Green Adelaide Rocky Reef Program:

Trends in the condition of rocky reef ecosystems of the greater Adelaide and Fleurieu Peninsula region, South Australia

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Cover photo: Pale mosaic seastar (*Echinaster arcystatus*) provided by D. Easton, Marine Science Team, Department for Environment and Water.

Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provide the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Ben Bruce
A/CHIEF EXECUTIVE
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1 Executive Summary

Subtidal rocky reefs support a high biodiversity of marine life and provide a range of ecosystem services (e.g. shoreline protection, provision of food resources) while also supporting significant public amenity and economic value through recreational activities and tourism. Along with seagrass, rocky reefs are one of the most important nearshore marine ecosystems in Gulf St Vincent. A recent study published in the journal *Nature* (Edgar et al. 2023) showed that shallow reef systems are under significant pressure with populations of several species of fish and invertebrates in decline.

The Green Adelaide Rocky Reef (GARR) Program was established in 2016 to increase knowledge and understanding of temperate rocky reef ecosystems across the greater Adelaide and Fleurieu Peninsula region with the aim to improve management of these important marine ecosystems. The current report provides the most comprehensive assessment to date of the status of shallow subtidal reefs in this region using the longest time series of biodiversity data ever assembled for a marine ecosystem in South Australia.

The major outcomes/findings were:

- Creation of one of the longest running and most comprehensive marine biodiversity data sets in South Australia spanning 17 years (2005– 2022) from over 40 sites by integrating historical and current data on rocky reefs. This dataset enabled the robust analysis of long-term trends in rocky reef condition in the greater Adelaide and Fleurieu region.
- In general, the status of subtidal reefs in the greater Adelaide and Fleurieu Peninsula region was stable or improving based on the analysis of several indicators of reef condition. However, the distribution of monitoring data was uneven across the region and projected trends for some subregions need to be treated with caution until additional data is collected to improve the confidence in indicator trajectories.
- The stabilization and in some cases potential recovery of macro-algal cover in the vicinity of Adelaide represents a significant 'good news' story as previous reports have raised concerns over reef condition with documented declines in reef condition particularly macro-algal cover (Turner 2004, Turner et al. 2007, Connell 2008). The reasons for this are unknown but possibly linked to improvements in water quality in the last 40 years.
- Data collected by volunteer divers trained as part of the Reef Life Survey citizen science program was integral to enabling sufficient spatio-temporal coverage and resolution to undertake analysis of trends in indicators of reef health.
- This report has demonstrated that long term monitoring at a relevant spatial scale is essential to discriminate long term trends from natural inter-annual and inter-site variation in these systems.
- The GARR program, through current and previous work, has established a foundation for effective monitoring to inform management of rocky reefs in the greater Adelaide and Fleurieu Peninsula region. Results of the present study will assist to inform the current Green Adelaide Strategic Plan Performance Reporting Framework, national State of Environment (SOE) reporting, and have provided the data for the creation of a new State Report Card on macro-algal cover.
- The GARR program was established to provide relevant information to help improve the management of rocky reef ecosystems. Five key indicators related to different aspects of reef ecosystem condition were identified and which require regular assessment to provide the information needed to track the status of reefs in the greater Adelaide and Fleurieu Peninsula region. It is strongly recommended to continue to monitor these indicators at relevant spatio-temporal scales and improve coverage where necessary.

2 Background and objectives

2.1 Subtidal rocky reefs of the greater Adelaide and Fleurieu Peninsula regions

Subtidal rocky reefs are a critical component of marine ecosystems found in waters along coastlines of the greater Adelaide and Fleurieu Peninsula region. Subtidal reefs in this region occur from Port Parham in the north to Bashams Beach in the south near Victor Harbor on the Fleurieu Peninsula. These reef ecosystems range in depth from intertidal to 20+ m and form part of the Great Southern Reef ecosystem (Bennet et al. 2015), which is a series of interconnected temperate reefs that extend from Western Australia, along the Great Australian Bight (GAB), through South Australia and Victoria, and across to New South Wales (NSW).

Subtidal reef ecosystems in the Gulf St Vincent (GSV) and Fleurieu South coasts 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 there (Turner et al. 2006, Gaylard et al. 2020). They are particularly unique due to extreme seasonal environmental conditions that include thermal and salinity gradients that occur in the GSV from south to north. During the austral summer limited water circulation combined with the formation of a thermohaline front acts as an environmental barrier impeding significant water exchange to the Southern Ocean and shelf (Nunes and Lennon 1986, Middleton and Bye 2007, Petrusevics et al. 2011, Kaempf 2014).

Kelp and other canopy forming macro-algae provide the main habitats that sustain these productive and diverse ecosystems and are a critical component in structuring these communities (Turner et al. 2007, Bennett et al. 2015). Many iconic species considered of conservation concern such as western blue groper (*Achoerodus gouldii*), harlequin fish (*Othos dentex*), and southern blue devil (*Paraplesiops meleagris*) are site attached and dependent on these reef ecosystems (Bryars 2010, Bryars et al. 2012, Bryars and Rogers 2016). For other species that may be wider ranging such as snapper, stingrays and leatherjackets, reefs are an integral component among the mosaic of seagrass and mangrove habitats that are critical to different stages in their life history (Barrett 1995, Shepherd and Edgar 2013, Baker et al. 2007, 2011).

Reef ecosystems in South Australia support valuable commercial and recreational fisheries (e.g. snapper, whiting, rock lobster, abalone, squid, rock cod and sweep). The estimated value of recreational and commercial fishing (expenditure) for these regions is approximately $52.4 M and $29.1 M per annum respectively, with combined revenue of ~20% for South Australia's $474 M fishing sector (Deloitte 2017). Additionally, these ecosystems attract significant investment through the state's tourism sector with eco-tourism for reefs in the Adelaide and Fleurieu region driven by accessibility to Adelaide and high amenity value, thus offering a wide range of local recreational scuba diving, snorkelling and educational pursuits.

Understanding the natural drivers that structure reefs including the pressures and stressors that impact them is critical to effectively manage these important marine ecosystems. A recent study by Edgar et al. (2023) demonstrated that temperate reef systems in Australia were under a greater threat than tropical reef systems because of high levels of endemism and lack of suitable areas for species to migrate to under a climate warming scenario – essentially, they inhabit a 'climate trap'.

2.2 The Green Adelaide Rocky Reef (GARR) Program

The Green Adelaide Rocky Reef Program (GARR) was established in 2016 to increase knowledge and understanding of temperate reef ecosystems across the northern, metropolitan and southern parts of GSV, and the lower Fleurieu Peninsula region where reefs are exposed to the Southern Ocean. The program was originally established as the Adelaide and Mount Lofty Reef Health (Subtidal Reef Health) Program (2016) under the previous *Natural Resources Management Act 1984* and current *Landscapes Act South Australia 2019* managed by the then Adelaide and Mt Lofty Ranges (AMLR) NRM Board.

Development of the program was based on recognition that reef ecosystems within the greater Adelaide and Fleurieu Peninsula region are interconnected and a coordinated survey program is required to capture long term knowledge of condition across the breadth and types of reefs present. Prior to its development, information on reef condition/health was limited both by spatio-temporal extent and inconsistency in survey approaches. As a result, the GARR program has developed components iteratively, with each building upon previous work that has led to significant progress toward a better understanding of these systems (see Brock et al. 2017, Imgraben et al. 2019, Brook et al. 2020). Iterative evaluations through the development and implementation of the program since 2016 has led to key outputs and initiatives, specifically:

1) Modelling of historical reef data and establishing a spatial network of 42 long term reef monitoring sites that are representative of the region/s (defined as 8 subregions) (Brock et al. 2017).

2) Identification of the key indicators to be implemented for reporting reef condition across the regions. (Brook et al 2019).

3) Development of an expert-driven conceptual model framework to describe condition and threats to reef ecosystems in the broader GSV region (Imgraben et al. 2019).

4) Characterisation of the spatial distribution of marine biodiversity (macro-algae, fish and invertebrates) at 41 sites representative of the broader regions across the eastern GSV and Fleurieu Peninsula regions (Landscape regions) facilitating baseline reporting for temperate reefs in the regions (Brook et al. 2020).

5) Implementation of the Reef Life Survey (RLS) methodology to establish a standardized approach to data collection (Stuart smith et al. 2009)

6) Establishment of RLS volunteer citizen science and community outreach to improve capacity building through engagement of community trained divers to assist in the collection of scientific data (Edgar et al. 2009, Reef Life Survey video).

7) Improvement of national accessibility to the temperate reef data and storage of information through uploads to the Australian marine and climate science data repository (Australian Ocean Data Network, AODN) RLS data.

The conceptual reef model framework (Imgraben et al. 2019) identified water quality, sedimentation and fishing as three key pressures impacting rocky reefs in the region, and that marine biodiversity is strongly structured along a north–south gradient related to water temperature and wave exposure. In addition, other potential and emerging issues were identified and include coastal urban expansion and impacts from runoff, marine debris (plastics), emergence and establishment of invasive species, and various climate change impacting scenarios including sea level rise, increasing marine water temperatures, ocean acidification and salinity leading to changes in habitat and food web structure, and impacting fisheries, aquaculture and tourism (Bryars 2013a, Brook et al. 2020, Imbragen et al. 2019, Peters and Flaherty 2011, Mellin et al. 2021).

The review and recommendation of sites and indicators for monitoring the condition of near-shore subtidal reef communities in the Adelaide and Mount Lofty Ranges NRM region (Brock et al. 2017) further revealed that reef biodiversity across the region/s is highly variable (Brook et al. 2020) requiring a well-designed systematic monitoring program to accommodate habitat variability and spatial patterns in diversity. It also recommended to assess long term trends in relevant indicators of reef health where data sets were available.

This current report, which builds upon the baseline reef status and biodiversity patterns report (Brook et al. 2020), describes the indicator datasets used for analysis and documents the status of subtidal reefs for the region/s. This is the first time fine-scale information on the trends of key indicators has been able to be documented in its geographical context, providing unique insights into condition of reef ecosystems for the region/s that can be used for future management of them. For this report, the areal extent of these reefs will be referred to as the greater Adelaide and Fleurieu Peninsula regions as this encompasses the reefs across the three Landscape regions (Northern and Yorke, Green Adelaide, Hills and Fleurieu) formerly known as the Adelaide and Mount Lofty Ranges NRM region (Figure 1).

For more detail and information on the evolution of the program and outputs see the Green Adelaide Rocky Reef Report Series:

- Brock D, Brook J and Peters K (2017). Review and recommendation of sites and indicators for monitoring the condition of near-shore subtidal reef communities in the Adelaide and Mount Lofty Ranges NRM region, DEWNR Technical report DEWNR-TR-2017-32, Government of South Australia, Department of Environment, Water and Natural Resources, Adelaide.
- Imgraben S, Peters K and Brock D (2019). Conceptual models of nearshore reefs in the Adelaide and Mount Lofty Ranges region. DEW Technical note DEW-TR-2018-10, Government of South Australia. Department for Environment and Water, Adelaide.
- Brook J, Peters K, Bryars S, Owen S, Hicks J, Miller D, Easton D, Eglington Y, Meakin C and Brock D (2020). Subtidal Reef Health Program: Baseline status of subtidal reefs and associated biodiversity patterns in the AMLR, DEW Technical report DEW-TR-2020-01, Government of South Australia, Department for Environment and Water, Adelaide.

2.3 Objectives

Long term datasets are invaluable for managing natural resources but are particularly rare for marine ecosystems (Hughes et al. 2017). Formal monitoring of subtidal reef ecosystems first commenced in South Australia in 1996 and while there were several different methods employed over the years, they were often 'variants on a theme'. Consequently, aspects of the data collection are compatible and can be integrated to create a time series of data longer than any one method or program.

The objective of the current report was to analyse compatible reef monitoring datasets to describe trends in key ecological indicators related to condition of subtidal reefs in the greater Adelaide and Fleurieu Peninsula region. The specific aims of the current report were to:

1. Identify reefs in the Northern and Yorke, Green Adelaide and Hills and Fleurieu Landscape regions with data sets suitable for long term analysis (>4 years).
2. Integrate compatible datasets and analyse trends in indicators related to reef condition.
3. Document the status of temperate reefs across the greater Adelaide and Fleurieu Peninsula region.

Figure 1. Map showing study area, landscape regions and distribution of subtidal rocky reefs across the Adelaide and Fleurieu Peninsula region. Reefs utilised in this study are those found inside the "study region" (brown line).

2.4 Trend and conditon reporting

Reporting on the trend and condition of our natural resources is critical to effective management and forms a legislative requirement of most environmental agencies. The Minister for Environment and Water under the *Landscape South Australia Act 2019* is required to '*monitor, evaluate and audit the state and condition of the State's natural resources, coasts and seas; and to report on the state and condition of the State's natural resources, coasts and seas*' (9(1(a-b)). This reporting provides information to support decision making and ultimately measures the effectiveness of the management actions being undertaken.

In 2013 the Department for Environment and Water (DEW) in collaboration with other state agencies released the first series of trend and condition report cards to communicate the current condition of our environment and how it is trending over time (DEW 2013). These report cards give the most complete picture we have on South Australia’s long-term environmental trends. The results of the current study will provide the basis for the ‘Subtidal Macro-algae Condition Report Card’ in the next tranche of state reporting due in 2023.

The analysis of trends in key indicators related to reef condition in the current report will assist the Green Adelaide and regional Landscape Boards to manage nearshore marine ecosystems by providing a sound evidence base for decision making. The current information will be used to report on the recent Green Adelaide (GA) Regional Landscape Plan 2021–2026 (Green Adelaide, 2021) as a key program for the Performance Framework. The GA Plan highlights the interconnectivity of landscapes and seascapes using a “hills to sea” approach, reflecting the inherent connection between land and sea environments. Among the GA Plans’ seven key priorities, the goal for coastal management is to conserve and restore coastal and marine habitats and biodiversity.

The GA Plan emphasises investment on:

i) restoration and conservation of marine habitats,
ii) improving outcomes for coastal and marine biodiversity and species considered of conservation concern, and
iii) to conserve or restore key coastal and marine habitats to maintain or improve current and future carbon sequestration (e.g., kelp and algal reef ecosystems, and seagrass communities).

Similarly, the recent Hills and Fleurieu Landscape Region Regional Landscape Plan has conservation of natural ecosystems and wildlife as a core function of their 2021–2026 strategy (Hills and Fleurieu Regional Landscape Plan, 2021–2026). Focal areas and success of this latter Plan highlight conservation and protection of estuarine and marine habitats including fish nurseries and marine biodiversity with emphasis on ecosystem health.

Understanding the health and connectivity between ecosystems therefore remains a key driver of these Plans, and together with objectives of the *Landscape South Australia Act 2019* (Division 2, section 7a-f), and reporting on state and national State of Environment provides a valuable mechanism to benchmark success and return for long term financial and ecological investment.

3 Methods

3.1 Selection of reef monitoring sites with data suitable for long term analysis

3.1.1 Background – method compatability

Monitoring of subtidal reefs using underwater visual census (UVC) methods commenced in South Australia in 1996 when the Environment Protection Authority (EPA) funded a “Reef Health” study of Adelaide’s metropolitan reefs by Adelaide and Flinders Universities (Reef Health Program, Gaylard 2003). 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 Fleurieu Peninsula region, some of which are part of ongoing monitoring programs (e.g. current GARR program and marine parks). For a review of these programs see Brock et al. (2017).

The main UVC methods employed to assess subtidal reefs in the AMLR Region have been (Table 1):

- Reef Health (Cheshire et al. 1998)
- Marine Protected Area (MPA) (Barrett and Buxton 2002)
- Reef Watch (Westphalen 2015)
- Reef Life Survey (RLS) (Edgar et al 2016).

All of these methods are based on scuba divers surveying a belt transect and collecting information on the fish, macro-invertebrate and macro-algae communities seen along each transect. For the macro-invertebrate/cryptic fish surveys, there are variations in the suite of species recorded. For example, the Reef Watch program groups a number of species together, the RLS program limits macro-invertebrate species to those with adult size >2.5 cm, and certain bivalves and ascidians recorded for the RLS and MPA programs may not have been consistently recorded for the Reef Health program.

Table 1. Summary of features of the main methods for assessing rocky reefs in the AMLR region. Note that more than one method has been applied at many sites.

