework for the conceptual model project with a description of their purpose**

<table>
<thead>
<tr>
<th>Output</th>
<th>Relevant report section</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function table</td>
<td>Table 2.1</td>
<td>Captures the key functions and drivers of nearshore reefs in the AMLR region</td>
</tr>
<tr>
<td>Conceptual models:</td>
<td>Section 3.5.1</td>
<td>The overarching reef function model depicts the information in the function table as a pictorial conceptual model.</td>
</tr>
</tbody>
</table>
2. **Pressure models** | Sections 3.5.2, 3.5.3 and 3.5.4 | Pictorial pressure models have been developed for the key pressures (sedimentation, nutrients, extractive resource use) demonstrating the impact of pressures on reef function.

**Synthesis tables** | Appendix three | Expands the function table by providing clear statements of hypothesised responses to drivers and pressures, along with references to document supporting information. Contains a confidence ranking for each statement.

**Reef characterisation** | Section 4.2 | Uses the subregional groupings described in Brock et al. (2017). Each subregion is characterised using the function table as a template, and using existing data and expert knowledge. Provides a benchmark for each subregion.

**Evidence library** | Section 4.3 | A record of all references used for the project
Figure 2.2. Framework for the AMLR reef conceptual modelling project illustrating the hierarchy of information and project outputs. See Table 2.2 for a description of each component of the framework.
3 Conceptual models

'Synthesised science is more likely to be integrated into policy, planning, management, community understanding—it is more likely to be used to make a difference' (Heydon and Vandergragt 2011).

3.1 Audience

The conceptual models need to be suitable for a wide range of potential audiences including Natural Resources ALMR, DEW, other state agencies, external stakeholders and the general public. With such a wide range of intended stakeholders the project outputs need to be designed in a way that information is provided at increasing resolutions in order to meet the needs of different audiences. The framework has been designed to achieve this, as well as to provide references for all information used so that further detail can be sought if required.

3.2 Purpose of the models

It is anticipated that the conceptual models will be used for the following purposes:

- Management
  - Designing a monitoring program
  - Identifying knowledge gaps
  - Planning and prioritising future research
  - Planning and prioritising management actions
- Understanding
  - Establishing a baseline
  - Interpreting monitoring data and results
- Reporting
  - NRM plan and regional targets
  - State NRM Report Cards
  - Marine Parks Performance Program
- Communication

By synthesising and presenting information in a clear and consistent manner it is hoped that catchment managers and those monitoring reef systems within the AMLR region and other programs or regions implementing reef-type programs (e.g. artificial reefs) are able to access better information to support their decisions. In particular the conceptual models and supporting information may assist in achieving the following outcomes:

- Aligned and consistent monitoring programs in the AMLR region
- The right research being funded and knowledge gaps being filled
- Better recognition of the values of reefs in the AMLR region (both anthropogenic and ecological) and their threats
- The acknowledgement of reefs as connected marine systems (both to the catchment and to other marine systems).

3.3 Scope

The conceptual models are applicable to reef ecosystems within the AMLR region, however they do not specifically apply to any on-ground geographic location; rather they illustrate the representative types of reef ecosystems that may be found within the region. They may be applied to reefs in other regions in South Australia, but were not developed specifically for this purpose.
It is outside of the scope of this project to develop goals, targets or thresholds for reef ecosystems within the ALMR region.

3.4 Format

Conceptual models are important communication tools, as they can show how ecosystem components relate to one another in a spatial context, without the need for lengthy descriptive text (Wiebkin 2014). Conceptual models can be communicated to stakeholders in an engaging way and can also guide natural resource managers to choose indicators that track the condition of the system and the impacts of key threats (Wiebkin 2014). There are a number of formats that may be used when developing conceptual models such as written text, tables, pictorial models and box and arrow diagrams (Wilkinson et al. 2007).

The participants of workshop one decided that the models would be pictorial models that illustrate a set of relationships between factors that are believed to impact or lead to a target state or condition. The models will be focused on the function of reef ecosystems in the AMLR with the understanding that state/condition should reflect function.

3.5 The conceptual models

A number of different models have been developed as part of this project and are presented in the sections below. The first is an overarching reef function conceptual model, which depicts the information captured in the function table (Table 2.1).

In addition models have been developed for the key pressures which were selected and prioritised during workshop two. A model has been developed for each of the three chosen key pressures:

- sedimentation
- eutrophication/nutrients
- extractive resource use (e.g. fishing)

Each model has a simple summary model which is more suited to general communication along with a more detailed model that should be used for planning and decision making purposes. The models may also have accompanying sub-models to provide greater detail on some aspects of the model.

Models are presented in Figure 3.1 to Figure 3.10.
3.5.1 Reef function model

**Figure 3.1: Reef function conceptual model for reefs in the AMLR region**

KEY VALUES
- Values of reefs in the AMLR region can be described using the ecosystem services framework (Millennium Ecosystem Assessment 2005):
  - CULTURAL SERVICES: recreation, tourism, aesthetic value, spiritual value, education.
  - PROVISIONING SERVICES: fishing and other extractive use, genetic diversity and biodiversity, iconic species.
  - SUPPORTING SERVICES: Provision of habitat, primary production, nutrient cycling, water quality.
  - REGULATING SERVICES: Wave attenuation and coastal protection.

KEY PRESSURES
- The key pressures impacting reefs in the AMLR region are:
  - Sedimentation
  - Increased nutrients
  - Over-extraction (e.g. of plants, fish and invertebrates)
  - Toxins
  - Climate change

HABITAT
- The physical structure of the reef provides habitat for other plants and animals on the reef. A diverse and multi-layered macroalgal community and a complex rocky substrate is important, and usually linked to biodiversity and other values.

