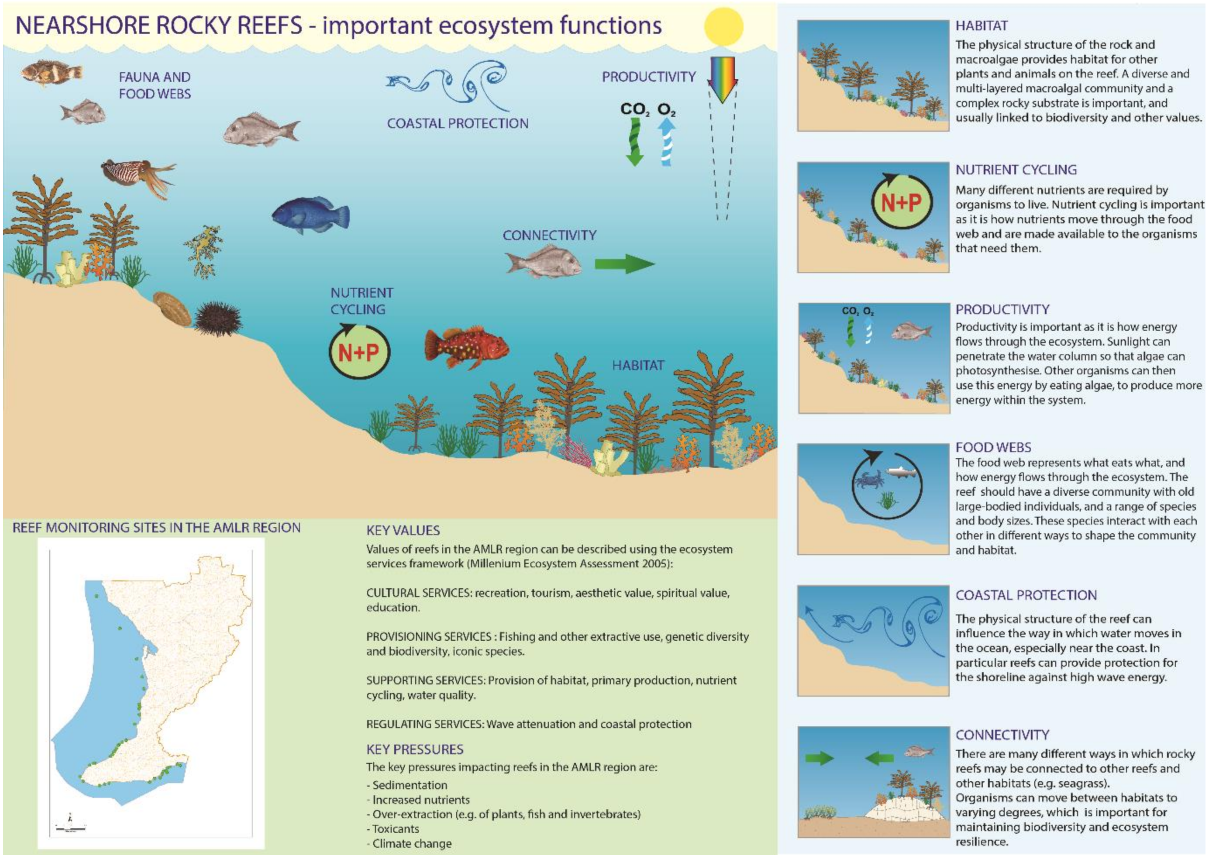
Conceptual models of nearshore reefs in the Adelaide and Mount Lofty Ranges region

Sarah Imgraben, Kristian Peters and Danny Brock

Department for Environment and Water

April, 2019

DEW Technical note DEW-TR-2018-10



Government of South Australia

Department for Environment and Water

Department for Environment and Water

GPO Box 1047, Adelaide SA 5001

Telephone National (08) 8463 6946

International +61 8 8463 6946

Fax National (08) 8463 6999

International +61 8 8463 6999

Website www.environment.sa.gov.au

Disclaimer

The Department for Environment and Water and its employees do not warrant or make any representation regarding the use, or results of the use, of the information contained herein as regards to its correctness, accuracy, reliability, currency or otherwise. The Department for Environment and Water and its employees expressly disclaims all liability or responsibility to any person using the information or advice. Information contained in this document is correct at the time of writing.

Cover photographs: Danny Brock

ISBN 978-1-925805-56-7

Preferred way to cite this publication

Imgraben, S., Peters, K. and Brock, D. (2019). *Conceptual models of nearshore reefs in the Adelaide and Mount Lofty Ranges region.* DEW Technical note DEW-TER-2018-10, Government of South Australia, Department for Environment and Water, Adelaide

Download this document at https://data.environment.sa.gov.au

Acknowledgements

The workshop attendees are gratefully acknowledged for sharing their expertise and time so generously (in no particular order): Sam Gaylard (EPA), Dr Tim Kildea (SA Water), Dr Michelle Waycott (DEW), Dr Jason Tanner (SARDI), Keith Rowling (PIRSA), James Brook, Dr Rick Stuart-Smith (UTAS), David Miller (DEW), Dr Craig Meakin (DEW), Dr Simon Bryars (DEW), Danny Brock (DEW), Dr Kristian Peters, Jamie Hicks (DEW), Dan Easton (DEW).

Dan Easton and Jamie Hicks of the Marine Parks Team are also acknowledged for the support they provided during the workshop. Dr Simon Bryars is thanked for his guidance and support throughout the project, as well as for review of the final outputs.

Some of the symbols used in the conceptual models were provided courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (www.ian.umces.edu/symbols/).

Contents

List of tables

1 Background

Nearshore sub tidal 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).

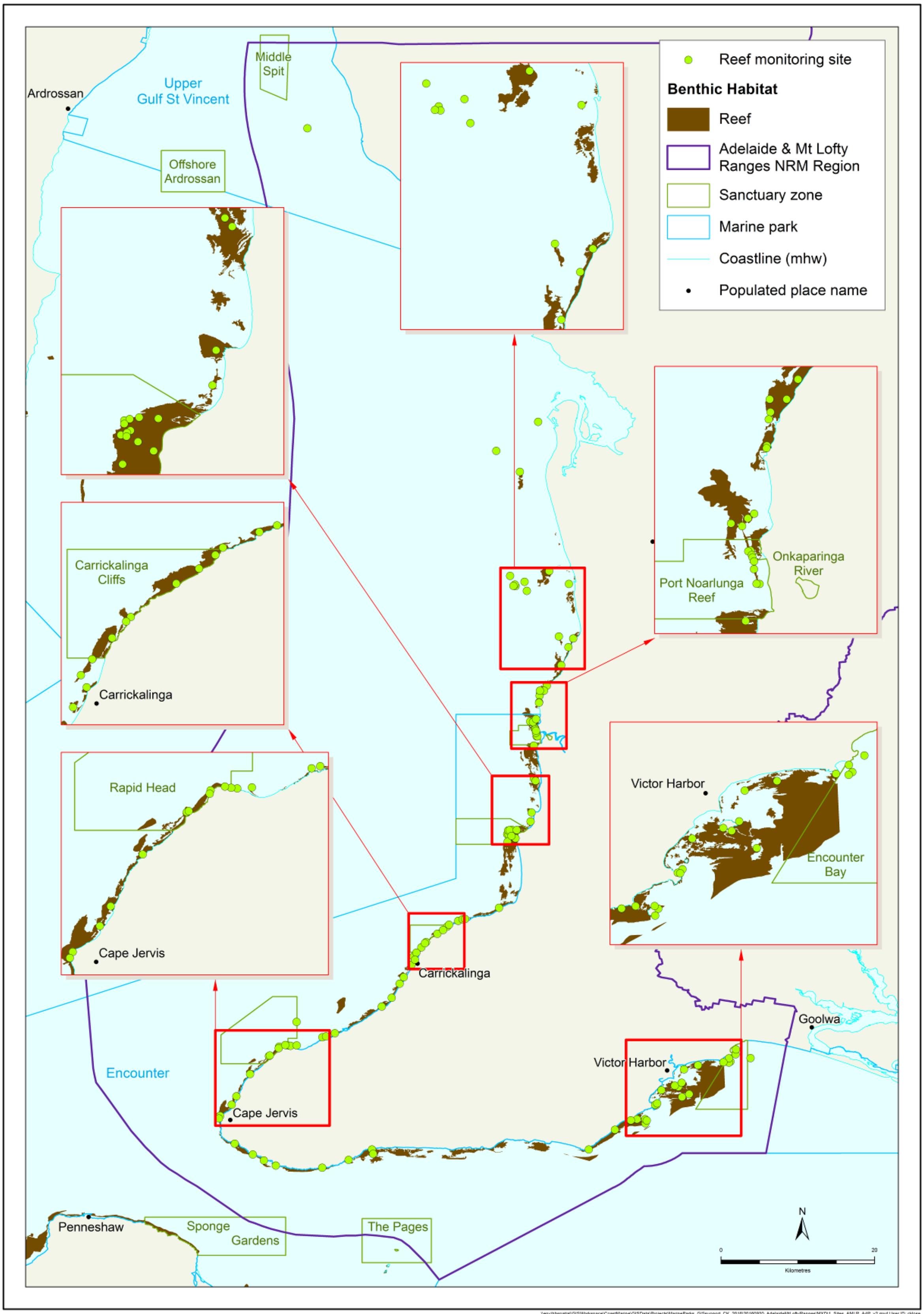


Figure 1.1: Established monitoring sites for various reef programs within the AMLR region and mapped extent of known reefs. Source: Reef Life Survey (2016), Collings et al. (2008), Brook and Bryars (2014), DEWNR unpublished data, DEWNR (2016a, b) (mhw = mean high water). Map taken from Brock et al. 2017.

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.

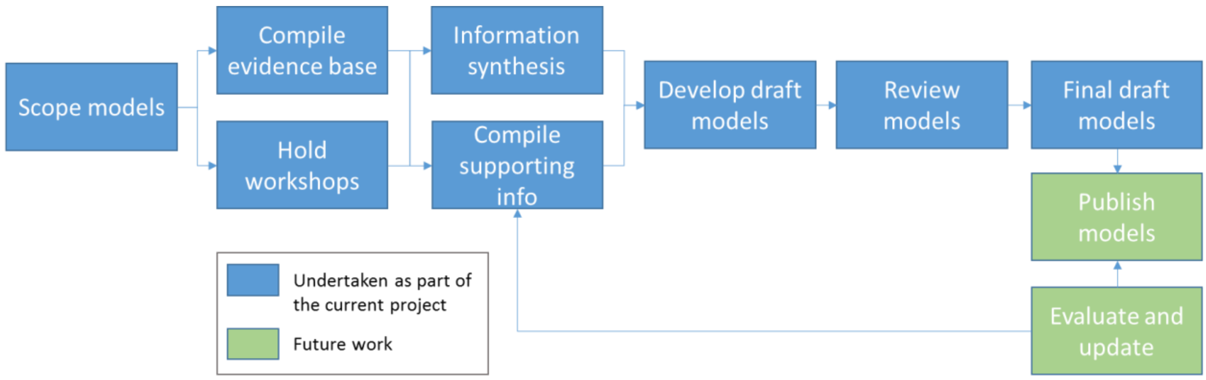


Figure 2.1. The steps taken to develop conceptual models as part of the current project (indicated in blue) along with suggested future work (indicated in green).

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.

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

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

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

Output	Relevant report section	Purpose
Function table	Table 2.1	Captures the key functions and drivers of nearshore reefs in the AMLR region
Conceptual models: 1. Overarching reef function model	Section 3.5.1	The overarching reef function model depicts the information in the function table as a pictorial conceptual model.