Method	Time Series	No. of Sites	Fish	Macro-invertebrates and cryptic fish	Macro-algae
Reef Health	1996-2015	34	Belt survey 250 m^2	Belt survey 50 m^2	Line Intercept Transect (LIT)
Marine Protected Area	2005–2013	45	Belt survey 500 m^2	Belt survey 50 m^2	In situ quadrats
Reef Watch	1996–present	33	Belt survey 250 m^2	Belt survey 50 m^2	LIT
Reef Life Survey (RLS)	2007–present	41	Belt survey 500 m^2	Belt survey 100 m^2	Photoquadrats

Compatibility of data is contingent on the method of collection and degree of training. For the purposes of this report, datasets using the MPA and RLS methods were chosen as the basis for reporting on trends, because:

1. Collectively, they provide the most surveys across the most sites and years.
2. The RLS method evolved from the MPA method and as such the standards and training are consistent between the approaches thus minimising collection bias.
3. The datasets have already been integrated for fish and macro-invertebrate data.

The main challenge with combining the RLS and MPA data is the method of assessing macro-algae. The MPA method records data from an *in situ* quadrat during the survey, and the RLS method uses a photoquadrat that is analysed post-field.

Another difficulty is that the MPA method uses 50 point intercepts to quantify the cover of each taxon, but in a three-dimensional manner that considers each different species as if there were no other species present. The total percentage cover of overlapping species can therefore exceed one hundred per cent (100%). In contrast, post-field analysis of the RLS photoquadrats (using point intercepts or other cover calculation methods) can inherently provide only a percentage cover of the biota that are visible from plan view. There are various ways to normalise the *in situ* quadrat data to a total cover of 100%. The method of Brook and Bryars (2014) was adopted because it is suited to calculating total canopy cover. Where there is only one canopy-forming species, the percentage canopy cover will just be the cover of that species. Where there are multiple species, the two most extreme scenarios are considered: maximum possible spatial overlap of the species, i.e. using the maximum of the different covers for each species; or no overlap between the species, i.e. summing the percentage covers for each species (capped at 100%). These scenarios provide lower and upper bounds, respectively, for the percentage cover as if it had been calculated from plan view, e.g. using a photoquadrat. The mean of the lower and upper bounds can then be used to represent a single value for the canopy cover of each quadrat.

Further to the reasons above for selecting the MPA and RLS datasets for the current report, additional reasons why data from the Reef Health and Reef Watch programs were not considered include:

- there are incompatibilities and uncertainties regarding the suite of species used for macro-invertebrate surveys, particularly for Reef Watch;
- different sampling effort of fish surveys is problematic for diversity measures; particularly for Reef Watch; and
- it would introduce a third method for calculating canopy cover. Although a comparison of data collected simultaneously using the LIT and photoquadrat methods showed that in general there was a strong relationship between canopy cover as estimated by LIT and photoquadrats at site level[1] (J Brook pers. comm.).

Nevertheless, use of the Reef Health data would allow the time series at some sites to be extended, albeit with some modifications to the RLS/MPA dataset used for this report and future investigation of integrating this data is warranted.

[1]There was a tendency for the photoquadrat method to overestimate canopy cover for higher covers (>50%), and to underestimate canopy cover at transect level.

3.1.2 Selection criteria and data reconciliation

A review of existing reef sites identified 102 sites where data had been collected using the rationale described in Section 3.1.1. The criteria for selection of subregions and sites for trend analysis were based on a set of minimum requirements to enable statistical analyses to provide meaningful outcomes. Specifically, the pre-requisites for various analyses were the availability of data for at least:

- Four years of data for that site, and
- three sites per subregion.

There were 42 sites that met the criterion of data availability for at least four years of data per site for fish and macro-invertebrate data, and 38 sites that met the criterion for macroalgal data. The distribution of these sites amongst subregions is shown in Figure 2 (also listed in Appendix A). This discrepancy was generally the result of a lack of post-field analysis of photoquadrat images.

Two-thirds of these sites were in Subregion 4 (Table 2). There were only two sites in Subregion 2 with fish/macro-invertebrate or macro-algal data that met the criteria and only one site in Subregion 1 that met the criteria for macro-algal cover. For the purposes of this study, these subregions (1 and 2) were amalgamated to meet the requirement of three sites per subregion. There were six sites in Subregion 3 for fish and invertebrates, but only three for macro-algae. It has previously been recommended that Subregions 5 and 6 be combined (Brook et al. 2020) and this has been done to ensure there were a minimum of three sites for analysis.

Table 2. Summary of sites per subregion with data for at least four years.

	Number of sites	
Subregion	**Fish/macro-invertebrate data**	**Macro-algal data**
1 Northern	3	1
2 Metro	2	2
3 Southern Metro	6	3
4 Central Fleurieu	25	25
5/6 Southern Fleurieu/South Coast	3	3
7 Encounter Bay	3	3

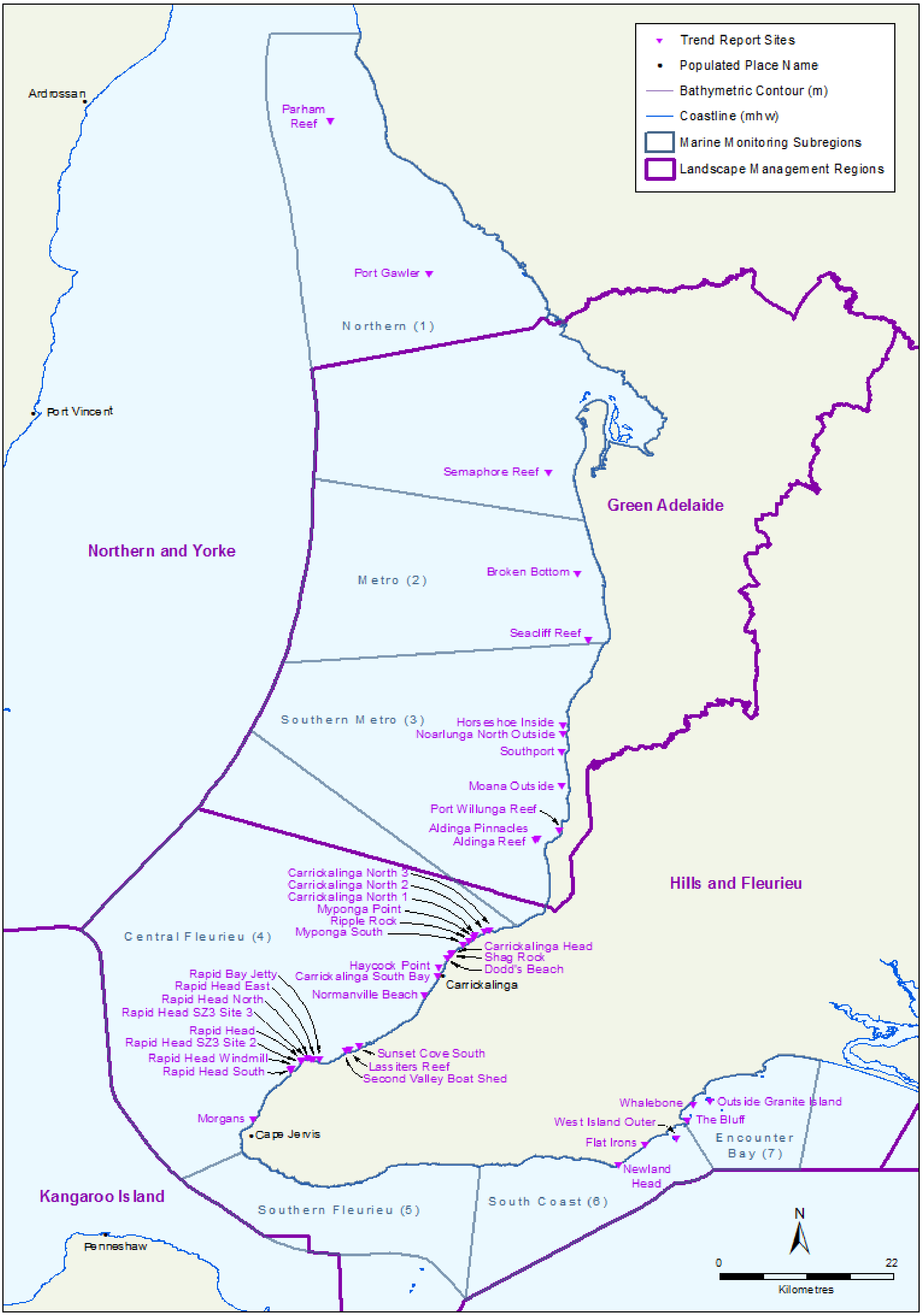

Figure 2. Map showing the distribution of 42 sites used for the analysis of trends of temperate reef indicators across eastern Gulf St Vincent and Fleurieu Peninsula.

3.2 Indicators to inform Reef status

3.2.1 Rationale

A range of indicators of reef condition were selected to assess the status of subtidal reefs across the subregions. The indicators were chosen based on the recommendations from the previous review of reef monitoring in the AMLR region (Brock et al. 2017 pp. 67-68) as well as to align with the subtidal reef conceptual models developed as part of the GARR program (Imgraben et al. 2019). The conceptual models identified sedimentation, nutrients and extractive resource use (e.g. fishing) as the main pressures on subtidal reefs in the Fleurieu region. Climate change was explicitly recognized as a longer term pressure that can be captured through the Reef Fish Thermal Index (RFTI) (Waldock et al. 2019). The indicators chosen are consistent with those used nationally and internationally to describe the status of temperate reef ecosystems, and are as follows:

- community structure of fish and mobile invertebrates.
- reef fish thermal index (RFTI).
- species richness of fish and macro-invertebrates.
- percent cover of canopy forming macro-algae.
- biomass of large fish.
- biomass of targeted fish.
- size and abundance of focal species.

3.2.1 Definition and context of indicators

Descriptions of the indicators adopted for this report are provided below, with detail on their calculation provided in Appendix B.

Species richness of fish and macro-invertebrates

Species richness is the total number of species recorded and is a measure of ecosystem biodiversity. Higher species richness is an indicator of higher biodiversity. Maintaining biodiversity is often a key requirement of Natural Resource Management and is important because loss of biodiversity reduces ecosystem resilience and function and can compromise ecosystem services (Duffy et al. 2016).

Community structure of fish and macro-invertebrates

Community structure is defined as what species are present in a given location, in what numbers and how they relate to each other. Examination of community structure is a powerful tool for examining changes through time; including recovery from disturbance and change in trophic status. Research has shown that protected marine communities can revert to a state quite different from unprotected ones (Edgar et al. 2009). Community structure is assessed using multivariate statistical techniques to display species assemblages across sites in multidimensional space (Clarke 1993).

Reef Fish Thermal Index

Reef Fish Thermal Index (RFTI) is a measure of the average thermal affinity of communities (Bates et al. 2014, Stuart-Smith et al. 2015). Most communities are comprised of species with a broad range of thermal distributions. One of the potential outcomes of global warming is the replacement of cooler-affinity species with warmer ones. Well managed and intact systems are predicted to improve resilience in some cases and therefore buffer ecosystems to some extent, from the impacts of external drivers such as climate change. A recent study has shown that diverse, intact communities are less affected by rising temperature than less diverse ones (Duffy et al. 2016). RFTI can be used to measure community responses to climate change.

Size and abundance of targeted fish species (biomass of targeted fish)

Targeted species (Appendix C) often come from higher trophic levels (e.g. snapper, kingfish, harlequin fish) and these fish can be extremely important in regulating ecosystems as they can exert top down control by reducing prey numbers (Baum and Worm 2009, Boyce et al. 2015). Measuring the size and abundance of targeted fish species by commercial and recreational fishers will give an indication of harvesting levels. For the purposes of this report targeted fish species are considered to be those species actively sought by recreational or commercial fishers.

Size and abundance of large fish (biomass of large fish)

Large fish are prized by both commercial and recreational fishers and are often caught in disproportionately high numbers. Larger fish play an important role in structuring communities as they consume larger prey and have much higher fecundity than smaller fish resulting in the production of disproportionately higher numbers of recruits than smaller fish (Berkeley et al. 2004, Sato and Suzuki 2010). A reduction in the number of large fish can contribute to reduced ecosystem function and resilience. Large fish sometimes referred to as B20 are defined here as fish >200 mm and this measure has been demonstrated to be a robust indicator of fishing pressure (Stuart-Smith et al. 2017).

Percent cover of canopy forming macro-algae

Large, brown canopy-forming macro-algae, defined here as species from the orders Laminariales (kelps) and Fucales, are important within temperate marine ecosystems for primary productivity and creating habitat complexity in support of substantial faunal communities (Turner et al. 2007). Due to their central role in a range of ecological processes, the loss of canopy forming algae is likely to lead to the significant loss of associated species and ecological function (Gaylard et al. 2013). These taxa have also been shown to be susceptible to declining water quality (e.g. Cheshire and Westphalen 2000, Gorgula and Connell 2004, Turner 2004).

Size and abundance of focal species

Individual species can be important for a range of reasons. They may be keystone species, critical to ecosystem functioning (e.g. rock lobsters, kelp *Ecklonia radiata*), iconic species valued by divers (e.g. blue groper, leafy sea dragon), fishes of conservation concern (e.g. blue devil), highly sought after recreational species (e.g. sweep, snapper), or vulnerable species less resilient to environmental change. Such species may be locally acknowledged and have aesthetic value, may be valued both culturally and by those that may never observe them in the wild but provide a sense of well-being and for some, a sense of place and identity.

The size and abundance of focal species are relatively easy to measure, which can provide opportunity to assess management actions and promote reef ecosystem health. Given the nature and connectivity people have for iconic or focal species, assessing changes in abundance and documenting new occurrences in their distribution can generate useful information to build knowledge in the community. It should be noted that RLS methods provide data on a range of individual species and focal species.

3.3 Approach to analysis of indicators

3.3.1 Analysis of mutivariate indicators

Temporal changes in fish and invertebrate communities were analysed using non-metric Multidimensional Scaling (nMDS). These analyses were run in the software program R (R Development Core Team 2019) using the 'metaMDS' function in the R package 'vegan' for community analysis. The main advantage of nMDS is to reduce multidimensional patterns (e.g., driven by multiple species) to two or three dimensions, showing patterns of similarity over time and space. MDS was used to investigate differences in community structure between sites within subregions and between successive survey years.

Multivariate data (abundance-by-site matrices for fish and invertebrate communities) were converted to a Bray-Curtis distance matrix relating each pair of sites after square-root transformation. This transformation was applied to down-weight the relative importance of the dominant species at a site, and to allow less abundant species to also contribute to the plots. nMDS was followed up with Permutational Multivariate Analysis of Variance (PERMANOVA) (function 'adonis' in R package 'vegan') to test the significance of spatial differences in community structure (i.e., between subregions) and temporal differences (i.e., between years).

3.3.2 Temporal trends in univariate indicators

Temporal trends in univariate indicators (such as fish or invertebrate species richness, large fish biomass etc.) within each subregion were modelled using Generalized Additive Linear Models (GAMMs) (Wood 2004). GAMMs attempt to fit a smooth term (spline function) to the data, and thus to capture any year-to-year fluctuations over the time series. GAMMs were fitted with a 'year' fixed effect and a 'site' random effect to account for the hierarchical structure of the dataset (i.e., transects nested within sites in each subregion). Only sites with at least 4 years of survey were retained for the analysis to ensure the reliability of inferred temporal trends. GAMMs were calibrated in R using the 'mgcv' package.

In addition to identifying any temporal fluctuations in univariate indicators, we identified any linear trend (i.e., increase or decrease) in ecological indicators over the last five years using Generalized Linear Mixed-effect Models. Where significant, the slope associated with the 'year' fixed effect was reported, with a positive slope indicating an increase in the indicator over the last five years, and a negative slope indicating a decrease.

4 Results

4.1 Community change through time

4.1.1 Fish community change

Fish communities were strongly structured spatially, with the subregion explaining 24% of the variation in fish community structure, and the survey year explaining an additional 4% of the total variation (PERMANOVA; P <0.001; Appendix D). This spatial structure was also evident in the nMDS site ordination (Figure 3), whereby the ellipses corresponding to each subregion were ordered along the first nMDS axis (yet largely overlapping for subregions 5, 6 and 7). Year-by-year trajectories of fish community structure (trajectories in ellipses) at the subregion level were mostly contained within each ellipse, except for years 2014 and 2015 in subregion 3 (labelled in Figure 3). The species contributing (>20% dissimilarity) to patterns in subregions ellipses in Figure 3 are shown in Figure 4 with accompanying pictures of some species in situ for context (Figure 5). The latter years were mostly explained by a lower abundance of Parapriacanthus elongatus (elongate bullseye) and greater abundance of Scorpis aequipinnis (sea sweep) in 2014; and conversely, a lower abundance of Scorpis aequipinnis and a greater abundance of Parapercis haackei (wavy grubfish) in 2015 (Figure 4). These abundance shifts nevertheless reverted to the long-term average community structure in the following years and no evidence of consistent 'drift' in community composition was observed.