NUTRIENT CYCLING
- Many different nutrients are required by organisms to live. Nutrient cycling is important as it is how nutrients move through the food web and are made available to the organisms that need them.

PRODUCTIVITY
- Productivity is important as it is how energy flows through the ecosystem. Sunlight can penetrate the water column so that algae can photosynthesise. Other organisms can then use this energy by eating algae, to produce more energy within the system.

FOOD WEBS
- The food web represents what eats what, and how energy flows through the ecosystem. The reef should have a diverse community with old large-bodied individuals, and a range of species and body sizes. These species interact with each other in different ways to shape the community and habitat.

COASTAL PROTECTION
- The physical structure of the reef can influence the way in which water moves in the ocean, especially near the coast. In particular reefs can provide protection for the shoreline against high wave energy.

CONNECTIVITY
- There are many different ways in which rocky reefs may be connected to other reefs and other habitats (e.g. seagrass). Organisms can move between habitats to varying degrees, which is important for maintaining biodiversity and ecosystem resilience.
3.5.2 Sedimentation

Figure 3.2: Summary conceptual model for the impact of sedimentation on reefs in the AMLR region.
Figure 3.3: Detailed conceptual model for the impact of sedimentation on reefs in the AMLR region.
Figure 3.4: Sedimentation sub-model 1 – the impact of sedimentation on food web and community structure of reefs in the AMLR region.
SUBMODEL 2: factors influencing sediment deposition on nearshore reefs

Influence of topography:
High profile reefs are generally less susceptible to sedimentation as the steeper sections will not accumulate sediments. However, low points in the reef accumulate sediment, which reduces habitat complexity by filling in crevices and this sediment is less likely to be resuspended. Remaining sediment is transported elsewhere by currents and water movement.

Factors contributing to sediment disturbance regime:
- The characteristics of sediment particles: sediment grain size, shape, density, and mineral and chemical composition
- The mixing, flow and turbulence of water which may change with season
- The extent, degree, location, frequency and duration of sediment burial

Low profile reefs are generally more susceptible to sedimentation as sediments can settle more easily and impact a broader area. These environments are also more susceptible to resuspension of sediments.

High energy environments: coarse sediment fractions will be retained, fine sediment fractions will be resuspended and flushed.

Low energy environments: fine sediment fractions will settle along with coarse sediment fractions. There will likely be greater accumulation of sediments if flushing does not occur.

Figure 3.5: Sedimentation sub-model 2 – the factors influencing sediment deposition on nearshore reefs in the AMLR region.
3.5.3 Eutrophication/nutrients

Figure 3.6: Summary conceptual model for the impact of increased nutrients on reefs in the AMLR region.
Figure 3.7: Detailed conceptual model for the impact of increased nutrients on reefs in the AMLR region
3.5.4 Extractive resource use

Figure 3.8: Summary conceptual model for the impact of extractive resource use on reefs in the AMLR region

Pressures on nearshore rocky reefs: EXTRACTIVE RESOURCE USE

EXTRACTION METHODS

- Hook and line fishing
- Pots and traps
- Scuba diving, spear fishing and hand collection
- Harvesting in intertidal (fjaggl)

NO EXTRACTION

FAUNA
A diverse community including a range of species body sizes and age classes. Large predators present. Low presence of pest species.

HABITAT
A diverse and multi-layered ecosystem community and a complex rocky substrate comprising diverse community structure.

PHYSICAL IMPACTS
There may be physical damage to the reef from anchors, ropes, lines, pots and anchoring.

OVER EXTRACTION

FAUNA
Loss of predators and large-bodied fish, and a shift to a community of small-bodied fish and invertebrates. Pest species can more easily invade the habitat. A change in community can lead to a change in trophic structure and interactions.

HABITAT
The habitat may change due to physical damage, or through indirect pressure mediated by a change in community dynamics.

Pathway of change

- Extractive resource use (fishing & harvesting)
- Selective removal of individuals
- Change in size structure of community
- Change to ecosystem functions and values

Examples of fished species: Swallowtail (left) and Sweep (right)

There are a number of rules in place to regulate extraction in South Australia, including:
- Size, bag and boat limits
- Closed and aquatic reserves
- Rock lobster pot registration
- Restrictions on certain types of fishing gear
- Protected species
- Sanctuary zones

More information can be found at: www.pir.sa.gov.au/fishing
Figure 3.9: Detailed conceptual model for the impact of extractive resource use on reefs in the AMLR region
SUBMODEL 1: impact of extractive resource use on food web and community structure

Changes to food web and community structure

- Population shift toward younger and/or smaller bodied individuals which leads to a change in the functional roles and diversity in the ecosystem, as well as a change in the size structure of the community.
- A reduction in fish biomass (by decreasing the proportion of large individuals in the population) as well as a potential change in the sex ratios of fish populations.
- A potential reduction in the reproductive output and recruitment of target species. A change in these traits generally reduces the resilience of fish communities and reduces the capacity for population recovery.
- Fishing may lead to potential behavioural changes in target species, which may differ between site-attached and mobile species.
- Potential for invasion by pest species.
- Change in macroalgal community due to trophic interactions, which may be moderated by grazers.

Figure 3.10: Nutrient sub-model 1 – the impact of extractive resource use on food web and community structure of reefs in the AMLR region

There are a number of rules in place to regulate extraction in South Australia, including:

- Size, bag and boat limits
- Closures and aquatic reserves
- Rock lobster pot registration
- Restrictions on certain types of fishing gear
- Protected species
- Sanctuary zones

More information can be found at: www.pir.sa.gov.au/fishing

Knowledge gaps

- A potential change in invertebrate fauna and macroalgae due to reduced predation.