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

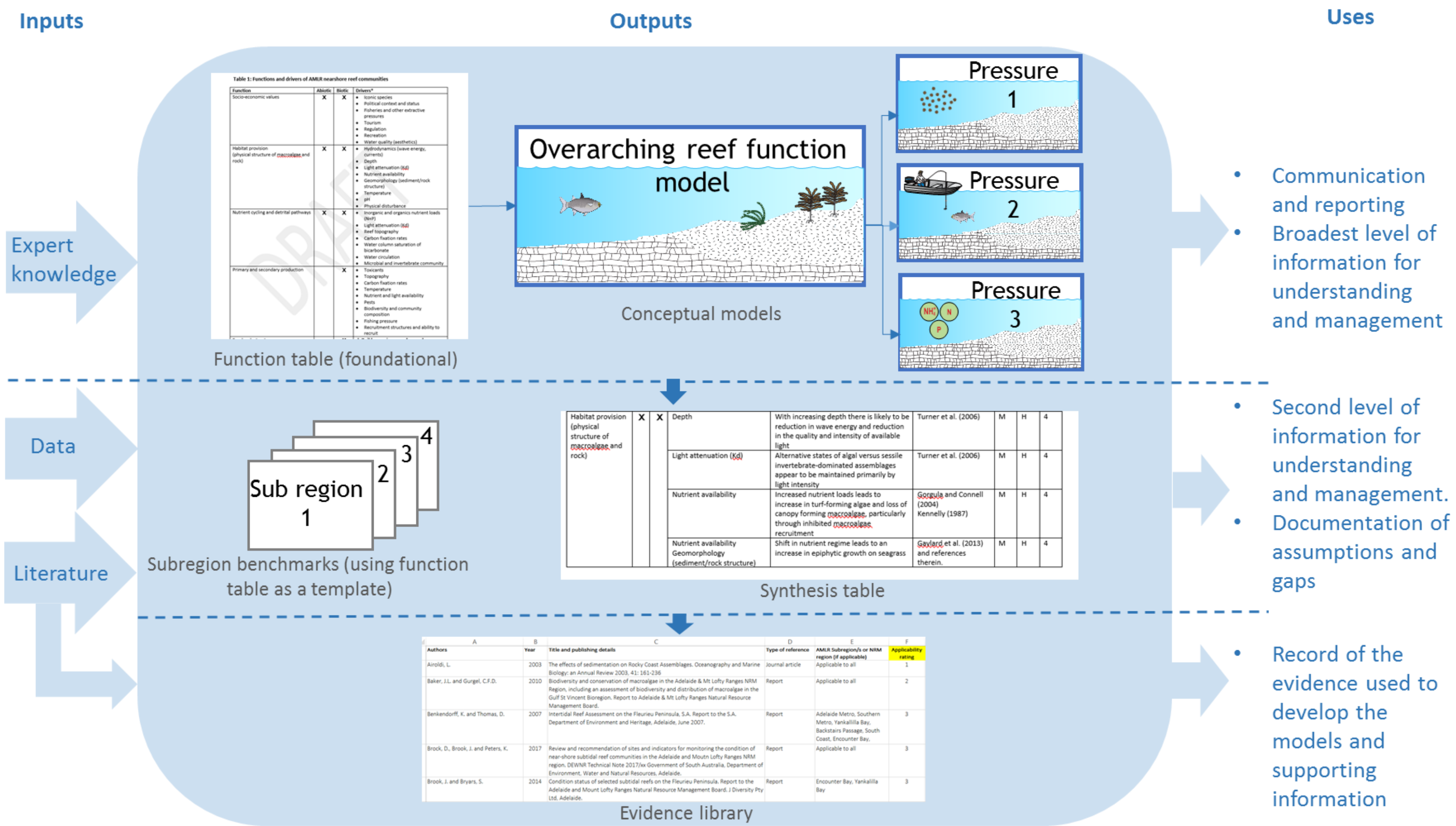


Figure 2.2. Framework for the AMLR reef conceptual modelling project illustrating the hierarchy of information and project outputs. See Table 2.2 for a description of each component of the framework

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

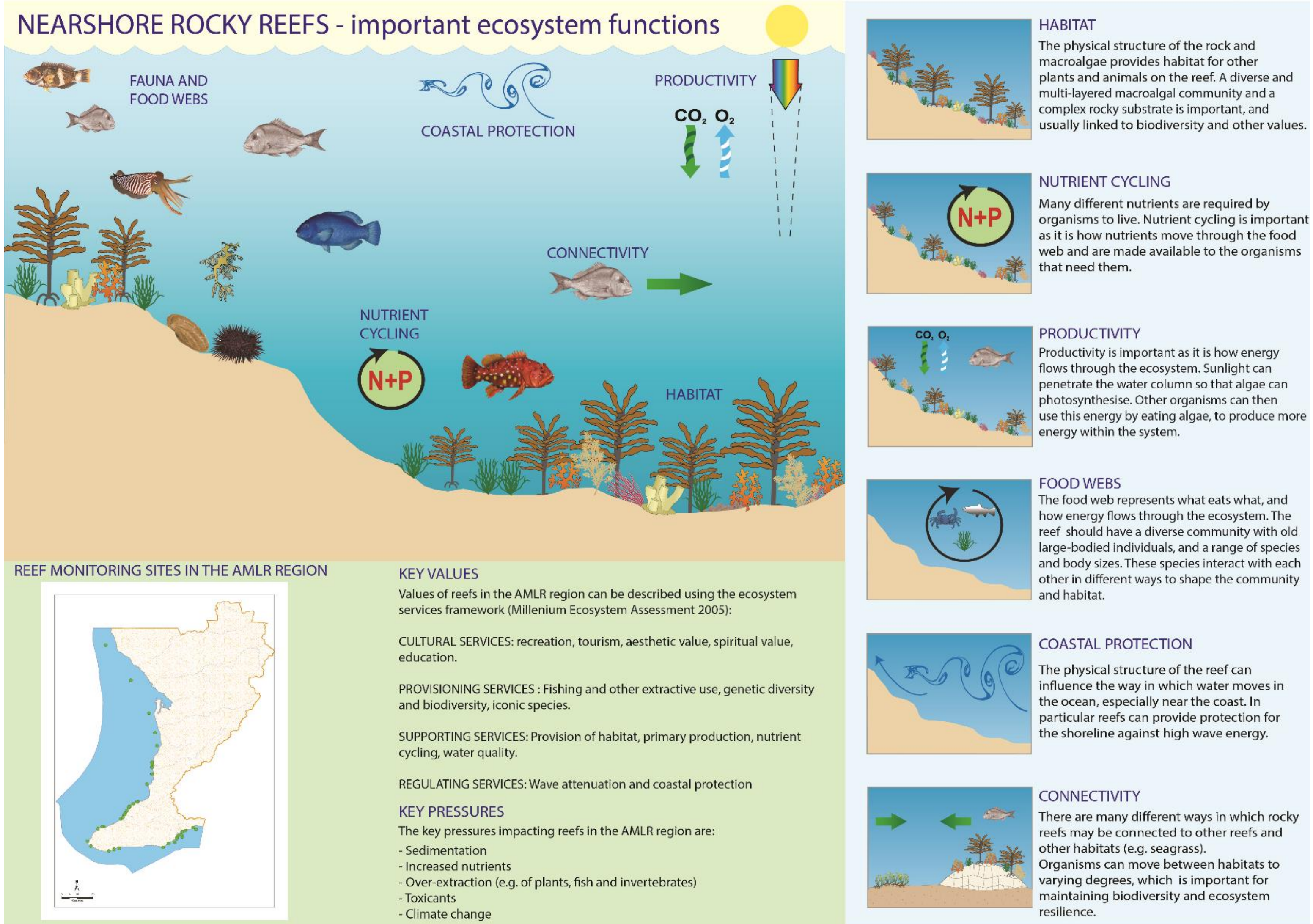


Figure 3.1: Reef function conceptual model for reefs in the AMLR region

3.5.2 Sedimentation

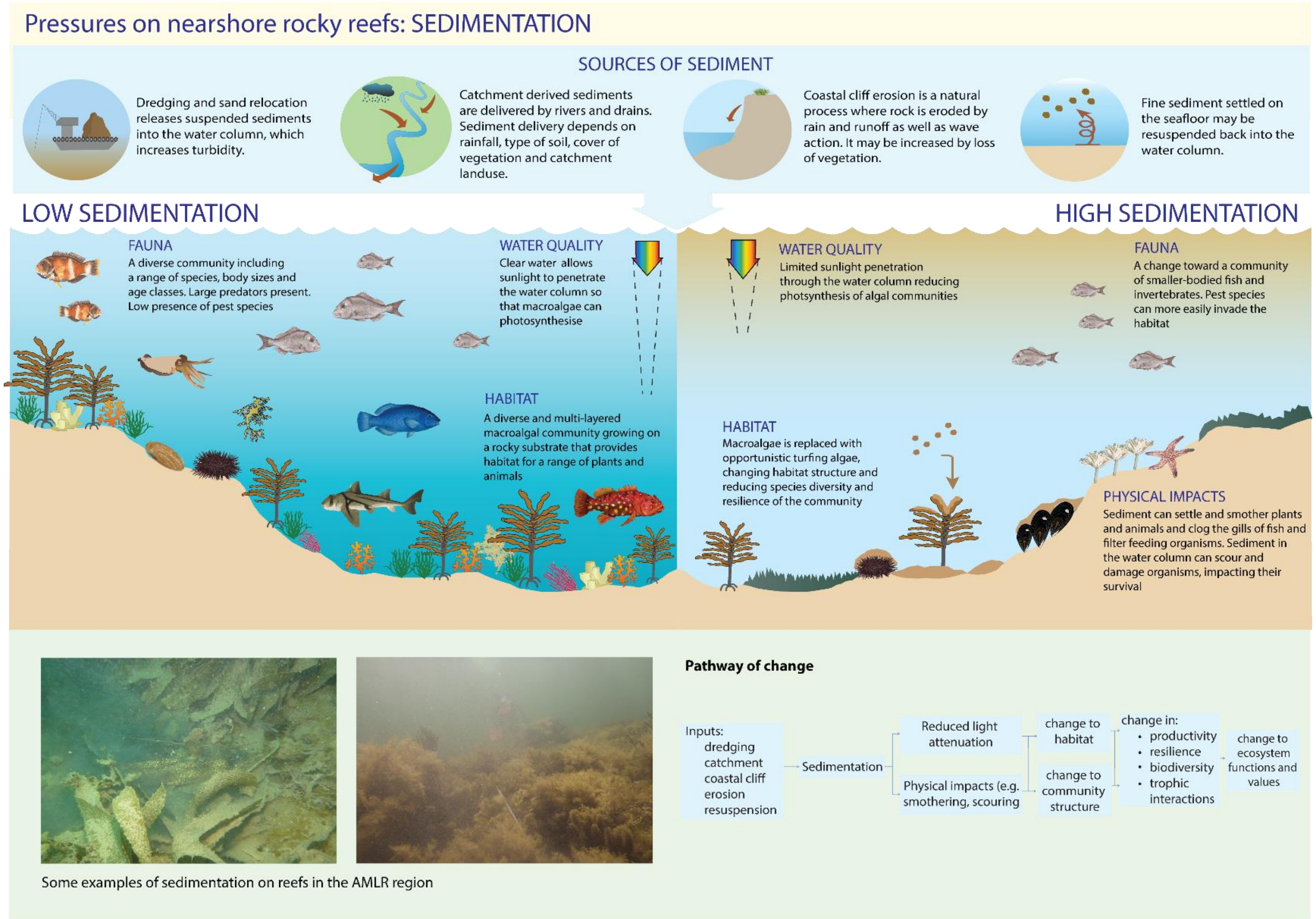


Figure 3.2: Summary conceptual model for the impact of sedimentation on reefs in the AMLR region.

