AMLR Subtidal Reef Program: Review and recommendations for monitoring the health of subtidal reefs in the Adelaide and Mt Lofty Ranges NRM region.

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Summary

Near-shore subtidal reefs are a major component of the coastal ecosystems of the Adelaide and Mt Lofty Ranges NRM region. They are biodiverse and provide important ecosystem services in addition to supporting a range of industries and recreational activities. These systems are extremely important to the healthy functioning of the Gulf St Vincent marine environment and if maintained in a healthy state will provide an important buffer to help ameliorate the impacts of climate change. Currently there are a number of key pressures on near-shore reef habitats including pollution, water quality, invasive species, over-harvesting and climate change. To effectively manage these habitats and determine the effectiveness of management actions requires an adequate and consistent monitoring program to assess the condition of these systems.

This report, commissioned by Natural Resources Adelaide and Mount Lofty Ranges (NR AMLR), aims to provide strategic direction in where and how near-shore subtidal reef condition monitoring is conducted in the AMLR region. There were two main objectives. The first was to use available data to identify potential reef sites for long term monitoring of condition such that the sites were representative, could assess the impact of land based inputs and monitor the status of regionally significant resident species. The second objective was to provide recommendations on the frequency of resurvey and indicators for assessing reef condition.

A list of 40 sites (31 existing and 9 new) was identified for monitoring near-shore reef condition in the AMLR region. An iterative approach was taken to identify this list of reef sites. In the last 30 years there have been over 110 reef survey sites established in the AMLR region by multiple agencies. These sites were used as a starting point in the iterative process. To select sites that were representative, a biophysical approach was taken that partitioned reefs into subregions based on attributes including water temperature, exposure to wave energy, rugosity, depth and profile. To select sites for assessing land-based impacts, a control/impact approach was used, based on identified threats within each subregion, with additional sites aimed at monitoring the impact of major catchment discharges. Previous work on marine species of conservation concern in the AMLR region (Baker 2007) was used as the basis for selecting regionally significant resident species to monitor. Clear decision rules were defined for each criteria with the aim to minimise the final number of sites recommended for monitoring. The decision rules were applied sequentially and where the existing pool of sites did not meet the criteria a new site was chosen.

It is recommended that re-survey frequency be inter-annual where resourcing allows rather than intra-annual as change at this scale is more relevant and measuring more cost effective given the long time frames over which monitoring will take place . A number of indicators aimed at assessing condition and informing management actions are recommended to be used as part of any ongoing monitoring program with the main features being that:

- Different components of the food web (fish, macroalgae, invertebrates) are targeted.
- Macroalgae continue to be a key component of any assessment of reef condition.
- Reef condition is determined by a weight-of-evidence approach informed by tracking each indicator individually over time (i.e. indicators are not combined in a single index of condition except for high level reporting and as a communication tool).

In addition to suitable indicators to assess reef condition this report recommends that conceptual models to describe reef condition and its drivers be developed to provide a reporting and management framework for assessing condition and management actions. Lastly, it is necessary that methods to measure macroalgae cover be reviewed with the aim to choose the most cost effective for ongoing monitoring.

1 Introduction

1.1 Nearshore reef ecosystems in the AMLR region

Subtidal reefs are a critical component of the nearshore marine ecosystems in the Adelaide and Mount Lofty Ranges (AMLR) NRM region, both in areal extent and the ecological communities dependent on them (Collings et al. 2008). They extend from Parham Reef in the north to the eastern border of the region near Middleton (Figure 2). These reef systems range in depth from intertidal to more than 20 m and are comprised mainly of limestone, schist or granite formations and their profile can range from flat platform-like structures to high relief complexes.

The nearshore reef systems in the AMLR region support a diverse array of species, ecological communities and processes that in turn provide significant ecosystem services and socio-economic benefits to the over million people that live in the region. Kelp and other canopy forming macroalgae provide the main habitats that sustain these productive and diverse ecosystems and are an important factor in structuring these communities (Turner et al. 2007). Many species of conservation concern such as blue groper, blue devils and harlequin fish are site attached and dependant on types of reefs (Bryars 2010), while for other species such as snapper, stingrays and leatherjackets these reefs form part of a mosaic of habitats including seagrasses and mangroves that are critically linked to different stages in their life history (Baker 2007).

Several species of fish and macro-invertebrates (e.g. snapper, sweep, rock lobster and abalone) that are dependent on nearshore reefs are also vitally important to recreational and commercial fisheries. The vibrant marine life and its accessibility also provide significant public amenity value and form an important asset for other recreational water sports such as the snorkelling and diving community.

1.2 Threats to reefs in the AMLR region

The key threats to marine biodiversity can be categorised as land-based impacts, resource use, marine biosecurity, marine pollution, and climate change (Marine Biodiversity Decline Working Group 2008). For the purpose of this report, impacts can be broadly classed as those associated with land-based inputs of pollution, and those that extract living resources, i.e. fishing. In the case of land-based inputs, this report will consider all such threats, but has a particular focus on impacts associated with the main catchments in the AMLR region.

Land-based impacts in the AMLR are generally associated with inputs of nutrients and sediments via wastewater, stormwater and poor quality catchment water (Bryars 2013a). Highly modified catchments have resulted in pulsed inputs of nutrients and sediments following heavy rains to a marine environment that evolved with steady inputs of water containing low levels of nutrients and sediments (Bryars 2013a). Nutrients and sediments can impact reefs through a number of mechanisms, and can cause a shift from communities dominated by canopy-forming macroalgae to turfing algae (Connell et al. 2008).

Threats associated with fishing relate to both those species that are targeted or caught as bycatch and are removed from the system (direct impacts) and also effects on other components of the ecosystem (secondary and tertiary impacts) often called 'trophic cascades' whereby the removal of predator or prey species can eventually result in increases or decreases of other species, including habitat forming species such as macroalgae (Barrett et al. 2007, 2009; Edgar et al. 2007, 2009; Babcock et al. 2010).

While both land based impacts and resource extraction can impact reef systems in different ways the general effect of both, if severe enough, results in ecosystems with simplified food webs, compromised functional integrity and reduced provision of ecosystem services and resilience to secondary impacts such as marine pest invasion and climate change (Bailey et al. 2012, Baden et al. 2012).

1.3 Natural resources management framework

The South Australian Government, through the State Natural Resources Management Plan, has responsibilities under the *Natural Resources Management Act 2004* (The Act) to provide for monitoring and evaluation of the state and condition of the natural resources of the state on an ongoing basis.

Marine ecosystems are ecologically and socio-economically important for the AMLR region, and near-shore reefs provide important habitat for local and regional biodiversity and are important public amenity assets. The nearshore proximity of reefs subjects them to extrinsic pressures, e.g. catchment and stormwater discharge, and sedimentation, which can influence long-term condition and resilience.

The AMLR Natural Resources Management (NRM) Board has a responsibility under the Act to ensure that the Regional NRM Plan developed for the region includes information about the issues surrounding the management of natural resources at the regional and local level. More specifically, the NRM Plan must include information about arrangements to ensure proper management of wetlands and estuaries, and marine resources, with particular reference to the relationships between catchment, wetland, estuarine and marine systems.

The Regional NRM strategic plan for the region is intended by the *Natural Resources Management Act 2004* to apply to all stakeholders managing natural resources in the AMLR region.

The AMLR NRM Board supports a range of programs and management strategies that facilitate the maintenance and ongoing sustainability of both terrestrial and marine ecosystems in keeping with the regional NRM Strategic Plan. These activities aim to contribute to NRM Plan regional targets, and form a key strategic alignment to inform the regional conceptual models within their Regional NRM Plan. Relevant regional targets for marine ecosystems include:

- T9: Improvement in conservation prospects of native species from current levels
- T10: Land based impacts on coastal, estuary and marine processes reduced from current levels
- T11: Halt the decline of seagrass, reef and other coast, estuarine and marine habitats, and a trend toward restoration.

The AMLR NRM Board has supported the implementation of regional action plans that aim to facilitate the conservation, protection and maintenance of natural resources, establish conservation priorities and identify threatening processes for places and areas within the region. These plans include the Southern Fleurieu Action Plan (Caton et al. 2007), the Southern Fleurieu Estuaries Action Plan and the Metropolitan Adelaide and Northern Coastal Action Plan (Caton et al. 2009). Bryars (2013a) complemented these action plans, identifying the key values, threats and condition status of local benthic near shore habitats across the AMLR region, and developing priority actions and local mitigation strategies to reduce land-based threats and impact.

Development and implementation of a long term monitoring program for nearshore reefs in the AMLR region is fundamental to facilitate reporting on the state and condition of these important ecosystems and to provide a basis for guiding and assessing management actions designed to address threats to these systems.

1.4 Aims and approach

1.4.1 Aims

The aims of this document are to:

1. Use available data to identify potential reef sites for long term monitoring of nearshore reef condition in the AMLR region. The requirements of the reef sites are that they:
   - are representative of reef systems in the AMLR region

- can be used to assess the impact of land based inputs
- can be used to monitor the persistence and status of regionally significant resident species

2. Provide recommendations on
   - The frequency of resurvey for long term monitoring.
   - Indicsators that facilitate monitoring of reef condition.

1.4.2 Approach

The report is divided into two components, in line with the above aims; (1) Sections 2 to 6 and (2) Section 7. The first component details the steps taken to identify a list of sites that represent the range of reef types and that can be used to assess land based impact and status of regionally significant resident species in the AMLR region. An iterative process was adopted where a set of criteria was defined and then a framework for applying them was employed to minimise the number of sites needed to satisfy the criteria.

Sections 2 to 5 provide the necessary information to inform an iterative selection process that is undertaken in Section 6 (Figure 1). The existing reef monitoring sites were identified in Section 2 on the assumption that they will form the basis for ongoing monitoring. Sections 3, 4 and 5 used a range of data sets including biological data from the existing site list to develop criteria to select sites on the basis of representativeness and suitability for assessing land based impacts and regionally significant resident species. In Section 6 the list of available sites was iteratively assessed against the criteria. At each subsequent step sites were selected that met the criteria until a final list of sites was arrived at that achieved the starting objectives.

Section 7 provides the second component, namely the recommendations on frequency of monitoring and indicators to assess condition.

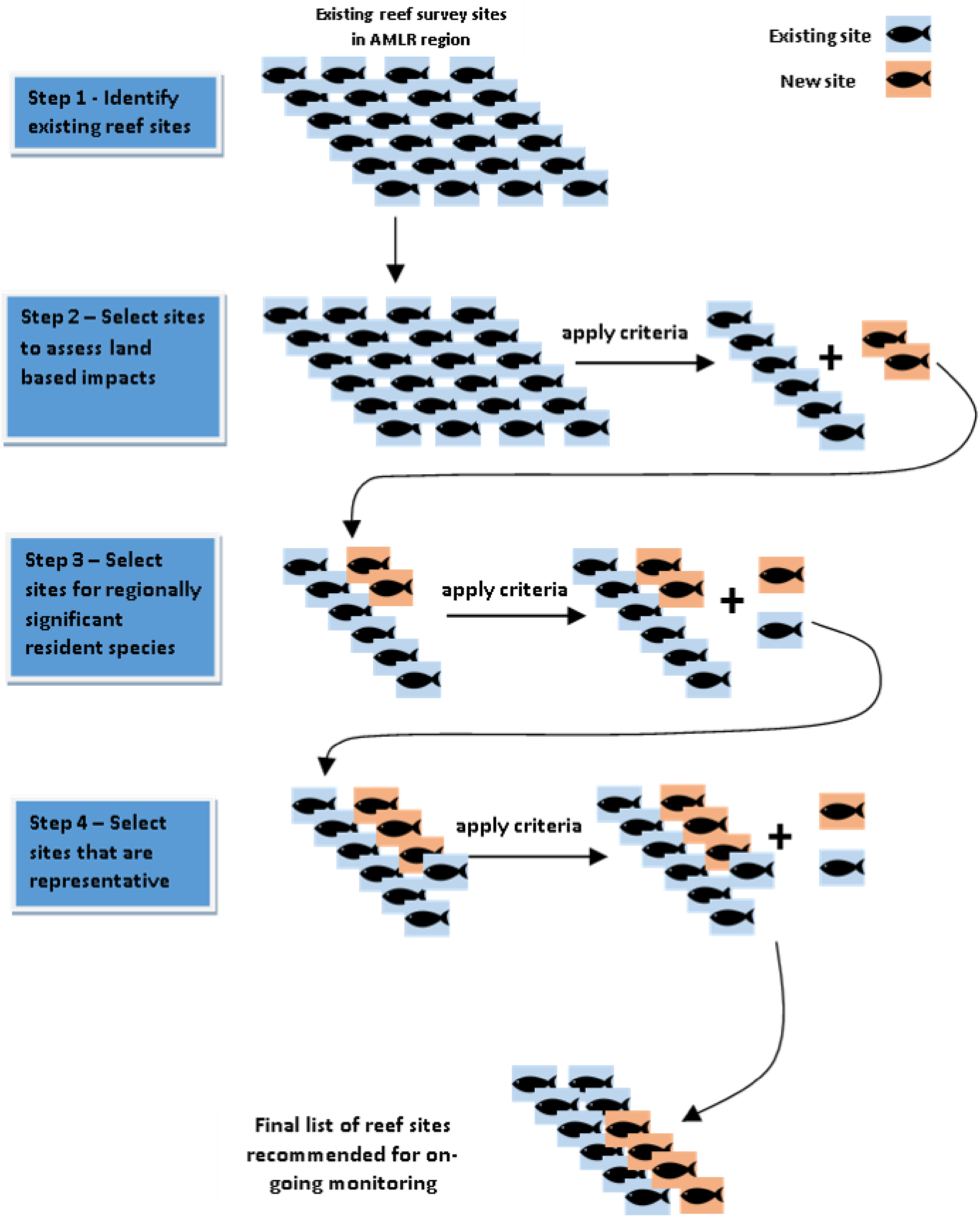

Figure 1. Schematic showing the application of selection criteria and the iterative process to select reef sites for ongoing monitoring

2 Reef monitoring programs in the AMLR NRM Region – past and present

2.1 Background

Formal monitoring of subtidal reefs using underwater visual census (UVC) methods commenced in South Australia in 1996 when the Environment Protection Authority (EPA) funded a study of Adelaide's metropolitan reefs by Adelaide and Flinders Universities (Reef Health). Since then there have been numerous programs led by government agencies, universities, discharge licence holders and non-government organisations, either separately or in collaboration. Some of these programs are local, e.g. Reef Watch, while others are part of a national program, e.g. Reef Life Survey. The outcome has been the establishment of a large number (>100) of reef monitoring sites in the AMLR Region, some of which are part of ongoing monitoring programs. The following section describes the main programs, including their methods and focus areas. It is anticipated that a subset of these existing sites will form the basis of ongoing monitoring in the AMLR region.

2.2 Programs and associated methods

2.2.1 Marine Protected Area program

University of Tasmania and its fisheries research arm (Tasmanian Aquaculture and Fisheries Institute, now Institute of Marine and Antarctic Studies) commenced marine park monitoring at Maria Island in Tasmania in 1992 and then gradually extended to other temperate water states around Australia. The associated UVC method, generally referred to as the "marine protected area (MPA) method", is described in detail by University of Tasmania (2010). It surveys three distinct components of reef communities, namely:

- Emergent fish, i.e. those that can be viewed swimming in the water column or above the macroalgal canopy or near the mouth of caves and ledges. The survey method is a belt survey covering 200 m x 5 m on each side of a transect line (total area = 2000 m^2).
- Mobile invertebrates and sedentary or cryptic fish, often hidden under ledges within caves, or underneath the macroalgal canopy. The survey method is a belt survey covering 200 m x 1 m on one side of a transect line (total area = 200 m^2).
- Macroalgae, sessile invertebrates and substrate information. The survey method is a 0.25 m^2 quadrat replicated 20 times at 10 m intervals along the transect line.

Monitoring in South Australia commenced in 2004, and continued through to 2013 after which the similar Reef Life Survey program methods (see Section 2.2.2) have been used for marine park monitoring. The MPA surveys were undertaken by or (in the case of invertebrate surveys) under the supervision of professional marine scientists.

A total of 45 sites have been established within the AMLR region, mostly between Myponga and Carrickalinga, between Rapid Head and Deep Creek Conservation Park or in Encounter Bay.

University of Tasmania is the data custodian but provides data extracts on request to the Department of Environment, Water and Natural Resources (DEWNR), which is developing a corporate database to maintain this data.

2.2.2 Reef Life Survey program

The Reef Life Survey (RLS) program was established in 2007 in order to make diver-based UVC surveys accessible to well-trained community divers. Reef surveys were initially focused on temperate waters in Australia but it is now a global program. In practice, most of the data collected in South Australia has been in conjunction with professional scientific divers at RLS training events or on dedicated RLS survey trips, or by professional scientific divers from government agencies or private consultancies.

The survey method was adapted from the MPA method and is described in detail by Reef Life Survey (2015). The main differences to the MPA method are:

- The macroalgae, sessile invertebrates and substrate component is surveyed using photoquadrats rather than in-situ quadrat surveys. This provides for percentage-cover estimates but does not include understorey species to the same extent as the MPA method.
- The area covered by the invertebrate and cryptic fish survey is doubled by surveying on both sides of the transect line (total area = 400 m^2).
- There is greater flexibility in the scalability and level of replication within surveys, with surveys based on a scalable number of independent 50 m transects rather than a single composite 200 m transect.

RLS surveys for DEWNR's South Australian marine parks monitoring, evaluation and reporting (MER) program are configured as four contiguous 50 m transects, in order to maintain consistency with the baseline data collected using the MPA method.

A total of 29 RLS sites within the AMLR region have been established in the south-western Fleurieu Peninsula (between Myponga and Cape Jervis) and around Port Noarlunga.

The RLS Program (University of Tasmania) is the data custodian but provides extracts on request to DEWNR, which will maintain a copy of these data in a corporate database. The data are also available from the RLS data portal (Reef Life Survey 2016). The RLS Program also has a data sharing arrangement with Reef Watch (see Section 2.2.4).

2.2.3 Reef Health programs

The first Reef Health program in South Australia, undertaken in 1996, was commissioned by the Environment Protection Authority and was a collaboration between Adelaide and Flinders Universities (Cheshire et al. 1998). It provided a baseline on the community composition of reefs of the Adelaide Metropolitan and southern Metropolitan coast to facilitate monitoring of the effect of human impact on these reefs. The study was repeated in 1999, with some additional sites (Cheshire and Westphalen 2000).

A similar program (also named Reef Health) was undertaken between 2005 and 2007 by a consortium of organisations and government agencies led by the South Australian Research and Development Institute (SARDI). This program extended the suite of sites to additional regions, including Yorke Peninsula, the Investigator Group, the southern Fleurieu Peninsula and a site north of Adelaide (Port Parham).

Further monitoring of the southern Fleurieu Peninsula and Metropolitan coast using the Reef Health (and RLS) methods was undertaken by consultants on behalf of the AMLR NRM Board in 2012/13 and 2015/16, respectively (Brook and Bryars 2014, Brook unpublished data).

The primary survey method is the line intercept transect that provides detailed information on macroalgal assemblages over 20 m transects, typically replicated four times (Cheshire et al. 1998, Turner et al. 2007). The fish and invertebrate fauna were also surveyed in 1996, and since 2005, using revised methods that are more compatible with the MPA and RLS methods (total area = 1000 and 200 m^2, respectively). The 2012/13 and 2015/16 surveys included both the Reef Health and RLS methods.

A total of 34 sites have been established within the AMLR region, centered around the Metropolitan coastline (from Port Parham to Aldinga), the south-western Fleurieu Peninsula (Carrickalinga to Second Valley) and Encounter Bay (the Bluff to Pullen Island).

SARDI is the data custodian for the 2005 to 2007 surveys, and has provided these data to DEWNR. The AMLR NRM Board is the data custodian for the 2012/13 and 2015/16 surveys. Most of the AMLR NRM Board data have also been or will be submitted to the RLS Program, the exception being the line intercept transect data.

2.2.4 Reef Watch

The Reef Watch program was established in 1996 through a working group of researchers, community and dive groups and managed by the Conservation Council of South Australia. Funding has been provided at different times by the Environment Protection Authority, the Australian Government through CoastCare and other funding and Envirofund via the interim AMLR NRM Board. Since 2008, NRM Levy funding has been provided by the AMLR NRM Board. Reef Watch surveys have been held in various parts of South Australia but most effort is concentrated in the AMLR region. The program encourages marine stewardship and trains community divers to collect scientific data on reef community composition, using the Reef Health methods (Reef Watch 2016).

Reef Watch surveys have been undertaken at a total of 33 sites in the AMLR region, although most effort has been at 13 sites. Port Noarlunga has been a particular focus for monitoring by Reef Watch, with surveys at four sites at Port Noarlunga since 2000 (previous surveys were not differentiated into these four sites). Since 2009, monitoring has focused on six sites including two of the Noarlunga sites (North and South Inside), Broken Bottom (Metropolitan coast), Hallett Cove, Second Valley and the Bluff at Victor Harbor (Westphalen 2015).

The Conservation Council of SA is the data custodian. Data are available on request.

2.2.5 SA Murray-Darling Basin NRM Board marine biodiversity project

The South Australian Murray-Darling Basin NRM Board funded a study of the ecology of the Coorong bioregion, including diver surveys of near-shore reefs in December 2004. These surveys were at the western extent of the Coorong bioregion, within the AMLR region (Haig et al. 2006).

A hybrid of the Reef Health and Marine Protected Area methods was used, with line intercept transects, fish and mobile invertebrate counts conducted along 25 m transects (total area = 125 m^2 and 25 m^2 for fish and invertebrates, respectively. A total of 7 sites were established in shallow water (<10 m) within the AMLR region. Most of these were within 1 km of Pullen Island, the exception being West Island. Reef sites were also identified in deeper water offshore from Middleton using swath and video mapping (Haig et al. 2006).

The data custodian is unknown, but DEWNR have a copy of the data.

2.2.6 EPA aquatic ecosystem condition reporting

The EPA have used towed video to quantify the percentage cover of habitats, including reef habitat, at 37 sites between Port Parham and Aldinga (Nelson et al. 2013). At nine reefs with a significant quantity of reef habitat, the percentage cover of canopy forming algae, turfing algae and bare substrate were determined from analysis of the video and used to grade the overall reef condition (Nelson et al. 2013, Gaylard et al. 2013).

2.2.7 Adelaide Desalination Plant monitoring

Monitoring of reefs in the vicinity of the Adelaide Desalination Plant has been undertaken for Adelaideaqua Pty Ltd by the University of Adelaide between 2009 and 2012 (Russell and Connell undated a,b,c, 2010, 2011a, b, 2012a, b), and by private consultants (J Diversity Pty Ltd) in 2016.

The monitoring was undertaken using the Reef Health method in all years, supplemented by the RLS method in 2016.

The surveys were undertaken at five locations between Marino Rocks/Hallett Cove and Moana, with two sites at each location.

The data custodian is Adelaidequa Pty Ltd, who have entered into a data sharing arrangement with the AMLR NRM Board.

2.2.8 Christies Beach Waste Water Treatment Plant monitoring

SA Water undertook reef surveys at Port Noarlunga Reef (outside), Horseshoe Reef, Port Stanvac and Hallett Cove in autumn of 2014 and 2016 to meet licence requirements for the Christies Beach Waste Water Treatment Plant (WWTP) (Connell 2016).

The methods were based on the Reef Health method but the level of replication was increased from four to eight transects, the invertebrate surveys were reduced from 50 to 20 m length and emergent fish surveys were not undertaken (Connell 2016).

