Technical information supporting the 2023 Subtidal macroalgae: percentage cover environmental trend and condition report card

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Acknowledgement of Country

We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past and present. We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country. We also pay our respects to the cultural authority of Aboriginal and Torres Strait Islander people and their nations in South Australia, as well as those across Australia.

Acknowledgement

This document was prepared by Craig Meakin and Danny Brock (DEW). Simon Bryars (DEW) provided principal oversight throughout and technical review of this report. Brady Stead (DEW) provided mapping support. Data analysis was conducted by Camille Mellin from Adelaide University. Improvements were made to this report and associated report card based on reviews by Amy Ide (DEW).

Contents

List of figures

List of tables

Summary

The 2023 release of South Australia's environmental trend and condition report cards summarises our understanding of the current condition of the South Australian environment, and how it is changing over time.

This document describes the indicators, information sources, analysis methods and results used to develop this report and the associated 2023 Subtidal macroalgae: percentage cover report card. The reliability of information sources used in the report card is also described.

The Subtidal macroalgae: percentage cover report card sits within the report card Biodiversity theme and Coastal and marine sub-theme. Report cards are published by the Department for Environment and Water and can be accessed at www.environment.sa.gov.au.

1 Introduction

1.1 Environmental trend and condition reporting in SA

The Minister for Climate, 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)). Environmental trend and condition report cards are produced as the primary means for the Minister to undertake this reporting. Trend and condition report cards are also a key input into the State of the Environment Report for South Australia, which must be prepared under the *Environment Protection Act 1993*. This Act states that the State of the Environment Report must:

- include an assessment of the condition of the major environmental resources of South Australia (112(3(a))), and
- include a specific assessment of the state of the River Murray, especially taking into account the Objectives for a Healthy River Murray under the *River Murray Act 2003* (112(3(ab))), and
- identify significant trends in environmental quality based on an analysis of indicators of environmental quality (112(3(b))).

1.2 Purpose and benefits of SA's trend and condition report cards

South Australia's environmental trend and condition report cards focus on the state's priority environmental assets and the pressures that impact on these assets. The report cards present information on trend, condition, and information reliability in a succinct visual summary.

The full suite of report cards captures patterns in trend and condition, generally at a state scale, and gives insight to changes in a particular asset over time. They also highlight gaps in our knowledge on priority assets that prevent us from assessing trend and condition and might impede our ability to make evidence-based decisions.

Although both trend and condition are considered important, the report cards give particular emphasis to trend. Trend shows how the environment has responded to past drivers, decisions, and actions, and is what we seek to influence through future decisions and actions.

The benefits of trend and condition report cards include to:

- provide insight into our environment by tracking its change over time
- interpret complex information in a simple and accessible format
- provide a transparent and open evidence base for decision-making
- provide consistent messages on the trend and condition of the environment in South Australia
- highlight critical knowledge gaps in our understanding of South Australia's environment
- support alignment of environmental reporting, ensuring we 'do once, use many times'.

Environmental trend and condition report cards are designed to align with and inform state of the environment reporting at both the South Australian and national level. The format, design and accessibly of the report cards has been reviewed and improved with each release.

1.3 Importance of macroalgal cover on South Australian subtidal reefs

The marine environment regulates our climate, supports regional tourism, commercial and recreational fishing, aquaculture and shipping, and has significant cultural value for Aboriginal people.

Globally, nearshore marine ecosystems, comprised of habitats such as reefs, seagrasses, mangroves and saltmarshes face a number of pressures associated with: population growth, coastal pollution and developments, overfishing, habitat modification, mining exploration, pest species, climate change and human-animal interactions/disturbance.

Adequate macroalgal cover is a critical component of reef health. Temperate subtidal reefs are highly productive systems and support complex ecosystems containing macroalgae and a high diversity of invertebrate and fish species (Turner et al. 2006). Subtidal reefs are a major component of marine ecosystems and are found around almost the entire South Australian coastline, extending to >50 m depths. More broadly South Australia's subtidal reefs form part of the Great Southern Reef (GSR) – a macro-algae dominated reef system with high levels of endemism that extends over 8000 km from Western Australia to Queensland. The GSR generates over $10 billion per year through tourism and fishing (Bennett et al. 2015).

In South Australia, kelp and other canopy forming macro-algae provide the main habitats that sustain these productive and diverse subtidal reef 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 leafy seadragons (*Phycodurus eques*), western blue groper (*Achoerodus gouldii*) and the southern blue devil (*Paraplesiops meleagris*), are site attached and dependent on these reef ecosystems (Bryars 2010). For other species that may be wider ranging, such as snapper, stingrays and leatherjackets, and those with specific larval-reef settlement phases (e.g. southern rock lobster), subtidal reefs are an integral component among the mosaic of seagrass and mangrove habitats that are critical to different stages in their life history (Shepherd and Edgar 2013; Baker et al. 2007, 2011).