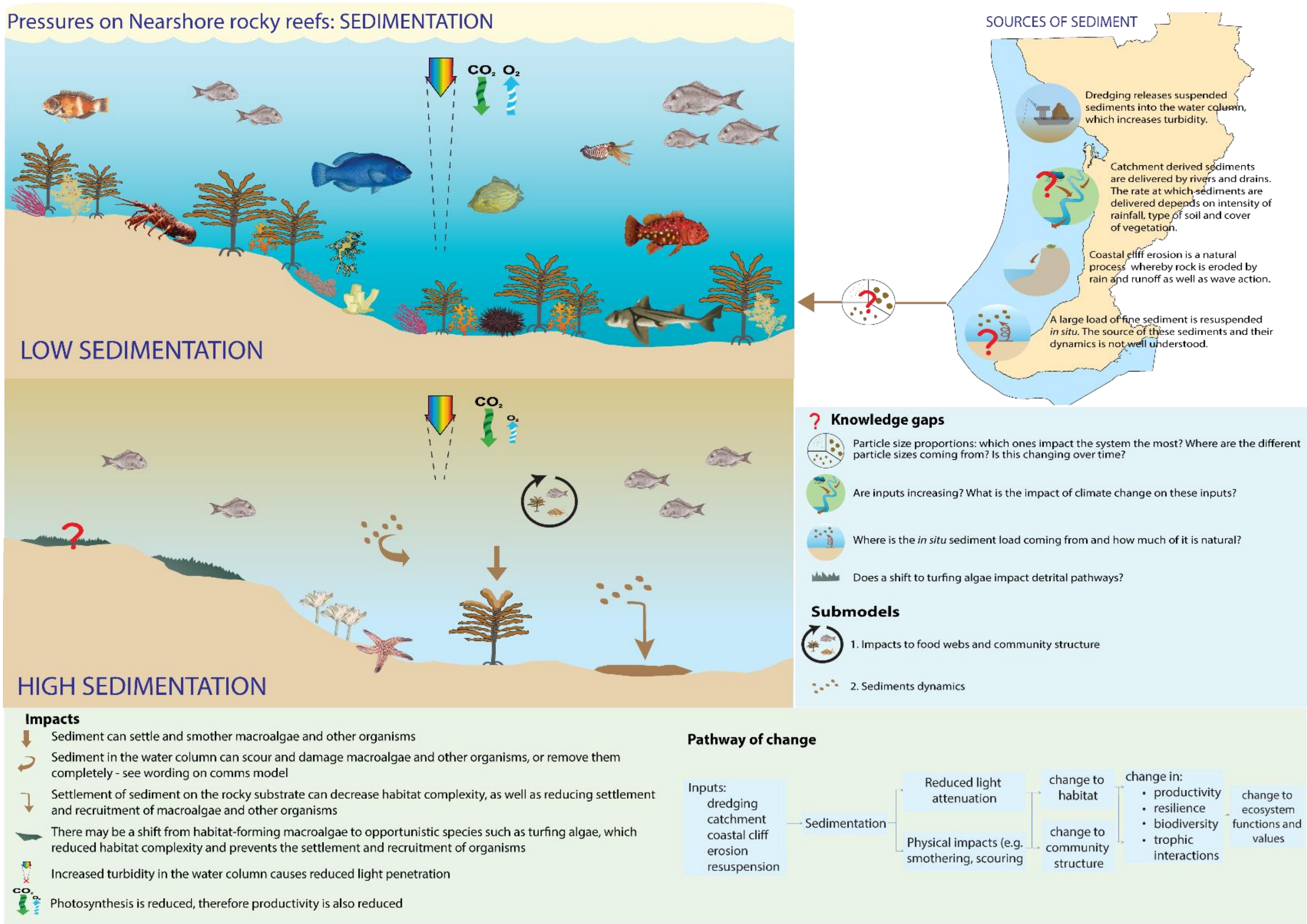


Figure 3.3: Detailed conceptual model for the impact of sedimentation on reefs in the AMLR region.

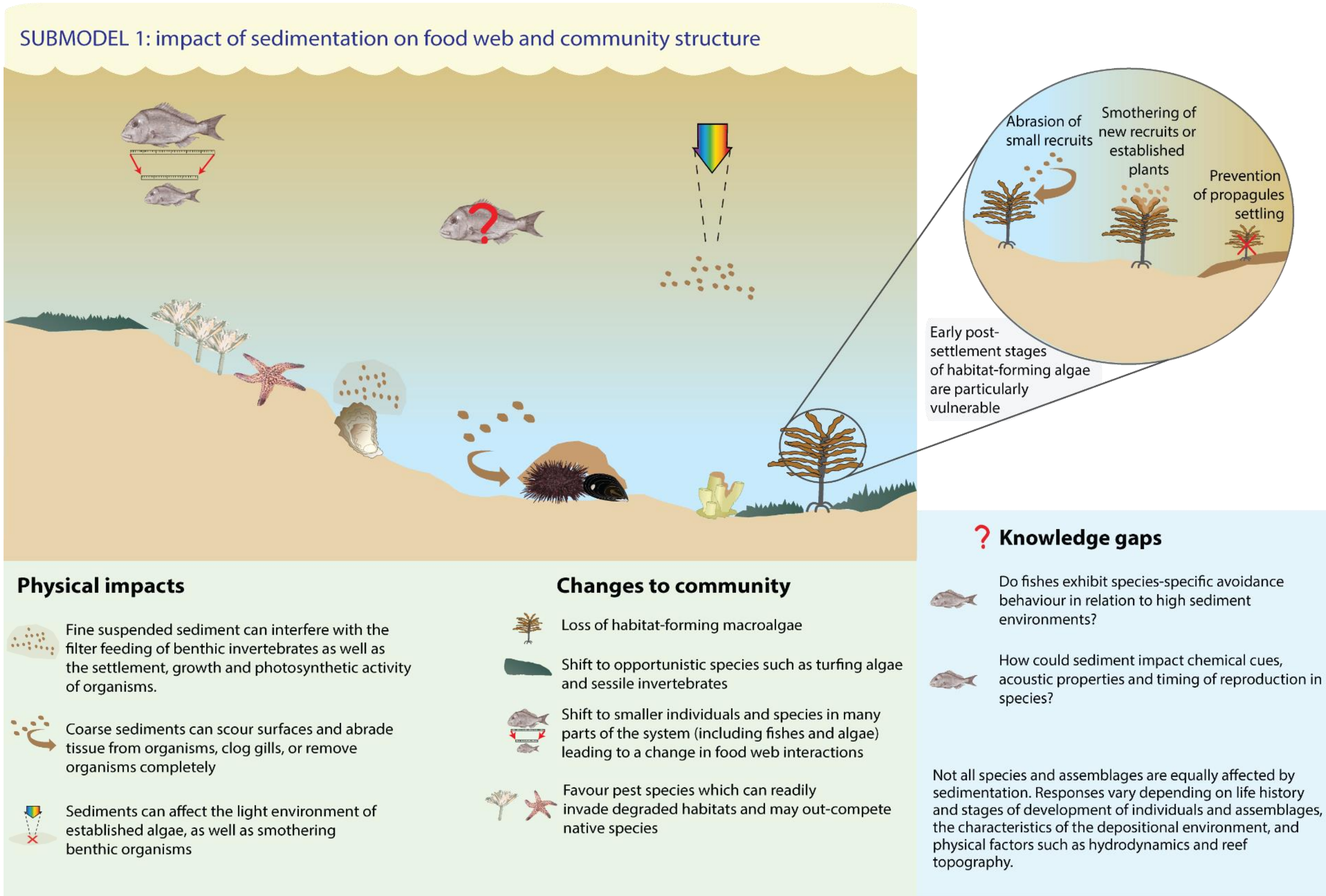


Figure 3.4: Sedimentation sub-model 1 – the impact of sedimentation on food web and community structure of reefs in the AMLR region.

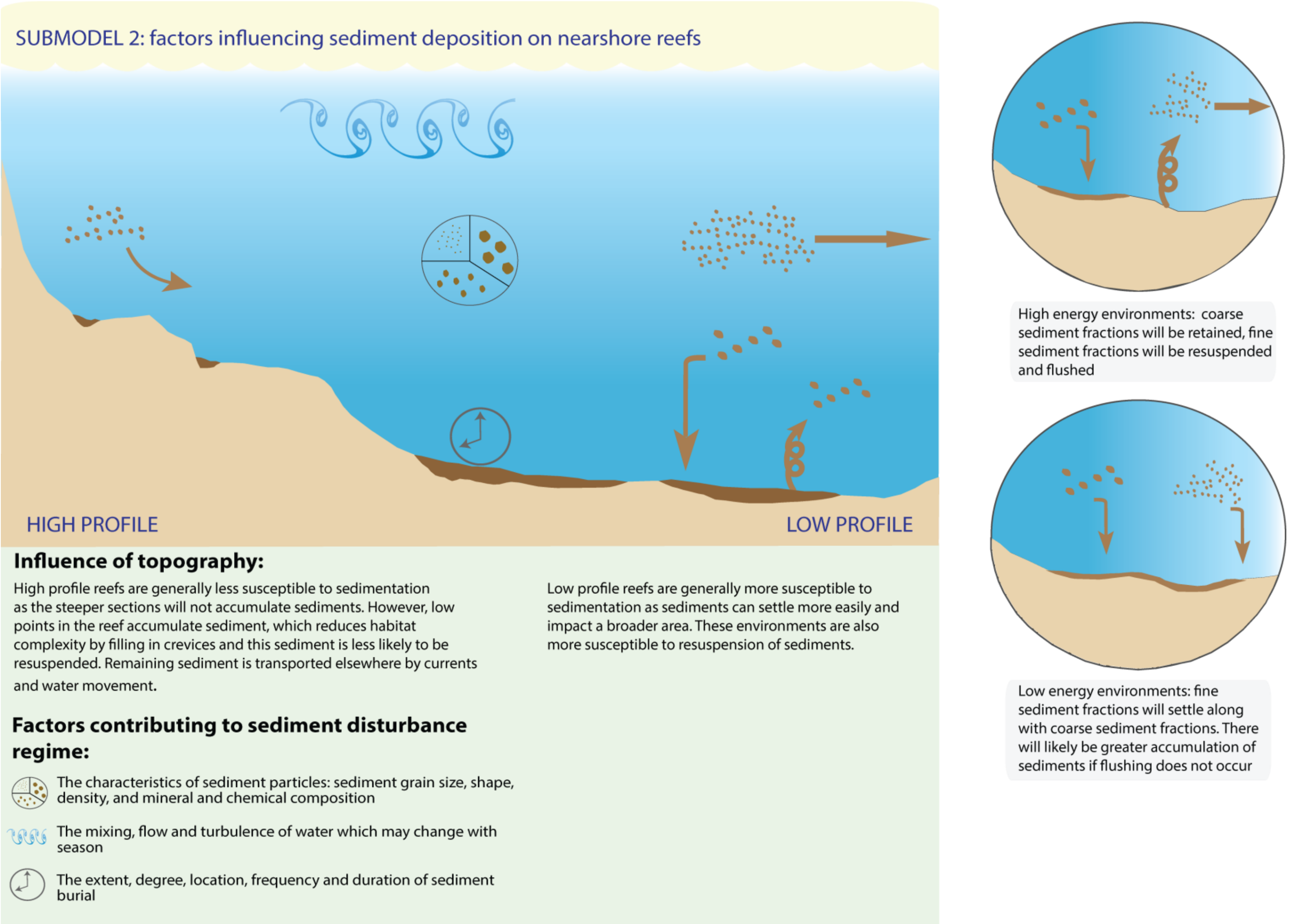
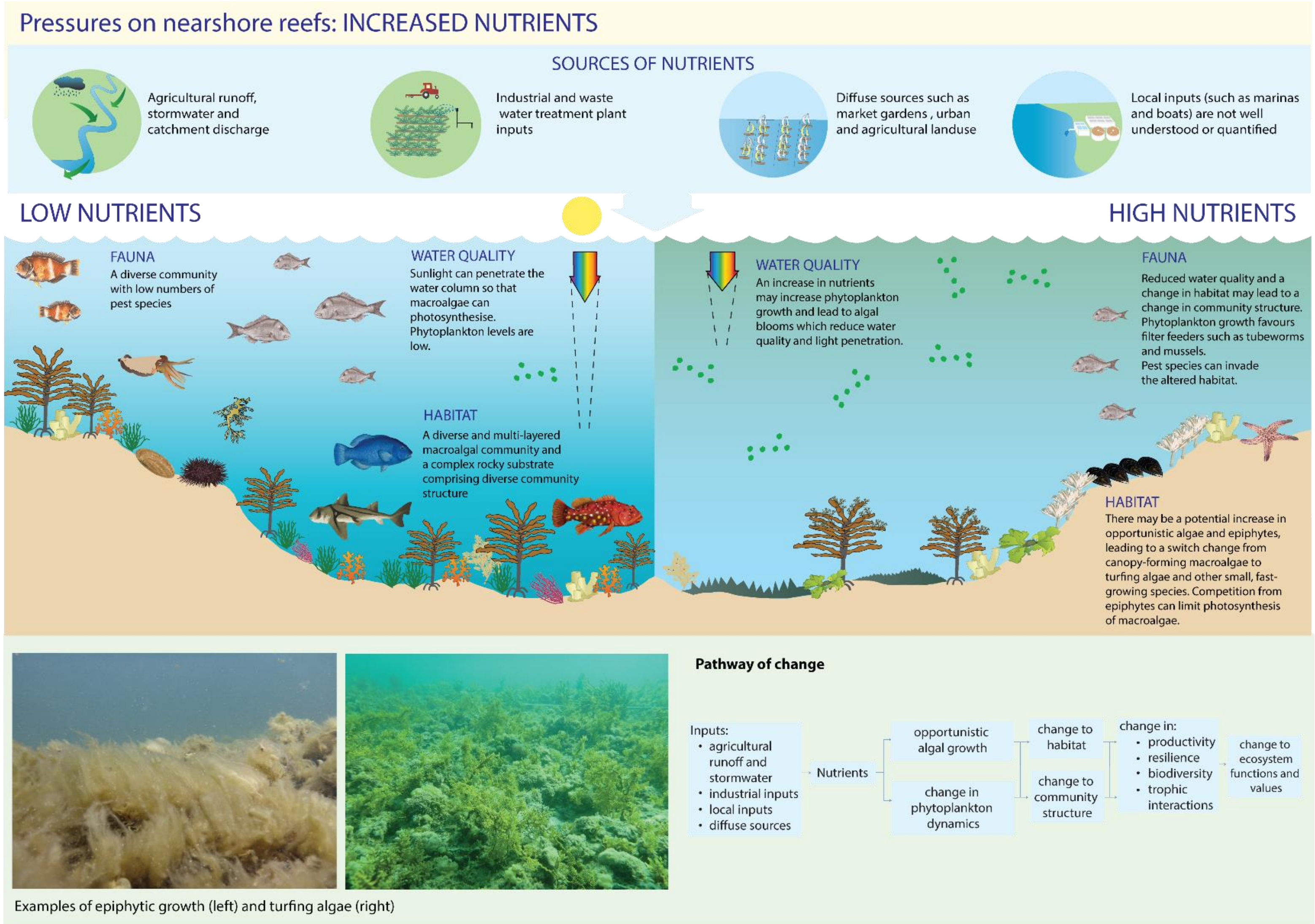