Not all species and assemblages are equally affected by extractive resource use.
4 Supporting information

4.1 Synthesis tables

Developing an adequate evidence base for each conceptual model is a way to summarise the supporting references, assumptions and knowledge gaps for the models, as well as establishing a rigorous and transparent methodology for developing the model outputs (Department of Environment, 2015).

Each conceptual model has an accompanying synthesis table which expands the function table by providing clear statements of hypothesised responses to drivers and pressures, along with references to document supporting information. The synthesis tables for conceptual models of reef function, sedimentation, eutrophication/nutrients, and extractive resource use can be found in Appendix three and provide a clear evidence base for each model developed as part of this project.

The synthesis tables should be updated when the conceptual models are reviewed in the future when new data or other evidence becomes available. It is recommended that any future conceptual models are developed using a similar synthesis table to ensure consistency with the outputs of the current project, as well as to provide a sound evidence base for models produced.

The synthesis tables also present qualitative estimates of evidence, agreement and confidence (following the Intergovernmental Panel on Climate Change (IPCC) 2013 approach described below) for each hypothesis.

The approach used by the IPCC (2013) to predict the effects of future climate change expresses uncertainty in a qualitative manner, based on the extent of agreement between evidence from different sources (low, medium and high) and the quality and consistency of this evidence (limited, medium and robust). Combining the agreement and quality of the evidence resulted in five grades of confidence:

1. Very low: low agreement, limited evidence
2. Low: low agreement, medium evidence; medium agreement, limited evidence
3. Medium: low agreement, robust evidence; medium agreement, medium evidence; high agreement, limited evidence
4. High: high agreement, medium evidence; medium agreement, robust evidence
5. Very high: high agreement, robust evidence.

4.2 Subregional benchmarks

Using the subregional groupings described in Brock et al. (2017), each subregion will be characterised using the function table as a template, and using existing data and expert knowledge. This provides a benchmark for each subregion as well as testing the applicability of the function table to a number of different reef types in the AMLR region. This work will be published separately.

4.3 Evidence library

All references used to develop the conceptual models are recorded in an evidence library which serves multiple purposes. Firstly, it provides a clear record of all information used so that new or missing materials can be easily identified and included. Secondly, the evidence library allows users of the conceptual models to seek clarification or further information from the sources used if required.
The evidence library is in an Excel spreadsheet and should be updated if the conceptual models are revised using updated information. A copy of the evidence library is provided in Appendix four.
5 Conclusions and recommendations

5.1 Knowledge gaps

A summary of the key knowledge gaps identified during the development of the conceptual models can be found in Table 5.1. These knowledge gaps have not been ranked or prioritised, but this process could be undertaken if required to develop a targeted approach to future management and prioritise funding.

Table 5.1. Summary of key knowledge gaps identified during the project based on the conceptual model outputs and supporting information

<table>
<thead>
<tr>
<th>Model</th>
<th>Knowledge gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimentation</td>
<td>Which particle size proportions have the greatest impact on the reefs?</td>
</tr>
<tr>
<td></td>
<td>Where do the different particle sizes come from and is this changing over time?</td>
</tr>
<tr>
<td></td>
<td>Are inputs of sedimentation increasing over time and what is the impact of climate change on these inputs?</td>
</tr>
<tr>
<td></td>
<td>Where is the in situ sediment load coming from and how much of it is natural?</td>
</tr>
<tr>
<td></td>
<td>Does a shift to turfing algae impact detrital pathways?</td>
</tr>
<tr>
<td></td>
<td>Do fishes exhibit species-specific avoidance behavior in relation to high sediment environments?</td>
</tr>
<tr>
<td></td>
<td>How could sediment impact chemical cues, acoustic properties and timing of reproduction in species?</td>
</tr>
<tr>
<td>Increased nutrients</td>
<td>What is the contribution of nutrients from diffuse sources?</td>
</tr>
<tr>
<td></td>
<td>What is the contribution of nutrients from local sources?</td>
</tr>
<tr>
<td></td>
<td>How does sediment interact with nutrients?</td>
</tr>
<tr>
<td></td>
<td>What is the interaction between nutrients and grazers and does this drive changes in macroalgal assemblages?</td>
</tr>
<tr>
<td></td>
<td>What is the threshold for macroalgal tolerance of nutrients?</td>
</tr>
<tr>
<td>Extractive resource use</td>
<td>Which species benefit from fewer predators in the system?</td>
</tr>
<tr>
<td></td>
<td>What are the possible pathways for change in habitat, productivity and food webs and what drives these changes?</td>
</tr>
<tr>
<td></td>
<td>What are the mechanisms by which changes in species composition and size structure alter food web dynamics and interactions between grazers and macroalgae?</td>
</tr>
<tr>
<td></td>
<td>What is the potential change in invertebrate fauna and macroalgae due to reduced predation?</td>
</tr>
</tbody>
</table>
5.2 Recommendations

5.2.1 Publication of models

The current conceptual models have been designed for publication in a report or as A3 and A4 hard copies. The most effective way to publish conceptual models however, particularly for use by a wider audience, is the use of an agency webpage (for example on AMLR’s website). This can allow a greater audience to access the models and can also allow for more interactivity with the models through the use of hyperlinks and pop-out submodels. It is recommended that the current models are published online once review has been finalised, along with any of the supporting information that is considered appropriate for wider publication.

