Potential social, economic and ecological indicators for integrated ecosystem assessment of Spencer Gulf

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Executive Summary

Traditionally, management of marine activities has occurred on a sector-by-sector basis, with limited consideration of the interactions between different activities and users, or their cumulative impacts. There is increasing global recognition of the need for Integrated Management (IM) of the complex array of commercial and recreational activities that occur in marine environments, and their impacts on the socio-ecological assets that comprise these systems. An integrated monitoring program that includes social, economic and ecological indicators is an essential element of IM.

Spencer Gulf is a region of high economic and cultural importance to South Australia. It was the focus of a broad attempt to establish ecosystem-based management of the State's coastal, estuarine and marine environments in the early 2000s. This initiative resulted in the *Living Coast Strategy* and *Marine Planning Framework for South Australia*, but neither was implemented beyond the development of an initial pilot study in Spencer Gulf. The Spencer Gulf Ecosystem and Development Initiative (SGEDI) was established in 2011, when a broad range of stakeholders recognised the need for a more integrated approach to development in the area. The focus of SGEDI has been to develop pilot tools to support IM and demonstrate the benefits of a more integrated approach.

Management of Spencer Gulf is currently delivered under at least 15 different South Australian Government Acts, with limited cross-referencing between different pieces of legislation, despite many having broadly similar objectives. Management decisions are often made without fully considering the overall social, economic and ecological status of the region, at least in part because of the time-consuming task of trying to track down all the relevant data from different agencies and organisations. In particular, cumulative impacts are not considered. There is also no clear basis for assessing trade-offs between different uses of the environment. An integrated monitoring program that includes social, economic and ecological indicators has not been established for Spencer Gulf.

This report collates existing information on the threats to the ecosystems of Spencer Gulf and its industries and communities. Datasets that may provide a useful indicator for one or more assets or threats are collated. The focus is on datasets for which there are available time-series data. Most existing monitoring programs are designed to assess the impacts of and/or manage individual activities, or to monitor particular species. While we have identified a broad range of valuable data sets for Spencer Gulf (~170), we have also identified many gaps, and a number of data sets that are only collected sporadically, and for which there is no guarantee of continuation.

From a socio-economic perspective, there are good data on a wide range of indicators for the communities surrounding the gulf, although few that specifically identify the marine contribution to these communities. Employment and economic production from fisheries and aquaculture are an exception. From a cultural perspective, there are few data that we have been able to identify, with the exception of perception surveys undertaken for marine parks. There are a wider range of data sets on the marine environment and ecology, although there are still many gaps. In particular, there is a paucity of data on unvegetated soft sediments, which dominate the deeper waters of the gulf. Seagrass has also not been mapped for the entire gulf region. There are good data sets on commercially-important fish and crustacean species, but few on non-commercial species. There are a few data sets on threatened, endangered and protected species, but these have been pieced together from a range of projects, and none are planned, ongoing, long-term monitoring programs. Many of the threats to the gulf are also poorly monitored. There are good data on commercial fishing and aquaculture (but not recreational fishing), and on discharges from waste water treatment plants, but little else for local threats.

Overall, we have identified around 170 different data time-series that could be used as the basis for a suite of indicators of the overall social, economic and ecological status of Spencer Gulf, as well as numerous data gaps. One challenge identified by this work is that a number of potentially important data sets are collected and reported at spatial scales that are not useful for examining the status of

Spencer Gulf. This data is either collected/reported at a statewide scale, or for terrestrially-based natural resources management regions. The next step is be to consolidate the datasets collated here into a smaller subset that provide a useful and amenable set of actual indictors that can be utilised to monitor the status of the gulf and assess the impacts of the range of activities undertaken in it, going forward. The collation of information undertaken in this report is an important steps towards undertaking an Integrated Ecosystem Assessment of Spencer Gulf.

Keywords: development, sustainable, environment, socio-economics, Spencer Gulf, indicators.

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1 Introduction

1.1 Need for integrated management of marine systems

Traditionally, management of marine activities has occurred on a sector-by-sector basis, with limited consideration of the interactions between different activities and users or their cumulative impacts (e.g. Begg et al. 2015). The 3-dimensional nature of the marine environment, and the inherently high levels of connectivity across large distances, mean that there is a high potential for different marine activities to interact, overlap, compete (e.g. for space, resources or ecosystem services) and combine to cause cumulative impacts. These problems have been exacerbated by the rapid growth of coastal populations, and expanding demand for access to marine resources from a progressively broader range of user groups (e.g. renewable energy sector). As a result, there is increasing global recognition of the need for Integrated Management (IM) of the complex array of commercial and recreational activities that occur in marine environments and their impacts on the socio-ecological assets that comprise these systems (Sarda et al. 2014, Walther and Mollmann 2014, Cormier et al. 2017, Link and Browman 2017).

Drawing on lessons from a range of international and Australian case studies, Begg et al. (2015) defined Integrated Marine Management as the "*co-ordinated management of diverse activities with consideration of ecological, economic, social and institutional objectives to sustainably develop marine resources*". Begg et al. (2015) noted that transition to IM is likely to be slow and iterative, and that many early attempts to implement IM have failed; Australia's Ocean Policy was cited as a prime example. Begg et al. (2015) also recognised that there have been a small number of cases where some (but not all) key issues have been successfully addressed by implementing a more integrated approach to marine management, with Australia's Great Barrier Reef being a well-known example. Begg et al. (2015) concluded that IM is not a replacement for sector-specific management, but addresses several key issues not covered by the single sector approach including: integrated governance; broad ecological, economic, social and institutional objectives; scenario comparison and structured decision-making; attention to interactions and tradeoffs among sectors; and consideration of cumulative impacts.

Based on the lessons learned from a range of Australian case studies, Smith et al. (2017) defined Ecosystem Based Management (EBM, another term for IM) as "*balancing human activities and environmental stewardship in a multiple-use context*". Like Begg et al. (2015), they concluded that although EBM is widely accepted as the best means of managing complex interactions in marine systems, progress towards operationalisation has been slow. Based on the case studies considered, Smith et al. (2017) identified several essential elements that are needed to improve implementation of EBM, including: clear articulation of the need for an integrated approach; stakeholder ownership; a well-defined governance framework to co-ordinate decision-making; and scientific tools to deal with conflicts and trade-offs.

Implementation of IM requires identification of a suite of ecological, economic and social objectives and indicators. Objectives related to ecological sustainability, productivity, biodiversity and protection of habitat are often well articulated, but others (including social objectives) are often not articulated or stated in vague, general terms. There has been recent work in Australia and internationally (e.g. Stephenson et al. 2018 and references therein) to try to articulate the spectrum of objectives associated with major international agreements related to sustainability in the marine/coastal zone. While specific objectives will be articulated by regional authorities, Stephenson et al. (2018) put forward a set of 'candidate objectives' that demonstrate the spectrum of ecological, social/cultural, economic and institutional information that is required for decision-making under an ecosystem-based approach, and for comprehensive evaluation of sustainability.

Drawing on examples from Australia and Canada, Stephenson et al. (2019) identified that the primary rationale for implementing IM is to address the four main deficiencies of sector-based management, namely: 1) separate sectors are managed by different agencies using independent approaches; 2) management focuses on ecological objectives (social, economic and institutional objectives are often poorly defined); 3) trade-offs among sectors and objectives are not evaluated; and 4) cumulative impacts are not considered (Figure 1). Stephenson et al. (2019) define IM as "*An approach that links (integrates) planning, decision-making and management arrangements across sectors in a unified framework, to enable a more comprehensive view of sustainability and the consideration of cumulative effects and trade-offs*." They argued that IM will be most easily and effectively achieved by linking and modifying existing sector-based plans in an overarching approach (Figure 2). The nine key features of IM identified by Stephenson et al. (2019) are: 1) Recognition of need for IM; 2) A shared vision by stakeholders and decision-makers for IM; 3) Appropriate legal and institutional frameworks for coordinated decision-making; 4) Sufficient and effective processes for stakeholder engagement and participation; 5) A common and comprehensive set of operational objectives; 6) Explicit consideration of trade-offs and cumulative impacts; 7) Flexibility to adapt to changing conditions; 8) Processes for ongoing review and refinement; and 9) Effective resourcing, capacity, leadership and tools (Figure 3). Stephenson et al. (2019) also identify five likely phases in the implementation of IM, namely: 1) Preconditions and drivers of change; 2) Intentional design and institutional rearrangement; 3) Enablers and disablers; 4) An implemented IM process; and 5) Review of IM performance and modification (Figure 3).

The best recent example of the implementation of IM in an Australian jurisdiction is the New South Wales (NSW) Marine Estate Management Authority (MEMA, see **Box 1**). The NSW journey to implementing IM began in 2011 when the NSW Government commissioned an Independent Scientific Audit of Marine Parks (MEMA 2018). The aim of the audit was to enable the NSW Government to develop balanced policies that provided for protection of the marine environment as well as supporting a wide range of other uses, including recreational activities (MEMA 2018). The two over-arching recommendations from the audit were that: 1) governance of the NSW Marine Estate be reorganised to bring the entire estate under one legislative and administrative structure; and 2) science for the NSW Marine Estate be reorganised under an independent Scientific Committee with greater emphasis placed on social and economic research and the application of findings to management (Beeton et al. 2012). The NSW MEMA and independent Marine Estate Expert Knowledge Panel (MEEKP) were established in 2013 (Brooks and Fairfull 2017, Smith et al. 2017), and the *NSW Marine Estate Management Act* proclaimed in 2014. The organisational governance structure for the NSW Marine Estate is shown in Figure 4.

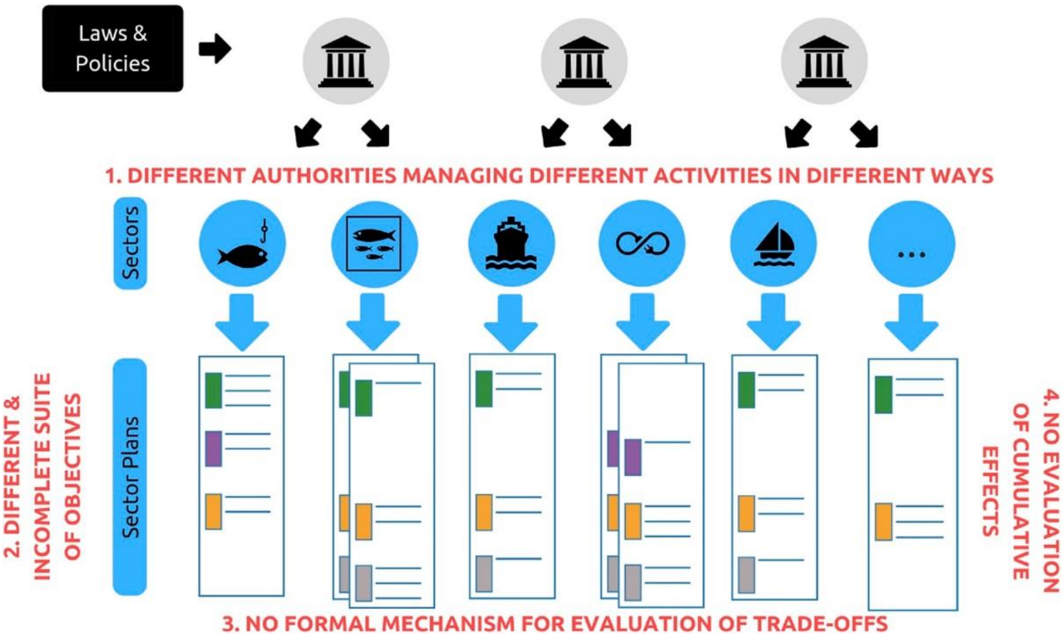

Figure 1. Conceptual representation of the major shortcomings (red) of current sector-based management. Laws and policies shape the managing authorities, which are responsible for different sectors (blue icons, including fisheries, aquaculture, transportation, energy, recreation, and other activities), each of which may have multiple plans (blue boxes) containing diverse objectives (represented by coloured rectangles and lines). Plans use an incomplete suite of different objectives, there is no formal mechanism for evaluating trade-offs (either among objectives within activities or between activities) and there is no evaluation of cumulative effects. Source: Stephenson et al. (2019).

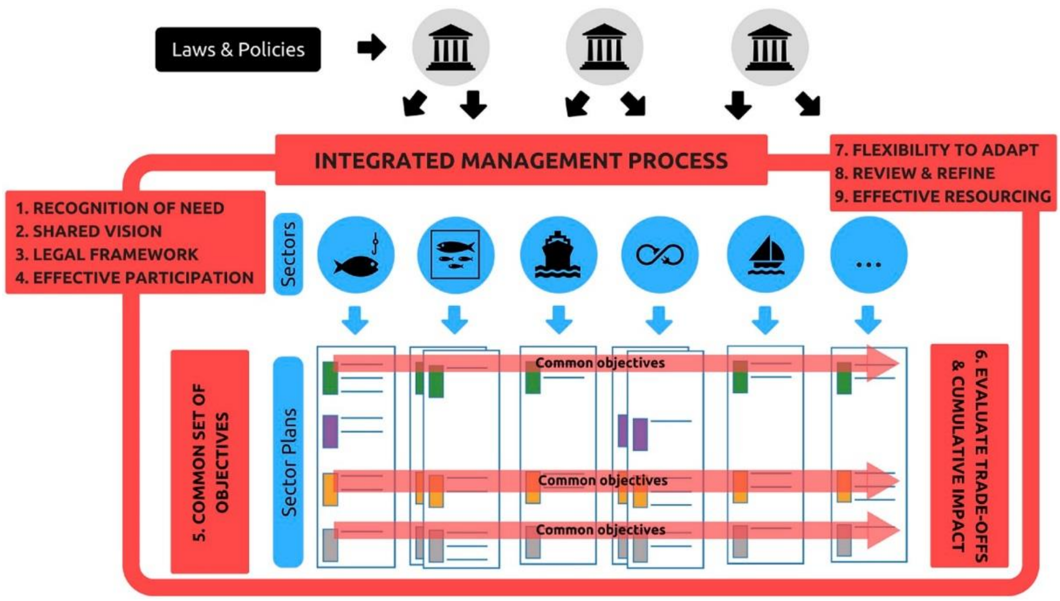

Figure 2. Conceptual representation of a practical framework for Integrated Management, which would overcome the major shortcomings of current management with minimum change to existing sector-based management structure and function. Sectors (blue icons) retain specific management plans (represented by blue rectangles), but a participatory Integrated Management process would influence a key set of objectives across sector plans so as to be able to evaluate trade-offs and cumulative effects. Features (structure and function) of the vision for IM are elaborated in the text. Source: Stephenson et al. (2019).

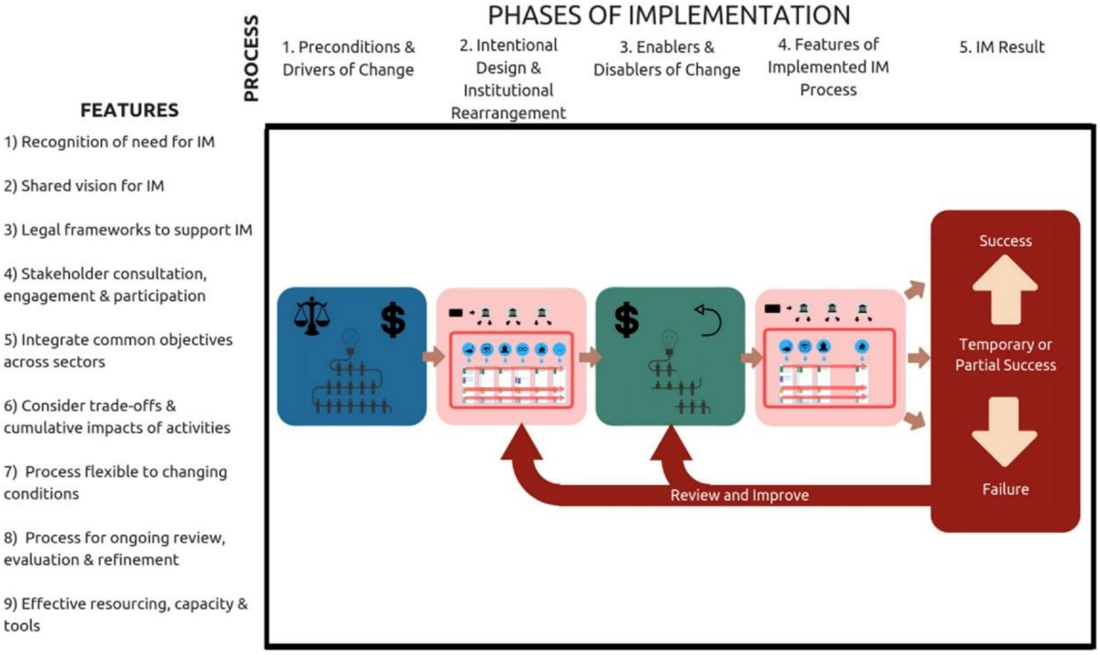

Figure 3. The nine key features of Integrated Management (IM) and five phases that make up the likely process of implementation. Source: Stephenson et al. (2019)..

MEMA was established to achieve the NSW Government's vision for "*A healthy coast and sea, managed for the greatest wellbeing of the community, now and into the future*". The five-step decision-making process of MEMA is shown in Figure 5. The Marine Estate Management Strategy 2018–2028 reaffirmed the NSW Government's commitment to maintaining and improving holistic management of the marine estate as one continuous system, and outlines how threats to the environmental assets and social, cultural and economic benefits that the community derives from the marine estate will be managed (Box 1, MEMA 2018). A comprehensive ten-year marine integrated monitoring program was implemented in 2018 to monitor the condition of assets and benefits, and measure success in reducing the priority threats and filling key knowledge gaps.

Box 1 – NSW Marine Estate Management Strategy

The NSW Marine Estate Management Strategy integrates with existing coastal and marine programs to provide an overarching approach to management by all levels of government. Using the best available evidence, with input from key stakeholders (scientists, the community, Aboriginal people, industry, and government and non-government organisations), it outlines methods for managing threats to environmental assets and socio-economic benefits, identifies evidence-based management priorities, and sets policy directions to manage the marine estate as a single continuous system.

The ten underpinning principles for managing the marine estate are:

1. Effective community engagement to identify and prioritise benefits and threats
2. Identification of priority actions will be based on threat and risk assessment
3. Values will be assigned to enable trade-off decisions between alternative uses of the marine estate
4. Best available information will be used in trade-off decisions, but judgement will still be required
5. The wellbeing of future generations will be considered
6. Existing access arrangements will be respected
7. The precautionary principle will be applied
8. Efficient and cost-effective management will be used to achieve community outcomes
9. Management decisions will be transparent and adjust in response to new information
10. Management performance will be measured, monitored and reported, and information pursued to fill critical knowledge gaps

Nine related management initiatives are aimed at addressing the priority and cumulative threats by:

1. Improving water quality and reducing litter
2. Delivering healthy coastal habitats with sustainable use and development
3. Planning for climate change
4. Protecting the Aboriginal cultural values of the marine estate
5. Reducing impacts on threatened and protected species
6. Ensuring sustainable fishing and aquaculture
7. Enabling safe and sustainable boating
8. Enhancing social, cultural and economic benefits
9. Delivering effective governance

The Marine Integrated Monitoring Program currently being implemented will be used to assess the effectiveness of management initiatives and their actions to address the identified threats, to guide adaptive management, and to fill key knowledge gaps identified in the State-wide Threat and Risk Assessment (State-wide TARA) in a co-ordinated state-wide program.

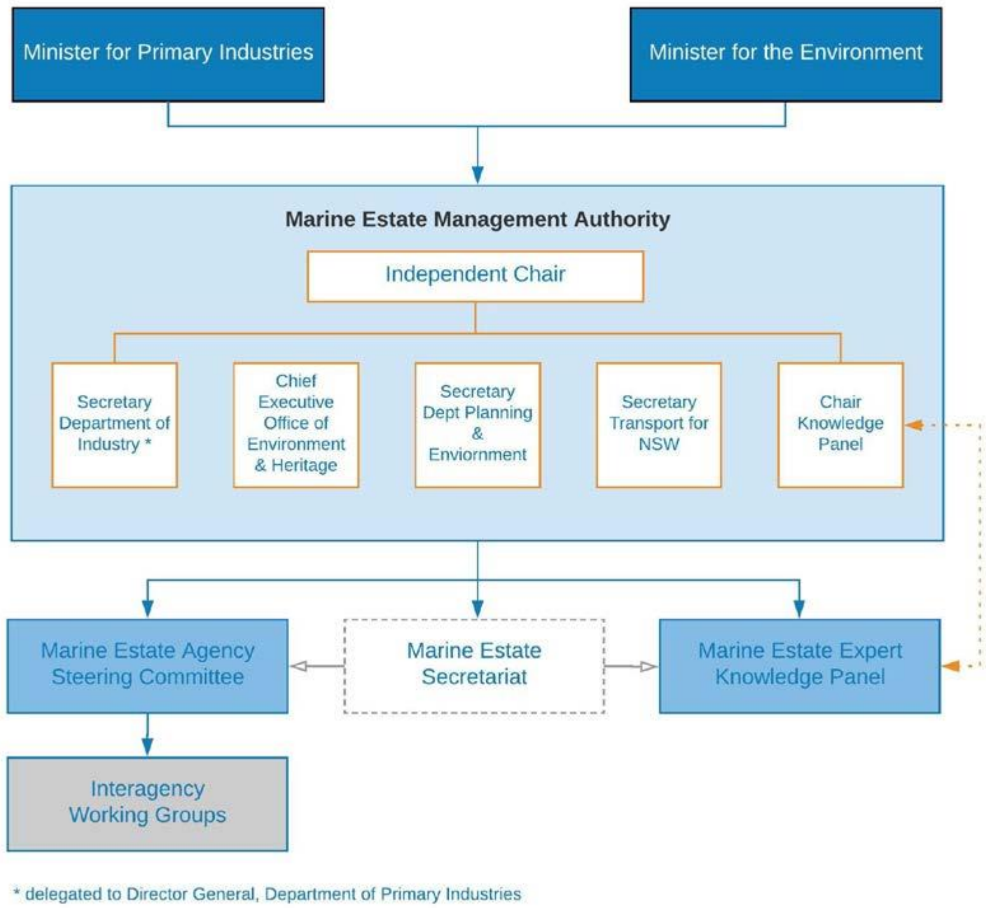

Figure 4. Organisational governance structure for the New South Wales Marine Estate (Source: MEMA 2018b).

Figure 5. The New South Wales Marine Estate Management Authority's five-step decision-making process (Source: MEMA 2018a).

1.2 Need for integrated monitoring programs

Integrated monitoring programs that include social, economic and ecological indicators are an essential element of IM. A good example of a long-term integrated monitoring program that has been established to support an IM initiative is the California Current Integrated Ecosystem Assessment (CCIEA, Box 2). The CCIEA is one of five regional Integrated Ecosystem Assessments (IEA) undertaken by the United States of America's National Oceanic and Atmospheric Administration (NOAA).

IEAs integrate all components of an ecosystem, including humans, into the decision-making process so that managers can balance trade-offs and determine what is more likely to achieve their desired goals. The five key elements of IEAs are: 1) defining the system and goals; 2) selecting indicators; 3) assessing the ecosystem; 4) assessing risk; and 5) evaluating management strategies (see Figure 6). The first step involves identifying relevant ecological, social, and economic characteristics, and their relationships with partners and stakeholders, and documenting management or planning goals and objectives. The second step, selecting indicators and assessing the ecosystem, includes identifying, selecting, and when needed, developing indicators that capture the status and trends of key components of the ecosystem. The third step involves assessing the status of the ecosystem using the selected indicators. The fourth step is a risk assessment that determines the probability of undesirable events occurring to key components of the ecosystem. The fifth step is to analyse trade-offs through management strategy evaluation. The process is explicitly adaptive and iterative.

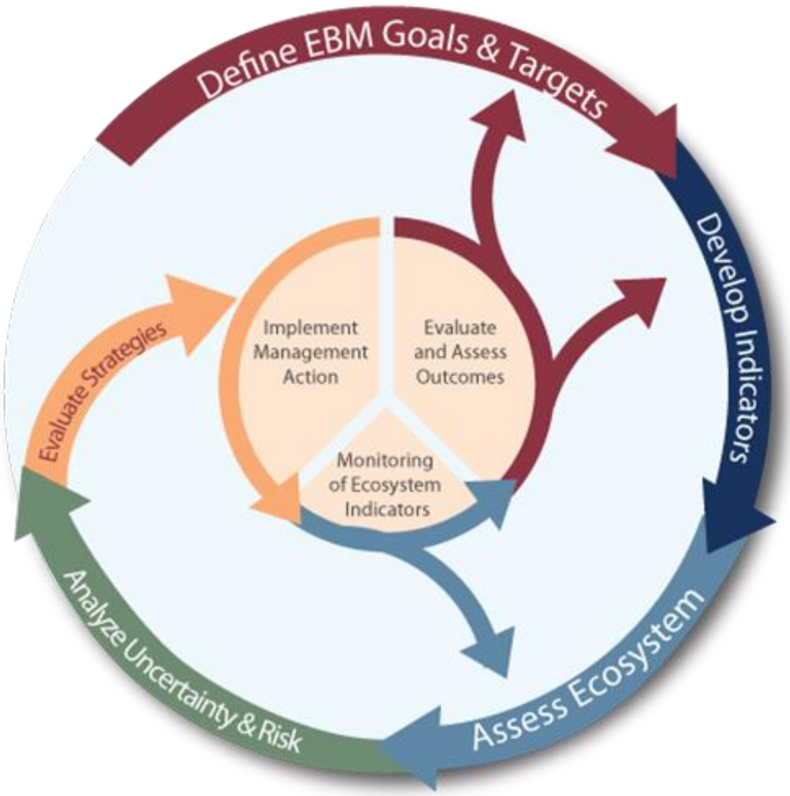

Figure 6. The United States of America's National Oceanic and Atmospheric Administration (NOAA) approach to Integrated Ecosystem Assessments, also known as Ecosystem Based Management (EBM) (Source: https://www.integratedecosystemassessment.noaa.gov/).

Box 2 - California Current Integrated Ecosystem Assessment (CCIEA)

The CCIEA is focused on the California Current Large Marine Ecosystem (CCLME) in the eastern North Pacific Ocean. Spanning nearly 3000 km from Canada to Mexico including the United States of America's (USA) exclusive economic zone, the coastal land-sea interface, and terrestrial watersheds, the CCLME is a highly productive ecosystem which supports small pelagic fish, and migratory fish, birds and mammals. Primarily fuelled by seasonal upwelling, the productivity of the CCLME is influenced by large-scale climate drivers like El Nino/La Nina and the Pacific Decadal Oscillation. The ecosystem is of high economic importance to the west coast of the USA, and supports commercial and recreational fishing industries, tourism, energy production, and transport industries, which generate $44B for regional economies, with ~540,000 individuals employed. The area plays an important role in climate regulation, and is ecologically important as habitat for Pacific salmon, tuna and billfish, sea lions, orca, and grey whales. The CCLME holds significant cultural heritage values to Native Americans.

Topics of key focus for the CCIEA are climate, fisheries, and energy, and its objectives are as follows:

- To inform the management of diverse, potentially conflicting, ocean use sectors
- To contribute to a better understanding of management trade-offs in the CCLME by:
    - improving baseline ecosystem science and data
    - discerning complex interactions between species, sectors, and ecosystem function
    - examining links between human activity and ecosystem health
- To understand the interactions that link drivers and pressures to Ecosystem Based Management (EBM) components, and forecast how the status of these components is affected by changes in environmental conditions and management actions
- To involve and inform a wide variety of stakeholders and agencies that rely on science support for EBM, and to integrate their datasets/information

The CCIEA examines the status and trends of a range of ecological and socio-economic indicators developed for EBM components of CCLME, including drivers and pressures (climate and ocean drivers, social drivers), focal components (e.g. species abundance, ecological integrity, human wellbeing), mediating components (habitat, local social systems), and human activities (commercial, recreational, cultural). Assessment of the California Current ecosystem is interpreted by examining the status and trends of a range of indicators which include:

- Population abundance
- Information on focal species, selected to ensure representation across trophic levels, habitats, sensitivity to environmental changes, and vulnerability to human activity
- Population condition indicators (growth rate, age structure diversity)
- Biodiversity and trophic structure (diversity, mean trophic level, biomasss of specific, ecologically important taxa)
- Habitat indicators (e.g. mean maximum temperature, measures of flow)
- Climatic and oceanographic variables (e.g. DO concentration at depth, Aragonite saturation, Multivariate ENSO index, Upwelling index, SST)
- Fishing effort for various regions and species
- Other human impacts (e.g. coastal engineering, shipping, aquaculture, invasive species, nutrient load, oil and gas activity etc)

Reports on the status and trends of the above key indicators are provided annually to the Pacific Fishery Management Council as part of their Fishery Ecosystem Plan. Other reports include overview and synthesis reports that developed the technical background for IEA in the California Current, and regionally specific reports that develop indicators and conceptual models for local, state, and federal partners.

An ecosystem status report that synthesises indicators to provide an overview of the status, trends, and possible future conditions of components of the California Current ecosystem is provided annually to the Pacific Fishery Management Council, and West Coast National Marine Sanctuaries Office, West Coast state governments and other marine resource management organisations. Ecosystem status reports are instrumental in facilitating ecosystem-based management of the California Current ecosystem.

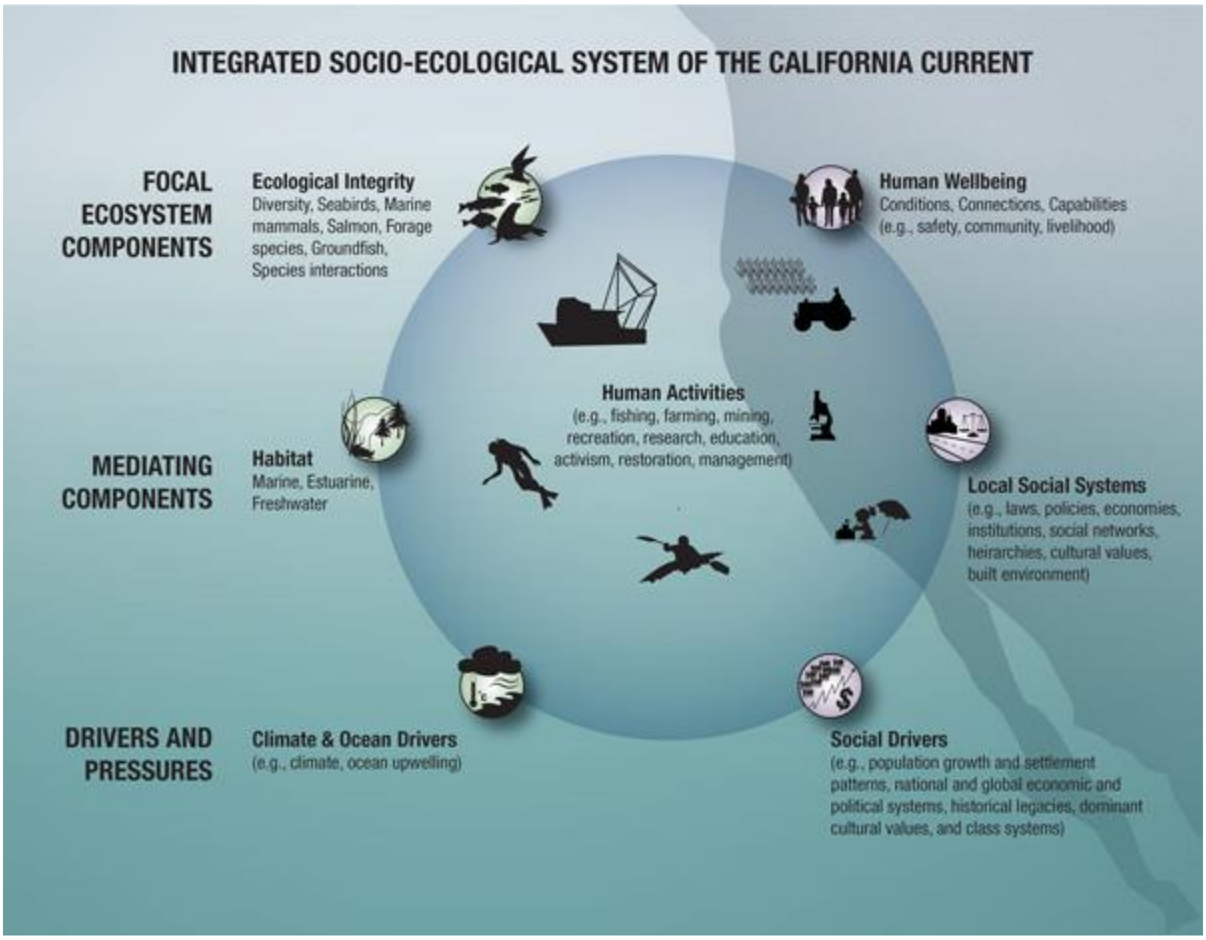

Figure 7. Key components of the integrated socio-ecological ecosystem of the California Current (Source: https://www.integratedecosystemassessment.noaa.gov/).

1.3 South Australia and Spencer Gulf

1.3.1 Defining the system and goals

Much of the information needed to identify the ecological, social, and economic characteristics of Spencer Gulf, their relevance to partners and stakeholders, and the management goals and objectives, has been compiled in a suite of projects funded by the Spencer Gulf Ecosystem and Development Initiative (SGEDI, https://www.adelaide.edu.au/environment/water/spencer-gulf/). Comprehensive summaries of existing knowledge of the environment and ecology of Spencer Gulf, including the key activities, stressors and impacts, and key knowledge gaps, are provided by Gillanders et al. (2013) and Shepherd et al. (2014).

Spencer Gulf (Figure 8) is a large (~24,750 km^2) shallow, inverse estuary characterised by low rainfall and high rates of evaporation (Nunes Vaz 2014). During summer, a frontal system that forms at the mouth of Spencer Gulf prevents the gulf's warm saline waters mixing with cooler waters on the shelf (Petrusevics et al. 2011). In contrast, during winter, water from the shelf flows into the gulf along the western side of the gulf and plumes of cool waters flow out from the gulf (Nunes Vaz et al. 1990, Teixeira 2010, Middleton et al. 2013). Primary and secondary productivity peak during late summer and early autumn, then decline during winter, reaching their lowest points in spring (Van Ruth 2009, Van Ruth et al. 2009, Middleton et al. 2013).

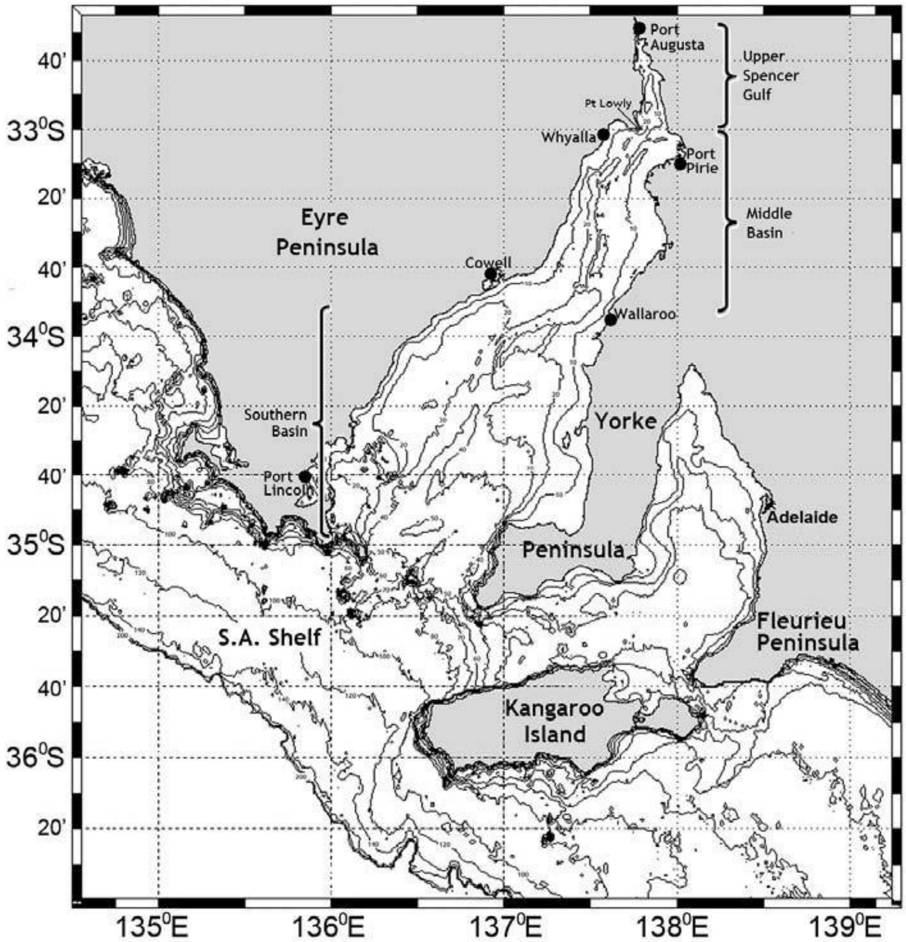

Figure 8. Map of Spencer Gulf from Shepherd et al. (2014).

A diverse assemblage of pelagic fishes occurs in Spencer Gulf, including a large population of Australian sardine (*Sardinops sagax*) (e.g. Shepherd et al. 2014). There is also a high diversity of benthic fishes, with the species present differing between benthic habitats. Not a lot is known about those assemblages living over deeper soft sediments, although there has been some information gathered from prawn-trawl bycatch surveys (Dixon et al. 2014). Reef associated fish assemblages are better known, having been documented directly in several studies, and are summarised in Shepherd and Baker (2014). McDonald (2008), has undertaken a comprehensive series of surveys of fish and large mobile invertebrates in shallow subtidal seagrass and sand habitats. Key iconic fish species that occur in Spencer Gulf include leafy and weedy sea dragons (*Phycodurus eques* and *Phyllopteryx taeniolatus*), along with 26 other syngnathid species, western blue grouper (*Achoerodus gouldii*), snapper (*Chrysophyrs auratus*), and King George whiting (*Sillaginodes punctatus*). Spencer Gulf also hosts some of the largest adult white shark (*Carcharodon carcharias*) aggregations in Australia, especially at Dangerous Reef and Neptune Islands.

Spencer Gulf is an important foraging and breeding ground for a range of iconic, threatened and protected species, including cetaceans, pinnipeds, sharks, and a large number of resident and migratory seabirds. Key cetacean species include two dolphins, the short-beaked common dolphin (*Delphinus delphinus*) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), which are present year-round; and two baleen whale species, the southern right whale (*Eubalaena australis*) and humpback whale (*Megaptera novaeangliae*), which are migratory and commonly seen in the winter months (Gibbs and Kemper 2014). The region contains nationally significant pinniped populations, including nine breeding sites for the threatened Australian sea lion (*Neophoca cinerea*), making up around 25% of the species-wide pup production; and five breeding sites for the long-nosed fur seal (*Arctocephalus forsteri*), accounting for ~40% of the national pup production for the species (Goldsworthy et al. 2014, Shaughnessy et al. 2015). Spencer Gulf is significant for many seabird species. The most numerous being migratory petrels, short-tailed shearwaters (*Ardenna tenuirostris*), flesh-footed shearwaters (*A. carneipes*) and white-faced storm petrels (*Pelagodroma marina*) that nest on many of the gulf's islands, but for which there is limited information on their status, trends in abundance and ecology (McLeay 2014). Little penguins (*Eudyptula minor*), cormorants (black-faced *Phalacrocorax fuscescens* and pied cormorants *P. varius*) and several species of terns (crested *Thalasseus bergii*, Caspian *Hydroprogne caspia* and fairy terns *Sternula nereis*) are important fish predators (McLeay 2014). The region is also important to many shorebirds and migratory waders (Carpenter and Langdon 2014). Several iconic marine species, including the white shark, giant Australian cuttlefish (*Sepia apam*a), and Australian Sea Lion, also form important ecotourism attractions to the region (see below).