Figure 3.5: Sedimentation sub-model 2 – the factors influencing sediment deposition on nearshore reefs in the AMLR region.

3.5.3 Eutrophication/nutrients



Examples of epiphytic growth (left) and turfing algae (right)

Figure 3.6: Summary conceptual model for the impact of increased nutrients on reefs in the AMLR region.

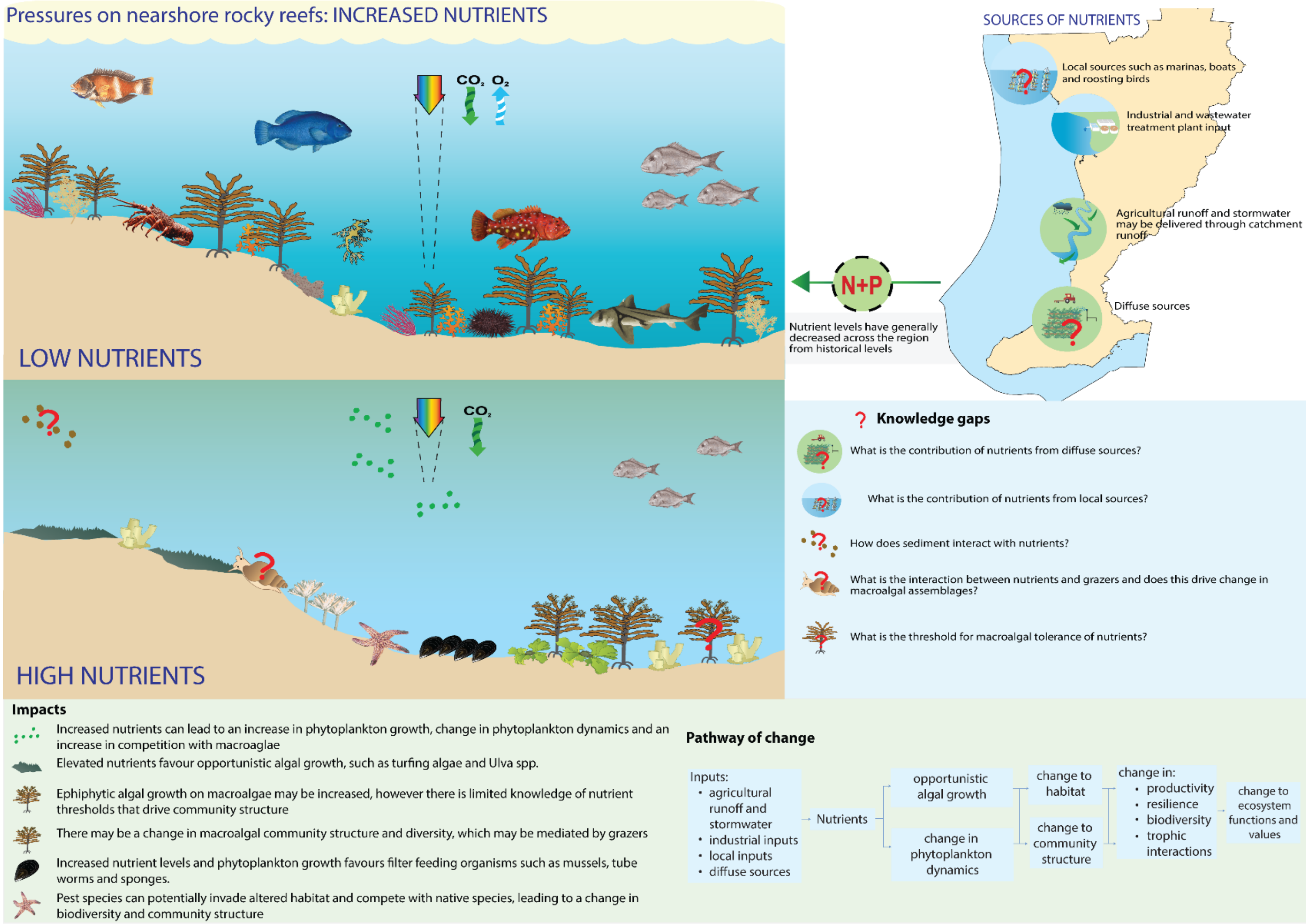


Figure 3.7: Detailed conceptual model for the impact of increased nutrients on reefs in the AMLR region

3.5.4 Extractive resource use

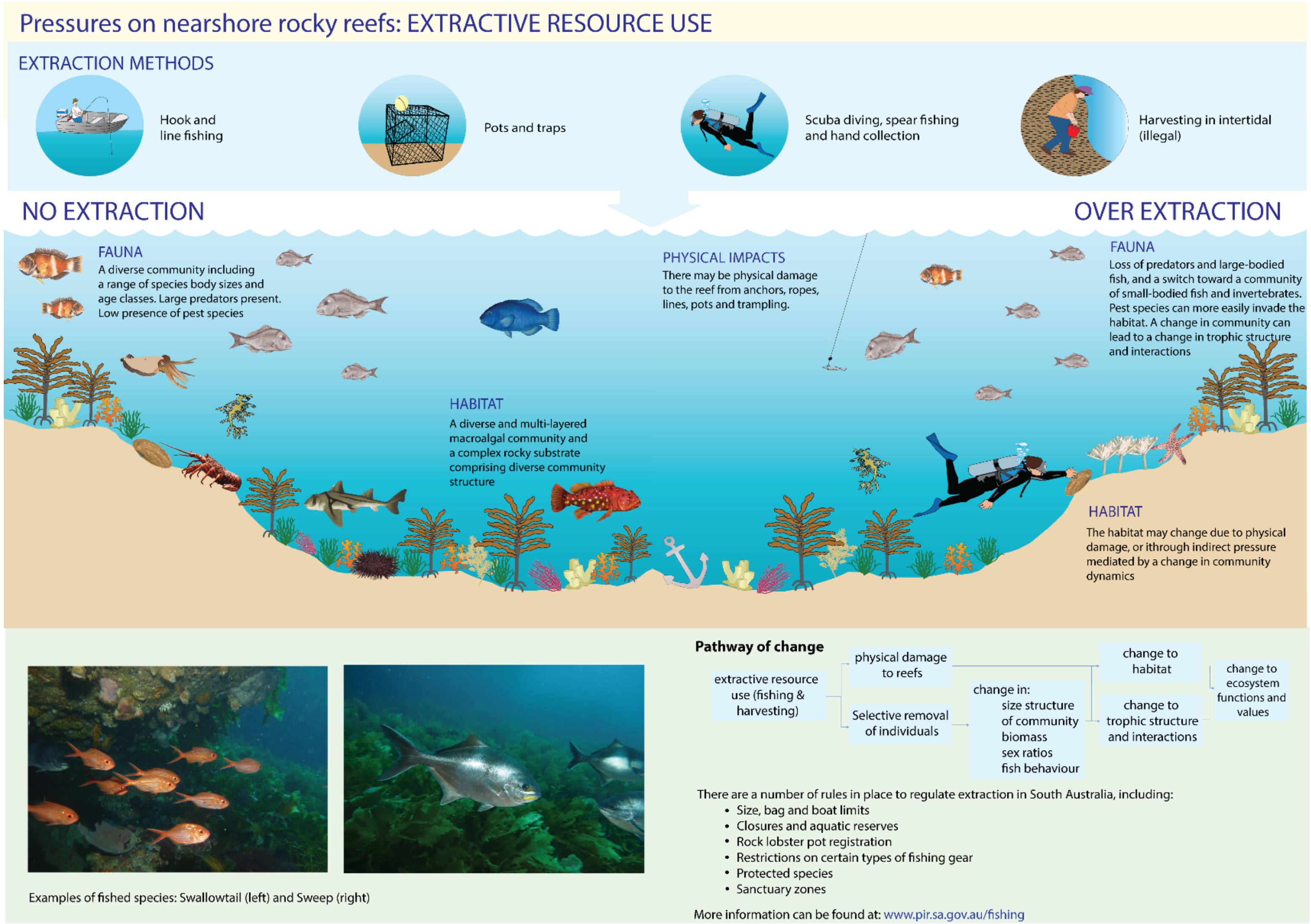


Figure 3.8: Summary conceptual model for the impact of extractive resource use on reefs in the AMLR region