Subtidal 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 Gulf St Vincent and Kangaroo Island regions is approximately $52.4 million and $29.1 million per annum respectively, with combined revenue of ~20% for South Australia's $474 million fishing sector (Deloitte 2017). Additionally, these ecosystems attract significant investment through the state's tourism sector with ecotourism for reefs in the Fleurieu Peninsula region in particular driven by accessibility to Adelaide and high amenity value, thus offering a wide range of local recreational scuba diving, snorkelling and educational pursuits.

Historically, overfishing and poor water quality related to industrialisation and urbanisation-related pollution has negatively impacted these reefs resulting in loss of macroalgal cover, and over-exploitation of some fish species (e.g. groper, Shepherd and Brook 2003, EPA 2003). The consequence of pressures such as excessive extraction and pollution results in the destruction of reef habitats and ecosystems, leading to a loss of marine biodiversity, ecosystem function and ecosystem services.

A number of indicators including percentage cover of subtidal macroalgae have been selected to assess the current status of subtidal reefs in the Green Adelaide (GA) and Hills and Fleurieu (HF) landscape regions. The indicators have been chosen based on the recommendations of a review of historical reef monitoring in the GA and HF regions (formerly referred to as the Adelaide and Mount Lofty Ranges Natural Resources Management (AMLR NRM) region, Brock et al. 2017 pp. 67-68), and conceptual models developed by Imgraben et al. (2019). The conceptual models identified that sedimentation, nutrients and extractive resource use attributed largely to fishing are the main pressures on subtidal reefs in the GA and HF regions.

This report presents information on macroalgal cover on subtidal reefs collected from underwater visual census surveys conducted by trained divers. Diver surveys are conducted to assess macroalgal cover, fish and invertebrate size and abundance, species diversity, and the presence of invasive species as an overall assessment of reef health.

The “percentage cover of subtidal macroalgae” is an appropriate measure of reef health because of its foundational role in providing the habitat for subtidal reef ecosystems, and it is subject to pressures both direct (i.e. pollution) and indirect (i.e. due to changes in fish and invertebrate populations) (Turner et al. 2007, Gaylard et al. 2013).

The only data set containing a consistent time series comes from the AMLR National Parks region which encompasses the GA and HF landscape regions. The report presents information for macroalgal cover on subtidal reefs from these regions. Reefs close to highly populated areas are more likely to be influenced by anthropogenic activity.

2 Methods

2.1 Indicator

The indicator used for the Subtidal macroalgae report card is percentage cover of macroalgae on subtidal reefs. For this report the focus is on large, brown canopy-forming macroalgae, defined here as species from the orders Laminariales (kelps) and Fucales (fucoids) (Figure 2.1).