The data custodian is SA Water.

2.2.9 Reef fish surveys

Monitoring of western blue groper and other reef fish was undertaken by Dr Scoresby Shepherd of SARDI, partly in collaboration with Reef Watch. Fish surveys were belt transects of 100 m length by 5 m width (total area = 500 m^2). Most of these surveys were undertaken by snorkel.

Surveys were undertaken at 24 sites in the AMLR region, on the Fleurieu Peninsula south from Horseshoe Reef and in Encounter Bay (Shepherd and Baker 2008).

Dr Shepherd is the custodian of the data and has made it freely available to the Conservation Council of SA and DEWNR.

2.2.10 DEWNR threatened species monitoring

Monitoring of the population demographics and site fidelity of harlequin fish and/or southern blue devil was undertaken by divers at a number of sites within the AMLR region between 2009 and 2013 (Bryars 2010, 2011, 2013b). Both these species have characteristic body markings that allow photographic identification of individual fish and capture-mark-recapture techniques.

The sites included Aldinga Reef (near the drop-off at depths between 12 and 18 m), Northern Outer Reef, Milkies Reef, Macs Reef, and Seacliff Reef. At some sites, fixed transects were used to resurvey fish populations (Bryars 2013b).

2.2.11 South Australian Conservation Research Divers – Rare Species project

South Australian Conservation Research Divers (SACReD) is a group of marine citizen-science volunteers founded by marine ecologist Janine Baker. SACReD members and associates have participated in marine science projects managed by Ms Baker since 2007.

In recent years SACReD has concentrated on learning more about the distribution and habitats of rarely recorded and endemic marine invertebrates at various locations along the central South Australian coast. Field-surveys totalling 60 diver-hours were undertaken at 14 subtidal reef sites, 3 jetties, and 3 wreck sites within the AMLR region between July 2013 and October 2014. The sites were along the Metropolitan coast, the south-western Fleurieu coastline, and in Encounter Bay (Baker et al. 2015).

2.2.12 Sedimentation surveys

The AMLR NRM Board commissioned SARDI to determine sedimentation rates along Adelaide's coastal reefs after major rainfall events, and to provide information on the potential sources of these sediments. Sediment traps were deployed at 12 reefs between Semaphore and Aldinga in winter, summer and autumn 2007/08 (Fernandes et al. 2008, Fernandes 2008).

2.3 Existing reef monitoring sites

Table 1 summarises the main features of the above mentioned monitoring programs. In total there have been 112 monitoring sites established by these programs, some of which are ongoing (Appendix A). The majority of the reef sites have been established by the MPA, RLS and Reef Health Programs. Some sites have been surveyed only once while others have been resurveyed multiple times.

About one third of the sites have been established on reefs near the main population areas particularly Adelaide and its southern suburbs, and about 80% of all sites (including some southern metropolitan sites) are in the Encounter Marine Park (Figure 2). Overall, nearly 80% of sites occur along the north-west facing coastline compared to the southern coasts where sites are more sparsely distributed except in Encounter Bay where there is a group of around 20 sites associated with another population centre, Victor Harbor (Figure 2). Most of the reef systems in the AMLR region have monitoring sites associated with them however there are some areas of reef where there are no monitoring sites. The largest extent of such reef occurs along the south coast between Deep Creek and Newland Head with smaller extents on the reef system south of Aldinga and between Carrickalinga and Wirrina.

Table 1. Summary of reef monitoring programs in the AMLR NRM region

Program	Proponent	Objectives	Areas	Duration	No. of sites	Method	Future status
Marine Protected Area	DEWNR/University of Tasmania	Evaluate effect of marine park zoning	Granite Island to Aldinga	Since 2005	45	Fish and invertebrate belt transects, "3D" quadrats	Ongoing but generally superseded by the RLS program
Reef Life Survey	University of Tasmania (with partners including DEWNR)	Gather high quality data on reef biodiversity to inform management	Fleurieu Peninsula, southern metro coast	Since 2007	29	Fish and invertebrate belt transects, photo-quadrats	Ongoing
Reef Health	The University of Adelaide/Flinders University, SARDI (with multiple partners), Consultants for AMLR	Monitor reef condition	Metro coast (including Port Parham), Fleurieu Peninsula	1996, 1999, 2005, 2007 (both areas), 2012/13 (Fleurieu), 2015/16 (Adelaide Metro)	34	Line intercept transects, photoquadrats (since 2012), fish and invertebrate belt transects (since 2005).	Unknown
Reef Watch	CCSA for AMLR	Monitor reef condition	Metro coast, Fleurieu Peninsula	Since 1996	33 (6 main sites)	Fish and invertebrate belt transects, line intercept transects, and incidental sightings of introduced pests and species of conservation concern (the 'Feral or In Peril' program)	Ongoing
SAMDB Biodiversity mapping and inventory	DEWNR for SAMDB	Gather inventory data for reef ecosystems	Eastern Fleurieu Peninsula	Summer 2004/05	7	Fish and invertebrate belt transects, line intercept transects	Completed
EPA Aquatic Ecosystem Report Cards	EPA	Gather data on reef condition	North from Aldinga	Autumn and Spring 2010 and 2011	37 sites (9 reef)	Towed video transects.	To be resurveyed in 2017 (S. Gaylard (EPA) 2016, pers. comm..) EPA)
Adelaide Desalination Plant	The Adelaide University and other consultants for Adelaide Aqua (licence condition)	Monitor potential impacts of desalination return water on reef condition	Southern metro coast	Since 2010	10	Fish and invertebrate belt transects, line intercept transects, photoquadrats (since 2016)	Ongoing – every three years (as per licence condition)

Program	Proponent	Objectives	Areas	Duration	No. of sites	Method	Future status
Waste Water Treatment Plant	SA Water (licence condition)	Monitor impacts of treated wastewater on reef condition	Southern metro coast	Autumn 2014 and 2016	4		Unknown. SA Water's current monitoring plan does not extend beyond 2016
Blue groper surveys	Dr Scoresby Shepherd (with collaboration from Reef Watch)	Monitor reef fish populations	Southern metro coast, Fleurieu Peninsula	Rolling survey between 2002 and 2008	24	Fish belt transects (100 m x 5 m)	Unknown
Threatened species	Simon Bryars/ DEWNR for AMLR NRM Board	Determine population demographics, site fidelity and home range of site-attached fish	Metro coast	2009 to 2013	5	Capture-mark-recapture using photo identification	Completed, but may be continued with ad-hoc funding
Rare species	SACReD	Increase knowledge of the distribution and habitats of rarely recorded, endemic, and other marine species of conservation interest	Metro coast, Fleurieu Peninsula	2013 and 2014	20		Ongoing, subject to ad-hoc funding
Sediment surveys	SARDI for AMLR NRM Board	Determine sedimentation rates along Adelaide's coastal reefs after major rainfall events, and provide information on the potential sources of these sediments	Metro coast	2007/08 (3 seasons)	12	Sediment traps	Completed

Note: Some sites are used by multiple programs.

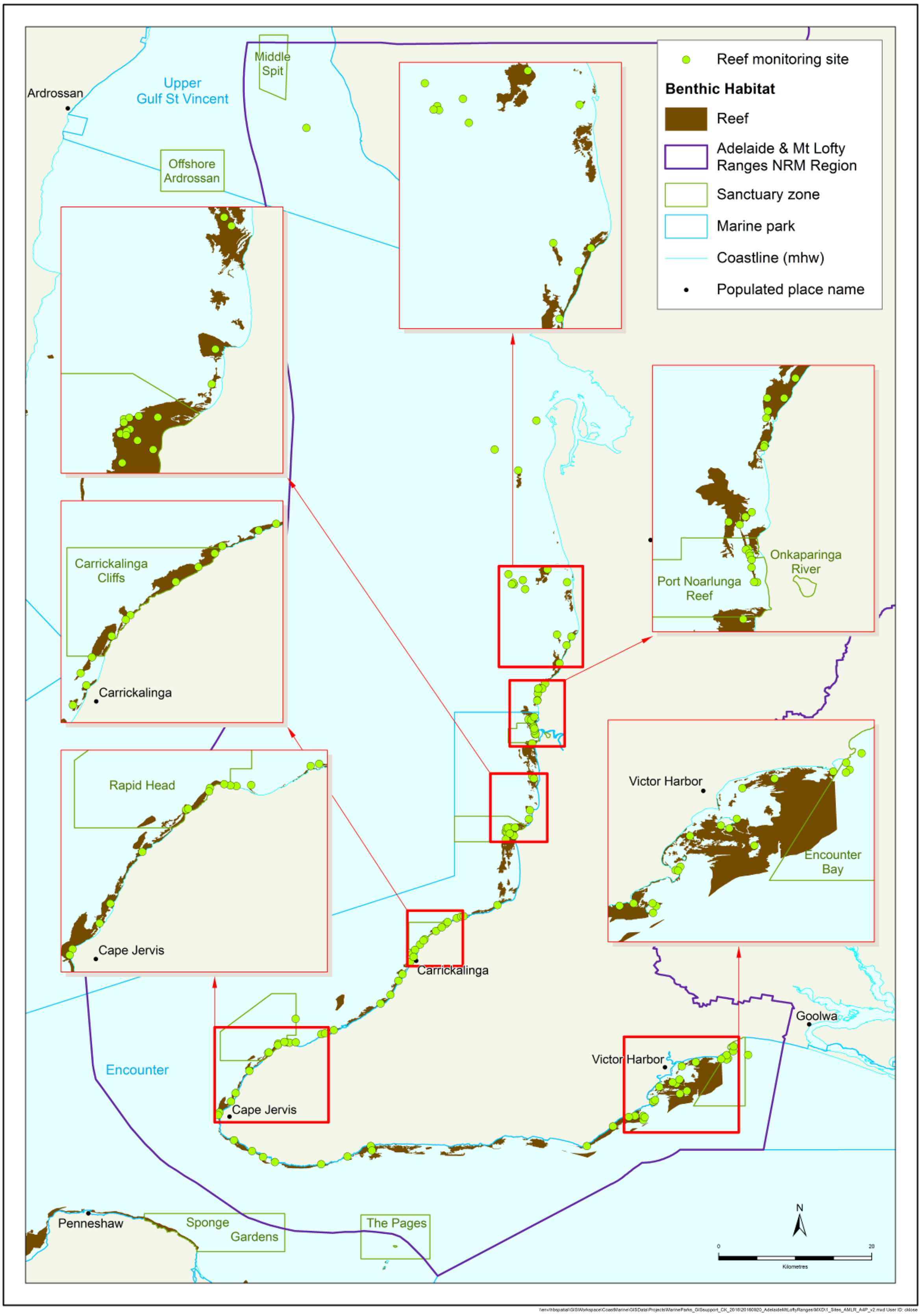

Figure 2. Established monitoring sites for various reef programs within the AMLR region and mapped extent of known reefs. Source: Reef Life Survey (2016), Collings et al. (2008), Brook and Bryars (2014), DEWNR unpublished data, DEWNR (2016a, b) (mhw = mean high water)

3 Selection of representative sites

3.1 Approach to site selection

Reef communities are structured by a variety of physical and biological factors, both natural and anthropogenic, which apply at a range of scales (Turner et al. 2006). One aim of this report is to select sites that are representative of reef systems within the AMLR region. For this purpose, it is considered appropriate to primarily consider the physical factors known to drive community composition rather than biological factors or the community composition itself, which are both likely to be confounded by anthropogenic impacts

The first step, addressed in Section 3.4, was to classify reefs according to the natural, physical factors that have most influence on reef structure.

The first step was informed by two related analyses. The first examined physical factors within the AMLR region (Section 3.3) and looked for distinct changes in their distribution along the coastline that might be used to define subregion boundaries, while the second used the existing suite of reef sites and undertook hierarchical clustering of these sites based on their physical attributes (Section 3.5).

The second step was to validate this classification against existing community composition data (Section 3.5). While all biological components of reef systems interact and influence each other, the macroinvertebrate/cryptic fish community data (from the MPA, RLS and Reef Health methods) was considered the most appropriate to explore the validity of the subregional groupings based on physical factors. Emergent fish data were considered to be prone to confounding by inter-survey variations in visibility and relief (associated with small-scale spatial variability). Macroalgal community data were also not considered suitable because they were:

- not available for much of the RLS data
- not fully compatible between programs
- only consistently available at a coarse taxonomic level that is not useful for defining community structure
- more likely to be confounded by reef condition and impacted by anthropogenic influences, given that canopy cover is the key indicator (Cheshire et al. 1998, Turner et al. 2007, Collings et al. 2008, Gaylard et al. 2013).

3.2 Drivers of nearshore reef community structure

Physical factors such as wave energy, depth, temperature and reef composition are key drivers of community structure on temperate reef systems (Shepherd and Edgar 2013). Wave energy has been demonstrated to be an important factor controlling the distribution of macroalgae, fish and other components of reef systems (Pedersen et al. 2012; Thomson et al. 2012, Friedlander et al. 2003) and most species are restricted to certain thermal ranges that influence their distribution (Duffy et al. 2016). Reefs along the AMLR coastline experience significant gradients of both wave energy and temperature (Bye and Kämpf 2008) and therefore these drivers exert a strong influence on the species abundance and diversity found at any particular location. Depth also influences community structure by attenuating light (in the case of macroalgae) and wave energy (Shepherd and Womersley 1970). Reefs within the AMLR region range in depth from intertidal to more than 20 m.

The physical structure of reefs also influences community structure. Both macroalgae and fish diversity can increase with increasing relief (Shepherd and Baker 2008, Alexander et al. 2009, Harman et al. 2003). Shepherd and Baker (2008) found that the total abundance of fish increased up to a relief of about 0.5 m. Other aspects of reef topography, particularly the density of refuges (crevices and holes) have been found to influence the structure of mobile invertebrate communities (Alexander et al. 2009). Reef composition is also relevant, with fish and macroalgal communities found to differ between granite and limestone reefs (Harman et al. 2003). Reef composition and structure varies across the AMLR region, with natural reefs comprised of schist, limestone or granite, and relief ranging from 0 to at least 4 m.

Anthropogenic impacts are another driver that is becoming increasingly important as human populations grow and coastal settlements increase in size and extent (Mora et al. 2011). Anthropogenic influences are generally associated with either a reduction in water quality caused by increased nutrient and sediment inputs and or resource extraction resulting in removal of biomass from the ecosystem. In the AMLR region, reduced water quality has already resulted in significant changes in community structure as canopy forming macro algae foundation species have been replaced by faster growing turfing algae (Connell et al. 2008). Resource extraction commonly in the form of fishing targets larger animals often from higher trophic levels leading to changes in trophic structure and can result in trophic cascades that dramatically modify reef ecosystems (Babcock et al. 2010, Ling et al. 2009, Soler et al. 2015). In general, anthropogenic factors can lead to reduced diversity and simplified food webs (Stuart Smith et al. 2015).

3.3 Physical factors

The physical factors and data sources used to classify reef systems in the AMLR region are provided in Table 2.

Table 2. Physical factors chosen to classify AMLR reef sites

Factor	Distribution	Data source	Levels
Temperature	Alongshore gradient	Raster data provided to DEWNR by the Adelaide University/CSIRO	°C classified using natural breaks (Jenks)
Wave exposure	Alongshore gradient	Shoreline spatial layer (DEWNR 2016c)	Ordinal: very low, low, moderate, high
Depth	Offshore gradient	Bathymetry contours spatial layer (DEWNR 2016d)	Metres (ranges 0–10, >10)
Profile	Discrete	Turner et al. (2007), Collings et al. (2008), Shepherd, unpublished data	Low (platform), high
Substrate type	Regional/discrete	Turner et al. (2007), Collings et al. (2008), Shepherd, unpublished data	Limestone, schist, granite, artificial

3.3.1 Temperature

Sea surface temperature, averaged over ten years (1992–2002) for each season, was available from the Adelaide University/CSIRO. Summer was deemed the most appropriate season for classifying the AMLR coastline because:

- Temperatures have the widest range
- Temperatures reach their annual peak
- The majority of reef monitoring occurs at the end of Summer/beginning of Autumn.

Four temperature ranges relevant to the AMLR region were determined using the ESRI ArcGIS natural break (Jenks) algorithm (Figure 3), namely (in °C):

- 18.5–19.4
- 19.4–20.5
- 20.5–22
- 22–26

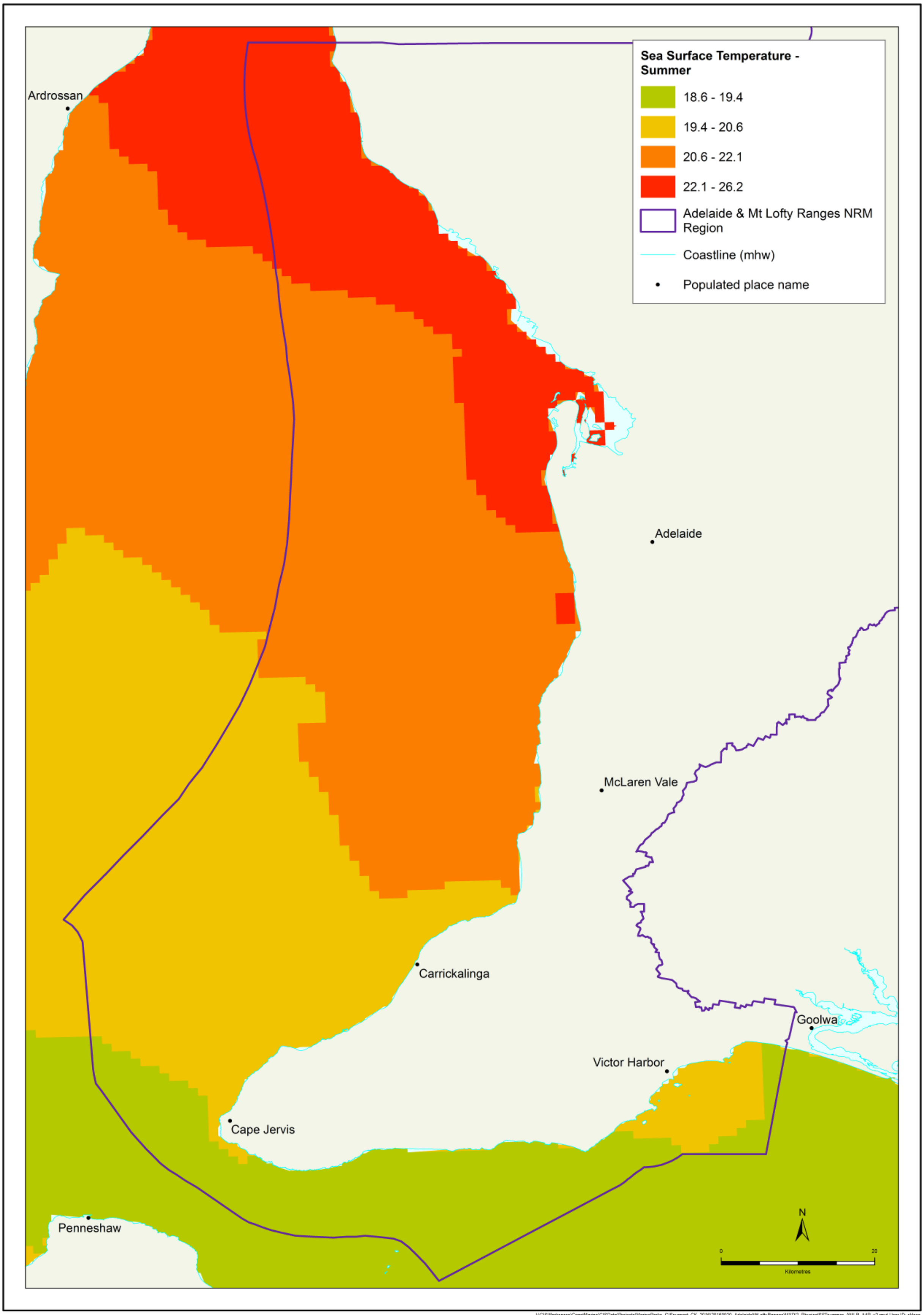

Figure 3. Summer sea surface temperatures averaged over ten years (1992–2002). Source: CSIRO and the Adelaide University unpublished data.

3.3.2 Wave exposure

Two metrics have been used by DEWNR (2016c) to classify wave exposure along the South Australian shoreline, namely wave energy and relative exposure (Figure 4). These datasets are restricted to mainland shoreline and cannot take into account local variations to wave exposure likely to occur at offshore sites and around islands, or in the lee of particular reefs, e.g. Port Noarlunga. Nevertheless, they are considered to be adequate to inform a broad classification of wave exposure in the AMLR region at the scale of tens of kilometres. The two measures have been combined into a single classification with levels ranging from very low to high, comprising:

- North of Adelaide – very low
- Adelaide to Cape Jervis – low
- Cape Jervis to Tunkalilla – moderate
- Tunkalilla to Rosetta Head (including the Pages) – high
- Rosetta Head to Middleton Point – moderate
- East of Middleton Point – high

The definition of this broad-scale classification of wave exposure does not preclude consideration of differences between reefs at a local scale, e.g. the reefs inside and outside of Noarlunga Reef (e.g. see Section 4).

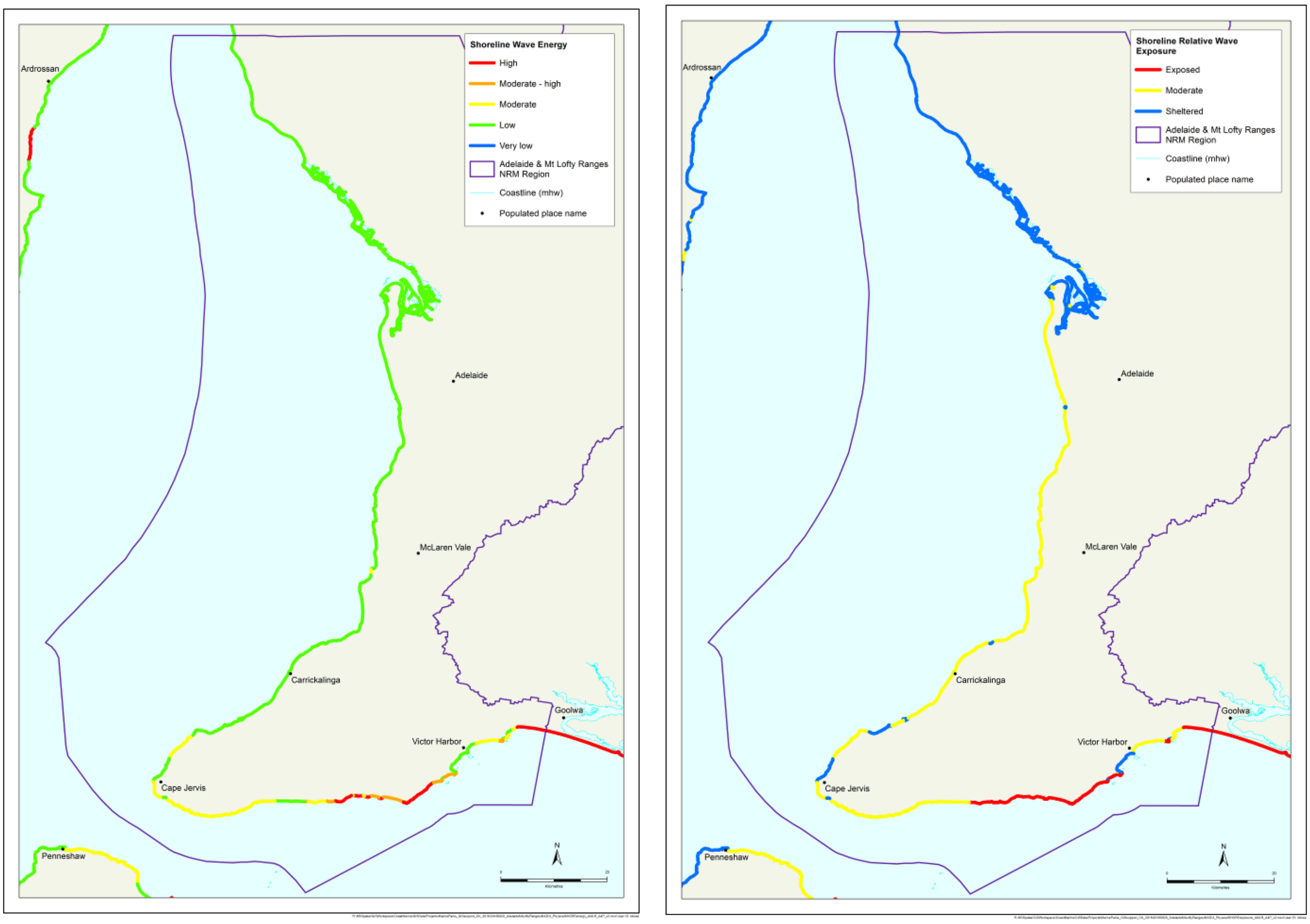

Figure 4. Two measures of wave exposure, wave energy (left) and relative exposure (right). Source: DEWNR (2016c).