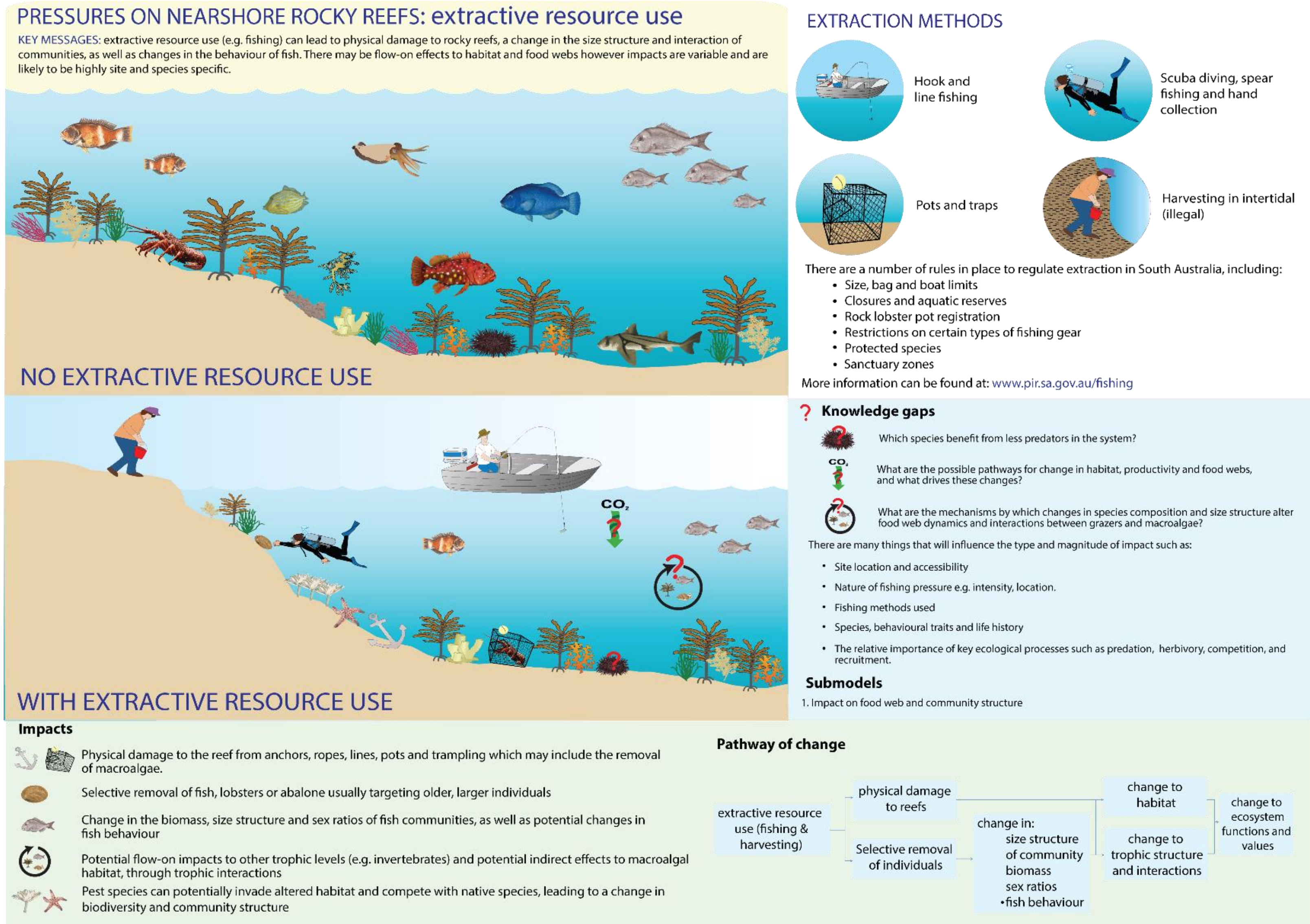


Figure 3.9: Detailed conceptual model for the impact of extractive resource use on reefs in the AMLR region

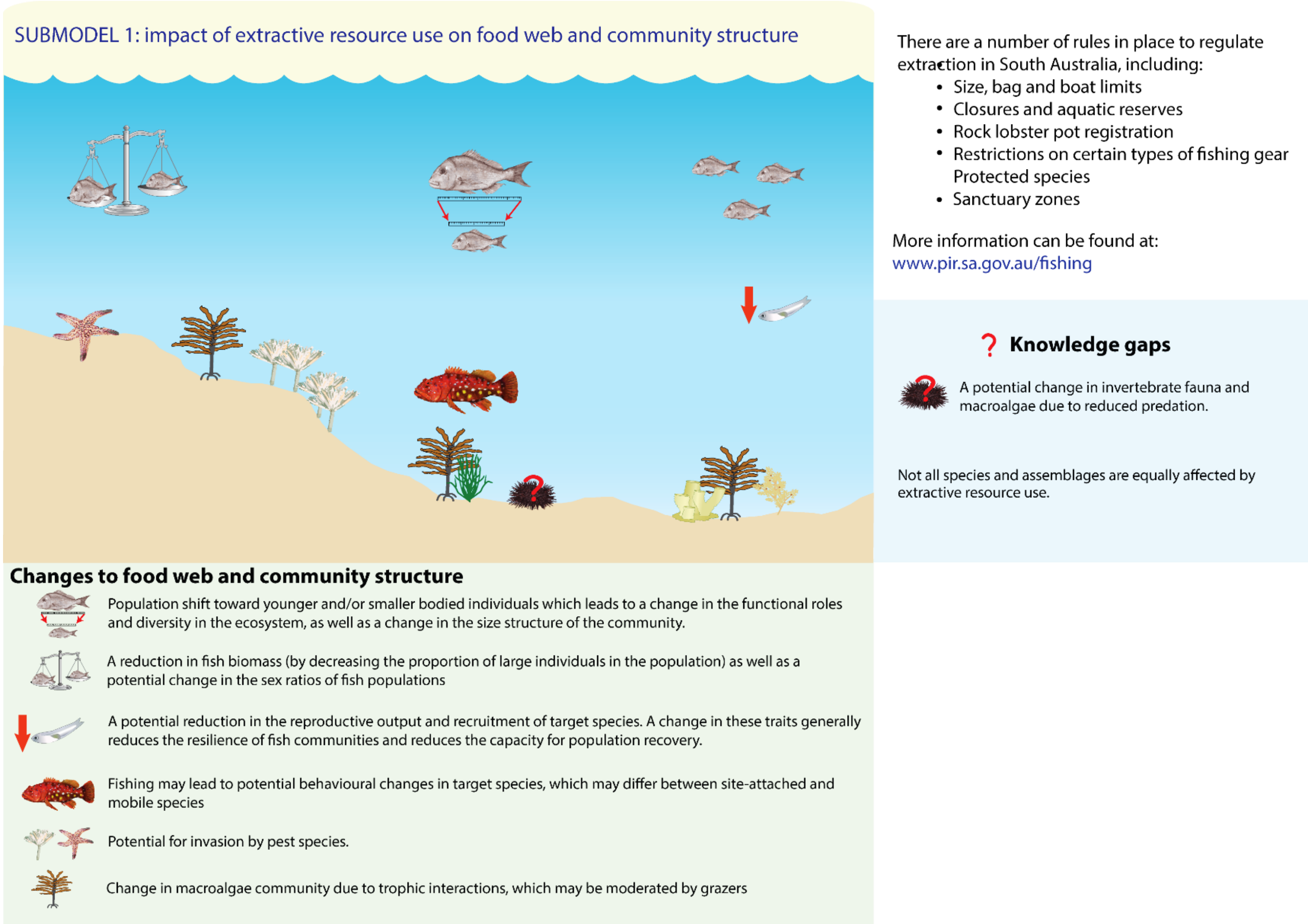


Figure 3.10: Nutrient sub-model 1 – the impact of extractive resource use on food web and community structure of reefs in the AMLR region

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

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

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.

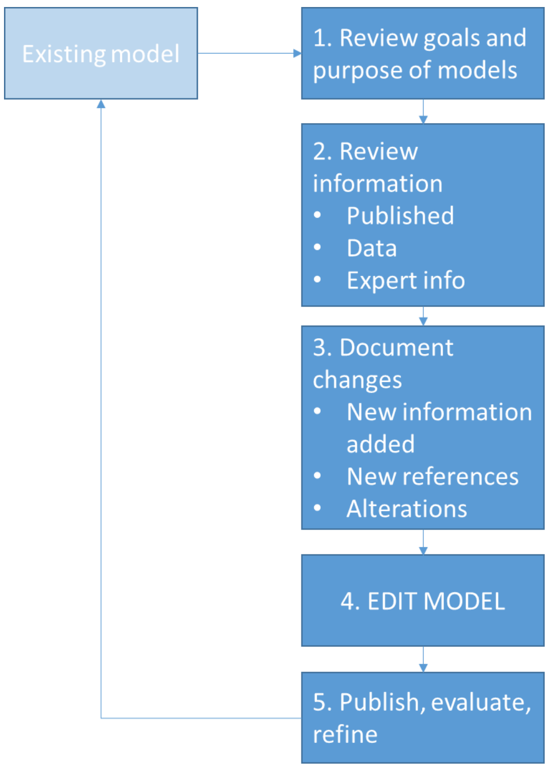


Figure 5.1. Work flow diagram illustrating the suggested steps for editing and refining the existing conceptual models.

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.

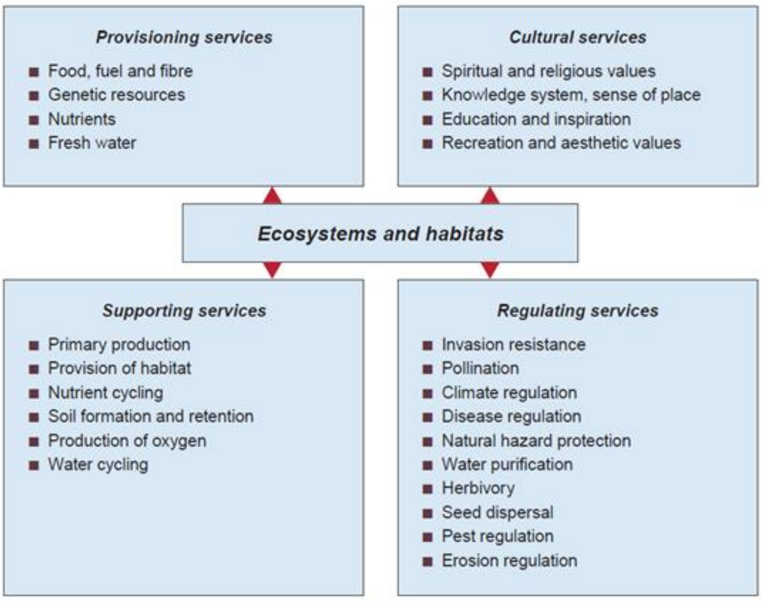


Figure 5.2. An overview of the four categories of ecosystem services as described in the Millennium Ecosystem Assessment (2005) (diagram reproduced from DEWHA 2009)

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

Pressure	Reason for exclusion
Toxicity	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.
Invasive species	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.
Climate change	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.

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

Brock, D., Brook, J. and Peters, K. (2017). *Review and recommendation of sites and indicators for monitoring the condition of near-shore subtidal reef communities in the Adelaide and Mount Lofty Ranges NRM region*. DEWNR Technical note 2017/XX. Government of South Australia, Department of Environment, Water and Natural Resources.

Brook, J. and Bryars, S. (2014) *Condition status of selected subtidal reefs on the Fleurieu Peninsula*. Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board. J Diversity Pty Ltd, Adelaide.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Vandenbelt, M. (1997). 'The value of the world's ecosystem services and natural capital', *Nature* 387:253–260.