In 2013, the Premier announced a Declaration of Open Data to make government data available for use by business and the community. In the future it may be possible to use the conceptual models as a central point for organising and linking information online, including reef health data that is collected annually along with any data describing pressures. Using an online format the conceptual models could be linked with mapping, data, relevant publications, monitoring methodology and sites, and any relevant management actions or projects so that people have access to a consolidated and comprehensive information base about nearshore reefs in the AMLR region.

5.2.2 Review of models

Useful and robust conceptual models should be iterative and periodically updated. The models developed for the current project can be re-evaluated and updated as new field sampling data (evidence) becomes available or as knowledge gaps are filled. Planned, periodic review is the most certain means to ensure the conceptual models continue to reflect current knowledge (Gross 2003), but at a minimum the draft conceptual models should be reviewed at least once during development and again at some point in the future. Figure 5.1 illustrates a suggested process for evaluating and editing the conceptual models.

It is important to note that if the conceptual models are updated so too should the synthesis tables and evidence library to ensure all information is consistent and up to date.

Figure 5.1. Work flow diagram illustrating the suggested steps for editing and refining the existing conceptual models.
5.2.3 Links to monitoring

Newton et al. (1998) identify the following advantages of conceptual models for monitoring programs, which are relevant for the current project:

1. They provide general scientific agreement for the ecological framework of the system;
2. They provide a basis to identify gaps in knowledge and understanding;
3. They provide a basis for managers to ask questions, to see the complexity of the information required for answers, and to see relationships between management activities and ecosystem responses;
4. They provide a basis for designing monitoring and research programs to answer questions; and
5. They provide context for presenting results.

These conceptual models and supporting information should be considered in conjunction with the outputs of the wider Reef Condition Assessment project to review the suitability of current indicators and monitoring methods for assessing reef condition in the AMLR region. As the current project focuses on the key pressures on reef ecosystems it is important to consider whether current monitoring adequately assesses the source of pressures, particularly those originating from the wider catchment.

5.2.4 Links to ecosystem services

The concept of ecosystem services is often used to describe the value of natural environments (DEWHA 2009). Ecosystem services are the benefits provided to humans through the transformations of resources (including land, water, vegetation) into a flow of essential goods and services e.g. clean air, water, and food (after Constanza et al. 1997). Figure 5.2 provides a summary of the ecosystem services as described in the Millennium Ecosystem Assessment (2005).

Ecosystem services help to articulate the value of reef habitats but could also provide a mechanism for characterising the economic value of these ecosystems. A strength of the function-based approach used in this project is that the described functions translate easily into ecosystem services. This means that the outputs of this project could readily be used as a basis for future work describing the economic value of nearshore reef habitats in the AMLR region.

![Figure 5.2. An overview of the four categories of ecosystem services as described in the Millennium Ecosystem Assessment (2005) (diagram reproduced from DEWHA 2009)](image-url)
5.2.5 Additional models

The framework and methodology described in this report can be used to further develop models for marine ecosystems. In particular, models for seagrass ecosystems could be developed in a similar way to provide consistency between outputs for different marine habitat types within the AMLR region.

During the workshops there were other pressures that were discussed however these pressures were not prioritised for model development as part of the current project.

Table 5.2 Summary of additional pressures discussed at the conceptual modelling workshop and reason/s why models were not developed as part of the current project

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Reason for exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toxicity</td>
<td>Not a huge concern in the region, the levels of toxicity that are seen are not enough to make a big impact compared to other pressures.</td>
</tr>
<tr>
<td>Invasive species</td>
<td>This can be considered more of a risk and is the result of niches created by the impacts of other pressures. Invasive species are synergistic with other pressures and will be captured in each separate conceptual model.</td>
</tr>
<tr>
<td>Climate change</td>
<td>Is critical but difficult to manage and address at this scale. It can be used as an overarching lens to understand how other pressures may be intensified under climate change scenarios.</td>
</tr>
</tbody>
</table>

5.2.6 Conclusion

The current project has undertaken work in developing conceptual models to support the broader Reef Condition Assessment project being undertaken by the DEW Science and Information Group for the AMLR NRM Board. This report has outlined a conceptual modelling framework for developing models of reef function and pressure in the AMLR region.

This has produced a suite of conceptual models that can be further refined and developed in the future, along with supporting information to ensure robust and transparent outputs.
6 References


Appendix One

AMLR reef conceptual models workshop one: scoping

Workshop summary

This Appendix is a record of discussions that occurred during the workshops and are not verified facts or the views of the Department. Instead they are a direct record of statements and key points made in the workshops and may be inaccurate, incorrect or without context.

Thursday 22nd February 2018, 10am-2pm

Attendees: Danny Brock, Kristian Peters, Craig Meakin, David Miller, James Brook, Jason Tanner, Michelle Waycott, Sam Gaylard, Simon Bryars, Keith Rowling, Sarah Imgraben, Dan Easton

Apologies: Tim Kildea, Tony Flaherty, Bryan McDonald, Jamie Hicks

2. AMLR Reef Condition Assessment Project (Danny Brock)

Danny Brock provided an overview of the AMLR Reef Condition Assessment Project (AMLR RCAP).

AMLR RCAP is an extension of the review undertaken by Brock et al (2017) “review and recommendation of sites and indicators for monitoring the condition of near-shore subtidal reefs communities in the Adelaide and Mount Lofty Ranges NRM region”.

The AMLR RCAP was funded to implement the recommendations in Brock et al (2017). The development of conceptual models for nearshore reefs in the AMLR region was one of the recommendations.

The AMLR RCAP has four main components:

1. Develop conceptual models of AMLR reef ecosystems to provide a framework and context for assessing reef condition.
2. Review current methods for assessing macroalgal communities and select the most appropriate and cost effective approach (comparison of LIT and photo quadrats)
4. Establish baseline condition of the 41 reef sites for long term monitoring in the AMLR region using data collected from the annual survey and prepare a final report.