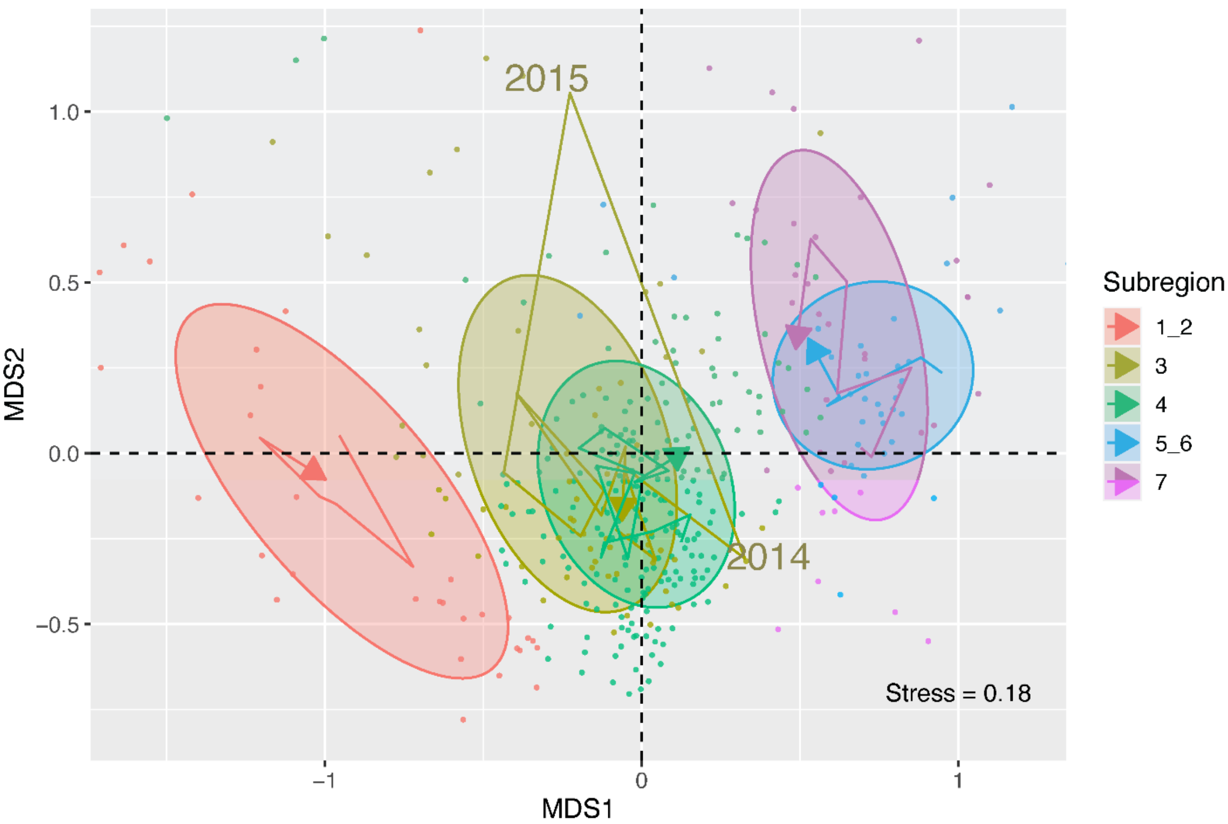

Figure 3. Non-metric multidimensional scaling of fish communities, showing distribution of sites along two MDS axes. Dots indicate the site-by-year community structure and are colour-coded by subregions. Ellipses indicate the standard deviation of all sites and years within each subregion. Trajectories indicate the mean community structure for each subregion and in each year.

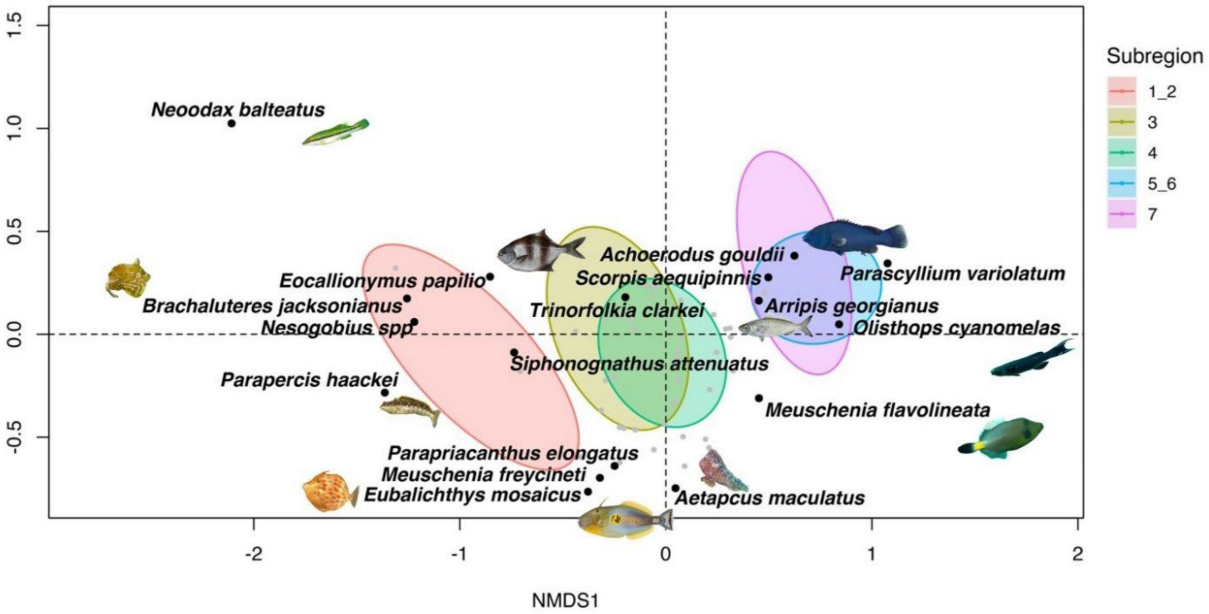

Figure 4. Species scores associated with non-metric multidimensional scaling shown in Figure 3. For clarity, labels are shown for species with best fit to the ordination plot for each subregion, i.e. species that explain >20% of total dissimilarity (shown as black dots, grey dots are those species <20% total dissimilarity). Ellipses indicate the standard deviation of all sites and years within each subregion.

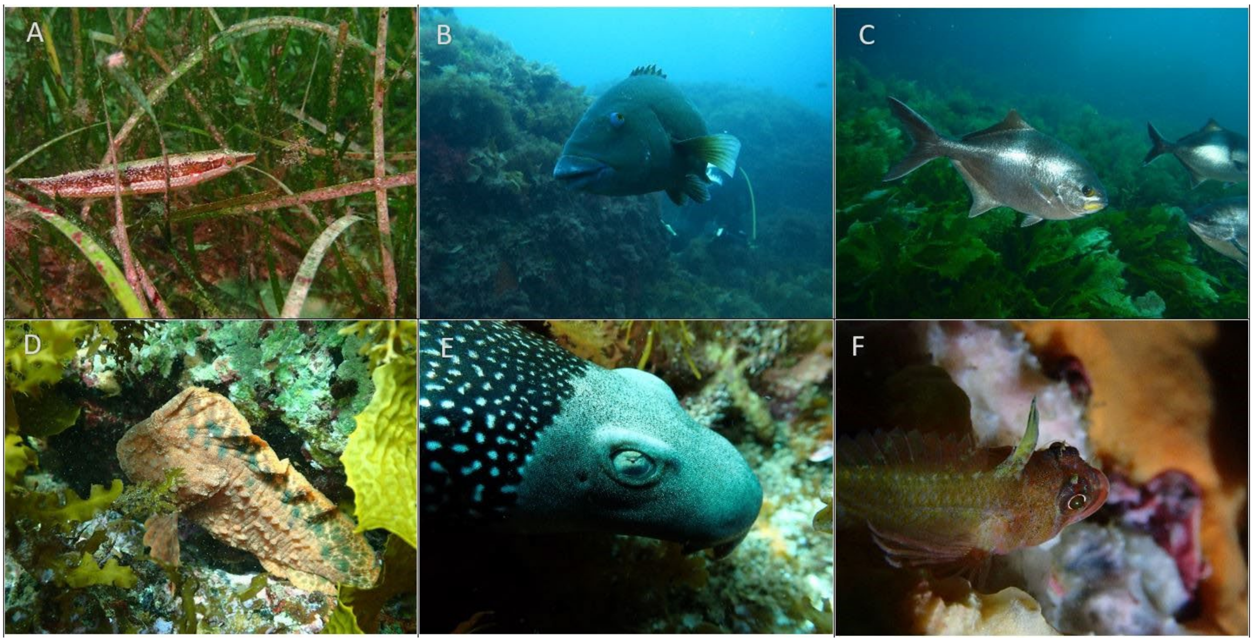

Figure 5. Examples of bony fish and elasmobranch species listed in Figure 4 which are indicative of subregion community structure; A) Little Weed Whiting (*Neoodax balteatus*); B) Western Blue Groper (*Achoerodus gouldii*); C) Sea sweep (*Scorpis aequipinnis*); D) Warty prowfish (*Aetapcus maculatus*); E) Varied carpetshark (*Parascyllium variolatum*) and F) Common threefin (*Trinorfolkia clarkei*).

4.1.2 Macro-Invertebrate community change

Invertebrate communities were also structured spatially, with the subregion explaining 25% of the variation in fish community structure, and the survey year explaining an additional 6% of the total variation (PERMANOVA; *P* <0.001; Appendix E). Like fish community structure, ellipses corresponding to each subregion were primarily ordered along the first MDS axis, with a proportion of overlap for subregions 3 and 4; and 5, 6, and 7 respectively (Figure 6). Stress values were calculated in two and three dimensions (3D stress = 0.18), with the, 2D plots based on the first two axes shown as Figures 6 and 7 and 3D ordination shown in Appendix F. Years identified as outliers (i.e., outside of ellipses corresponding to each subregion) were 2008 and 2014 for subregion 3. The species contributing (>20% dissimilarity) to patterns in subregions ellipses in Figure 6 are shown in Figure 7 with accompanying pictures of some species in situ for context (Figure 8). In 2008, communities of subregion 3 had particularly high abundances of *Dicathais orbita*, and relatively low numbers of *Haliotis* spp. and *Haliotis rubra* (blacklip abalone). Conversely, in 2014 these communities had higher numbers of *Goniocidaris tubaria* (pencil urchin) and *Pentagonaster dubeni* (firebrick star) (Figure 7). A consistent "drift" in community composition towards the negative side of the first axis appeared for subregions 1, 2, 5, 6 and 7, but will need to be confirmed once future data are available.

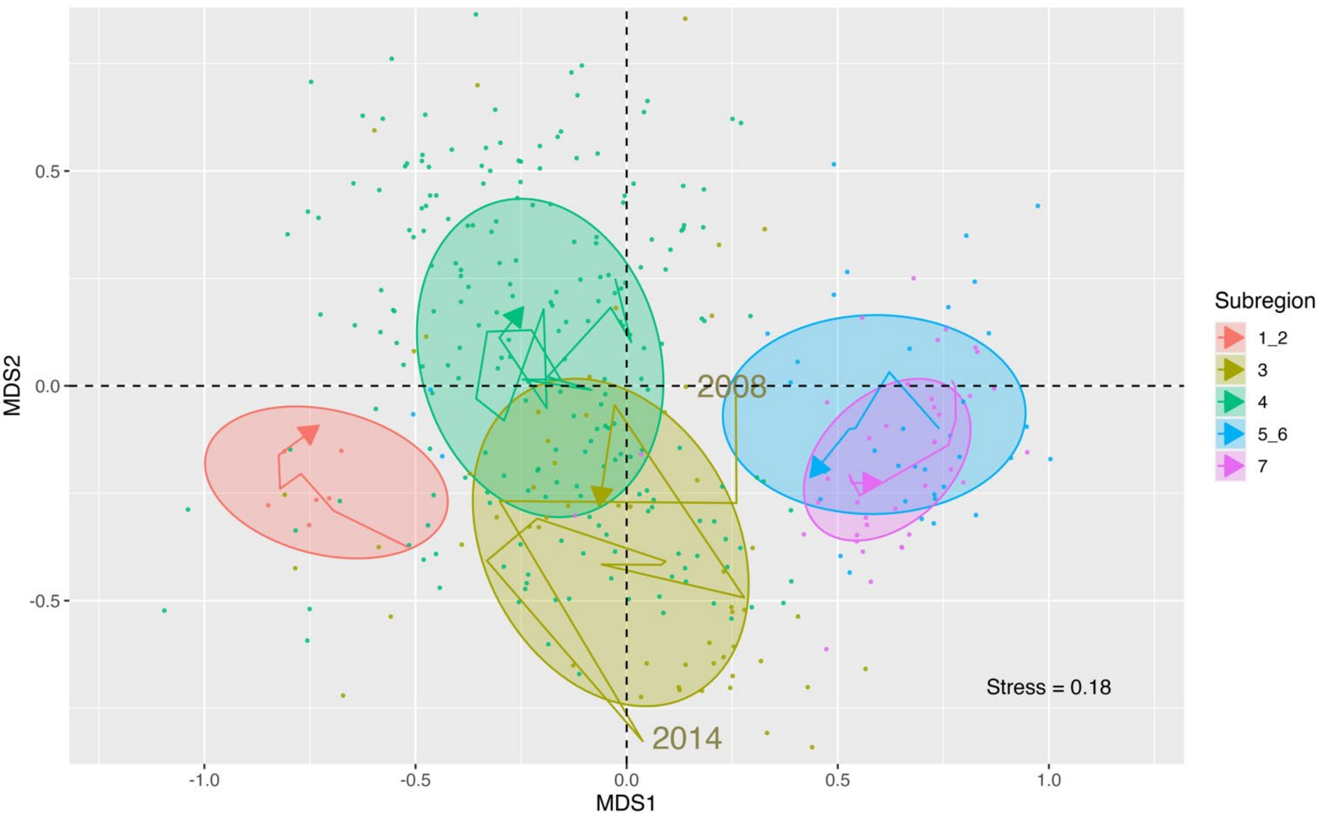

Figure 6. Non-metric multidimensional scaling of macro-invertebrate communities, showing distribution of sites along two MDS axes. Dots indicate the site-by-year community structure and are colour-coded by subregions. Ellipses indicate the standard deviation of all sites and years within each subregion. Trajectories indicate the mean community structure for each subregion and in each year.

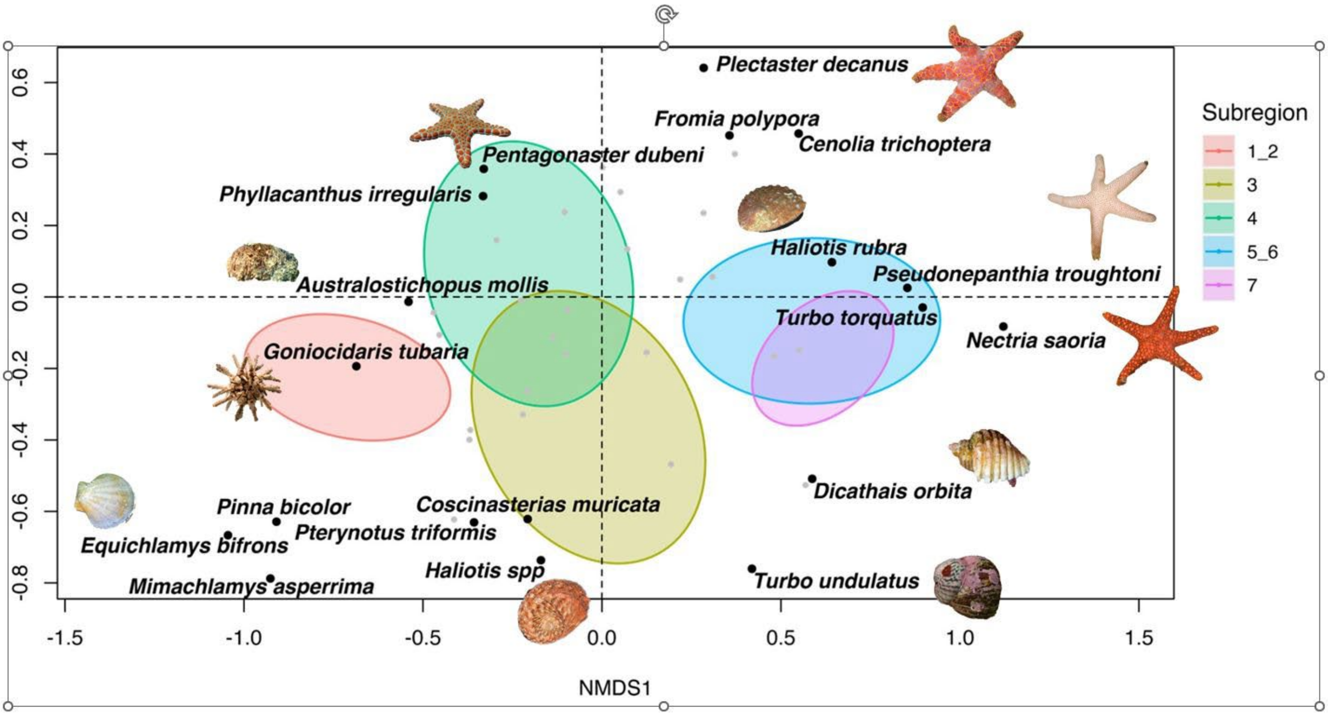

Figure 7. Species scores associated with non-metric multidimensional scaling shown in Figure 6. For clarity, labels are shown for species with best fit to the ordination plot for each subregion, i.e. species that explain >20% of total dissimilarity (shown as black dots, grey dots are those species <20% total dissimilarity). Ellipses indicate the standard deviation of all sites and years within each subregion.