Department of the Environment, Water, Heritage and the Arts (2009). *Ecosystem Services: Key Concepts and Applications*, Occasional Paper No 1, Department of the Environment, Water, Heritage and the Arts, Canberra.

Department of Environment (2015) *Modelling water-related ecological responses to coal seam gas extraction and coal mining*. A report commissioned by the Department of the Environment on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). Commonwealth of Australia.

Gross, J.E. (2003). *Developing Conceptual Models for Monitoring Programs.* Discussion paper available online: http://science.nature.nps.gov/im/monitor/docs/Conceptual_modelling.pdf (last accessed 09/01/2018)

Heydon, L and Vandergragt, M (2011) *Connecting wetland science with managers and the community using conceptual models*, Joint meeting of Society of Wetland Scientists, WETPOL and Wetland Biogeochemistry Symposium, 3–8 July 2011, Prague.

IPCC (2013). *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-Being: Our Human Planet: Summary for Decision Makers*. The Millennium Ecosystem Assessment Series, Volume 5, Island Press, Washington DC.

Newton, J., Mumford, T., Dohrmann, J., West, J., Llanso, R., Berry, H., and Redman, S. (1998) *A conceptual model for environmental monitoring of a marine system developed for the Puget Sound Ambient Monitoring Program*. Prepared by Washington State University and Puget Sound Water Quality Action Team.

Roman, C.T. and Barrett, N.E. (1999). *Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore*. USGS Patuxent Wildlife Research Centre, Cooperative National Park Studies Unit, University of Rhode Island.

Wiebkin, A. S. (2014). *Developing conceptual models – a guide for facilitating workshops*, DEW Technical Note 2014/04, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide

Wilkinson, J., Souer, N., and Fairweather, P. (2007). *Best Practice Framework for the Monitoring and Evaluation of Water-Dependent Ecosystems 2: Technical Resources*. DWLBC Report 2007/13 Government of South Australia Department of Water Land and Biodiversity Conservation, Adelaide.

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)
3. Conduct two annual diver surveys (2017/2018) at the 41 reef sites identified for long term monitoring in the AMLR region (Brock et al. 2017) using the Reef Life Survey method (Reef Life Survey 2015)
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

- State NRM Report Cards
    - Marine Parks Performance Programme
- Communication

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 3: Functions and drivers of AMLR nearshore reef communities

Function	Abiotic	Biotic	Drivers*
Socio-economic values	X	X	• Iconic species • Political context and status • Fisheries and other extractive pressures • Tourism • Regulation • Recreation • Water quality (aesthetics)
Habitat provision (physical structure of macroalgae and rock)	X	X	• Hydrodynamics (wave energy, currents) • Depth • Light attenuation (Kd) • Nutrient availability • Geomorphology (sediment/rock structure) • Temperature • pH • Physical disturbance
Nutrient cycling and detrital pathways	X	X	• Inorganic and organics nutrient loads (N+P) • Light attenuation (Kd) • Reef topography • Carbon fixation rates • Water column saturation of bicarbonate • Water circulation • Microbial and invertebrate community
Primary and secondary production		X	• Toxicants • Topography • Carbon fixation rates • Temperature • Nutrient and light availability • Pests • Biodiversity and community composition • Fishing pressure • Recruitment structures and ability to recruit
Food web structure		X	**↓ Builds on primary and secondary production.** • Community composition • Functional diversity and redundancy • Timing
Wave attenuation and hydrodynamics	X	X	**↔ Direct link to and feedback with habitat provision** • Climate change • Bottom structure • Depth • Geomorphology • Biological structure • Climate
Connectivity	X	X	• Hydrodynamics • Proximity (source of recruits) and adjacent habitat • Biological structures (life history and directionality) • Community composition • Trophic processes

			• Behavioural traits • timing
Other pressures: • Adjacent landuse • Catchment pressures • Resource extraction • Physical disturbance (anthropogenic)			

* Drivers are presented in no particular order

Table 4: Functions and drivers case study: Moana high relief reef

<table>
<tr><th>Function</th><th>Drivers</th><th>Data availability</th></tr>
<tr><td>Socio-economic values</td><td>• Fishing (general, no target spp)
• Recreational – diving (low level)
• Scientific</td><td>• Kristian to investigate</td></tr>
<tr><td>Habitat provision

(physical structure of macroalgae and rock)</td><td>• 1 habitat type, limestone base with variable topography
• Dense uniform canopy cover of Ecklonia (3D biotic substrate)
• High relief</td><td>• No rugosity data
• Data for most other variables</td></tr>
<tr><td>Nutrient cycling and detrital pathways</td><td>• Modest inputs (Onkaparinga)
• Hydrodynamics: low-moderate exposure
• Canopy forming brown algae (fixation of carbon)
• 5-7m depth
• Tidal - typical</td><td>• Sediment data
• Plume maps
• Pressures and inputs
• SST & hydrodynamics</td></tr>
<tr><td>Primary and secondary production</td><td>• Canopy forming brown algae and associated community composition
• Fished (all species, including crayfish)</td><td rowspan="2">• Fish data
• BRUVS
• Invertebrates
• Mapping</td></tr>
<tr><td>Food web structure</td><td>• High diversity of fish (due to relief) and invertebrates
• Lower algal diversity
• Low pests</td></tr>
<tr><td>Wave attenuation and hydrodynamics</td><td>• Site provides wave attenuation
• Abiotic and biotic factors influence this, however the abiotic drivers add additional benefit to the abiotic 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 and life history), these need to be defined and explored on a case by case basis.

• Discrete reef
• Adjacent habitat is sand
• Expectation of exemplar spp – indicative that movement between reefs is possible</td><td>• Ranges of species? – Kristian
• Mapping – distance between reefs</td></tr>
<tr><td colspan="3">Potential differentiating factors:

• Relief
• Ecklonia (presence, cover)
• Connectivity
• Tidal influence
• Protection (e.g. sanctuary zones)
• Gradients</td></tr>
</table>

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

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

6	Climate change	• This is really important but difficult for us to manage at this scale • Use as overarching lens to understand how it may intensify current pressures • Synergistic impacts NO MODEL WILL BE DEVELOPED FOR THIS

3. 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).

Function	Hypothesis	Reference	E	A	C
Habitat provision	Deposition is dependent on hydrodynamic conditions and the nature of the sediment, e.g. fine sediments will be resuspended in high wave energy environments.	Turner et al. (2006)	Medium	High	High
	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	Expert elicitation	Low	High	Medium
	Increased turbidity and sedimentation reduces the amount of light reaching algal communities, reducing photosynthesis	Turner et al. (2006)	Medium	High	High
	Changes in the physical characteristics of the bottom surface which can result in loss of habitat suitable for settlement	Airoldi (2003) Turner (2004)	Medium	High	High
	Decrease in habitat complexity with loss of macroalgal structure and filling in of crevices in the rock	Expert elicitation	Low	High	Medium
	Shift from macroalgae to opportunistic species, especially turfing algae	Expert elicitation	Low	High	Medium
	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	Expert elicitation	Low	High	Medium

Function	Hypothesis	Reference	E	A	C
Nutrient cycling and detrital pathways	**GAP**: will a shift from macroalgae to turfing algae impact detrital pathways?	Expert elicitation	Limited	Low	Very low
Primary and secondary production	Smothering or burial of macroalgae can lead to reduced availability of light, oxygen or nutrients, which can lead to decreased productivity	Airoldi (2003) Expert elicitation	Medium	High	High
Food web structure	Switch from macroalgae to turfing algae	Gorgula and Connell (2004)	Medium	High	High
	Change in the size structure of the community, with a shift to smaller species and individuals	Expert elicitation	Low	Medium	Medium
	Scour or abrasion resulting in damage or removal of whole organisms or their parts, or clogging of gills of sessile invertebrates	Airoldi (2003), Schiel et al. (2006)	Medium	High	High
	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.	Airoldi (2003), Schiel et al. (2006), Vadas et a. (1992)	Robust	High	Very high
	Not all species and assemblages are equally affected by sedimentation and responses vary over space and time, depending on: • the characteristics of the depositional environment, • life histories of species and the stage of development of individuals and assemblages, • Variable physical factors, including hydrodynamics, light intensity and bottom topography	Airoldi (2003)	Medium	High	High
	Intertidal habitats are likely to have breaking waves, and greater turbulence, flow, and tidal movement than subtidal habitats so there	Schiel et al. (2006)	Medium	High	High

Function	Hypothesis	Reference	E	A	C
Wave attenuation and hydrodynamics	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.	Airoldi (2003), Schiel et al. (2006)	Medium	High	High
Connectivity	Increased sediment may lead to loss of habitat, which in turn may create more patchiness and less connectivity between habitats.	Expert elicitation	Low	Medium	Medium
	GAP: do fishes exhibit species-specific sediment avoidance behaviour? How could sediment impact chemical cues, acoustic properties and timing of reproduction?	Expert elicitation	Limited	Low	Very low
Other	Factors contributing to sediment disturbance regime: • characteristics of sediment particles (e.g. grain size) • the extent, degree, location, frequency and duration of sediment burial • flow and turbulence of water	Airoldi (2003), Schiel et al. (2006)	Medium	High	High

Table 7: Synthesis table of assumptions about the influence of eutrophication/nutrients on reef function

Function	Hypothesis	Reference	E	A	C
Habitat provision	Algal blooms and epiphytic growth are observed in eutrophic waters.	Turner et al. (2006) Russell et al. (2005)	Robust	High	Very high
	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.	Russell and Connell (2005)	Medium	High	High
	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).	Russell and Connell (2005), Gorgula and Connell (2004)	Robust	High	Very high
	Grazers may be important in controlling opportunistic algae, but cannot override the effects of increasing eutrophication on biodiversity and community structure	Worm and Lotze (2006)	Low	Medium	Medium
	Loss of habitat forming macroalgae opens space for establishment of invasive species	Stuart-Smith et al. (2015)	Medium	High	High
Nutrient cycling and detrital pathways	Hypothesis: Nutrient inputs on oligotrophic (low in nutrients) coasts may have larger effects than on coasts with high ambient nutrient concentrations	Russell et al. (2005)	Low	Medium	Medium
Food web structure	Nutrient availability stimulates phytoplankton growth that promotes an increase in filter-feeding organisms like sponges, tubeworms and mussels.	Turner et al. (2006)	Medium	High	High
	The loss of canopy –forming algae can be a precursor to nutrient-driven changes of benthic assemblages	Russell and Connell (2005)	Medium	High	High
	Hypothesis: as SA has typically low nutrients ecosystems may be more strongly influenced by bottom-up inputs rather than top-down.	Russell and Connell (2005)	Low	Medium	Medium

Function	Hypothesis	Reference	E	A	C
	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)	Fowles et al. (2018)	Low	Medium	Medium
	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).	Ling et al. (2008)	Medium	High	High

Table 8: Synthesis table of assumptions about the influence of extractive resource use on reef function

Function	Hypothesis	Reference	E	A	C
Habitat provision	Physical damage from anchors, ropes, pots, trampling	Expert elicitation	Medium	High	Medium
	Removal of large fish biomass may have an impact on the macroalgae through trophic interactions	Expert elicitation	Low	Medium	Low
Primary and secondary production	Altering size structure of the community can alter carbon in the environment	Expert elicitation	Low	Medium	Low
	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	Expert elicitation	Low	Medium	Low
Food web structure	Fishing may reduce average fish size, fecundity and lead to behavioural changes in the target species. Also cascading effects on other marine biota.	Turner et al. (2006) Stuart-Smith et al. (2017)	Medium	High	High
	Reduced fish biomass by substantially decreasing the proportion of large/old individuals	Kuparinen et al. (2016) Stuart-Smith et al. (2017)	Medium	High	High
	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.	Stuart-Smith et al. (2008)	Medium	High	High
	Impacts may depend on species and fishery characteristics.	Stuart-Smith et al. (2008)	Medium	High	High
	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	Stuart-Smith et al. (2008)	Medium	Medium	Medium