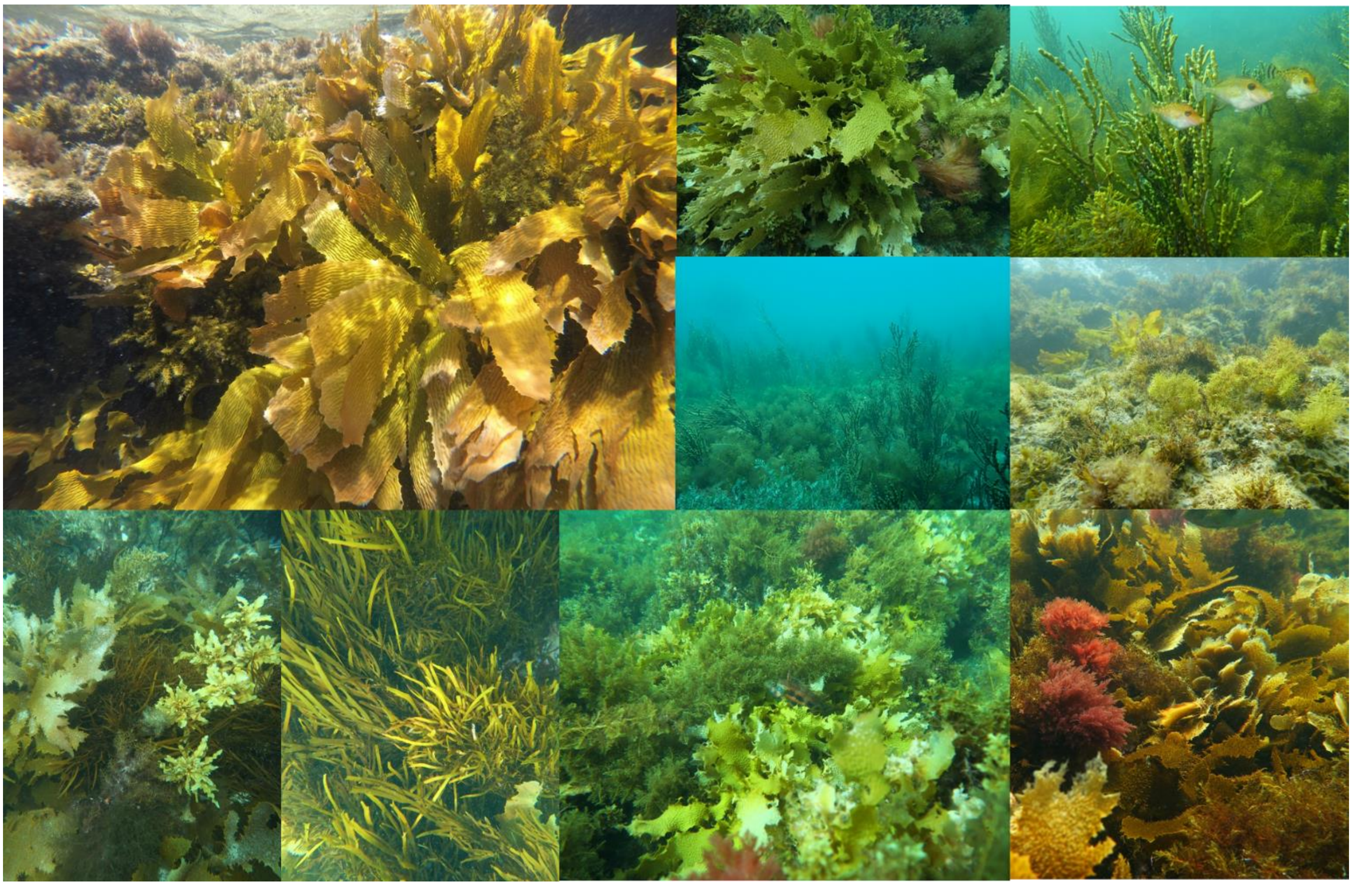


Figure 2.1. Examples of large canopy forming macroalgal species on the Fleurieu Peninsula

These macroalgal types 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 et al. 2006).

2.2 Data source and collection

Subtidal reefs are a major component of South Australia's coastal marine ecosystems. Reef condition data for all the landscapes regions is not available. Consequently, the data sourced for this report card utilises data from just two regions, GA and HF. Subtidal reefs in these regions are present from Port Parham in the north of Gulf St Vincent to Goolwa in the south of the region. For this report, these regions are further split into 8 subregions representing differences in subtidal biological communities and analysed for macroalgal cover and reef condition (Table 2.1, Figure 2.2).

Table 2.1. Physical characteristics of reefs surveyed within the Green Adelaide and Hills and Fleurieu region

Subregion number	Subregion	Defining features
1	Northern	Warmest summer water, very low wave energy, depth < 10 m, limestone platform reefs
2	Adelaide Metro	Warm summer water, low wave exposure, depth 10–20 m, limestone, relief 0.5–1 m
3	Southern Metro	Warm summer water, low wave exposure, variable depth, limestone, variable relief
4	Yankalilla Bay	Cool summer water, moderate wave energy, depth < 10 m, schist, platform reef or relief 1–3 m
5	Backstairs Passage	Coolest summer water, moderate wave energy, depth variable, schist, relief 1–3 m
6	South Coast	Coolest summer water, high wave energy, depth variable, schist, relief 1–3 m
7	Encounter Bay	Cool summer water, moderate wave energy, depth variable, granite and limestone reefs, relief 0–3 m
8	Goolwa	Coolest summer water, high wave energy, depth 15 m, low profile reef, likely limestone