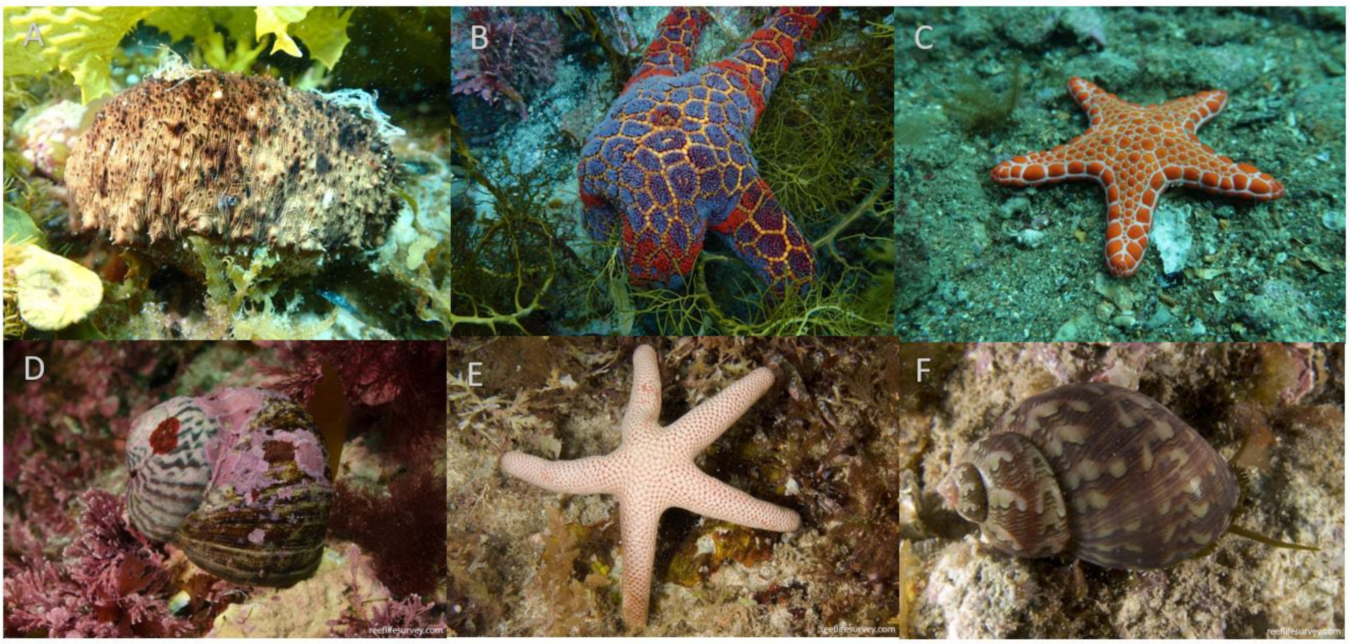

Figure 8. Examples of macro-invertebrate species listed in Figure 7 which are indicative of subregion community structure; A) Sea Cucumber (*Australostichopus mollis*); B) Mosaic seastar (*Plectaster decanus*); C) Fire-brick star (*Pentagonaster dubeni*); D) Turban Shell (*Turbo undulatus*); E) Troughtons seastar (*Pseudonepanthia troughtoni*) and F) Pheasant Shell (*Phasianella ventricosa*).

4.2 GAMM analysis of trends in key indicators

4.2.1 Fish species richness

Fish species richness increased over the last five years in subregions 1and2 and decreased slightly in subregion 3 (Figure 9; Table 3 ; $P < 0.05$). Temporal trends in fish species richness appeared relatively stable in subregions 4, 5, 6, and 7, however fewer data were available there, potentially explaining the non-detection of any significant trends (Figure 9; Table 3 ; $P > 0.05$).

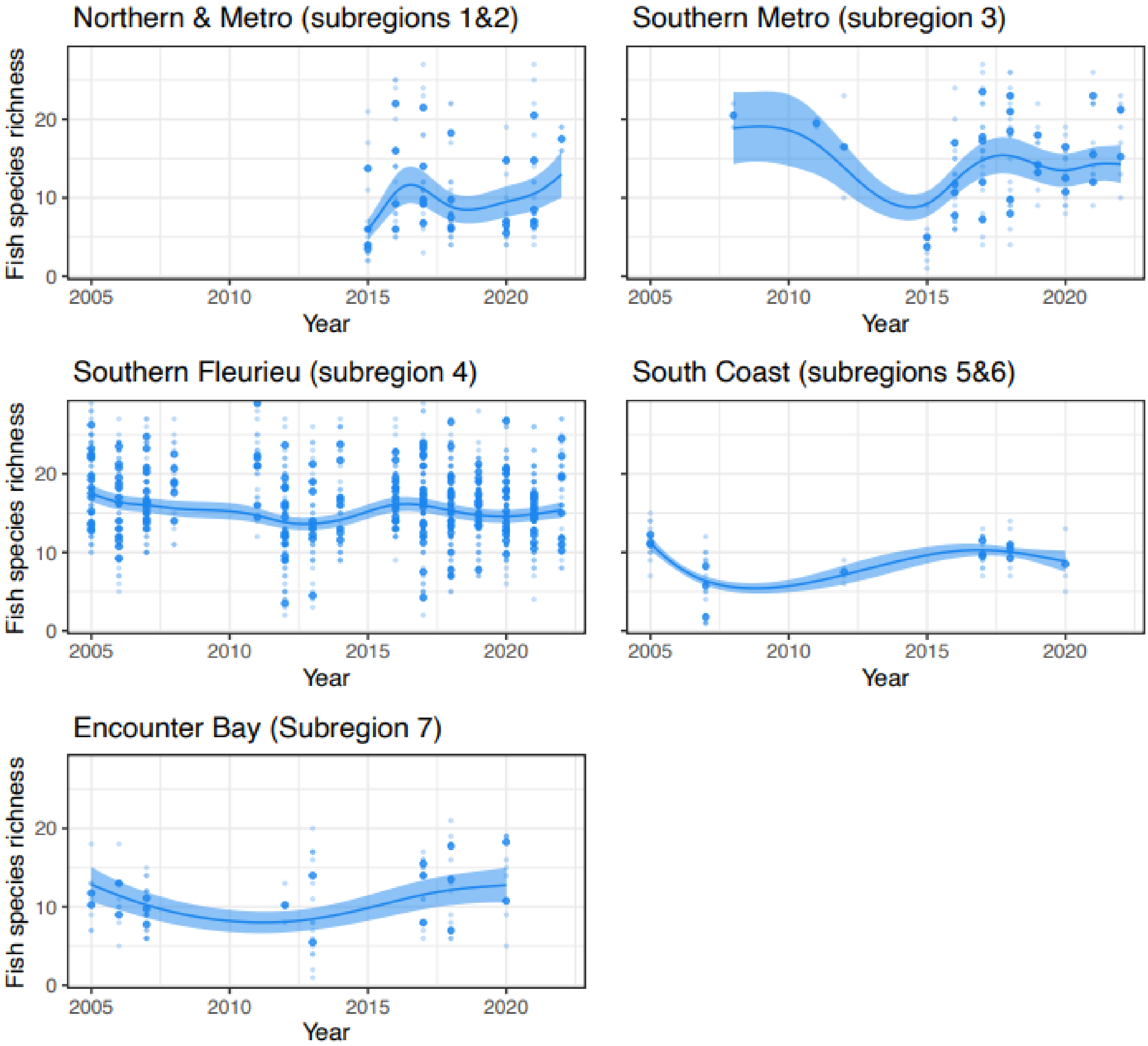

Figure 9. Temporal trends in fish species richness within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines, with envelopes indicating 95% confidence intervals.

4.2.2 Macro-Invertebrate species richness

Temporal trends in invertebrate species richness were variable across the region. There was a significant decrease in macro-invertebrate richness since 2015 in subregions 1 and 2 and an increase in subregions 4, 5and6 and 7, (Figure 10; Table 3 ; $P < 0.05$). Macro-invertebrate species richness remained stable in subregion 3, however recent years indicate a declining trend in the number of macro-invertebrate species in this subregion.

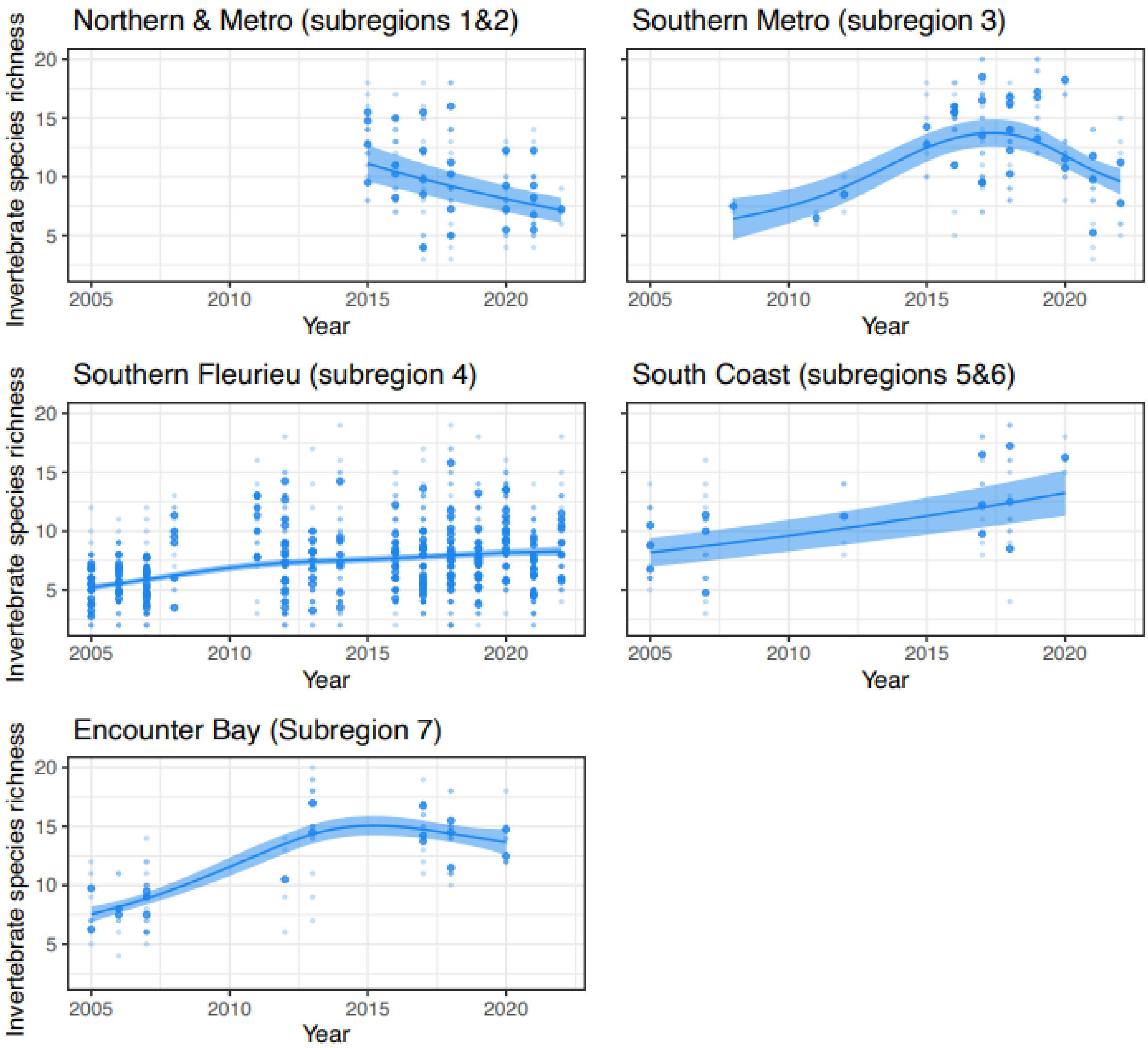

Figure 10. Temporal trends in invertebrate species richness within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines, with envelopes indicating 95% confidence intervals.

4.2.3 Large fish biomass (B20)

Large fish biomass (B20) was relatively stable across the region. There was a significant decline in large fish biomass (B20) in subregion 4, however all other subregions showed no significant trend in change of large fish biomass (Figure 11; Table 3 ; *P* <0.05).

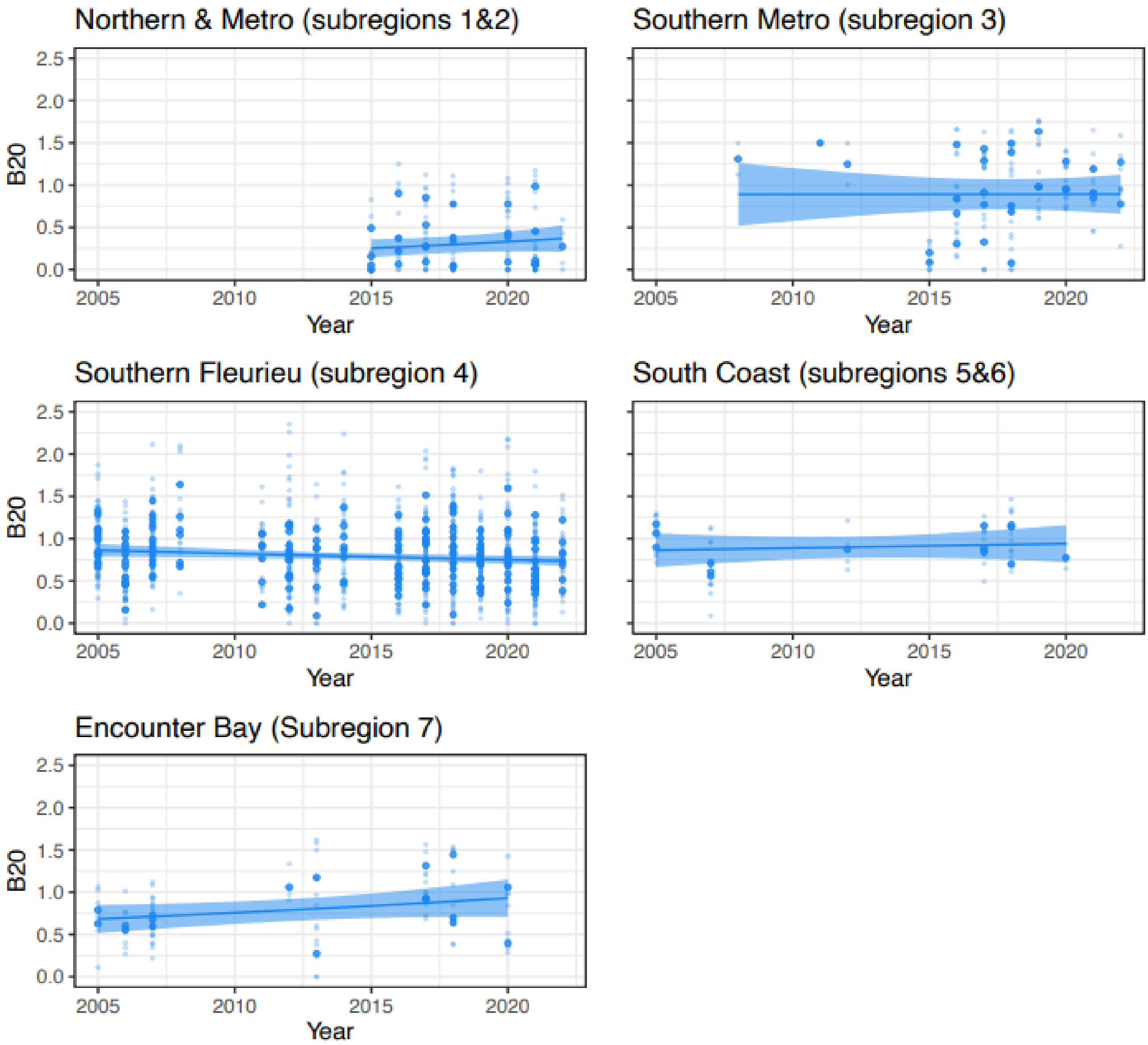

Figure 11. Temporal trends in large fish biomass (*B20*) within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines, with envelopes indicating 95% confidence intervals.