Function	Hypothesis	Reference	E	A	C
	Our ability to detect patterns in the impacts of fishing is probably greater for species with high site fidelity	Stuart-Smith et al. (2008)	Medium	Medium	Medium
	Physical diversity and genetic diversity may be reduced	Expert elicitation	Low	Medium	Low
	Reduced functional diversity, cohorts, species - reducing frequency of things that grow large	Expert elicitation	Low	Medium	Low
	population shifts towards young, small, and more quickly maturing individuals	Kuparinen et al. (2016)	Medium	Medium	Medium
	Passive and active fishing methods will impact species, communities and fish behaviour differently.	Pauli and Sih (2016)	Medium	Medium	Medium
	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.	Walsh et al. (2006)	Medium	Medium	Medium
Connectivity	Greater fishing impacts occur at more accessible sites, with greater fishing impacts at sites closest to boat ramps.	Stuart-Smith et al. (2008)	Medium	Medium	Medium

Appendix Four – evidence library

Authors	Year	Title and publishing details	Type of reference	AMLR Subregion/s or NRM region (if applicable)	Availability
Abelson, A. and Denny	1997	Settlement of marine organisms in flow. Annual Review of Ecology and Systematics 28: 317-339.	Journal article		
Airoldi, L.	2003	The effects of sedimentation on Rocky Coast Assemblages. Oceanography and Marine Biology: an Annual Review 2003, 41: 161-236	Journal article	Applicable to all	http://www.ecology.unibo.it/page/04_ocea907.pdf
Baker, J.L. and Gurgel, C.F.D.	2010	Biodiversity and conservation of macroalgae in the Adelaide & Mt Lofty Ranges NRM Region, including an assessment of biodiversity and distribution of macroalgae in the Gulf St Vincent Bioregion. Report to Adelaide & Mt Lofty Ranges Natural Resource Management Board.	Report	Applicable to all	
Benkendorff, K. and Thomas, D.	2007	Intertidal Reef Assessment on the Fleurieu Peninsula, S.A. Report to the S.A. Department of Environment and Heritage, Adelaide, June 2007.	Report	Adelaide Metro, Southern Metro, Yankallilla Bay, Backstairs Passage, South Coast, Encounter Bay,	https://data.environment.sa.gov.au/Content/Publications/Benkendorff%20and%20Thomas%202007_Intertidal%20reef.pdf
Brock, D., Brook, J. and Peters, K.	2017	Review and recommendation of sites and indicators for monitoring the condition of near-shore subtidal reef communities in the Adelaide and Mount Lofty Ranges NRM region. DEWNR Technical Note 2017/xx Government of South Australia, Department of Environment, Water and Natural Resources, Adelaide.	Report	Applicable to all	

Brook, J. and Bryars, S.	2014	Condition status of selected subtidal reefs on the Fleurieu Peninsula. Report to the Adelaide and Mount Lofty Ranges Natural Resource Management Board. J Diversity Pty Ltd, Adelaide.	Report	Encounter Bay, Yankalilla Bay	
Bryars, S.	2010	Monitoring marine fishes of conservation concern on Adelaide's coastal reefs: results of 2009/2010 surveys for the southern blue devil and harlequin fish. Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board. Department of Environment and Natural Resources. 29 pp.	Report	Adelaide metro, Southern Metro	
Bryars, S.	2011	Monitoring marine fishes of conservation concern on Adelaide's coastal reefs: combined results of 2009/2010 and 2010/2011 surveys for the southern blue devil and harlequin fish. Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board. Department of Environment and Natural Resources, Adelaide.	Report	Adelaide metro, Southern Metro	https://data.environment.sa.gov.au/Content/Publications/Bryars%202011_MonitoringMarineFishesCons.pdf
Bryars, S.	2013	Nearshore marine habitats of the Adelaide and Mount Lofty Ranges NRM region: values, threats and actions. Report to the Adelaide and Mount Lofty Ranges Natural Resource Management Board, Dr Simon Richard Bryars, Adelaide.	Report	Applicable to all	
Bryars, S.	2014	Nearshore seagrass and reef condition in Yankalilla Bay. Report to the Adelaide and Mount Lofty Ranges Natural Resource Management Board, Dr Simon Richard Bryars, Adelaide.	Report	Yankalilla Bay	
Bryars, S., Brook, J., Meakin, C., McSkimming, C., Eglington, Y.,	2016	Baseline and predicted changes for the Encounter Marine Park. DEWNR Technical Report 2016/25, Government of South Australia, through	Report	Encounter Bay	

Morcom, R., Wright, A. and Page, B.		Department of Environment, Water and Natural Resources, Adelaide.			
Bryars, S., Brook, J., Meakin, C., McSkimming, C., Eglington, Y., Morcom, R., Wright, A. and Page, B.	2017	Baseline and predicted changes for the South Australian Marine Parks Network. DEWNR Technical Report 2017/06, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.	Report	Applicable to all	
Bryars, S., Page, B., Waycott, M., Brock, D. and Wright, A.	2017	South Australian Marine Parks Monitoring, Evaluation and Reporting Plan, DEWNR Technical Report 2017/05, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.	Report		
Bryars, S., Rogers, P. and Miller, D.	2012	Protecting the harlequin fish within South Australia's new system of marine parks: acoustic tracking to determine site fidelity and movement patterns. Report to the Department of Environment, Water and Natural Resources Wildlife Conservation Fund Project Number 1455, Department of Environment, Water and Natural Resources, Adelaide.	Report	Kangaroo Island NRM region	
Bulleri, F., Russell, B.D. and Connell, S.D.	2012	Context-dependency in the effects of nutrient loading and consumers on the availability of space in marine rocky environments. PLoS ONE 7(3) e33825 pp1-9			
Cheshire, A.C.	2015	Developing a conceptual model for the Adelaide Coastal Waters Quality Improvement Plan. Final Report prepared for SA Environment Protection	Report	Applicable to all	

		Authority by Science to Manage Uncertainty. Pp 53.			
Cheshire, A.C., Hall, S., Havenhand, J. and Miller, D.J.	1998	Assessing the status of temperate reefs in Gulf St. Vincent II: survey results. A report to the Environment Protection Agency of SA. Pp 57.	Report	Northern, Adelaide Metro, Southern Metro	
Cheshire, A.C., Havenhand, J., Hall, S., Matsumoto, G. and Butler, A.J.	1998	Assessing the status of temperate reefs in Gulf St. Vincent I: Background and methodology for assessments. A report to the Environment Protection Agency of SA. Pp 53.	Report	Northern, Adelaide Metro, Southern Metro	
Cheshire, A.C. and Westphalen, G.	2000	Assessing the status of reefs in Gulf St Vincent IV: Results of the 1999 survey. A report to the Environment Protection Agency of South Australia. Pp 32.	Report	Gulf St. Vincent	
Colella, D. and Miller, D.	2012	An assessment of Fish assemblages adjacent Port Stanvac. Interim field summary to Adelaide Aqua for the Adelaide Desalination plant project Winter/Spring 2012 (Sept-Oct). Marine Parks Project, Department of Environment, Water and Natural Resources.	Report	Southern Metro	
Colella, D., Miller, D., Holland, S. and Rutherford, H.	2010	An assessment of fish assemblages adjacent to Port Stanvac. A report to Adelaide Aqua for the Adelaide desalination plant project 2009-2010. Prepared by the Coast and Marine Conservation Branch Branch Department of Environment and Natural Resources, September 2010.		Southern Metro	
Colella, D., Miller, D. and Rutherford, H.	2011	An assessment of fish assemblages adjacent to Port Stanvac. A report to Adelaide Aqua for the Adelaide desalination plant project 2009-2011. Prepared by the Marine Parks Branch Department	Report	Southern Metro	

		of Environment and Natural Resources, August 2011.			
Collings, G., Bryars, S., Turner, D., Brook, J. and Theil, M.	2008	Examining the health of subtidal reef environments in South Australia, Part 4: Assessment of community reef monitoring and status of selected reefs based on the results of the 2007 surveys. SARDI Publication Number F2008/000511-1 South Australian Research and Development Institute (Aquatic Sciences), Adelaide.	Report	Applicable to all	
Connell, S.D.	2005	Assembly and maintenance of subtidal habitat heterogeneity: synergistic effects of light penetration and sedimentation. Marine Ecology Progress Series, 289:53-61	Journal article	Encounter Bay	
Connell, S.D.	2007	Water quality and the loss of coral reefs and kelp forests: alternative states and the influence of fishing. In: Connell, S.D and Gillanders, B. (eds) Marine Ecology, Oxford University Press, Melbourne. P 556-568	Book Chapter	Applicable to all	
Connell, S.D., Russell, B.D., Turner, D.J., Shepherd, S.A., Kildea, T., Miller, D., Airoldi, L. and Cheshire, A.	2008	Recovering a lost baseline: missing kelp forests from a metropolitan coast. Marine Ecology Progress Series 360: 63-72.	Journal article	Adelaide Metro, Southern Metro, Yankalilla Bay	
Department for Environment and Heritage	2008	Marine habitats in the Adelaide and Mount Lofty Ranges NRM Region. Final report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board for the program: Facilitate Coast, Marine and Estuarine Planning and	Report	Applicable to all	

		Management by establishing regoinal baselines. Prepared by the Department for Environment and Heritage, Coast and Marine Conservation Branch.			
Dutton, A. and Benkendorff, K.	2008	Biodiversity Assessment and Monitoring of the Port Stanvac intertidal reef. Report to the Adelaide and Mt Lofty Natural Resource Managament Board. School of Biological Sciences, Flinders University, June 2008.	Report	Southern Metro	
Edyvane, K.S.	1999	Coastal and marine wetlands in Gulf St. Vincent, South Australia: understanding their loss and degradation. Wetlands Ecology and Management 7: 83-104.	Journal article	Gulf St. Vincent	
Edyvane, K.S.	1999	Conserving marine biodiversity in South Australia - Part 1 - Background, status and review of approach to marine biodiversity conservation in South Australia. Report number 38, South Australian Research and Development Institute.	Report	Applicable to all	
Edyvane, K.S.	1999	Conserving marine biodiversity in South Australia - Part 2 - Identification of areas of high conservation value in South Australia. Report number 39, South Australian Research and Development Institute.	Report	Gulf St. Vincent	
Fernandes, M.	2008	Sedimentation surveys of Adelaide's coastal reefs, Part 2 (autumn): a report prepared for the Adelaide and Mount Lofty Ranges Natural Resources Management Board. SARDI Aquatic Sciences Publication Number F2008/000103-2. South Australian Research & Development Institute (Aquatic Sciences), Adelaide, 13 pp.	Report	Northern, Adelaide Metro, Southern Metro	

Fernandes, M., Theil, M. and Bryars, S.	2008	Sedimentation surveys of Adelaide's coastal reefs, Part 1 (winter and summer): a report prepared for the Adelaide and Mount Lofty Ranges Natural Resources Management Board. SARDI Aquatic Sciences Publication Number F2008/000103-1. South Australian Research & Development Institute (Aquatic Sciences), Adelaide, 19 pp.	Report	Northern, Adelaide Metro, Southern Metro	
Fowler-Walker, M.J. and Connell, S.D.	2002	Opposing states of subtidal habitat across temperate Australia: consistency and predictability in kelp canopy - benthic associations. Marine Ecology Progress Series 240: 49-56	Journal article	Fleurieu Peninsula (actual sites unknown)	
Gaylard, S.	2009	A risk assessment of threats to water quality in Gulf St. Vincent	Report	Gulf St. Vincent	
Gaylard, S.	2003	The health of subtidal reefs along the Adelaide metropolitan coastline 1996-99. Environment Protection Authority, Adelaide.	Report	Northern, Adelaide Metro, Southern Metro	
Gaylard, S., Nelson, M. and Noble, W.	2013	The South Australian monitoring, evaluation and reporting program for aquatic ecosystems: rationale and methods for the assessment of nearshore marine waters. Envionment Protection Authority, Adelaide.	Report	Applicable to all	
Gillanders, B.M., Able, K.W., Brown, J.A., Eggleston, D.B. and Sheridan, P.F.	2003	Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series 247: 281-295.	Journal article		
Gorgula, S.K. and Connell, S.D.	2004	Expansive covers of turf-forming algae on human-dominated coast: the relative effects of increasing nutrient and sediment loads. Marine Biology 145: 613-619.	Journal article	Adelaide Metro, Yankalilla Bay, Backstairs Passage, South Coast	