3.3.3 Depth

The depth of reefs varies along the coastline of the AMLR (Figure 5):

- North of Adelaide, reefs in shallow water (<10 m)
- Along the metropolitan coastline, reefs are deep (>10 m), with the exception of the Glenelg Blocks, an artificial reef.
- From Marino to Second Valley, reefs are predominantly in shallow water (<10 m deep) with exceptions at Aldinga Reef, offshore from Horseshoe Reef, near the gap at Noarlunga Reef, in the south bay of Carrickalinga (J. Brook (J Diversity) 2016) and offshore from Wirrina.
- Reef extends to depths greater than 10 m near Rapid Head and to depths of at least 20 m between Cape Jervis and Middleton.

3.3.4 Profile and substrate composition

The reefs north of Adelaide (Semaphore, Port Parham) are platform reef (<0.5 m relief). The reefs offshore from Metropolitan Adelaide tend to have a relief of up to 1 m. Otherwise, areas of platform reef and reefs of higher relief are distributed haphazardly throughout most of the AMLR region, with both often being present at the same site.

Natural reefs north of Myponga are limestone (Figure 6). Between Myponga and Encounter Bay, the reefs are generally schist. Encounter Bay has a combination of granite reef, typically around the headlands and islands, and limestone reef (Figure 6).

There are a number of artificial reefs e.g. shipwrecks including Glenelg Dredge, Glenelg Barge, Lumb, MV Seawolf and the ex-HMAS Hobart wreck, tyre reefs including at Glenelg and jetties including Port Stanvac and Rapid Bay.

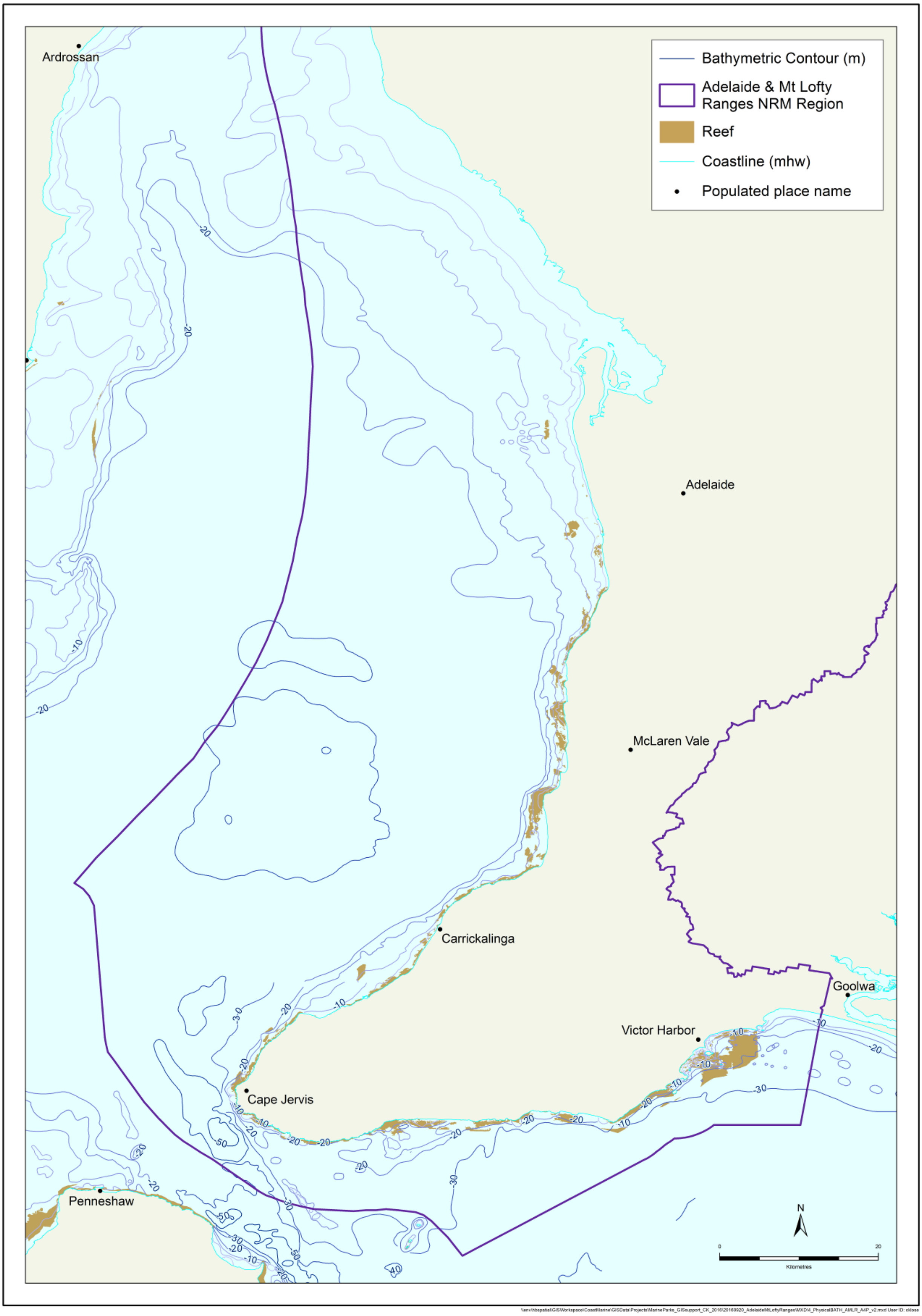

Figure 5. Bathymetry of the AMLR region in relation to mapped reef habitat. Source: DEWNR (2016d).

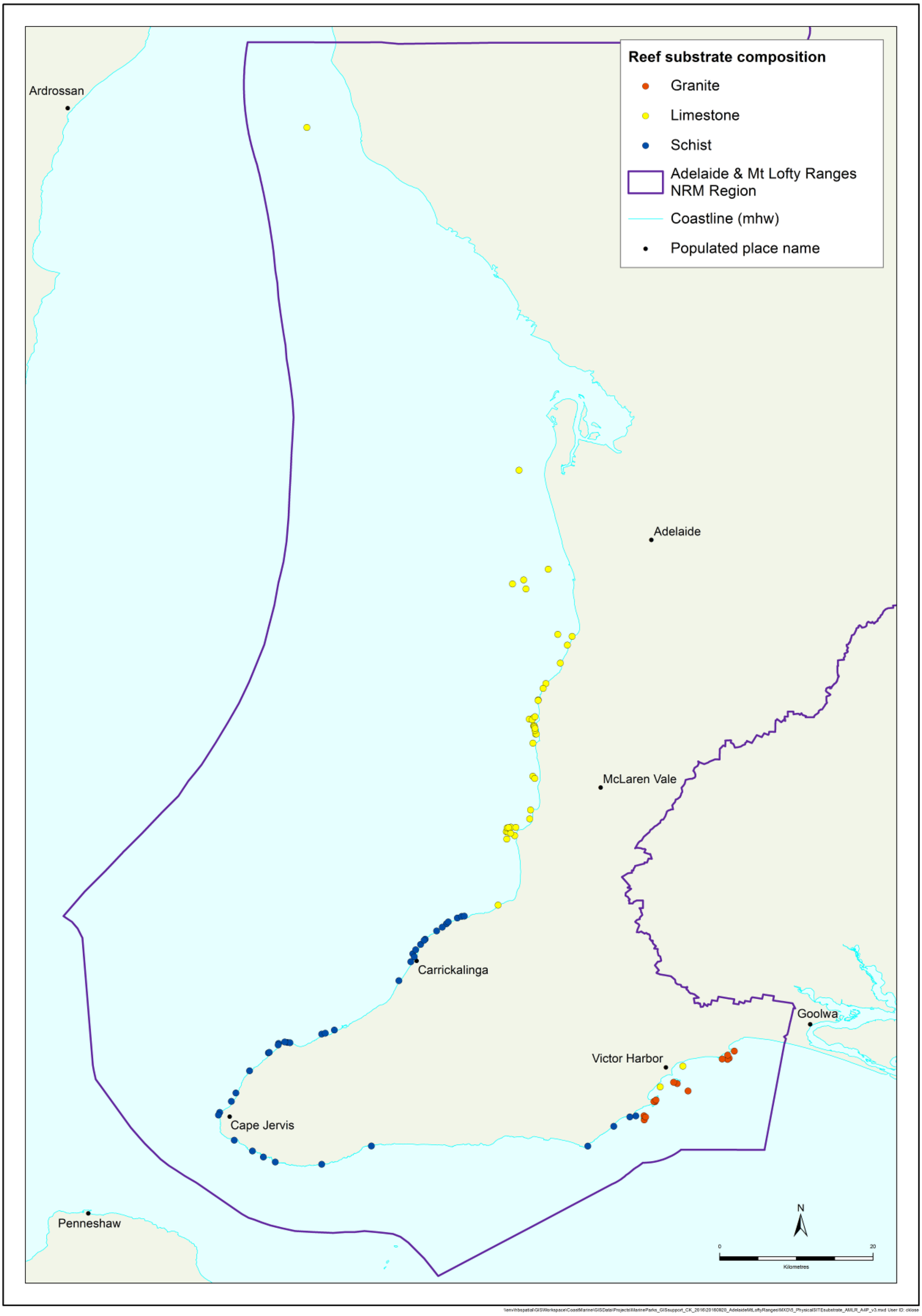

Figure 6. Reef substrate composition at established sites in the AMLR region. Source: Turner et al. (2007), Collings et al. (2008), Shepherd unpublished data.

3.4 Regional classification of AMLR region reefs based on physical factors

Based on the above summaries of physical factors, eight subregions of similar physical characteristics/drivers were identified (Table 3, Figure 8). It is recommended that these subregional groupings, taking into account the variation in substrate type and relief within some subregions, be used as a framework for representing the variety of reefs available in the AMLR region. Inclusion of some reef sites from each subregion will ensure that reefs representative of the AMLR region are part of any long term monitoring program.

Table 3. Subregional groupings of physical factors

Subregion	Location	Temperature (°C)	Wave exposure	Substrate	Depth	Relief
Northern	Northwards from Grange	22–26	Very low	Limestone	5-8 m	<0.5 m
Adelaide Metro	Grange to just north of Marino Rocks	20.5–22	Low	Limestone	10-20 m	0.5–1 m
Southern Metro	Marino Rocks to Myponga	20.5–22	Low	Limestone	<10 m >10 m	Variable
Yankalilla Bay	Myponga to Cape Jervis	19.4–22	Moderate	Schist	0-10 m	<0.5 m 2-3 m
Backstairs Passage	Cape Jervis to Tunkalilla	18.5–19.4	Moderate	Schist	<10 m >10 m	1-3 m
South Coast	Tunkalilla to Kings Beach	18.5–19.4	High	Schist	<10 m >10 m	1-3 m
Encounter Bay	The Bluff to Middleton Point	19.4–20.5	Moderate	Granite Limestone	<10 m >10 m	0-3 m
Goolwa	East of Middleton Point	18.5–19.4	High	Unknown	Unknown[1]	Unknown[1]

1. Low profile limestone reef has been mapped in depths of 20–30 m from about 5 km offshore from Middleton (Haig et al. 2005).

3.5 Hierarchical clustering of existing reef sites based on physical factors

The analysis was performed using the CLUSTER routine of PRIMER-E Ltd PRIMER 6 software (Clarke and Warwick 2001; Clarke and Gorley 2006). A dissimilarity matrix for the 112 sites was based on Euclidean distance between pairs of sites based on temperature (continuous), wave exposure (ordinal), depth (ordinal), profile (ordinal) and substrate composition (nominal – four categories including 'artificial').

The results show that the physical characteristics of the established sites aligned well with the subregions (Figure 7). All subregions clustered together although there was some overlap in the transition between Subregions 1, 2 and 3.

3.6 Analysis of invertebrate/cryptic fish communities

Macroinvertebrate (and cryptic fish) data from the Marine Protected Area, Reef Life Survey and Reef Health programs between 2005 and 2015 were combined and average abundances calculated for each of the 78 sites used by these programs. A dissimilarity matrix was calculated using the Bray-Curtis distance measure for two versions of the dataset; untransformed and square root transformed. Non-metric multidimensional scaling (nMDS) was applied to investigate whether similarities in these communities reflected the subregional groupings based on physical characteristics.

In general the groupings of sites by their macroinvertebrate/cryptic fish communities showed patterns generally consistent with the subregions based on physical characteristics (Figure 9). This was similar for both the untransformed and square-root transformed datasets. The stress level (0.14) for the 3D ordination indicated a reasonable fit with the data (Clarke 1993). An Analysis of Similarities (ANOSIM) showed that there were significant differences between the subregions (R=0.477, *P*=0.001). All pairwise tests were significant (*P* at various levels) except between the Backstairs subregion and South Coast subregions, Adelaide Metro and the Southern Metro subregions, and the Northern and Adelaide Metro subregions. The invertebrate community structure was highly correlated with rank order of sites along the coastline from west to east (R=0.351, *P*=0.001), providing further reassurance that a subregionalisation is an appropriate way to address the issue of representativeness.

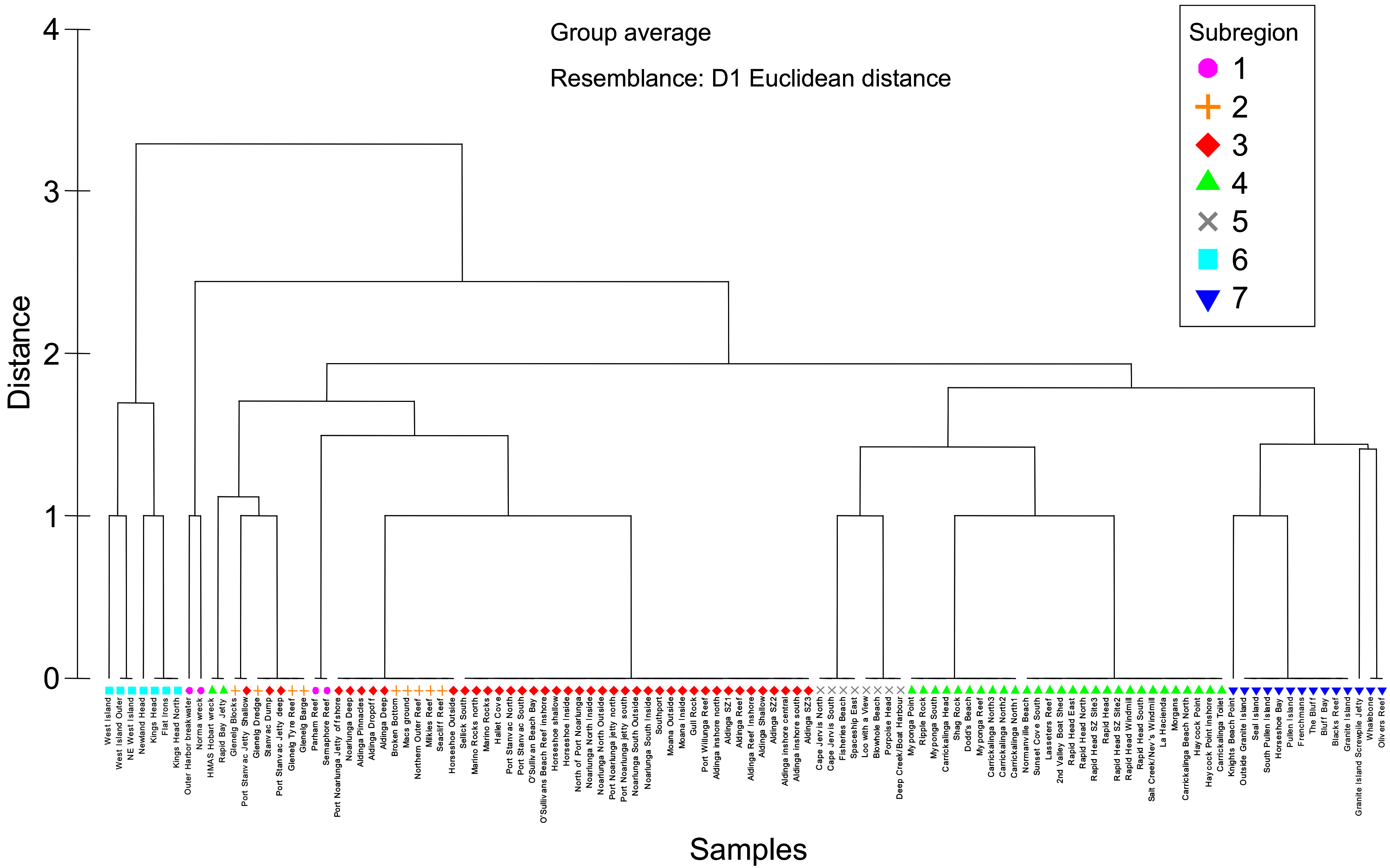

Figure 7. Dendrogram showing clustering of sites against subregions that are based on physical factors (see Figure 8).

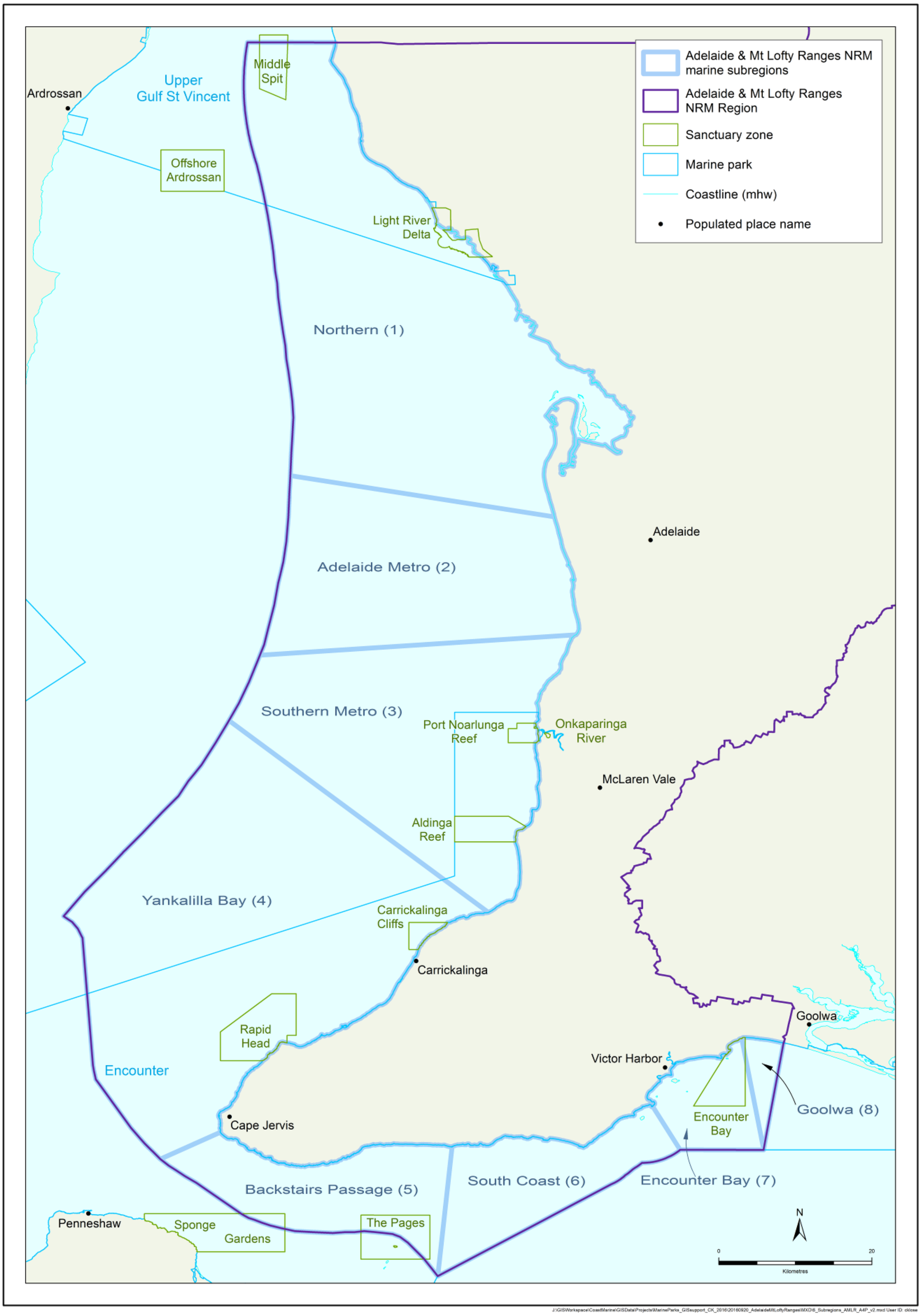

Figure 8. Subregion groupings based on physical factors

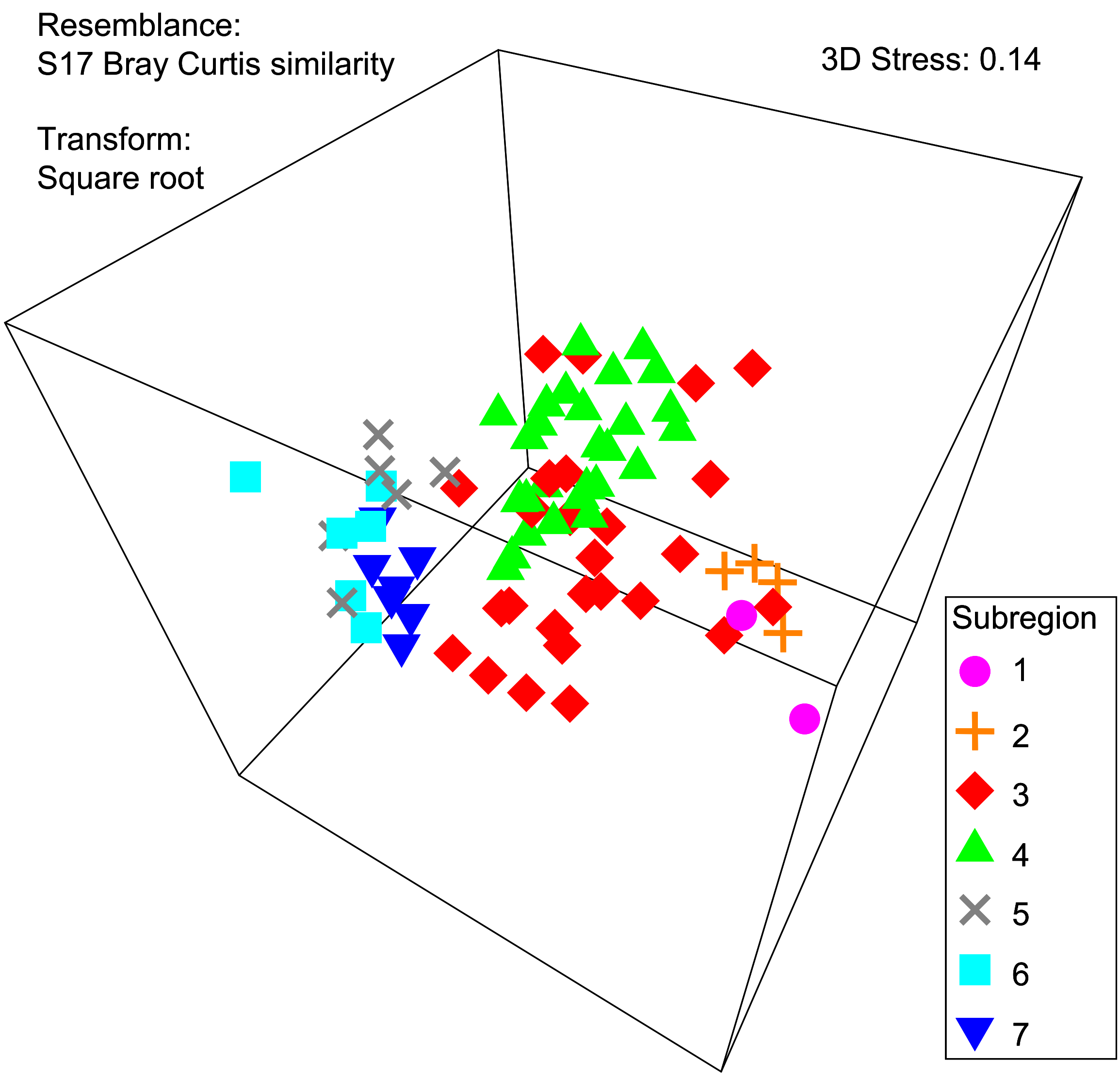

Figure 9. nMDS plot showing relative similarity of site-averaged mobile invertebrate/cryptic fish community structure against subregions that are based on physical factors (see Figure 8)

4 Selection of sites to assess land based impacts

4.1 Approach

In the AMLR region the major sources of land based inputs into the marine environment are from wastewater, stormwater and catchment sources (Wilkinson et al. 2005). The main impacts are associated with increased nutrient and sediment loads that reduce water quality and light levels, smother marine organisms and lead to replacement of habitat forming species with smaller faster growing species.