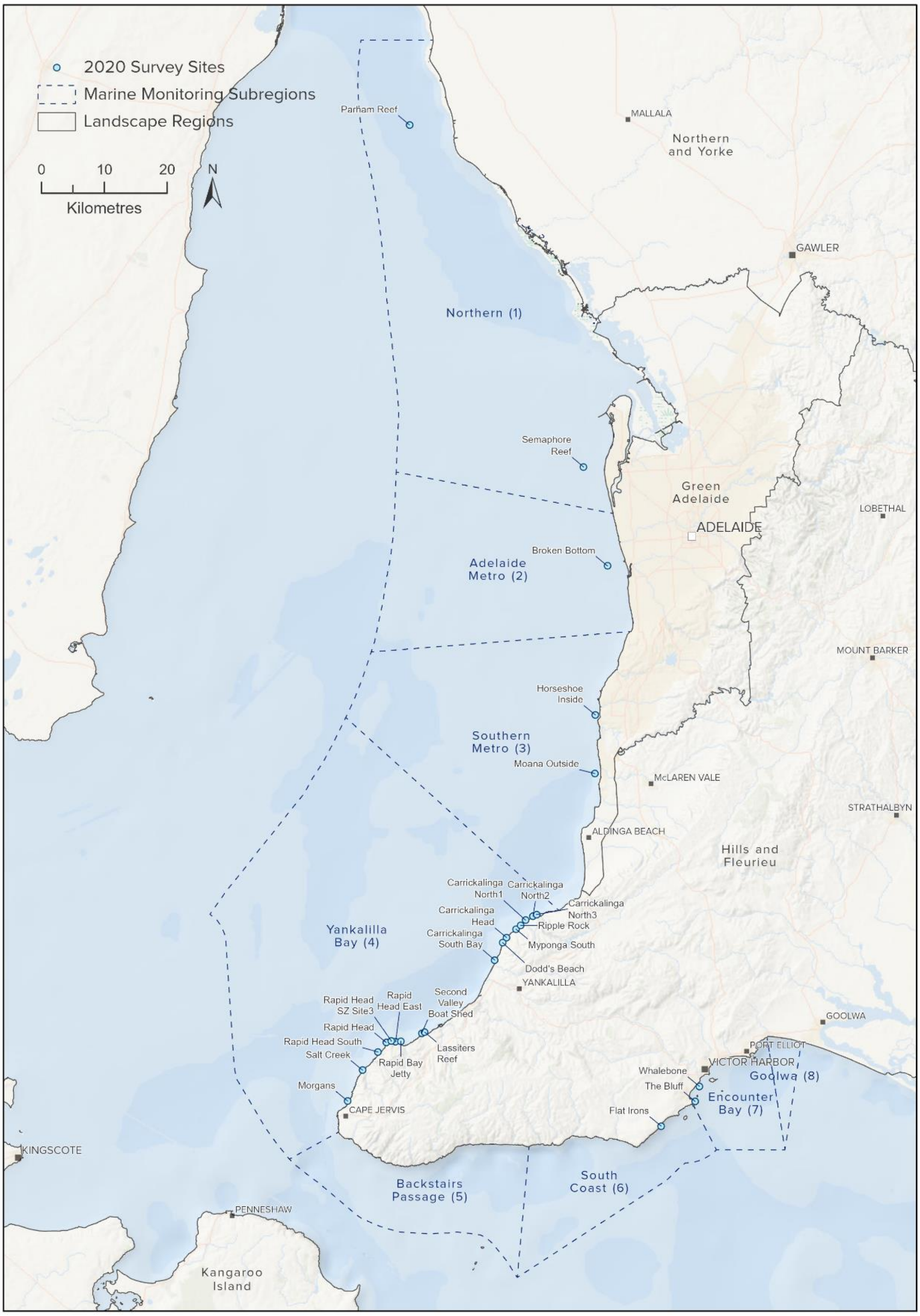


Figure 2.2. Reef survey sites throughout Green Adelaide and Hills and Fleurieu landscape regions in 2020

Data on macroalgae was collected by trained scuba divers surveying a belt transect. Historic and present data was combined from two survey methods: the Marine Protected Areas (MPA) method and the Reef Life Survey (RLS) survey method, which evolved from the MPA method. The two methods are slightly different with the MPA method recording data from an in situ quadrat during the survey, while the RLS method uses a photoquadrat that is analysed post-field (Table 2.2). These methods have been shown to be reasonably consistent in measuring macroalgal cover and combining the two methods increases the spatial and temporal resolution of the data set. For more information on methods and data collection see Brock et al. (in prep).

Table 2.2. Diver survey methods

Method	Time Series	No. of Sites	Fish	Macro-invertebrates and cryptic fish	Macroalgae
Marine Protected Area (MPA)	2005–2013	45	Belt survey 500 m^2	Belt survey 50 m^2	In situ quadrats (50 intercept points)
Reef Life Survey (RLS)	2007–present	41	Belt survey 500 m^2	Belt survey 100 m^2	Photoquadrats (photo every 2.5m)

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:

- 4 years per site, and
- 3 sites per subregion.

There are currently 3 subregions (3, 4 and 7) that meet the above criterion for the macroalgal coverage data analysis (Table 2.3. Summary of sites per subregion with at least four years of macroalgae data

). There are 4 subregions that did not quite meet the above criteria and have subsequently been combined with a neighbouring subregion (subregions '1 & 2' and '5 & 6'). The macroalgal data for these subregions should be interpreted with caution given the paucity of data. Subregion 8 was excluded from analysis due to insufficient data.

Table 2.3. Summary of sites per subregion with at least four years of macroalgae data

Subregion	Number of sites with at least 4 years of macroalgae data
1 & 2	4
3	3
4	25
5 & 6	3
7	3

2.3 Data analysis

Temporal trends in percentage macroalgae cover within each subregion were modelled using Generalized Additive Linear Models (GAMMs) (Wood 2004). GAMMs allow a smooth term (spline function) to be fit to the data, and thus 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 macroalgae cover, any linear trend (i.e. increase or decrease) in percentage macroalgae cover over the period of the time series was identified using Generalized Linear Mixed-effect Models (GLMMs). As above, GLMMs included a 'year' fixed effect and a 'site' random effect. Where significant, the slope associated with the 'year' fixed effect was reported, with a positive slope indicating an increase in the indicator over the time series and a negative slope indicating a decrease.

2.4 Methods to assign trend, condition and reliablity

2.4.1 Trend

Descriptions and thresholds for the report card trend classes are shown in Table 2.4.