4.2.4 Targeted fish biomass (BTarget)

Temporal trends in targeted fish biomass (Btarget) largely reflected those in large fish biomass. Targeted fish biomass was stable across the region showing no significant increase or decrease in any of the subregions (Figure 12; Table 3 ; $P < 0.05$).

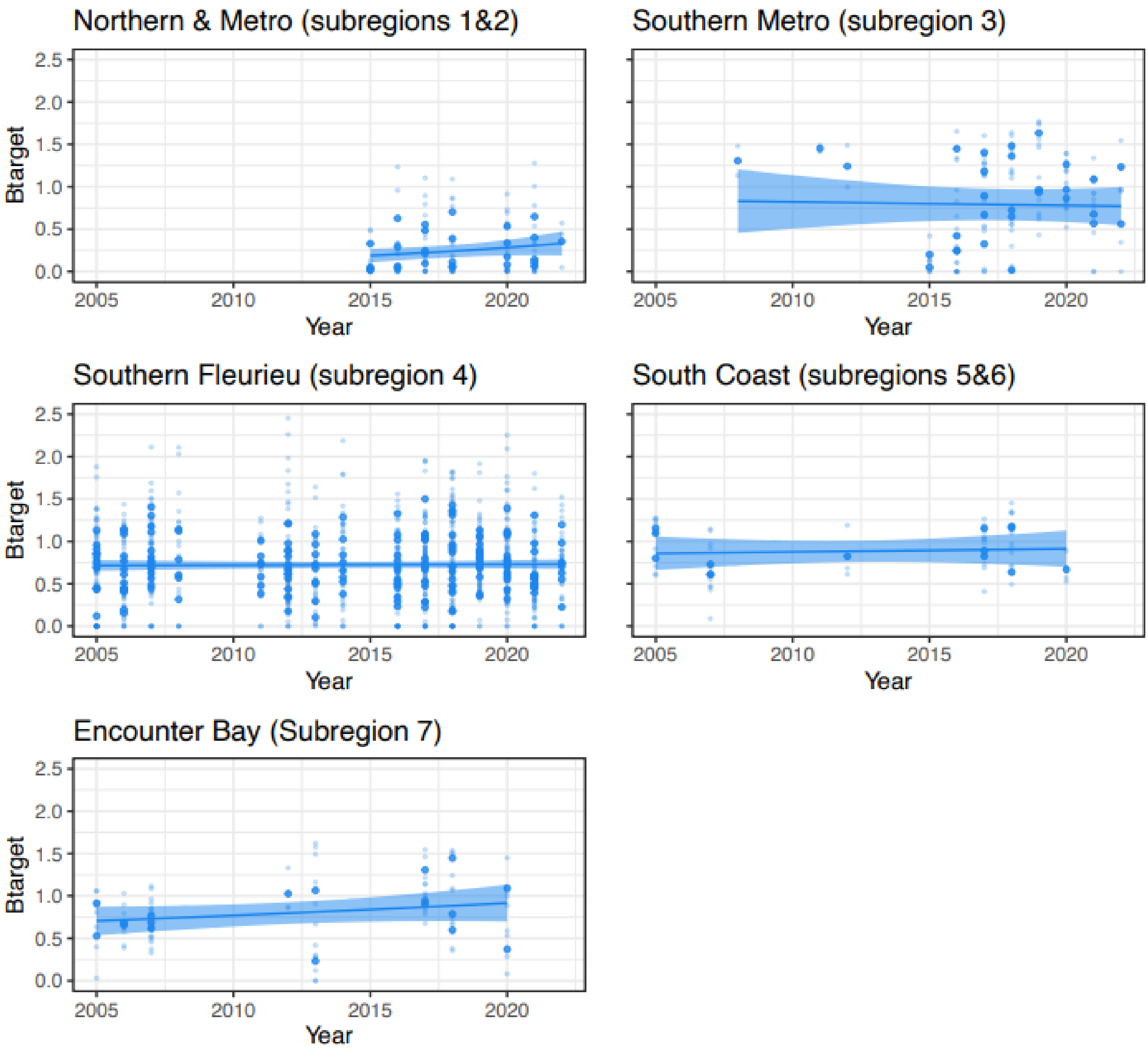

Figure 12. Temporal trends in targeted fish biomass (*Btarget*) within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines, with envelopes indicating 95% confidence intervals.

4.2.5 Percent cover of canopy-forming algae

Trends in the percent (%) cover of canopy-forming algae across the region were stable or increasing. There was no significant trend in canopy cover in subregions 1and 2 or 3 while percent canopy cover increased in subregions 4, 5and6 and 7 (Figure 13; Table 3 ; *P* <0.05).

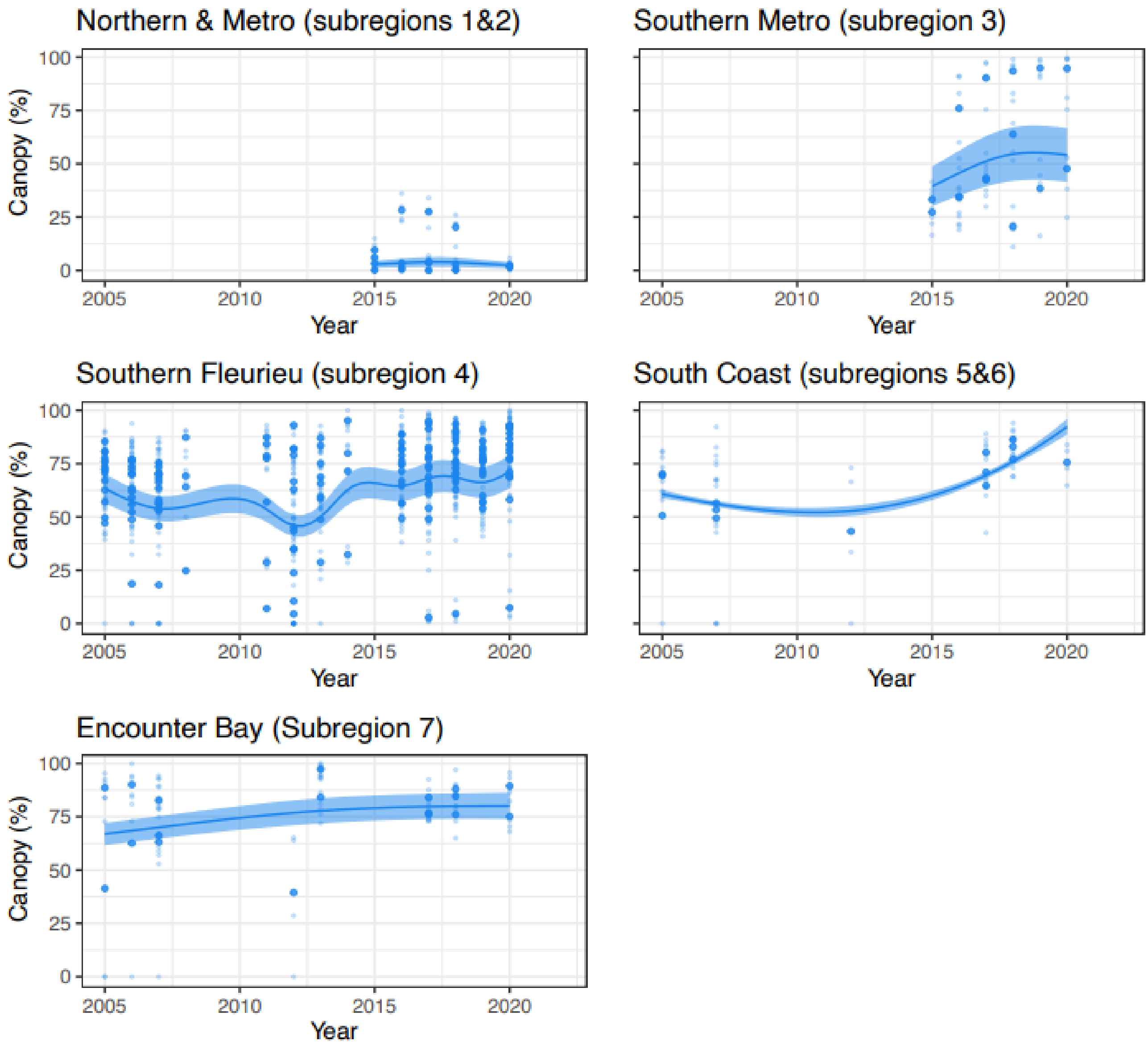

Figure 13. Temporal trends in the percent cover of canopy-forming algae (*Canopy*) within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines, with envelopes indicating 95% confidence intervals.

4.2.6 Reef Fish Thermal Index (RFTI)

RFTI was mostly stable over the time period assessed (Figure 14; Table 3 ; *P* <0.05). Slight increases in RFTI were observed in subregions 1 and 2, 5 and 6, and 7 over the entire study period (Figure 14) but these were not significant based on the most recent data (Table 3 ; *P* >0.05).

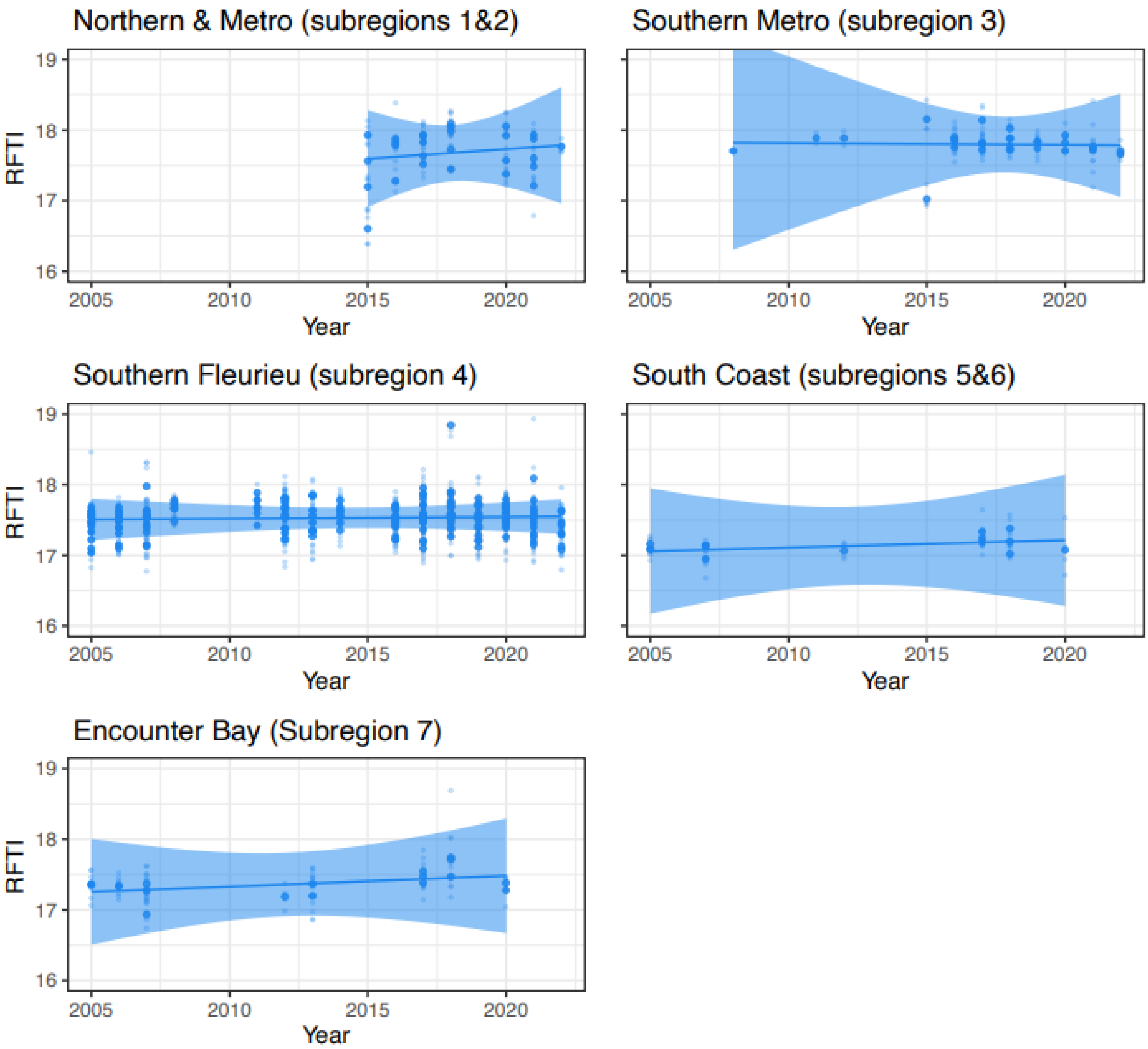

Figure 14. Temporal trends in the reef fish thermal index (*RFTI*) within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines, with envelopes indicating 95% confidence intervals.

Table 3 . Temporal trends in univariate ecological indicators between 2015 and 2020. Numbers represent the slope associated with the 'year' fixed effect of generalized linear mixed-effect models fitted to each indicator. Therefore, positive slopes indicate a significant increase in a given indicator, while negative slopes indicate a significant decrease (*P* <0.05). Non-significant slopes (*P* >0.05) are shown as zero.

Subregion	Fish species richness	Invertebrate species richness	Large fish biomass	Target fish biomass	% Canopy cover	Reef fish thermal index
1&2	0.022	-0.023	0	0	0	0
3	0	0	0	0	0	0
4	-0.002	0.01	-0.002	0	0.01	0
5&6	0	0.013	0	0	0.025	0
7	0	0.018	0	0	0.019	0

4.2.7 Summary of main indicators across regions

A visual summary of fish and macro-invertebrate richness, large fish biomass and percent cover of macro-algae is presented in Figure 15. A basic key based on Table 3 is used to depict whether the indicator significantly increased, decreased, or remained unchanged. In most cases, the trend was stable or increasing across all indicators and subregions (Figure 15). Each positive or negative slope indicates a significant increase or decrease in a given indicator (P <0.05) and non-significant slopes (*P* >0.05) are shown as zero. For example, fish species richness: stable (subregion 3, 5 and 6, and 7), increasing (subregion 1 and 2), and decreasing (subregion 4).