Bryars (2013a) examined the risks associated with the following key threatening processes to the nearshore marine habitats of the AMLR region:

- Stormwater (drains direct from urbanised areas)
- Wastewater (wastewater treatment plant outfalls and industrial discharges)
- Catchment water (poor water quality due to degraded catchments, coastal cliff erosion, indirect urban stormwater)
- Physical disturbance (dredging, anchoring, trampling, erosion, sedimentation)

Bryars (2013a) created a series of 'marine cells' each with an extent between 2 and 15 km of the AMLR region coastline, and summarised the threats relevant to each marine cell. The threat rating for each cell (low, medium or high) was assigned to each of the established reef monitoring sites located within that cell.

The approach taken to assess land based impacts was to select sites subject to low ('control') and high ('impact') putative levels of threat, as well as sites for which there is evidence that the reefs have already been impacted ('impacted'). The second step was to identify the major catchments and associated discharges to facilitate the selection of sites such that each major discharge has a 'far' and a 'near' site.

It is recognised that monitoring of impacts associated with river discharges will be confounded by other land-based threats, and in some cases the 'control' and/or 'impact' sites for general land-based threats may be the same as 'far' and 'near' sites for river discharges, respectively.

4.2 General land-based threats

Using Bryars (2013a), Table 4 identifies potential reef sites that are considered at 'high', 'medium' or 'low' threat due to land-based impacts for each subregion.

Table 4. Matrix of sites by subregion and threat level as determined by Bryars (2013a)

Sub-region	High threat	Medium threat	Low threat	None
1	Norma wreck, Outer Harbor breakwater south inside, Semaphore Reef		Parham Reef	
2	Broken Bottom, Glenelg Barge, Glenelg Blocks, Glenelg Dredge, Glenelg Tyre Reef, Macs ground, Milkies Reef, Northern Outer Reef	Seacliff Reef		

Sub-region	High threat	Medium threat	Low threat	None
3	Horseshoe Inside*, Horseshoe Outside, Horseshoe shallow, Noarlunga Deep, Noarlunga North Inside*, Noarlunga North Outside*, Noarlunga South Inside*, Noarlunga South Outside*, North of Port Noarlunga, O'Sullivan Beach Bay, O'Sullivan Beach Reef inshore, Port Noarlunga jetty north, Port Noarlunga Jetty offshore, Port Noarlunga jetty south, Port Stanvac Jetty deep, Port Stanvac Jetty Shallow, Port Stanvac North, Port Stanvac South, Stanvac Dump	Aldinga Deep, Aldinga Dropoff, Aldinga inshore central, Aldinga inshore north, Aldinga inshore south, Aldinga Pinnacles, Aldinga Reef, Aldinga Reef Inshore, Aldinga Shallow, Aldinga SZ1, Aldinga SZ2, Aldinga SZ3, Hallet Cove, Marino Rocks, Marino Rocks north	Gull Rock, Moana Inside, Moana Outside, Port Willunga Reef, Sellicks South	
4	Ex-HMAS Hobart wreck, Rapid Bay Jetty, Rapid Head East, Rapid Head North, Rapid Head SZ Site3	Carrickalinga Beach North, Carrickalinga South Bay, Haycock Point, Haycock Point inshore, La Hacienda, Lassiters Reef, Morgans, Normanville Beach, Rapid Head, Rapid Head South, Rapid Head SZ Site2, Rapid Head Windmill, Salt Creek, Second Valley Boat Shed, Sunset Cove South	Carrickalinga Head, Carrickalinga North1, Carrickalinga North2, Carrickalinga North3, Dodd's Beach*, Myponga Point*, Myponga Reef, Myponga South*, Ripple Rock, Shag Rock*	
5		Cape Jervis North, Cape Jervis South	Blowhole Beach, Deep Creek/Boat Harbour, Fisheries Beach, Loo with a View, Porpoise Head, Spaceship East	
6			Flat Irons, Kings Head, Kings Head North, NE West Island, Newland Head, West Island, West Island Outer	
7	Granite Island, Granite Island Screwpile Jetty, Olivers Reef, Outside Granite Island, Seal Island	Blacks Reef, Whalebone	Bluff Bay, Horseshoe Bay, Knights Beach Point, Pullen Island, South Pullen Island, The Bluff	Frenchmans

* indicates reefs with evidence of decline in canopy cover

The matrix in Table 4 can be used to identify reefs subject to relatively high and low levels of threat (impact and control sites) within each subregion.

A number of sites have been identified as being of poor health, based on a composite index comprising indicators relating to macroalgae, fish and invertebrates (Collings et al. 2008). Caution has been expressed about the interpretation of reef health based on this composite index (Turner et al. 2007, Collings et al. 2008, Brook and Bryars 2014, Westphalen 2015), but these and other authors (Gaylard et al. 2013, Connell et al. 2008) recognise that a decline in the percentage cover of canopy-forming macroalgae is a valid indicator of declining reef health.

The sites within high threat areas for which there is evidence of a decline in canopy cover include Horseshoe Inside, Noarlunga North Inside, Noarlunga North Outside, Noarlunga South Inside and Noarlunga South Outside (Connell et al. 2008, Collings et al. 2008, AMLR unpublished data), There is however some evidence of recent recovery from Horseshoe Inside (SA Water unpublished data).

There are also a number of reefs in the ‘Low threat’ areas of Yankalilla Bay that are also showing signs of declining canopy cover and may not be suitable as ‘control’ sites. These include Myponga Point, Myponga South, Shag Rock and Dodd’s Beach. These reefs may be impacted by stormwater runoff from nearby cliffs.

4.3 Catchment inputs

There are six river basins overlapping the AMLR region, namely (DEWNR 2016e, Figure 10):

- Gawler River (Northern subregion)
- Torrens River (Adelaide Metro subregion)
- Onkaparinga River (Southern Metro subregion)
- Myponga River (Yankalilla Bay subregion, adjacent to Southern Metro subregion)
- Fleurieu Peninsula (Yankalilla Bay, Backstairs Passage, South Coast and Encounter subregions)
- Lower Murray River (Goolwa subregion)

Collectively these river basins have 76 distinct catchments that abut the coastline of the AMLR region (DEWNR 2016e, Figure 10)

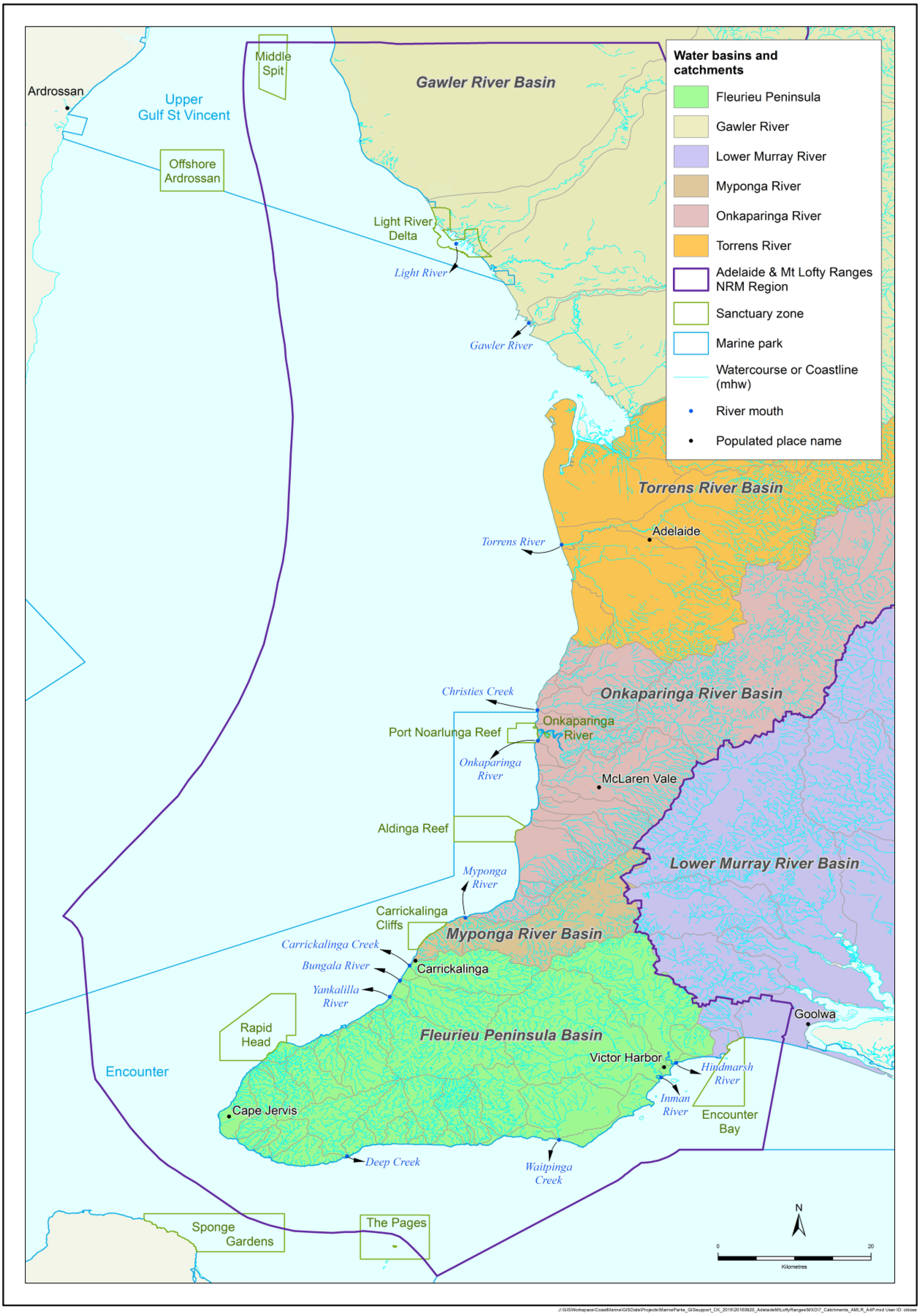

Figure 10. River basins, catchments and watercourses in the AMLR region. The discharge points (river mouths) are shown for watercourses discussed in this report. Source: DEWNR (2016e, f).

The main discharge points for the Gawler, Torrens, Onkaparinga and Myponga River Basins are their namesake rivers. These rivers all have reef sites at a range of distances from their mouths. The Onkaparinga River is estimated to discharge 758 tonnes of suspended matter per year into the marine environment, and reefs between Port Noarlunga and Southport experienced sedimentation rates that were up to 67 times values measured elsewhere along the metropolitan coastline following a significant rainfall event (Fernandes et al. 2008).

For the Fleurieu Peninsula River Basin, 21 estuaries have been identified (DEH 2007). The Hindmarsh and Inman Rivers are considered to be of most significance in terms of potential impacts from river discharge (Bryars 2013a, SKM 2010a, b), and impacts on inshore reef near the Carrickalinga Creek and Yankalilla and Bungala Rivers are evident (Bryars 2013a). Inclusion of Deep Creek and Waitpinga Creek ensures that all four subregions that overlap the Fleurieu Peninsula River Basin are represented, the seven estuaries selected for this Basin have the largest catchment sizes in the AMLR region (DEH 2007), and some likely unimpacted catchments are included as well as those likely to be impacted.

The River Murray is outside the AMLR region but is the most significant discharge likely to impact the Goolwa and Encounter regions. It should be noted that outputs from this river will potentially confound monitoring of the impact of discharge of the Hindmarsh and Inman Rivers.

The distance of each reef to the nearest of the above discharge points (river/creek mouths) was collated for all relevant sites in the AMLR region. It is acknowledged that distance is a simple measure of the level of impact which does not take into account coastal hydrodynamics, including the fact that some discharges are likely to impact several reef sites. Reefs of a similar nature to these 'near' sites were sought along a gradient from the discharge points.

4.4 Discussion of individual catchments

4.4.1 Gawler River

The nearest established reef sites to the mouth of the Gawler River are the Outer Harbour breakwater and the Norma wreck, which are 13 and 17 km from the Gawler River, respectively. These artificial reefs are much closer to the mouth of the Port River than the Gawler River. There is known to be hard substrate at a fishing ground 'Goannas' about 8 km away (James 2013) and there may be sufficient reef to establish a new site, but this would require exploration. Parham Reef is 35 km to the north of the mouth of the Gawler River.

The Light River is not a recognised estuary within the AMLR region (DEH 2007).

4.4.2 Torrens River

The nearest reef site to the mouth of the Torrens River is Broken Bottom, at 3.6 km. Offshore there are reefs of a similar composition relief but in deeper water, namely Macs Ground (6.2 km), Milkies Reef (7 km) and Northern Outer Reef (7.5 km). Along the coast, the nearest reef with similar composition and relief is Seacliff Reef (12 km).

There are a range of artificial reefs in the region that are at a variety of distances from the mouth of the Torrens, including the Glenelg Blocks, Glenelg Barge, Glenelg Dredge and Glenelg Tyre Reef but the topographies of these reefs are considered to be too variable and likely to confound gradient-based monitoring.

4.4.3 Christies Creek

The nearest reef site to the mouth of Christies Creek (and also to the Christies Beach WWTP) is Horseshoe Reef (about 1 km). This reef has a shallow inshore area (about 2 m depth), with deeper reef on the exposed side of the reef (4 m depth but up to 11 m further offshore). Further south (1.4 km from the mouth) there is reef ('North of Port Noarlunga') in about 4 m depth. There are a number of exposed and sheltered sites along Port Noarlunga Reef (2 to 3 km from the mouth) that are similar in depth, exposure composition and relief to the sites on either side of Horseshoe Reef. However, these sites are also within 1 to 2 km of the mouth of the Onkaparinga River (Section 4.4.5).

There is shallow reef (about 2 m depth) near O'Sullivan Beach to the north of Christies Creek (1.3 km). SA Water monitors reef further north at Port Stanvac and Hallett Cove as part of its monitoring program for the Christies Beach WWTP.

4.4.4 Onkaparinga River

The nearest reef to the mouth of the Onkaparinga is Southport (0.7 km). Care is required when interpreting data from this reef, which consists of a series of flat platforms with small patches of sand and occasional rocky outcrops (Collings et al. 2008). It had a relatively high cover of canopy macroalgae in 2005 and 2007 (Collings et al. 2008) compared with 2015/16, when only very sparse canopy forming algae on the platform areas of the reef (AMLR unpublished data). The difference in canopy cover may represent change over time, but may also be the result of small-scale spatial variation that can occur over reefs with heterogeneous structure. This reef is recommended as the near site because of its proximity to the mouth of the Onkaparinga, but care is required during future monitoring to ensure that transects locations with respect to reef structure are consistent between surveys.

The nearest similar reef site to the south of the Onkaparinga is at Moana Inside (5 km), but this reef is also variable with sections of low platform reef adjacent to sections of 1 to 2 m relief and so the same caveats apply as for Southport.

The sites around Port Noarlunga Reef provide a gradient of sheltered and exposed sites at distances ranging from about 1 to 2 km from the mouth of the Onkaparinga, although those to the north are also close to Christies Creek. The reef at Moana outside (4.7 km) provides an additional distant site that is of similar exposure, composition, depth and relief to the exposed Port Noarlunga sites.

4.4.5 Myponga River

There are seven sites of similar depth, exposure, composition and relief at distances ranging from 0.3 to 3.6 km south from the mouth of Myponga River. These sites are Myponga Reef, Carrickalinga North 1, 2 and 3, Myponga Point, Ripple Rock and Myponga South. No quantitative surveys have been undertaken at the Myponga Reef site but it was surveyed by SACReD (Baker et al. 2015).

Sellicks Reef is the closest reef to the north (3.7 km).

4.4.6 Carrickalinga Creek

There is about 0.25 km^2 of reef mapped immediately adjacent to the mouth of Carrickalinga Creek but no sites have been established on this reef. The nearest established reef site is at Carrickalinga South Bay (0.5 km). Even if a new impact site is established at the mouth, the Carrickalinga South Bay site cannot be a control site as the influence of the creek can extend several hundred metres along the coast (Bryars 2013a). There is reef extending from 1.5 to 2 km to the north (including Haycock Point and Carrickalinga Beach North sites), further offshore but in a similar depth to the Carrickalinga South Bay reef. There is similar reef further north at Dodd's Beach (3 km). To the south large areas of reef have been mapped but this reef is known to be patchy (Bryars 2014) and no sites have been established between Normanville and Carrickalinga.

4.4.7 Bungala River

Reef has been surveyed at the Normanville Beach site immediately adjacent to the mouth of the Bungala River (Brook and Bryars 2014). This reef is low profile platform reef considered to be the result of the erosion of overlying seagrass and sediment followed by colonization of macroalgae (Bryars 2014). Mapping by DEWNR suggests that there is extensive reef extending a few hundred metres offshore between the mouths of the Bungala and Yankalilla Rivers. However, mapping by Bryars (2014) showed that this area is dominated by seagrass with only isolated occurrences of macroalgae. No other sites have been established in the area, with the nearest site to the south being Sunset Cove (10 km), south of Yankalilla River and the nearest site to the north being Carrickalinga South Bay (2.7 km), north of

Carrickalinga Creek. A control site for the Bungala River would need to be established amongst patchy reef to the north of Normanville.

4.4.8 Yankalilla River

Reef has been mapped for several kilometres to the north and south of the mouth of the Yankalilla River but to date no sites have been established. Mapping by Bryars (2014) showed that this area is dominated by seagrass with only isolated occurrences of macroalgae, but some of these patches were near the mouth of the Yankalilla River so it may be possible to establish a new survey site there, and a control site near Lady Bay.

4.4.9 Deep Creek

Continuous reef has been mapped along the coast to the east and west of the mouth of Deep Creek but the nearest established sites are at Boat Harbor Beach to the east (2.8 km) and Porpoise Head to the west (3 km). There are additional sites with a similar depth, composition and exposure further west, including Blowhole Beach (7.7 km), 'Loo with a View' (9 km) and Spaceship East (10.2 km). There are numerous small creeks feeding into the Backstairs Passage subregion but the site at Porpoise Head appears to be the most isolated from these (Figure 10).

4.4.10 Waitpinga Creek

Reef has been mapped at most places from 1.3 km to the west and 2 km to the east of the mouth of Waitpinga Creek but the nearest established site is at Newland Head (3 km). The Flat Irons site, a few kilometres further to the north-east, has similar exposure, depth, composition, relief to the Newland Head site.

4.4.11 Inman River

The nearest established reef sites to the mouth of the Inman River are Whalebone Reef and Granite Island, each about 1.3 km away. Whalebone reef is a limestone reef in about 5 m depth with a relief of 2–3 m. There are no established sites with similar composition and relief, but Whalebone Reef is extensive and it is likely that at least one additional site could be established closer to the mouth. The two reefs near Granite Island are of granite and with relief of 2–3 m. The second reef is about 1.7 km from the mouth of the Inman River. Similar reefs further away are Seal Island (3.2 km offshore) and Black's Reef and The Bluff (3.0 and 3.3 km to the south).

4.4.12 Hindmarsh River

The nearest site to the mouth of the Hindmarsh River is directly offshore (0.6 km) at the western end of Oliver's Reef, a low profile, limestone reef in approximately 5 m depth. There are no established sites at reefs with similar composition and relief, but Oliver's Reef extends for up to 2 km to the west. There is also reef mapped at a similar depth about 1 km south of the mouth of Oliver's Reef that may be suitable.