Table 2.4. Definition of trend classes used

Trend	Description	Threshold
Getting better	Over a scale relevant to tracking change in the indicator it is improving in status with good confidence	Generalized Linear Mixed-effect Models analysis indicating significant ($P<.05$) increase
Stable	Over a scale relevant to tracking change in the indicator it is neither improving nor declining in status	Generalized Linear Mixed-effect Models analysis indicating no significant change ($P<.05$)
Getting worse	Over a scale relevant to tracking change in the indicator it is declining in status with good confidence	Generalized Linear Mixed-effect Models analysis indicating significant ($P<.05$) decrease
Unknown	Data are not available, or are not available at relevant temporal scales, to determine any trend in the status of this resource	
Not applicable	This indicator of the natural resource does not lend itself to being classified into one of the above trend classes	

2.4.2 Condition

Descriptions and thresholds for the report card condition classes are shown in Table 2.5.

Table 2.5. Definition of condition classes used

Condition	Description	Threshold
Very good	The natural resource is in a state that meets all environmental, economic and social expectations, based on this indicator. Thus, desirable function can be expected for all processes/services expected of this resource, now and into the future, even during times of stress (e.g. prolonged drought)	≥80% cover
Good	The natural resource is in a state that meets most environmental, economic and social expectations, based on this indicator. Thus, desirable function can be expected for only some processes/services expected of this resource, now and into the future, even during times of stress (e.g. prolonged drought)	≥60 to <80% cover
Fair	The natural resource is in a state that does not meet some environmental, economic and social expectations, based on this indicator. Thus, desirable function cannot be expected from many processes/services expected of this resource, now and into the future, particularly during times of stress (e.g. prolonged drought)	≥40 to <60% cover
Poor	The natural resource is in a state that does not meet most environmental, economic and social expectations, based on this indicator. Thus, desirable function cannot be expected from most processes/services expected of this resource, now and into the future, particularly during times of stress (e.g. prolonged drought)	<40% cover
Unknown	Data are not available to determine the state of this natural resource, based on this indicator	
Not applicable	This indicator of the natural resource does not lend itself to being classified into one of the above condition classes	-

2.4.3 Reliability

Information is scored for reliability based on the minimum of subjective scores (1 [worst] to 5 [best]) given for information currency, applicability, and level of spatial representation. Definitions guiding the application of these scores are provided in Table 2.6 for currency, Table 2.7 for applicability and Table 2.8. Guides for applying spatial representation of information (sampling design) for spatial representation.

Table 2.6. Guides for applying information currency

Currency score	Criteria
1	Most recent information >10 years old
2	Most recent information up to 10 years old
3	Most recent information up to 7 years old
4	Most recent information up to 5 years old
5	Most recent information up to 3 years old

Table 2.7. Guides for applying information applicability

Applicability score	Criteria
1	Data are based on expert opinion of the measure
2	All data based on indirect indicators of the measure
3	Most data based on indirect indicators of the measure
4	Most data based on direct indicators of the measure
5	All data based on direct indicators of the measure

Table 2.8. Guides for applying spatial representation of information (sampling design)

Spatial score	Criteria
1	From an area that represents less than 5% the spatial distribution of the asset within the region/state or spatial representation unknown
2	From an area that represents less than 25% the spatial distribution of the asset within the region/state
3	From an area that represents less than half the spatial distribution of the asset within the region/state
4	From across the whole region/state (or whole distribution of asset within the region/state) using a sampling design that is not stratified
5	From across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design

2.5 Data transparency

Data transparency for this report card is represented in Appendix A.

3 Results

3.1 Trend

Based on data available, the statewide trend in macroalgae cover has been assessed as stable. The percentage cover of canopy-forming macroalgae was stable in the combined subregions 1 & 2 and showed a non-significant increase in sub-region 3 between 2015–2020 (Figure 3.1). The percentage cover of canopy-forming macroalgae showed significant increase between 2012 and 2020 in subregions 4, combined 5 & 6, and 7, and was generally substantially higher than in the combined subregions 1 & 2 and sub-region 3 (Figure 3.1, Table 3.1).