Spencer Gulf supports a diverse range of sub-tidal benthic habitats, including some of the world's largest seagrass beds (Irving 2014), which provide important habitat to a wide array of species, including many of recreational, commercial and conservation significance (Tanner and McDonald 2014). There are also important areas of rocky reef, especially in the southern gulf. Deeper areas are poorly characterised, but can support diverse epifaunal invertebrate assemblages (Dixon et al. 2014). Overall, the pelagic environment occupies the greatest area, as it overlies all subtidal benthic habitats, followed by subtidal soft sediments; the latter may also include invertebrate, rhodolith and sparse algal communities (Jones et al. 2018). Intertidally, there are extensive stands of mangroves in the northern gulf, as well as areas of saltmarsh. The southern areas of the gulf are more dominated by sandy beaches, with small areas of rocky shorelines (Jones et al. 2018).

Spencer Gulf is a region of high economic and cultural importance to South Australia. This unique ecosystem supports a wide variety of marine industries (fishing, aquaculture, shipping, tourism) and recreational pursuits (fishing, diving, surfing). Marine-based industries in Spencer Gulf provide over $500 M to the South Australian economy (Figure 9). In 2015-16, over half (58%) of South Australia's total seafood production ($523 M) was produced by commercial fisheries and marine aquaculture industries located in Spencer Gulf ($299M). Similarly, 41% of South Australia's total annual expenditure on recreational fishing ($68M) occurs in Spencer Gulf ($161M) (Deloitte Access Economics 2017).

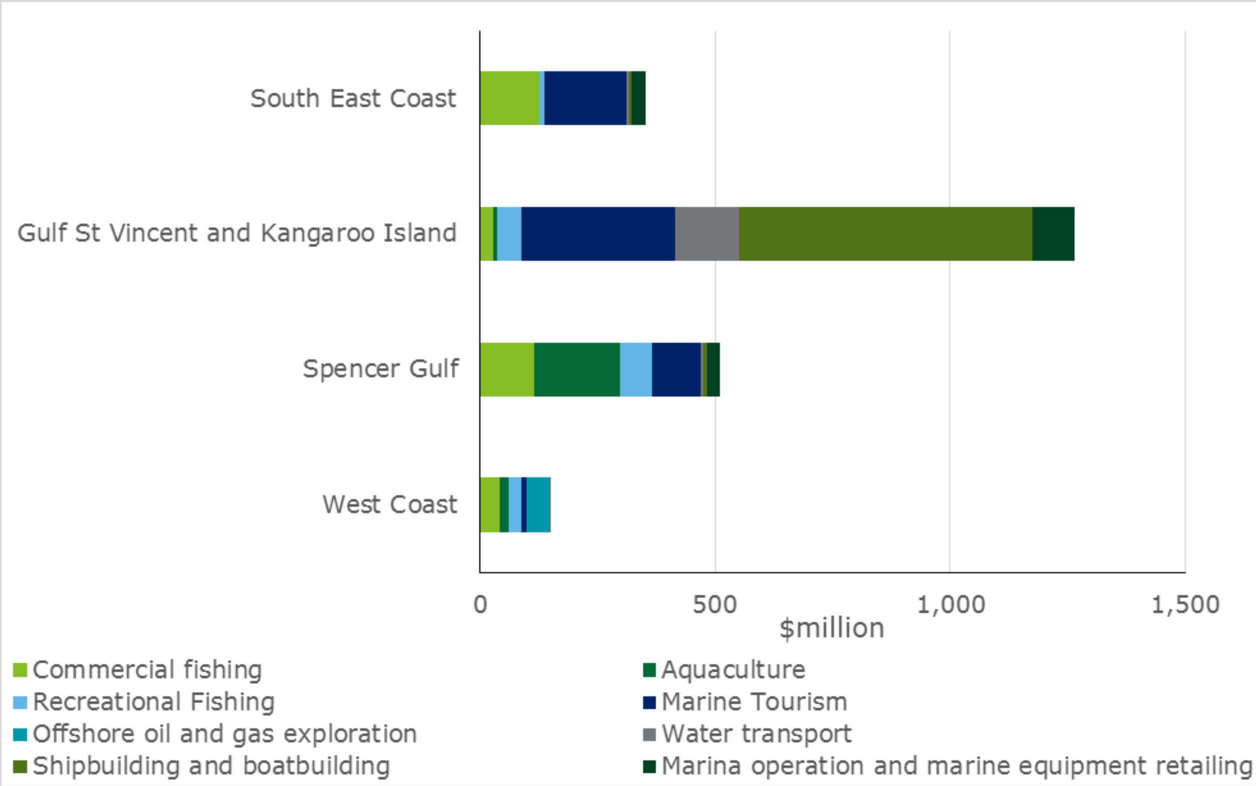

Figure 9. Value of marine industry production for key sectors and regions, 2015-16. Source: Deloitte Access Economics (2017).

In 2015/16, the total value of marine industries in Spencer Gulf was $509.8 million, ~22% of the state marine industries total, and total employment (direct and indirect) was 2778 full time equivalents (FTE), ~19% of the state total (Deloitte Access Economics 2017). This compares to a total Gross State Product for that time period of $101,096 million and total SA employment of 1,209,600 FTE. It should be noted that values for the gulf do not include the value of imports/exports shipped through the gulf, the value of surrounding activities whose environmental footprint may impinge upon the gulf (e.g. mining, agriculture), or non-monetary values such as recreation.

Of the marine based industries, aquaculture added the most total value to the economy in Spencer Gulf during the 2015/2016 financial year ($141.8M), followed by commercial fishing ($88.5M) and domestic marine tourism ($85.4M) (Deloitte Access Economics 2017). Recreational fishing added a total value of $39.8M in 2015/2016, with international marine tourism contributing $23.5M. Marine equipment retailing added a total value of $13.6M to the Spencer Gulf economy in 2015/2016, and marina operation added $9.7M. Water transport and boatbuilding each added <$5M during this time. The direct and indirect values of each of these sectors generally showed similar patterns to the total value, with the exception that the recreational fishing sector value was entirely indirect. It should be noted that tourism values are estimates based on the proportion of marine related activities that tourists undertook.

Marine based aquaculture also added the most total employment to the economy in Spencer Gulf during the 2015/2016 financial year (803 total FTEs), followed by domestic marine tourism (683 total FTEs), commercial fishing (613 total FTEs), and recreational fishing (382 total FTEs) (Deloitte Access Economics 2017). Marine equipment retailing added 174 total FTEs, and international marine tourism added 155 total FTEs. Marina operation contributed 59 total FTEs in 2015/2016, with boatbuilding and water transport each adding ~30 total FTEs. Again with the exception of recreational fishing, the patterns were similar for direct and indirect employment.

Other activities that occur in and around the gulf include desalination, urban development, resource development, energy and industrial power production, shipping, ports and dredging, defence, agriculture, recreation, ecotourism and conservation (Gillanders et al. 2013), although their economic and employment contributions to the region could not be determined. Important agriculture lands surround Spencer Gulf. It is also the 'gateway' too much of the state's mining and energy resources. There are five existing port facilities in Spencer Gulf, however, there are currently no deep-water bulk commodity port facilities to meet future demand (Gillanders et al. 2016).

1.3.2 Progress towards integrated management

Progress toward IM in South Australia and Spencer Gulf began as part of a broad attempt by the South Australian Government to establish ecosystem-based management of its coastal, estuarine and marine environments in the early 2000s. The Living Coast Strategy (DEH 2004) outlined a range of actions that included the establishment of a Coast and Marine Authority and a marine planning framework. The Marine Planning Framework for South Australia (DEH 2006b) was based on the principles of ecosystem-based management, ecologically sustainable development and adaptive management (Day et al. 2008, Paxinos et al. 2008). Spencer Gulf was chosen as a pilot study to refine and test the application of the framework because of its economic, social and environmental importance to the state. The draft Spencer Gulf Marine Plan defined goals, objectives and strategies for four ecological zones (DEH 2006a). Its vision was to ensure the conservation and ecologically sustainable use of the gulf by integration of marine and land use management through partnerships between community, industry and government. A performance assessment system was established to evaluate the effectiveness of the plan. The Marine Planning Framework for South Australia was not implemented and has not been developed further than the initial pilot project in Spencer Gulf.

The Spencer Gulf Ecosystem and Development Initiative (SGEDI) was established in 2011, when a broad range of stakeholders recognised the need for a more integrated approach to development in the area (https://www.adelaide.edu.au/environment/water/spencer-gulf/). SGEDI was established because of concerns about the potential impact of expanded mining, shipping and desalination activities on the environment, iconic species (e.g. cuttlefish) and the fisheries and aquaculture sectors. SGEDI has been important in bringing stakeholders together, and has facilitated some of the initial science required for IM. It is a participatory structure with diverse representation. The focus of SGEDI has been to develop pilot tools to support IM and demonstrate the benefits of a more integrated approach. As relatively few South Australian Government departments have been actively involved in SGEDI to date, recent progress towards IM has been limited. There is currently no shared vision or legal framework for IM of Spencer Gulf. An integrated monitoring program also has not been established for Spencer Gulf.

Management of Spencer Gulf is currently delivered under at least 15 different South Australian Government Acts, with limited cross-referencing among Acts, despite many having broadly similar objectives (Table 1: Existing objectives from management Acts covering Spencer Gulf (Source: Begg et al. 2015). A single tick indicates that the objective is implied in the Act, but not specifically mentioned; 2 ticks indicates that it is mentioned; and 3 ticks indicates that there is detailed discussion of the objective.). As a consequence, many management decisions are made without fully considering the overall social, economic and ecological status of the region, at least in part because of the time-consuming task of trying to track down all the relevant data from different agencies and organisations. In particular, cumulative impacts of multiple developments are not considered, with each development instead being assessed in isolation. This approach has the potential to lead to adverse social, environmental and economic impacts even if each individual development is acceptable in and of itself. Between them, the 15 Acts cover the four pillars of sustainable management articulated by Stephenson et al. (2018), although only seven Acts actually address all four pillars.

The wide range of stakeholders that use Spencer Gulf, and the increasing demands being placed on its resources, increases potential for conflict between different user groups whose activities may impinge upon each other and impact, both individually and collectively, on the ecosystem (see Gillanders et al. 2013, Gillanders et al. 2016). Perhaps the best example of this conflict to date was the controversy surrounding BHP's plans to build a desalination plant near Whyalla to supply its proposed expansion of Olympic Dam. Potential impacts on prawn nursery habitats and giant Australian cuttlefish populations were key issues of concern. While this development did not proceed, other similar conflicts could arise again in the future. Currently, there is no formal framework in place to address these conflicts, or to consider potential tradeoffs, in a way that ensures that the best overall outcome for the region is achieved. Relatively few planning tools are available for proponents of new developments to broadly optimise their proposals in the early stages of their planning (see Bailleul and Ward 2019).

1.3.3 Current monitoring framework

Several programs are currently in place to monitor the status of South Australia's marine resources, including those in Spencer Gulf. For example, the Environment Protection Authority (EPA) produces a State of the Environment Report (SOER) for South Australia at least every 5 years that addresses marine issues including climate change (e.g. rainfall, temperature, sea level) and coastal and marine assets (e.g. mangrove, saltmarsh, MPAs, seagrass, sub-tidal reefs, coastal and marine native flora and fauna, fish stocks and coastal and marine biosecurity). The South Australian Department for Environment and Water (DEW) also prepares trend and condition report cards that document the status of the environment and include climate indicators (e.g. rainfall, temperature, sea level) and coastal and marine indicators (e.g. mangroves, saltmarshes, MPAs, seagrass, sub-tidal reefs, fish stocks, biosecurity). The EPA SOERs are presented at a State-level and recognise eight marine bioregions (EPA 2018), although much of the underlying data is collated to align with the terrestrially-based Natural Resource Management regions. The DEW report cards also present data for six terrestrially-based Natural Resource Management regions (https://data.environment.sa.gov.au/Trend-and-condition-reports/Pages/default.aspx). As these terrestrial regions do not align with the marine bioregions, or even marine geographic features such as the South Australian gulfs, it is difficult to extract data from them that do align with natural marine boundaries. EPAs SOERs and DEWs report cards both use a trend, condition and reliability framework to assess the status of the environment. There is no direct link between the South Australian SOER or trend and condition reports and the Commonwealth SOER (https://soe.environment.gov.au/) which uses a different framework (i.e. drivers, pressures, state and trends) and has separate themes for coasts and the marine environment.

Table 1: Existing objectives from management Acts covering Spencer Gulf (Source: Begg et al. 2015). A single tick indicates that the objective is implied in the Act, but not specifically mentioned; 2 ticks indicates that it is mentioned; and 3 ticks indicates that there is detailed discussion of the objective.

	Fisheries and Parks				Environment Protection					Resource Management			Transport	Culture	
ACTS / OBJECTIVES	Fisheries	Aquaculture	Marine Parks	National Parks	Environment Protection	Coast Protection	Prevention of pollution from Ships	Sea dumping	Climate Change & Greenhouse Emissions Reduction	Natural Resources Management	Petroleum and Geothermal Energy	Offshore Minerals	Harbors and Navigation	Native Title	Historic Shipwrecks
Conservation - productivity	✓✓	✓			✓				✓✓	✓✓✓					
Conservation - biodiversity	✓✓		✓✓✓	✓	✓				✓✓	✓✓✓		✓✓			
Conservation - habitat	✓✓		✓✓✓	✓✓	✓	✓✓✓	✓	✓✓		✓✓✓	✓✓	✓✓	✓✓		
Economic	✓✓✓	✓			✓✓✓				✓✓	✓✓✓.	✓✓		✓✓✓		
Social & cultural	✓✓✓	✓✓	✓✓✓	✓✓	✓✓✓	✓✓✓				✓✓	✓✓✓		✓✓	✓✓	✓✓
Institutional governance	✓✓✓	✓✓	✓✓✓		✓✓✓	✓✓		✓✓	✓✓	✓✓✓	✓✓✓		✓✓✓		
Research & education	✓✓	✓✓	✓			✓✓			✓✓✓	✓					

The South Australian Department of Primary Industries and Regions (PIRSA) monitors effort and catches in South Australia's commercial fisheries and assesses the status of key fisheries for commercially harvested species (PIRSA 2015). The status of Australia's key fish stocks is reported every two years (Stewardson et al. 2018).

1.4 Aims and objectives

The aim of this report is to use existing datasets to develop a suite of potential social, economic and ecological indicators for Spencer Gulf. These indicators will be available for use in future assessments of the status of the gulf's communities, industries and ecosystems. The approach taken draws heavily on the IEA approach used in the Californian Current ecosystem. The report is designed to facilitate progress towards a more integrated approach to the monitoring, assessment and management of Spencer Gulf. A key outcome of the report will be the identification of data gaps that limit our ability to assess the current status of the gulf and monitor future changes in its status over time.

1.5 Approach

This report is one of three in the project entitled 'A socio-ecological assessment of the ecosystems, industries and communities of Spencer Gulf'. This report summarises the collation of existing information on the threats to the ecosystems of Spencer Gulf and its industries and communities, and datasets that may provide useful indicators for one or more assets or threats. The focus was on datasets for which there are time-series, although some datasets with only a few time points are included if it is likely that monitoring will continue into the future. While many of the data sets are derived from existing marine monitoring programs (Table 2: Summary of existing marine monitoring programs in or including Spencer Gulf which may provide data of use to integrated management. Summarised from Appendix 1.), a number of others are derived from broader data collection efforts, such as those undertaken by the Australian Bureau of Statistics and the Bureau of Meteorology (BoM). With the exception of the EPA's Aquatic Ecosystem Condition Reporting, none of the existing marine monitoring programs occur at a gulf-wide scale or are designed to provide a whole of ecosystem overview of the gulf's condition. Instead, most programs are designed to assess the impacts of and/or manage individual activities, or to monitor particular species.

A previous report from this project (Bailleul & Ward 2019) collated a variety of spatial data sets for Spencer Gulf, and makes them available through a new software platform that allows users to easily interrogate and overlay relevant datasets for any area of interest. The platform allows users to obtain information about the environmental, ecological and economic characteristics (e.g. depth, sea surface temperature, activities undertaken) of a specific location. Users have control over the selection criteria used to identify parts of the gulf that may be suitable for particular activities (e.g. aquaculture, desalination and ports).

Table 2: Summary of existing marine monitoring programs in or including Spencer Gulf which may provide data of use to integrated management. Summarised from Appendix 1.

Program	Scope	Location	Temporal scale	Comments
Southern Australian Integrated Marine Observing System (SAIMOS)	Physical, biological and chemical oceanography	Mouth of Spencer Gulf, and eastern GAB	2008 - present	Additional mooring to be installed near Whyalla in 2019.
Fisheries monitoring programs	Catch and effort for commercial species, and some biological data	Gulf-wide	1983-present in some cases	
Aquaculture Economics	Economic performance of industry by sector and geographic region	SA	1998-present	Mostly assessed at a statewide scale, and terrestrially-based geographic regions, but some sectors can be broken down to derive data for Spencer Gulf.
Aquaculture Environmental Monitoring Program	Oceanography, pelagic and benthic habitats	Spencer Gulf	2000-2018	Data collection changes over time in response to changes in both industry and our understanding of key concerns.
Shellfish Quality Assurance Program	Water quality and phytoplankton	Shellfish production areas	2000-present	Monitoring is for specific taxa of concern only, and available data do not lend themselves to the easy analysis of change over time.
EPA Aquatic Ecosystem Condition Reporting	Water quality, benthic habitats, phytoplankton	State-wide	2010-present	Surveys ~ every 5 years. Focus on nearshore waters to 15 m depth.
Metals in sentinel mussels	Heavy metals	State-wide	2005	Currently one-off, but likely to be repeated in next year or so. Not included in this report.
Historic pollution in seagrasses	Heavy metals	Port Pirie, Whyalla, Port Broughton	Thousands of years	Provide historical context, but not ongoing monitoring. Not included in this report.
Liberty OneSteel Seagrass Assessment	Seagrasses	False Bay	1992-present	Has not been made available for this report.
Persistent Pollutants in Dolphins	Chemical	State-wide	Snapshot	Metals collected in the mid 2000's. Not ongoing. Not included in this report.
Marine Park Monitoring	Biological assemblages, public perception	State-wide, including 3 parks in Spencer Gulf	2005-present	Currently only ecological data for 4 sanctuary zones in 3 Spencer Gulf parks for 2016/17. Also phone survey results for 2011, 2013, 2015 & 2017.
Sea Eagle and Osprey Monitoring	Abundance	State-wide	2008-present	Has not been made available for this report.

Shorebirds	Abundance	State-wide	2000-present	Can be purchased from BirdLife Australia. Not included in this report.
Port Marine Pest Monitoring	Abundance	State-wide	2008-present	Sporadic and no time-series. Not included in this report.
White Shark Cage Diving	Visitor numbers and value	Neptune Islands	2008-present	Visitor number will continue to be collected as part of the white shark cage diving industry monitoring program.
Australian Sea-Lions	Abundance	State-wide	1980-2015	Intermittent, with no commitment to ongoing monitoring.
Long-Nosed Fur Seals	Pup production	State-wide	1988-2014	Intermittent, with no commitment to ongoing monitoring.
Seabird Monitoring	Penguin, tern and shearwater abundance	State-wide	1988-2014	Opportunistic and intermittent. Includes colonies in southern Spencer Gulf. Not included in this report.
Giant Australian cuttlefish	Abundance	Whyalla	1998-2019	Unlikely to continue past 2019, or may continue as a citizen science program.

2 Methods

2.1 Data sources

Data were obtained from a range of sources, including publicly accessible online databases, the report authors and their organisations, and via approaches to known or suspected data custodians. While every attempt was made to source all available data, some known data sets were not provided by their custodians for inclusion, and it is likely that there are a few relevant data sets that have been missed. We also identified a number of data sets that are state-wide or national in scope, or that collect data on terrestrial regions that cannot be matched to Spencer Gulf. While these may contain potentially useful data, the resources were not available to try and tease these apart, and thus they have not been included. All suitable data that could be located is included for completeness, and inclusion does not imply that the data set will be important for an integrated monitoring program. The source of each individual data set, and any post processing undertaken for this report, are described when each is first presented. A complete summary of all data sets, and how to access them, is provided in Appendix 2.

2.2 Spatial extent

One of the biggest challenges in collating the data sets described below was defining the extent of the data to be included. Ideally there would be a single consistent spatial domain for all data, but this was not the case. As the data used were collected by a range of individuals/organisations for a range of different purposes, there are a range of different spatial domains. The two main issues encountered were: 1) defining the extent of Spencer Gulf; and 2) dealing with data sets that were collected to coincide with terrestrial management regions.

At its simplest, Spencer Gulf could be considered as the line between the southern tips of Eyre and Yorke peninsulas. However, previous modelling work (Gillanders et al. 2015), has used a slightly expanded definition which includes some of the islands a little further offshore and the north-western coast of Kangaroo Island (**Error! Reference source not found.**). We have also included considerable o ceanographic data from just outside the gulf, in part because there is limited time-series data from inside the gulf proper, and in part because this data describes the characteristics of the water entering the gulf. Notwithstanding this, as we collated data from existing sources, the exact boundary of the gulf can vary slightly between data sets, and the primary aim is to ensure consistency within a data set rather than between data sets.

A second issue was that much of the available data were collected to align with terrestrial management regions, and whilst this could probably be disentangled given time and resources, it was not possible to do this here. The social data were available for local government areas, which include some inland communities as well as coastal communities outside the gulf. We have taken a pragmatic approach and include the whole of each local government area that borders on Spencer Gulf. A number of environmental data sets align with the terrestrial natural resource management regions. Spencer Gulf is bisected by the boundary between the Eyre Peninsula and Northern & Yorke regions, both of which include substantial coastline outside of the gulf (the west coast for the former, and western Gulf St Vincent for the later). Consequently, much of the NRM reporting cannot be used directly to inform this report, although where possible we have obtained the underlying data sets and partitioned out the data relevant to Spencer Gulf. Other data, such as aquaculture production and economic indicators, are only reported at a whole of industry level. These data are only reported here if the industry only occurs in Spencer Gulf.

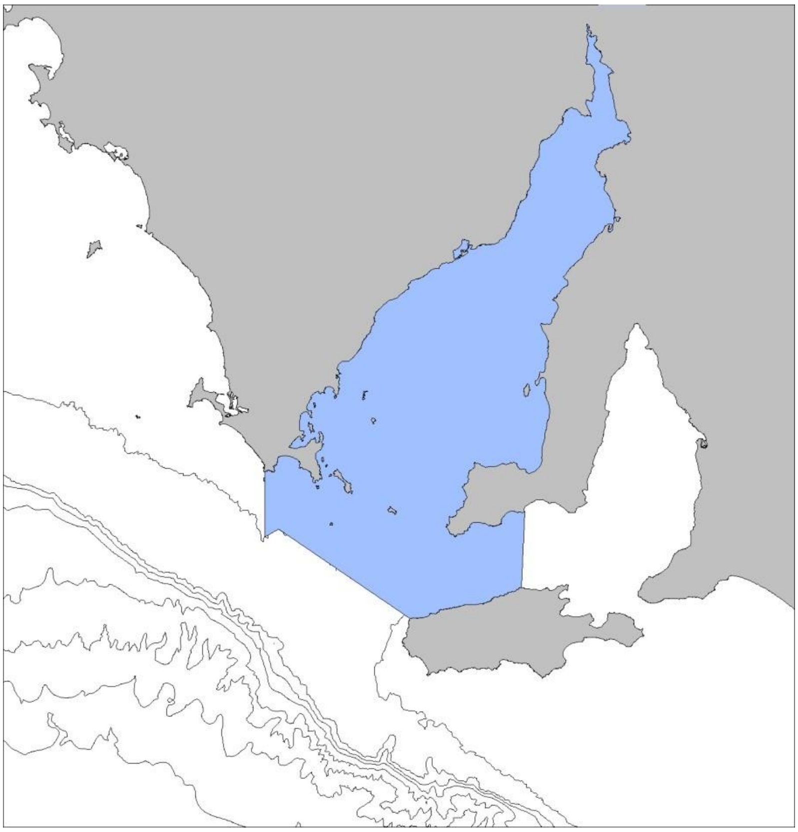

Figure 10. Extent of Spencer Gulf (blue) used for previous modelling studies, and which is followed here where possible (Source: Gillanders et al. 2015).

2.3 Temporal extent

The focus here is on ongoing time-series data sets that provide some indication as to the current state of Spencer Gulf. We include some data sets with only one or a few data points if they are intended to be ongoing (e.g. EPA data on seagrass and algal cover), or if the data are available to extend the time-series, but need substantial analysis before this can be done (e.g. shipping traffic and ecosystem model outputs). We do not include short-term data sets that are not part of ongoing monitoring programs, although these may be useful if any future relevant monitoring program is established. We also do not include data sets that do not extend past 2010.

2.4 Explanation of graphs

The graphs of indicators provided below are formatted as follows. The x-axis shows the time period. The solid black line, if present, shows the aggregated data for Spencer Gulf as a whole. The red dotted and dashed lines, if present, show the time-series mean and standard deviation respectively. The arrow to the right of each panel indicates whether the trend analysis in the orange shaded area is positive, negative, or non-significant. If there is no orange shaded area, then the trend analysis is over the whole time series. Trend analysis was undertaken using simple linear regression in R.

3 Communities

3.1 Socio-economic indicators

The 12 Local Government Areas (LGA) bordering Spencer Gulf were selected as the spatial scale for analysing the region's socio-economic indicators (Figure 11). The Australian census data can be organised geographically by administrative boundaries or population scales. Fixed administrative boundaries are more appropriate for comparing communities through time than population scales as the boundaries of these change with population change.

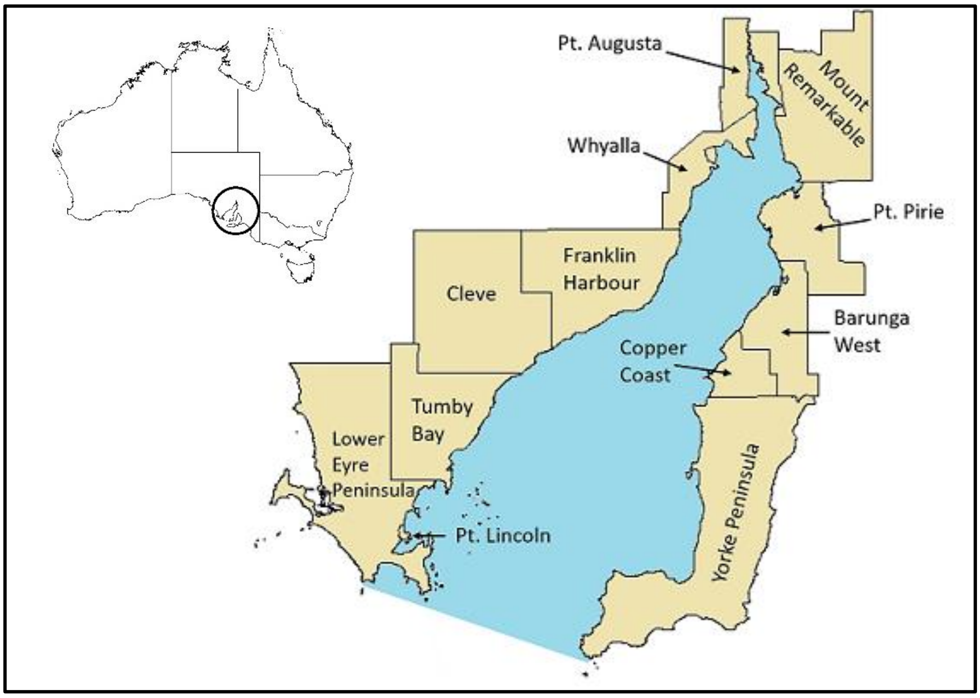

Figure 11. Map of Spencer Gulf showing surrounding Local Government Areas.

To understand how communities respond to change, we considered a community's assets, wealth, and tangible and intangible resources (capital). The availability and status of a community's capital affects a community's vulnerability, resilience, and capacity to adapt to disturbances. The sustainable rural livelihoods framework developed by Scoones (1998), and modified by Metcalf et al. (2015), provides an approach to assessing drivers of community vulnerability, resilience and adaptive capacity by analysing capital indicators that relate to a community's socio-economic standing. The framework distinguishes five types of capital to allow for the calculation and interpretation of community-based variables (Scoones 1998; Metcalf et al. 2015):

- *Human capital*: education, skills, health, ability to contribute to labour and general well-being for the pursuit of a livelihood.
- *Social capital*: actual or potential resources and support which are linked to social bonding and bridging. Social bonds are the social networks among similar groups of people whereas social bridges are the cooperative connections between groups of dissimilar people.

Volunteering participation, community associations, family networks and change in population all have an influence on a community's social capital.

- *Financial capital*: condition of income sources, level of income, access to credit and other assets, debts and living costs, all influence financial stability and flexibility to achieve livelihoods.
- *Physical capital*: built capital items such as houses and business ownership or management used to support a livelihood.
- *Natural capital*: productivity of a natural system and environmental services from which resources and services to support livelihoods are derived. This is particularly important in a direct sense for regional communities which are often natural resource based.

The aim here was to develop time-series of social and economic indicators from existing Australian Bureau of Statistics census data that relate to the five types of capital defined, to indicate community vulnerability to disturbances. The results provide a framework for future integrated assessments of Spencer Gulf and a basis for evaluating the sustainability of new developments.

'General Community Profiles' were downloaded for each of the 12 Local Government Areas from four censuses: 2001, 2006, 2011 and 2016. 'Time-series Profiles' were used to access information for the 1991 and 1996 censuses, as these were not available through the General Community Profiles. The Australian censuses were undertaken on the following dates: 6th August 1991, 6th August 1996, 7th August 2001, 8th August 2006, 9th August 2011, and 9th August 2016. Indicator availability varied between 1991 and 2016, therefore some indicators could only be compared from 2001 or 2006 onwards (Table 3). Rather than using the absolute values of chosen indicators, proportions were used to allow for the comparison of areas with differing populations. Table 3 lists all of the indicators that were obtained, and where applicable, what the indicator is a proportion of.

Table 3: Summary of the indicators collected for each capital category with the shaded boxes indicating the years for which the indicators were available.

Capital category	Indicators	1991	1996	2001	2006	2011	2016
Human	Assistance with core activities (proportion of population)				■	■	■
	Part-time employment (proportion of employed)	■	■	■	■	■	■
	Women employed (proportion of female labour force)			■	■	■	■
	Completion of year 12 or equivalent (proportion of people out of school)			■	■	■	■
	Unemployed (proportion of labour force)	■	■	■	■	■	■
Social	Provided unpaid assistance to persons with a disability (proportion of labour force)				■	■	■
	Provided unpaid child care (proportion of labour force)				■	■	■
	Residence unchanged from one year ago (proportion of population)			■	■	■	■
	Volunteers (proportion of people aged over 15 years)				■	■	■
	One parent families with dependent children <15 years (proportion of families)				■	■	■
Financial	Median monthly mortgage repayment				■	■	■
	Median weekly household rental payment				■	■	■
	Median household income				■	■	■
Physical	Private households owned outright (proportion of private households)	■	■	■	■	■	■
	Business owners (proportion of employed)				■	■	■
Natural	Employment in agriculture (proportion of employed)				■	■	■
	Employment in aquaculture (proportion of employed)				■	■	■
	Employment in fishing, hunting and trapping (proportion of employed)				■	■	■
	Employment in mining (proportion of employed)	■	■	■	■	■	■
	Employment in Natural Resources (proportion of employed)	■	■	■	■	■	■

3.1.1 Population

The Australian Bureau of Statistics (ABS) publishes annual data on various population metrics for each local government area (LGA) in Australia, with data available from 2012 (ABS 2019). The population size for each LGA around Spencer Gulf has remained relatively stable since 2012, although declined in Whyalla in 2017 (Figure 12). The largest population centres are Whyalla and Port Pirie, followed by the Copper Coast and Port Lincoln. The median age in most LGA's has increased steadily, while the percentage of the population of working age has declined. With the exception of Port Augusta, Port Lincoln and Whyalla, all LGA's around Spencer Gulf have a higher median age than South Australia as a whole, while all but Lower Eyre, Port Augusta and Whyalla have a lower proportion of the population of working age than the state as a whole.

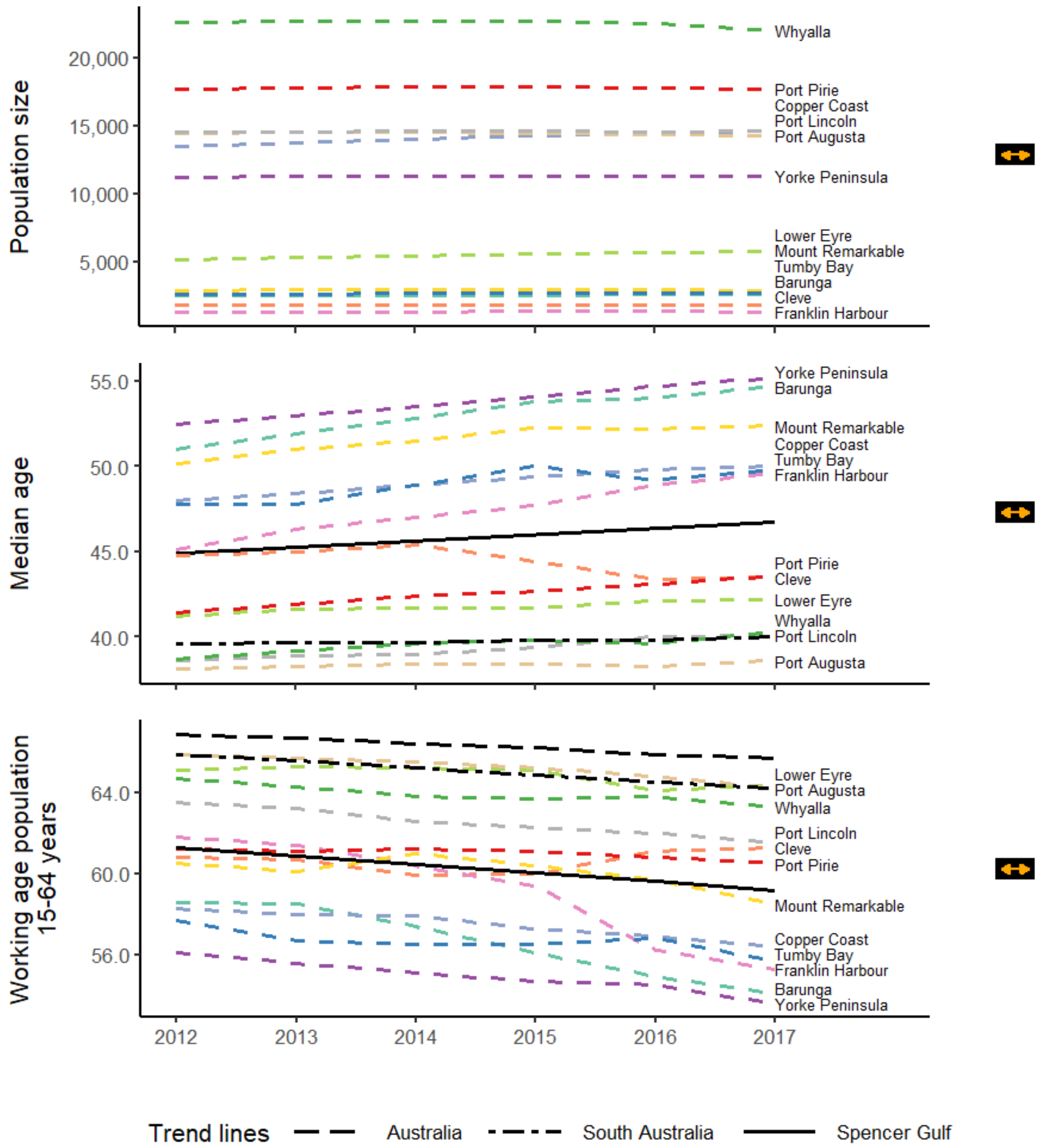

Figure 12. Population statistics for local government areas around Spencer Gulf. Source: ABS (2019). See graph explanation on page 21.

3.1.2 Housing

The ABS also started publishing annual data on median house sales prices and volume of turnover from 2014 (ABS 2019). While Australian and South Australian house prices increased over the three years for which data are available, those around Spencer Gulf mostly decreased, with the exceptions being Cleve, Lower Eyre Peninsula and Mount Remarkable (Figure **13**). The volume of house sales generally declined in the larger centres, and remained fairly steady in the smaller ones.

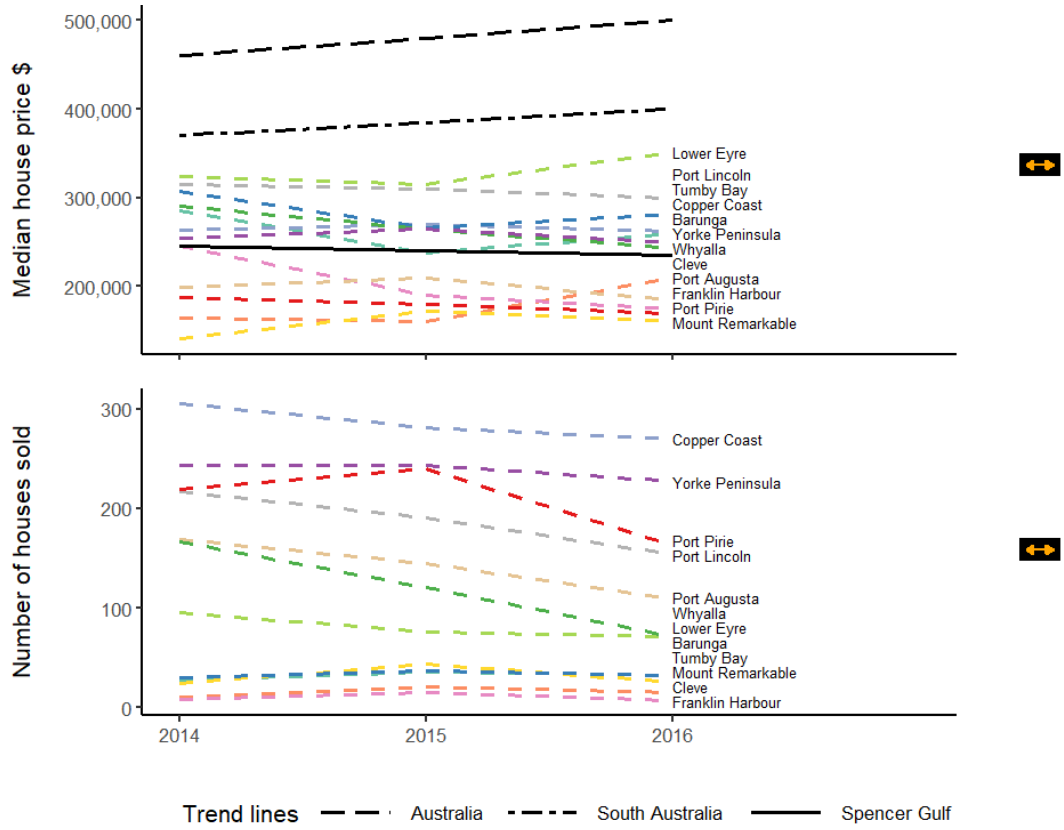

Figure 13. House sales prices and number sold for local government areas around Spencer Gulf. Source: ABS (2019). Aggregated data for volume are not presented due to scale issues. See graph explanation on page 21.