Table 5. Summary of proximity of sites for monitoring catchment-based impact on nearshore reefs

Discharge point	Near site (distance in km)	Far site (distance in km)
Gawler River	Potential new site near Goannas fishing ground (11)	Port Parham (35)
Torrens River	Broken Bottom (3.6)	Macs Ground (6.2), Milkies (7), Northern Outer Reef (7.5), Seacliff (12)
Christies Creek	Horseshoe Reef Shallow (0.9)	O'Sullivan Beach (1.3), Port Stanvac North (2.9), Noarlunga North Inside (2), Hallett Cove (6.6)
	Horseshoe Reef Inner (1.1)	North of Port Noarlunga (1.4), Noarlunga North Outside (2), Noarlunga South Outside (3)
Onkaparinga River	Southport (0.7),	Moana Inside (5),
	Noarlunga South Outside (1), Noarlunga South Inside (1)	Moana Outside (4.7), Noarlunga North Outside (2),
Myponga River	Myponga Reef (0.3)	Carrickalinga North 3 (0.6), Carrickalinga North 2 (1), Carrickalinga North 1 (2), Myponga Point (2.3), Ripple Rock (2.9), Myponga South (3.6) and Sellicks South (3.7)
Carrickalinga Creek	Carrickalinga South Bay (0.5) or new site in mapped reef area adjacent to mouth	Haycock Point (1.5), Carrickalinga Beach North (2) and Dodd's Beach (3)
Bungala River	Normanville (0.2)	New site in mapped reef area north of Normanville jetty
Yankalilla River	No suitable sites	No suitable sites
Deep Creek	Boat Harbor Beach (2.8), Porpoise Head (3) or new site in mapped reef area adjacent to mouth	Boat Harbor Beach (2.8), Porpoise Head (3), Blowhole Beach (7.7), 'Loo with a View' (9) and Spaceship East (10.2)
Waitpinga Creek	Newland Head (3)	Flat Irons (7)
Inman River	Granite Island (1.3), Granite Island Outside (1.7),	The Bluff (3.3)
	New site towards northern end of Whalebone Reef (0.5)	Whalebone Reef (1.2)
Hindmarsh River	Oliver's Reef (0.6)	Oliver's Reef eastern end (1–2) or new site in mapped reef area south of Oliver's Reef site (1)

Note: Distance (km) from discharge point in parentheses

5 Selection of sites for regionally significant resident species

5.1 Background

Fish are one of the more conspicuous animals in nearshore reef ecosystems because of their size, colours and habits. As in most taxonomic groups they have evolved a range of life histories for maintaining their existence in their preferred environments. Many reef fish species in the AMLR region have relatively small home ranges and are site attached (Shepherd and Baker 2008). This means they can be particularly susceptible to localized threats such as pollution or fishing.

Many of these fish, e.g. harlequin fish and blue devils, also have low growth rates and fecundity that mean these populations recover very slowly (Bryars 2010). They are often targeted by spearfishers, are caught incidentally by line fishers (Bryars 2010) and are susceptible to barotrauma when brought to the surface from depth (Saunders et al. 2010). There is little information about the distribution, abundance and life history of many of these species however, some such as blue groper, an important resident reef species, were heavily fished and are now protected in central and gulf waters (Baker 2007, Bryars 2010).

Several of the resident reef species are iconic because of their vivid colouring (harlequin fish, blue devils) or size and behaviour (blue groper) and are considered "flagship" species used in outreach programs to encourage appreciation and conservation of the marine environment.

5.2 Approach to selection of regionally significant resident species

One of the objectives of this report is to identify sites that can be used to monitor the persistence and condition of regionally significant resident species (hereafter RSRS). The first step is to identify a list of RSRS. The AMLR NRM Board has previously commissioned a report on marine and estuarine fishes of conservation concern in the region (Baker 2007). The Baker (2007) report provided two lists:

1. a full list of fish species of potential conservation concern in the AMLR region (248 species). This list includes species which rarely or never inhabit reefs.
2. marine and estuarine fishes of principal conservation concern, in the AMLR region, grouped mainly by habitat.

The Baker (2007) report was used as the basis for determining RSRS based on the following assumptions:

- reef fish are generally resident
- significance refers to conservation significance.

A list of species suitable for monitoring was generated by comparing the full list of fish species of conservation concern (Item 1 above) with the list of species recorded during standardised reef surveys, namely those from the Reef Life Survey, Marine Protected Area and Reef Health programs.

The outcome was a list of 78 species. The list was further refined to select the species for which there were sites where abundances were considered sufficient for monitoring. Specifically, species were selected if they were recorded with an average abundance of at least one per 10 m x 200 m belt survey for either the fish or cryptic fish survey, over a minimum of three surveys. It is acknowledged that this threshold is somewhat arbitrary, but is a practical way to prioritise the suite of species to be monitored. The outcome was a list of 20 species, including five leatherjackets and six wrasses (Table 6). The remaining species recorded during structured surveys but not considered to be recorded commonly enough to support monitoring are listed in Appendix B. It should be noted that some of these species are likely to have had much higher abundances prior to European settlement, and that exploitation has reduced their numbers to such an extent that they are rarely seen on reefs in the AMLR region (e.g. Harlequin fish). It is anticipated that for some of these species a representative suite of monitoring sites will detect any significant recovery in their populations despite them not being selected in the final list of RSRSs.

Table 6. Species recorded during standard reef surveys sufficiently commonly for monitoring

Taxonomic group	Species	Common name
Leatherjackets	*Acanthaluteres brownii*	Spinytailed leatherjacket
	Eubalichthys mosaicus	Mosaic leatherjacket
	Meuschenia freycineti	Sixspine leatherjacket
	Meuschenia galii	Bluelined leatherjacket
	Meuschenia hippocrepis	Horseshoe leatherjacket
Wrasses	*Achoerodus gouldii*	Western blue groper
	Austrolabrus maculatus	Blackspotted wrasse
	Dotalabrus aurantiacus	Castelnau's wrasse
	Notolabrus parilus	Brownspotted wrasse
	Notolabrus tetricus	Bluethroat wrasse
	Pictilabrus laticlavius	Senator wrasse
Other	*Aplodactylus arctidens*	Southern sea carp
	Dactylophora nigricans	Dusky morwong
	Girella tricuspidata	Luderick
	Hypoplectrodes nigrorubrum	Banded seaperch
	Paraplesiops meleagris	Western blue devil
	Pentaceropsis recurvirostris	Longsnout boarfish
	Trachinops noarlungae	Yellowhead hulafish
	Trinorfolkia cristata	Crested threefin
	Vincentia conspersa	Southern cardinalfish

The mean abundances of these 20 species were quantified for all sites where they met the above abundance criteria (Table 7). To choose a set of sites for monitoring of RSRS from the data in Table 7, the following criteria were applied (see Section 6.6):

- Any one of the sites that meet the abundance criteria, for the following species that are considered common and found in sufficiently high numbers across existing sites for monitoring:
  - *Notolabrus tetricus*
  - *Austrolabrus maculatus*
  - *Meuschenia hippocrepis*
  - *Trachinops noarlungae*
- At least one of the three sites of highest density must be selected for the remaining 16 RSRS listed in Table 6. The three sites of highest density, as determined from Table 7, are shown in Table 8.

5.3 Gap analysis of principal fish species of conservation concern

The second list provided by Baker (2007) was marine and estuarine fishes of principal conservation concern in the AMLR region, organised in groups including the following that are relevant to reefs:

1. small, benthic marine fishes in seagrass and reef habitats
2. uncommon reef species
3. commercially and/or recreationally significant reef fishes
4. commercially and/or recreationally significant mixed habitat fishes
5. sharks
6. other (rays, stingarees)

A gap analysis was undertaken to identify the extent to which these reef associated species of principal conservation concern can be monitored using the standard surveys (Table 9).

Table 7. Mean number of individuals of each species recorded at sites with a mean abundance of at least one individual over at least three surveys.

Site	*Acanthaluteres brownii*	*Achoerodus gouldii*	*Aplodactylus arctidens*	*Austrolabrus maculatus*	*Dactylophora nigricans*	*Dotalabrus aurantiacus*	*Eubalichthys mosaicus*	*Girella tricuspidata*	*Hypoplectrodes nigrorubrum*	*Meuschenia freycineti*	*Meuschenia galii*	*Meuschenia hippocrepis*	*Notolabrus parilus*	*Notolabrus tetricus*	*Paraplesiops meleagris*	*Pentaceropsis recurvirostris*	*Pictilabrus laticlavius*	*Trachinops noarlungae*	*Trinorfolkia cristata*	*Vincentia conspersa*
Semaphore Reef				1.7														10.0		
Broken Bottom				7.7						5.3				1.0				1637.3		
Seacliff Reef	1.0			36.7	2.0							1.0	4.3	4.7	5.0			3390.7		
Hallett Cove	32.0			3.4		1.2							3.7	1.8				187.7		
Horseshoe Inside				2.1								1.1	3.2	2.1				16.8		
Horseshoe Outside				13.7	2.1								2.3	1.3				48.0		
Noarlunga North Inside	4.6			3.1								3.4		1.2				917.2		
Southport				5.3								2.0	2.0	7.0				13.3		
Moana Inside	1.3				1.3						1.3	1.3						171.2		
Moana Outside	1.8			2.8						2.8		3.7	1.2	1.8				285.2		
Aldinga Reef Inshore																			3.3	
Carrickalinga North 3																			14.0	
Carrickalinga North 1																			6.7	
Myponga Point				14.8	1.0	3.8						5.3	4.0	36.5			4.8	154.5		
Ripple Rock	1.5			7.3	2.8	2.8				1.3		31.0	4.0	51.5			8.3	375.8	2.6	
Myponga South	4.6			29.6		1.2						6.6	6.2	42.0			5.0	883.2	1.6	
Carrickalinga Head	5.7			14.3	3.0	1.0			1.0		2.0	19.7	3.7	40.3			3.3	805.7		
Shag Rock	2.8			21.3	1.3							6.6	5.9	17.1		1.5	1.3	843.0	3.0	
Dodd's Beach				9.8		2.5						4.5	3.8	34.3			4.5	328.5		
Haycock Point	6.7			41.7		2.0						8.2	1.0	11.8			2.7	988.5		

Site	*Acanthaluteres brownii*	*Achoerodus gouldii*	*Aplodactylus arctidens*	*Austrolabrus maculatus*	*Dactylophora nigricans*	*Dotalabrus aurantiacus*	*Eubalichthys mosaicus*	*Girella tricuspidata*	*Hypoplectrodes nigrorubrum*	*Meuschenia freycineti*	*Meuschenia galii*	*Meuschenia hippocrepis*	*Notolabrus parilus*	*Notolabrus tetricus*	*Paraplesiops meleagris*	*Pentaceropsis recurvirostris*	*Pictilabrus laticlavius*	*Trachinops noarlungae*	*Trinorfolkia cristata*	*Vincentia conspersa*
Carrickalinga South Bay	3.3			2.9		2.6					1.3	14.5		3.9			2.0	1612.9		
Sunset Cove South	11.8			16.5	1.5						7.8	2.3		29.3			10.8	2415.0		
Lassiters Reef	14.3			5.8		1.5					4.0	9.8		6.5	1.8		6.5	5070.0		
Second Valley Boat Shed	10.2			1.6		1.6					1.0	11.2		11.9	1.1		1.5	3688.2		
Rapid Bay Jetty	4.9			36.0			8.3			4.9	1.2	2.8		13.5				959.1		
Rapid Head East				5.4	1.4	2.8							1.6	16.9	1.2		7.8	417.4	1.7	
Rapid Head North	28.7	1.0		5.0	1.0	2.0						5.7		39.0	1.0		19.7	1931.3		
Rapid Head SZ Site 3															1.7				1.7	
Rapid Head	2.8			2.1		1.7			1.2			19.4	1.5	65.2	4.3		10.6	906.9		
Rapid Head Windmill	23.5			2.0	1.5	1.5		2.5				7.8		68.5			13.8	344.0		
Rapid Head South				13.7		2.0						5.7	15.0	70.7	2.2		12.7	92.0	1.4	
Salt Creek	5.3			2.7	1.0	2.3						3.0	2.0	82.3			17.3	15.0		
Morgans				2.0	1.8	1.5						11.0	1.5	46.5			8.0			
Flat Irons		1.5							1.0			3.8		61.8			2.0			
The Bluff		1.0										4.4		5.6						1.1
Whalebone		1.5			3.8							12.8		66.5						
Seal Island												2.3		11.3						
Outside Granite Island			1.0									3.0		7.5						

Table 8**. Highest density sites for RSRS**

Site	1st	2nd	3rd
Acanthaluteres brownii	Hallett Cove	Rapid Head North	Rapid Head Windmill
Achoerodus gouldii	Flat Irons	Whalebone	The Bluff
Aplodactylus arctidens	Outside Granite Island		
Dactylophora nigricans	Whalebone	Carrickalinga Head	Ripple Rock
Dotalabrus aurantiacus	Myponga Point	Ripple Rock	Rapid Head East
Eubalichthys mosaicus	Rapid Bay Jetty		
Girella tricuspidata	Rapid Head Windmill		
Hypoplectrodes nigrorubrum	Rapid Head	Carrickalinga Head	Flat Irons
Meuschenia freycineti	Broken Bottom	Rapid Bay Jetty	Moana Outside
Meuschenia galii	Sunset Cove South	Lassiter's Reef	Carrickalinga Head
Notolabrus parilus	Rapid Head South	Myponga South	Shag Rock
Paraplesiops meleagris	Seacliff Reef	Rapid Head	Rapid Head South
Pentaceropsis recurvirostris	Shag Rock		
Pictilabrus laticlavius	Rapid Head North	Salt Creek/Nev's Windmill	Rapid Head Windmill
Trinorfolkia cristata	Carrickalinga North 3	Carrickalinga North 1	Aldinga Reef Inshore
Vincentia conspersa	The Bluff		

Table 9. Effectiveness of standard fish surveys for monitoring reef fish species of principal conservation concern in the AMLR region. Source: Baker (2007)

Common name	Scientific Name	Baker category	Suitability for monitoring using standard surveys
Western blue groper	*Achoerodus gouldii*	3	Sufficiently abundant at some sites
Bluethroated wrasse (and other large wrasses)	*Notolabrus tetricus*	3	Sufficiently abundant at most sites
Harlequin fish	*Othos dentex*	3	Not sufficiently abundant. Monitoring has occurred through a dedicated program (Bryars et al. 2011, 2013c)
Rock ling	*Genypterus tigerinus*	3	Not sufficiently abundant
Longsnout boarfish	*Pentaceropsis recurvirostris*	3	Sufficiently abundant at some sites
Brownspotted boarfish	*Paristiopterus gallipavo*	3	Not sufficiently abundant
Short boarfish	*Parazanclistius hutchinsi*	3	Not recorded during standard reef surveys
Banded sweep	*Scorpis georginana*	3	Not sufficiently abundant
Western blue devil	*Paraplesiops meleagris*	3	Sufficiently abundant at some sites. Monitoring has also occurred through a dedicated program (Bryars et al. 2011)
Banded seaperch	*Hypoplectrodes nigrorubrum*	3	Sufficiently abundant at some sites
Knifejaw	*Oplegnathus woodwardi*	3	Not recorded during standard reef surveys. Usually found in offshore waters of depths between 50 and 400 m.
Southern blue morwong		3	Not sufficiently abundant
Anglerfish		2	Rodless anglerfish and Tasselled anglerfish recorded on standard reef surveys but not sufficiently abundant

Common name	Scientific Name	Baker category	Suitability for monitoring using standard surveys
Clinids, especially Spotted snake blenny and Eel snake blenny	Family Clinidae	1	Spotted snake blenny and Eel snake blenny not recorded during standard reef surveys. Other clinids not sufficiently abundant
Clingfishes	Family Gobiesocidae	1	Some species uncommonly recorded on standard reef surveys but not sufficiently abundant.
Crested threefin	*Trinorfolkia cristata*	1	Sufficiently abundant at some sites
Scarlet cardinalfish	*Vincentia badia*	1	Not recorded during standard reef surveys
Southern cardinalfish	*Vincentia conspersa*	1	Sufficiently abundant at some sites
White nose pigfish	*Perryena leucometopon*	2	Not recorded during standard reef surveys
Handfish	Family Brachionichthyidae	2	Not recorded during standard reef surveys
Warty prowfish	*Aetapcus maculatus*	2	Not sufficiently abundant
Red velvetfish	*Gnathanacanthus goetzeei*	2	Not sufficiently abundant
Blindfish	Family Amblyopsidae	2	Not recorded during standard reef surveys
Silver trevally	*Pseudocaranx dentex*	4	Not sufficiently abundant
Dusky morwong	*Dactylophora nigrcans*	4	Sufficiently abundant at some sites
Leatherjackets	Family Monacanthidae	4	Sufficiently abundant at some sites (most sites for Horseshoe leatherjacket).
Gurnard perches and Scorpionfish	Family Neosebastidae	4	Some species uncommonly recorded on standard reef surveys but not sufficiently abundant.
Wobbegongs	Family Orectolobidae	5	Not sufficiently abundant
Coastal stingaree	*Urolophus orarius*	6	Not sufficiently abundant

6 Selection of nearshore reef monitoring sites for long term monitoring

6.1 Approach

Currently all sub tidal reef monitoring is reliant on some form of Underwater visual census (UVC) conducted by divers. This makes it a costly exercise given the need for vessels and trained divers. Therefore any process of site selection to identify suitable sites for on-going monitoring should look to minimise the number of sites needed to satisfy the objectives. The approach we have taken in this report is to:

1. Develop a set of decision criteria
2. Run an iterative process that minimises the number of sites required to satisfy the criteria.

For the purposes of this report the site selection process was considered sufficiently tractable to undertake manually however the process could equally be tackled analytically by a mathematical optimisation process using a "greedy algorithm" approach or similar (Cormen et al. 2009).

6.2 Selection criteria

The aim of the site selection process is to identify a suite of sites that:

- are representative of the AMLR Region
- can assess land based impacts
- are suitable for monitoring regionally significant resident species (RSRS).

To achieve this we have defined a number of selection criteria to guide the process:

1. There must be at least two sites for each subregion defined by physical factors (representative)
2. Where present, all combinations of depth, profile and substrate composition should be included (representative)
3. Where possible there must be a control and impact site with similar characteristcs in each subregion in relation to major land based threats as identified by Bryars (2013a) (land based impacts)
4. Where possible there must be one near and one far site for each major river discharge (land based impacts)
5. There must be at least one site with an adequate abundance (as defined by criteria in Section 5.2) for monitoring each of the selected RSRS (monitoring RSRS).

In cases where there are more than one site that satisfies the criteria then preference will be given to sites that meet the following secondary criteria:

1. Have existing data
2. Are part of an ongoing monitoring program
3. Are shallow (<10 m) for practicality in relation to dive surveys, noting that there will still need to be some deep sites to achieve representativeness.
4. Help to meet other primary criteria in an iterative selection process (see Section 6.3)

6.3 Application of selection criteria

To apply the defined criteria and minimise the final list of sites, each criterion was applied stepwise with sites added as required. Where no existing sites met the criteria, a new site was recommended. The following outlines the iterative steps:

Step 1. Address Criteria 1 and 3. Select from each subregion one putatively impacted (hereafter 'impact') and one putatively unimpacted (hereafter 'control') site based on Section 4. For each pair of sites, prioritise sites that have similar physical characteristics (depth, relief, substrate, wave exposure) and are ideally homogenous in those characteristics, to reduce the possibility of small scale spatial variation. If there are several options then apply the secondary criteria listed in Section 6.2.

Step 2. Address Criterion 4, "Where possible there must be one near and one far site for each major discharge (land based impacts)", and add sites as necessary.

Step 3. Address Criterion 5, "There must be at least one site with an adequate abundance for monitoring for each of the selected significant resident species", and add sites as necessary.

Step 4. Address criteria 1 and 2, "Where present all combinations of depth, profile and substrate should be represented (representative)", and add sites as required.

6.4 Step 1: Select one control and impact site for each land based threat

The first iterative step of selecting control and impact sites for land based threats identified 14 suitable reef sites (Table 10), drawn from the matrix of sites by subregion and threat level provided by Table 4 except for one new site. The following subsections state which reefs were selected as control and impact sites, and any secondary criteria used to support that selection.

6.4.1 Northern subregion (1)

There are only two established natural reef sites in the Northern subregion, one control (Parham Reef) and one impact (Semaphore). Both reefs are low profile limestone reef in depths less than 10 m. There has been some historical monitoring through the Reef Health program – 7 surveys between 1996 and 2016 at Semaphore, and 3 surveys between 2007 and 2016 at Parham Reef.

6.4.2 Adelaide Metro subregion (2)

Natural reefs in the Adelaide Metro subregion are all limestone with a relief of about 1 m and are at least 10 m deep. All reefs are in an area subject to a high level of threat with the exception of Seacliff Reef which is subject to a medium level of threat and is therefore chosen as the control site. Broken Bottom is a natural reef with the most similar depth to Seacliff and there have been 20 historical surveys including 16 by Reef Watch. Broken Bottom is therefore chosen as the impact site for the Adelaide Metro subregion. Broken Bottom is also the closest site to the mouth of the Torrens River ('near' site) and is suitable for monitoring four of the priority fish of conservation concern.

6.4.3 Southern Metro subregion (3)

Of the five sites subject to a low level of threat, Moana Outside has the longest monitoring history (9 surveys up to 2016), and is part of an ongoing monitoring program (Adelaide Desalination Plant). Furthermore, it is suitable for monitoring seven of the priority fish of conservation concern. Moana Outside is therefore selected as the control site.

There are a number of impact sites with similar physical characteristics to Moana Outside (exposed to swell, high relief, 5 m depth). The Horseshoe Reef Inside site (actually on the exposed side of the reef) has been surveyed 12 times since 2009 and is part of the ongoing monitoring for the Adelaide Desalination Plant. It is the closest site to the mouth of Christies Creek and is suitable for monitoring five of the priority fish of conservation concern. Noarlunga North Outside has more homogenous relief than the Horseshoe Inner reef. It has been surveyed 25 times since 1998 (including 14 surveys by Reef Watch). It is part of the ongoing Adelaide Desalination Plant and Reef Watch monitoring programs. Noarlunga North Outside is within a Sanctuary Zone but is not a designated Marine Park monitoring site (D. Miller (DEWNR) 2016).

6.4.4 Yankalilla Bay subregion (4)

There are 10 established sites in an area subject to a low level of threat between Myponga and Carrickalinga, although Myponga South, Myponga Point, Shag Rock and Dodd's Beach are showing evidence of declining health (Section 4.2). Ripple Rock has been selected as the control site. It is a designated Marine Park monitoring site and has been monitored 4 times between 2005 and 2016. It can be used as a 'far' site for monitoring the impact of the Myponga River discharge, and it is suitable for monitoring 11 of the priority fish of conservation concern.

There are three natural reefs considered to be subject to a high level of threat in the Yankalilla Bay subregion. Of these, Rapid Head East site has been selected as the impact site. It has been surveyed most often (5 times between 2005 and 2016), and is a designated Marine Park monitoring site. It is suitable for monitoring five of the priority fish of conservation concern.

6.4.5 Backstairs Passage subregion (5)

Fisheries Beach has been selected as a control site from the list of sites subject to a low level of threat (Table 4) as it has been surveyed the most often (twice in 2007). None of the potential control sites are suitable for monitoring the priority fish of conservation concern.

There are no established sites that are subject to a high level of threat, but there are two sites near Cape Jervis where fish surveys have been previously undertaken (Shepherd and Baker 2008) that are subject to a moderate level of threat. Cape Jervis South has been selected as the impact site.

6.4.6 South Coast subregion (6)

All sites in this subregion are subject to a low level of threat, and therefore a single site has been selected to represent this subregion for this step. The Flat Irons site has been surveyed the most often (four times between 2005 and 2012) and is suitable for monitoring five priority fish of conservation concern in the subregion. It serves as a 'far' site from the mouth of Waitpinga Creek.

6.4.7 Encounter Bay subregion (7)

Sites in this subregion that are subject to a low level of threat include The Bluff and a range of sites near Pullen Island. The Bluff has been selected as the control site. It has been surveyed most often (8 times by scientific divers and 18 times by Reef Watch between 2005 and 2016), and is suitable for monitoring five of the priority fish of conservation concern.

Of the reefs subject to a high level of threat that have physical characteristics (depth, relief, composition) most similar to The Bluff, the Outside Granite site has been selected as the impact site. It has been surveyed most often (4 times between 2005 and 2008) and is suitable for monitoring 3 priority fish of conservation concern.

6.4.8 Goolwa subregion (8)

This subregion is subject to a low level of threat throughout, therefore a single new site is required to represent it for this step. A site has been selected within the existing mapped offshore reef area.