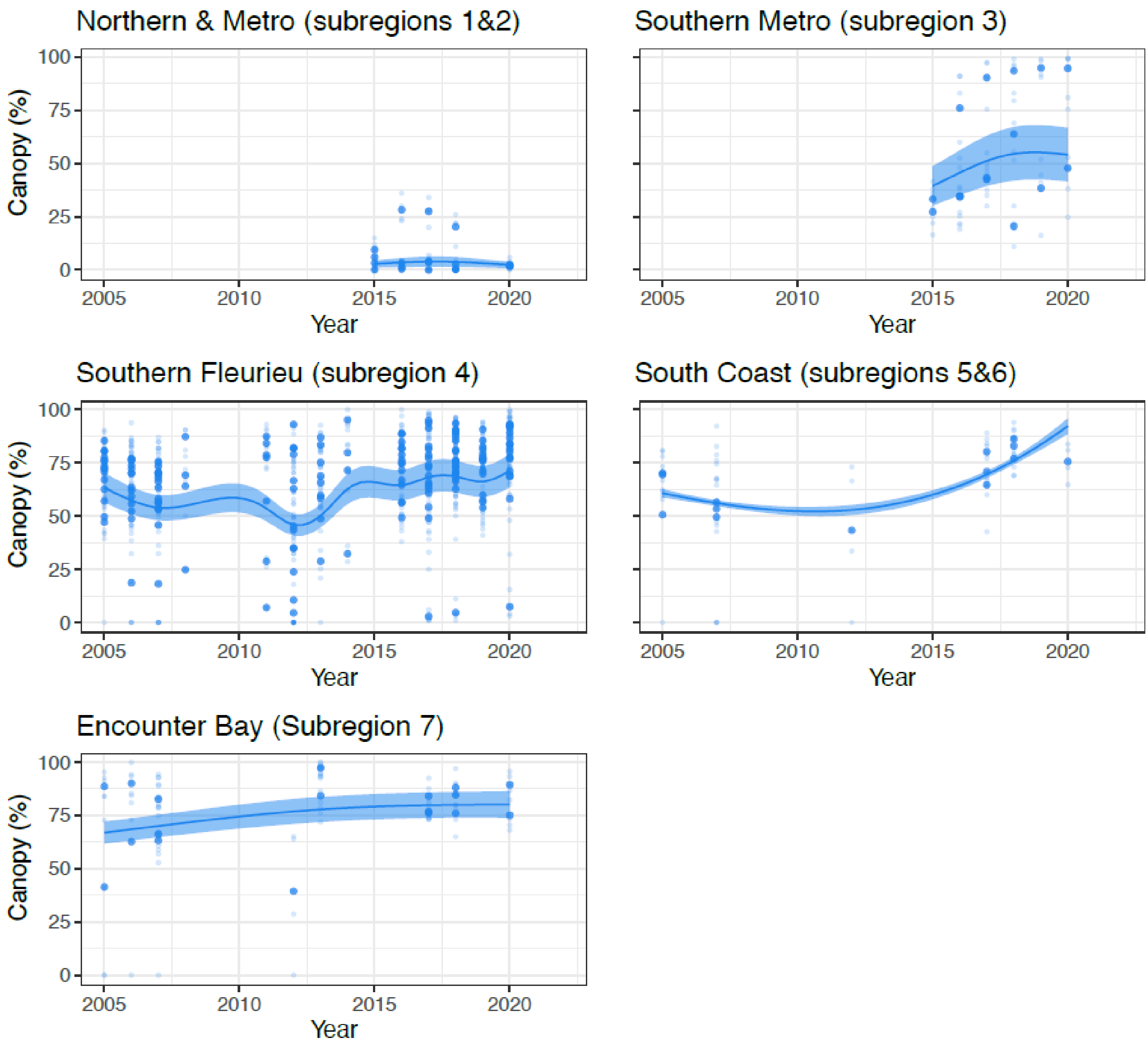


Figure 3.1. Temporal trends in the percentage cover of canopy-forming macroalgae within each subregion, fitted using generalized additive mixed-effect models. Small dots indicate values for individual transects, and larger dots show the mean value at the site level. The mean predicted trends are shown as solid lines with envelopes indicating 95% confidence intervals

Table 3.1. Subregional trends with significance values indicating significant positive increase in cover from the Generalized Linear Mixed–Effect Model analysis

Indicator – reef condition (% cover macroalgae)				
Landscape region	**Subregion**	**Subregion trend**	**Landscape region trend**	**Significance**
Green Adelaide	1 & 2	Stable	Stable	-
	3	Stable		-
Hills and Fleurieu	4	Getting better	Getting better	0.01
	5 & 6	Getting better		0.025
	7	Getting better		0.019

3.2 Condition

Condition of subtidal macroalgae cover in 2020 is assessed as good where cover is known. Most existing data relate to the GA and HF landscape regions and data are inadequate to make a robust assessment of reef condition across the rest of the state. Condition of reefs in the GA and HF landscape regions is poorer in the north and improves towards the south (Figure 3.2,

Table 3.2).