Please see attached report (Brock et al. 2017) for more information on the review (Attachment A).

3. Use and purpose of the conceptual models

Kristian explained that currently the AMLR regional models are broad-scale and focus primarily on seagrass. More detailed models for reef systems are needed particularly to support regional NRM planning. The Regional Targets for AMLR may be changing, however no information is currently known.

Identified uses for the conceptual models:

- Management
  - Designing the monitoring program
  - Identifying knowledge gaps
  - Planning and prioritising investment and future research
  - Planning and prioritising management actions
- Understanding
  - Establishing a baseline
  - Interpreting monitoring data and results
- Reporting
  - NRM plan and regional targets
It was highlighted that planning and prioritising management actions should be one of the key uses and that uncertainty needs to be captured in the models.

**KEY OBJECTIVE FOR MODELS:** Pictorial models that illustrate a set of relationships between factors that are believed to impact or lead to a target state/condition. Models will be focused on the function of reef systems, with the understanding that state should reflect function.

4. **Baseline and capturing change**

Key questions:
- What do we expect these reefs to look like?
- Do we want them to change?
- What do we accept as change?
- What is the trajectory of change?

It was identified that it may be possible to define a reference (or pre-European) condition for some reefs. The group discussed three options for the trajectory of reef condition: maintaining, improving and declining.

It was recognised that there needs to be a discussion around goals and targets, but it is not the job of this project to set targets, goals or thresholds for reef ecosystems. There was however, agreement that current state should be a baseline that should be maintained and we don’t want reefs to get any worse.

5. **Types of models to be developed**

It was initially proposed that a model be developed for each of the 8 subregions identified in Brock et al. (2017) (refer to workshop Attachment B) however the group decided that there could be fewer models based on categories of function of reefs within the AMLR region.

Variability of habitats and locations also needs to be taken into account.

It was identified that the Southern Metro region would be a good starting point as Moana is relatively un-impacted.

A number of variables were identified which may be used to separate reef ecosystems within the AMLR region:
- Level of impact
- Level of protection (e.g. sanctuary zone, non-sanctuary zone)
- Canopy cover
- Topography
- Inputs

6. **Development of function and driver matrix**

The group worked together to develop a functions and drivers matrix for nearshore reefs in the AMLR Region to begin mapping out function categories. See Table 3 for the matrix developed during the workshop.

This matrix will form the foundation for the first conceptual model, which will be a base model of reef function and drivers. Additional sub- models will be developed only when there is too much variability to capture all information in the base model.

7. **Case study: Moana high relief reef**

The function/driver matrix was completed using Moana high relief reef as a case study (Table 4). Applicable data is also highlighted in the third column of Table 2.
<table>
<thead>
<tr>
<th>Function</th>
<th>Abiotic</th>
<th>Biotic</th>
<th>Drivers*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-economic values</td>
<td>X</td>
<td>X</td>
<td>• Iconic species</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Political context and status</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fisheries and other extractive pressures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Tourism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Regulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Recreation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water quality (aesthetics)</td>
</tr>
<tr>
<td>Habitat provision</td>
<td>X</td>
<td>X</td>
<td>• Hydrodynamics (wave energy, currents)</td>
</tr>
<tr>
<td>(physical structure of macroalgae and rock)</td>
<td></td>
<td></td>
<td>• Depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Light attenuation (Kd)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Nutrient availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Geomorphology (sediment/rock structure)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• pH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Physical disturbance</td>
</tr>
<tr>
<td>Nutrient cycling and detrital pathways</td>
<td>X</td>
<td>X</td>
<td>• Inorganic and organics nutrient loads (N+P)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Light attenuation (Kd)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Reef topography</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Carbon fixation rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water column saturation of bicarbonate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water circulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Microbial and invertebrate community</td>
</tr>
<tr>
<td>Primary and secondary production</td>
<td>X</td>
<td></td>
<td>• Toxicants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Topography</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Carbon fixation rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Nutrient and light availability</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Pests</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Biodiversity and community composition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fishing pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Recruitment structures and ability to recruit</td>
</tr>
<tr>
<td>Food web structure</td>
<td></td>
<td>X</td>
<td>↓ <strong>Builds on primary and secondary production.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Community composition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Functional diversity and redundancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Timing</td>
</tr>
<tr>
<td>Wave attenuation and hydrodynamics</td>
<td>X</td>
<td>X</td>
<td>↔ <strong>Direct link to and feedback with habitat provision</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Climate change</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bottom structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Geomorphology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Biological structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Climate</td>
</tr>
<tr>
<td>Connectivity</td>
<td>X</td>
<td>X</td>
<td>• Hydrodynamics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Proximity (source of recruits) and adjacent habitat</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Biological structures (life history and directionality)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Community composition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Trophic processes</td>
</tr>
<tr>
<td>Behavioural traits</td>
<td>Other pressures:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Adjacent landuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Catchment pressures</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Resource extraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Physical disturbance (anthropogenic)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Drivers are presented in no particular order
<table>
<thead>
<tr>
<th>Function</th>
<th>Drivers</th>
<th>Data availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-economic values</td>
<td>● Fishing (general, no target spp)</td>
<td>● Kristian to investigate</td>
</tr>
<tr>
<td></td>
<td>● Recreational – diving (low level)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Scientific</td>
<td></td>
</tr>
<tr>
<td>Habitat provision</td>
<td>● 1 habitat type, limestone base with variable topography</td>
<td>● No rugosity data</td>
</tr>
<tr>
<td>(physical structure of macroalgae and rock)</td>
<td>● Dense uniform canopy cover of <em>Ecklonia</em> (3D biotic substrate)</td>
<td>● Data for most other variables</td>
</tr>
<tr>
<td></td>
<td>● High relief</td>
<td></td>
</tr>
<tr>
<td>Nutrient cycling and detrital pathways</td>
<td>● Modest inputs (Onkaparinga)</td>
<td>● Sediment data</td>
</tr>
<tr>
<td></td>
<td>● Hydrodynamics: low-moderate exposure</td>
<td>● Plume maps</td>
</tr>
<tr>
<td></td>
<td>● Canopy forming brown algae (fixation of carbon)</td>
<td>● Pressures and inputs</td>
</tr>
<tr>
<td></td>
<td>● 5-7m depth</td>
<td>● SST &amp; hydrodynamics</td>
</tr>
<tr>
<td></td>
<td>● Tidal - typical</td>
<td></td>
</tr>
<tr>
<td>Primary and secondary production</td>
<td>● Canopy forming brown algae and associated community composition</td>
<td>● Fish data</td>
</tr>
<tr>
<td></td>
<td>● Fished (all species, including crayfish)</td>
<td>● BRUVS</td>
</tr>
<tr>
<td>Food web structure</td>
<td>● High diversity of fish (due to relief) and invertebrates</td>
<td>● Invertebrates</td>
</tr>
<tr>
<td></td>
<td>● Lower algal diversity</td>
<td>● Mapping</td>
</tr>
<tr>
<td></td>
<td>● Low pests</td>
<td></td>
</tr>
<tr>
<td>Wave attenuation and hydrodynamics</td>
<td>● Site provides wave attenuation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Abiotic and biotic factors influence this,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>however the abiotic drivers add additional benefit to the abiotic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>drivers (which would always be there)</td>
<td></td>
</tr>
<tr>
<td>Connectivity</td>
<td>Connectivity depends on which species are of interest (different ranges</td>
<td>● Ranges of species? – Kristian</td>
</tr>
<tr>
<td></td>
<td>and life history), these need to be defined and explored on a case</td>
<td>● Mapping – distance</td>
</tr>
<tr>
<td></td>
<td>by case basis.</td>
<td>between reefs</td>
</tr>
<tr>
<td></td>
<td>● Discrete reef</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Adjacent habitat is sand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Expectation of exemplar spp – indicative that movement between reefs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>is possible</td>
<td></td>
</tr>
</tbody>
</table>