6.5 Step 2: Selection of control and impact sites for each major catchment discharge

An additional 15 sites were added to the list of sites generated in Step 1 to satisfy Criteria 3 – " Where possible there must be one near and one far site for each major discharge (land based impacts)" resulting in a total of 30 sites after Step 2 (Table 10). The majority of these sites were added in the Yankalilla Bay subregion where there are six river/creek discharges. The 15 additional sites include six new sites that will need to be established.

6.5.1 Gawler River Basin

There are no reefs near the mouth of the Gawler River, and the nearest potential reef is 8 km away, therefore no near or far site has been selected for this river basin.

6.5.2 Torrens River Basin

Broken Bottom and Seacliff Reef, selected as representative sites for the Adelaide Metro subregion, also provide a near and far site for discharge from the River Torrens, respectively.

6.5.3 Onkaparinga River Basin

The Horseshoe Reef Inner site chosen as an impact site for the Southern Metro subregion is the second closest to the mouth of Christies Creek (the Horseshoe Reef Shallow site is 0.2 km closer) and has been selected as the near site. Noarlunga North Outside and Noarlunga South Outside sites have both been selected as far sites to allow a gradient effect from the mouths of both the Christies Creek and Onkaparinga River to be monitored. There have been 25 surveys (including 14 by Reef Watch) at Noarlunga North Outside and 13 surveys (including 11 by Reef Watch) at Noarlunga South Outside.

The closest reef to the mouth of the Onkaparinga is Southport which has been selected as the near site for that river. Care is required when selecting a suitable reef section due to the heterogeneity of reef profile (see Section 4.4.4).

6.5.4 Myponga River Basin

The Myponga Reef site is nearest the river mouth and has been selected as the near site. The Myponga South site chosen to represent the Yankalilla Bay subregion was selected as a far site for discharge from the Myponga River.

6.5.5 Fleurieu Peninsula Basin

The nearest established reef to the mouth of the Carrickalinga Creek is the Carrickalinga South Bay reef (about 0.7 km away). It has been surveyed 11 times between 2005 and 2016 and is suitable for monitoring 8 priority fish of conservation concern, and has been selected as the near site rather than establishing a new site nearer to the mouth. Dodd's Beach is recommended as a far site. It has been surveyed 4 times between 2005 and 2012 and is suitable for monitoring 7 priority fish of conservation concern.

The Normanville Beach site has been selected as the near site for the Bungala River. A far site for the Bungala River would need to be established amongst patchy reef to the north of Normanville.

For the Yankalilla River, it may be possible to establish a new survey site over limited reef area immediately adjacent to the mouth. A new far site can be established at the extensive reef near Lady Bay (Figure 2).

For Deep Creek, a new site is required near the mouth of Deep Creek as a near site, with Porpoise Head as a far site.

The nearest established reef site to the mouth of Waitpinga Creek is Newland Head which has been selected as the near site rather than establishing a new site at the reef about 2 kilometres to the west of the mouth. The Flat Irons, already selected as a representative site for the South Coast subregion, is selected as the far site.

Outside Granite Island and The Bluff have already been selected to represent the Encounter region and are suitable near and far sites, respectively, for monitoring the impact of the Inman River discharge.

Oliver's Reef is the closest reef to the mouth of the Hindmarsh River and has been selected as the near site. Given that Oliver's Reef (limestone platform) is quite different from the high relief granite sites selected to represent the Encounter region, a new site on reef mapped to the south or a site further to the east along Oliver's Reef will be required.

6.6 Step 3: Selection of sites to monitor regionally significant resident species

The list of sites established for steps 1 and 2 satisfied the selection criteria for 11 of the RSRS, including the four species which are considered common and found in sufficiently high numbers across existing sites for monitoring.

The selection criteria were not met for the following species:

- *Acanthaluteres brownii*
- *Dactylophora nigricans*
- *Eubalichthys mosaicus*
- *Girella tricuspidata*
- *Meuschenia galii*
- *Notolabrus parilus*
- *Pentaceropsis recurvirostris*
- *Pictilabrus laticlavius*
- *Trinorfolkia cristata*

To satisfy the criteria for selection of sites suitable for monitoring significant priority species of conservation concern an additional five sites were selected (Table 10):

- Carrickalinga Head
- Carrickalinga North 3
- Rapid Bay Jetty
- Rapid Head Windmill

- Shag Rock

The application of Step 3 increased the overall number of recommended sites to 35.

6.7 Step 4: Selection of sites such that they are representative of the AMLR Region

Representation of the range of reef types in the AMLR region was largely addressed at Step 1 by selecting two sites from each subregion defined by physical characteristics (Criterion 1). However, in some cases representation of the variety of depth, profile and substrate composition within each subregion was not achieved (Criterion 2), and is addressed in Step 4 (this section). Artificial reefs were not considered for this step.

To achieve a suit of representative sites based on the specified physical factor criteria an additional six sites need to be included, consisting of three existing sites and three new ones (Table 10).

6.7.1 Northern and Adelaide Metro

No further additions necessary.

6.7.2 Southern Metro

The sites selected during earlier steps are shallow. Deeper established sites include Horseshoe Outer, Noarlunga Deep and Aldinga Deep. Horseshoe Outer has been surveyed 11 times between 2009 and 2016 and is part of the ongoing Adelaide Desalination Plant monitoring program. Noarlunga Deep was surveyed 3 times in 2005 (including two by Reef Watch) but is of limited extent (only 100 m surveyed in 2005). Aldinga Deep has been monitored 3 times between 2005 and 2016. Horseshoe Outer and Aldinga Deep are less desirable as monitoring sites because their heterogeneity of relief means that estimates of canopy cover can be confounded by small-scale spatial variation, as canopy forming algae at these sites tend to be restricted to rocky outcrops. This is demonstrated by the range of canopy cover estimates ranging between zero and 92 per cent during 14 transects over 7 survey events at Horseshoe Outer between 2010 and 2012 (Russell and Connell 2012a).

As an alternative, the Aldinga Pinnacles was selected as a deeper site. It was surveyed by SACReD (Baker et al. 2015) and Bryars et al. (2011), in the latter case in relation to surveys of harlequin fish and blue devils, where some have now been tracked using photo identifications.

6.7.3 Yankalilla Bay

Adequately represented

6.7.4 Backstairs Passage

There are no established sites on deeper reefs (>10 m), and therefore a new site is required. Gurgel (2013) sampled macroalgae from reef at 15 metres depth at an unspecified site offshore from Deep Creek Conservation Park. This could also act as a far site in an offshore gradient from Deep Creek.

6.7.5 South Coast

The sites selected to represent control and impact sites and fishes of conservation concern in the South Coast subregion are shallow. Two sites have been established in 10 m depth at West Island, of which West Island Outer has the longest monitoring history (two surveys between 2005 and 2008).

6.7.6 Encounter Bay

The sites selected to represent control and impact sites and fishes of conservation concern in the Encounter Bay subregion are shallow and are generally granite apart from low profile limestone at Oliver's Reef.

High profile limestone reef can be represented by the Whalebone Reef, which has been surveyed 4 times between 2007 and 2013. There is extensive reef in deeper water from which a new site could be established (DEWNR 2016a, b).

6.7.7 Goolwa

The new site selected in Step 1 lies within deep water (about 15 m), so ideally a shallow site would be added. However, the inshore area has been mapped as sand, with the exception of a small strip of reef near Middleton Point that is unlikely to be sufficient for monitoring..

It may be necessary to add sites in future to reflect a greater understanding of reefs in this subregion, e.g. if both limestone and granite reefs were to be identified.

6.8 Final list of sites recommended for long term monitoring of nearshore reefs in the AMLR region

The application of all criteria resulted in a total of 40 reef sites being recommended for long term monitoring in the AMLR Region, the final site list and how sites were included in the iterative process are shown in Table 10 and their distribution along the coastline in Figures 11–18. Of these 40 sites, 31 are existing reef monitoring sites and 9 are new sites. This suite of sites is considered to be the minimum number that satisfies the selection criteria to ensure the final list of sites are:

- are representative of reef systems in the AMLR Region
- can be used to assess the impact of land based inputs
- can be used to monitor the persistence and condition of regionally significant resident species.

The number of sites per subregion ranges from two in Northern and Metro Adelaide subregions to 14 in the Yankalilla subregion (Table 10, Figure 11).

When assessed against the selection criteria, the final list of sites achieves the following:

- There are at least two sites represented from each subregion, with the most being 14 in the Yankalilla Bay subregion (Table 11)
- All combinations of depth, profile and substrate composition identified in Table 3 are represented
- 18 control sites (8 required) and 12 impact sites (6 required)
- 12 near sites (12 required) and 23 far sites (12 required) (Table 12)
- at least 2 sites adequate for monitoring for each of 15 of the RSRS (1 required) (Table 13).

This final list of sites is not meant to be definitive, and resourcing and priorities may change over time that could influence which sites are considered for monitoring. Several of the criteria have arbitrary cut offs (e.g. RSRS inclusions) or are subjective assessments ('near' and 'far' from major discharges). The criteria have also been applied without weighting such that individual elements (e.g. catchment discharges, fish species) are weighted evenly when clearly some elements may be more significant than others; for example the sediment and nutrient loads delivered to the marine environment by the Onkaparinga River compared to the Myponga River.

The use of a clear set of decision criteria and a logical framework to apply them provides flexibility in the site selection process to accommodate changes in focus and resourcing. For example, focusing on only catchment discharges and RSRS will reduce that total number of sites required for ongoing monitoring. Conversely, expanding the list of RSRS and including sites to assess a gradient of impacts from major discharges will greatly increase the number of sites needed for monitoring above the list recommended here. In addition, greater priority could be given to monitoring catchment impacts. In this report all discharges have been considered equal whereas some catchments could be considered to have more impact than others (e.g. Onkaparinga River vs Bungala Creek) and require more monitoring sites rather than just a “near” and “far”.

Table 10. List of reef sites recommended for long term monitoring in the AMLR Region. Items in bold in columns for Steps 1 to 4 indicate sites that were added during that step.

Sub-region	Site	Step 1: Threats	Step 2: Discharge	Step 3: RSRS	Step 4. Representative
1	Parham Reef	**control**			
1	(new site)		**Gawler River (near)**		
1	Semaphore	**impact**			
2	Broken Bottom	**impact**	Torrens (near)	*Meuschenia freycineti*	
2	Seacliff Reef	**control**	Torrens (far)	*Paraplesiops meleagris*	
3	Horseshoe Reef Inside	**impact**	Christies Creek (near)		
3	Noarlunga North Outside		**Onkaparinga, Christies Ck (far)**		
3	Noarlunga South Outside		**Onkaparinga, Christies Ck (far)**		
3	Southport		**Onkaparinga (near)**		
3	Moana Outside	**control**		*Meuschenia freycineti*	
3	Aldinga Pinnacles				**deep site**
4	Myponga Reef		**Myponga River (near)**		
4	Ripple Rock	**control**	Myponga River (far)	*Dactylophora nigricans, Dotalabrus aurantiacus*	
4	Carrickalinga North 3			***Trinorfolkia cristata***	
4	Carrickalinga Head			*Dactylophora nigricans,* ***Meuschenia galii***	
4	Shag Rock			***Notolabrus parilus, Pentaceropsis recurvirostris***	
4	Dodd's Beach		**Carrickalinga Creek (far)**		
4	Carrickalinga South Bay		**Carrickalinga Creek (near)**		
4	(new site needed)		**Bungala River (far)**		
4	Normanville Beach		**Bungala River (near)**		
4	(new site needed)		**Yankalilla River (near)**		
4	(new site needed)		**Yankalilla River (far)**		
4	Rapid Bay Jetty			***Eubalichthys mosaicus***	
4	Rapid Head East	**impact**		*Dotalabrus aurantiacus*	
4	Rapid Head Windmill			***Acanthaluteres brownii, Girella tricuspidata, Pictilabrus laticlavius***	
5	Cape Jervis South	**impact**			
5	Fisheries Beach	**control**			
5	(new site needed)		**Deep Creek (near)**		
5	(new site needed)				**deep site**
5	Porpoise Head		**Deep Creek (far)**		
6	Newland Head		**Waitpinga Creek (near)**		
6	Flat Irons	**control**	Waitpinga Creek (far)	*Achoerodus gouldii, Hypoplectrodes nigrorubrum,*	
6	West Island Outer				**deep site**
7	The Bluff	**control**	Inman River (far)	*Achoerodus gouldii, Vincentia conspersa*	
7	Whalebone				**limestone**

Sub-region	Site	Step 1: Threats	Step 2: Discharge	Step 3: RSRS	Step 4. Representative
7	(new site needed)				**deep site**
7	Outside Granite Island	**impact**	Inman River (near)	*Aplodactylus arctidens*	
7	(new site needed)		**Hindmarsh (far)**		
7	Olivers		**Hindmarsh (near)**		
8	(new site needed)	**control**			

Table 11**. Representation of subregions and control and impact sites in the recommended list of monitoring sites**

Subregion	Total number of sites	Number of control sites	Number of impact sites
Northern	3	2	1
Adelaide Metro	2	1	1
Southern Metro	6	1	4
Yankalilla Bay	14	4	2
Backstairs Passage	5	4	1
South Coast	3	3	
Encounter Bay	6	1	3
Goolwa	1	1	

Table 12**. Representation of near and far sites for river discharges in the recommended list of monitoring sites**

Basin	River	Number of near sites	Number of far sites
Gawler	Gawler	1	1
Torrens	Torrens	1	1
Onkaparinga	Christies Creek	1	2
	Onkaparinga	1	3
Myponga	Myponga	1	5
Fleurieu	Carrickalinga Creek	1	1
	Bungala	1	1
	Yankalilla	1	1
	Deep Creek	1	3
	Waitpinga Creek	1	1
	Inman	1	3
	Hindmarsh	1	1

Table 13. Representation of RSRS in the recommended list of monitoring sites. Commonly recorded species are indicated by an asterisk. Note that species with a total of 1 do not have alternative sites suitable for monitoring.

Species	Common name	Total number of sites suitable for monitoring	Number of top three sites
Acanthaluteres brownii	Spiny tailed leatherjacket	8	1
Achoerodus gouldii	Western blue groper	3	3
Aplodactylus arctidens	Southern sea carp	1	1
*Austrolabrus maculates**	Black-spotted wrasse	14	n/a
Dactylophora nigricans	Dusky morwong	7	3
Dotalabrus aurantiacus	Castelnau's wrasse	6	2
Eubalichthys mosaicus	Mosaic leatherjacket	1	1
Girella tricuspidata	Luderick	1	1
Hypoplectrodes nigrorubrum	Banded sea perch	2	2
Meuschenia freycineti	Six-spine leatherjacket	4	3
Meuschenia galii	Blue-lined leatherjacket	3	1
*Meuschenia hippocrepis**	Horseshoe leatherjacket	15	n/a
Notolabrus parilus	Brown-spotted wrasse	9	1
*Notolabrus tetricus**	Blue-throat wrasse	17	n/a
Paraplesiops meleagris	Western blue devil	2	1
Pentaceropsis recurvirostris	Long-snouted boarfish	1	1
Pictilabrus laticlavius	Senator wrasse	8	1
*Trachinops noarlungae**	Yellow-headed hulafish	14	n/a
Trinorfolkia cristata	Crested threefin	4	1
Vincentia conspersa	Southern cardinalfish	1	1

6.9 Additional considerations

While 40 sites have been selected as the minimum number recommended to achieve the monitoring objectives it is worth highlighting some other considerations. In terms of spatial coverage the distribution of sites provides good coverage for most areas except for between Deep Creek and Newland Head. It may be worth further investigation of the reefs in this area to determine whether they are unique or representative of the larger region.

Harlequin fish have been the focus of previous studies in the AMLR region (Bryars 2013c) and used as "flagship" species to help engage local communities. They are also one of the few top order, site attached reef predators and as such play an important role in structuring reef communities. There are no sites specifically selected for monitoring harlequin fish based on the selection criteria in this report, however they have been recorded at four sites (The Pinnacles, Carrickalinga North 1, Second Valley and Rapid Head South) that have been identified for ongoing monitoring. Given their iconic status, previous research and potential as an indicator of reef health it would be useful to conduct some timed searches targeting harlequin fish at these reef sites as part of any UVC surveys.

Hallett Cove and Second Valley reef sites have long time-series but have not been included in the final site list. Second Valley is subject to a medium level of threat, has been surveyed 31 times (including 20 times by Reef Watch) between 2005 and 2016. It is suitable for monitoring nine of the priority fish of conservation concern. Hallett Cove lies within an area with a moderate threat level between the high threat areas on the Adelaide and southern metropolitan coasts. It has a long monitoring history, with 38 surveys since 2005 (including 27 by Reef

Watch) and is part of the ongoing Adelaide Desalination Plant monitoring program. Where resourcing allows these two sites should be considered for inclusion in any long term monitoring program.

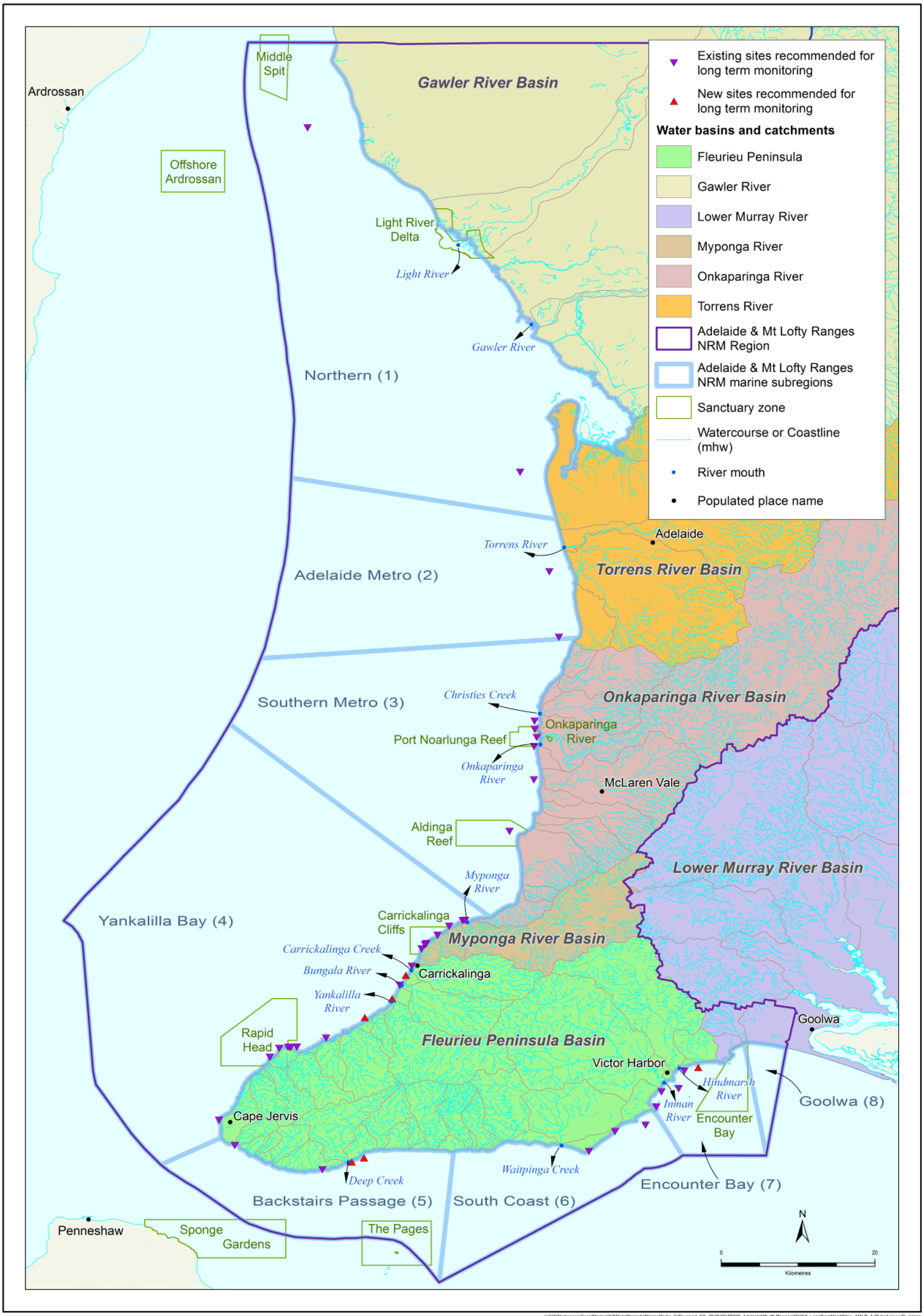

Figure 11. Reef sites recommended for long term monitoring in the AMLR region.