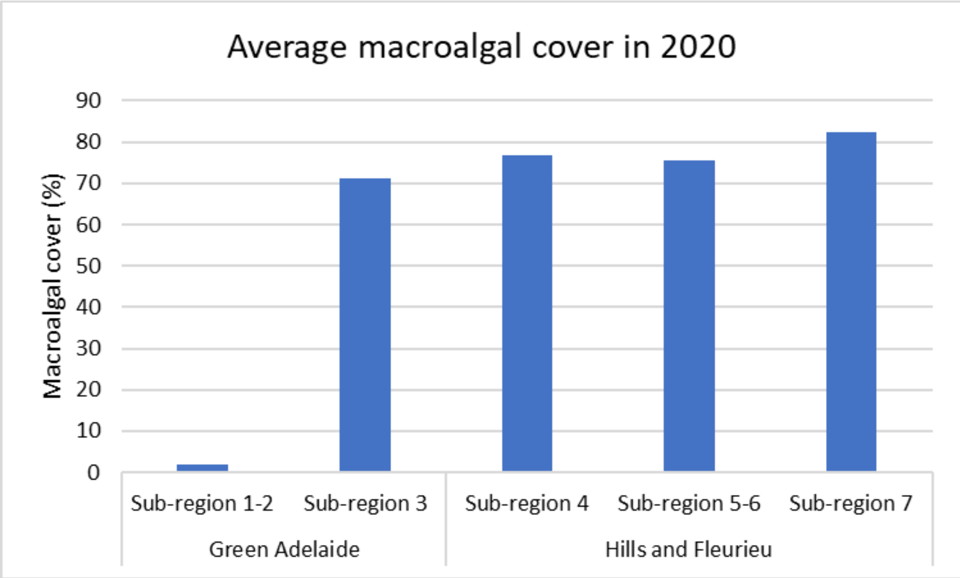


Figure 3.2. Sub-regional average macroalgae cover (%) for the Green Adelaide and Hills and Fleurieu landscape regions in 2020

Table 3.2. Sub-regional condition classification for each landscape region in 2020

	Indicator – reef condition (% cover macroalgae)		
Landscape region	**Sub-region**	**Average cover (%)**	**Condition**
Green Adelaide	1 & 2	2	Poor
	3	71	Good
Hills and Fleurieu	4	77	Good
	5 & 6	76	Good
	7	82	Very Good

3.3 Reliability

The overall reliability score for this report card is 2 out of 5 based on Table 3.3. This is considered 'Fair' reliability.

Table 3.3. Information reliability scores for subtidal macroalgae: percentage cover trends

Indicator	Applicability	Currency	Spatial	Reliability
Subtidal macroalgae cover (%)	5	5	2	2

3.3.1 Notes on reliability

While the data is based on a direct measure of the indicator (applicability score of 5), the spatial distribution of the data is restricted to only two landscape regions (spatial score of 2). While these regions are likely to be more influenced by metropolitan Adelaide and anthropogenic impacts and provide an indication for statewide condition, care should be taken when extrapolating this data to other regions across the state. The most recent data were no more than 3 years old, therefore an information currency score of 5 was allocated.

4 Discussion

4.1 Trend and condition

The trend and condition for subtidal macroalgal percentage cover across South Australia has been assessed as 'Stable' and 'Good' respectively. This assessment is based on a limited spatial area (i.e. parts of GA and HF landscape regions) and the general condition of macroalgae cover on reefs in these regions was stable or improving. Even though macroalgal cover has only been measured across a small portion of the state's coastal waters, the health of macroalgal cover in these highly anthropogenic affected areas may provide an indication for the patterns of reef health expected across the state. Acute localised affects aside, subregions 4 to 7 (southern metropolitan) showed good macroalgae cover and would be more representative of reefs across the state based on population density when compared to the northern areas which are highly populated and impacted by anthropogenic effects such as stormwater, sewage outfalls and dredging. The increasing trend in subregions 4 to 7 is not expected to be observed across the whole state as improvements to water quality along the metropolitan coast are not a factor in more regional areas. Given the stable or improving condition observed in the metropolitan waters, the trend is expected to be stable at a statewide level.

This report indicates that, at least for the sites assessed, the historic decline in macroalgae canopy cover has stabilised and may be recovering in some areas (e.g. subregions 4, combined 5 & 6, and 7, EPA 2003). This potentially represents a 'good news' story given the history of decline in kelp forests since the 1970s on reefs in closer proximity to Adelaide and the importance of macroalgae in maintaining healthy nearshore and reef ecosystems (Turner et al. 2007). This improved outlook may be related to a number of 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 sludge outfalls, improvements to water reclamation and waste water treatment plants, and reduction in nutrient inputs (e.g. Penrice Soda, EPA 2014).

It is however important to note the following important caveats associated with spatial variations, data limitations and lack of historical benchmarks for the current dataset.