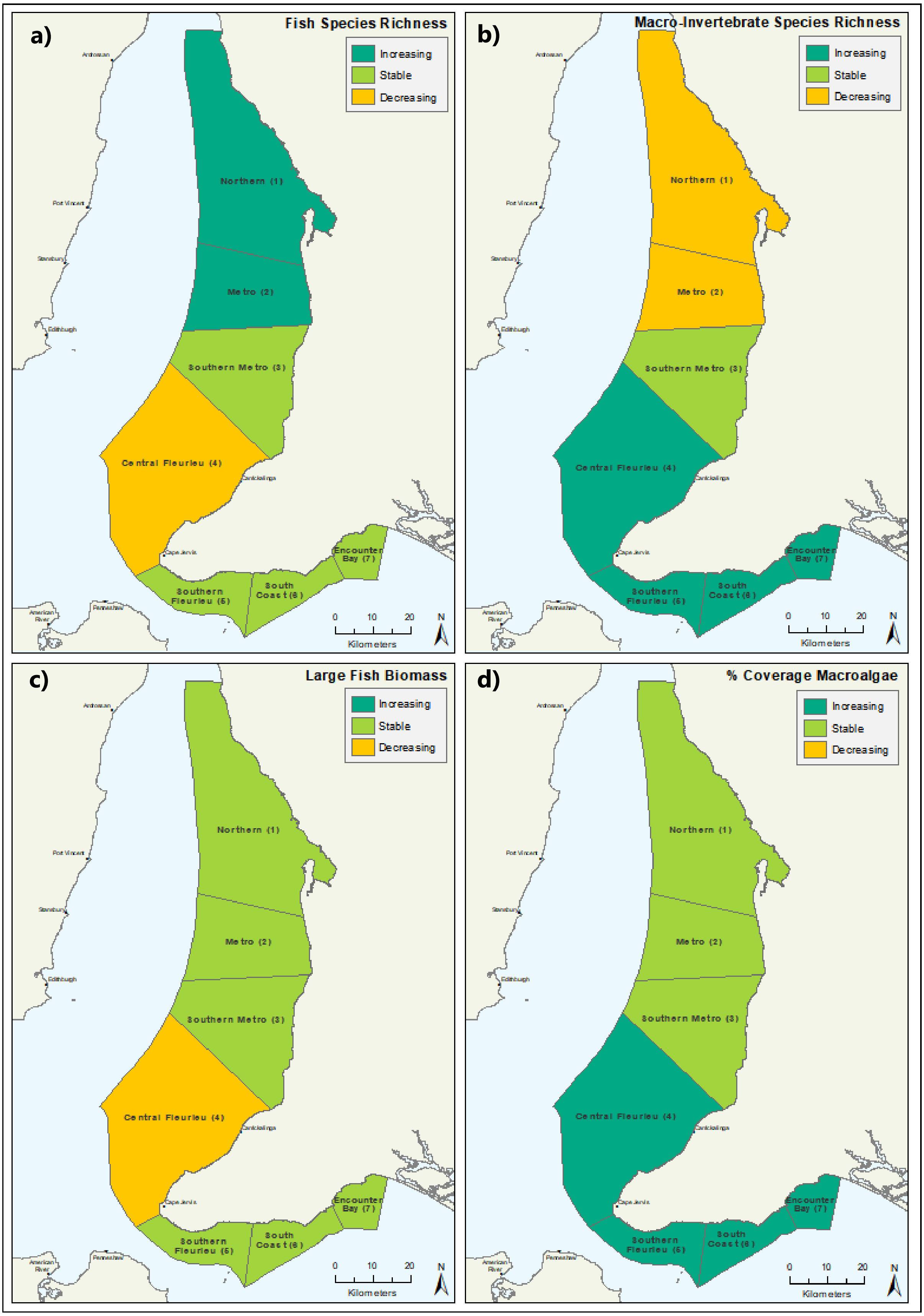

Figure 15. Map series showing trends in indicators; a) fish species richness, b) macro-invertebrate species richness, c) large fish biomass and d) macro-algal cover. Trends in indicators (increasing, decreasing, stable) are based on GAMM analysis outputs across the subregions (Table 3).

4.2.8 Trends in focal species abundance and biomass

While the RLS method captures information on over 100 different species of fish, the abundance of any one species is highly variable. Blue throat wrasse (*Notolabrus tetricus*) is one of the most abundant focal species recorded by number. Assessment of temporal trends in the abundance of blue throat wrasse and other focal species was attempted, however, it was not possible due to the sparse nature of the data and high degree of zero-inflation that is typical of single-species records (e.g., Appendix G). Other methods will therefore need to be considered to monitor populations of focal species (i.e. those that are iconic species or are of conservation concern).

5 Discussion

5.1 Overview

The results of this study are based on over 18 years of data spanning the entire eastern Gulf St Vincent and Fleurieu coasts that encompass the current Green Adelaide and Hills and Fleurieu Landscape regions (formerly the Adelaide and Mount Lofty Ranges region). This represents the longest, most comprehensive, and consistent marine biodiversity dataset in South Australia and provides the basis for examining long term trends in the status of subtidal reef systems in the region for the first time.

The major finding of this study is that, in general, the status of subtidal temperate reefs across the Adelaide and Fleurieu regions appear to be stable and, in some instances, improving. Trends in most of the indicators chosen to assess reef health in each subregion were consistent over time or increasing, with only two subregions indicating declines in invertebrate and fish richness and large fish biomass (subregions 1 and 2 and 4, respectively, Figure 11). This conclusion was supported by the results from the multivariate analyses of fish assemblages which showed largely no directional change in composition or structure, however, there was some indication of directional shifts in invertebrate communities in some subregions.

These results are particularly encouraging given the declines in macroalgal cover and concerns over reef health documented in other studies of reef sites in the region and more generally for temperate reef ecosystems found elsewhere in Australia (Connell 2008, Turner 2007, Edgar et al. 2023). The stabilization of macro-algal cover and in some instances potential increase may be related to significant improvements to water quality since the 1980s associated with ceasing sewage sludge outfalls to the marine environment, changes to waste-water treatment and removal of nutrient inputs since the 1980s (Meakin et al. 2023 in press).

Edgar et al. (2023) recently showed that temperate reef species, particularly some fish and macro-invertebrates, were declining across southern Australia and because of their deep phylogenetic roots and lack of suitable refuges, are particularly sensitive to climate change. Sea surface temperature anomalies are also known to contribute to changes in distribution of species, which, for the east and west coasts of Australia, have been associated with the southward movement and expansion of tropical species and contraction in range of others (Gervais et al. 2021). Contemporary range shifts in marine species also generally progress over longer temporal scales and require extensive baselines to detect change (Champion et al. 2021). The results of the current study showed that fish community structure based on temperature affinity measured as Reef Fish Thermal Index has overall, not changed. This is supported by the temporal and spatial extent of the datasets (~10–18 years) and mostly stable state of the other indicators observed. Temperate reefs within the Gulf St Vincent part of the study area experience significant seasonal temperature and salinity variations (Bye et al. 2008) that may inadvertently provide some adaptive resilience to potential ocean warming. Notwithstanding, increases in sea surface temperatures over time may override such temperate reef thresholds and species tolerances inducing distributional change (e.g., southward movement).

Our study has shown the importance of how integrating historical reef data can be important to creating long term datasets to assess trends in reef status (see Brock et al. 2017, Brook et al. 2020) and that such an approach can provide the resolution to account for natural variability in long term temporal and spatial patterns. Previous biodiversity studies show temperate reefs in the region have high inter-annual and intra-site variability (Turner et al. 2007, Brook and Bryars 2014) which have been useful to determine similarities and differences at smaller spatial scales (Brook, 2018). However, multi-site datasets are needed to see 'past' the natural variability to assess the long-term trends. In this study, broader spatial trends were calculated from means and their confidence limits across many sites within each subregion for the range of indicators. It did show there are limitations in the availability of time series, indicator data, and number of sites that are available or met the minimum requirements for the analyses, which has meant trajectories for some subregions (and sites) are preliminary. For example, subregions 1 and 2 have a reduced time series of 8 years compared to subregions 3 – 7. There is also variation between subregions in the number of sites available for including in analyses (subregions 1–3 ~3 sites c.f.

subregion 4, >20 sites). In contrast, subregion 4 has both a longer time series and the largest number of sites than any other subregion, with indicators exhibiting narrow confidence intervals and the most stable and consistent trends. It is anticipated that with continued investment and monitoring, there will be improved robustness to predict trends in subregions with shorter time series, fewer sites and less indicator data.

5.2 Community structure

The partitioning of the study area into eight subregions based on geophysical characteristics such as exposure, sea surface temperature and other reef structural data (Brock et al. 2017), enabled greater resolution in identification of longer-term differences in the community structure of fish, invertebrates, and algal communities. Analysis of fish and macro-invertebrate biodiversity showed a strong gradient of community structure in line with changes in latitude when moving from north to south along the coast. This gradient becomes weaker when moving in an easterly direction from Cape Jervis to Victor Harbor. This is expected as the strongest environmental gradients in water temperature and wave energy operate in a north-south gradient within GSV and was documented in a report establishing a biodiversity baseline for the region (Brook et al. 2020).

Fish assemblages appeared relatively stable within each subregion with little evidence of directional shift in community structure over time. However, for macro–invertebrate communities there was some evidence of a consistent ‘drift’ in community structure for most subregions over time. Macro-invertebrate communities in all subregions except subregion 4 appeared to show similar directional shifts in community structure. This could be indicative of environmental changes for benthic invertebrate communities within the subregions, however, ongoing monitoring is required to confirm that this not a random statistical effect. Macro-invertebrates play critical roles in marine ecosystems such as nutrient recycling, restructuring habitat, and providing food resources, and as such are considered good indicators of environmental change. A recent global study of temperate reef ecosystems (Edgar et al. 2023) indicated that temperate marine invertebrate communities had undergone the most change over the last 10 years with significant reductions in their abundance and community structure suggesting a tendency to be of high extinction risk.

5.3 Biodiversity indicators

Fish biodiversity, as indicated by the number of species present or species richness, was stable or increasing in all subregions apart from subregion 4 that showed a decrease in fish species richness. This result is unexpected as the latter subregion contains several marine park sanctuary zones and protection from fishing generally maintains or enhances species richness (Edgar et al. 2017). The decline of large fish biomass also observed in the subregion could be correlated. Interestingly, this subregion had a significant increase in the diversity of invertebrate communities. The trend in this subregion appears to have been stable since 2019 (past 5 years) suggesting the importance of continued surveys using these indicators to improve resolution of the current trajectory to determine whether this represents natural variation or disturbance.

As for fish, invertebrate species richness was stable or increasing in all subregions apart from subregions 1 and 2 which exhibited a decline. For the latter, this appears rapid and could either indicate natural variability or a significant level of disturbance. The low number of available sites to survey and the frequency of data collected in this region, especially subregion 1, may be a contributing factor to this outcome. This is apparent from the baseline study of temperate reefs in the northern region of the GSV conducted in 2017–2020 (Brook et al. 2020). It indicated that mean transect invertebrate species richness was considerably lower in subregion 1 (2 sites) than all other subregions except Yankalilla Bay (subregion 4). In addition, Port Gawler (sub region 1) has previously exhibited very low invertebrate richness and may be a contributor to this result (Brook et al. 2020). This contrasts with the trajectory for invertebrate richness in subregion 4 (Yankalilla Bay), which has many sites available for the analysis and appears to be increasing Nevertheless, rapidly declining invertebrate populations could be alarming given the important trophic role such species provide to temperate reefs. Continued surveys to improve the temporal resolution is critical to explore such trajectories and warrants further investigation.

5.4 Habitats

Temperate reefs are generally dominated visually and in terms of biomass by large canopy forming brown macro-algae that form dense, often closed canopies sometimes referred to as 'kelp forests'. Within southern Australia, the main groups contributing to brown macro-algae composition are from the orders Fucales (*Scytothalia, Seirococcus, Cystophora* and *Sargassum*) and Laminariales (*Ecklonia* and *Macrocystis*) (Appendix H). Brown macro-algae are a critical component of nearshore rocky ecosystems that span the entire southern coastline of Australia – The Great Southern Reef (Bennett et al. 2015). Macro-algae provide food, shelter, and habitat for a diverse range of marine life, helping to maintain extremely productive systems in these cold-water environments (Steneck et al. 2002, Layton et al. 2020), and often protecting coastlines from increased erosion by buffering waves.

Kelp forests (macro-algae) are in decline in many regions globally, particularly in Australia (Wernberg et al. 2016, Johnson et al. 2011, Verges et al. 2019) and have declined significantly in the greater metropolitan Adelaide area (Connell et al. 2008, Gorman and Connell 2009). One of the major issues impacting nearshore marine environments in the greater Adelaide region historically has been poor water quality. Freshwater inputs into Gulf St Vincent from stormwater and wastewater treatment plants can introduce nutrients, pollutants, and suspended sediments which impact key marine habitats such as seagrass and reefs (Turner et al. 2006, EPA 2009). Concern about potential declines in macro-algae along the Adelaide metropolitan coastline was a catalyst for establishing the first reef health surveys in 1996 (Cheshire et al. 1998).

Our study indicates that, at least for the sites assessed, the previous decline in macro-algae canopy cover has stabilised and may be recovering in some areas (e.g. subregion 3and4). This recovery potentially represents a significant 'good news' story given the history of decline in kelp forests since the 1970's on reefs in closer proximity to Adelaide (Turner et al. 2007) and the importance of them to maintaining healthy nearshore ecosystems. This improved outlook may be related to several initiatives designed to improve the water quality discharging to marine environments in the vicinity of Adelaide that commenced in the 1980s (Wilkinson et al. 2005). This has included the decommissioning of sewage sludge outfalls, improvements to water reclamation and waste-water treatment plants, and reduction in nutrient inputs such as the closure of the Penrice Soda plant (Meakin et al. 2023 in press). Recent evidence of seagrass recovery in some areas of the Adelaide metropolitan coastline have also been linked to the improvements in water quality discharging into the marine environment (Fernandez pers com.).

5.5 Large fish and targeted fish biomass

The biomass of large fish is one of the more critical indicators of reef health because of the role large fish play in the structuring of food webs and the sensitivity of this indicator to fishing. In recognition of its importance the biomass of large fish was adopted to report on the AICHI Targets established by the Convention on Biological Diversity Convention on Biological Diversity. In the context of this program the large fish indicator is used as a surrogate to assess trophic structure.

Apart from subregion 4, where there was a slight decline, biomass of large fish has remained stable across the region. Maintenance of water quality and the presence of Marine Park sanctuary zones are possible reasons for this observation. It is likely that biomass of large fish was historically much higher across the region as documented in a previous GARR report by Brook et al. (2020) that showed biomass of large fish at sites with long term protection from fishing (i.e., Aldinga and Port Noarlunga SZs protected since 1971) were two to three times higher than nearby sites without protection. The slight decline in subregion 4 was not anticipated as two SZs, Rapid Head and Carrickalinga, were established in this subregion in 2014.

The trends in Targeted Fish Biomass were nearly identical to those of Large Fish Biomass. The Targeted Fish Biomass indicator is intended to assess the impacts of fishing however given fishers generally target the largest fish it is likely that TFB is essentially a subset of LFB and probably auto correlated. Given how similar the trend results are between the TFB and LFB and to simplify reporting it is recommended that LFB be used as the indicator in future.

Given the presence of Marine Park sanctuary zones across the region associated with the Encounter Marine Park it is recommended to examine the effects of these SZs on the indicators assessed here as this will provide valuable insight into the effectiveness of Marine Park SZs as a management tool in maintaining and enhancing reef systems in the region. In addition, it is possible that the inclusion of sites within Marine Park SZs and potential benefits associated with protection may be masking declines in sites outside the SZs. In theory, the presence of higher numbers of large fish should increase food web stability and buffer these areas to climate change and other disturbances (Duffy et al. 2016).

5.6 Climate change

The reef fish thermal index (RFTI) is a measure of the net thermal affinities of fish in a particular region. RFTI has also been adopted to report on the AICHI Targets established by the Convention on Biological Diversity Convention on Biological Diversity. In a warming climate scenario, fish with higher thermal affinities will displace those with lower ones and the RFTI of the community will increase. The RFTI indicator is therefore a good measure of the rate of change in community structure affected by climate change.

Overall, the RFTI was stable for all subregions with no significant trend. This is in contrast to the pattern of warming that has occurred along the western and eastern coastlines of Australia over the same time period (Gervais et al 2021). It is possible that waters of the study regions are buffered somewhat by the large temperature fluctuations experienced in the gulf and the Southern Ocean, however, it is likely that warming will occur over longer timeframes. Distance is also likely to play a role as warmer water species need to travel a long way to appreciable impact local community temperature affinities.

Changes in species assemblages under a warming scenario has the potential to impact reef ecosystems and the ecosystem services they provide. The results presented here are relatively short for detecting temporal patterns in species or ecosystem change that may be related to longer term warming trends. It would be useful to map the species RFTI in relation to temporal and spatial profiles of sea surface temperature in the GSV and Southern Ocean. This could then be used to develop a predictive model of future potential species declines (or resilience), community structure, or overall reef biodiversity change. This information could be particularly useful to drive initiatives to support management actions and decision making (e.g. further rehabilitation processes for reefs and seagrass communities, understanding future outbreaks and impacts from urchins) and opportunities to educate and raise awareness on climate change impacts in the community.

5.7 Focal Species

Individual species can be important for a range of reasons and for the purposes of our report the collective term 'focal species' is used. As discussed previously (section 3.2.1) focal species may be species that are important for ecosystem function, iconic, of conservation concern, cultural value or a number of other reasons. There was insufficient data to support current analyses of individual fish or focal species from our study. The current GARR program is focused on a range of indicators to capture the extent of biodiversity values across reef ecosystems that differ in physical attributes and species composition. The current set of indicators were not designed to assess the prevalence of single species, although routine surveys will provide some broad baseline information about single species distributions.

There are a range of species that would benefit from more detailed and targeted surveys, particularly those considered 'keystone' species (e.g. lobsters) that are known to provide 'top-down' regulation of temperate reef ecosystems (Eddy et al. 2018). In addition, targeted surveys could also include 'iconic' or those taxa listed of conservation concern such as long-lived and/or site attached species (e.g. southern blue devil *Paraplesiops meleagris*) and various sharks and rays that are important residents of reef ecosystems but remain key gaps in knowledge for the region/s. These species are considerable economic drivers for tourism on Adelaide's reefs as they enrich the experiences of recreational divers and snorkeling activities along the coast.