**Potential differentiating factors:**

- Relief
- *Ecklonia* (presence, cover)
- Connectivity
- Tidal influence
- Protection (e.g. sanctuary zones)
- Gradients
Appendix Two

AMLR reef conceptual models workshop two: model development

Workshop summary

Wednesday 2nd May 2018

Attendees: Danny Brock, Kristian Peters, Craig Meakin, David Miller, James Brook, Jason Tanner, Sam Gaylard, Simon Bryars, Sarah Imgraben, Dan Easton, Tim Kildea, Jamie Hicks, Rick Stuart-Smith

Apologies: Tony Flaherty, Bryan McDonald, Michelle Waycott, Keith Rowling

1. Introduction

The objectives of the conceptual models are to:

- Capture our current understanding of the drivers and function of reef systems in the AMLR region in a simple pictorial format that can be understood by a non-technical audience
- Pictorial models that illustrate a set of relationships between factors that are believed to impact or lead to a target state/condition.
- Models will be focused on the function of reef systems, with the understanding that state should reflect function.

The models will be used for:

- MANAGEMENT
  - Designing a monitoring program
  - Identifying knowledge and gaps
  - Planning and prioritising future research
  - Planning and prioritising management actions

- UNDERSTANDING
  - Establish a baseline
  - Interpreting monitoring data and results

- REPORTING
  - NRM plan and regional targets
  - State NRM Report Cards
  - Marine Parks Performance Program

- COMMUNICATION

Overall we want to empower decision makers and make things easier for the people managing catchments and monitoring reefs in the AMLR region by creating products that help us change the way we do some things. This may include:

- Aligned and consistent monitoring programs
- The right research being done (and knowledge gaps being filled)
- Better recognition of the values of reefs in the AMLR region (both anthropogenic and ecological) and their threats
Acknowledgement of reefs as connected marine systems (both to the catchment and to other marine systems).

The framework for the conceptual models and accompanying supporting information was presented which builds on the function table developed during workshop one and includes the following outputs:

- Function and driver table (developed during workshop one)
- Overarching reef function conceptual model (and sub-models if applicable)
- Conceptual models for key pressures (and sub-models if applicable)
- Characterisation of each subregion (or reef type) using the function table as a template (out of session)
- Synthesis table which describes our hypotheses for the relationships between drivers and functions, and evidence for each hypothesis.
- Evidence library of all references used.

2. Prioritisation exercise

Small groups worked on an exercise to prioritise the key pressures impacting nearshore reefs in the AMLR region.