3.1.3 Human capital

Unemployment in the Spencer Gulf region has decreased since 1991, following similar trends to that observed in South Australia and Australia (Figure 14a). While 2011 had the lowest unemployment rates, in many of the communities a slight increase in unemployment occurred in 2016. Whyalla had the highest unemployment in 2016 when a major employer, the iron ore miner and steelmaker Arrium, went into voluntary administration, with the company having now been taken over by Liberty OneSteel. This is a good example of how regional communities that have a large proportion of people employed in one particular industry or by a large company, can be more vulnerable than metropolitan communities with diverse economies. If an industry or company collapses, a large proportion of the population is directly affected, with knock-on impacts to the broader community.

Part-time employment increased significantly from 1991 to 2016, although showed a variable trend through time (Figure 14b). Part-time employment can represent underemployment, where people want to work full-time but can only find part-time work. Underemployment can put people in a more vulnerable working position with fewer hours and lower income. The increase in part-time employment is also seen in the Australian and South Australian data. It is worth noting that part-time employment is more prevalent in South Australia, and the Spencer Gulf region, than Australia as a whole. The number of women employed as a proportion of the labour force has remained relatively steady since 2001, and is similar to South Australia and Australia as a whole (Figure 14c). Women are generally more likely to be employed in lower paid jobs. Lower paid employment tends to fluctuate, and is susceptible to impacts on a community (Morrow 1999).

The proportion of people who require assistance with core activities (self-care, mobility and communication) increased over time in almost all LGAs, with the exception of Barunga West (Figure 15a). This trend could be related to the aging population within Australia. A higher proportion of people require assistance with core activities in the Spencer Gulf region than Australia as a whole, indicating a greater need for carer services and resources. The proportion of people who have a year 12 education or equivalent increased and followed a similar trend to South Australia and Australia, but is significantly lower in the Spencer Gulf region (Figure 15b). Higher education is associated with better employment opportunities and access to resources (Heinz Centre for Science Economics and the Environment 2000). By comparison to the rest of Australia, completion of year 12 education is one of the Spencer Gulf region's most susceptible areas in regards to human capital. While the employment numbers are similar to state and national averages, the communities of the Spencer Gulf region lag behind with regards to completion of high school education.

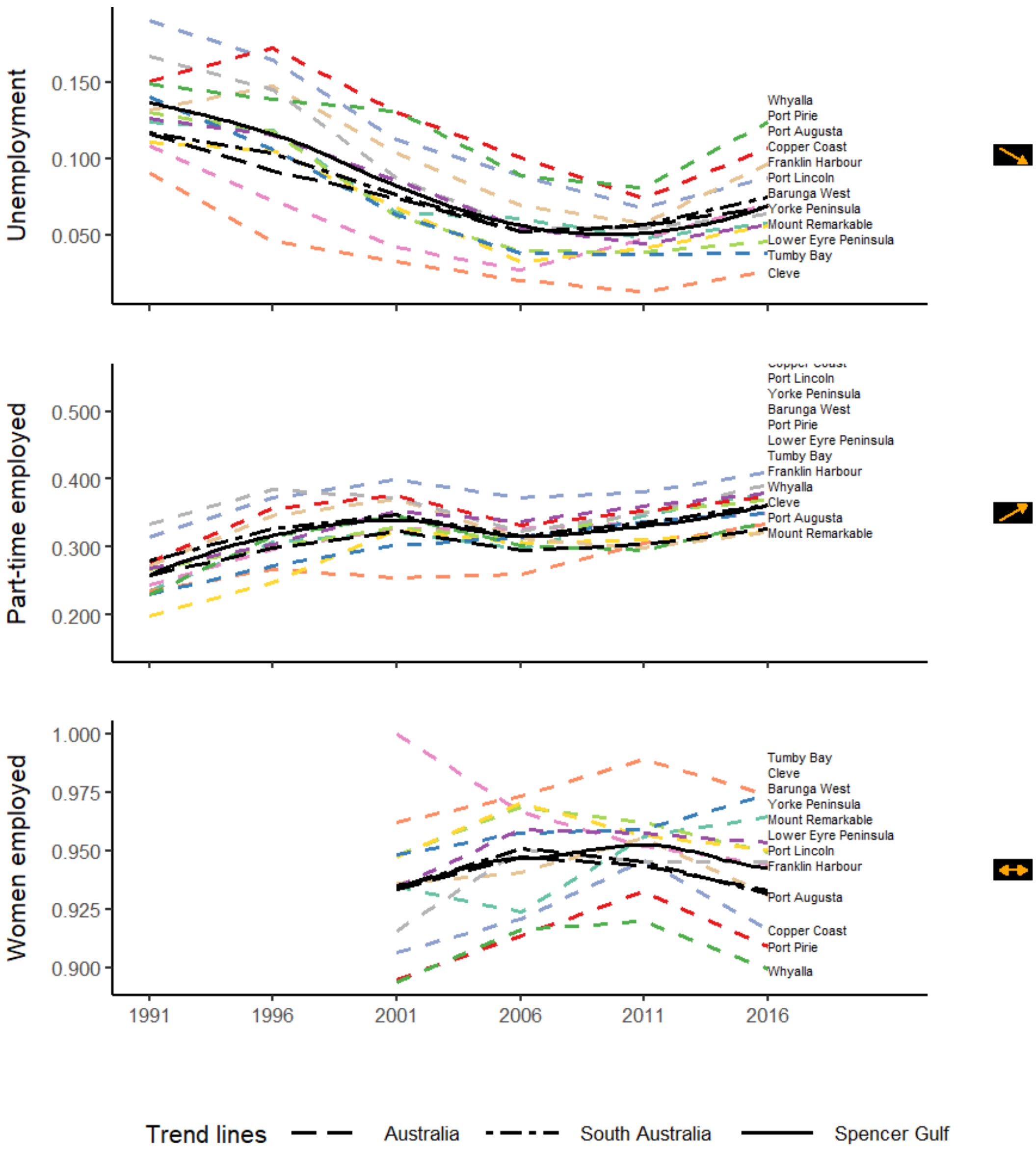

Figure 14. Proportion of (a) labour force that is unemployed, (b) people who are employed part-time, (c) proportion of female labour force that is employed, in each Spencer Gulf local government area. See graph explanation on page 24.

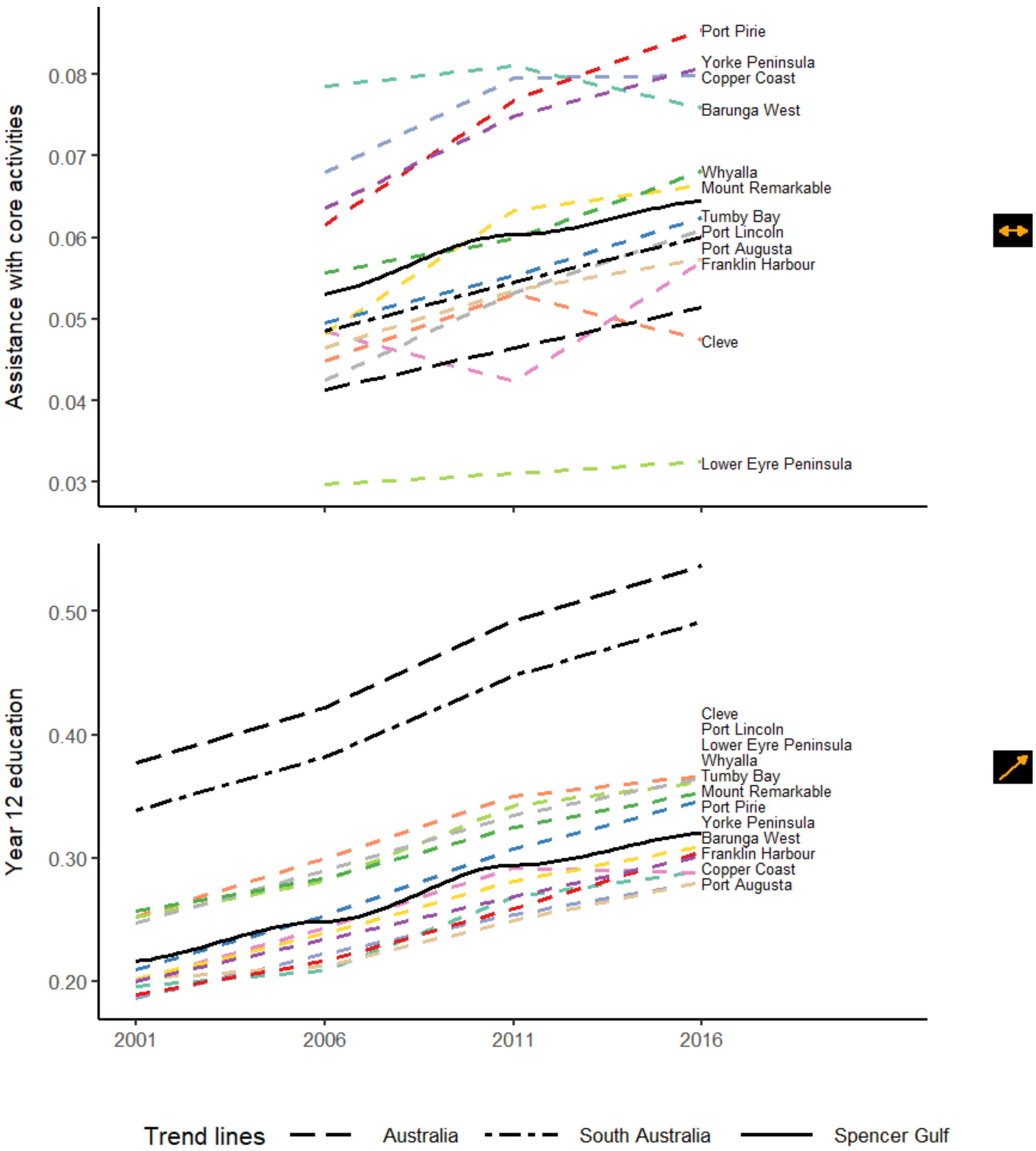

Figure 15. Proportion of (a) population that requires assistance with core activities, (b) people out of school whom have completed year 12 or equivalent education, in each Spencer Gulf local government area. See graph explanation on page 21.

3.1.4 Social capital

The proportion of people who volunteer, or provided unpaid disability assistance and child care, did not change significantly through time, and remained higher in the Spencer Gulf region than South Australia and Australia as a whole, especially in regards to volunteering (Figure 16). The provision of these services is evidence of social cohesion (Everingham 2001, Maru et al. 2007, Ziersch et al. 2009, Moran and Mallman 2019). It demonstrates a stronger level of social care and provision of unpaid labour in the Spencer Gulf communities. However, it also shows that there is a substantial amount of unpaid labour occurring in regards to disability and child care. This indicates there is a greater need for more caring services, especially when considering that there is also a high proportion of people who require assistance with core activities in the Spencer Gulf region (Figure 16a).

The proportion of residence unchanged is higher in the Spencer Gulf region than Australia (Figure 17a). This indicates that Spencer Gulf communities remain fairly stable year to year, without residents having a strong need to move residences. However, Port Augusta has a noticeably higher proportion of residential change compared to the rest of the Spencer Gulf (Figure 17a). The proportion of one parent families in the Spencer Gulf communities is similar to South Australia and Australia as a whole. Whyalla and Port Augusta are exceptions to this trend, with substantially more one parent families than the regional average (Figure 17b). Single parent households and recent residents are known to be at a higher risk of socio-economic impacts (Morrow 1999). Single parent families in particular are likely to experience greater financial burden due to rising costs of living, especially those with many dependants (Morrow 1999). While most of the Spencer Gulf region is similar or more stable than South Australia and Australia as a whole, the high proportion of single parent families potentially make the communities of Whyalla and Port Augusta more susceptible to socio-economic impacts.

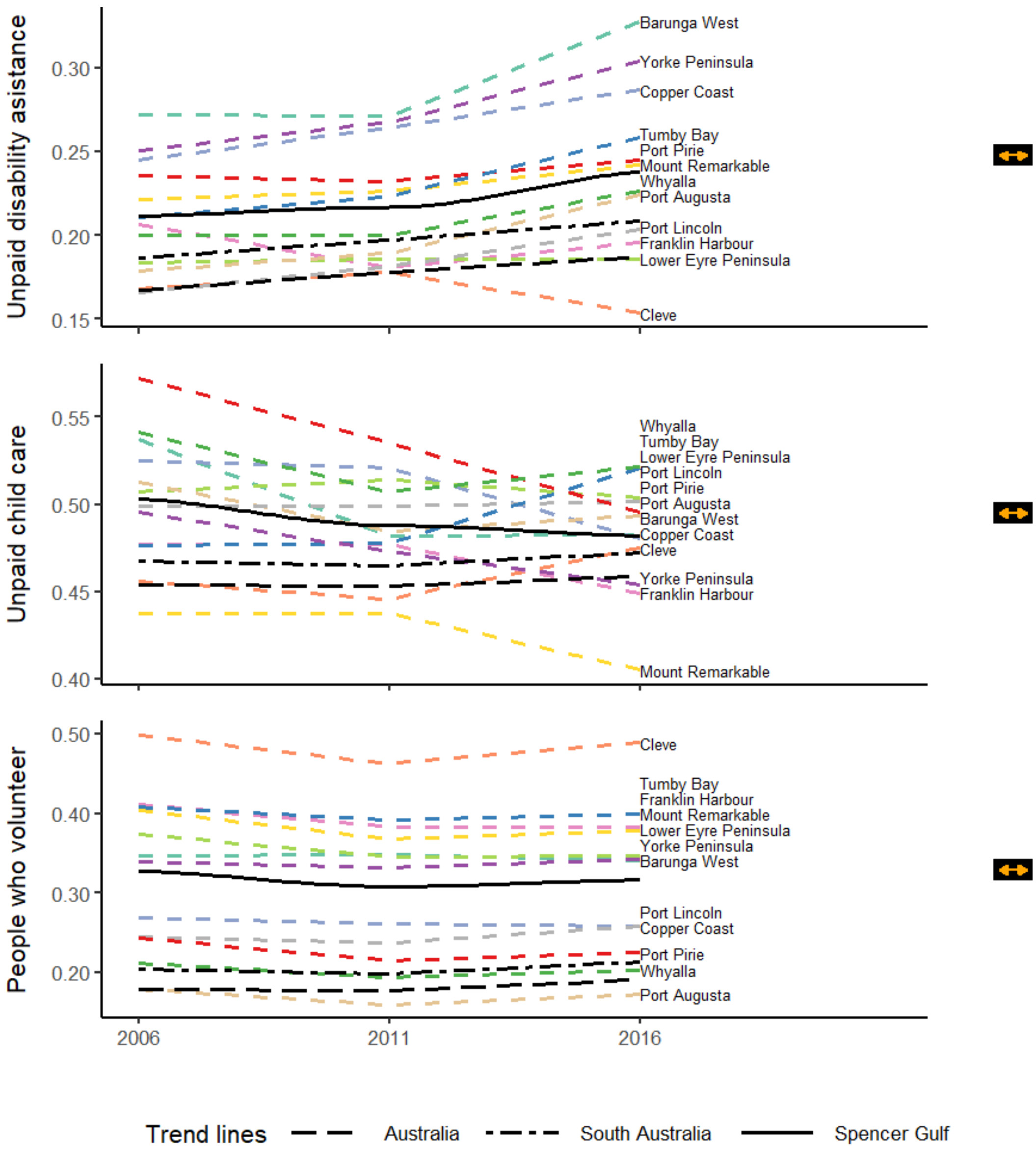

Figure 16. Proportion of labour force (persons aged 15 and over) who provide (a) unpaid assistance to persons with a disability, (b) unpaid child care, (c) that volunteer for a group or organisation, for each Spencer Gulf local government area. See graph explanation on page 21.

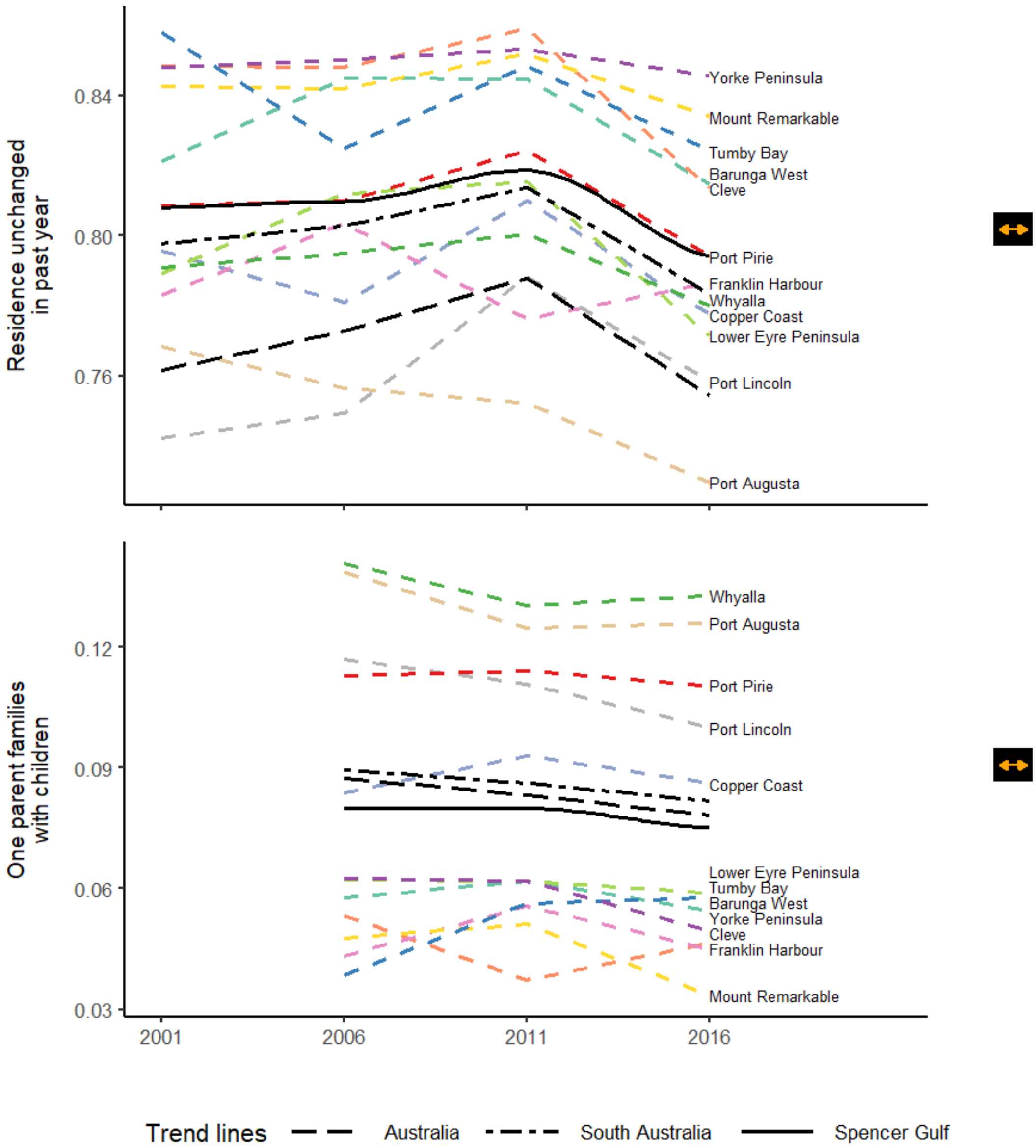

Figure 17. Proportion of (a) population whose residence is unchanged from one year ago (b) families that have one parent and have dependent children under 15 years old, for each Spencer Gulf local government area. **See graph explanation on page 21.**

3.1.5 Financial capital

Financial capital indicates the availability of finances to facilitate a livelihood. Financial capital is primarily fuelled by income and reduced by household expenses and debts. Wealth enables communities to mitigate and recover from losses or impacts. In the Spencer Gulf region, income and housing costs have followed similar trends to those at the national and state level. Monthly mortgage payments have plateaued since 2011, but increased significantly between 2006 and 2011 (Figure 18a), although monthly payments remain lower in all Spencer Gulf communities than elsewhere. Weekly rental payments, on the other hand, have continued to increase since 2006, although again remain low compared to South Australia and Australia as a whole (Figure 18b). Lower Eyre Peninsula had the highest mortgage repayments and the Copper Coast had the highest rent prices in 2016 (Figure 18). However, Port Lincoln was a close second in both cases, making it more expensive place to live with regard to housing. Cleve was the most affordable place to live in 2016, on average having both the lowest rental and mortgage payments. Median household income was also substantially lower in the Spencer Gulf communities compared to South Australia and Australia as a whole (Figure 18c). While all of the communities have experienced an increase in median household income, only the Lower Eyre Peninsula rose above the state average. Generally the communities with higher housing costs have higher incomes and vice versa. However some communities do not fit this trend, such as Cleve, which has the lowest housing costs but one of the highest median incomes. As a whole, the Spencer Gulf region has more affordable housing compared to South Australia and Australia, but lower median income. While housing costs may be lower, lower incomes may put the Spencer Gulf region in a more vulnerable financial position, since other living expenses are subject to influences from outside the region.

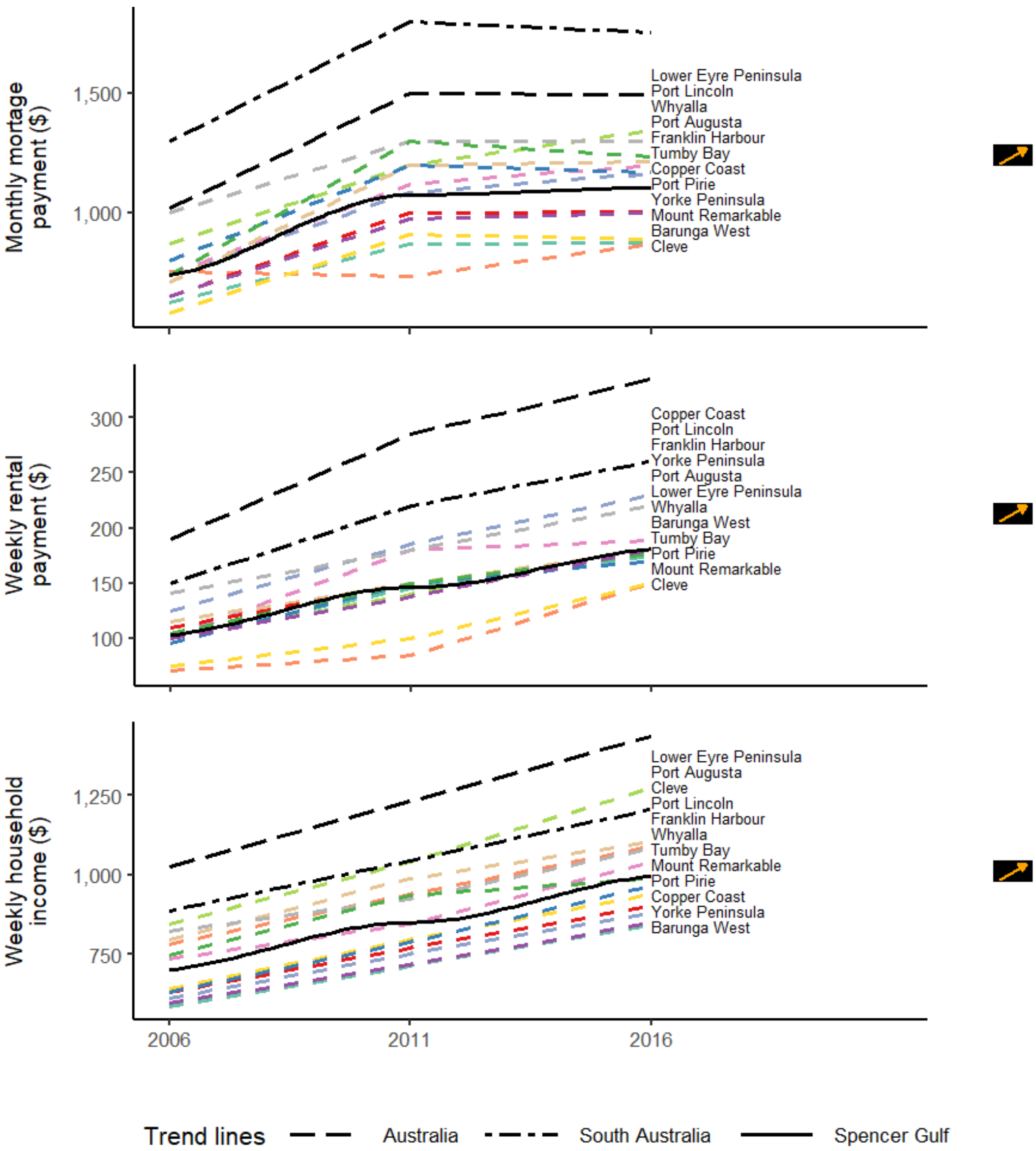

Figure 18. Median (a) monthly household mortgage repayments, (b) weekly household rental payments, and (c) weekly total household income, for each Spencer Gulf local government area. See graph explanation on page 21.

3.1.6 Physical capital

Physical capital in a community pertains to the ownership of property and businesses. The assumption is that owners of property and businesses have a greater capacity to support their livelihood, as well as contribute finances, resources and assets that could assist the broader community in adapting to social or economic change (Metcalf et al. 2015). The proportion of houses owned outright has decreased significantly since 1991, but between 2006 and 2016 the proportion remained steady (Figure 19a). This trend was not only seen in the Spencer Gulf, but also more broadly in South Australia and Australia (Figure 19a). Changes in the composition of Australian households from couple families to other family types (e.g. single parent) produce a downward pressure on the home ownership rate (Kryger 2009). Housing affordability and alternative investment opportunities to housing, such as superannuation and shares, also potentially influence home ownership levels. Business ownership has remained relatively steady since 2006 (Figure 19b). On average, business ownership is significantly higher in the Spencer Gulf region than the South Australian or Australian averages. The natural resource based communities with smaller populations have much higher rates of business ownership compared to the larger regional cities of Whyalla, Port Augusta, Port Pirie and Port Lincoln. For the most part, home ownership is also higher in the smaller communities. This difference in physical capital highlights a distinction between the small and large communities in the Spencer Gulf region.

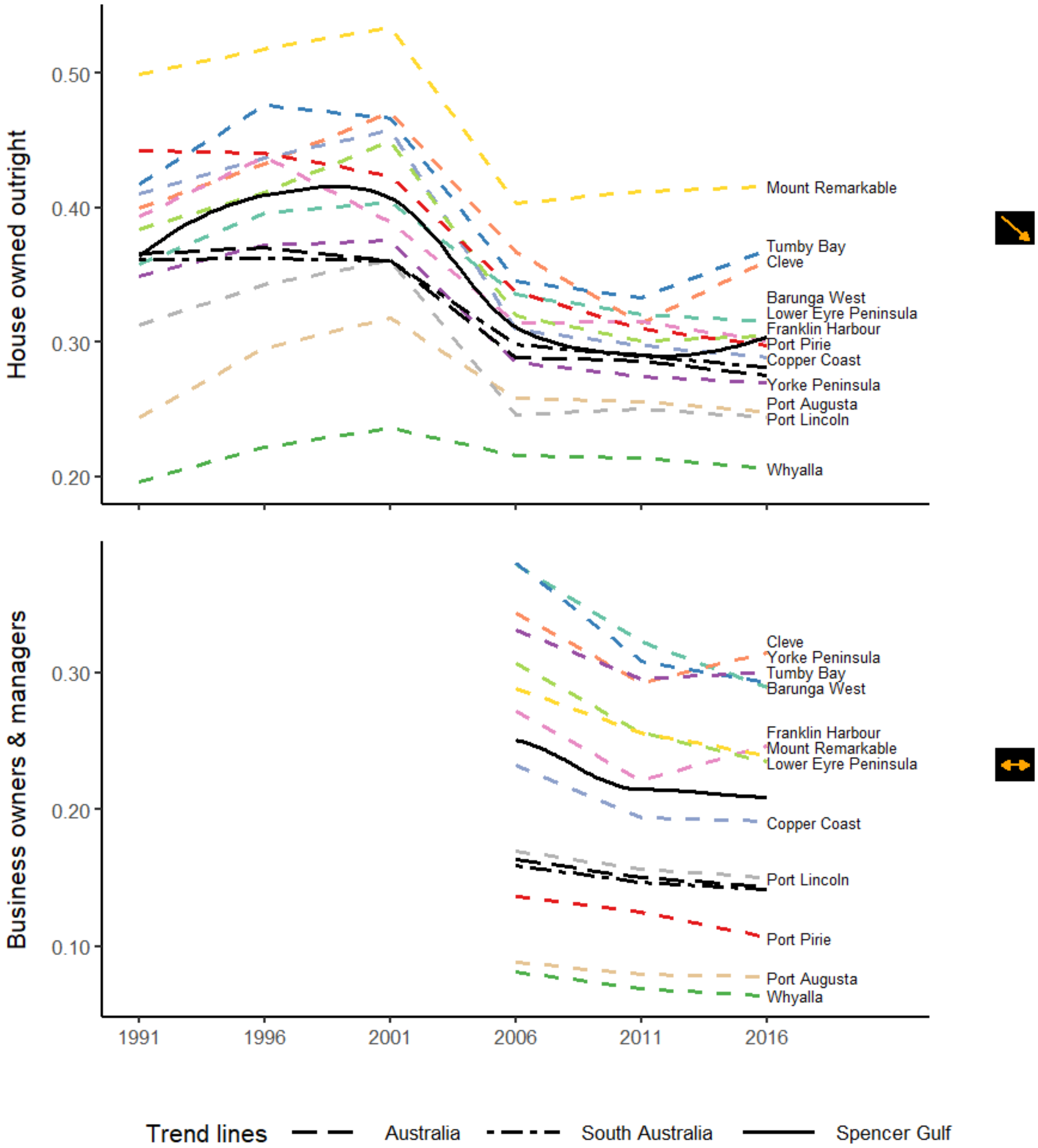

Figure 19. Proportion of (a) private households that are owned outright with no remaining mortgage, (b) employed people who are business owners and managers, for each Spencer Gulf local government area. See graph explanation on page 21.

3.1.7 Natural capital

Employment in natural resource industries provides a good indication of a community's reliance and benefit from the sector. Overdependence on one economic sector can reduce a community's resilience and capacity to adapt if that sector becomes impaired (Cutter et al. 2000, McLeman et al. 2011). Natural resources are particularly prone to influences beyond human control such as natural disasters and often exhibit 'boom' and 'bust' periods. Communities with a heavy reliance on a natural resource during a 'bust' period are vulnerable to socio-economic impacts (Cutter et al. 2003).

The natural resource industries that were analysed in the Spencer Gulf region were: agriculture; aquaculture; fishing, hunting and trapping (noting that fishing could not be assessed separately, but is likely to be close to 100% of this category); and mining. Since 2006 employment in agriculture, aquaculture and fishing, hunting and trapping has not changed significantly around Spencer Gulf (Figure 20). However, particular communities have experienced large changes. Agriculture is the largest natural resource industry in the Spencer Gulf region. Barunga West, Tumby Bay and Mount Remarkable have close to 30% of people employed in agriculture and Cleve has 35%. However, in these smaller agricultural-based communities, employment has declined in the sector since 2006. The movement of younger generations away from agriculture and increased mechanisation are likely contributors to this decline (Alston 2004, Gibson 2008, Alston 2012, Vidyattama et al. 2016). Aquaculture is a comparatively recent sector to the region but now has higher proportions of employment than fishing. Franklin Harbour, Lower Eyre Peninsula and Port Lincoln have the largest proportions of people working in the Aquaculture industry. Port Lincoln and Lower Eyre Peninsula have comparatively larger fishing-based economies along with Barunga West (Figure 20).

Employment in mining has seen a significant increase since 1996, but has plateaued in recent years with several exceptions (Figure 20). Whyalla and Franklin Harbour had the largest proportions of employment in mining, but Franklin Harbour saw a large decrease from 2011 to 2016, whereas Whyalla continued to grow. Employment in the natural resource industries is higher in the Spencer Gulf region compared to South Australia and Australia as a whole, but there are two distinct groups of communities. The larger communities have lower proportions of people employed in natural resource based industries, whereas smaller communities have higher proportions of people employed in those industries but have experienced a decline (Figure 20, Figure 21).

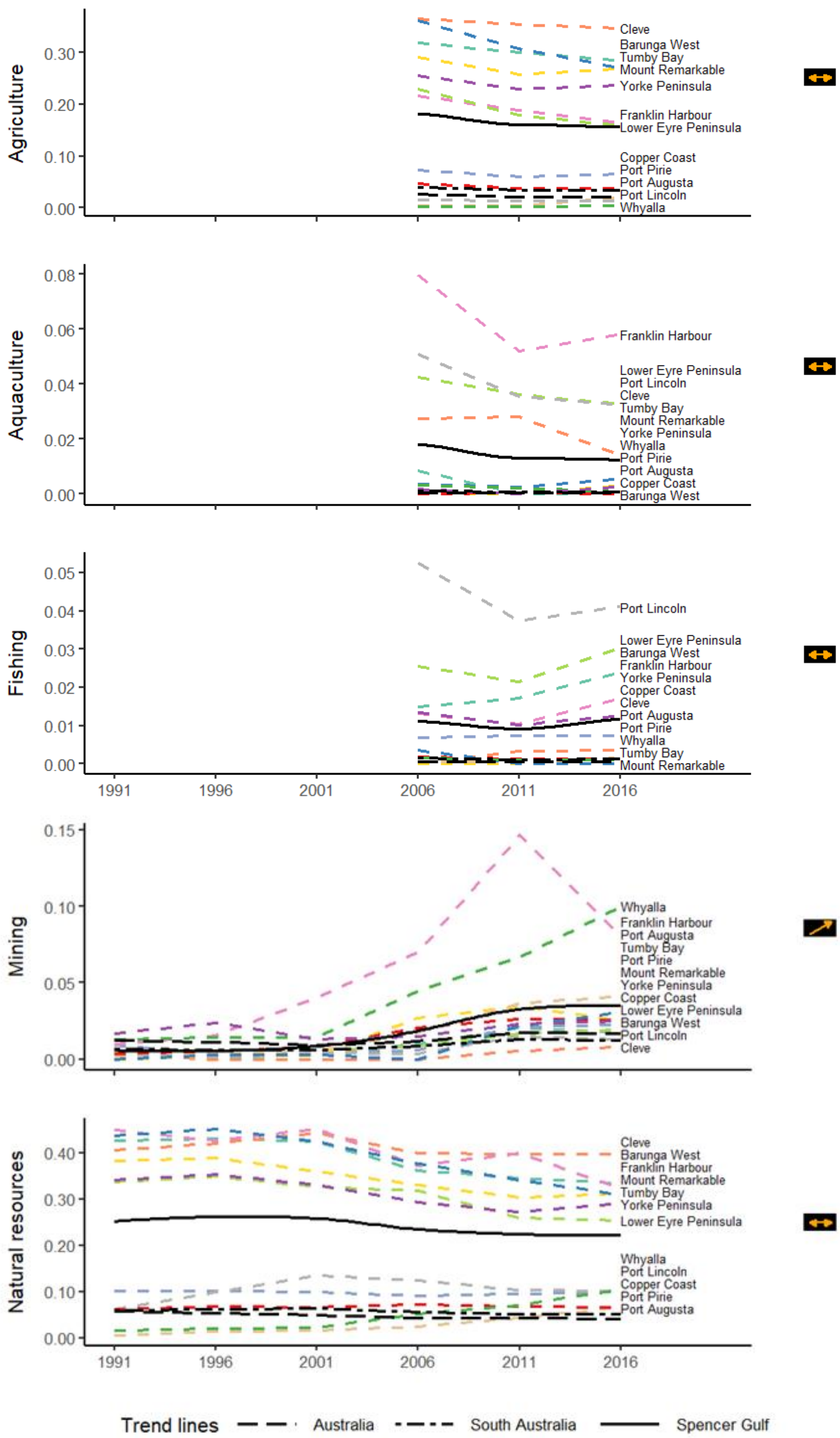

Figure 20. Employment in key industry sectors as a proportion of people who are employed, for each Spencer Gulf local government area. See graph explanation on page 21.

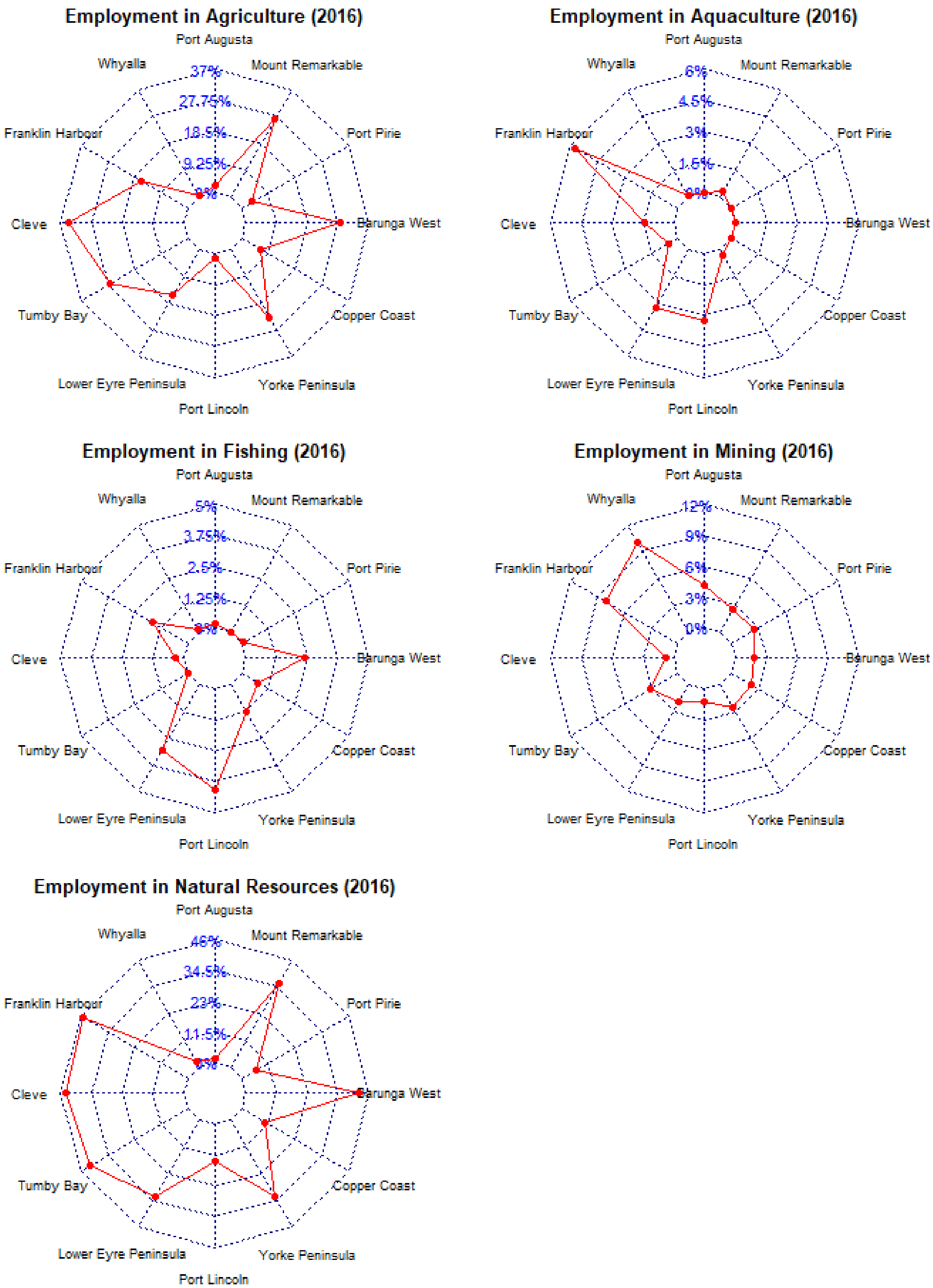

Figure 21. Employment in industry sectors as a proportion of people who are employed in 2016, for each Spencer Gulf local government area.