Janetzki, N., Fairweather, P.G. and Benkendorff, K.	2015	Inventory of rock types, habitats, and biodiversity on rocky seashores in South Australia's two south-east marine parks: pilot study. A report to the South Australian Department of Environment, Water and Natural Resources. Flinders University, June 2015.	Report	South East NRM Region	
Kennelly, S.J.	1987	Physical disturbances in Australian kelp community. II. Effects on understorey species due to differences in kelp cover. Marine Ecology Progress Series 40:155-165	Journal article		
Kennelly, S.J.	1987	Physical disturbances in Australian kelp community. I. Temporal effects. Marine Ecology Progress Series 40:145-153.	Journal article		
Kuparinen, A., Boit, A., Valdovinos, F.S., Lassaux, H. and Martines, N.D.	2016	Fishing-induced life-history changes degrade and destabilize harvested ecoystems. Nature: Scientific Reports. 6:22245 | DOI: 10.1038/srep22245	Journal article		
Ling, S.D., Davey, A., Reeves, S.E., Gaylard, S., Davies, P.L., Stuart-Smith, R.D. and Edgar, G.J.	2018	Pollution signature for temperate reef biodiversity is short and simple. Marine Pollution Bulletin, 130: 159-169	Journal article		
Littler, M.M., Martz, D.R. and Littler, D.S.	1983	Effects of recurrent sand deposition on rocky intertidal organisms: importance of substrate heterogeneity in a fluctuating environment. Marine Ecology Progress Series 11: 129-139	Journal article		
Miller, D.J., Cheshire, A.C., Hall, S. and Havenhand, J.	1998	Assessing the status of temperate reefs in Gulf St. Vincent III: Evaluation and description of methodologies. A report to the Environment Protection Agency of SA. Pp 52.	Report	Northern, Adelaide Metro, Southern Metro	

O'Hara, T.D.	2001	Consistency of faunal and floral assemblages within temperate subtidal rocky reef habitats. Marine and Freshwater Research, 52: 853-63.	Journal article	Victoria	
Pauli, B.D. and Sih, A.	2017	Behavioural responses to human-induced change: why fishing should not be ignored. Evol. Appl. 10(3): 231-240	Journal article		
Reef Watch South Australia	2009	Reef Watch South Australia: The first decade of community reef monitoring. Reef Watch intertidal monitoring program, Conservation Council of SA, Adelaide.	Report	Applicable to all	
Russell, B. and Connell, S.	2005	A novel interaction between nutrients and grazers alters relative dominance of marine habitats. Marine Ecology Progress Series 289: 5-11.	Journal article	South Coast	
Russell, B. and Connell, S.	2009	Reef habitats of Gulf St Vincent. Autumn progress report to Adelaide Aqua. Southern Seas Ecology Laboratories, University of Adelaide.	Report	Adelaide Metro	
Russell, B. and Connell, S.	2009	Reef habitats of Gulf St Vincent. Spring progress report to Adelaide Aqua. Southern Seas Ecology Laboratories, University of Adelaide.	Report	Adelaide Metro	
Russell, B. and Connell, S.	2011	Reef habitats of Gulf St Vincent. Data report to Adelaide Aqua April-May 2011. Southern Seas Ecology Laboratories, University of Adelaide.	Report	Southern Metro	
Russell, B. and Connell, S.	2012	Rocky subtidal assemblages across the Adelaide Metropolitan coast, a baseline in relation to future coastal desalination for Adelaide City: Winter 2012 Final report. Published by the School of Earth and Environmental Science, University of Adelaide.	Report	Adelaide metro, southern metro	

Russell, B.D., Elsdon, T.S., Gillanders, B. and Connell, S.D.	2005	Nutrients increase epiphyte laods: broad scale observations and an experimental assessment. Marine Biology 147(2): 551-558	Journal article		
Russell, B., Thompson, J-A., Falkenberg, L.J. and Connell, S.D.	2009	Synergistic effects of climate change and local stressors: CO_2 and nutrient-driven change in subtidal rocky habitats. Global Change Biology, 2009; 15(9): 2153-2162	Journal article	Applicable to all	
Rutherford, H., Colella, D. and Miller, D.	2011	An assessment of fish assemblages adjacent Port Stanvac. Interim field summary to Adelaide Aqua for the Adelaide Desalination plant project Autumn 2011 (May). Marine Parks Project, Department of Environment, Water and Natural Resources.	Report	Southern Metro	
Rutherford, H., Colella, D. and Miller, D.	2012	An assessment of fish assemblages adjacent Port Stanvac. Interim field summary to Adelaide Aqua for the Adelaide desalination plant project Summer 2012 (March)	Report	Southern Metro	
Rutherford, H., Colella, D. and Miller, D. and Bloomfield, A.	2011	An assessment of fish assemblages adjacent Port Stanvac. Interim field summary to Adelaide Aqua for the Adelaide desalination plant project Summer 2011 (February). Coast and Marine Conservation Branch, Department of Environment and Natural Resources.	Report	Southern Metro	
Schiel, D.R., Wood, S.A., Dunmore, R.A. and Taylor, D.I.	2006	Sediment of rocky intertidal reefs: effects on early post-settlement stages of habitat-forming seaweeds. Journal of Experimental Marine Biology and Ecology 331: 158-172	Journal article		
Scholz, G., von Baumgarten, P.,	2017	Monitoring, Evaluation and Reporting framework for Marine Parks Program, DEWNR Technical Note 2017/06, Government of South Australia, through	Report	Applicable to all	

Wilson, H., Wright, A. and Bryars, S.		the Department for Environment, Water and Natural Resources, Adelaide.			
Scientific Working Group	2011	The vulnerability of coastal and marine habitats in South Australia. Marine Parks, Department of Environment, Water and Natural Resources South Australia.	Report	Applicable to all	
Shepherd, S.A. and Brook, J.B.	2005	Foraging ecology of the Western Blue Groper, *Achoerodus gouldii,* at the Althorpe Islands, South Australia. Transactions of the Royal Society of South Australia 129(2):202-208.	Journal article		
Stewart, T., Baring, R., and Benkendorff, K.	2009	Intertidal Monitoring: Autumn/Winter Report 2009. A report to Adelaide Aqua. Flinders University, Bedford Park.	Report	Southern Metro	http://www.naturalresources.sa.gov.au/adelaidemtloftyranges/about-us/our-regions-progress/monitoring-and-evaluation/coast-and-marine/port-stanvac-intertidal-reef-surveys
Stuart-Smith, R., Barrett, N., Crawford, C., Edgar, G. and Frusher, S.	2008	Condition of rocky reef communities: A key marine habitat around Tasmania. NRM/NHT Final Report.Tasmanian Aquaculture & Fisheries Institute, University of Tasmania.	Report	Tasmania	
Stuart-Smith, R.D., Barrett, N.S., Crawford, C.M., Frusher, S.D., Stevenson, D.G. and Edgar, G.J.	2008	Spatial patterns in impacts of fishing on temperate rocky reefs: Are fish abundance and mean size related to proximity of fisher access points? Journal of Experimental Marine Biology and Ecology, 365:116-125	Journal article	Tasmania	

Stuart-Smith, R.D., Edgar, G.J., Stuart-Smith, J.F., Barrett, N.S., Fowles, A.E., Hill, N.A., Cooper, A.T., Myers, A.P., Oh, E.S., Pocklington, J.B. and Thompson, R.J.	2015	Loss of native rocky reef biodiversity in Australian metropolitan embayments. Marine Pollution Bulletin, 95(1): 324-332.	Journal article	Applicable to all	
Stuart-Smith, R.D., Edgar, G.J., Barrett, N.S., Bates, A.E., Baker, S.C., Bax, N.J., Becerro, M.A., Berkhout, J., Blanchard, J.L., Brock, D.L., Clark, G.F., Cooper, A.T., Davis, T.R., Day, P.B., Duffy, J.E., Holmes, T.H., Howe, S.A., Jordan, A., Kininmonth, S., Knott, N.A., Lefcheck, J.S., Ling, S.D., Parr, A., Strain, E., Sweatman, H. and Thomson, R.	2017	Assessing national biodiversity trends for rocky and coral reefs through the integration of citizen science and scientific monitoring programs. BioScience, 67 (2) 134-146	Journal article	Applicable to all	
Turner, D.J.	2004	Effects of sedimentation on the structure of a phaeophycean dominated macroalgal community. PhD Thesis, Department of Environmental Biology, University of Adelaide, Adelaide, Australia.	Thesis		

Turner, D.J., Kildea, T.N. and Murray-Jones, S.	2006	Examining the health of subtidal reef environments in South Australia, Part 1: Background review and rationale for the development of the monitoring program. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 62 pp. SARDI Publication Number RD03/0252-3.	Report	Applicable to all	
Turner, D.J., Kildea, T.N. and Westphalen, G.	2007	Examining the health of subtidal reef environments in South Australia, Part 2: Status of selected South Australian reefs based on the results of the 2005 surveys. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 62 pp. SARDI Publication Number RD03/0252-6	Report	Adelaide metro, Southern Metro, Yankalilla Bay, Backstairs Passage, South Coast	
Turner, S.J., Thrush, S.F., Hewitt, J.E., Cummings, V.J. and Funnell, G.	1999	Fishing impacts and the degradation or loss of habitat structure. Fisheries Management and Ecology, 6:401-420	Journal article		
Underwood, A.J. and Kennelly, S.J.	1990	Ecology of marine algae on rocky shores and subtidal reefs in temperate Australia	Journal article	Applicable to all	
Vadas, R.L., Johnson, S. and Norton, T.A.	1992	Recruitment and mortality of early post-settlement stages of benthic algae	Journal article		
Walsh, M.R., Munch, S.B., Chiba, S. and Conover, D.O.	2006	Maladaptive changes in multiple traits casued by fishing: impediments to population recovery. Ecology Letters, 9:142-148	Journal article		
Westphalen, G.	2009	Reef Watch South Australia Surveys across reefs in the Adelaide and Mt Lofty Ranges natural	Report	Applicable to all	

		resource management region 2008-2009. A report to the Conservation Council of South Australia Inc.			
Westphalen, G.	2011	Reef Watch South Australia Surveys across reefs in the Adelaide and Mt Lofty Ranges natural resource management region 2010-2011. Reef Watch Monitoring Program, Conservation Council of South Australia.	Report	Applicable to all	
Westphalen, G.	2013	The Reef Watch intertidal monitoring program analysis and interpretation of surveys from 2006-2012. A report to the Conservation Council of South Australia and Reef Watch. Westphalen Consulting.	Report	Southern Metro, Yankalilla Bay, Encounter Bay.	
Womersley, H.B.S. and Edmonds, S.J.	1958	A general account of the intertidal ecology of South Australian Coasts. Australian Journal of Marine and Freshwater Research 9: 217-206	Journal article	Applicable to all	
Worm, B and Lotze, H.K.	2006	Effects of eutrophication, grazing, and algal blooms on rocky shores. Limnology and Oceanography 51:569-579			