The pressures were prioritised in the following way by each group (with pressures that models will be developed for highlighted in grey):

**Table 5: results of the prioritisation exercise to rank key pressures on reefs in AMLR region**

<table>
<thead>
<tr>
<th>Number</th>
<th>Pressure</th>
<th>Notes/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sedimentation/turbidity</td>
<td>• Higher in metro area</td>
</tr>
<tr>
<td>2</td>
<td>Extractive resource use</td>
<td>• Include physical damage in this</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Non-discriminant collection (all species)</td>
</tr>
<tr>
<td>3</td>
<td>Eutrophication</td>
<td>• Potentially under control as has definitely come down from past levels.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Urban/rural – fertilised farms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Murray Mouth</td>
</tr>
<tr>
<td>4</td>
<td>Toxicity</td>
<td>• Not a huge concern</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Hydrocarbons, antifouling an issue but not a huge concern in AMLR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The levels we see are not enough to be a real impact compared to other things</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO MODEL WILL BE DEVELOPED FOR THIS</td>
</tr>
<tr>
<td>5</td>
<td>Invasive species</td>
<td>• Localised</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AMLR may be higher than other regions?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• This is synergistic with other pressures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• This can be considered more of a risk, the result of niches created by impacts of other pressures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO MODEL WILL BE DEVELOPED FOR THIS</td>
</tr>
</tbody>
</table>
6. Conceptual Models

Workshop participants discussed each of the top three key pressures (Table 5) and identified the key impacts from each pressure on the function of reefs in the AMLR region. Information was recorded on the whiteboard.

These inputs have been incorporated into the conceptual models.

4. Indicators

Rick Stuart-Smith provided an overview of the work he has been involved in developing a monitoring program for Rottnest Island which has been summarised below:

- They started with key values (e.g. reef, seagrass, intertidal, tourist values)
- During a workshop the key pressures were identified
- A set of indicators were chosen that relate to the key pressures and reef condition
- The first three years of RLS monitoring data was used as a baseline, and change is tracked in relation to that baseline (within 2 standard deviations to account for variability)
- Indicators should be chosen with consideration of generality, specificity (to pressure), sensitivity (to pressure), and temporal lag (i.e. how long until we see changes).

Participants then discussed reef condition indicators.

Considerations were:

- Capturing variability and baseline is difficult
- Multiple lines of evidence should be collected/used
- There should be indicators for reef health/condition, but also indicators that link to the catchment and pressures.
- Long term datasets can be a valuable indication of variability within a system.
- At a minimum we should strive to maintain what we currently have
- A suite of indicators have been defined by UTAS, published in Bioscience 2017

Indicators that people thought were working well:

- Macroalgae (composition and canopy cover)
- Sedentary invertebrates
- Bare substrate
- Mussels
- BRUVS is a good approach for fish, mitigates visibility issues and is more standardised than diving
- Fish size and community metrics
Appendix Three

References in this section can be found in the evidence library for the project which is presented in Appendix four and more information about the synthesis table and confidence ratings can be found in Section 4.1.

Table 6: synthesis table of assumptions about the influence of sedimentation on reef function, and corresponding confidence ratings for evidence (E), agreement (A) and overall confidence (C).

<table>
<thead>
<tr>
<th>Function</th>
<th>Hypothesis</th>
<th>Reference</th>
<th>E</th>
<th>A</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat provision</td>
<td>Deposition is dependent on hydrodynamic conditions and the nature of the sediment, e.g. fine sediments will be resuspended in high wave energy environments.</td>
<td>Turner et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Finer sediments will settle in low energy environments, whilst in high energy environments coarser sediments will be retained but finer sediments will be resuspended and flushed</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Increased turbidity and sedimentation reduces the amount of light reaching algal communities, reducing photosynthesis</td>
<td>Turner et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Changes in the physical characteristics of the bottom surface which can result in loss of habitat suitable for settlement</td>
<td>Airoldi (2003)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Decrease in habitat complexity with loss of macroalgal structure and filling in of crevices in the rock</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Shift from macroalgae to opportunistic species, especially turfing algae</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Low profile reefs are more susceptible to accumulation of sediment than high profile reefs, with the low points and crevices of high profile being susceptible to accumulation of sediment</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Function</td>
<td>Hypothesis</td>
<td>Reference</td>
<td>E</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td><strong>Nutrient cycling and detrital pathways</strong></td>
<td><strong>GAP</strong>: will a shift from macroalgae to turfing algae impact detrital pathways?</td>
<td>Expert elicitation</td>
<td>Limited</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td><strong>Primary and secondary production</strong></td>
<td>Smothering or burial of macroalgae can lead to reduced availability of light, oxygen or nutrients, which can lead to decreased productivity</td>
<td>Airoldi (2003)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Food web structure</strong></td>
<td>Switch from macroalgae to turfing algae</td>
<td>Gorgula and Connell (2004)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Change in the size structure of the community, with a shift to smaller species and individuals</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Scour or abrasion resulting in damage or removal of whole organisms or their parts, or clogging of gills of sessile invertebrates</td>
<td>Airoldi (2003), Schiel et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Suspended settlement can interfere with filter feeding of benthic invertebrates, and the deposition of sediment can interfere with settlement, growth and photosynthetic activity of organisms.</td>
<td>Airoldi (2003), Schiel et al. (2006), Vadas et al. (1992)</td>
<td>Robust</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>Not all species and assemblages are equally affected by sedimentation and responses vary over space and time, depending on:</td>
<td>Airoldi (2003)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>• the characteristics of the depositional environment,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• life histories of species and the stage of development of individuals and assemblages,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Variable physical factors, including hydrodynamics, light intensity and bottom topography</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intertidal habitats are likely to have breaking waves, and greater turbulence, flow, and tidal movement than subtidal habitats so there</td>
<td>Schiel et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Function</td>
<td>Hypothesis</td>
<td>Reference</td>
<td>E</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Wave attenuation and hydrodynamics</td>
<td>may be differences in the magnitude and type of effect of sedimentation. Sheltered habitats are likely to exhibit settlement and accretion of fine sediments, whilst exposed habitats are likely to be characterised by resuspension and abrasion by coarse sediments.</td>
<td>Airoldi (2003), Schiel et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Increased sediment may lead to loss of habitat, which in turn may create more patchiness and less connectivity between habitats.</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Other</td>
<td>Factors contributing to sediment disturbance regime:</td>
<td>Airoldi (2003), Schiel et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Table 7: Synthesis table of assumptions about the influence of eutrophication/nutrients on reef function