4 Environmental conditions

4.1 Environmental indicators

4.1.1 Sea surface temperature

Temperature affects marine ecosystems in many ways including its physical effects on thermodynamics, stratification and oxygen carrying capacity (Hoegh-Guldberg and Bruno 2010, Kaiser et al. 2011), as well as influencing many biological processes within and among species ranging from physiological responses to ontogenetic development (Harley et al. 2006). Satellite based measures of sea surface temperature (SST, °C) provide the longest time-series (24 years) of temperature records available for Spencer Gulf. To assess changes in temperature, monthly-averaged Level 3 day/night temperatures provided by the Integrated Marine Observing System (IMOS) were obtained from the Australian Ocean Data Network (https://portal.aodn.org.au/) on an equidistant grid at 0.02 degree resolution. SST data were spatially averaged over multiple points, equivalent to an area of ~36 km^2, to estimate mean and standard deviation values (reference range) for four representative regions centred along the major axis of Spencer Gulf (Figure 22).

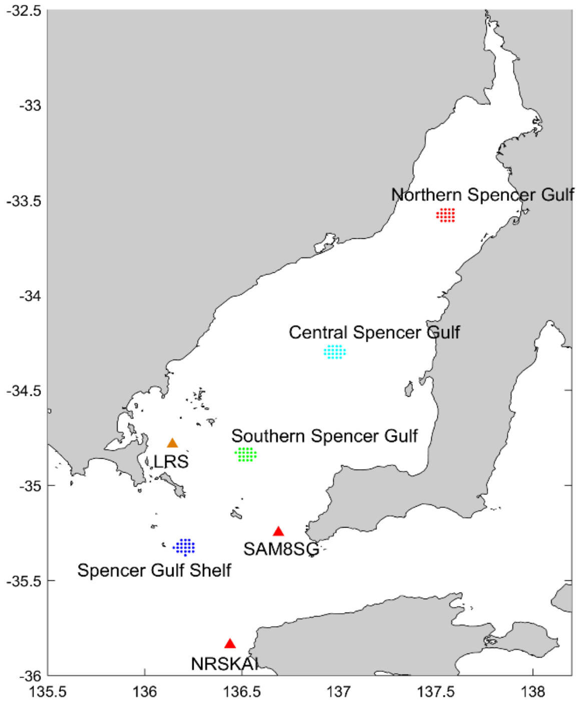

Figure 22. Location of representative regions used for the determination of sea surface temperatures and mooring locations (triangles) in Spencer Gulf.

Seasonal variation in monthly SST increases from south to north along the gulf, with monthly average SSTs ranging from 14.8 to 20.5° C in shelf waters and 12.6 to 24.9° in Northern Spencer Gulf (Figure 23). Across all locations, the long-term (24 years) average SST was ~18° C. Over the last 5 years of the time-series, monthly average SST trends have generally remained neutral, with the exception of shelf waters, which show a negative (i.e. cooling) trend. For all locations, the mean over the last 5 years of the time-series remained within one standard deviation of the long-term mean.

Monthly SST anomalies (Figure 24) show the difference between the monthly average SST values shown in Figure 23 and the long-term (24 year) climatological value for that month. Maximum positive anomalies across Spencer Gulf ranged between 1.44° C (central Spencer Gulf, May 2013) and 1.84 ° C (shelf waters, May 2013) and maximum negative anomalies ranged between -1.22° C (southern Spencer Gulf, March 2004) and -1.44° C (shelf waters, January 1996). Trends over the last five years of the time-series are negative, indicating a decrease in the magnitude of monthly SST anomalies. This trend is largely a consequence of the extended period of strong positive anomalies experienced over summer and autumn in 2013. For central and northern Spencer Gulf locations over the last five years of the time-series, monthly anomalies exceeding one standard deviation of the long-term mean have remained a regular feature during summer and winter months, however the means over the last 5 years of the time-series have remained within one standard deviation of the long-term means.

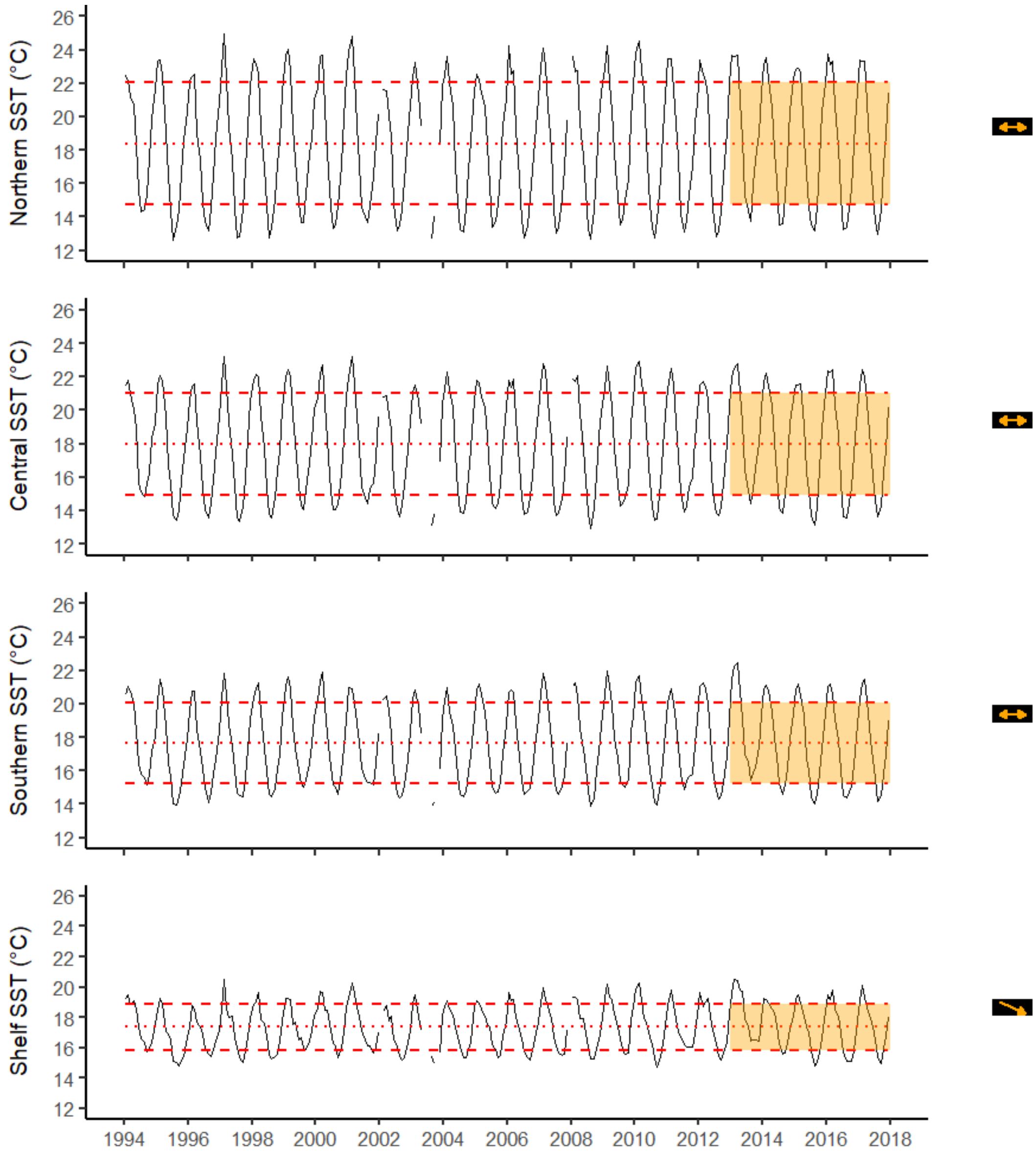

Figure 23. Monthly-average values of satellite derived sea surface temperature (SST, °C) for the four representative regions shown in Figure 22. (a) Shelf waters at the entrance to Spencer Gulf (b) Southern Spencer Gulf (c) Central Spencer Gulf and (d) Northern Spencer Gulf. See graph explanation on page 24.

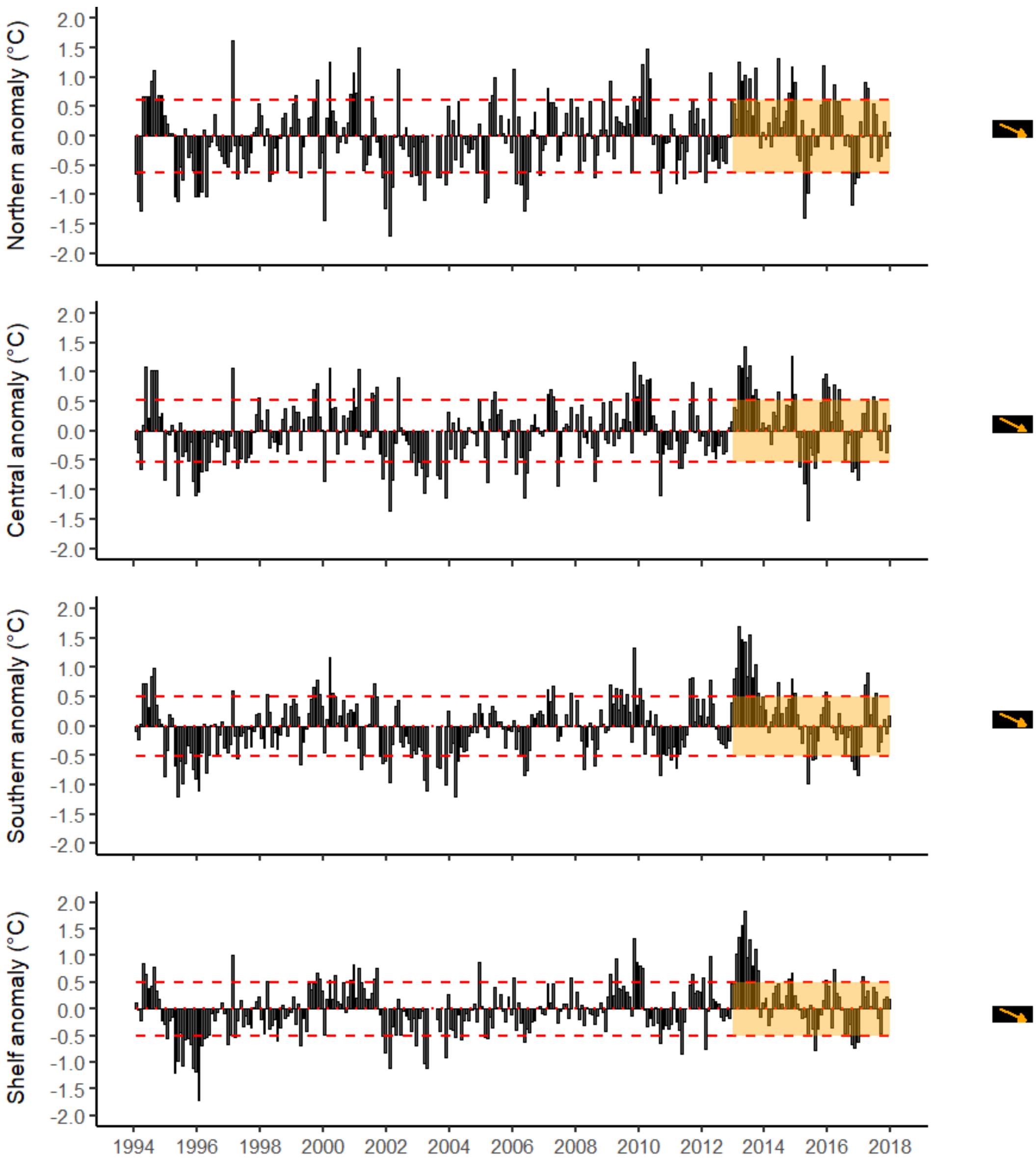

Figure 24. Monthly-average sea surface temperature (SST) anomalies (°C) for the four representative regions shown in Figure 22. (a) Shelf waters at the entrance to Spencer Gulf (b) Southern Spencer Gulf (c) Central Spencer Gulf and (d) Northern Spencer Gulf. See graph explanation on page 21.

To provide a greater understanding of SST trends experienced during the summer (i.e. December, January, February) and winter (June, July, August), when maximum and minimum temperatures in Spencer Gulf are expected, corresponding seasonal averages are presented in Figure 25 and Figure 26. Long-term (24 year) mean summer SST's increased with distance from the gulf's entrance, and ranged from 18.8 ± 0.07 ° C on the shelf to 22.6 ± 0.06 ° C in Northern Spencer Gulf. There were generally no trends over the last 5 years of the time-series, with the exception of Southern Spencer Gulf which showed a negative (cooling) trend. This negative trend is largely the result of the warm summer experienced in 2013 (21.0 ± 0.06° C). Long-term mean winter SST's decreased with distance from the gulf's entrance; and ranged from 16.2 ± 0.06 ° C on the shelf to 13.9 ± 0.06 ° C in Northern Spencer Gulf. Trends over the last 5 years of the time-series were neutral, with means within one standard deviation of the long-term mean.

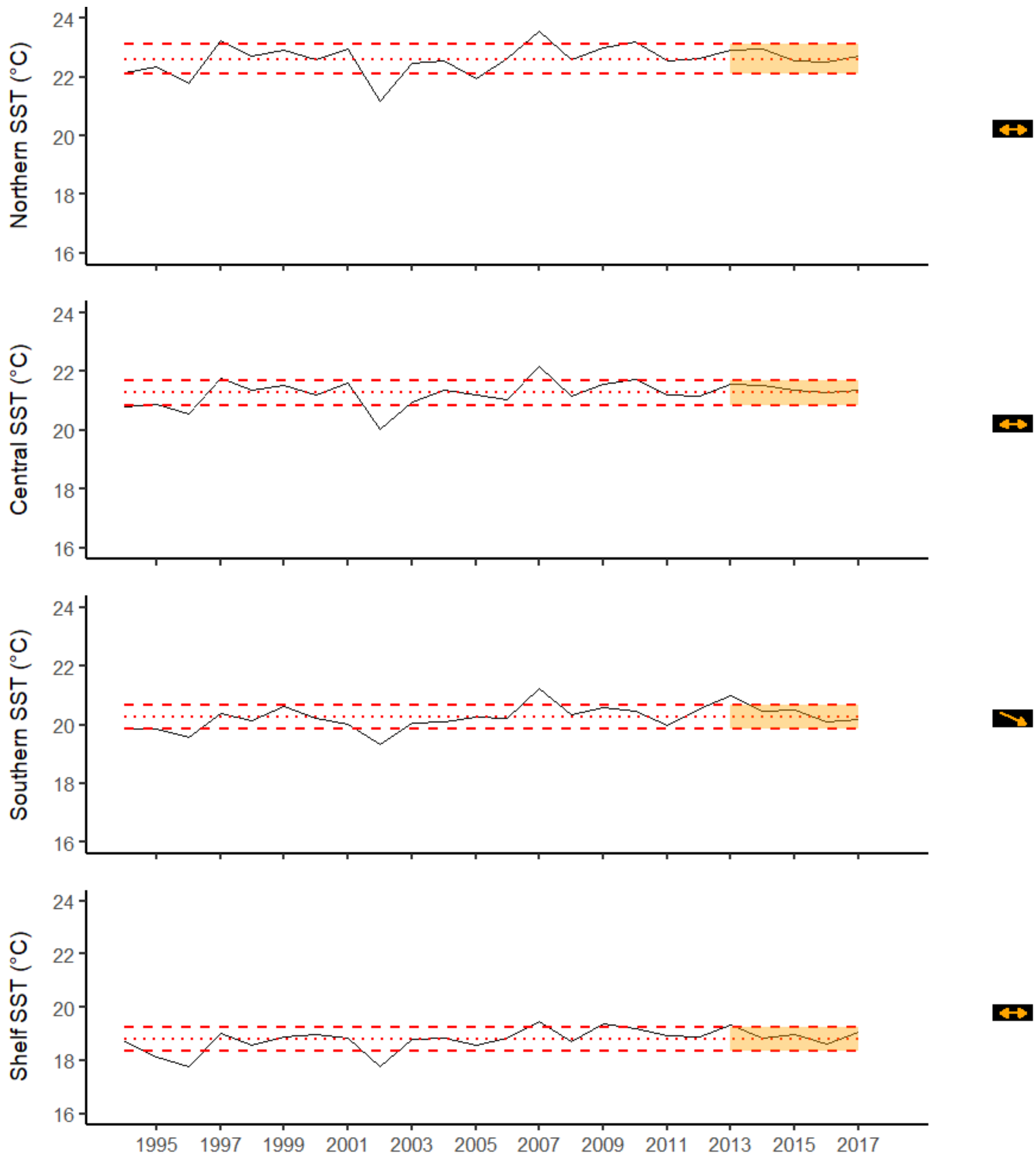

Figure 25. Summer average sea surface temperature (SST, °C) for the four representative regions shown in Figure 22. (a) Shelf waters at the entrance to Spencer Gulf (b) Southern Spencer Gulf (c) Central Spencer Gulf and (d) Northern Spencer Gulf. See graph explanation on page 24.

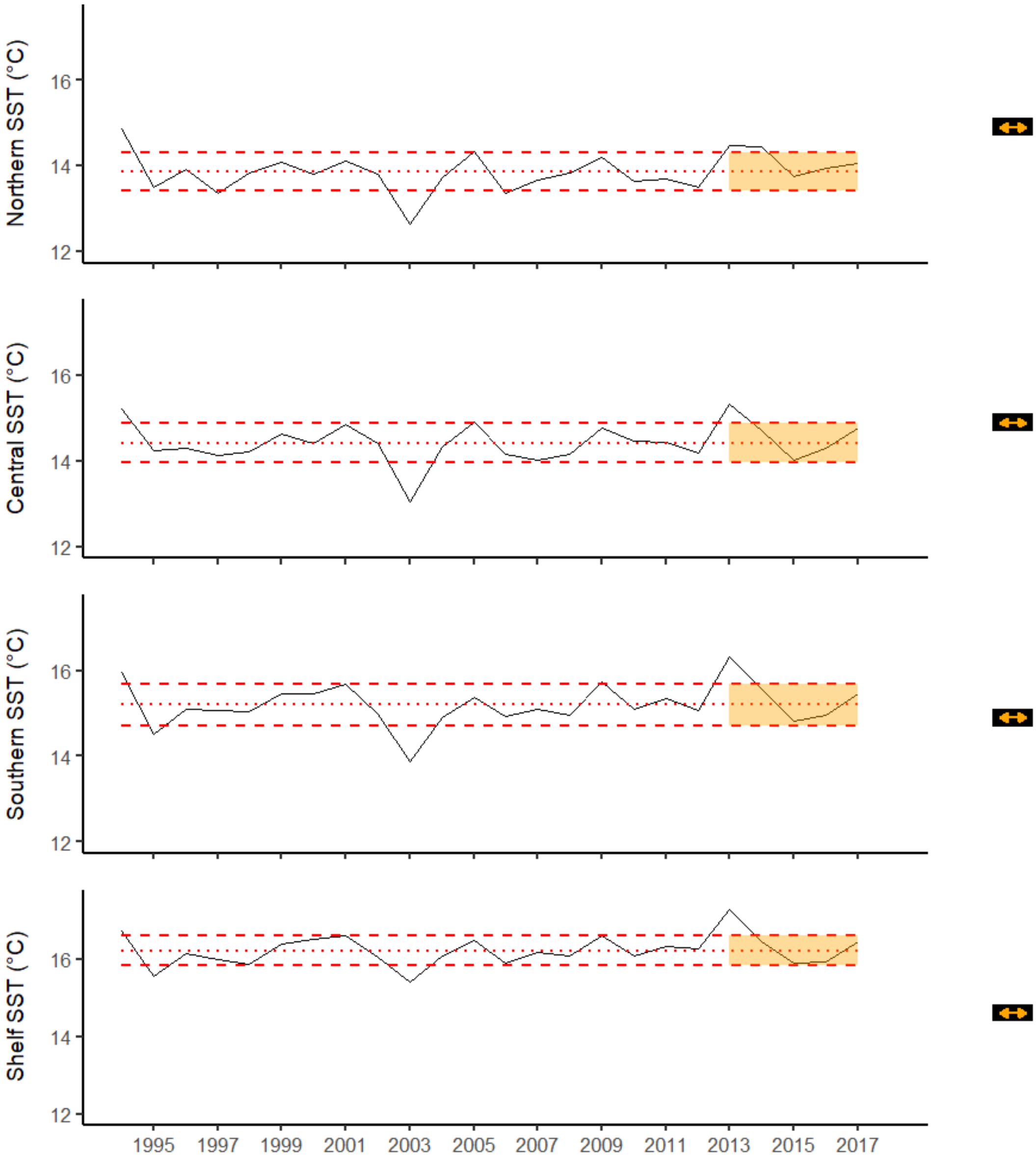

Figure 26. Winter average sea surface temperature (SST, °C) for the four representative regions shown in Figure 22. (a) Shelf waters at the entrance to Spencer Gulf (b) Southern Spencer Gulf (c) Central Spencer Gulf and (d) Northern Spencer Gulf. See graph explanation on page 24.

4.1.2 Bottom temperature and salinity

Time-series measures of near-bottom temperature and salinity averaged over a period of 7 days remove tidal variability and provide information on the thermohaline conditions, which influence benthic ecosystems; oceanographic processes such as upwelling in shelf waters (Middleton and Bye 2007, Doubell et al. 2018); and circulation features that influence annual exchange of waters between the shelf and Spencer Gulf (Nunes Vaz et al. 1990, Middleton et al. 2013).

The IMOS Kangaroo Island National Reference Station (NRSKAI) is located in approximately 100 m water depth to the west of Kangaroo Island and outside Spencer Gulf (Figure 22). Figure 27 shows the average bottom temperature and salinity at NRSKAI over the 10-year time series were 15.5 ± 1.6°C and 35.9 ± 0.4 practical salinity units (psu). Annual summer (December to March) temperature and salinity minima below 15°C and 35.6 psu are associated with upwelling processes (van Ruth et al. 2018), with the lowest temperature of 11.9°C and corresponding salinity 34.94 psu measured in March 2016. The trend over the last five years of the time-series was positive for both temperature and salinity. This trend is, in part, the result of decreases in the magnitude of summertime temperature and salinity minima in 2017 and 2018 relative to the previous three years.

The IMOS Spencer Gulf station (SAM8SG) is located in approximately 40 m water depth to the west of the tip of Yorke Peninsula (Figure 22). Figure 27 shows the 10-year average bottom temperature and salinity at NRSKAI were 16.2 ± 1.7°C and 36.1 ± 0.5 psu. Two distinct peaks occur in the temperature signal, the first occurring in late summer (i.e. January to February) and the second occurring in the months of May to June corresponding with a peak in salinity associated with the annual outflow of dense waters from Spencer Gulf. This high salinity signal is observed several weeks after the annual peak in salinity at NRSKAI. There was no trend over the last five years of the time-series for either temperature or salinity.

Moored measures of bottom temperature and salinity for January to May for 2016 to 2018 have been taken as part of PIRSA’s Aquaculture environmental monitoring program at the Louth reference station (LRS) on the western side of Spencer Gulf near the gulf’s entrance (Figure 22). Figure 27 shows the average bottom temperature and salinity at LRS were 16.2 ± 1.7°C and 36.1 ± 0.5 psu. Temperature and salinity increased over summer months reaching peak values in mid to late March indicating limited connectivity with shelf waters due to the development of the temperature front across the entrance to Spencer Gulf (Petrusevics et al. 2011). Following this, temperature and salinity decreased rapidly over April and May indicating an inflow of water from the shelf, consistent with the outflow signals observed at the same time at the SAM8SG station (Figure 22).

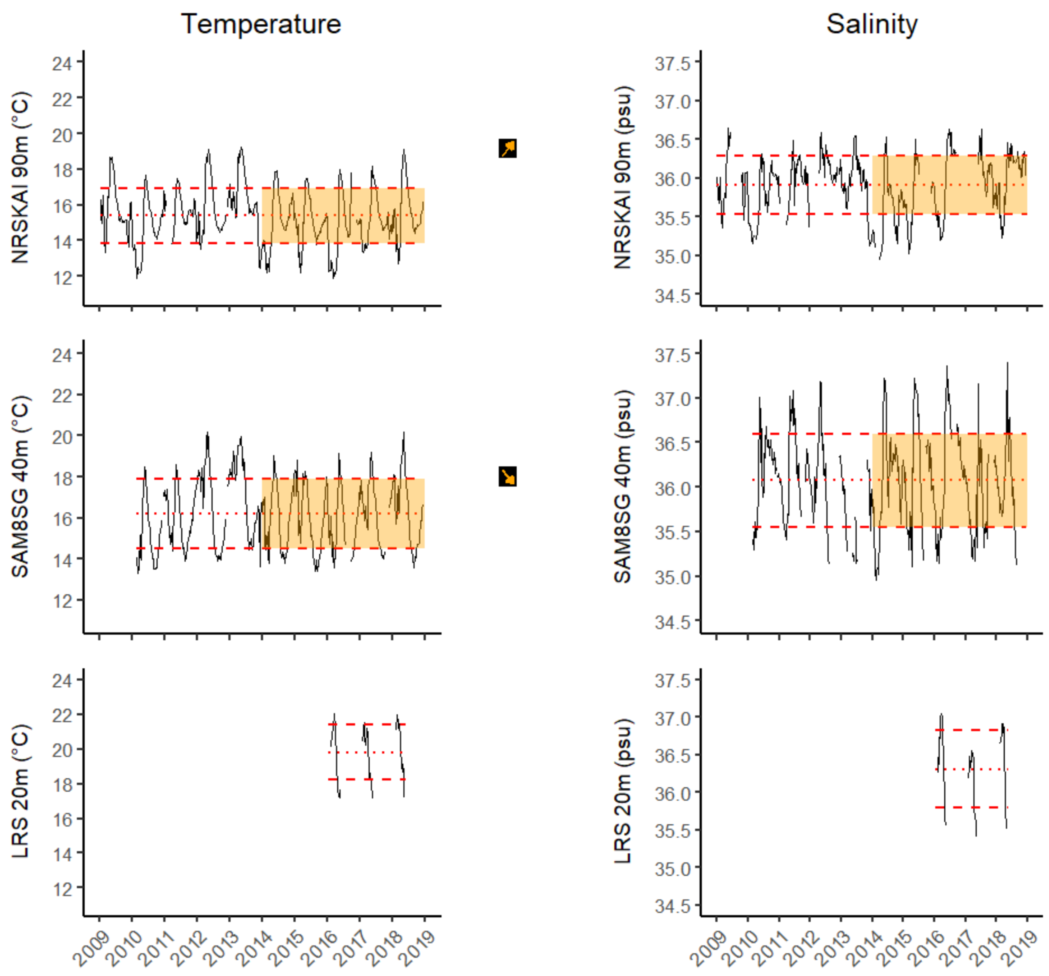

Figure 27. Measures of bottom temperature and salinity averaged over 7 days for the (top) Kangaroo Island national reference station (NRSKAI); (middle) Spencer Gulf SAM8SG station; and (bottom) Port Lincoln reference station (LRS). See graph explanation on page 24.

4.1.3 Sea level and waves

Current and projected sea level rise as a result of climate change (Church et al. 2006) is expected to significantly impact coastal communities through increased flooding and erosion (Abel et al. 2011). Australian tide gauge records available through the BoM provide long time-series to estimate sea level rise. Using these data, Church et al. (2006) estimated the average rate of sea level rise up to the year 2000 was 1.2 mm per year, with a significant correlation to El Nino Southern Oscillation index (ENSO) climate indices along the southern Australian coast. Spencer Gulf has a distinctive tidal regime characterised by the fortnightly occurrence of 'dodge' tides, and an increase in tidal amplitude towards the head of the gulf, with tidal phase changes along the gulf resulting in significant differences in the tides at neighbouring ports (Easton 1978). Tidal currents typically dominate current driven wind and thermohaline forcing (Teixeira 2010, Middleton et al. 2013), and both tidal currents and sea level are well predicted by regional oceanographic models (e.g. eSA Marine: https://pir.sa.gov.au/research/esa_marine/two_gulfs_model).

Figure 28 shows the monthly average mean sea level residual (SLR) (i.e. observed minus predicted) for three locations in Spencer Gulf. Monthly average SLR increased from approximately ± 20 cm at Port Lincoln to ± 22 cm at Wallaroo and ± 26 cm at Port Pirie. Large variations around monthly average SLR values demonstrate the effect atmospheric forcing (i.e. winds, pressure) plays in changing sea level compared to predicted tide levels, with monthly average standard deviations ranging from 27 cm at Port Lincoln to 50 cm at Port Pire. At hourly time scales (data not shown) storm surges were responsible for lifting sea levels by as much as 3 m at Port Pirie, 1.9 m at Wallaroo and 1.3 m at Port Lincoln. Fifty year mean SLR's at Port Pirie, Wallaroo and Port Lincoln were close to 0 cm, however linear regression over the entire time-series indicated a mean sea level rise of 0.04 ± 0.02mm per year across all sites. Trends over the last 5 years of the time-series were neutral at Port Pire with the 5 year mean above one standard deviation of the long-term mean. Five year trends at Wallaroo and Port Lincoln were negative, indicating sea level rise has slowed across this time period.

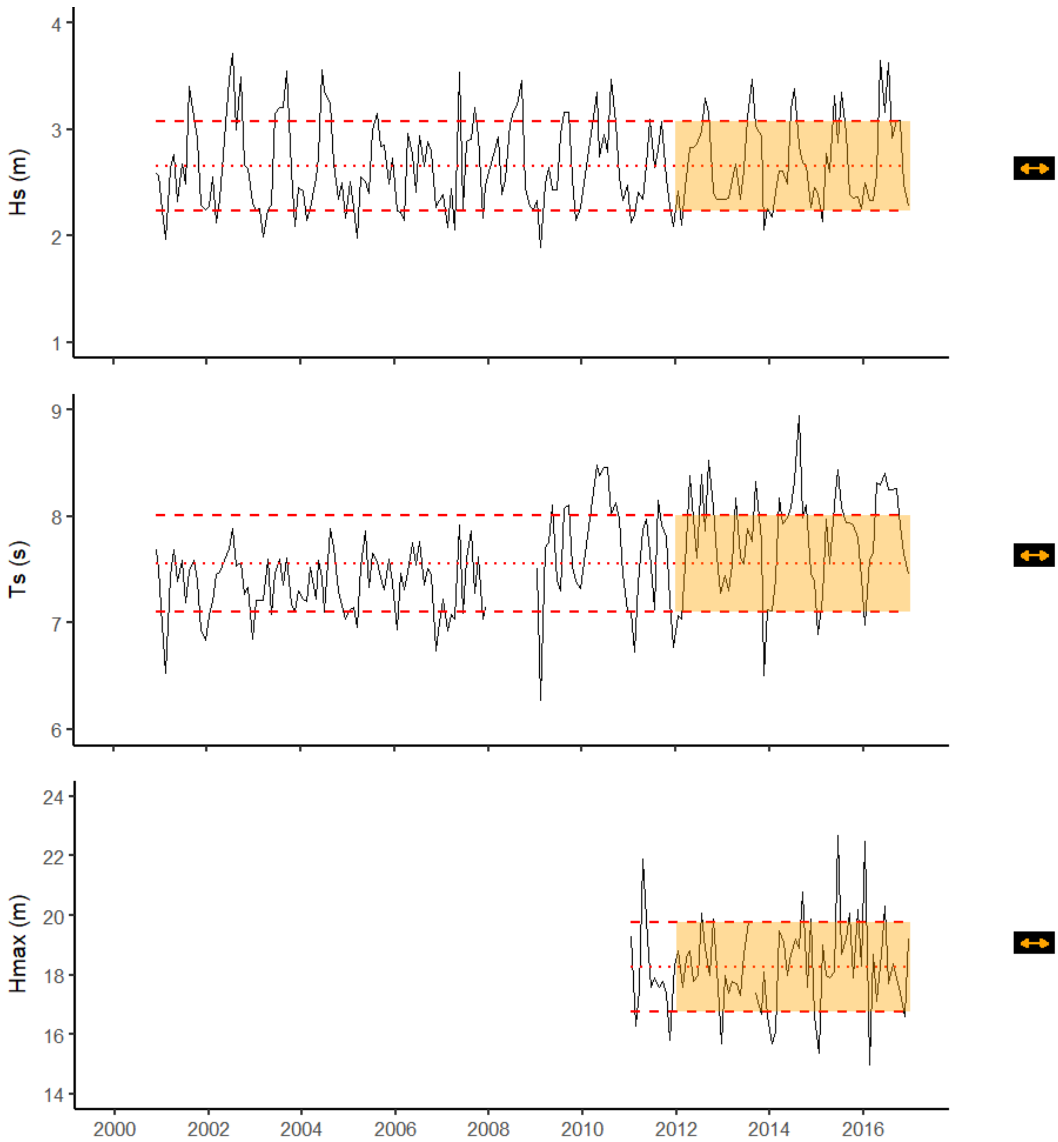

Figure 28. Monthly average sea level residuals (SLR, cm) for Port Lincoln (top); Wallaroo (middle) and Port Pirie (bottom). See graph explanation on page 21.

Climate change and variability has been shown to impact on the surface wave conditions experienced around southern Australia (Hemer et al. 2007), and coupled with sea level rise, are expected to impact coastal communities. For Spencer Gulf, wave models (Middleton et al. 2013) have shown significant wave heights and periods are highly predictable both near the entrance and head of the gulf, with waves entering the gulf being refracted shoreward by the bottom topography and wave height and energy dissipating with distance from the entrance and as water depth decreases.

Figure 29 shows the monthly average significant wave height (Hs) and period (Ts) measured by the BoM Cape Du Couedic wave buoy. The 16-year average significant wave height and period were 2.7 ± 0.4 m and 7.6 ± 0.5 s. Maximum and minimum monthly average wave heights of 3.7 and 1.9 m and corresponding periods of 8.9 and 6.3 s were characterised by significant variability, with maximum and minimum monthly wave height (Hmax) ranging between 15.0 and 22.7 m, with long-term mean value of 18.3 ± 1.5 (Figure 29). For all measures, there were no trends over the last five years of the time-series.

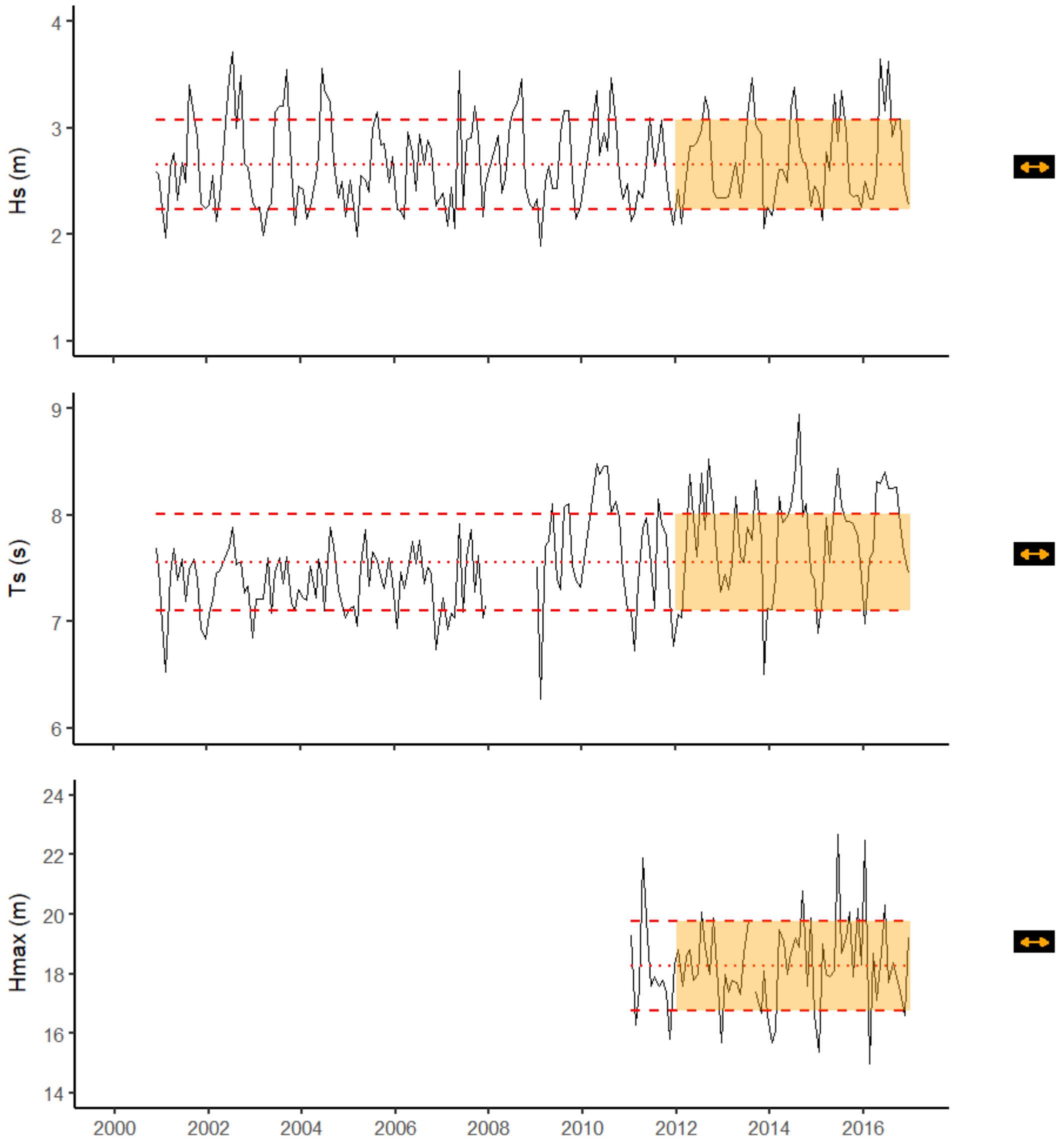

Figure 29. Wave statistics for Cape Du Couedic showing (top) monthly average significant wave height (Hs, m); (middle) monthly average significant period (Ts, s) and (bottom) maximum wave height (m). See graph explanation on page 21.