A focal species approach could also be used to gain a better understanding of the trophic relationships (or lack of) and impacts on local reef ecosystems. This could include investigations of overgrazing by species such as the short spined urchin which has impacted temperate reef ecosystems in Victoria. Selecting and monitoring such taxa could also provide the 'canary in the coalmine' approach to indicating potential reef ecosystem change or highlight reef biodiversity trophic deficiencies.

There is limited information and survey data currently available to assess the health of populations of focal species, particularly those of conservation concern in the greater Green Adelaide and Fleurieu region. For the GARR program, resourcing has focused on targeting and developing an understanding of the status of reef ecosystems across the regions, with a 5-year GARR reef strategic plan and aim to develop the biodiversity baselines and subsequent biodiversity trends to assess the health of local subtidal reefs, which has been achieved. The sites and trends developed as part of the GARR program will be fundamental to understanding any future changes to broad reef ecosystem viability. Building knowledge of specific focal species by redirecting some resources within the GARR program would complement and strengthen future baseline and trend information. As an example, a feasibility study to estimate the survey effort required to establish a current and robust population estimate of southern blue devil (*Paraplesiops melegaris*) at Seacliff Reef on the Adelaide metropolitan coast has been completed (Bryars et al 2023 in prep). The approach is based on previous historical surveys and information of known blue devil individuals (Bryars 2013b). It is recommended that the GARR program incorporate opportunities to implement these types of surveys, which with opportunities to map residency and migratory behavior, will provide better overall resolution and information on system functionality and interconnectivity at differing spatial and temporal scales.

5.8 Conclusion

Our study provides the most comprehensive assessment to date across the longest time series ever assembled for subtidal reefs in South Australia using well established indicators related to reef condition. Over 40 sites spanning up to 18 years were used in the analyses. Overall, the general status of reefs in the Adelaide and Fleurieu regions appear stable with most indicators showing limited change. For several reefs, particularly in vicinity of Adelaide's metropolitan coast, this represents an improved outlook compared to previous reports which recorded declines in cover of macro-algae and other indicators (Turner 2004, Turner et al. 2007, Connell 2008). The reasons for this are unknown but could be linked to the improvements in water quality in the last 40 years which has included changes to wastewater treatment plants, closure of sewage sludge outfalls, and closure of Penrice Soda Products (Meakin et al. 2023 in press).

It is important to note that data availability from some subregions is currently limited, with only two to three sites from which to analyse trends in indicators (e.g. subregion 1 and 2, and 5 and 6), and therefore long term trajectories should be treated with caution. The addition of more monitoring sites (if spatially present and accessible) within these subregions will ensure that long term trends will improve accuracy and better reflect the status of reefs within these subregions. In particular, there is a large spatial gap in the number of sampling sites between Cape Jervis and Newland Head Conservation Park that needs investigation.

No assessment was made in our study to constitute 'good or poor' condition in relation to subtidal reefs in the regions. The current structure of the program aimed to report on the range of indicators at each site that are comparable to international Reef Life Survey standards to maximise the information at broad spatial scales. Although site-by site analyses can also be achieved to determine specific information on each of the indicators assessed, it was not the overall objective of the current study. This differs from Brook (2018) who presented scaled and specific site "condition" analyses for 16 reefs along the Adelaide metropolitan coast. Most of the reef systems in these regions have been impacted in some way by anthropogenic influences and many, particularly those in closer to the city of Adelaide, are likely to be highly modified compared to their pre-European condition. We currently lack adequate historical data or existing reference sites to fully understand what these reefs 'should' comprise regarding their floral and faunal compositions. Bearing this in mind, the general positive outlook for the indicators measured does not imply that these reefs are in 'good condition'; merely that the trends are mostly stable or improving.

The GARR program was established to provide relevant information linked to the main stressors and drivers to help improve the management of these important ecosystems. Four key indicators: species richness of fish and macro-invertebrates, large fish biomass, percent cover of macro-algae and the Reef Thermal Index are independent indicators related to different aspects of reef ecosystem function that if regularly assessed should provide the information needed to track the status of reefs and effectiveness of management actions. It is strongly recommended to continue to monitor these indicators at relevant spatio-temporal scales and build on establishing baseline information on the key focal species which could be used to assess change or document potential threats such as climate change and overgrazing.

The GARR program also highlights the similarities in reef ecosystems across the GSV and the southern coasts but also that clear spatial subregional differences were evident. Future iterations of the GARR program should therefore continue with a similar spatial scale, which could be used to identify any new changes in the local nearshore marine environment. This is especially important along the Green Adelaide metropolitan coasts and other peri-urban areas that may have considerable population growth and contribute to greater anthropogenic disturbance.

Using Reef Life Survey methodology to establish the baseline and contemporary trend information has meant the information is comparable to temperate reef data evaluated at national and global scales (Edgar et al. 2023). As Reef Life Survey is conducted throughout Australia, it means that South Australia is now a critical location given its proximity to the Great Australian Bight, extent of the Great Southern Reef, and its location to map and document oceanographic influences involved in possible climate driven change. One of the key advantages of supporting this approach has facilitated a volunteer network within the local dive community, which have provided significant contributions to data collections and establishing the data profiles required for the trend analyses. Future efforts to foster these relationships will continue to improve community outreach and education and benefit the overall outcomes achievable in the future.

The establishment of a comprehensive temperate reef monitoring program across the Adelaide and Fleurieu regions has provided the first effective framework to systematically assess trends in key indicators and therefore the long-term health of these important ecosystems. Establishing trends in key condition indicators of marine biodiversity has significantly benefited from previous reef health studies that have documented biodiversity values for specific metropolitan and southern Fleurieu reef systems (e.g. Gaylard 2003, Brook 2018, Brook and Bryars, 2014). The systematic and strategic approach adopted by the GARR program has significantly improved the ability for Green Adelaide and other regions to effectively manage these ecosystems across the regions recognizing system interconnectivity, to achieve the primary objectives of the Green Adelaide Regional Landscape Plan (2021–2026), the *Landscape Act South Australia 2019* and other regional landscape plans, which aim to protect, enhance and improve outcomes for marine biodiversity. Continued investment further supports reporting on the State of Environment for the Department for Environment and Water (DEW), South Australia. This has recently been demonstrated by the macro-algal information from our study forming the basis of a new State Environmental Report Card. The information recorded from the GARR program and associated data are a critical component that support reporting and decision making of local, state and national marine environments and will be crucial for long term management of Adelaide's marine resources.

6 Recommendations

Since its inception in 2016, the GARR program has successfully implemented a strategic long-term monitoring initiative, effectively capturing and reporting on the status of subtidal reefs across the Green Adelaide and Fleurieu region to improve management. Key accomplishments of the program include:

- Successful creation of long-term monitoring sites utilising best practise methods for data collection and assessment.
- Establishment of a baseline reference from which to track trends in reef condition.
- Thorough documentation of regional marine biodiversity patterns associated with subtidal reefs.
- Comprehensive assessment of status of reefs in the region using standard indicators of reef health.
- Established a group of highly trained and dedicated volunteer divers actively involved and contributing to the success of the program.

The main recommendation is to undertake a comprehensive review and evaluation of the GARR program with the intent to identify priorities and guide future investment in the program to improve and expand future outputs and outcomes. Key areas for assessment include monitoring strategies, data analysis, volunteer engagement, threat mitigation, data integration and socio-economic considerations.

This evaluation should consider but not be limited to the following areas:

- Monitoring improvement: Strengthen reef condition assessments through long–term program improvements including site optimisation; review of survey frequency and spatial coverage.
- Trend Analysis Approach: Consider an analysis focused on the last 5 years' data to ensure trends in reef condition are current and not influenced by historical fluctuations.
- Focal Species Strategy: Revise focal species approach, enhancing opportunities and prioritizing monitoring based on risk and feasibility analysis.
- Threat Assessment and Action: Evaluate threats and potential management actions (e.g., stormwater, pests, overgrazing, fishing).
- Volunteer Engagement: Improve Reef Life Survey to enhance volunteer engagement, training, and participation.
- Data Integration and Protection: Explore 'Reef Health' data integration, compare protected and non-protected reef areas and assess protection effectiveness (e.g. marine park sanctuary zones).
- Socio-Economic Investigation: Study iconic reef species' values and identify ways to boost reef habitat significance.
- Development of communication tools to improve community outreach and education on reef biodiversity

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8 Appendices

A. Details of reef monitoring surveys undertaken at sites in the Gulf St Vincent – Southern Coasts – Fleurieu region, includes sites used for trend analysis based on selection criteria for inclusion.

Sub	Site	Code	Lat	Long	yrs	Used in Trend Analysis for Fish and macro-Inverts	Used in Trend Analysis for Macro-algal cover
1	Parham Reef	GSV134	-34.4444	138.1970	5	yes	yes
1	Port Gawler	GSV115	-34.619419	138.310516	3	yes	no
1	Outer Harbor breakwater	GSV109	-34.788514	138.46726	1	no	no
1	Semaphore Reef	GSV127	-34.847099	138.445953	5	yes	yes
2	Broken Bottom	GSV125	-34.963348	138.480286	5	yes	yes
2	Macs ground	GSV133	-34.975833	138.4514	2	no	no
2	Milkies Reef	GSV126	-34.986483	138.454017	2	no	no
2	Seacliff Reef	GSV132	-35.0399	138.4915	4	yes	yes
3	Marino Rocks	GSV105	-35.0525	138.5027	2	no	no
3	Hallett Cove	GSV140	-35.0736	138.4943	2	no	no
3	Port Stanvac North	GSV137	-35.0976	138.4775	2	No	No
3	Port Stanvac South	GSV139	-35.1034	138.4742	2	no	no
3	Port Stanvac Jetty deep	GSV101	-35.1071	138.4695	1	No	No
3	Port Stanvac Jetty Shallow	GSV102	-35.1092	138.469	1	no	no

Sub	Site	Code	Lat	Long	yrs	Used in Trend Analysis for Fish and macro-Inverts	Used in Trend Analysis for Macro-algal cover
3	O'Sullivan Beach Bay	GSV98	-35.116861	138.468464	1	No	No
3	Horseshoe Inside	GSV124	-35.13793	138.46292	6	Yes	Yes
3	Horseshoe Outside	GSV131	-35.13942	138.458054	3	No	No
3	Port Noarlunga North	GSV122	-35.138580	138.46115	1	No	No
3	Noarlunga North Inside	GSV135	-35.14727	138.4637	2	No	No
3	Noarlunga North Outside	GSV136	-35.14748	138.463028	5	Yes	no
3	Port Noarlunga Jetty offshore	GSV100	-35.149298	138.464297	2	No	No
3	Noarlunga South Outside	GSV112	-35.156921	138.465454	3	No	No
3	Southport	GSV128	-35.167751	138.462265	4	yes	yes
3	Moana Outside	GSV138	-35.206501	138.462219	5	Yes	Yes
3	Moana Inside	GSV53	-35.2091	138.4644	2	No	No
3	Gull Rock	GSV185	-35.2462	138.45956	1	No	No
3	Port Willunga Reef	GSV129	-35.256662	138.458489	2	Yes	Yes
3	Aldinga SZ1	GSV183	-35.26631	138.43649	1	No	No
3	Aldinga Pinnacles	GSV116	-35.266816	138.433643	2	Yes	no
3	Aldinga Reef	GSV93	-35.26825	138.43202	3	Yes	no
3	Aldinga Reef Inshore	GSV97	-35.27028	138.43387	3	No	No

Sub	Site	Code	Lat	Long	yrs	Used in Trend Analysis for Fish and macro-Inverts	Used in Trend Analysis for Macro-algal cover
3	Aldinga Deep	GSV130	-35.271599	138.430984	2	no	no
3	Aldinga SZ3	GSV182	-35.28036	138.43154	1	No	No
3	Sellick South	GSV171	-35.35784	138.42148	1	No	No
4	Myponga Reef	GSV111	-35.370824	138.381777	3	No	No
4	Carrickalinga North3	GSV47	-35.37119	138.37876	6	Yes	Yes
4	Carrickalinga North2	GSV46	-35.37312	138.37358	6	Yes	Yes
4	Carrickalinga North1	GSV45	-35.3777	138.36289	6	Yes	Yes
4	Myponga Point	GSV165	-35.379879	138.360687	4	yes	yes
4	Ripple Rock	GSV24	-35.38385	138.355896	8	Yes	Yes
4	Myponga South	GSV7	-35.38821	138.349228	9	Yes	Yes
4	Carrickalinga Head	GSV3	-35.397999	138.335907	8	Yes	Yes
4	Shag Rock Carrickalinga	GSV25	-35.39933	138.334564	10	Yes	Yes
4	Dodd's Beach	GSV9	-35.40416	138.330429	9	Yes	Yes
4	Carrickalinga Beach North	GSV164	-35.410368	138.324634	1	No	No
4	Haycock Point	GSV2	-35.41506	138.32132	6	Yes	Yes
4	Haycock Point inshore	GSV96	-35.4186	138.323	2	No	No
4	Carrickalinga South Bay	GSV1	-35.42445	138.319016	12	yes	yes
4	Carrickalinga Creek	GSV123	-35.428192	138.31475	1	no	no

Sub	Site	Code	Lat	Long	yrs	Used in Trend Analysis for Fish and macro-Inverts	Used in Trend Analysis for Macro-algal cover
4	Normanville Beach	GSV106	-35.446652	138.304966	4	Yes	Yes
4	South Shores	GSV114	-35.456089	138.299392	2	No	No
4	Yankalilla Mouth	GSV113	-35.465499	138.294647	2	no	no
4	Lady Bay	GSV110	-35.47356	138.281158	2	No	No
4	Sunset Cove South	GSV163	-35.504669	138.229233	4	Yes	Yes
4	Lasseter's Reef	GSV95	-35.50838	138.21873	6	yes	yes
4	Second Valley Boat Shed	GSV26	-35.50945	138.21449	13	yes	yes
4	Rapid Bay Jetty	GSV94	-35.51901	138.18452	8	yes	yes
4	Rapid Head East	GSV41	-35.519496	138.177187	6	yes	yes
4	Rapid Head North	GSV99	-35.519218	138.174164	6	yes	yes
4	Rapid Head SZ Site3	GSV43	-35.5186	138.17102	6	yes	yes
4	Rapid Head	GSV4	-35.52049	138.16382	12	yes	yes
4	Rapid Head SZ Site2	GSV42	-35.52262	138.16309	5	yes	yes
4	Rapid Head Windmill	GSV28	-35.530849	138.152893	6	yes	yes
4	Rapid Head South	GSV5	-35.531448	138.151901	6	yes	yes
4	Salt Creek	GSV34	-35.552601	138.129837	7	no	no
4	La Hacienda	GSV34	-35.57859	138.11379	1	no	no

Sub	Site	Code	Lat	Long	yrs	Used in Trend Analysis for Fish and macro-Inverts	Used in Trend Analysis for Macro-algal cover
4	Morgans	GSV18	-35.588451	138.108383	8	yes	yes
4	Cape Jervis South	GSV117	-35.60447	138.0933	3	No	No
5	Fishery Beach	GSV39	-35.634109	138.111832	3	No	No
5	Spaceship East	GSV157	-35.646751	138.133102	1	No	No
5	Loo with a View	GSV156	-35.653782	138.145966	1	No	No
5	Blowhole Beach	GSV155	-35.65974	138.159973	1	No	No
5	Porpoise Head	GSV30	-35.661930	138.21450	3	No	No
5	Deep Creek	GSV119	-35.65469	138.24448	3	No	No
5	Backstairs Deep	GSV118	-35.647815	138.25917	3	No	No
5	Deep Creek/Boat Harbour	GSV158	-35.640862	138.272659	1	No	No
6	Newland Head	GSV14	-35.640942	138.526627	4	Yes	Yes
6	Flat Irons	GSV15	-35.617809	138.557205	6	Yes	Yes
6	Kings Head North	GSV159	-35.606758	138.575943	2	No	No
6	Kings Head	GSV160	-35.605511	138.583084	2	No	No
6	West Island Outer	GSV12	-35.610291	138.592896	4	Yes	Yes
7	The Bluff	GSV17	-35.58913	138.60579	7	Yes	Yes
7	Whalebone	GSV40	-35.5714	138.611664	6	Yes	Yes
7	Seal Island	GSV162	-35.57618	138.644287	3	No	No