<table>
<thead>
<tr>
<th>Function</th>
<th>Hypothesis</th>
<th>Reference</th>
<th>E</th>
<th>A</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Habitat provision</strong></td>
<td>Algal blooms and epiphytic growth are observed in eutrophic waters.</td>
<td>Turner et al. (2006)</td>
<td>Robust</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>------------------------------------------------------------------------------------------------------</td>
<td>Russell et al. (2005)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>An increase in nutrients may have an interactive effect with grazers and canopy cover, in SA combined nutrients and herbivory (mostly molluscs) have the potential to change macroalgal assemblages.</td>
<td>Russell and Connell (2005)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Increasing nitrogen and phosphorous loading often favours small, fast-growing species, leading to a switch from canopy-forming algae to turfing algae (interaction with sedimentation).</td>
<td>Russell and Connell (2005), Gorgula and Connell (2004)</td>
<td>Robust</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>Grazers may be important in controlling opportunistic algae, but cannot override the effects of increasing eutrophication on biodiversity and community structure</td>
<td>Worm and Lotze (2006)</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Loss of habitat forming macroalgae opens space for establishment of invasive species</td>
<td>Stuart-Smith et al. (2015)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Nutrient cycling and detrital pathways</strong></td>
<td>Hypothesis: Nutrient inputs on oligotrophic (low in nutrients) coasts may have larger effects than on coasts with high ambient nutrient concentrations</td>
<td>Russell et al. (2005)</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Food web structure</strong></td>
<td>Nutrient availability stimulates phytoplankton growth that promotes an increase in filter-feeding organisms like sponges, tubeworms and mussels.</td>
<td>Turner et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>The loss of canopy–forming algae can be a precursor to nutrient-driven changes of benthic assemblages</td>
<td>Russell and Connell (2005)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Hypothesis: as SA has typically low nutrients ecosystems may be more strongly influenced by bottom-up inputs rather than top-down.</td>
<td>Russell and Connell (2005)</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Function</td>
<td>Hypothesis</td>
<td>Reference</td>
<td>E</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td>The relative importance of grazers and nutrients in controlling the development of turfing algae is context-dependent and varies between habitats and according to background environmental conditions (e.g. productivity)</td>
<td>Fowles et al. (2018)</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Elevated nutrients can also affect the size structure of food webs, with smaller species and individuals of fishes and algae (e.g. planktonic pathways may dominate over benthic pathways).</td>
<td>Ling et al. (2008)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
## Table 8: Synthesis table of assumptions about the influence of extractive resource use on reef function

<table>
<thead>
<tr>
<th>Function</th>
<th>Hypothesis</th>
<th>Reference</th>
<th>E</th>
<th>A</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Habitat provision</strong></td>
<td>Physical damage from anchors, ropes, pots, trampling</td>
<td>Expert elicitation</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Removal of large fish biomass may have an impact on the macroalgae through trophic interactions</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Primary and secondary production</strong></td>
<td>Altering size structure of the community can alter carbon in the environment</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>GAP: Large fish species in temperate regions are usually generalist feeders, so it is hard to predict the balance. There may be a number of pathways for impact on productivity and food web</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Food web structure</strong></td>
<td>Fishing may reduce average fish size, fecundity and lead to behavioural changes in the target species. Also cascading effects on other marine biota.</td>
<td>Turner et al. (2006)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Reduced fish biomass by substantially decreasing the proportion of large/old individuals</td>
<td>Kuparinen et al. (2016)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>The effects of fishing on aquatic communities will vary between locations due to heterogeneity in both fishing pressure and the relative importance of key ecological processes such as recruitment, predation, herbivory and competition.</td>
<td>Stuart-Smith et al. (2008)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Impacts may depend on species and fishery characteristics.</td>
<td>Stuart-Smith et al. (2008)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Greater number of larger fish at more distant sites but a greater abundance for all observed fish nearer boat ramps, possibly due to an increase of smaller fish following removal of larger fish by fishing and a subsequent reduction in competition or predation</td>
<td>Stuart-Smith et al. (2008)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Function</td>
<td>Hypothesis</td>
<td>Reference</td>
<td>E</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td>Our ability to detect patterns in the impacts of fishing is probably greater for species with high site fidelity</td>
<td>Stuart-Smith et al. (2008)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Physical diversity and genetic diversity may be reduced</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Reduced functional diversity, cohorts, species - reducing frequency of things that grow large</td>
<td>Expert elicitation</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Population shifts towards young, small, and more quickly maturing individuals</td>
<td>Kuparinen et al. (2016)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Passive and active fishing methods will impact species, communities and fish behaviour differently.</td>
<td>Pauli and Sih (2016)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Populations where large fish were selectively harvested (as in most fisheries) displayed substantial declines in fecundity, egg volume, larval size at hatch, larval viability, larval growth rates, food consumption rate and conversion efficiency, vertebral number, and willingness to forage. These genetically based changes in numerous traits generally reduce the capacity for population recovery.</td>
<td>Walsh et al. (2006)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Connectivity</td>
<td></td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Greater fishing impacts occur at more accessible sites, with greater fishing impacts at sites closest to boat ramps.</td>
<td>Stuart-Smith et al. (2008)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Appendix Four – evidence library

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Title and publishing details</th>
<th>Type of reference</th>
<th>AMLR Subregion/s or NRM region (if applicable)</th>
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