4.1.4 Meteorological conditions

Bureau of Meteorology data for air temperature and precipitation are presented for Neptune Island, Port Lincoln, Kadina and Whyalla in Figure 30 and Figure 31. Similar to the SST trends shown in Figure 23, monthly average air temperature increases from south to north along the gulf (Figure 30). Mean temperatures over the available time series ranged from 15.7 ± 3.3 5°C in Port Lincoln to 17.4 ± 4.6°C in Whyalla. Seasonal variation in monthly average air temperatures also increased from south to north along the gulf, with monthly average temperatures ranging between 12.3 and 20.8°C at Neptune Island to between 8.8 and 26.8°C at Whyalla. Across all locations, there were no trends over the last 5 years of the time-series.

Monthly precipitation values are shown in Figure 31. Mean monthly precipitation across all sites over the available time series ranged from 22.1 ± 21.2 mm in Whyalla to 35.8 ± 30.9 mm at Neptune Island. Across all locations, there were no trends over the last 5 years of the time-series.

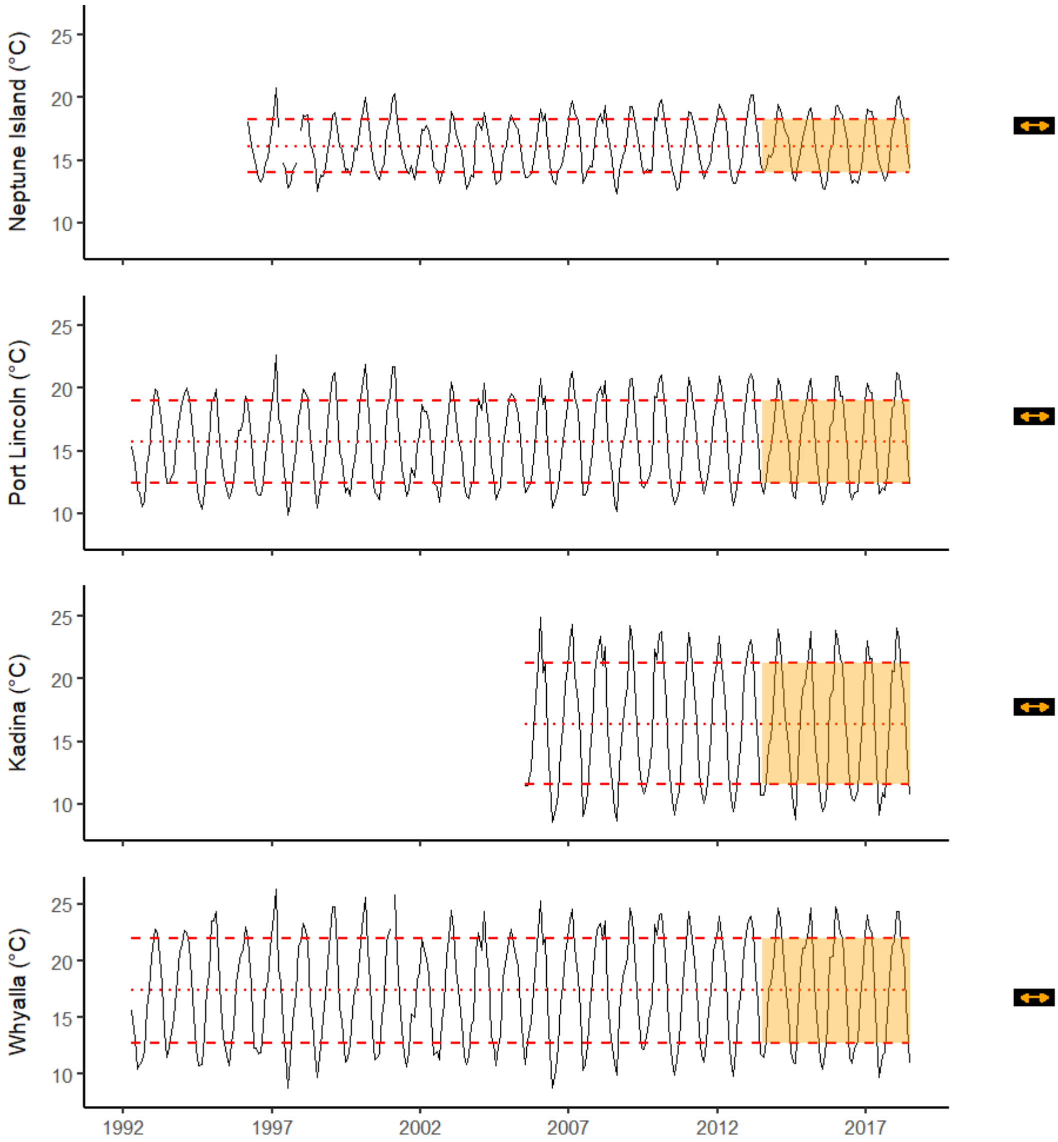

Figure 30. Monthly average air temperatures (°C) for a) Neptune Island, (b) Port Lincoln, c) Kadina and d) Whyalla. See graph explanation on page 24.

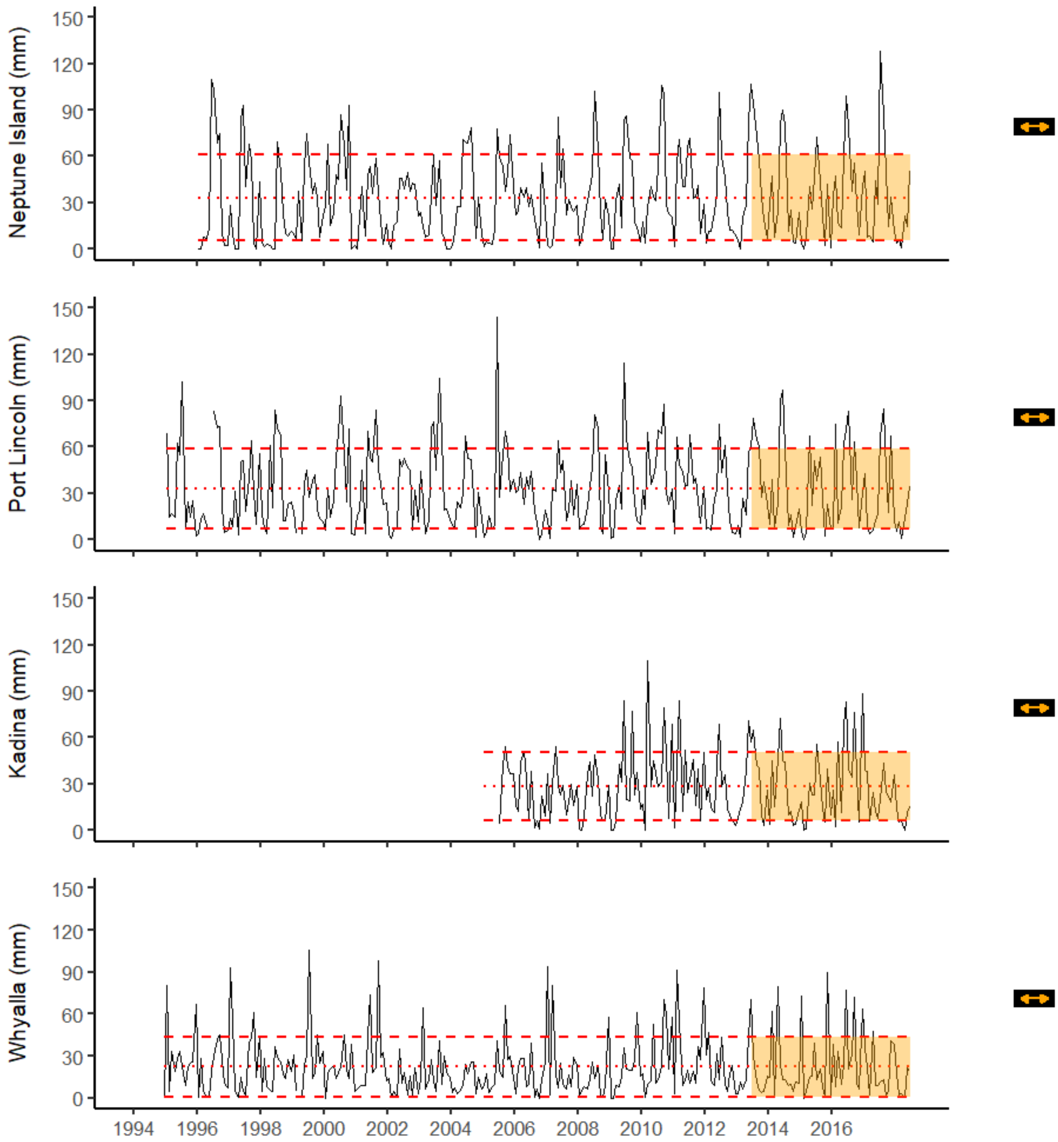

Figure 31. Monthly precipitation (mm) for a) Neptune Island, (b) Port Lincoln, c) Kadina and d) Whyalla. See graph explanation on page 24.

4.2 Climate indicators

The monthly climate indices shown in Figure 32 are commonly used to monitor the large-scale state of atmosphere and ocean conditions in the Pacific, Indian and Southern Oceans that influence the long-term ocean and atmospheric conditions experienced across Australia.

The Southern Oscillation Index (SOI) and Nino3.4 Index (NINO3.4) (Figure 32) are used to classify the status of the El Niño–Southern Oscillation (ENSO) climatic cycle, which defines the development and intensity of El Niño or La Niña events. For the South Australian marine environment, El Niño events have been shown to influence the local meteorology, and may enhance upwelling along the shelf by raising the oceanic thermocline (Middleton et al. 2007). Future increases in the frequency of La Niña events are predicted in response to global warming (Cai et al. 2015). Sustained values of the SOI less than -8 and NINO3.4 temperatures greater than 0.8^{o}C are indicative of El Niño episodes, with the most recent notable events occurring in 1997-98, 2009-10 and 2015-16. La Niña episodes are characterised by sustained values of SOI greater than +8 and NINO3.4 temperatures less than 0.8^{o}C, with the most recent events in 2007-08, 2008-09 and 2010-12 of weak to moderate intensity. Both the SOI and NINO3.4 indices show a return from the El Niño episode of 2015-16 to neutral conditions, with no trends over the last 5 years of the time-series.

The Southern Annular Mode (SAM) Index (Figure 32) monitors the north-south movement of the westerly winds which dominate the mid latitude regions of the southern hemisphere. This band of westerly winds influences the intensity and track of storm systems and, along with ENSO, influences the wave climate in the Southern Ocean (Hemer et al. 2007, O'Grady et al. 2015). Positive values are indicative of higher atmospheric pressures and the weakening of the westerly winds and cold fronts over southern Australia. SAM values of 4.92 in February 2015 and 4.36 in March 2016 were the highest values recorded since March 1982 (4.28). There is no trend over the last 5 years of the time-series.

The Dipole Mode Index (DMI, Figure 32) monitors the intensity of the Indian Ocean dipole (IOD) climate mode which influences ocean and atmosphere temperatures and rainfall distributions around Australia, including the passage of weather systems. Positive values are associated with a reduced chance of rainfall over South Australia and negative values are indicative of increased rainfall during the winter-spring period. Minimal influence on the South Australian climate is expected under neutral conditions and during the months spanning December to April. Since 2000, there has been a reduction in the magnitude and frequency of negative DMI values more than one standard deviation below the long-term mean (-0.25^{o}C). An increasing trend is observed over the last 5 years of the time-series.

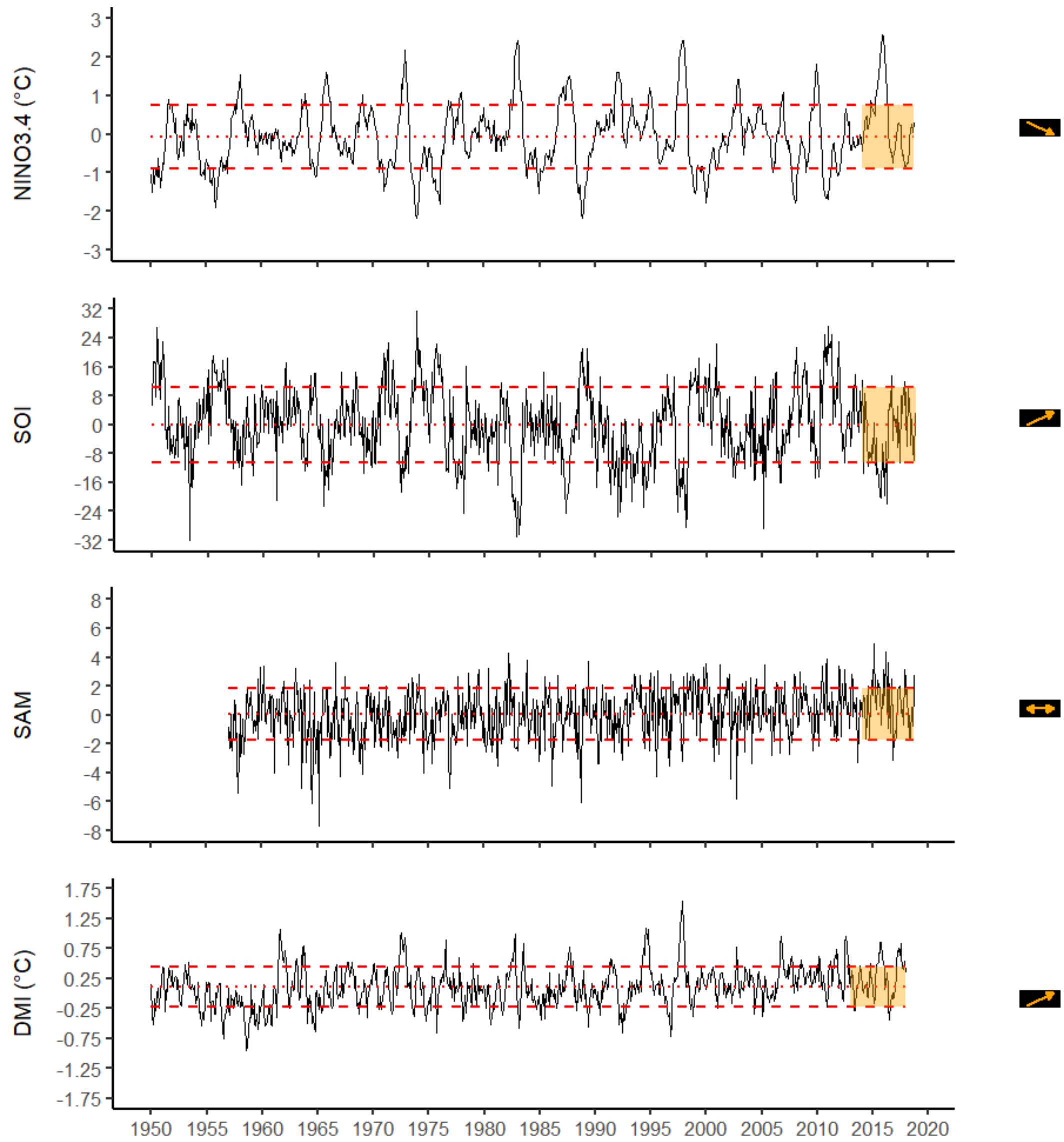

Figure 32. Monthly average values of (a) the Nino3.4 Index (NINO34; °C); (b) the Southern Oscillation Index (SOI); (c) the Southern Annular Mode Index (SAM); and (d) the Indian Ocean Dipole Mode Index (DMI; °C). See graph explanation on page 24.

4.3 Ocean acidification indicators

Ocean acidification results from CO_2 uptake by the ocean, which drives changes in ocean chemistry, including reductions in pH (i.e., acidification), and the saturation states of aragonite and calcite, the two minerals most important for shell/reef formation in marine calcifiers (Barton et al. 2015). When seawater becomes under-saturated with aragonite, calcareous shells start to dissolve (Doney et al. 2009). Detrimental impacts on calcifiers have been reported at aragonite saturation states as high as 2 (Barton et al. 2012, Waldbusser et al. 2015). Molluscs appear to be particularly susceptible to the effects of ocean acidification, which impedes spat development by delaying shell formation (Barton et al. 2012, Waldbusser et al. 2013). Crustaceans are similarly affected (Richards et al. 2015).

Water from the deep-reaching coastal upwelling system in the eastern Great Australian Bight is annually drawn into Spencer Gulf following the breakdown of the temperature front at the mouth of the gulf in ~ May. The Integrated Marine Observing System (IMOS) maintains a mooring in the upwelling centre off western Kangaroo Island through the Ocean Acidification mooring network, providing time-series data on aragonite saturation state and total pH at several depths in shelf waters outside Spencer Gulf. These data provide a long-term indicator of the potential impact of ocean acidification on Spencer Gulf.

Aragonite saturation state varied considerably with depth between 2008 and 2018, with higher values in near-surface waters (0 – 30 m, ~2.6 – 3.2), and lower values in deeper waters (50 – 100 m, ~2.1 – 3.0) (Figure 33). Long-term means in near-surface waters were ~2.8 – 2.9, with long-term means of ~2.4 – 2.6 in deeper waters. The lowest aragonite saturation states in the time-series were observed during periods of strong upwelling (e.g. at 75 m depth in summers of 2010, 2014, 2015, 2016, and at 100 m depth in summer 2010, 2014, 2016, 2017, 2018). At all depths, there was no trend in aragonite saturation state over the last five years of the time-series.

Total pH varied with depth between 2008 and 2018, but remained between 8.0 and 8.1 (Figure 34, note that as pH is on a log scale, this is a 30% difference in hydrogen ions). Higher values occurred in near-surface waters (0 – 30 m, generally ~8.05 – 8.10), with lower values in deeper waters (50 – 100 m, ~8.01 – 8.08). Long-term means in near-surface waters were ~8.06 – 8.08, with long-term means of ~8.05 – 8.06 in deeper waters. Lowest total pH in the time-series were observed during periods of strong upwelling (e.g. at 75 m depth in summers of 2015, 2017, and at 100 m depth in summer 2017). At all depths, there was no trend in total pH over the last five years of the time-series, except at 100 m depth where the trend was negative.

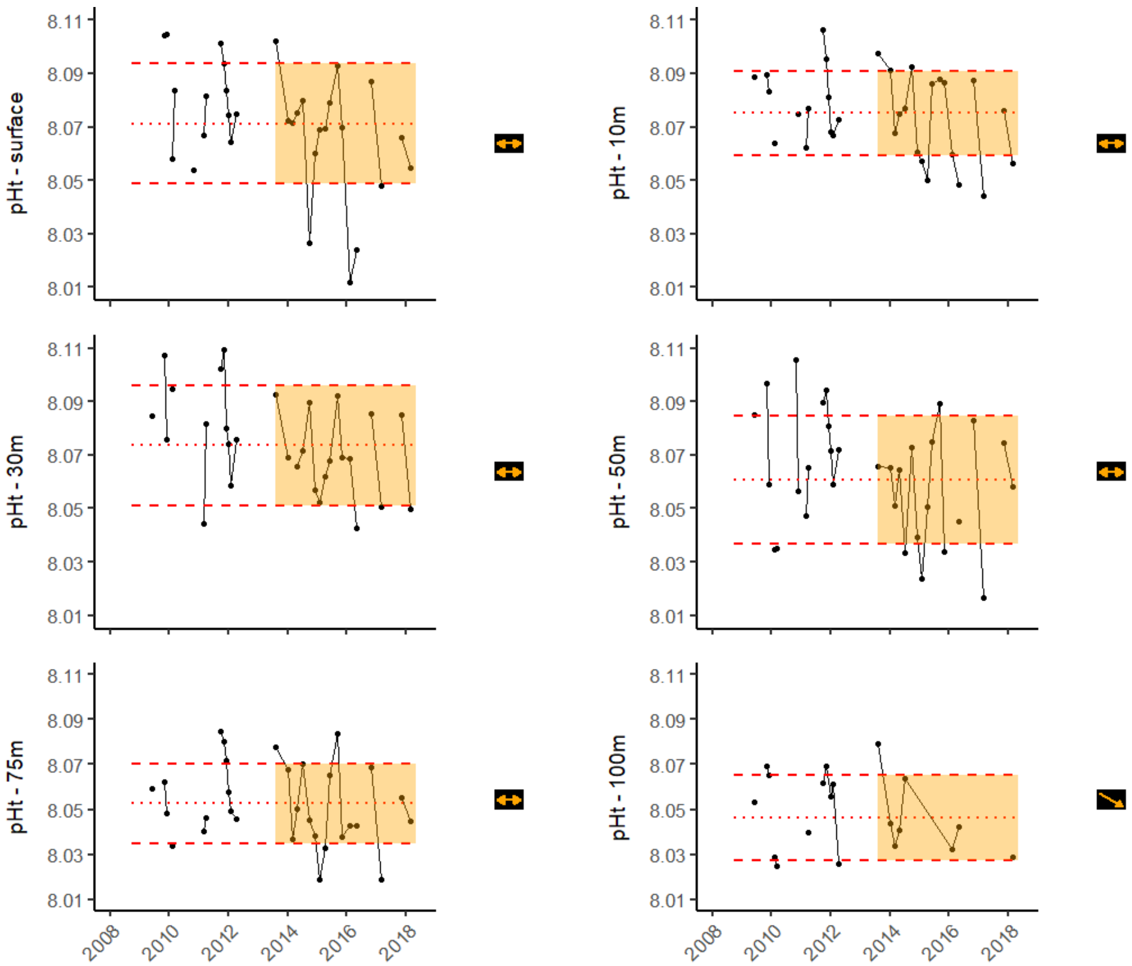

Figure 33. Long-term variation in aragonite saturation state with depth at the IMOS Kangaroo Island National Reference Station (NRSKAI). See graph explanation on page 24.

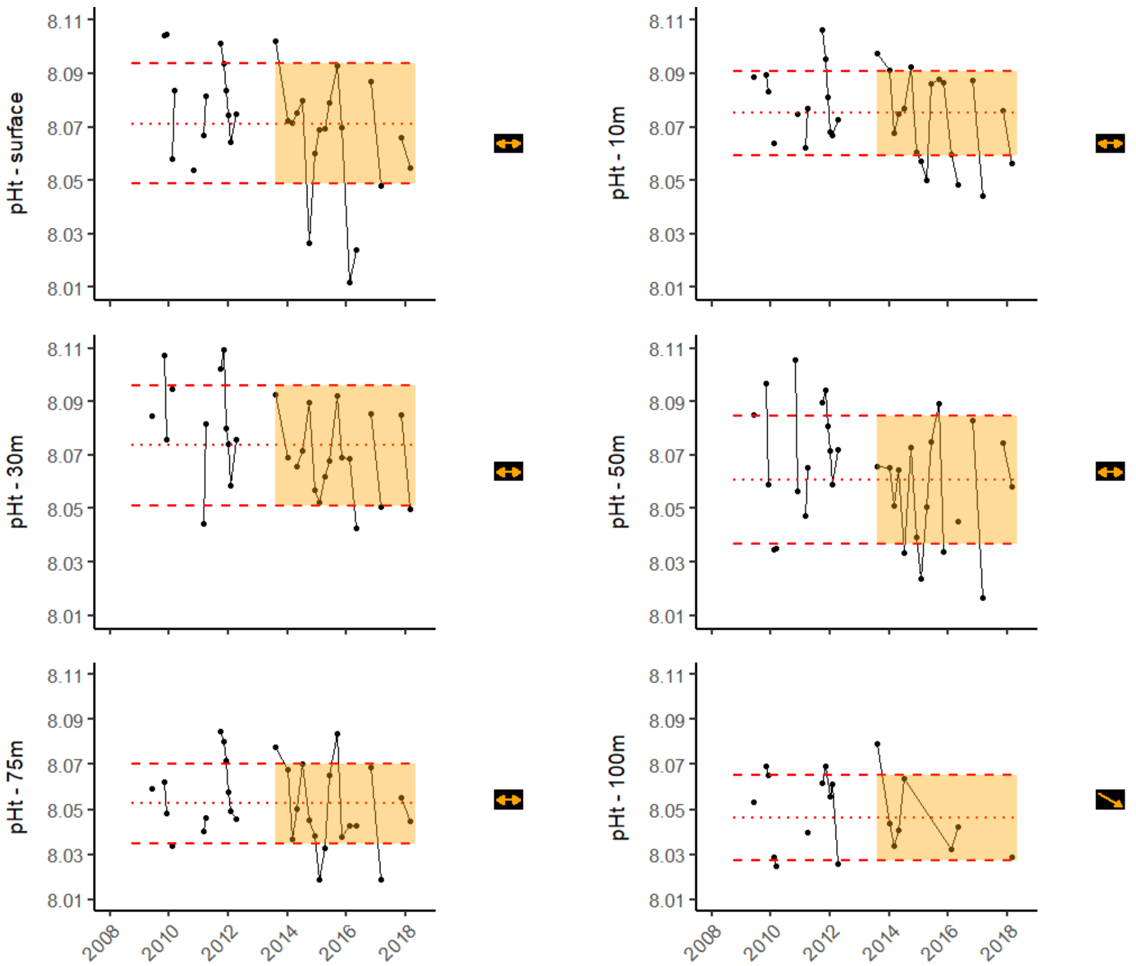

Figure 34. Long-term variation in total pH (pHt) with depth at the IMOS Kangaroo Island National Reference Station (NRSKAI). See graph explanation on page 24.

5 Marine industries

5.1 Shipping indicators

There are currently five operational ports in Spencer Gulf (Port Bonython, Port Lincoln, Port Pirie, Wallaroo and Whyalla), with a number of new ports at various stages of the planning process (Gillanders et al. 2016). New port development plans are primarily in response to a number of planned mining developments in the region, although some will also accommodate other goods, and if they go ahead will lead to increased shipping traffic in the region. Shipping intensity through the gulf has been mapped using Automatic Identification System data for 2013-14 (Gillanders et al. 2016), and shows several main channels in use through the central gulf (Figure 35). Gillanders et al. (2016) also break this down by vessel size. Data are also readily available from Flinders Ports, who operate Port Lincoln, Port Pirie and Wallaroo, relating to annual shipping movements and tonnage of exports and imports, since 2011 (Flinders Ports 2019).

The trend in shipping movements in Port Lincoln over the last five years of the time-series was neutral, and the mean over this time was stable (Figure 36). Similar patterns were observed for shipping movements in Port Pirie and Wallaroo. The trend in shipping tonnage in Port Lincoln over the last five years of the time-series was neutral, and the mean over this time was stable (Figure 37). A similar pattern was observed for shipping tonnage in Wallaroo. The trend in shipping tonnage in Port Pirie for the last five years of the time-series was positive, with the mean over this time being stable.

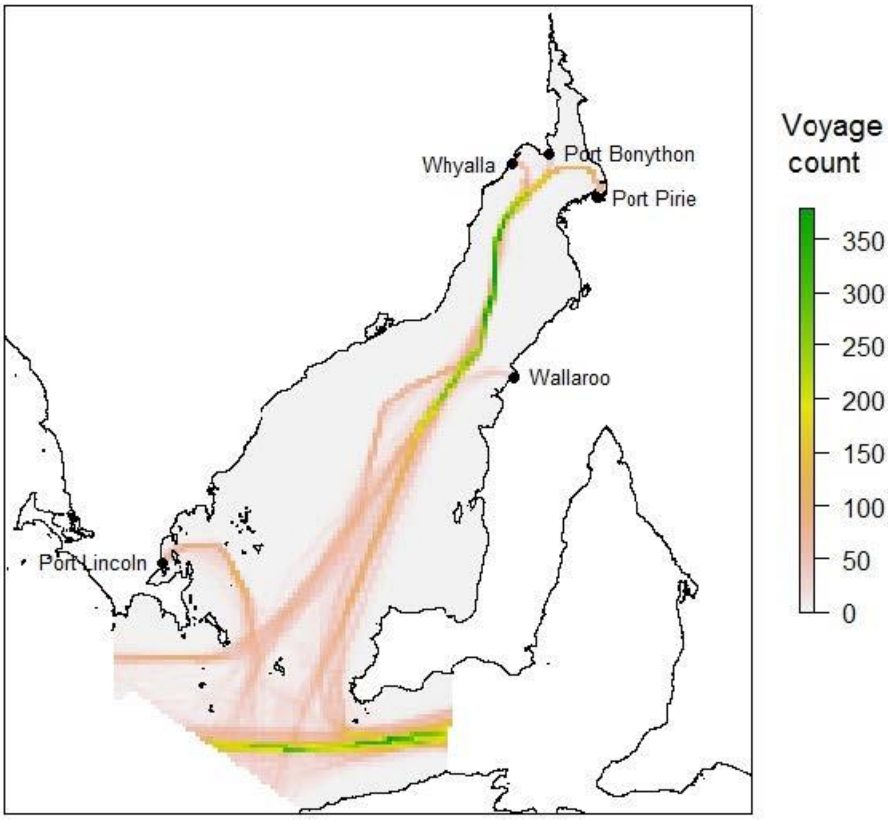

Figure 35. Map showing the number and route for all commercial shipping movements in Spencer Gulf from 1 August 2013 – 31 July 2014. Source: Gillanders et al. (2016).

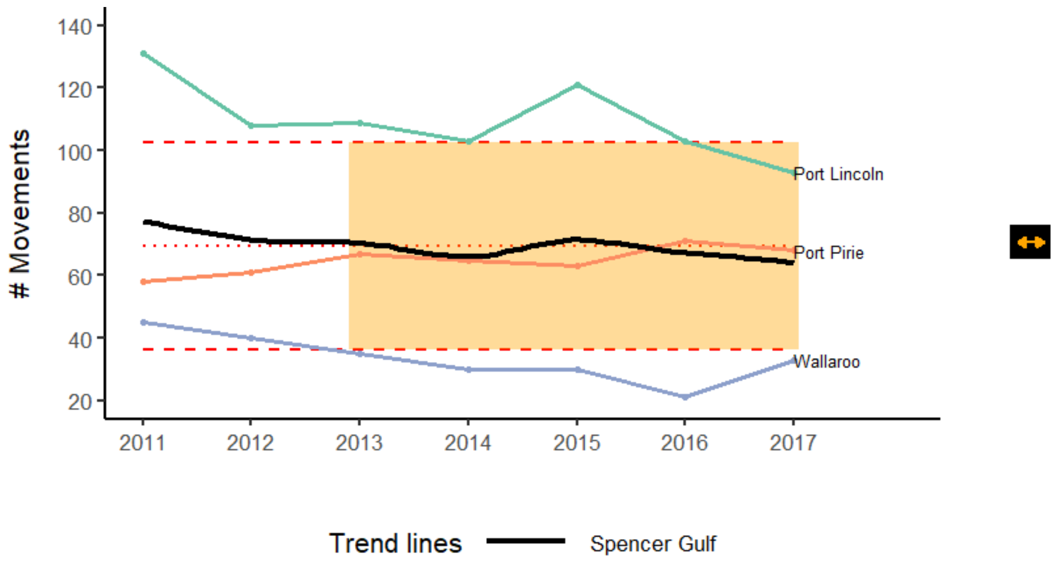

Figure 36. Number of shipping movements through Flinders Ports controlled ports in Spencer Gulf from 2011 to 2017. Data sourced from Flinders Ports (2019). See graph explanation on page 2424.

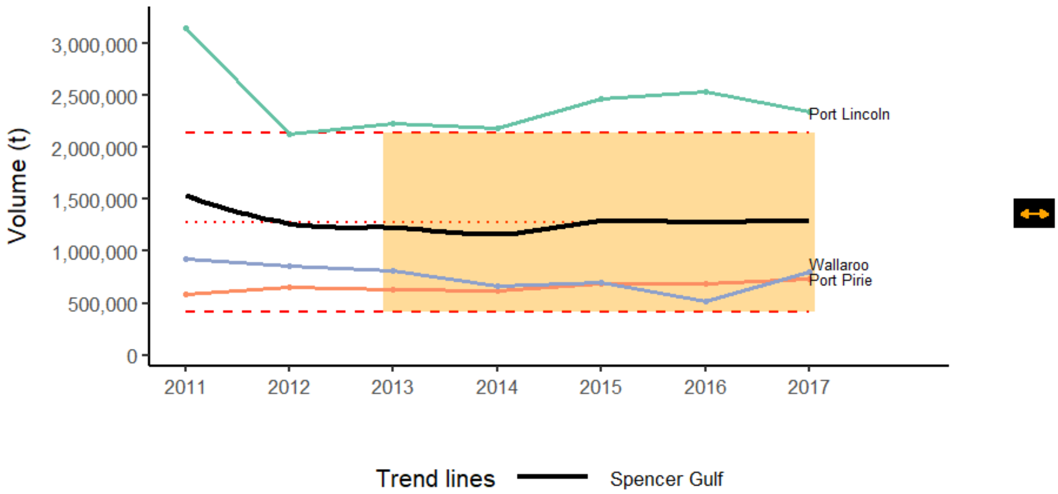

Figure 37. Volume of imports + exports through Flinders Ports controlled ports in Spencer Gulf from 2011 to 2017. Data sourced from Flinders Ports (2019). See graph explanation on page 24.

5.2 Fishery indicators

There are good long-term records of catch and effort for all of the commercial fisheries operating in Spencer Gulf. All fisheries are managed to maintain their productivity, and there is an increasing focus on ecosystem-based management. However, to date, there is little routine data collection on the broader ecological footprint of specific fisheries. One of the few exceptions is the western king prawn fishery, for which location data have been used to map the footprint of the fishery. Similar data are available for the sardine fishery, although these data have not yet been utilised for this purpose. Fishery production data for all fisheries in the gulf have been obtained from SARDI, while Econsearch provided economic data and employment figures.

5.2.1 Abalone fishery

Abalone catch remained relatively stable between 1997 and 2016 at ≥ 200 tonnes, while effort fluctuated by up to ~200 days (Figure 38). The long-term mean catch over this time was 228 tonnes, with a long-term annual mean effort of 538 days fished. Despite these fluctuations in catch and effort, the catch over the last five years of the time-series was stable, and the mean over this time was within the reference range. Similar patterns were observed for effort. Total output, contribution to gross state product (GSP) and employment in the industry have been relatively low since 2011/12, although appear to be slowly increasing.

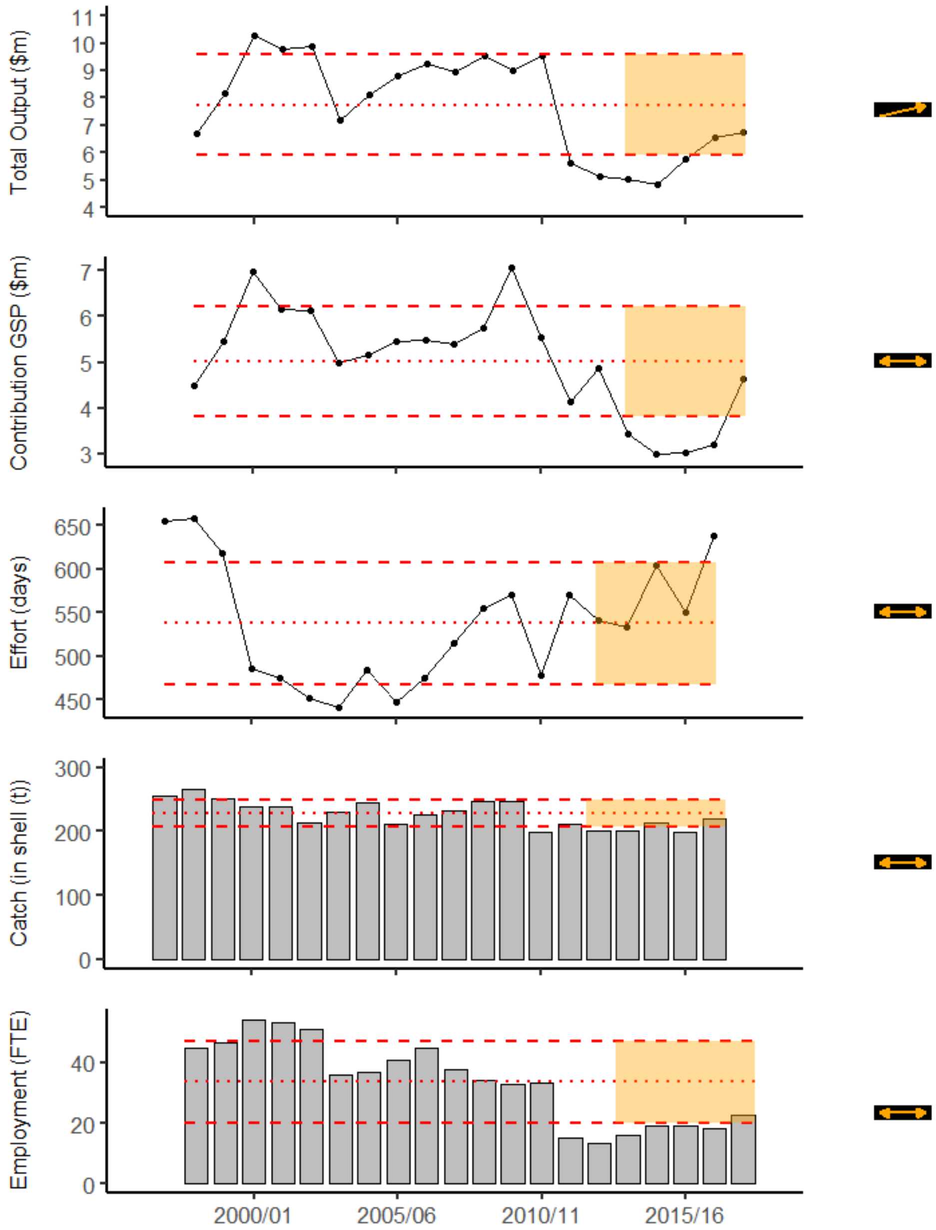

Figure 38. Employment, contribution to gross state product (GSP), total output, effort and catch in the Spencer Gulf abalone fishery between 1997 and 2018. See graph explanation on page 24.

5.2.2 Blue crab fishery

In the decade between 1997 and 2016, blue crab catch fluctuated between ~250 and 450 tonnes, with effort gradually halving over that period (Figure 39). The long-term mean catch was 365 tonnes. Long-term mean effort was 1004 boat days per year. Effort peaked at 1460 boat days in 1999, when catch was close to the long-term mean (363 tonnes). The catch and gross value of production over the last five years of the time-series were stable, and their means over this time were within the reference range. Effort was also stable, although the mean over the last 5 years of the time-series was below the reference range.