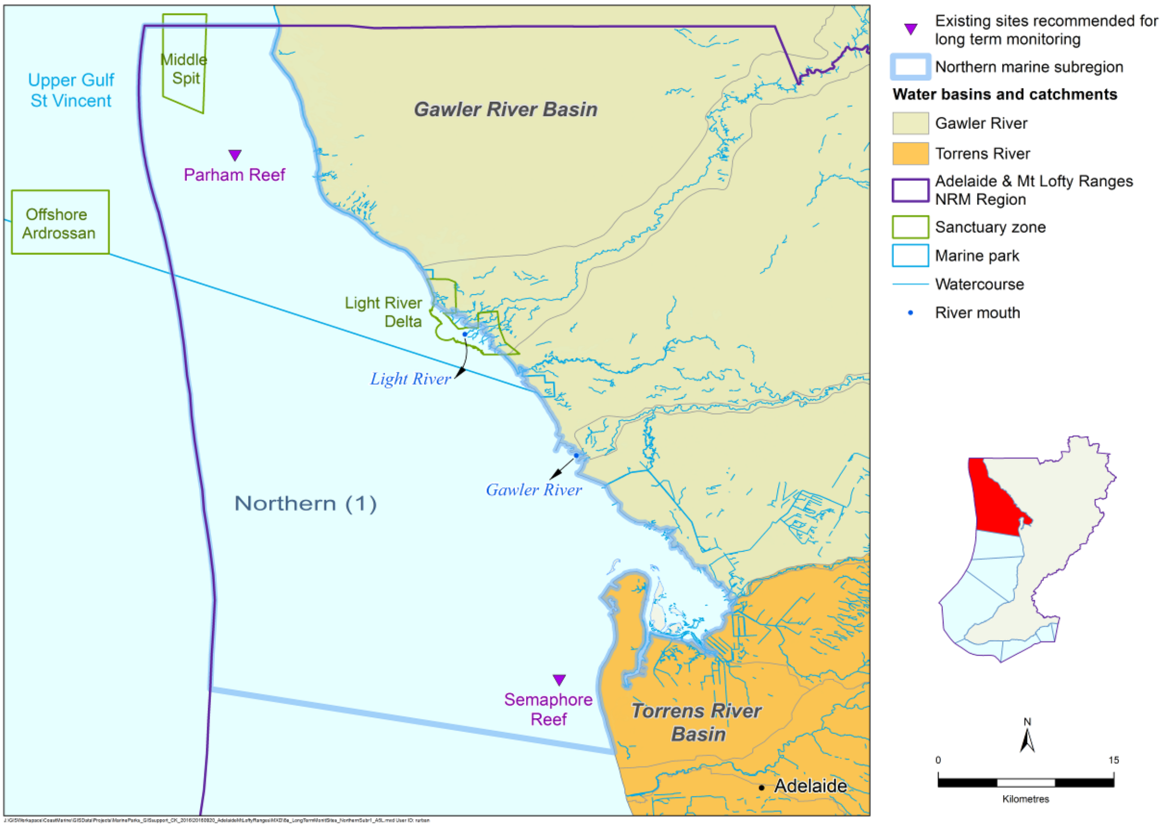

Figure 12. Reef sites recommended for long term monitoring in the Northern subregion

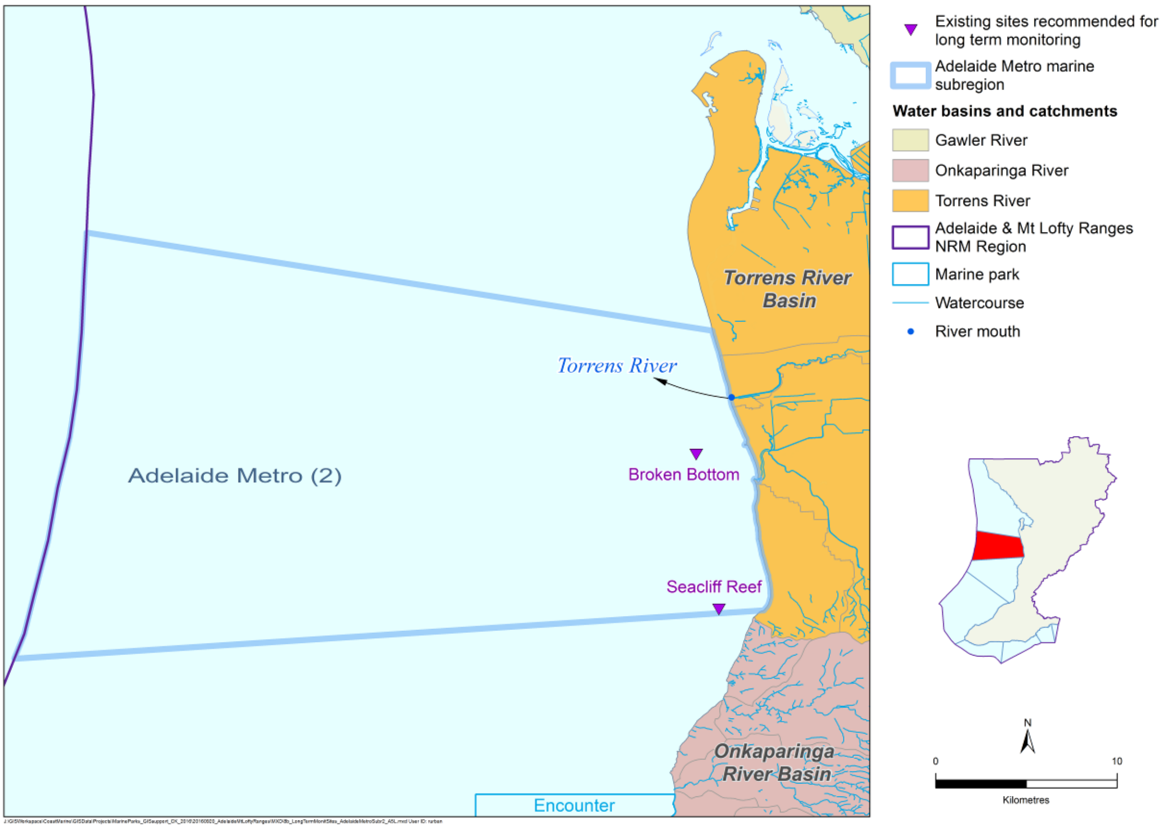

Figure 13. Reef sites recommended for long term monitoring in the Adelaide Metro subregion

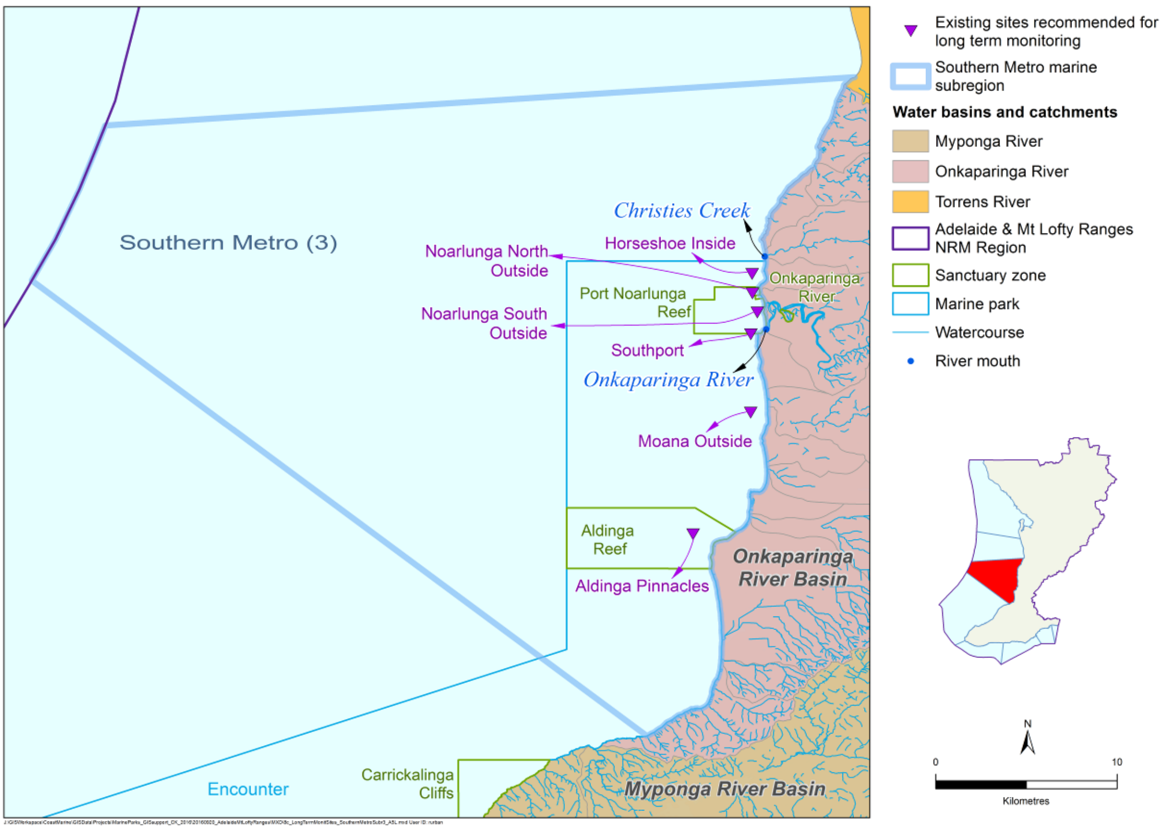

Figure 14. Reef sites recommended for long term monitoring in the Southern Metro subregion

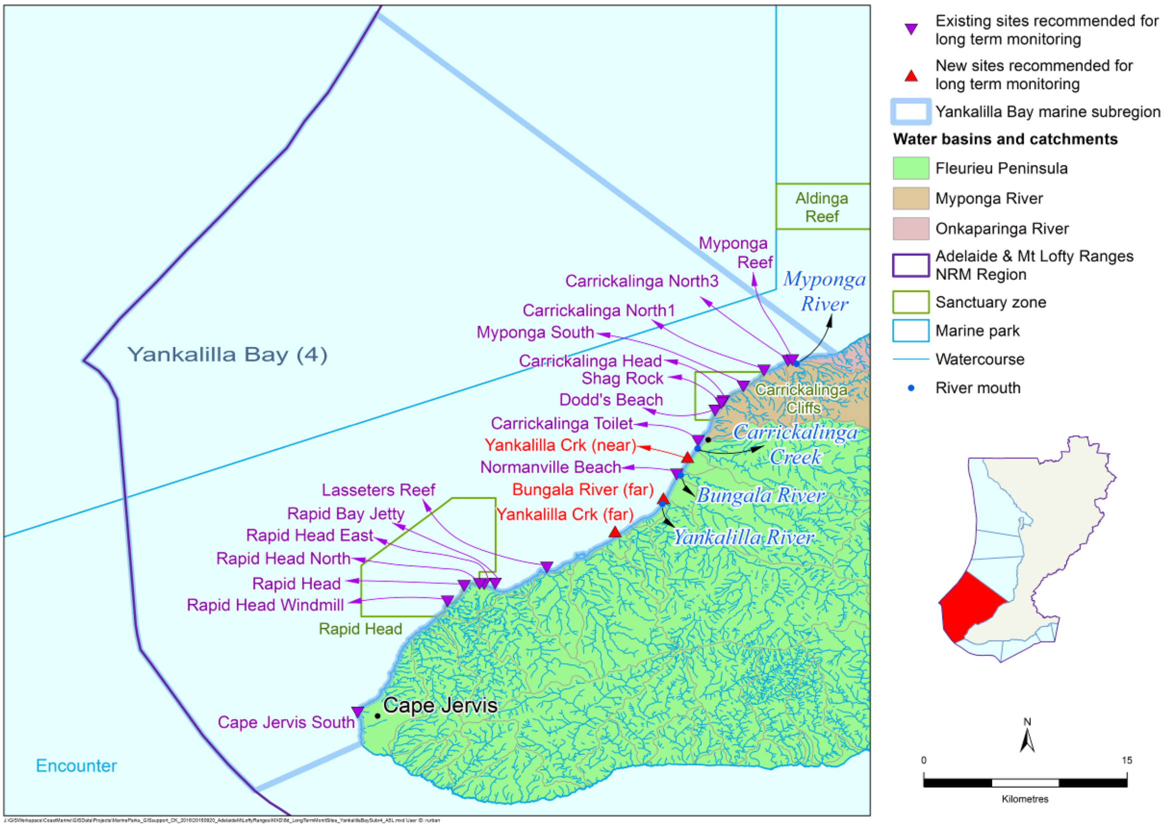

Figure 15. Reef sites recommended for long term monitoring in the Yankalilla Bay subregion

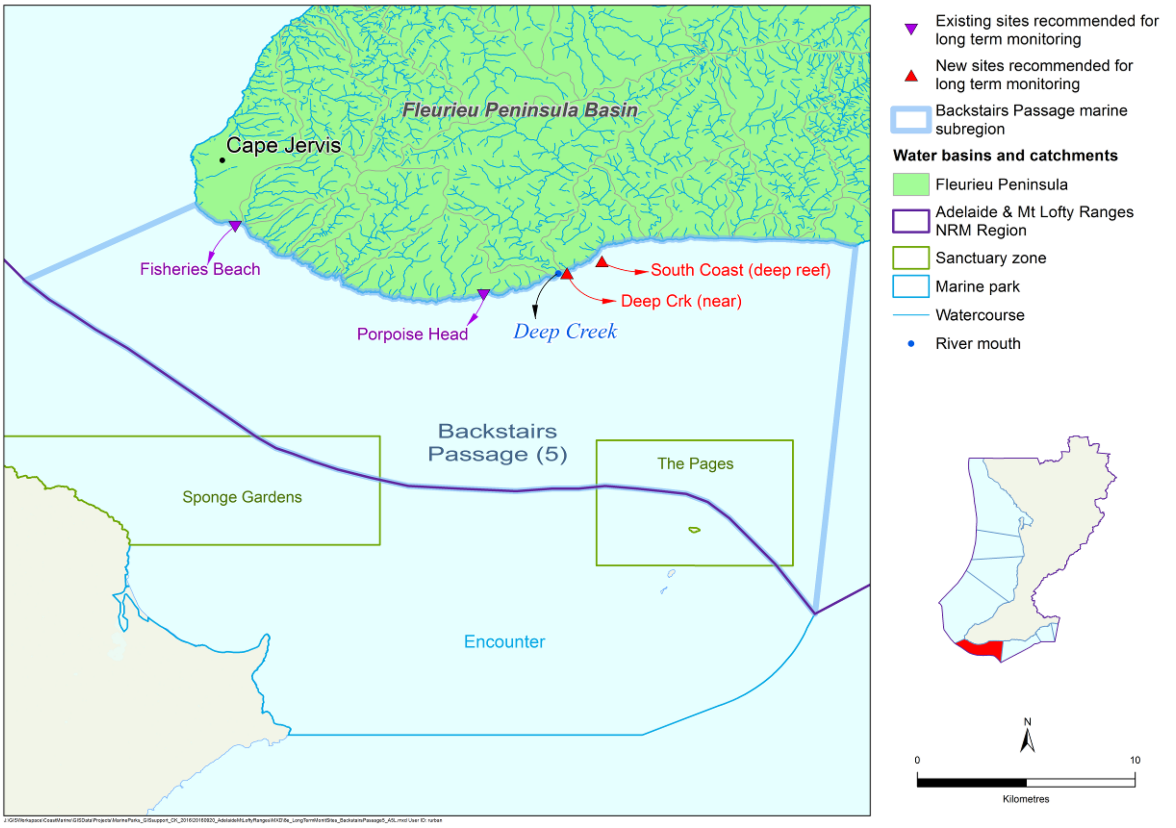

Figure 16. Reef sites recommended for long term monitoring in the Backstairs Passage subregion

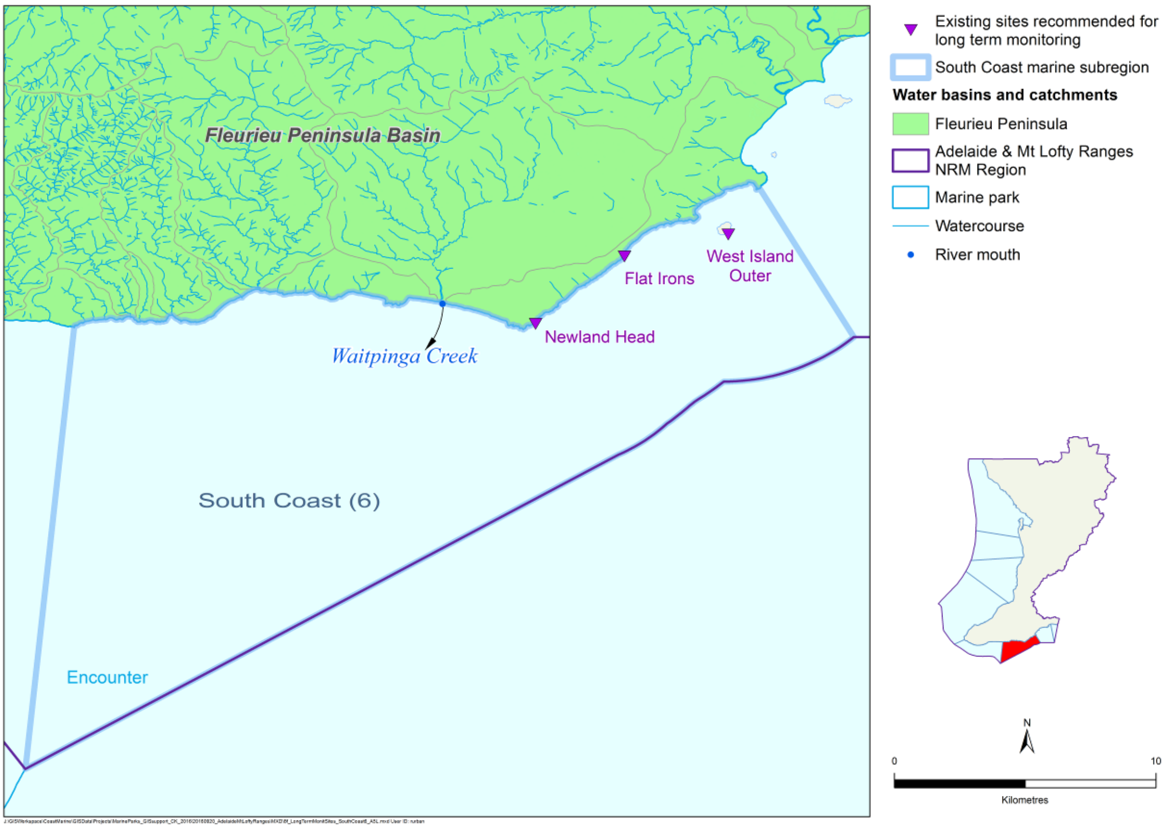

Figure 17. Reef sites recommended for long term monitoring in the South Coast subregion

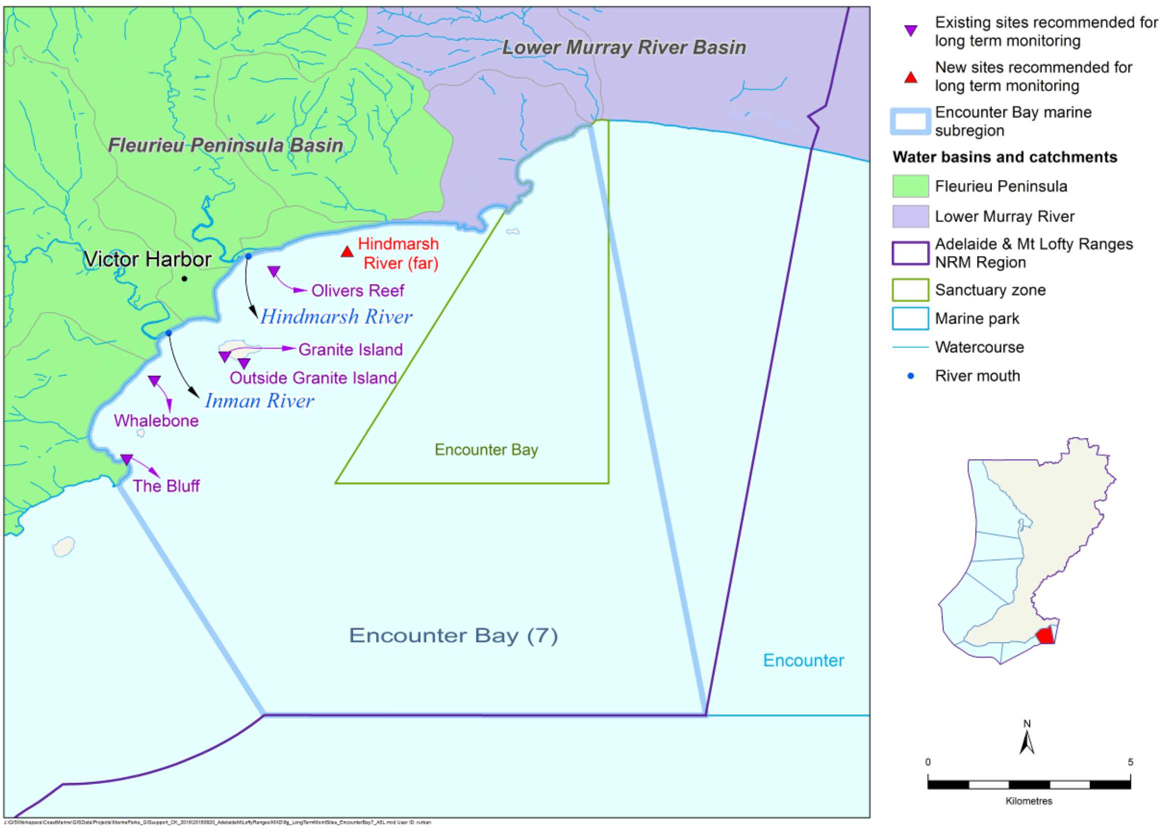

Figure 18. Reef sites recommended for long term monitoring in the Encounter Bay subregion

7 Recommendations on survey frequency and indicators to assess condition

7.1 Reef Conditon Assessment

7.1.1 Background

Assessing reef condition can be challenging due to a lack of unimpacted reference sites. Globally it is estimated that no marine ecosystems are unimpacted by humans (Halpern 2008) and more than 41%, are strongly affected by multiple drivers within coastal areas, including rocky reefs, being among the most affected (Halpern 2008). Without unimpacted sites as benchmarks it is difficult to "know" what good condition is and what components of the system are the best indicators for measuring condition.

Another challenge is disentangling the various anthropogenic stressors that may be impacting marine ecosystems. Fishing, global warming, pollution and invasive species are recognised as the most serious and pervasive threats to marine biodiversity, and can all be present and interacting in coastal seas (Crain et al. 2009, Edgar et al. 2005, Halpern et al. 2008).

The Environment Protection Authority in their MER program for assessing nearshore marine ecosystems in South Australia (Gaylard et al. 2013) identified the following as the most prevalent stressors of rocky reefs:

- turbidity and sedimentation
- climate change
- eutrophication
- extractive resource use
- toxicity due to a range of potential compounds
- invasive species.

Many of these stressors interact and often follow similar gradients in concentration (excepting climate change) such that many research papers use human population density as a surrogate for them (Soler et al. 2015, Duffy et al. 2016). In addition, their impacts on rocky reefs can be similar in favouring smaller earlier colonisers compared to slower growing climax species resulting in depauperate food webs and compromised ecosystem services (O'Gorman et al. 2012, Stuart Smith et al. 2015).

Despite these challenges there are still some areas that are relatively unimpacted that can provide a reference point for reef condition (e.g. Deep Creek which is adjacent to an uncleared catchment and is difficult to access by land or sea). In addition, limiting resource extraction and a number of other potential future disturbances within marine protected areas is leading to a return to a more natural state for many ecosystems and providing a greater understanding of their functioning (Edgar and Stuart Smith 2009, Edgar et al. 2014, Soler et al. 2015). New indicators and metrics for reef condition are being developed as advances in computing and analytical techniques mirror increases in our understanding of the functioning of these systems (Anderson et al. 2014, Soykan and Lewison 2015, Stuart Smith et al. in press).

7.1.2 Indicators for assessing reef condition

Nearly all large-scale reef survey techniques survey similar components of the ecosystem, namely fishes, macro-invertebrates or habitat forming species such as corals and macroalgae. This has been the case with surveys in the AMLR region with the Reef Health, MPA, RLS and Reef Watch programs using UVC methods to assess these three components. There are a large number of indicators that can be generated from this data which can range from indicators associated with individual species such as size and abundance to community level indicators that can assess species diversity and trophic structure.

Some indicators are specific to particular stressors such as the community temperature index (Devictor et al. 2008, Tayleur et al. 2016) which is used to measure community responses to global warming or biomass of targeted fish to assess extractive stressors (Edgar et al. 2014). However, many indicators associated with community structure and diversity are potentially influenced by a number of stressors that are difficult to disentangle and attribute to a particular cause. This in turn makes it difficult for natural resource managers to gauge the effectiveness of on-ground works/restoration and other associated works programs aimed at "improving" ecosystem health or condition.

In the AMLR region, one of the main methods of assessing reef condition has been the Reef Health Index (Turner et al 2007). This index combined a number of individual indicators into a single index. The efficacy of this approach has been extensively and independently reviewed (Collings et al. 2008, Brook and Bryars 2014, Westphalen 2015), finding a number of "conceptual, design and implementation issues" with this index (Brook and Bryars 2014). Recommendations include:

- Discontinue the use of a single unified index and focus on more useful individual indices
- Indices should be assessed as trends for individual reefs
- Continue to use macroalgal canopy cover as a primary index of reef condition
- Look for alternatives to the Reef Health line intercept transect method (see Turner et al 2007 for description) such as using photo quadrats
- Investigate using community-level indicators based on invertebrates
- Take into account visibility when utilising fish indices

7.1.3 Recommendations for assessing reef condition in the AMLR region

1. Select indicators and relevant metrics to target different parts of the biological hierarchy and food web (e.g. species, populations, fish, algae)

By selecting targeted indicators it will ensure that any monitoring program that is implemented can detect a range of potential changes. In addition it will provide greater understanding of how the system operates and better feedback for adaptive management.