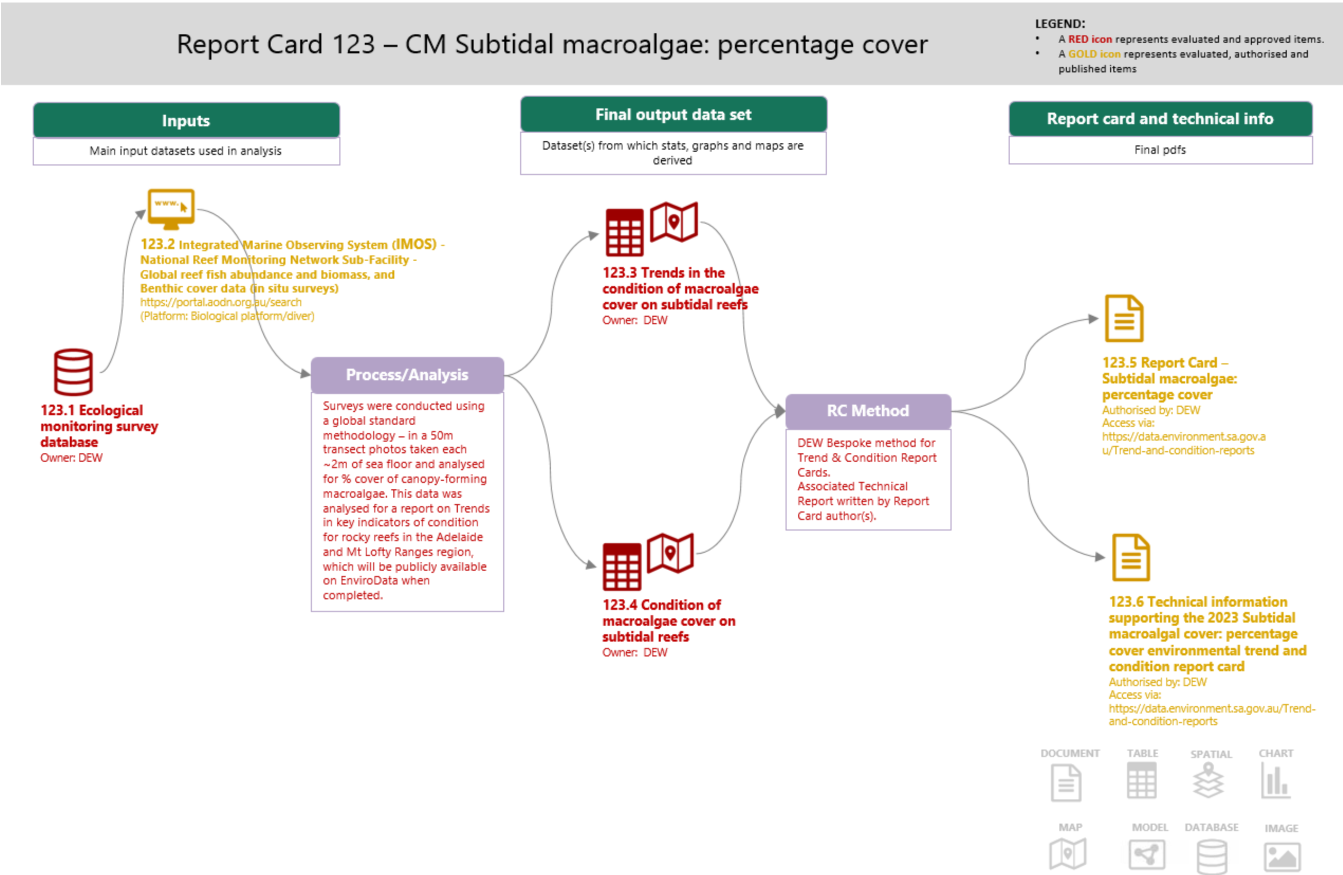
Reefs surveyed are selected based on location and also depth. The macroalgae surveyed for this report card are limited to depths between 5 and 10 m as this facilitates divers to dive for an adequate time to collect the required data. These shallow reef systems are subjected to greater variations in water temperature and wave action than deeper habitats and may exhibit different coverage patterns compared to deeper reefs.

As with most ecosystems, there is substantial variation in the distribution and abundance of plants and animals within the spatial extent that reef ecosystems may span. Macroalgae cover is substantially less in subregions 1 and 2 (<25% cover versus >50% for all other subregions). Subregions 1 and 2 are in the most northern parts of the study area (noting that subtidal reefs do not exist any further north in Gulf St Vincent). They are also in closest proximity to Adelaide. Natural and anthropogenic factors both likely contribute to the difference in cover at these northern sites. Macroalgal cover may have always been less in subregions 1 and 2 as a result of natural differences in geophysical (substrate type), chemical (salinity is higher in the northern Gulf St Vincent), physical (summer temperature is higher in the northern Gulf St Vincent), and hydrodynamic processes (wave action, tidal influence, flushing rate). Additionally, macroalgal cover in these subregions may have been the most impacted by anthropogenic stressors given the locations of these sites adjacent to the most populated areas of the coastline. Without adequate historic baselines the primary cause of the observed pattern is unknown. The condition scores for this report are not scaled for differences in location and do not take into consideration the fact that a 'Poor' condition score (based on <40% coverage) in the northern regions may in fact be the natural and expected state of these reefs based on species' natural distribution, and on their differing geophysical/hydrodynamic position within Gulf St Vincent.

Also of note is the inconsistencies within data holdings across subregions. Subregions 1, 2 and 3 have limited time series of only 5 years while subregions 5 & 6, and 7 have fewer sites from which to determine trends. These two factors explain some of the higher variation seen in these subregions compared to subregion 4 which has both a more comprehensive time series and a larger number of sites. It is anticipated that with continued investment and monitoring the robustness of the time series for these subregions and indicators will improve.

5 Appendices

A. Managing environmental knowledge chart for Subtidal macroalgae: percentage cover



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