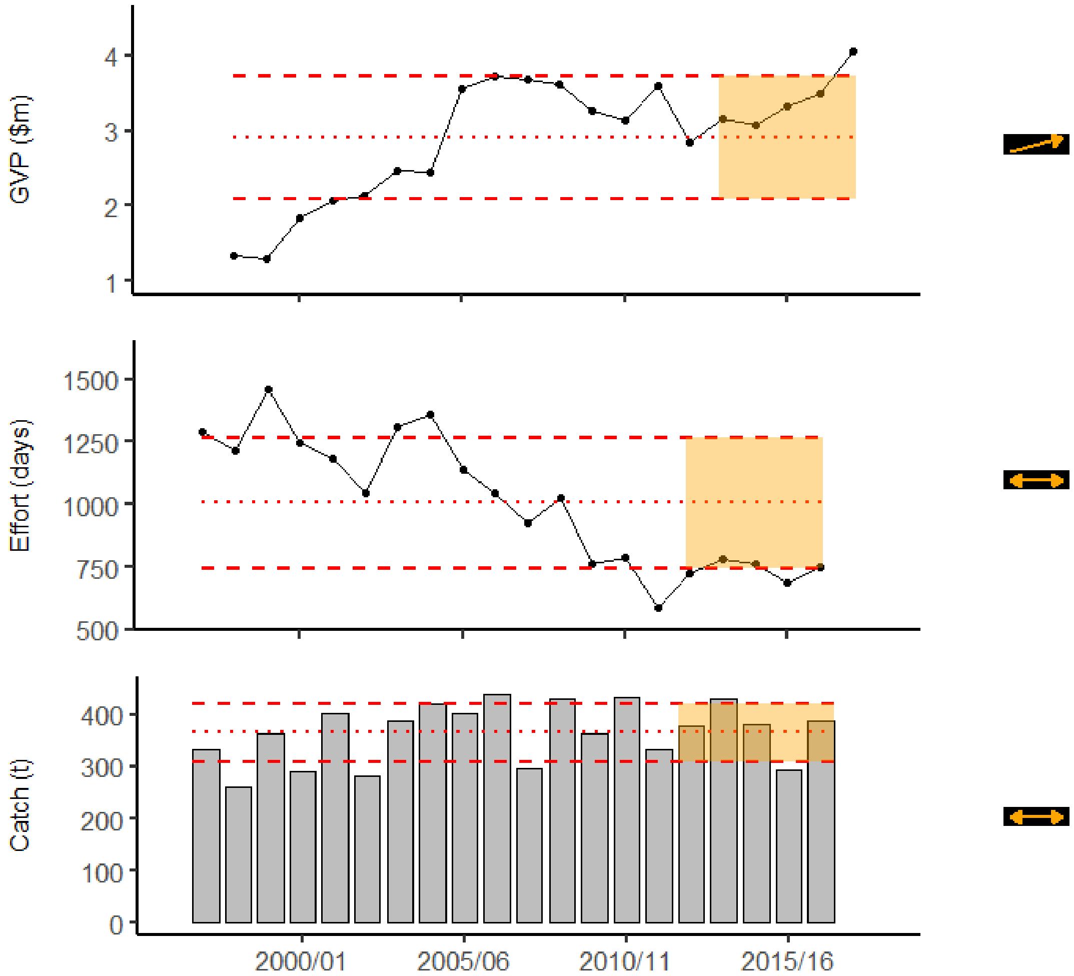

Figure 39. Gross value of production (GVP), effort and catch in the Spencer Gulf blue crab fishery between 1997 and 2018. See graph explanation on page 24.

5.2.3 Prawn fishery

Catch in the Spencer Gulf prawn fishery fluctuated between 1369 and 2729 tonnes through the 1997 – 2016 time-series, with effort declining from 2680 to 1945 days fished (Figure 40). Long-term mean catch from 1997 to 2016 was 1963 tonnes, and mean effort was 2108 days fished per year. There was no trend in catch over the last five years of the time-series, and the mean over this time was within the reference range. Similar patterns were observed for effort. Employment steadily declined through to 2013/14, and has increased slowly since that time. Total output was at close to record levels for the final four years of data, and the contribution to gross state product reached a record level in the final year, 2016.

The Spencer Gulf prawn fishery cumulative trawl footprint increased steadily from 758 km^2 in 2003, the year that suitable spatial data to calculate this value was first collected, to 4280 km2 in 2016 (Figure 41). The long-term mean trawl footprint between 2003 and 2016 was 2771 km^2. It must be noted that spatial data at the resolution needed to calculate the trawl footprint are only collected for the first, middle and final shot by each vessel on each night of trawling, which accounts for ~40% of all shots each year. Thus, total trawl footprint will be higher than suggested by these figures. As the cumulative footprint is still increasing, the 14 years of data currently available do not fully describe the spatial extent of the fishery, with new 'unfished' ground still being added each year (noting that 'unfished' ground may have been fished prior to 2003).

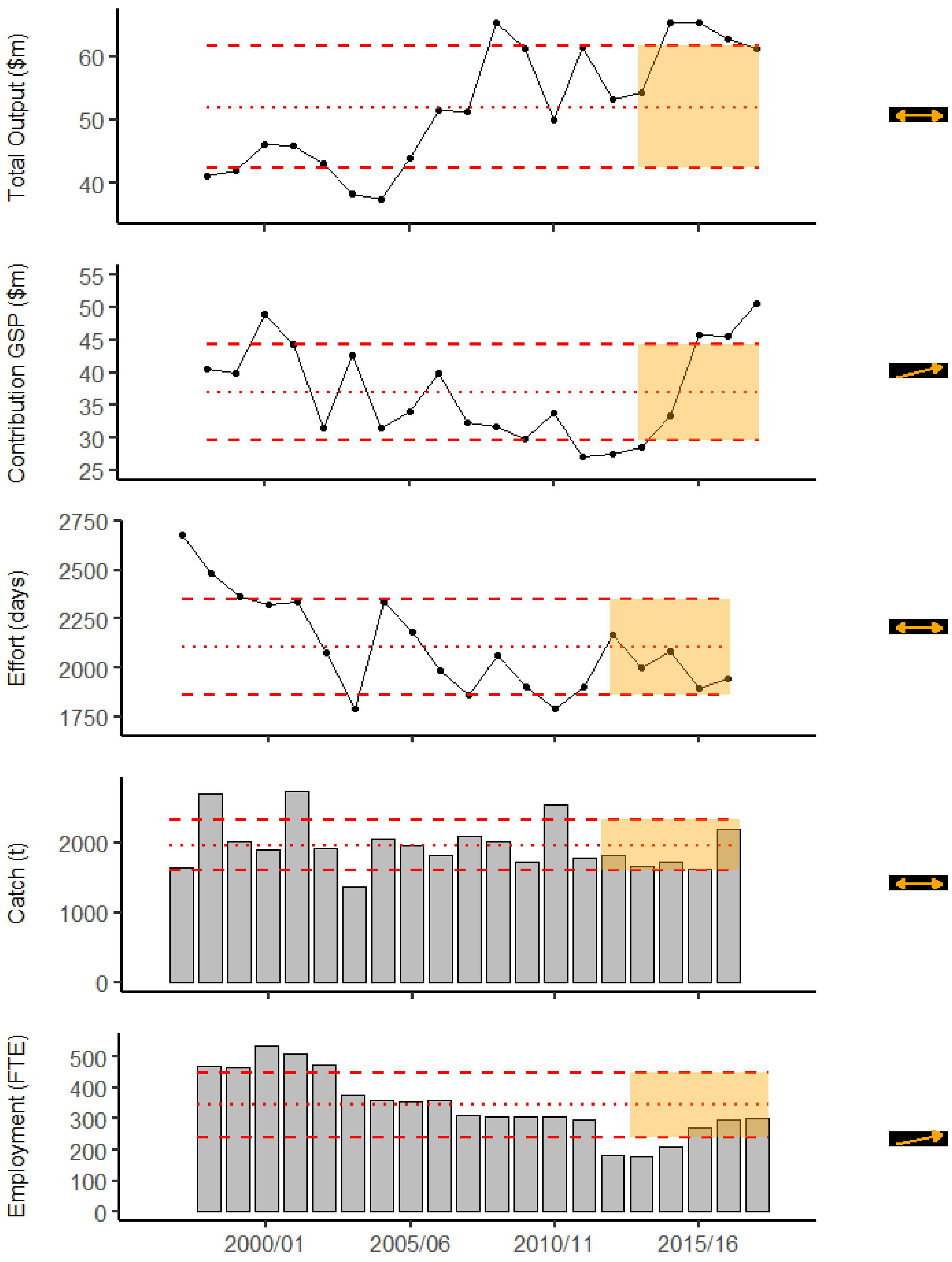

Figure 40. Employment, contribution to gross state product (GSP), total output, effort and catch in the Spencer Gulf prawn fishery between 1997 and 2018. See graph explanation on page 21.

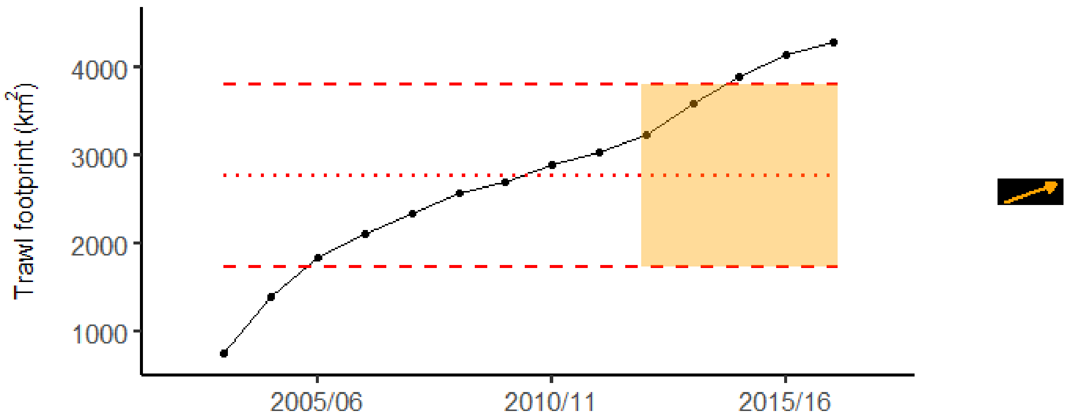

Figure 41. Spencer Gulf prawn fishery cumulative trawl footprint (km²) for ~ 40% of shots per year between 2003 and 2016. See graph explanation on page 21.

5.2.4 Calamari by-catch

Calamari are retained as bycatch in the Spencer Gulf prawn fishery, although data have only been collected since 2002. There was a steady increase in calamari bycatch from 2002 to 2016 (Figure 42, although effort fluctuated considerably during this time (Figure 40). Mean catch between 2002 and 2016 was 26 tonnes, from a mean effort of 1998 days fished per year across that period. The highest catch, 43 tonnes, was reported for 2016, when effort was relatively low at 1945 days fished. There was no trend in the catch over the last five years of the time-series, and the mean over this time was within the reference range. Similar patterns were observed for effort.

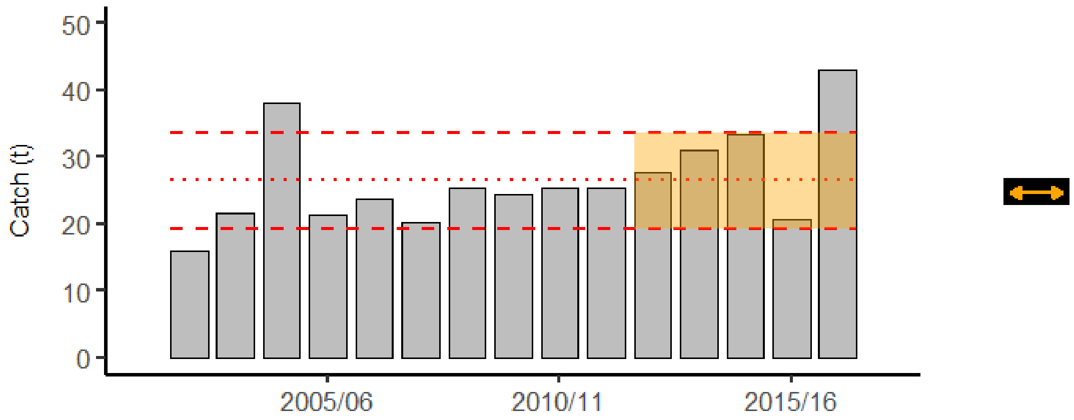

Figure 42. Catch (tonnes) of calamari in the Spencer Gulf from prawn fishery bycatch between 2002 and 2017. Effort is that of the prawn fishery (Figure 40). See graph explanation on page 21.

5.2.5 Sardine fishery

Long-term mean catch in the Spencer Gulf sardine fishery from 1999 to 2016 was 22,350 tonnes per year. Mean effort was 716 shots per year (Figure 43). Sardine catch in Spencer Gulf increased sharply between 1999 and 2005 when it peaked at 36,600 tonnes, before decreasing slightly but remaining relatively steady between 2006 and 2016 at ~20,000 to 30,000 tonnes. Effort also rose sharply from 1999 to a peak 1168 shots in 2005, before also decreasing slightly and then remaining relatively stable between 2006 and 2012 at ~800 to 900 shots. There was no trend in catch over the last five years of the time-series, and the mean over this time was within the reference range. The trend in effort for the last five years of the time-series was negative, with the mean over this time below the reference range. Employment peaked early in the fishery, before declining, and has been at or slightly below the long-term mean for the last 5 years. While output has been relatively steady for the last 12 years, the contribution to gross state product peaked in the final year for which data are available.

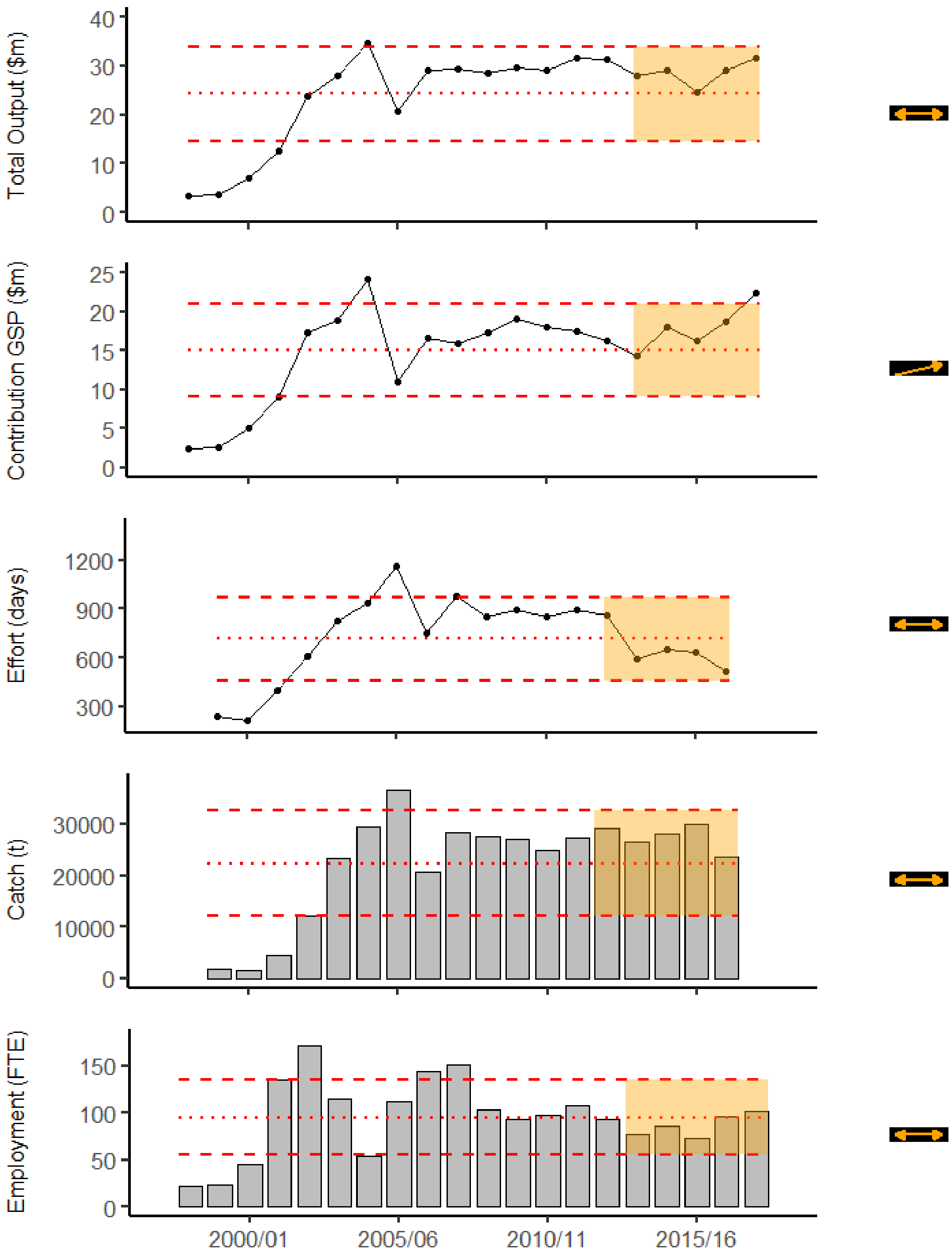

Figure 43. Employment, contribution to gross state product (GSP), total output, effort and catch in the Spencer Gulf Sardine fishery between 1997 and 2018. See graph explanation on page 21.

5.2.6 Charter boat fishery

Data for the Spencer Gulf charter boat fishery has only been collected since 2008. Catch was relatively high (~80,000 to 100,000 fish retained per year) between 2008 and 2012 before decreasing steadily between 2013 and 2016 (~50,000 to 60,000 fish retained per year; Figure 44). Effort followed a similar pattern, with ~1900 to 2000 trips per year recorded between 2008 and 2012, declining to ~1200 to 1400 trips per year between 2013 and 2016. Long-term mean annual catch was 72,209 fish retained, from a long-term mean effort of 1691 trips per year. The trend in catch over the last five years of the time-series was negative, with the mean over this time within the reference range. Similar patterns were observed for effort.

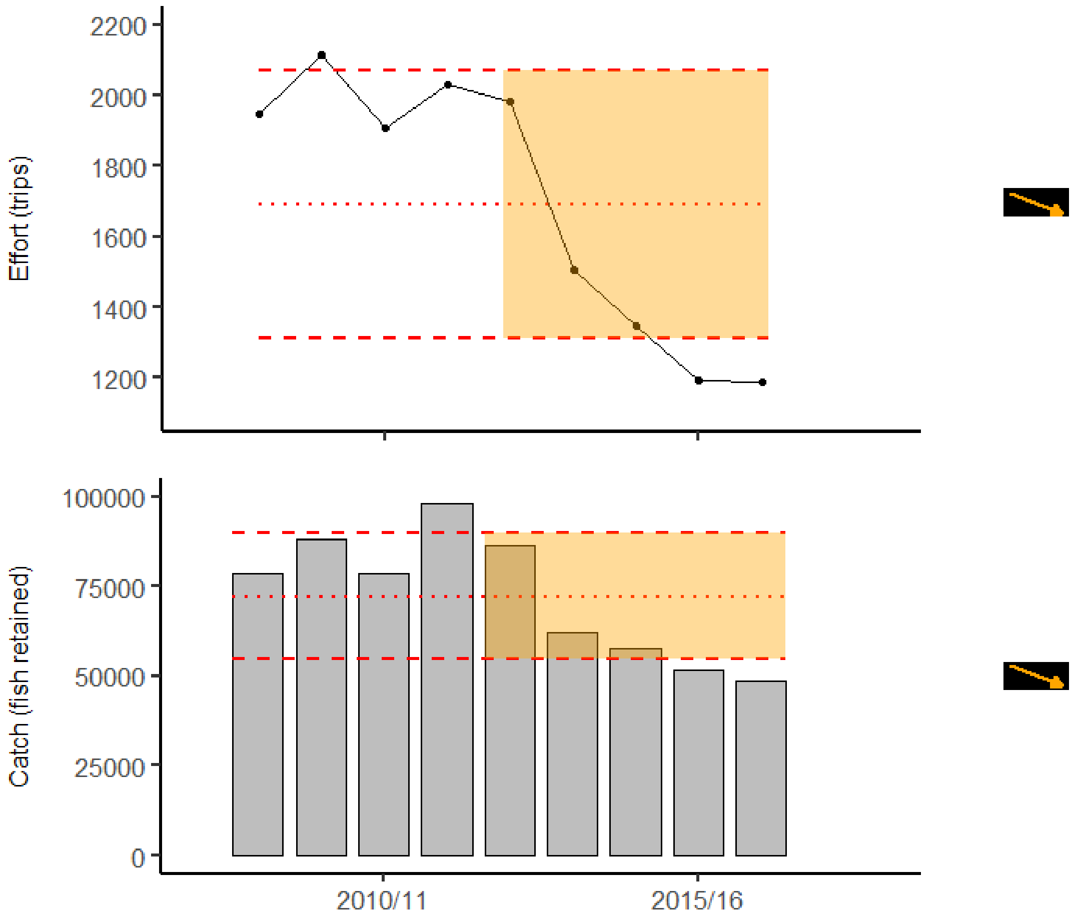

Figure 44. Catch (number of fish retained, bottom) and effort (number of trips, top) in the Spencer Gulf charter boat fishery between 2008 and 2016. See graph explanation on page 21.

5.2.7 Marine scalefish fishery

Catch and effort in the Spencer Gulf marine scalefish fishery have both steadily declined between 1997 and 2016. Long-term mean annual catch for that period was 1588 tonnes, from a mean effort of 29,137 days per year (Figure 45). Catch and effort peaked in 1997, when 2,777 tonnes were caught from 55,091 boat days. Lowest catch and effort occurred in 2013, with 903 tonnes caught over 19,078 boat days. There was no trend in catch over the last five years of the time-series, and the mean over this time was within the reference range. Similar patterns were observed for effort. Employment reached a minimum in 2013/14, and has slowly increased since. Total output has increased fairly steadily over the last 20 years, but contribution to gross state product has fluctuated considerably. Both reached a peak in the second last year for which data are available.

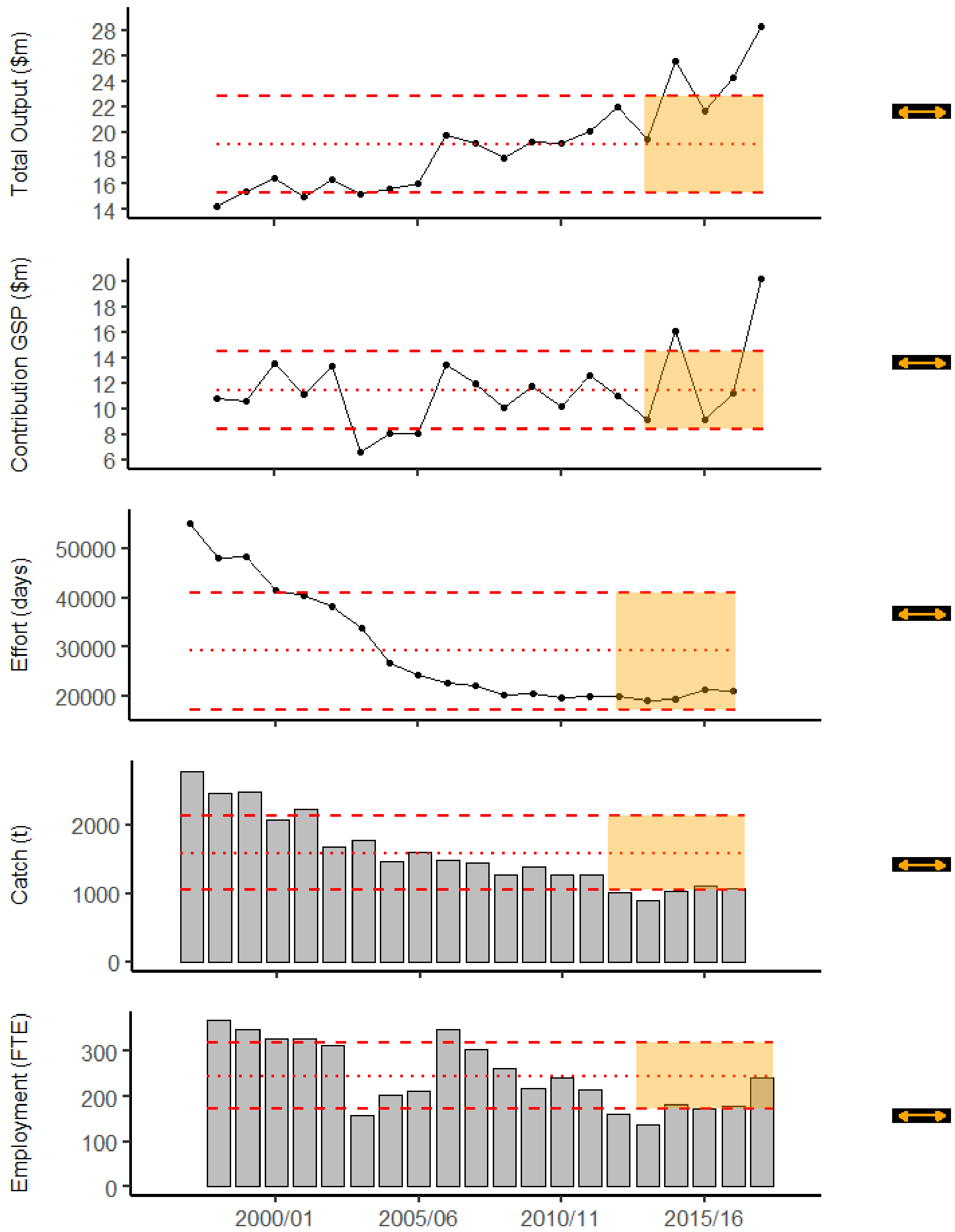

Figure 45. Employment, contribution to gross state product (GSP), total output, effort and catch in the Spencer Gulf marine scalefish fishery between 1997 and 2016. See graph explanation on page 21.

5.3 Aquaculture indicators

Aquaculture is an important industry in Spencer Gulf, with the majority of the State's production coming from the region. The major sectors are southern bluefin tuna, marine finfish (currently all yellowtail kingfish), mussels, oysters and abalone. The economic impacts of the industry are assessed on an annual basis for PIRSA Fisheries and Aquaculture by Econsearch (2018). While this assessment is carried out on a regional basis, these regions are terrestrially-based, and thus data for Spencer Gulf are split between the Eyre and Yorke Peninsula regions, both of which also include areas outside of the gulf. Currently it is only possible to reliably extract data for Spencer Gulf for tuna, finfish and mussels, all of which only occur in the gulf.

5.3.1 Tuna aquaculture

Aquaculture of southern bluefin tuna commenced off Port Lincoln in the early 1990's, based on the ranching of wild caught fish from the eastern Great Australian Bight. For the last 20-odd years, virtually the entire Australian quota of this species has been brought into aquaculture for grow-out prior to harvest. Over this period, fluctuations in production have almost entirely reflected changes in the Australian quota. Farming occurs entirely offshore from Port Lincoln. The value of the harvest declined sharply from a peak of $260-270 million in the early 2000's, and has fluctuated since with a slight downward trend (Figure 46). Much of this variation relates to the Australian dollar exchange rate, particularly with the Japanese yen, as the majority of the harvest is exported (Econsearch 2018). Employment (direct and indirect) has also declined relatively steadily since the first year that figures are available. The trend in employment (FTE) in Tuna aquaculture over the last five years of the time-series was neutral, and the mean over this time was within the reference range. Similar patterns were observed for processed weight ('000 kg), and total output ($m). The trend in farm gate value ($m) declined over this time, with the mean within the reference range. A similar pattern was observed for contribution to GSP ($m).

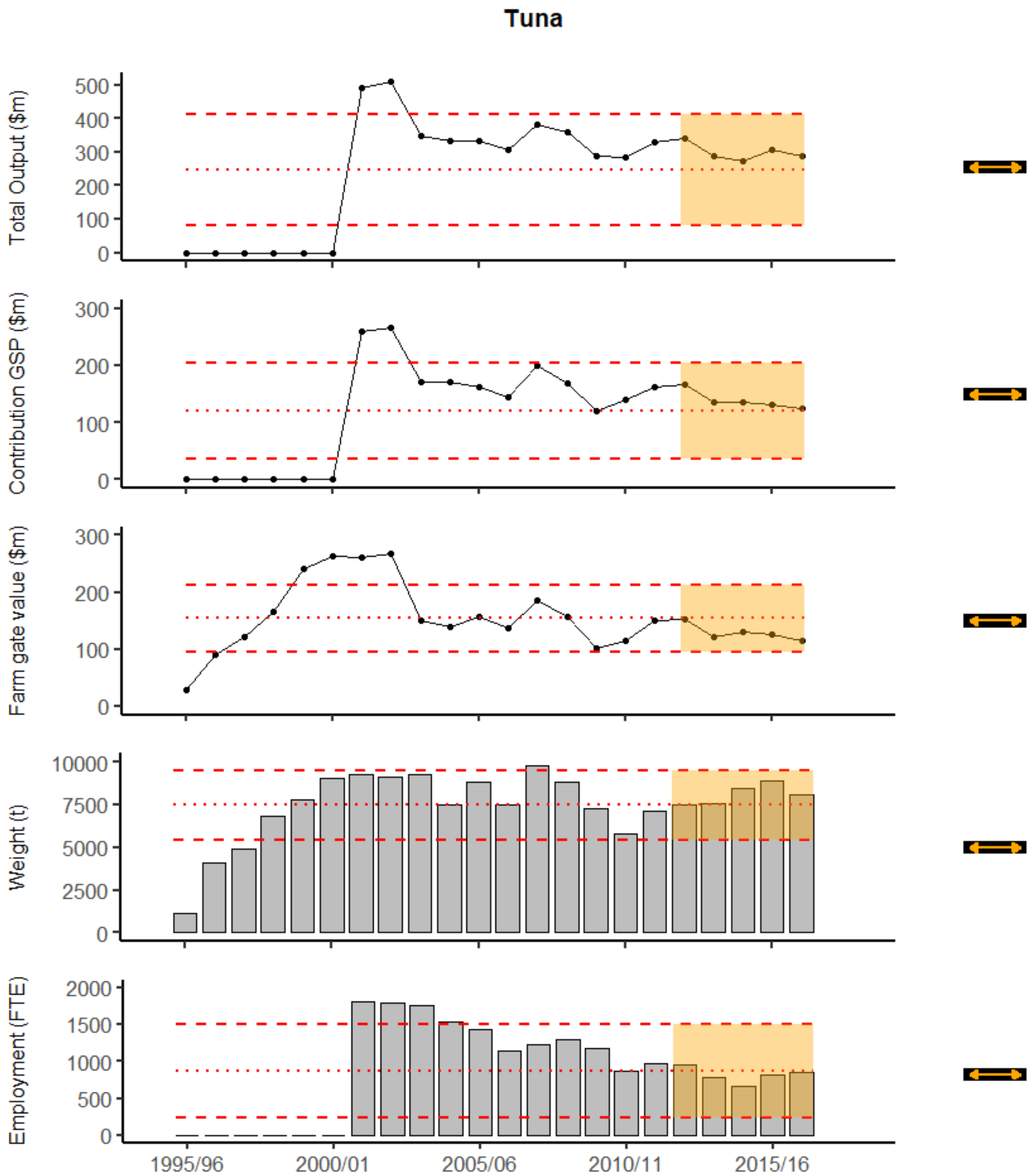

Figure 46. Southern bluefin tuna industry production (processed weight), value and employment. Contribution to GSP reflects Farm Gate Value plus any value add prior to export, whereas Total Output includes all flow-on economic impacts. Source: Econsearch (2018). See graph explanation on page 21.

5.3.2 Finfish aquaculture

Currently the finfish aquaculture industry in Spencer Gulf focuses exclusively on the production of yellowtail kingfish. Farming is currently focussed around Boston Bay, with a planned expansion back into Fitzgerald Bay, where the industry was focussed in its early days. The production and value of this sector has fluctuated considerably, due largely to fish health issues experienced from about 2011 to 2015. With these issues being largely resolved, production has increased steadily in the last few years, and industry plan to continue increasing over the next few (Figure 47). Total employment has followed a similar pattern. The trend in employment (FTE) in finfish aquaculture over the last five years of the time-series was neutral, and the mean over this time was within the reference range. Similar patterns were observed for processed weight (‘000 kg), farm gate value ($m), contribution to GSP ($m) and total output ($m).

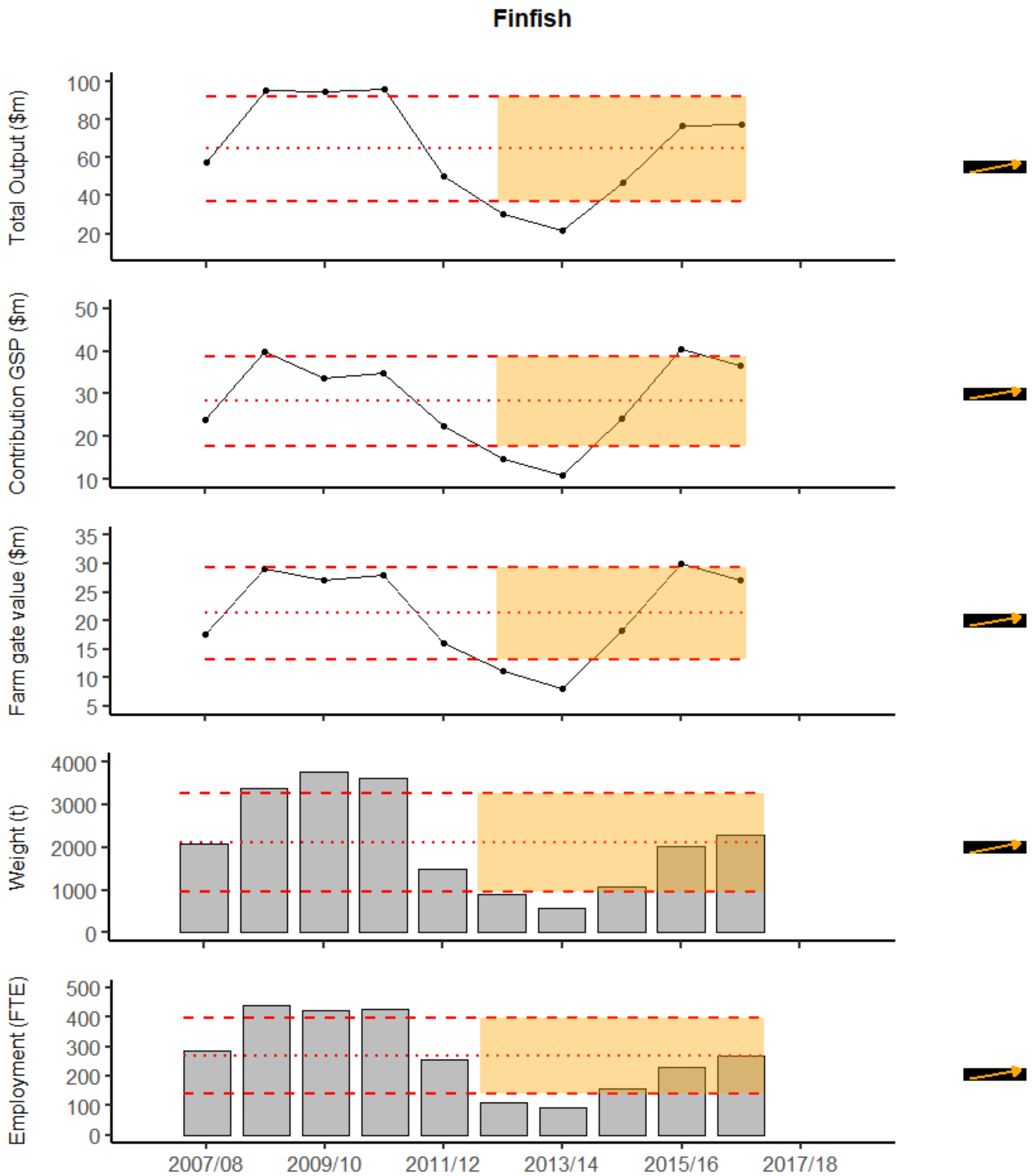

Figure 47. Marine finfish industry production (processed weight), value and employment. Contribution to GSP reflects Farm Gate Value plus any value add prior to export, whereas Total Output includes all flow-on economic impacts. Source: Econsearch (2018). See graph explanation on page 21.

5.3.3 Mussel aquaculture

The mussel industry in South Australia is also focussed around the Port Lincoln region. Production increased rapidly in the first ten years of the industry, then remained steady for almost a decade before another increase in 2015/16. Value has largely followed production, with the majority of the harvest consumed domestically. Employment increased steadily for the first eight years for which data are available, and then decreased sharply in 2010/11 (Figure 48). Since then, it has remained relatively steady. The trend in employment (FTE) in mussel aquaculture over the last five years of the time-series was neutral, and the mean over this time was within the reference range. The trend in processed weight ('000 kg) was positive, with the mean over this time within the reference range. A similar pattern was observed for farm gate value ($m) and contribution to GSP ($m). The trend in total output ($m) was neutral, although the mean over the last five years of the time-series was greater than the reference range.

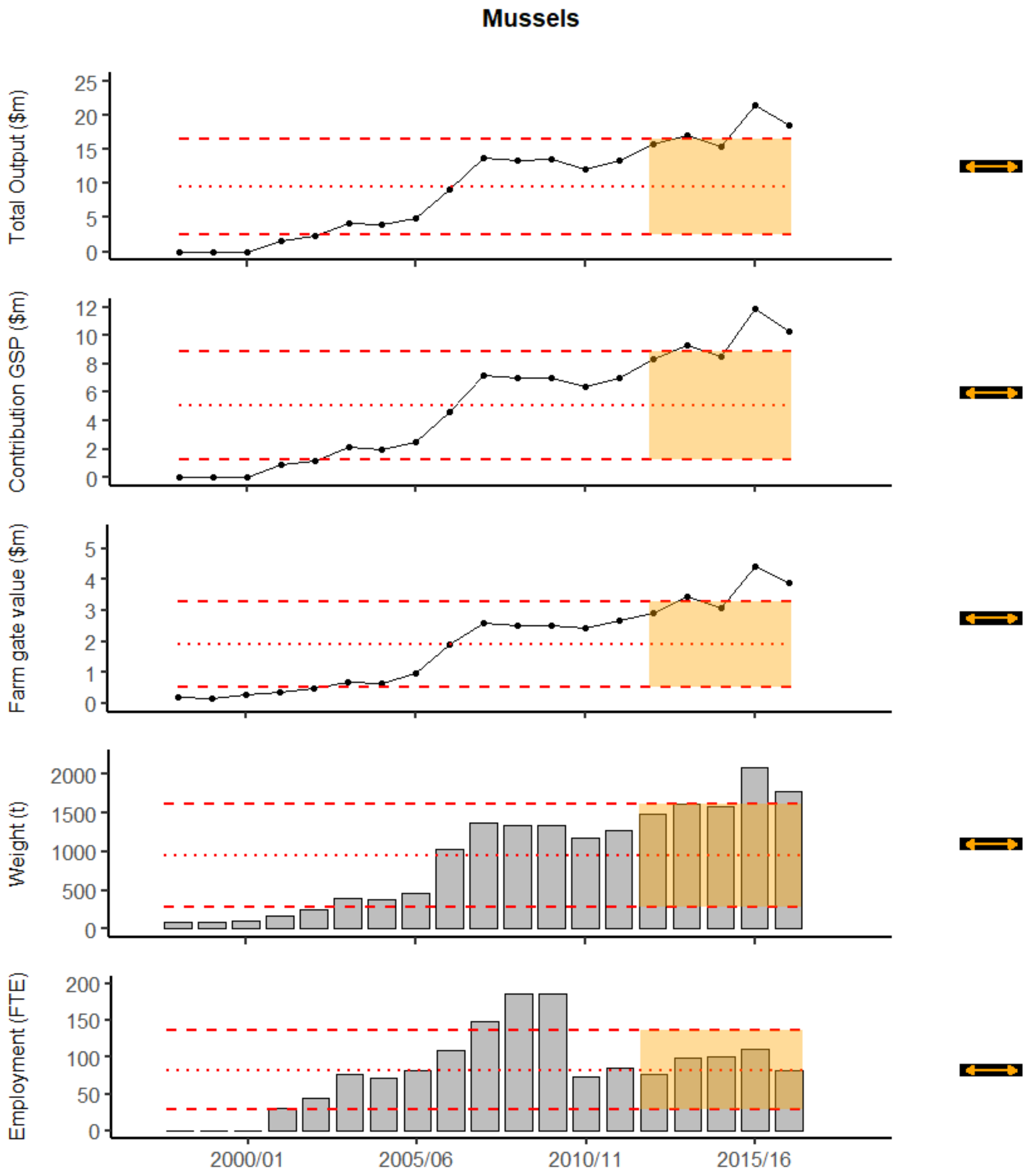

Figure 48. Mussel industry production (processed weight), value and employment. Contribution to GSP reflects Farm Gate Value plus any value add prior to export, whereas Total Output includes all flow-on economic impacts. Source: Econsearch (2018). See graph explanation on page 21.