2. Use a "multiple lines of evidence" approach to assess condition

In line with the suggestions of Brook and Bryars (2014) it is recommended to move from use of a single unified index of condition to a framework of multiple lines of evidence. Given the lack of clear understanding of the interactions between the various stressors/drivers and responses of nearshore reef ecosystems and the links to indicators used to assess them, it is suggested that a range of indicators and metrics (multiple lines of evidence) are tracked through time to assess condition. This is in line with the approach taken by the EPA in their evaluation and reporting of aquatic ecosystems (Gaylard et al. 2013) and acknowledges that "no single measure or group of measures will provide the perfect view of the stability and resilience of an ecosystem, and inconsistencies may regularly confound condition or 'health' assessments" (Fairweather 1999).

3. Assess each reef individually

Nearshore reef systems are often characterised by highly variable community structure at a number of scales (Stuart-Smith 2015). Given the spatial and temporal heterogeneity of the reef systems themselves and that anthropogenic influences impact these systems at different levels and at different spatial and temporal scales it is recommended that reefs are assessed individually. This approach doesn't preclude comparative analysis but emphasises that the condition of one reef subject to a specific set of natural and anthropogenic influences will not necessarily provide a valid or useful benchmark for another reef.

4. Develop conceptual models for reef condition

Despite a single unifying index not being recommended for assessing reef condition, conceptual models of what "good" reef condition should look like would provide a useful framework for interpreting monitoring results, reporting and assessing management strategies. There are a number of well-defined attributes that are typically assumed for a healthy reef, including:

- relatively high level of macro-algal cover
- presence of key predators in all size classes
- relatively low density of sea urchins.

However, these attributes will not apply to all reef types and a suite of models may be needed to conceptualise different types of reef ecosystems but should still be able to provide some idea of what desired state we expect or want these ecosystems to look like. In the EPA aquatic ecosystem monitoring program (Gaylard et al. 2013) conceptual models have been constructed around disturbance gradients to provide context for interpreting condition.

Drivers of reef condition should also be captured in the conceptual models so that links to and effectiveness of management actions can be evaluated

5. Incorporate more metrics based on fish communities

Recently significant advances have been made in the use of metrics based on fish communities to understand impacts on near shore reef systems (Duffy et al. 2016, Stuart Smith at al. 2016). Several metrics based around fish biomass have proven to be particularly robust and performed well compared to other metrics in assessing impacts on reef community structure (Soler 2015, Stuart Smith et al. in press). No changes in the current data collection methods are required to generate these metrics.

6. Where possible collect ancillary information that can either (a) help account for variations in data collection or (b) provide covariate data for interpretation of observed patterns.

Physical reef characteristics including substratum composition, topographic complexity, and substratum architecture will determine to some extent the types of biological communities that form on them (Alexander et al. 2009). Rugosity is one such measure of topographic complexity that can be effectively assessed by trained divers and has already been determined for a number of sites in the AMLR region (Turner et al. 2007). This would provide a useful covariate for later analyses, but other measures, e.g. the density of small refuges, may be more relevant (Alexander et al. 2009).

Visibility at the time of diver assessment will impact on the number and diversity of fish (Barrett and Buxton 2002, Brook and Bryars 2014). This parameter can be collected in a standardised way and can assist in the interpretation of patterns in community structure. A parameter of particular relevance to reef impact is sedimentation. Sediment traps have previously been deployed at 12 reefs between Semaphore and Aldinga during 2007/08 (Fernandes et al. 2008, Fernandes 2008). Analysis of the sediments collected can also provide information about sediment sources.

7. Potential indicators and metrics for consideration

The following indicators and associated metrics (in brackets) should be considered as part of the multiple lines of evidence approach to assess condition:

- Size (e.g. total length for fish) and abundance (number and biomass) of key species
- Abundance of key groups (e.g. biomass of targeted fish, biomass fish >20 cm)

- Abundance of canopy forming macroalgae (% cover)
- Presence of important taxa (e.g. number of regionally significant resident species, keystone predators, marine pests)
- Species diversity of fish, macroaalgae and macro-invertebrate communities (e.g. Species Richness, Shannon Weiner)
- Functional diversity of fish communities (trait based e.g. water column, gregariousness, diel activity pattern - see Coleman 2015)
- Community structure (biomass of different trophic groups e.g. herbivores/piscivores etc, relationship between sites and species in multidimensional space)
- Covariate information (reef rugosity, visibility and sediment ratings)

8. Undertake comparison of current methods for assessing macroalgal cover

A number of methods have been historically used in the AMLR region to collect information on macroalgal abundance (Table 1):

- The line intercept transect (LIT) method was used for the Reef Health program(s) and by Reef Watch
- Photoquadrats are used by the RLS Program
- 'Three dimensional' quadrats are used by the MPA program.

The LIT and photoquadrat methods can readily provide a measure of the percentage cover of canopy-forming macroalgae. The MPA method records macroalgae throughout the different layers of canopy and understorey, but does not record the degree of overlap between canopy - forming species that cover other such species. It is not possible to derive a precise estimate of canopy percentage cover from these data but a conservative estimate with upper and lower bounds can be determined (Brook and Bryars 2014). Although there may be ongoing use of the MPA method for the marine parks MER program, the RLS method is now more typically used.

The LIT method provides detailed percentage cover data over sections of 20 m of reef. Its implementation for the Reef Health program resulted in the survey of two sections of 40 m, typically separated by at least 60 m. It is relatively time-consuming, with an underwater component requiring 2–3 diver-hours per 200 m site, and additional office time to enter and check the data.

The photoquadrat method also provides percentage cover data, and is currently implemented by the RLS program by sampling at 2.5 m intervals over 200 m of reef. It is suitable for quantifying the percentage cover of canopy-forming macroalgae, but accurate quantification of turfing algae is more problematic (Brook and Cheshire, unpublished data), and may depend on image quality. The photoquadrat method, as implemented by the RLS program, only requires about a 0.2–0.3 diver hours per 200 m site and is performed by a diver that would otherwise just be swimming along while the line is laid out. The office processing time is similar to that required for LIT. The photoquadrat method allows for future review or alternative analysis of archived images.

In order to have confidence on the continuity of long-term datasets using a mixture of the LIT and RLS (photoquadrat) methods, consideration should be given to a study to compare the percentage cover data obtained through the LIT and photoquadrat methods. Recent studies commissioned by the AMLR NRM Board have collected data from both methods simultaneously (Brook and Bryars 2014, Brook unpublished data), with preliminary results (for four surveys) showing a good convergence between LIT and photoquadrat data (Brook and Bryars 2014).

Provided the LIT and photoquadrat methods produce comparable estimates of macroalgal cover, consideration should be given to adopting the photoquadrat method for future reef condition studies.

9. Undertake a pilot study that uses photoquadrats to characterise and monitor reefs over a range of spatial scales

Apart from increases in efficiency, the photoquadrat method provides opportunities to considerably enhance the monitoring of reef canopy cover and reduce the impact of small-scale spatial variation on assessments of change, particularly at some of the more heterogeneous reefs.

The efficiencies could be gained through the capture of additional images using cameras towed behind a boat or mounted on a remote operated vehicle, rather than divers. The acquisition of such images can be linked with GPS data to provide geo-referenced images which can then be used to:

- Characterise reefs across their entire extent.
- Provide a baseline for future statistical comparison across a range of spatial scales or gradients, by sub-sampling images to meet the requirements of particular analyses.
- Create compound, mosaicked images from overlapping images (acquired using slow drift speeds) in areas of particular importance. This has been made possible by advances in freely available image processing software.

It is recommended that a pilot study be undertaken to test the efficacy of this approach.

10. Where possible undertake timed searches for harlequin fish

Harlequin fish (*Othos dentex*) occur at several reef sites selected for ongoing monitoring. Given their low abundance it is recommended that timed searches targeting them be incorporated into surveys at sites where they have been recorded. If Harlequin fish recover at other locations (e.g. with protection from fishing) then additional sites can be added for timed searches.

11. Align assessment of reef condition with current reporting frameworks

While it is not recommended to combine individual indicators into a single condition index due to conceptual and other issues mentioned earlier in this report, it is recognised that there needs to be a framework for aggregating complex reef monitoring data into a more simple output to align with other reporting formats (e.g. State Report Cards, State of the Environment report) and as a communication tool for non-specialist audiences. In addition to adopting the "multiple lines of evidence" approach based on a range of indicators to assess reef trend and it is recommended to develop a logical and appropriate way to synthesize this data into a format compatible with the current reporting on state and condition of natural resources by DEWNR.

7.2 Survey timing and frequency

It is generally accepted that there is seasonal variation in reef community structure and some attributes used as indicators of reef condition, however it is not necessary to understand this variation in order to assess reef condition. Reef condition is the result of a number of interacting processes that generally develop over much longer time frames than those that operate seasonally. It is considered necessary to only exclude seasonal factors rather than understand them. This can be achieved by surveying during the same season each year, which is an approach taken by the University of Tasmania marine parks program (Edgar et al. 2006). The preferred season is the warm period during summer/autumn, because:

- Most historical data is from that period (see Table 1)
- Major storms events, which can cause short-term perturbations in indicators, are less likely during that period
- Boating and diving conditions are more favourable during that period.

The exception is Encounter Bay, when late winter/spring may provide more favourable boating and diving conditions, and during which time some historical data has been collected.

By surveying at one time of year only and not including a seasonal component, the cost of a long-term inter-annual monitoring program can be considerably reduced and/or allows the available budget to be used more effectively, e.g. by increasing the inter-annual frequency of surveys, or increasing the number of sites.

The frequency of inter-annual surveys at each site should take into account the extent of the existing baseline, e.g. it would be desirable to have annual surveys for an initial period at sites with little or no existing baseline. Timing of surveys should also have regard to the NRM State Plan's requirement for condition reporting every five years (Govt of South Australia 2012).

8 Appendices

A. Site list with attributes

Sub-region	Sitename	Depth	Composition	Relief	Res Sp	Surveys
1	Parham Reef	4	Limestone	0		3 (2016)
1	Outer Harbor breakwater south inside	5.5-7.2	Artificial	2		
1	Norma wreck	14	Artificial	2		
1	Semaphore Reef	8	Limestone	0	3	7 (2016)
2	Broken Bottom	10	Limestone	1	4	20 (2016)
2	Glenelg Tyre Reef	20	Artificial	2		
2	Macs ground	18	Limestone	2		2 (2016)
2	Glenelg Barge	17	Artificial	2		3 (2005)
2	Northern Outer Reef	20	Limestone	2		
2	Glenelg Dredge	16	Artificial	2		3 (2005)
2	Milkies Reef	18	Limestone	2		2 (2016)
2	Glenelg Blocks	5	Artificial	2		1 (2005)
2	Seacliff Reef	12	Limestone	2	9	8 (2016)
3	Marino Rocks north	4	Limestone	0		
3	Marino Rocks	4-4.3	Limestone	0		6 (2016)
3	Hallett Cove	5	Limestone	0	6	38 (2016)
3	Port Stanvac North	5-5.3	Limestone	1		6 (2016)
3	Port Stanvac South	3-3.3	Limestone	1		6 (2016)
3	Stanvac Dump	10-12	Artificial	2		
3	Port Stanvac Jetty deep	12.5-15.7	Artificial	2		1 (2015)
3	Port Stanvac Jetty Shallow	5-5.1	Artificial	2		1 (2015)
3	O'Sullivan Beach Bay	2	Limestone	0		1 (2010)
3	O'Sullivan Beach Reef inshore	0.5	Limestone	0		
3	Horseshoe shallow	3	Limestone	2		
3	Horseshoe Inside	3	Limestone	2	5	10 (2016)

Sub-region	Sitename	Depth	Composition	Relief	Res Sp	Surveys
3	Horseshoe Outside	12	Limestone	1	5	11 (2016)
3	North of Port Noarlunga	4	Limestone	1		
3	Noarlunga North Inside	5	Limestone	2	5	43 (2016)
3	Noarlunga North Outside	5	Limestone	2		25 (2016)
3	Port Noarlunga jetty north	3-7	Limestone	2		
3	Port Noarlunga Jetty offshore	5-10	Limestone	2		2 (2014)
3	Port Noarlunga jetty south	3-7	Limestone	2		
3	Noarlunga Deep	10	Limestone	2		3 (2005)
3	Noarlunga South Outside	5	Limestone	2		13 (2008)
3	Noarlunga South Inside	3	Limestone	2		30 (2016)
3	Southport	4	Limestone	1	5	5 (2016)
3	Moana Outside	5	Limestone	2	7	9 (2016)
3	Moana Inside	5	Limestone	0	5	9 (2016)
3	Gull Rock	5	Limestone	2		1 (2016)
3	Port Willunga Reef	6	Limestone	1		2 (2016)
3	Aldinga inshore north	3	Limestone	0		
3	Aldinga SZ1	5	Limestone	0		1 (2016)
3	Aldinga Pinnacles	9-12	Limestone	2		
3	Aldinga Dropoff	5-20	Limestone	2		
3	Aldinga Reef	6-9	Limestone	0		3 (2012)
3	Aldinga Reef Inshore	2.5-4	Limestone	0	1	3 (2012)
3	Aldinga Shallow	5	Limestone	0		4 (2007)
3	Aldinga Deep	12	Limestone	0		5 (2016)
3	Aldinga SZ2	5	Limestone	0		1 (2016)
3	Aldinga inshore central	4	Limestone	1		
3	Aldinga inshore south	4	Limestone	0		
3	Aldinga SZ3	5	Limestone	0		1 (2016)

Sub-region	Sitename	Depth	Composition	Relief	Res Sp	Surveys
3	Sellicks South	5	Limestone	2		1 (2016)
4	Myponga Reef	3.8-4.3	Schist	2		
4	Carrickalinga North 3	5	Schist	2	1	2 (2016)
4	Carrickalinga North 2	5	Schist	2		2 (2016)
4	Carrickalinga North 1	5	Schist	2	1	2 (2016)
4	Myponga Point	5	Schist	2	8	4 (2012)
4	Ripple Rock	5	Schist	2	11	4 (2016)
4	Myponga South	5	Schist	2	9	5 (2016)
4	Carrickalinga Head	5	Schist	2	11	3 (2007)
4	Shag Rock	4.9-7.5	Schist	2	10	9 (2016)
4	Dodd's Beach	5	Schist	2	7	4 (2012)
4	Carrickalinga Beach North	5	Schist	2		1 (2013)
4	Haycock Point	5-7.3	Schist	2	8	6 (2014)
4	Haycock Point inshore	2.9-3.5	Schist	1		2 (2011)
4	Carrickalinga Toilet	4.9-5.3	Schist	2	8	11 (2016)
4	Normanville Beach	2.1-2.4	Schist	0		2 (2013)
4	Sunset Cove South	5	Schist	0	8	4 (2012)
4	Lassiters Reef	3.5-5.1	Schist	2	9	7 (2014)
4	Second Valley Boat Shed	3.5-5.3	Schist	2	9	31 (2016)
4	Ex-HMAS Hobart wreck	10-26	Artificial	2		
4	Rapid Bay Jetty	6-10.1	Artificial	2	8	4 (2014)
4	Rapid Head East	4-6	Schist	2	9	5 (2016)
4	Rapid Head North	5	Schist	2	10	3 (2007)
4	Rapid Head SZ Site3	5	Schist	2	2	2 (2013)
4	Rapid Head	4.8-7.2	Schist	2	10	8 (2016)
4	Rapid Head SZ Site2	5	Schist	2		2 (2016)
4	Rapid Head Windmill	5	Schist	1	9	4 (2012)

Sub-region	Sitename	Depth	Composition	Relief	Res Sp	Surveys
4	Rapid Head South	5	Schist	1	9	2 (2016)
4	Salt Creek/Nev's Windmill	5	Schist	1	9	3 (2016)
4	La Hacienda	5	Schist	1		2 (2013)
4	Morgans	5	Schist	1	7	4 (2016)
5	Cape Jervis North	4	Schist	2		
5	Cape Jervis South	4	Schist	2		
5	Fisheries Beach	5	Schist	2		2 (2007)
5	Spaceship East	5	Schist	2		1 (2007)
5	Loo with a View	5	Schist	2		1 (2007)
5	Blowhole Beach	5	Schist	2		1 (2007)
5	Porpoise Head	5	Schist	2		1 (2007)
5	Deep Creek/Boat Harbour	5	Schist	2		1 (2007)
6	Newland Head	5	Schist	2		2 (2008)
6	Flat Irons	6	Schist	2	5	4 (2012)
6	Kings Head North	5	Schist	1		2 (2008)
6	Kings Head	5	Schist	0		2 (2008)
6	West Island Outer	10	Granite	2		2 (2008)
6	NE West Island	10	Granite	2		1 (2005)
6	West Island	5	Granite	2		1 (2005)
7	The Bluff	5-5.4	Granite	2	4	26 (2016)
7	Bluff Bay	2	Granite	0		
7	Blacks Reef	4-6	Granite	2		
7	Whalebone	5-5.4	Limestone	2	4	4 (2014)
7	Seal Island	5	Granite	2	2	4 (2008)
7	Granite Island	5-5.4	Granite	2		3 (2014)
7	Outside Granite Island	5	Granite	2	3	4 (2008)
7	Granite Island Screwpile Jetty	6	Artificial	2		
7	Oliver’s Reef	5.1-5.4	Limestone	0		2 (2014)
7	Knights Beach Point	8-10	Granite	2		1 (2005)

Sub-region	Sitename	Depth	Composition	Relief	Res Sp	Surveys
7	South Pullen Island	9	Granite	2		1 (2005)
7	Pullen Island	5-5.4	Granite	2		5 (2014)
7	Horseshoe Bay	4-6	Granite	2		1 (2005)
7	Frenchmans	4-5	Granite	2		1 (2005)

B. Species of conservation concern identified by Baker (2007) that were uncommonly recorded during standard reef surveys in the AMLR region between 2005 and 2016

Species	Common name	Total	Sites where recorded
Dasyatis brevicaudata	Smooth stingray	1	Noarlunga North Inside
Orectolobus ornatus	Ornate wobbegong	1	Hallet Cove
Paristiopterus gallipavo	Yellow spotted boarfish	1	Glenelg Dredge
Omegophora cyanopunctata	Blue-spotted toadfish	1	Aldinga SZ1
Phyllopteryx taeniolatus	Weedy seadragon	1	Lassiters Reef
Neatypus obliquus	Footballer sweep	1	Myponga South
Platycephalus speculator	Blue-spotted flathead	1	Shag Rock
Histiophryne cryptacanthus	Rodless anglerfish	1	Lassiters Reef
Orectolobus spp.	Wobbegong	1	Rapid Head North
Diodon nichthemus	Globe fish	1	The Bluff
Myliobatis australis	Eagle ray	1	Sunset Cove South
Stigmatopora nigra	Widebody pipefish	1	West Island
Cristiceps aurantiacus	weedfish	1	Second Valley Boat Shed
Caesioperca rasor	Barber perch	1	Second Valley Boat Shed
Aploactisoma milesii	Velvetfish	1	Second Valley Boat Shed
Anoplocapros lenticularis	White-barred boxfish	1	Deep Creek/Boat Harbour
Trygonoptera testacea	Common stingaree	1	Second Valley Boat Shed
Urolophus orarius	Coastal stingaree	1	Rapid Bay Jetty
Vanacampus poecilolaemus	Longsnout pipefish	1	Second Valley Boat Shed
Centroberyx gerrardi	Bight redfish	2	Second Valley Boat Shed, Glenelg Blocks
Meuschenia venusta	Stars-and-stripes leatherjacket	2	Carrickalinga North2, The Bluff
Anoplocapros amygdaloides	Western smooth boxfish	2	The Bluff, West Island Outer
Orectolobus halei	Banded wobbegong	2	Lassiters Reef
Heteroclinus kuiteri	Kuiter's weedfish	2	Normanville Beach, Ripple Rock
Pseudophycis bachus	Red cod	2	Lassiters Reef
Rhycherus filamentosus	Tasselled anglerfish	2	Lassiters Reef, Noarlunga North Inside
Pseudophycis barbata	Bearded cod	2	Pullen Island
Torquigener pleurogramma	Banded toadfish	2	Haycock Point inshore
Chironemus georgianus	Western kelpfish	3	Pullen Island, The Bluff
Heteroclinus roseus	Rosy weedfish	3	Second Valley Boat Shed, Rapid Head
Othos dentex	Harlequin fish	5	Second Valley Boat Shed, Carrickalinga North3, Rapid Head South, Sunset Cove South, West Island
Nemadactylus valenciennesi	Queen snapper	5	Carrickalinga Toilet, Pullen Island, Whalebone
Thamnaconus degeni	Degen's leatherjacket	5	Aldinga Shallow, Port Stanvac Jetty deep
Eubalichthys gunnii	Gunn's leatherjacket	5	Second Valley Boat Shed, Carrickalinga Toilet, Rapid Head North
Cheilodactylus spectabilis	Banded morwong	7	La Hacienda, Newland Head, Noarlunga Deep, West Island Outer
Phycodurus eques	Leafy seadragon	7	Carrickalinga North3, Haycock Point, Rapid Head East, Seacliff Reef, The Bluff
Threpterius maculosus	Kelpfish	7	Aldinga SZ1, Aldinga SZ2, Lassiters Reef

Species	Common name	Total	Sites where recorded
Glyptauchen panduratus	Goblin fish	8	Aldinga Reef, Aldinga Shallow, Haycock Point, Rapid Head, Seacliff Reef, Shag Rock
Heteroclinus johnstoni	Johnston's weedfish	8	Carrickalinga North3, Hallet Cove, Horseshoe Inside, Lassiters Reef, Morgans, Rapid Head South, Ripple Rock, Sunset Cove South
Cnidoglanis macrocephalus	Estuary catfish	8	Macs ground, Morgans, Parham Reef, Pullen Island
Eupetrichthys angustipes	Snake-skin wrasse	9	Second Valley Boat Shed, Aldinga Deep, Carrickalinga Toilet, Macs ground, Rapid Head North, Rapid Head Windmill, Shag Rock
Cristiceps australis	Crested weedfish	10	Second Valley Boat Shed, Broken Bottom, Marino Rocks, Semaphore Reef, Shag Rock
Neosebastes scorpaenoides	Common gurnard perch	10	Macs ground, Milkies Reef, Rapid Bay Jetty, Shag Rock, Whalebone
Heteroclinus tristis	Forster's weedfish	11	Aldinga Reef Inshore, Morgans, Port Noarlunga Jetty offshore, Port Willunga Reef, Rapid Head East, Rapid Head Windmill, Ripple Rock, Shag Rock
Scorpaena papillosa	Southern rockcod	12	Second Valley Boat Shed, Carrickalinga Toilet, Fisheries Beach, Macs ground, Newland Head, Shag Rock
Genypterus tigerinus	Rock ling	12	Second Valley Boat Shed, Haycock Point, Horseshoe Outside, Lassiters Reef, Morgans, Olivers Reef, Rapid Bay Jetty, Rapid Head North
Scorpis georgiana	Banded sweep	18	Aldinga Reef, Aldinga Reef Inshore, Granite Island, Horseshoe Inside, Moana Outside, Noarlunga Deep, Rapid Head, Shag Rock, Southport
Aetapcus maculatus	Warty prowfish	19	Second Valley Boat Shed, Carrickalinga Toilet, Haycock Point, Lassiters Reef, Pullen Island, Rapid Head, Rapid Head North, Semaphore Reef, Shag Rock, The Bluff
Pagrus auratus	Snapper	48	Aldinga Deep, Aldinga SZ1, Carrickalinga North1, Macs ground, Milkies Reef, Rapid Bay Jetty, Ripple Rock, Shag Rock

Note: Totals are based on uneven survey effort between sites.

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