Sub	Site	Code	Lat	Long	yrs	Used in Trend Analysis for Fish and macro-Inverts	Used in Trend Analysis for Macro-algal cover
7	Inman River mouth	GSV142	-35.56627	138.62228	1	no	no
7	Encounter Deep	GSV121	-35.57729	138.61845	3	No	No
7	Granite Island	GSV108	-35.56604	138.62732	3	No	No
7	Outside Granite Island	GSV11	-35.56753	138.63157	5	Yes	Yes
7	Olivers Reef	GSV107	-35.54715	138.63821	3	No	No
7	Chiton Rocks	GSV120	-35.54050	138.6540	2	No	No
7	Port Elliot Deep	COO19	-35.53932	138.6885	2	No	No
7	Pullen Island	COO18	-35.53777	138.6925	3	No	No
7	Basham's Beach	COO20	-35.52460	138.6999	2	no	no

B. Details of indicator calculations and interpretation notes

Indicator	Calculation Details and interpretation notes
Fish and mobile invertebrate species richness	No. of unique taxa across the total area sampled along each transect using Method 1 and Method 2, i.e. 500 m^2 for Method 1 and 100 m^2 for Method 2 for a complete transect using the RLS method. Richness indicators are sensitive to taxonomic resolution. In the case of fish, however, most identifications were to species level and are expected to be consistent among divers. The exceptions were the genera *Pseudocaranx* (trevally), *Ophiclinus* (snake blennies), the families Tripterygiidae (threefins) and Gobidae (gobies) and baitfish from the order Clupeiformes. Richness indicators are sensitive to taxonomic resolution. For mobile mobile invertebrates there are a number of organisms that cannot be identified to species level consistently by all divers in the field, and these have been grouped as genera or higher taxa, or species complexes. Furthermore, there are instances of surveyors recording species that are not from the list of mobile invertebrate groups defined by RLS (2015). Such species, for example bivalves other than scallops or razor clams, have been excluded from the dataset. In addition to the transect average, an overall site-level richness was calculated from the number of unique species in the pooled transect lists.
Richness of macroalgal functional groups	Functional groups were assigned to a fixed number of points overlain on photoquadrats during post-field analysis. The indicator was calculated from the number of unique functional groups assigned to a fixed number of points across 20 images per transect (occasionally plus or minus one image).
Fish and mobile invert community structure	Community structure was examined using the PRIMER 6 software package (Clarke and Warwick 2001, Clarke and Gorley 2006) with PERMANOVA+ addon (McArdle and Anderson 2001, Anderson 2001). A Bray-Curtis dissimilarity matrix was calculated from fourth-root-transformed data, which reduced the influence of schooling species, many of which are infrequently recorded. Other transformations were explored, including square-root and logarithmic, and dispersion weighting, with comparisons made of the patterns shown by multi-dimensional scaling (MDS) ordination plots and by using the 2STAGE routine. PERMANOVA factors were Site as a random factor nested in fixed Subregions, and crossed with Year as a fixed factor. Tests of the factor Year and its interaction with Subregion will indicate change in subregional communities over time.
Macroalgal community structure	As per fish and mobile invert community structure, with the Bray-Curtis dissimilarity matrix calculated from functional group percentage cover data.
Fish community temperature index	The midpoint of temperature ranges for each fish species was provided by University of Tasmania (R. Stuart-Smith, unpublished data). The transect value is the community-weighted mean whereby the logarithm (base 10) of biomass (plus one gram) was used to weight the temperature midpoint for each species.

Biomass of large fish	Biomass of fish exceeding 20 cm length, averaged over two blocks on each transect. It should be noted that the biomass of large fish can be influenced by the uncommon occurrence of large elasmobranchs, e. g. wobbegongs or rays, or of large schools of fish, e.g. Australian salmon *Arripis truttacea*. Biomass values were calculated by University of Tasmania.
Biomass of targeted fish	Species defined as 'targeted' are listed in Targeted Reef Species As for the 'biomass of large fish' indicator, this indicator can be influenced by the uncommon occurrence of large schools of fish, e.g. Australian salmon.
Percentage cover of canopy-forming macro-algae	Two functional groups (corresponding to kelps and large brown branching macro-algae (from the order Fucales) describe canopy-forming macro-algae. The percentage cover of these points was calculated from the proportion of point overlays on each transect that were assigned one of these functional groups.
Abundance of focal species (and FCCs)	Abundance of fish were calculated a mean per block, i.e. overlapping areas of 250 m^2 and 50 m^2 for methods 1 and 2, respectively.

C. Targeted Reef Species

Species name	Common name
Arripis georgianus	Australian herring
Arripis truttaceus	Western Australian salmon
Centroberyx gerrardi	Bight redfish
Cheilodactylus nigripes	Magpie perch
Chrysophrys auratus	Snapper
Dactylophora nigricans	Dusky morwong
Girella tricuspidata	Luderick
Leviprora inops	Longhead flathead
Meuschenia hippocrepis	Horseshoe leatherjacket
Myliobatis tenuicaudatis	Eagle ray
Nemadactylus valenciennesi	Queen Snapper
Notolabrus tetricus	Blue-throat wrasse
Othos dentex	Harlequin fish
Pentaceropsis recurvirostris	Long-snouted boarfish
Platycephalid spp.	Flathead
Platycephalus laevigatus	Rock flathead
Platycephalus speculator	Yank flathead
Pseudocaranx spp.	Trevally
Scorpis aequipinnis	Sea sweep
Scorpis georgiana	Banded sweep
Seriola lalandi	Yellow-tail kingfish
Sillaginodes punctatus	King George whiting
Sphyraena novaehollandiae	Snook
Thysanophrys cirronasa	Tasselsnout Flathead
Tilodon sexfasciatus	Moonlighter

Species name	Common name
Trachurus novaezelandiae	Yellow-tail scad
Upeneichthys vlamingii	Southern goatfish

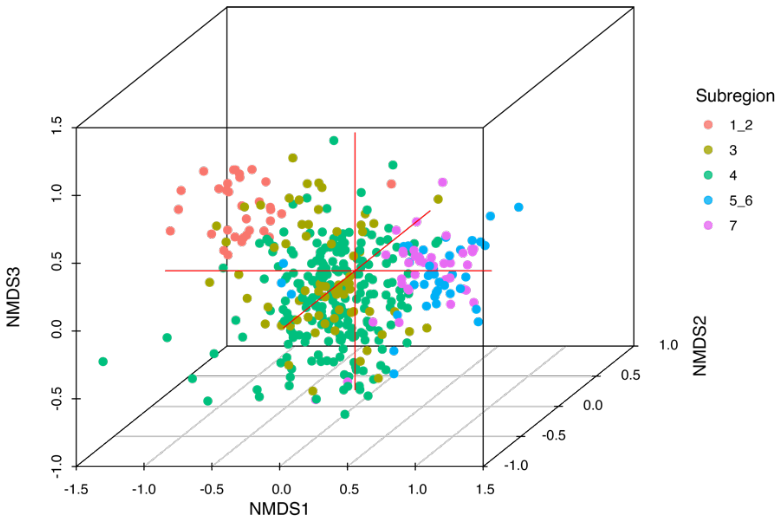
D. Permutational multivariate analysis of variance of the fish community data as a function of the subregion and year.

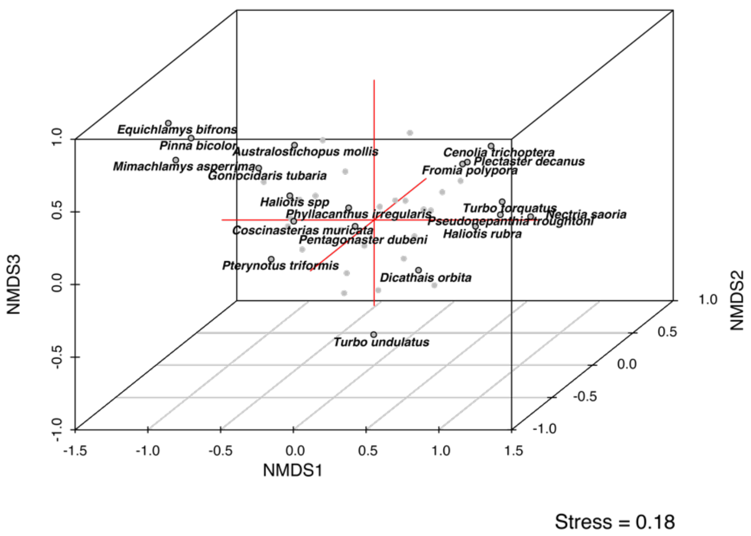
	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)
Subregion	4	17.639	4.410	28.283	0.236	0.005
Subregion:Year	5	2.927	0.585	3.754	0.039	0.005
Residuals	348	54.258	0.156		0.725	
Total	357	74.824			1	

E. Permutational multivariate analysis of variance of the invertebrate community data as a function of the subregion and year.

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)
Subregion	4	22.271	5.568	31.308	0.249	0.005
Subregion:Year	5	5.100	1.020	5.736	0.057	0.005
Residuals	350	62.243	0.178		0.695	
Total	359	89.614			1.000	

F. 3D non-metric multidimensional scaling of invertebrate communities showing the site (top) and species (bottom) ordination plots.



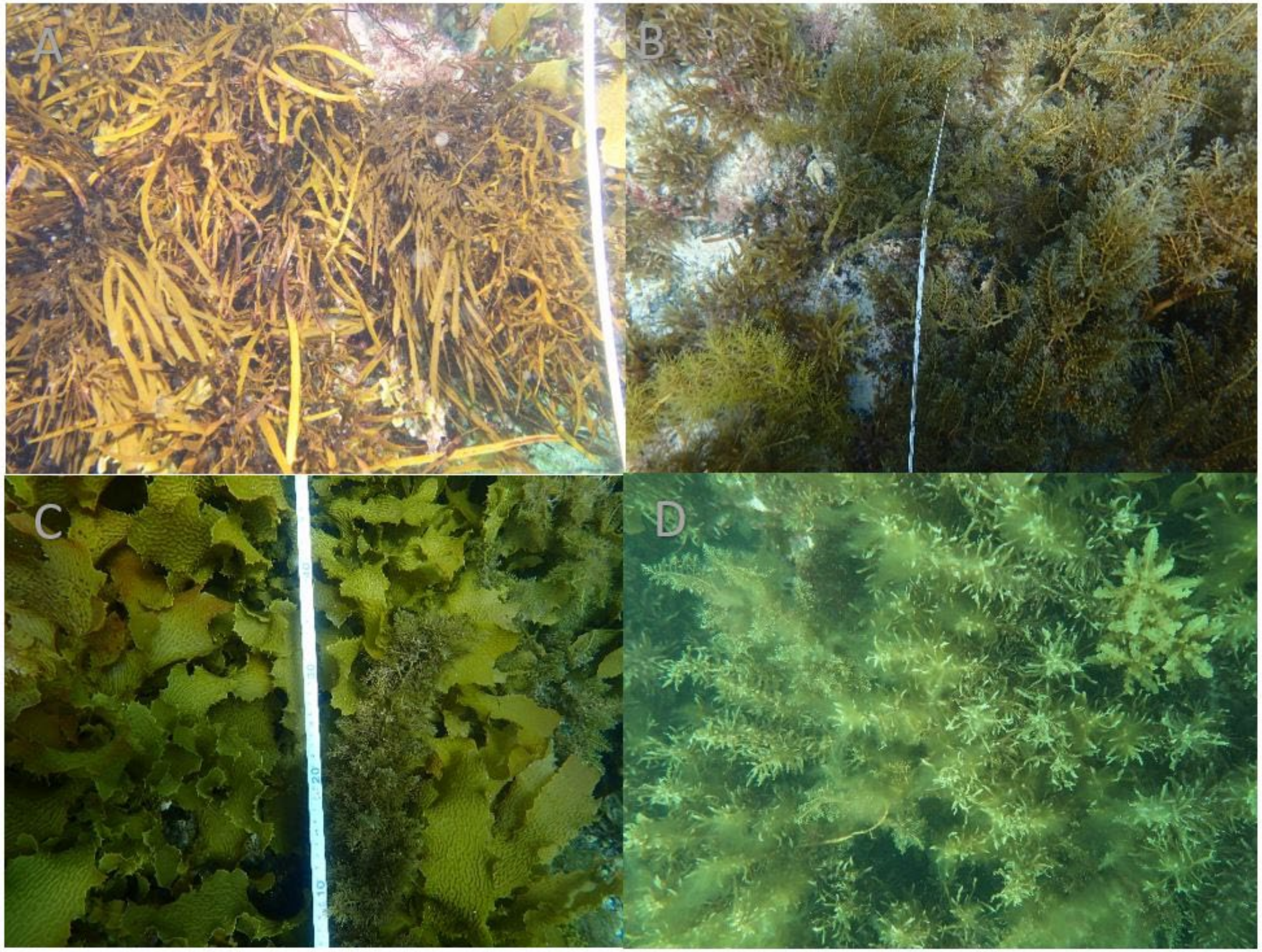


G. Blue throat wrasse (*Notolabrus tetricus*): mean biomass per transect (in grams) at each site and in each year.

Site Name	2005	2006	2007	2008	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Carrickalinga South Bay	85	74	527	585		550	918	2723		569	677	624	397	72
Haycock Point	339	216	339			47		184						
Carrickalinga Head	837	668	259			238					52	341	623	851
Rapid Head	1922	759	1583	247	784	515		714		179	872	565	812	46
Rapid Head South	2185									819	990	147	1590	564
Sunset Cove South	726	244	488			325								
Myponga South	100	530	227			1147				291	37	124	180	376
Myponga Point	773	390	1450			234								
Dodd's Beach	959	52	10			142				379	474	288	35	218
Seal Island	48	56	70											
Outside Granite Island	66	147	74								1159	3		
West Island Outer	16		669								612	1336		
Kings Head	476		74											
Newland Head	1872		4								3477	2156		
Flat Irons	250		928			754					1565	749		120
Kings Head North	1337		520											
The Bluff	241	67	244								3	7		
Morgans	116	654	1137							525	138	1735	4260	923
Ripple Rock	942	1426	2967							1337	1299	1132	234	38
Shag Rock Carrickalinga	72	1460	217	312	374	486		94		146	715	636		
Second Valley Boat Shed	570	172	198	472	41	260	247	33		564	148	629	32	7
Rapid Head North	272	499	196		6	749		469						
Rapid Head Windmill	1925	145	236			833					965	1373		
Porpoise Head			3549								1665	3164		
Deep Creek/Boat Harbour			1751											
Salt Creek			253			592				14	652	925	28	899
Blowhole Beach			1343											
Spaceship East			1588											
Carrickalinga South Bay			1442											
Fishery Beach			476								865	1391		
Whalebone			1311			2189	3263				3296	7644		538
Rapid Head East							517			259	670	63	124	397
Rapid Head SZ Site2							656			2526	354	36	1585	
Rapid Head SZ Site3						1513	795				1642	187	227	530
La Hacienda							1379							
Carrickalinga North1							277			592	285	24	177	74
Carrickalinga North2							28			598	466	390	13	64
Carrickalinga North3										159	3			199
Carrickalinga Beach North							1196							
Aldinga Reef				373	257	347								
Port Noarlunga Jetty offshore								87						
Port Stanvac Jetty deep								35						

Port Stanvac Jetty Shallow														
Rapid Bay Jetty				127	69	183		52			398	378	238	192
Lasseters Reef				190	357	136		153					85	84
Haycock Point inshore				868										
Aldinga Reef Inshore				442	611	887								
Olivers Reef							89				267	46		
Pullen Island							275							413
Normanville Beach														
Granite Island							253					3		613
Southport									15		287			
Semaphore Reef														
Seacliff Reef									544	534	829	675		
Port Willunga Reef														
Parham Reef														
Noarlunga South Outside														
Noarlunga North Outside										24	48	163	79	174
Noarlunga North Inside										25				
Moana Outside										334	299	269		143
Milkies Reef														
Macs ground														
Horseshoe Outside									526	272			24	
Horseshoe Inside									18	363	221	221	197	264
Hallett Cove														
Broken Bottom										25				
Aldinga Deep														
Aldinga SZ1										446				
Aldinga Deep										177				
Aldinga SZ3														
Gull Rock										126				
Moana Inside										623				
Sellick South										543				
Port Stanvac North														
Port Stanvac South													367	
Marino Rocks														
Aldinga Pinnacles											117	18		
Myponga Reef											20			
Cape Jervis South											750	740		12
Lady Bay											490	434		
South Shores											613	673		
Backstairs Deep											1488	157		523
Deep Creek											2360	1426		195
Chiton Rocks											593	98		
Encounter Deep											95	132		38
Port Elliot Deep												228		
Basham's Beach											529			
Inman River mouth														887
Carrickalinga Creek														326
Port Noarlunga North														133

H. Photo-quadrats of indicative macro-algal genera at monitoring sites within the Encounter Marine Park. A) *Seirococcus*, B) *Cystophora* C) *Ecklonia* and D) *Sargassum*.



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