5.4 White shark ecotourism indicators

The white-shark cage-diving industry began in the late 1970s in waters off the Eyre Peninsula in South Australia, and is the only ecotourism industry for which good data could be located. The industry has been restricted in operations to the Neptune Islands Marine Park located 60–70 km south of Port

Lincoln since 2002, with most cage-diving activities focussed at the North Neptune Island group. The locality is the only place where cage-diving with white sharks is permitted in Australia.

Data on white shark tourism have been collected since 1999. The number of days of operation was obtained from logbook entries recorded by the cage-diving industry but does not account for the number of operators present, i.e. a day of operation was counted as 1 regardless of whether there were one, two, or all three operators present. Three logbook datasets were obtained and combined to obtain the number of days of operation per year: (1) paper logbook curated by the CSIRO (July 1999–June 2013); (2) electronic logbook curated by SARDI – Aquatic Sciences (July 2013–June 2016); and (3) electronic logbook curated by Flinders University (July 2016– June 2018). The number of passengers was obtained from the Department for Environment and Water (DEW). The number of passengers from one of the three operators was not reported for July 2008 to June 2011, leading to the total number of passengers for these three financial years being underestimated. The value of the cage-diving industry was obtained using estimates from Huveneers et al. (2017).

In 2007, the industry expanded from two to three operators and the mean annual number of days when tours operated rose from 116 (1999/2000–2006/07) to 257 (2007/08–2017/18) (Figure 49). The total number of passengers increased from ~5,300 between July 2010 and June 2012 to ~8,500 between July 2012 to June 2018, with a peak of 10,322 in 2015–16 (Figure 49). Overall mean ± standard error is 8,156 ± 590 passengers. The value of the cage-diving industry across the whole period for which data are available is $5,843,321 ± 310,318, and peaked in 2015–16 at $7,893,409 (Figure 49). Although the value of the industry followed a similar trend to the number of passengers, it did not increase as much as the number of passengers did.

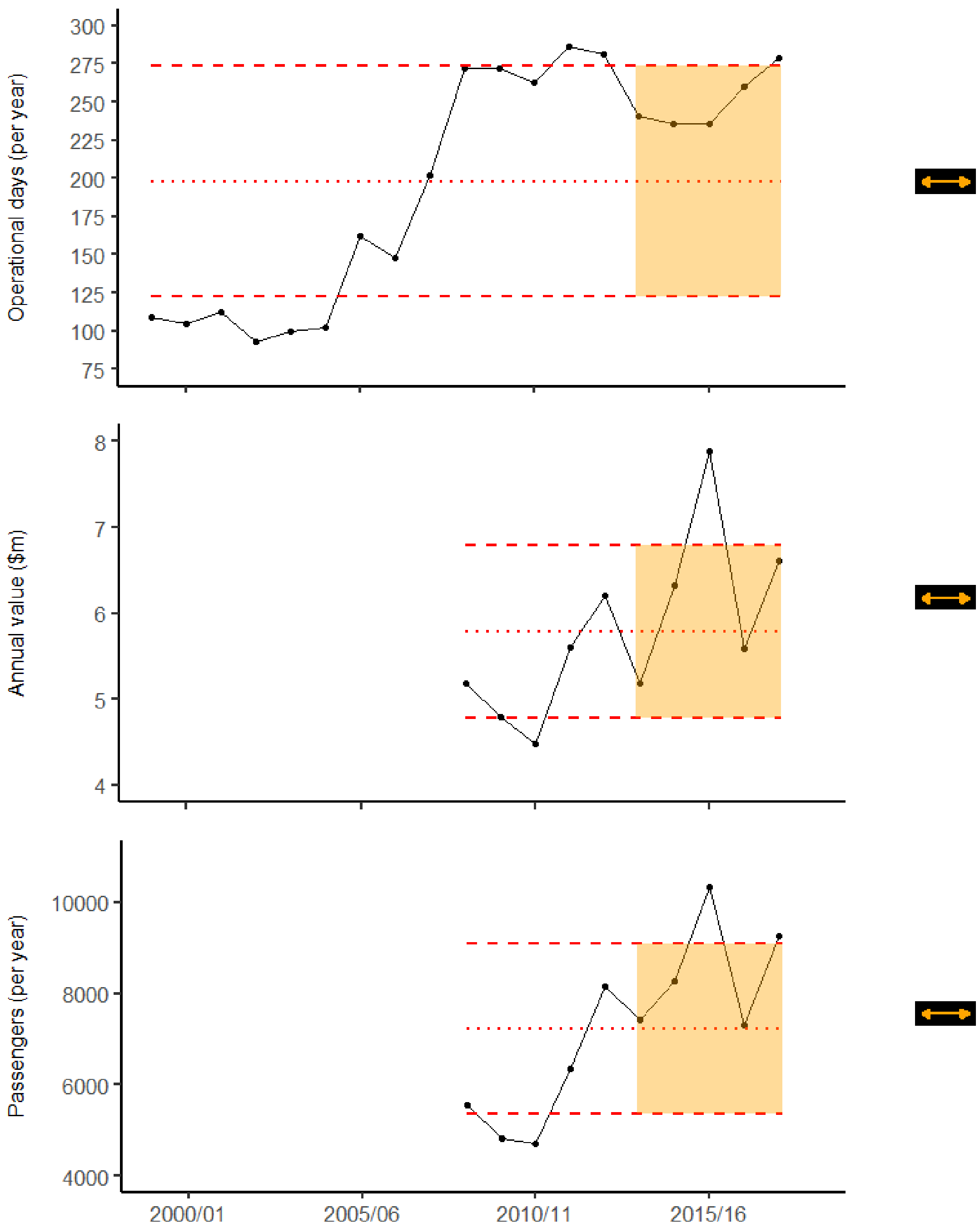

Figure 49. The number of days per year on which white shark cage diving operators visited the Neptune Islands (top), annual value of the industry (middle) and number of passengers (bottom). See graph explanation on page 24.

6 Ecological assets

6.1 Iconic species indicators

6.1.1 Giant Australian cuttlefish (*Sepia apama*)

The giant Australian cuttlefish (*Sepia apama*) forms a unique breeding aggregation each winter around Point Lowly, near Whyalla (Steer et al. 2016). This is the only known breeding aggregation of cuttlefish in the world, and has become a major drawcard for tourists. Annual estimates of abundance and biomass are available from 1998 to 2018, with gaps from 2002 to 2007 (Figure 50). Between 2011 and 2013, the breeding population experienced a major decline, leading to concern over the continued survival of the aggregation. However, numbers started to recover in 2014, and it is now thought likely that the population naturally experiences large fluctuations. There was no trend in cuttlefish biomass over the last five years of the time-series, and the mean over this time was within the reference range. However, the trend in cuttlefish abundance was positive, with the mean over this time within the reference range.

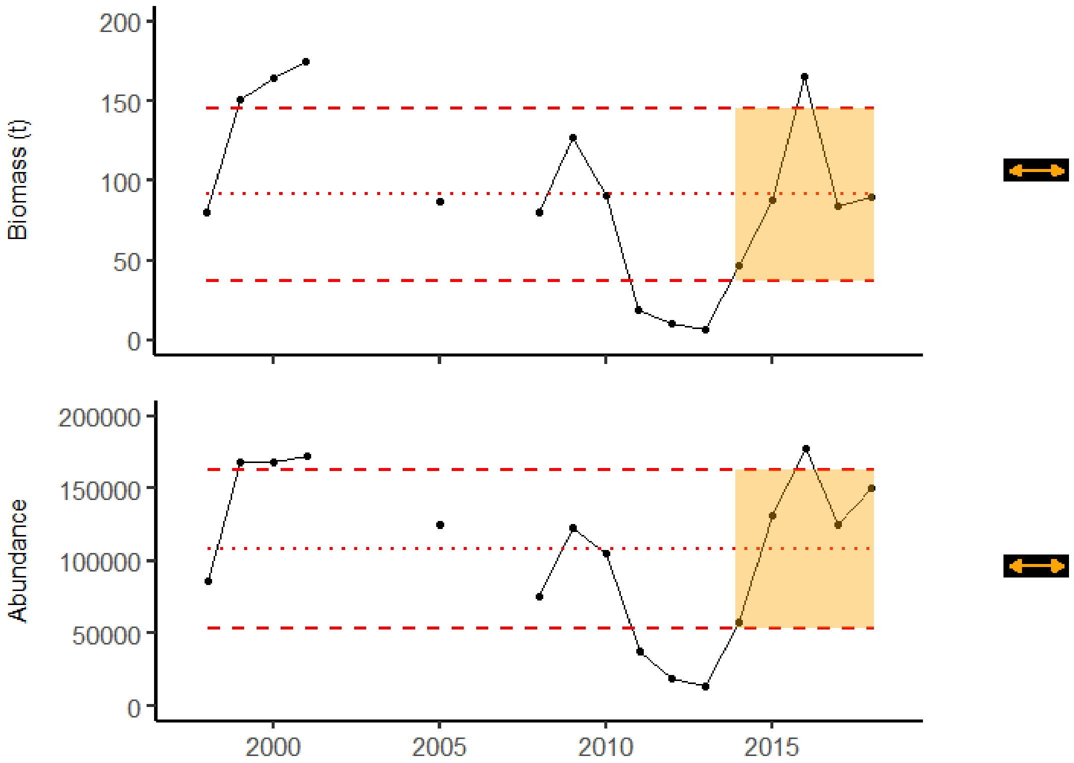

Figure 50. Cuttlefish (*Sepia apama*) abundance and biomass at the Point Lowly spawning grounds. See graph explanation on page 21.

6.1.2 Shorebirds

BirdLife Australia collate data on surveys of shorebird abundance in 9 survey areas in Spencer Gulf (Figure 51), although as this relies on volunteers to undertake the surveys, data may be patchy both spatially and temporally. Data are available for either $500 or $1100 per survey area (BirdLife Australia 2019), and thus have not been obtained to present here. Some data are also presented in Carpenter & Langdon (2014), although not in a time-series format.

Figure 51. Google Earth image showing location of shorebird survey areas for which counts are available from BirdLife Australia.

6.1.3 Australian sea lions

There are a number of Australian sea lion (*Neophoca cinerea*) colonies and haul-outs in south-western Spencer Gulf, with the largest being at Dangerous Reef (Figure 52). This is Australia's rarest pinniped species, and is restricted to South Australia and the south-west of Western Australia (Goldsworthy et al. 2017). In 2014/15, it is estimated that only 2,500 pups were born in the state, and this number is declining. In Spencer Gulf, 802 pups were produced, and births are declining at ~ 0.4% per year. Individual populations are small, with little movement between them, making the species even more vulnerable to impacts. The best data for this species in Spencer Gulf are for Dangerous Reef, and so we also present figures for just this colony (Figure 53). At Dangerous Reef, there was a generally increasing trend in pup production until a peak in 2006 and 2007, followed by a decline (Goldsworthy et al. 2015). No data is available beyond 2015.

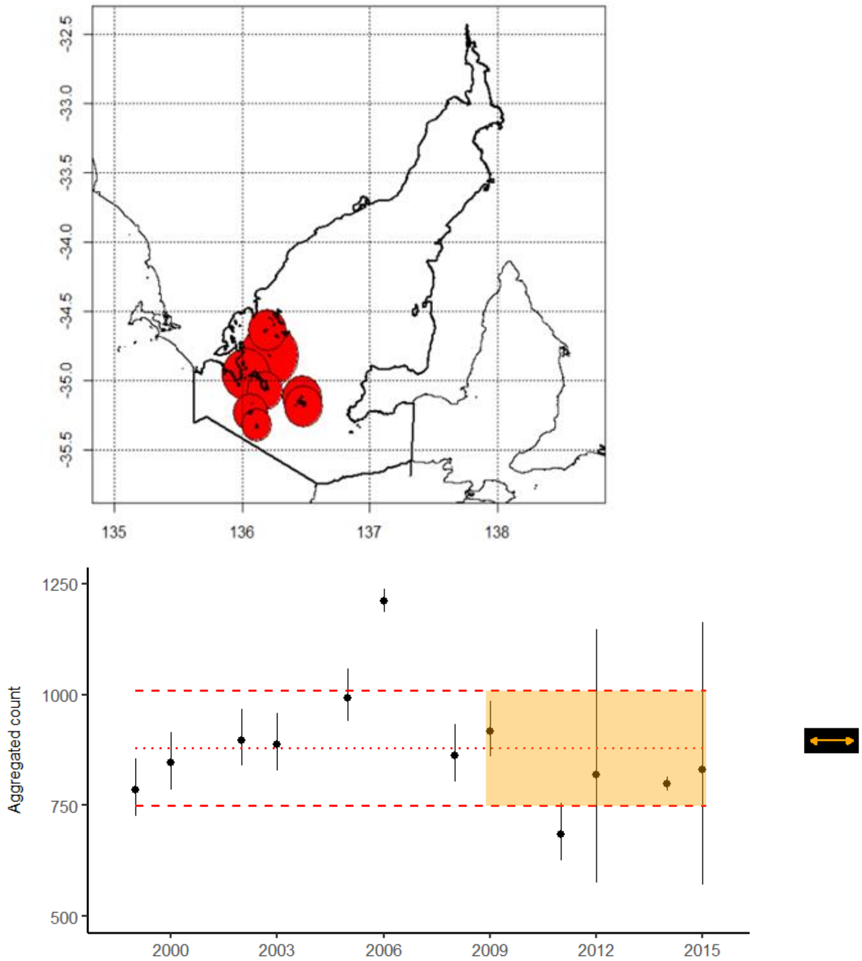

Figure 52. Location of Australian sea lion colonies and haul-outs (top), and trends in pup abundance (bottom) in Spencer Gulf. In the bottom panel, points represent the observed counts; the black vertical line around each point is the median posterior predictive abundance. Source: Goldsworthy et al. (2017). See graph explanation on page 24.

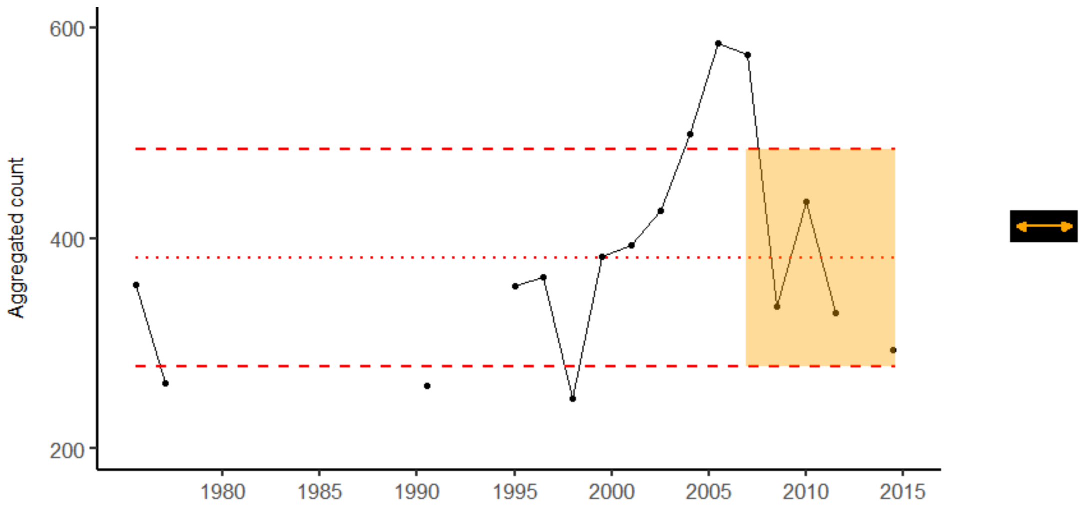

Figure 53. Pup abundance based on direct counts for the Dangerous Reef ASL colony. Points represent the observed counts. Source: Goldsworthy et al. (2015). See graph explanation on page 21.

6.1.4 Long-nosed fur seal

The long-nosed fur seal occurs across southern Australia, as well as in New Zealand. It was hunted extensively in the early 1800's, and it is only in the last few decades that populations have shown strong recovery. In Spencer Gulf, the main aggregations of these seals are at the Neptune Islands and Liguanea Island, where pup production has remained almost static since 2005 (Figure 54), following large increases in previous years (Shaughnessy et al. 2015, Goldsworthy et al. 2017).

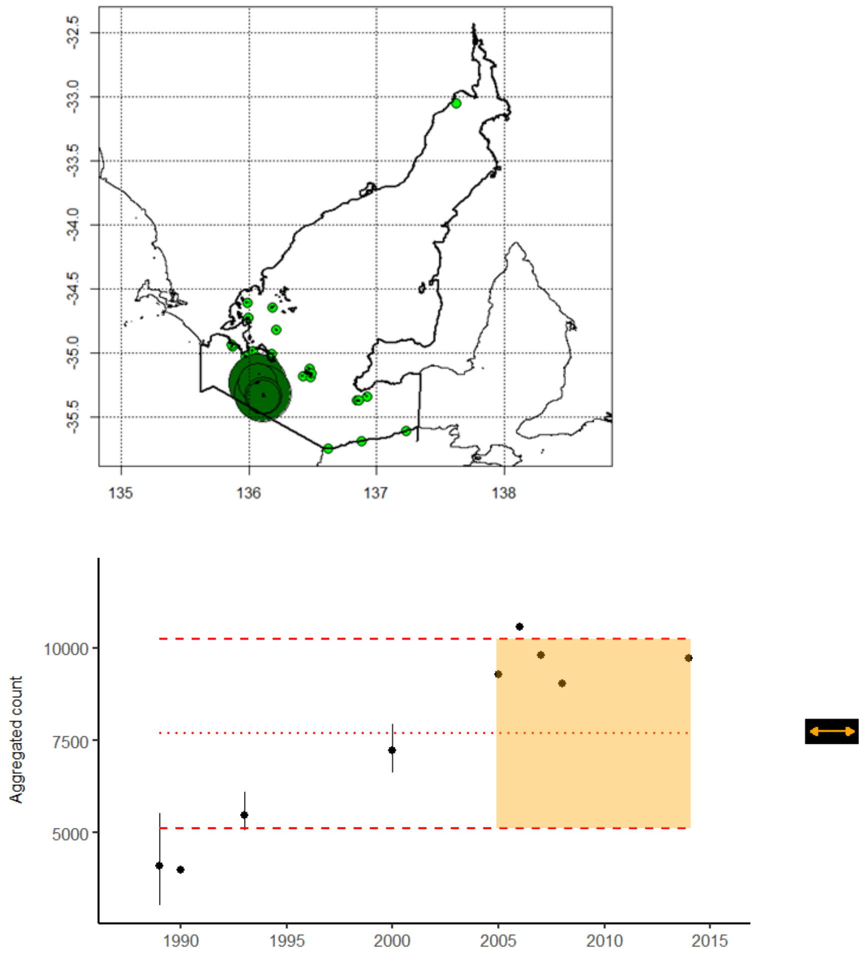

Figure 54. Location of long-nosed fur seal colonies and haul-outs (left), and trends in pup abundance (right) in Spencer Gulf. In the right panel, points represent the observed counts; the black vertical line around each point is the median posterior predictive abundance. Source Goldsworthy et al. (2017). See graph explanation on page 21.

6.2 Habitat indicators

6.2.1 Seagrass

Seagrasses are the major shallow water structurally complex habitat in Spencer Gulf, and are estimated to cover ~5,000 km^2 of the gulf, primarily in a band around the edges (Gillanders et al. 2015). Twelve species occur in the gulf, with the main habitat forming species in the genera *Posidonia* and *Amphibolis*, although *Zostera* and *Halophila* species are also present (Irving 2014). Seagrasses form important habitats for numerous other species, including a number of recreational and commercial importance, as well as threatened species such as syngnathids (Tanner and McDonald 2014), but have been subject to loss in several areas of the gulf (Irving 2014). There are no long-term records of seagrass cover in the gulf, and total cover is still to be fully mapped due to the difficulties of covering such a large area underwater, as remote sensing of deeper areas is problematic (Gillanders et al. 2015). There are also no good long-term records of cover at individual sites. However, the South Australian EPA recently commenced a program of Aquatic Ecosystem Condition Reporting that includes numerous sites in Spencer Gulf, many dominated by seagrasses. This program aims to conduct rolling surveys across the state with a return time of ~5 years. As part of this, Lower Spencer Gulf was surveyed in 2010 (Gaylard et al. 2010) and 2016, while the upper gulf was surveyed in 2012 (Noble et al. 2012) and 2018.

In addition, in response to localised decline in cover seen in Boston Bay in 2016, a subset of sites in this region were also surveyed in 2018. In lower Spencer Gulf, statistically significant declines in seagrass cover were only seen around the southern end of Boston Bay, with decline ranging between 8% and 35% cover (Figure 55). Further north in the Boston Bay region there were significant increases up to 30%. From 2016 to 2018, the largest declines in this region were in Peake Bay (25-30%), although Spalding Cove also continued to decline significantly (~9%) (Figure 56). While there were some large changes in other areas, particularly around the Sir Joseph Banks group of islands, these reflected at least in part patchy habitats, and were thus not statistically significant. Declines in upper Spencer Gulf were more substantial, with seven sites that declined significantly between 2012 and 2018 (Figure 55). The largest decline in upper Spencer Gulf was 58% (from 87% to 29%) at False Bay, with additional large declines at Black Point (60 % to 14%) and Miranda (78% to 38%). The largest increase was only 19%, in the vicinity of the Whyalla OneSteel plant.

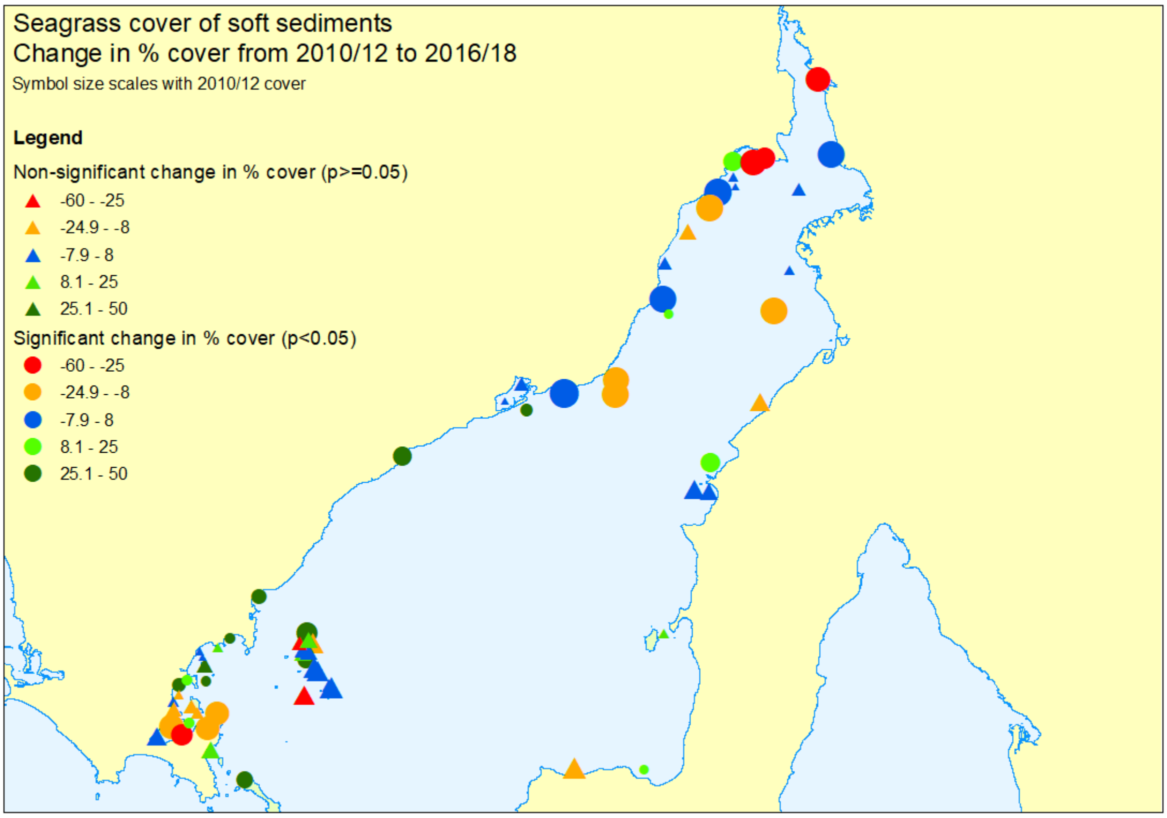

Figure 55. Map of seagrass change in Spencer Gulf between 2010 and 2016 (below the black line) or 2012 and 2018 (above the line). Sites that changed significantly according to ANOVA are indicated by circles, with non-significant changes indicated by triangles. Symbol size scales with initial cover, and colour coding indicates extent of change (changes are absolute change in percent cover of soft sediments only).

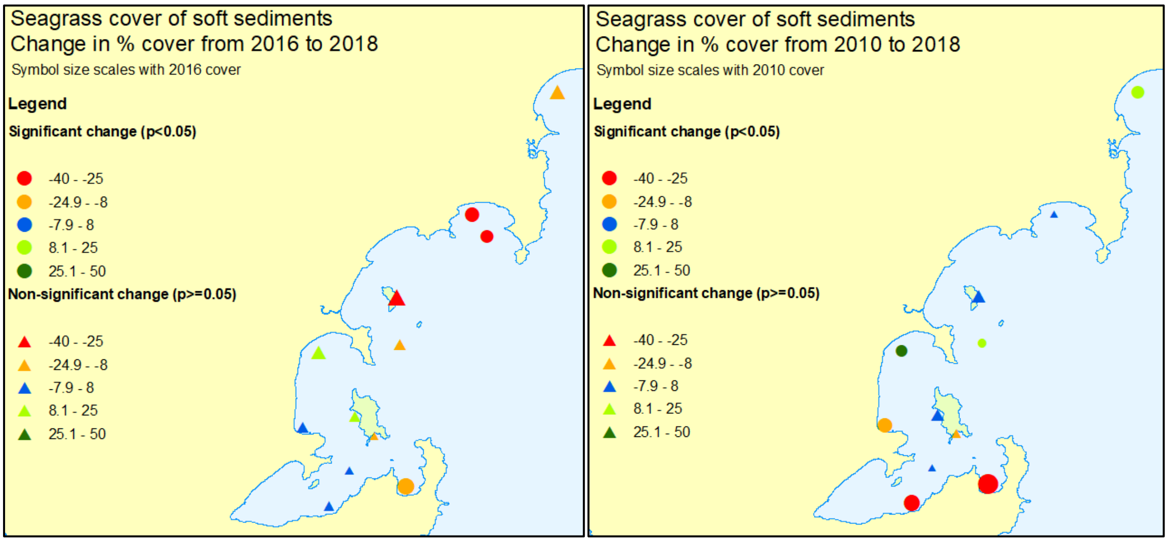

Figure 56. Seagrass change in Boston Bay from 2016 to 2018 (left) and 2010 to 2018 (right). See Figure 56 for change from 2010 to 2016.

6.2.2 Macroalgae

The EPA Aquatic Ecosystem Condition Reporting discussed above for seagrasses is also the only ongoing program of monitoring that collects data on macroalgal cover of reefs. Only five sites had sufficient reef cover to meaningfully assess change over time, all of which were located in southern Spencer Gulf (Figure 57). The three sites on the western side of the gulf did not change significantly, while one on the eastern side increased from 0 to 37% cover, while the other decreased from 48% to 0%. Additional reef sites were added to the program in 2016, although no data on change is yet available from these sites.

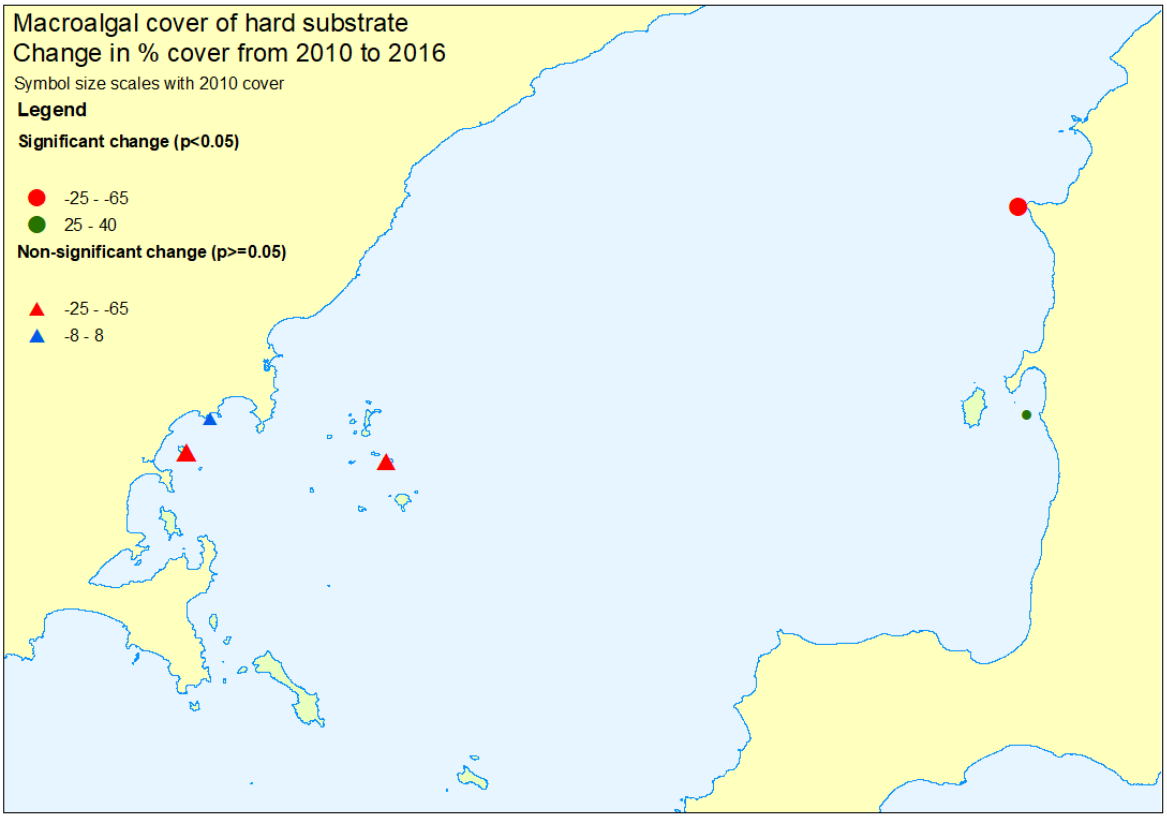

Figure 57. Map of macroalgal change in Spencer Gulf between 2010 and 2016. Sites that changed significantly according to ANOVA are indicated by circles, with non-significant changes indicated by triangles. Symbol size scales with initial cover, and colour coding indicates extent of change (changes are absolute change in percent cover of hard substrate only).

6.2.3 Mangrove and saltmarsh

To determine changes in mangrove and saltmarsh vegetation through time in Spencer Gulf, a shapefile for the area of interest was created in ArcGIS (ESRI 2018) and used to extract spatial data on the presence and absence of saltmarshes and mangroves from DEW's landcover dataset (using the most likely layers) (https://data.environment.sa.gov.au/Land/Data-Systems/SA-Land-Cover/Pages/default.aspx). This dataset classifies land cover across the whole of South Australia from 1987-2015 and is broken into 6 epochs (1987-1990, 1990-1995, 1995-2000, 2000-2005, 2005-2010 and 2010-2015). A more detailed description of how the most likely layers were generated can be found in Foster et al. (2019) and Willoughby et al. (2017). The most likely data layer was clipped to a coastal buffer of 5 km from the mean high-water mark to reduce the effect of incorrect classifications of mangrove and saltmarsh further inland. The cropped most-likely layers were then converted into binary rasters for both mangrove and saltmarsh within the Spencer Gulf area of interest, where cells with a value of 1 indicated presence of the focus vegetation and cells with a value of 0 represented all other vegetation types. This work was done in R (R Core Team 2018), using packages 'rgdal', 'raster', 'sp' and 'rastervis' (Pebesma and Bivand 2005, Bivand et al. 2018, Hijmans 2019, Lamigueiro and Hijmans 2019). The area covered by mangrove and saltmarsh in each epoch was then calculated by summing the number of presence cells in the area of interest. Area estimates take account of the un-projected (geographic) coordinate system of the dataset using the supplementary scaled grid raster provided by DEW (https://data.sa.gov.au/data/dataset/sa-land-cover/resource/40a84a12-031e-4155-b2a3-b62e5c1424d8).

From here the binary rasters were analysed using a function in R that compared change from one time period to the next. Change was classified using 4 categories:

- No change - present: cell class indicated presence at both adjacent time periods (e.g. mangrove was present in both time periods).
- No change – absent: cell class indicated absence at both adjacent time periods (e.g. saltmarsh was absent in both time periods)
- Gain: cell class changed from absent to present between adjacent time periods.
- Loss: cell class changed from present to absent between adjacent time periods.

Area of presence and areal gain/loss values were then documented for each vegetation class at each time period.

The landcover data indicate that there have been slight increases in the aerial extent of both habitats around Spencer Gulf since 1987, with an ~8% increase for mangroves and a 6% increase for saltmarsh (Figure 58). The majority of this increase occurred early in the time-series, especially for saltmarsh, which has remained essentially constant since 1990-95 except for a small dip in 2005-10. The trend in mangrove area over the last 25 years of the time-series was positive, and the mean over this time was within the reference range. The trend in saltmarsh area was neutral, with the mean within the reference range. It must be noted however, that there are large uncertainties in the accuracy of the classification of coastal vegetation communities in this dataset. External validation of the dataset carried out by Foster et al. (2019) indicates that misclassification of mangrove and saltmarsh was common, and relatively small changes in area from one epoch to the next (as are shown in Figure 58) should be interpreted cautiously.

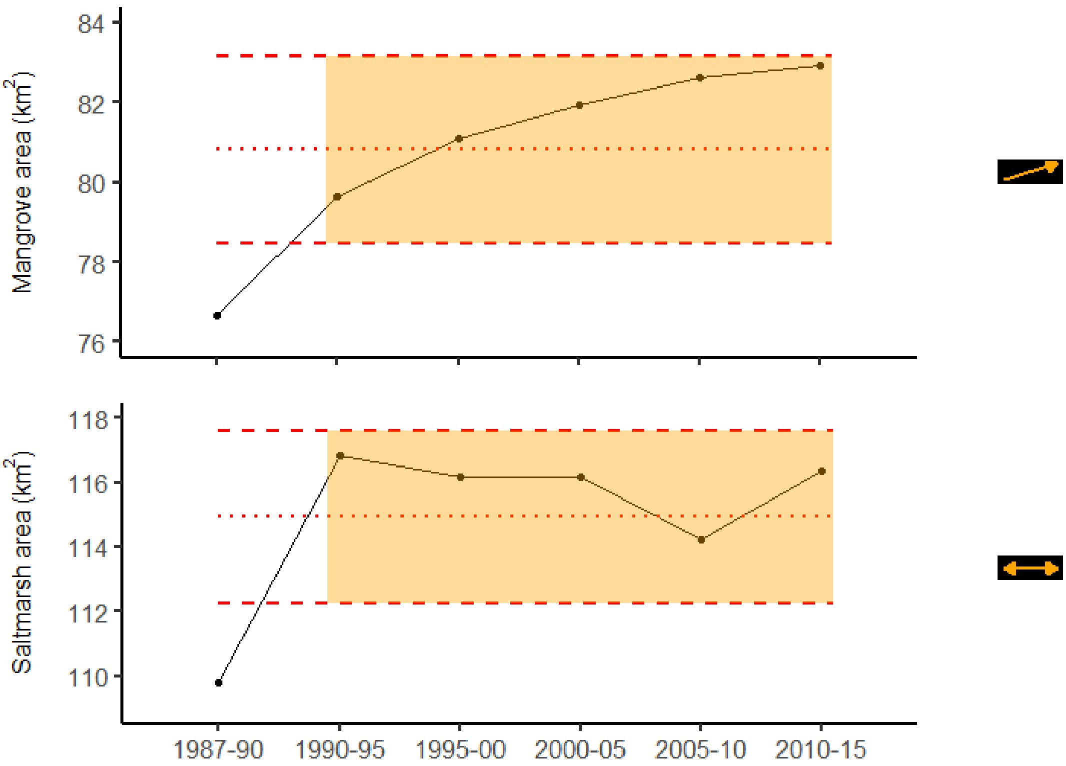

Figure 58. Changes in aerial extent of mangroves and saltmarsh based on analysis of Landsat imagery. See graph explanation on page 21.

6.3 Ecosystem indicators

An ecosystem model has been developed for Spencer Gulf that incorporates all the main trophic groups present in the gulf, as well as fisheries catches and aquaculture inputs (Gillanders et al. 2015). This model helps to summarise the energy flows through the gulf's food web, and can be used to help understand how different fishing scenarios or other manipulations of the ecosystem can flow through the entire food web. The model produces several ecosystem indicators that may be of use for understanding changes over time. The first of these is simply total catch across all fisheries in terms of biomass. The second is the mean trophic level of the catch, which indicates how many steps energy has taken through the food web before it is harvested. As fisheries become over-exploited, there is a tendency to move from high-trophic level species to lower trophic level species, and thus a decrease in the mean trophic level of the catch may provide an early warning of system-wide over-fishing. The third is the fishing in balance index (FIB), which indicates whether catches increase as trophic level decreases as expected based on trophic transfer efficiencies (when FIB~0), or if they deviate from this. Finally, Kempton's Q biodiversity index indicates how diverse the overall catch is. These indices for a model covering the period 1991-2010 are presented below (Figure 59). The main fluctuations over time are related to the development of the sardine fishery, which makes the FIB in particular difficult to interpret. Despite the development of this relatively low trophic level fishery during the period covered by the model, the mean trophic level of the catch actually increased over time. Extending the time-series requires more recent data on fishery catches to be incorporated, and the model to be rerun.

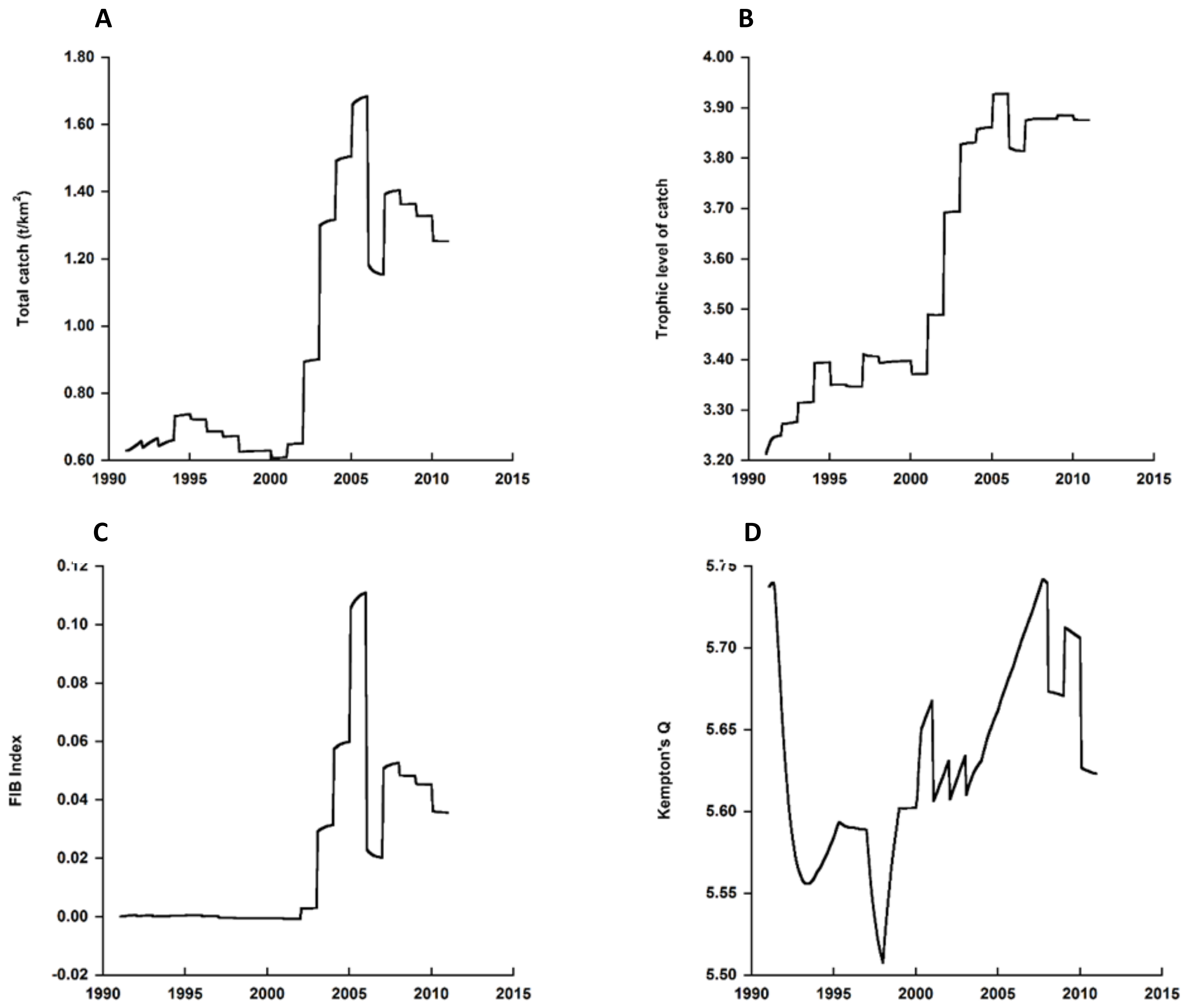

Figure 59. Ecosystem indicators calculated from the Spencer Gulf Ecosystem (Ecopath with Ecosim) model for the period 1991 to 2010. A. Changes in the landings of all fleets (total catch), B. Mean trophic level of the catch, C. Fishing in Balance (FIB) index, and D. Kempton's Q biomass diversity index. Reprinted fromSource: Gillanders et al. (2015).

7 Water quality

7.1 Pollution indicators

The Commonwealth Department of Environment and Energy provides the community, industry and government with free information about substance emissions in Australia through the National Pollutant Inventory. Data available include annual loads of ecologically important nutrients discharged into water by wastewater treatment plants (WWTP) and heavy industry. For Spencer Gulf, the OneSteel steel works is the only heavy industry which has reported nutrient discharges. Fluctuations in the availability of nitrogen and phosphorus can significantly influence marine primary productivity and potentially affect ecosystem dynamics.

7.1.1 Ammonia

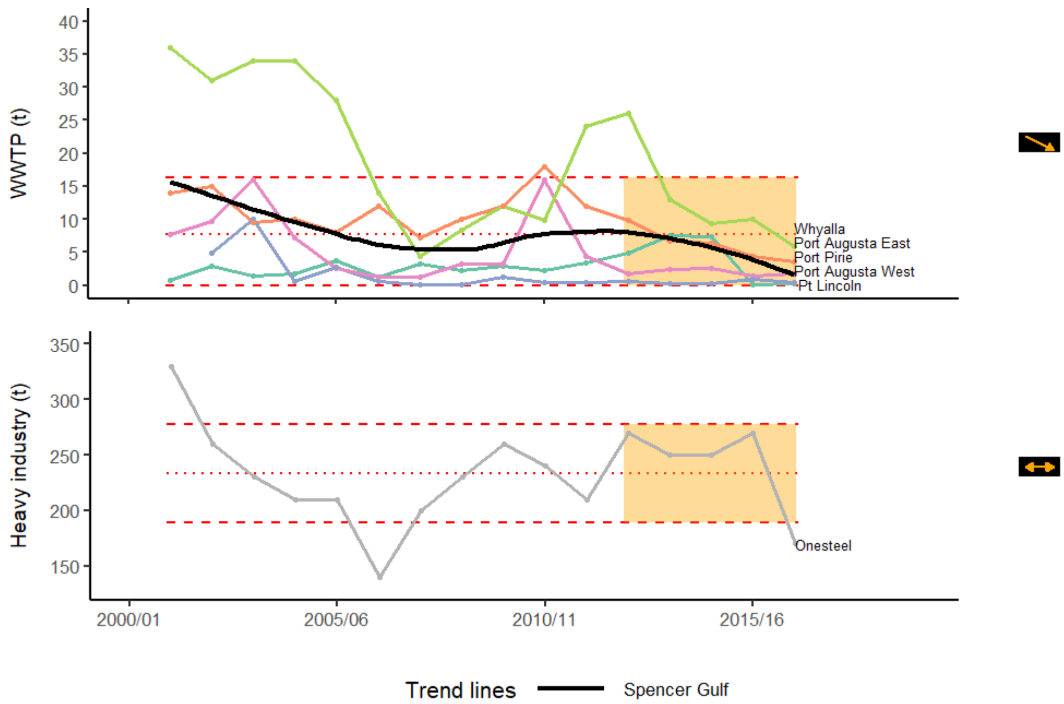

Figure 60. Annual load of ammonia discharged into the marine environment from Spencer Gulf Waste Water Treatment Plants (WWTP – black line shows mean over all WWTPs) and heavy industry (OneSteel). See graph explanation on page 24.

Although there was some variation between waste water treatment plants (WWTPs), the overall mean input of ammonia decreased over the 17 year data set from ~20 t to <5 t (Figure 60). The total load across all WWTPs discharging into Spencer Gulf in 2016/17 was 11.67 t. The load from the OneSteel steelworks in Whyalla exceeds that from all WWTPs by a factor of >10, and while at a near all-time low of 170 t in 2016/17, was a near all-time high levels of 250-270 t in the previous 4 years.

7.1.2 Total nitrogen

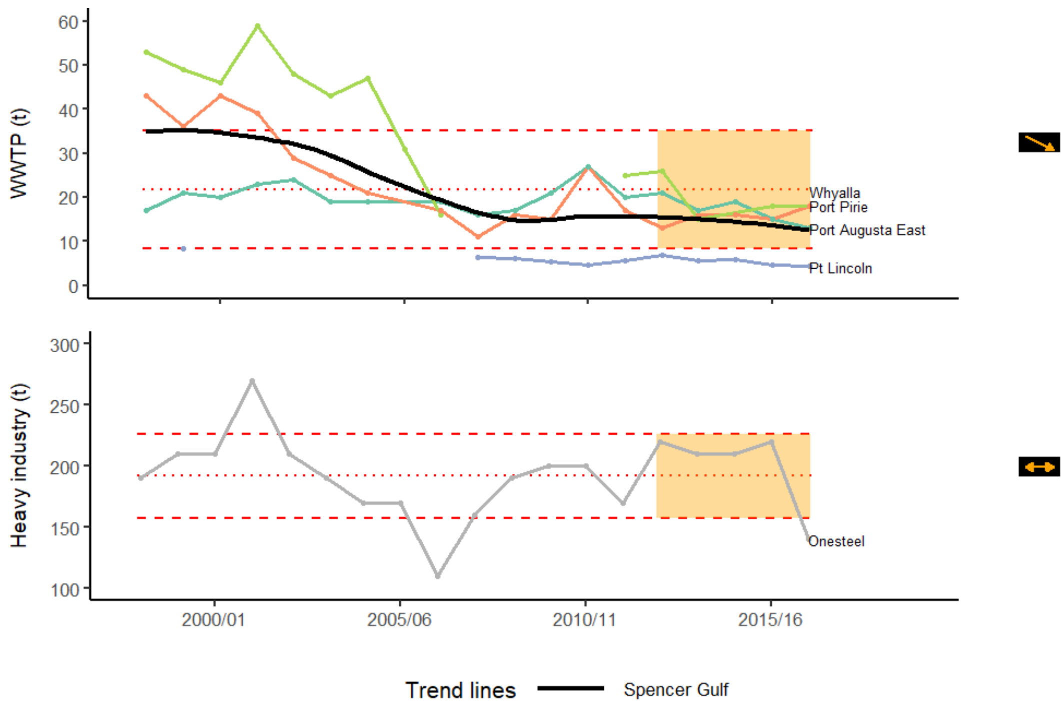

Figure 61. Annual load of total nitrogen discharged into the marine environment from Spencer Gulf Waste Water Treatment Plants (WWTP – black line shows mean over all WWTPs) and heavy industry (OneSteel). See graph explanation on page 21.

Total nitrogen inputs from WWTPs also declined fairly steadily over the first ten years of available data, from ~35 t per plant to ~15 t per plant, but then stabilised around 2008/9 (Figure 61). Total input from WWTPs in 2016/17 was 35.3 t. The pattern for OneSteel was similar to that for ammonia, with 140t in 2016/17, but 210-220 t in the previous 4 years.

7.1.3 Total phosphorus

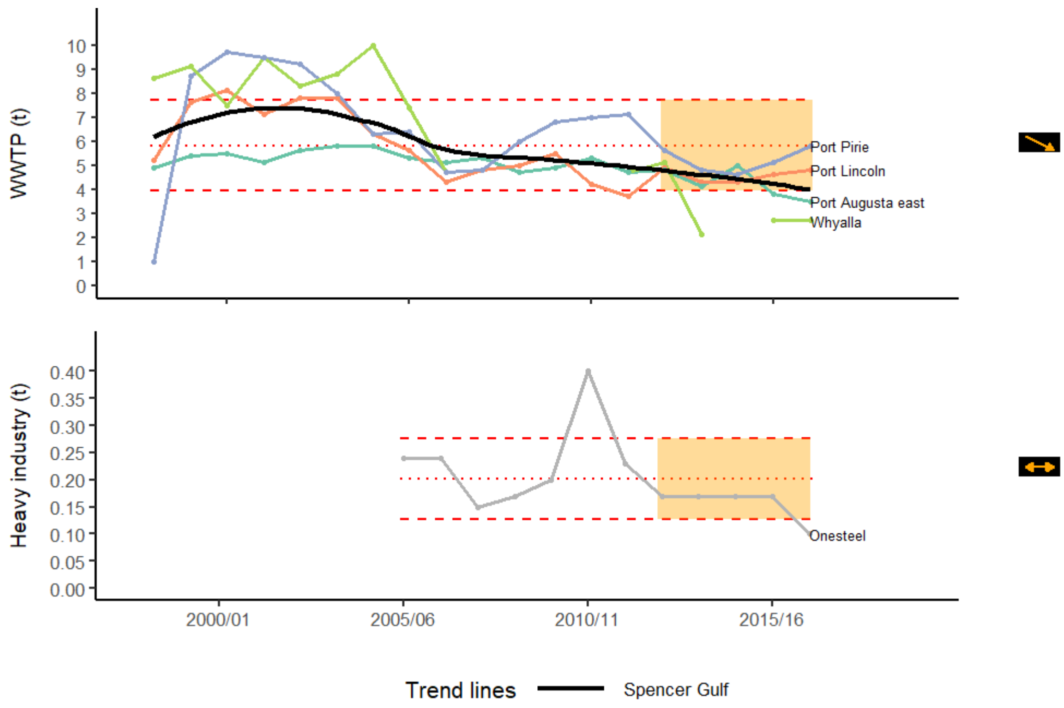

Figure 62. Annual load of total phosphorus discharged into the marine environment from Spencer Gulf Waste Water Treatment Plants (WWTP – black line shows mean over all WWTPs) and heavy industry (OneSteel). See graph explanation on page 21.

While phosphorus discharges from WWTPs also decreased over time, the decline was smaller, from ~7 t to ~4 t (Figure 62). Total WWTP inputs of phosphorus in 2016/17 were 14.1 t. In contrast to ammonia and total nitrogen, OneSteel had very low phosphorus discharges, with a peak of only 400 kg in 2010/11 and a minimum of 100 kg in 2016/17.

8 Conservation actions

8.1 Marine parks indicators

South Australia implemented management plans for 19 marine parks around the state in November 2012, with fishing restrictions in sanctuary zones within these parks commencing in October 2014 (DEWNR 2017). Seven of these marine parks are partly or fully within the waters of Spencer Gulf, being the Thorny Passage, Sir Joseph Banks Group, Gambier Islands Group, Franklin Harbour, Upper Spencer Gulf, Eastern Spencer Gulf and Southern Spencer Gulf marine parks (Figure 63). As part of the ongoing management of these marine parks, DEW has been undertaking a range of monitoring activities, particularly focussed on selected sanctuary zones. In Spencer Gulf, the four main sanctuary zones that are being monitored are Port Gibson (Franklin Harbour MP), Cuttlefish Coast and Fairway Bank (Upper Spencer Gulf MP) and Cape Elizabeth (Eastern Spencer Gulf MP). Monitoring is primarily undertaken using baited remote underwater videos (BRUVs) and/or diver surveys. The first comprehensive monitoring surveys were only undertaken in 2016/17, and so there are currently no time-series data with which to assess change, however, as this program is ongoing, useful data will be available in the future. Another component of ongoing monitoring is regular state-wide phone surveys to assess the public perception of marine parks since 2011. Whilst the original reporting (DEWNR 2017) does not allow Spencer Gulf to be separated, data for 2011, 2013, 2015 and 2017 are available by postcode, and thus can be reanalysed. For this purpose, data were obtained from DEW for all postcodes that lie entirely or predominantly in the local government areas that lie around the gulf (Figure 11).

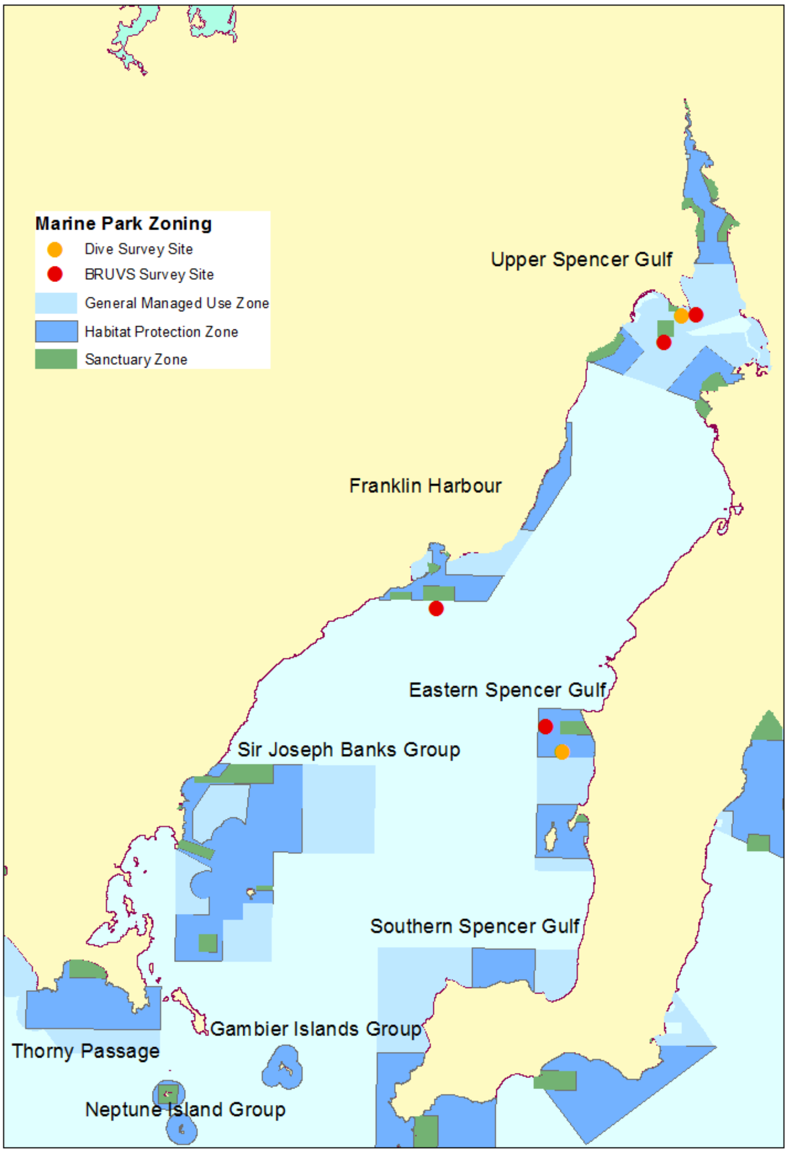

Figure 63. Location and management zones of marine parks in Spencer Gulf. The sites for ongoing monitoring using either diver surveys or baited remote underwater videos (BRUVs) are also indicated.

Following the implementation of sanctuary zones in 2014, some 21% of phone survey participants thought that they had seen a negative change in local businesses in 2015, while 14% were unsure (Figure 64). These figures declined to 17% and 1% respectively in 2017. It should be noted that whether or not this decline was due to the sanctuary zones was not explored. Conversely, only around 3% of participants thought that they had seen a positive change. The majority (55% in 2015 and 73% in 2017) of participants thought that they had not seen any change in local businesses.

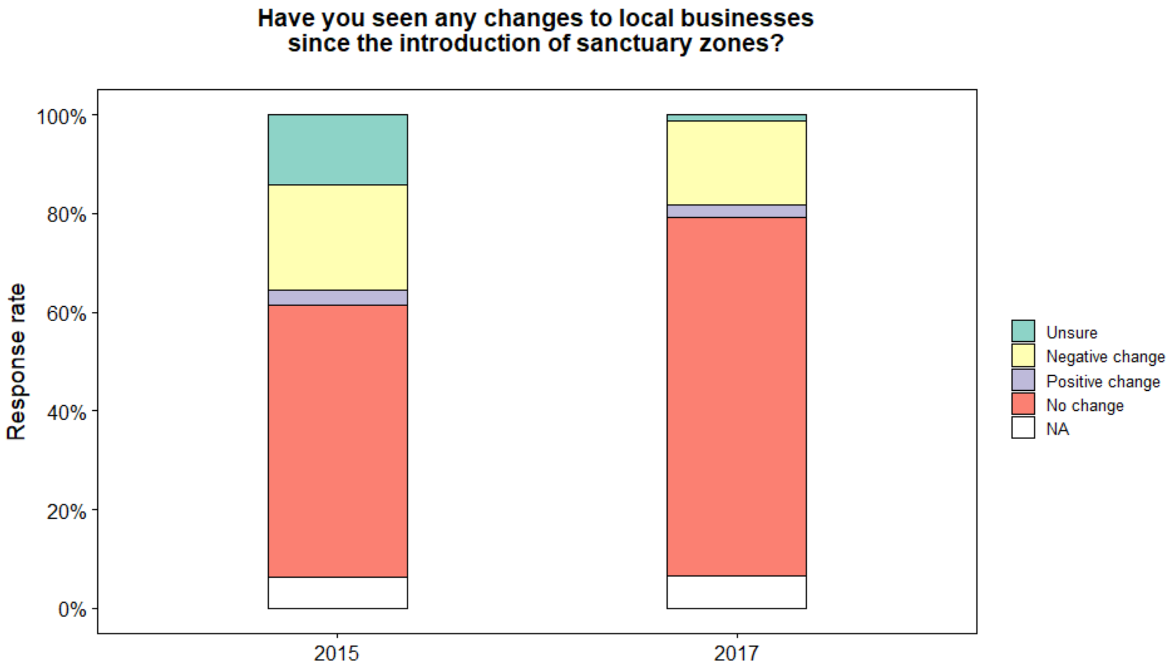

Figure 64. Response to the question: Have you seen any changes to local business since the introduction of sanctuary zones? Source: Data pertaining to local government areas around Spencer Gulf extracted from DEWNR (2017).

The percentage of participants in favour of marine parks in general was close to 80% in 2011, prior to the implementation of management plans (Figure 65). This declined to 70% following the commencement of fishing restrictions in sanctuary zones, but rose to 91% in 2017.

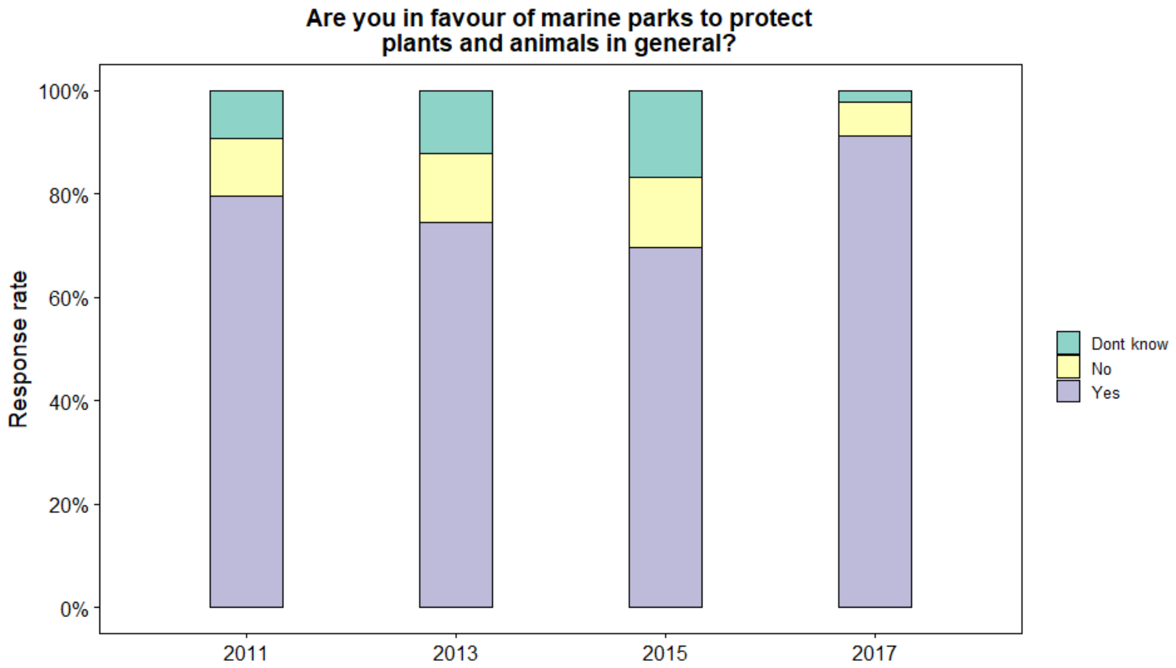

Figure 65. Response to the question: Are you in favour of marine parks to protect plants and animals in general? Source: Data pertaining to local government areas around Spencer Gulf abstracted from DEWNR (2017).

There has been a fairly consistent pattern over time in the percentage of participants who thought that the marine environment was under pressure from human activities, with this number fluctuating between 71% and 77% (Figure 66). The number who didn't think it was under pressure, however, remained stable at around 16%. The dominant perceived cause for human pressure was overfishing (from both commercial and recreational fishing), with pollution being the next most common reason nominated (Figure 67). There were no apparent trends over time in the perceived causes for pressure.

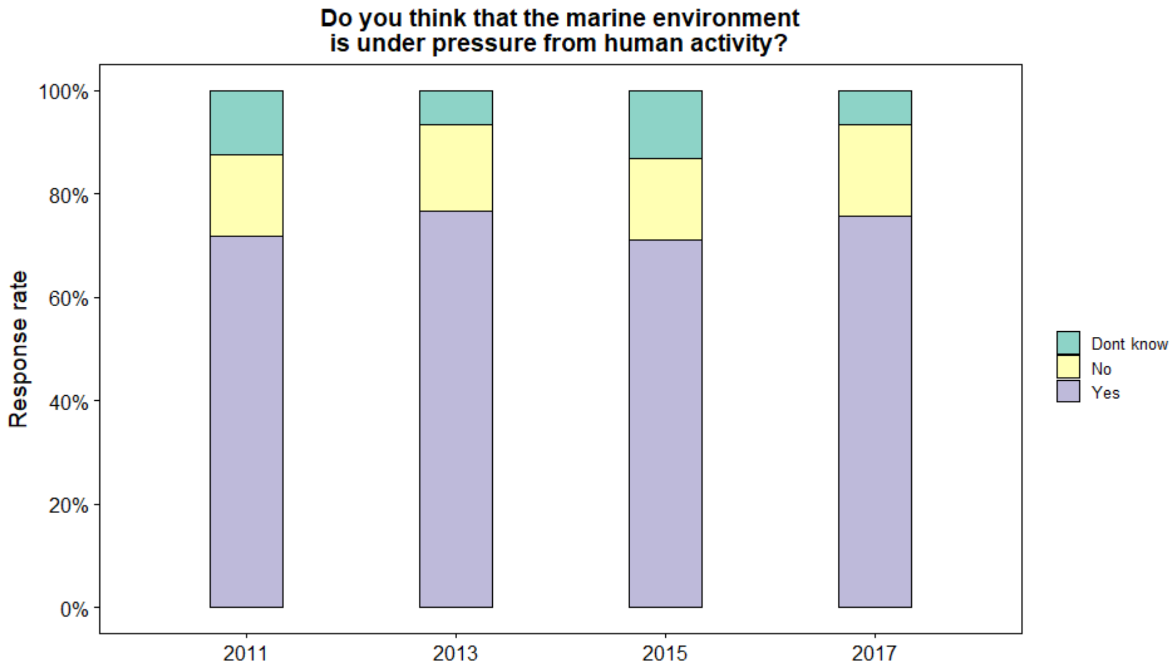

Figure 66. Response to the question: Do you think the marine environment is under pressure from human activity? Source: Data pertaining to local government areas around Spencer Gulf abstracted from DEWNR (2017).

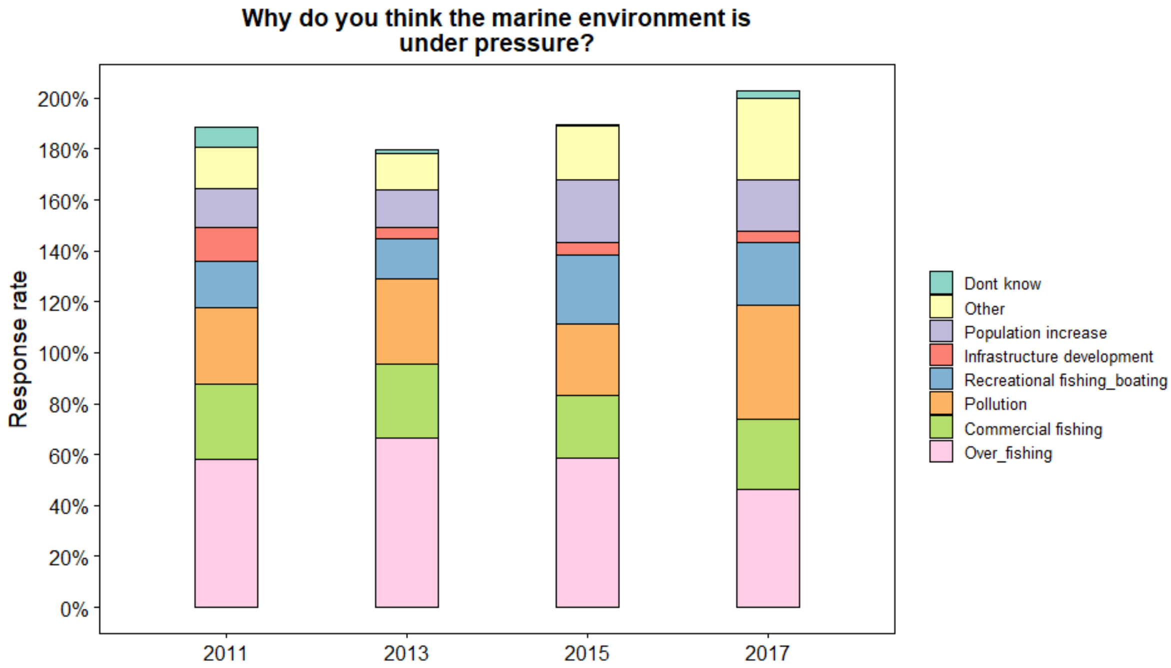

Figure 67. Response to the question: Why do you think the marine environment is under pressure? Respondents could nominate more than one cause, hence the total in each year exceeds 100%. Source: Data pertaining to local government areas around Spencer Gulf abstracted from DEWNR (2017).

9 Framework for a preliminary integrated ecosystem assessment of Spencer Gulf

9.1 Potential objectives and candidate performance indicators

Progress towards IM of Spencer Gulf will require the establishment of a suite of social, economic and ecological objectives and performance indicators for the gulf's communities, industries and ecosystems. Establishing this suite of objectives and indicators will require extensive input from a wide range of government agencies, industry and community stakeholders, and scientists from a wide range of disciplines. However, the key elements of this framework are likely be similar to those developed for other socio-ecological systems worldwide, such as Canada (e.g. Stephenson et al 2018). A list of potential objectives and performance indicators for Spencer Gulf is presented in Table 4. Whilst there are data available for some, there are also some substantial data gaps. Some of these gaps, especially in the social and economic spheres, may be able to be filled with further interrogation of existing data sets. Others, however, will require additional data collection

Table 4: Potential social, economic and ecological objectives and performance indicators for Spencer Gulf. Adapted from Stephenson et al (2018).

Potential objectives	Candidate performance indicators	
	Data available	Data gaps
Social		
Sustainable communities	Population Indicators, Human Capital Indicators, Social Capital Indicators	
Health and well-being		Life expectancy, well-being indices, occupational safety, suicide rates
Cultural identity		Indigenous cultural values
Economic		
Economic prosperity	Financial capital, economic diversity, status of marine industries, income, home ownership, house prices and sales, business owners	
Distribution of benefits		% of population below poverty line
Regional economic benefit	Employment in fisheries and aquaculture	Contribution of marine industries
Sustainable livelihoods	Housing affordability	Business viability
Ecological		
Productivity	Fisheries production, predator pup production	Fisheries recruitment (can be obtained for some species from fisheries models)
Trophic structure	Average trophic level of catch	Currently only available to 2010, but can be calculated from existing data for subsequent years Regime shifts
Biodiversity	Diversity indices, changes in species abundance, status of key species	Some data will be available from ongoing marine parks monitoring, but limited in spatial extent
Habitat and ecosystem integrity	Environmental conditions (sea surface temperature, salinity, acidification), status of key habitats, pollution, fisheries bycatch, trawl footprint	Food web structure, introduced species, pathogens and diseases

9.2 Preliminary risk assessment framework

9.2.1 Activities and benefits

Gillanders et al. (2013) identified thirteen key activities undertaken in and around Spencer Gulf (Table 5). In this report, we identify and evaluate the potential indicators available for each activity. No time-series datasets that could be used to develop indicators were identified for six of these 13 activities: desalination, recreation, urban development, energy and power production, defence and other infra-structure development. Indicators of varying spatial and temporal coverage and quality were developed for agriculture, fishing, aquaculture, ecotourism, shipping, ports and dredging, resource development and conservation. Again, a number of the data gaps that we have been identified could be filled by further analysis of existing data (e.g. shipping tracks), or by obtaining data that is likely to exist but could not be obtained for this report (e.g. shipping movements through ports not controlled by Flinders Ports). It will also be important to ensure that existing data collection efforts that occur at a whole of state level are carried out in such a way that it is easy to separate and analyse that component of the data that is specific to Spencer Gulf (e.g. abalone and oyster aquaculture production). All of these can provide additional important data streams with relatively little additional effort. Other data gaps will require new data collection to take place, either alongside existing efforts (e.g. to obtain fine spatial-scale catch and effort data for fisheries), or potentially as completely new activities (e.g. collection of data on ecotourism other than white shark cage diving). These activities are likely to require a higher level of resourcing, and will thus need more careful scrutiny to determine how valuable they are likely to be in the context of any future whole-of-gulf monitoring program.

9.2.2 Ecological assets and threats/stressors

Habitats

Gillanders et al. (2016) (see also Doubleday et al. 2017, Robbins et al. 2017, Jones et al. 2018) undertook risk assessments of key habitats (Table 6) against potential threats. Eight habitats were included in their risk assessment, with a further three excluded because of a lack of data and/or perceived minor importance. The mapping of subtidal habitats within the gulf is currently incomplete, particularly for areas deeper than 10-15 m, which are problematic to map using aerial photography and remote sensing. Better maps are available for intertidal habitats such as mangroves and salt marshes. The best current map (Figure 68) is provided by Jones et al. (2018), and is based on the collation of a range of data sources, as well as predictive modelling for seagrasses. The risk assessments were based on expert opinion rather than data, because such data are currently lacking for Spencer Gulf. In this report, we build on the work of Gillanders et al. (2016) by identifying potential indicators for each of the habitats and ecological threats/stressors.

No time-series datasets that that could be used to develop indicators were identified for six of the habitats listed by Jones et al. (2018): intertidal (soft), intertidal (rocky), soft-bottom, shellfish reef, rhodolith beds and sponge gardens. Indicators of varying spatial and temporal coverage were developed for saltmarshes, mangroves, seagrasses, rocky reef and pelagic. Apart from physico-chemical indicators for the pelagic environment, the best data set for marine habitats comes from the EPA’s aquatic ecosystem condition reporting program. This involves conducting clusters of video transects at numerous sites around the gulf on a 5-yearly basis, and currently provides good data on seagrass cover, with improving data on reef habitats. No other habitats are currently the focus of routine monitoring.

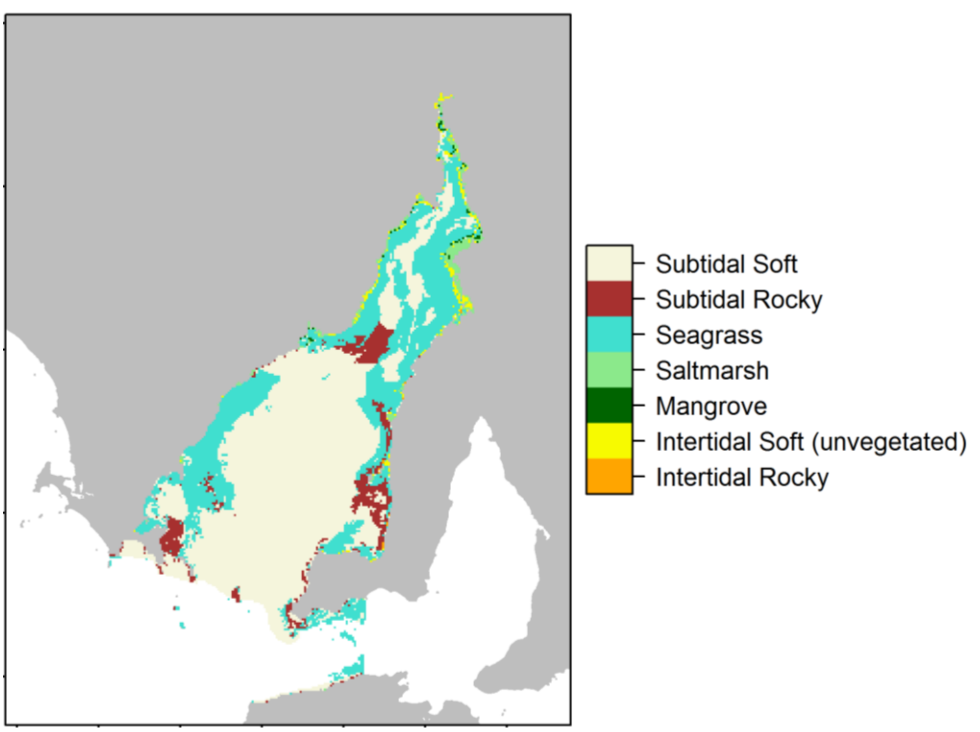

Figure 68. Benthic habitats of Spencer Gulf. Source: Jones et al. (2018).

Iconic, threatened, endangered and protected species

Gillanders et al. (2016) (see also Robbins et al. 2017) undertook risk assessments of iconic, threatened, endangered and protected species against potential threats. A list of 32 species/groups was established to inform the development of Table 7. This assessment was again based on expert opinion rather than data, because such data do not exist for most species.

The objectives, activities, ecological assets (habitats and protected species), threats/stressors and potential indicators are used to inform a gap analysis of the data streams available to undertake an integrated assessment of the status of Spencer Gulf. We evaluate the alignment between the existing datasets and monitoring programs and the key socio-economic and cultural benefits, ecological assets and key threats/stressors of Spencer Gulf. This report should be regarded as a demonstration of how an IEA might be undertaken, rather than a comprehensive assessment. A thorough assessment would require, among other elements, input from a range of key stakeholders to define the agreed objectives and performance indicators for the gulf.

No time-series datasets that that could be used to develop indicators were identified for 29 of the 32 threatened and protected species or species groups (wading birds and syngnathids) in the gulf (Table 7). The three species that do have good data, Australian sea lion, long-nose fur seal and giant Australian cuttlefish are not subject to routine ongoing monitoring, but rather the available data are the result of multiple short-term studies, with no commitment to ongoing funding. There is likely to be some data on a few other species, but it was not made available for this report.

Threats/stressors

In undertaking the risk assessments discussed above, Gillanders et al. (2016) compiled lists of potential threats and stressors for both habitats and iconic, endangered, threatened and protected species. We have combined these in Table 8. No suitable temporal data for assessing trends were identified for 20 of 39 stressors identified, including invasive species, disease, marine habitat modification and most forms of pollution. Again, while there are a large number of data gaps, some of these could be filled either by a reanalysis of existing data, or by small changes to data collection regimes that allow data from Spencer Gulf to be separated out from statewide data sets. Other gaps are likely to require new data collection efforts if deemed to be of sufficiently high priority to warrant the resources involved.

Table 5: Key activities undertaken in Spencer Gulf and potential indicators for which data could be identified.

Activity	Candidate performance indicators	
	Data available	Data gaps
Fishing	Catch and effort data, employment, value of production	Recreational fishing Fine-scale catch and effort, other than prawns (is available for sardines, but hasn't been analysed)
Aquaculture	Production, employment, value of production	Data for abalone and oysters could not be separated out for Spencer Gulf
Ecotourism	White shark cage diving participation	Data for other ecotourism activities is not available (e.g. diving, dolphin watching). Overall economic value of marine tourism has only been estimated indirectly.
Shipping, ports and dredging	Port shipping movements and tonnages, shipping activity	Data for ports not controlled by Flinders Ports were not obtained Vessel tracks only analysed for 2013/14
Desalination		No suitable data identified
Recreation		No suitable data identified
Agriculture	Employment in agriculture	Agricultural production, economic value
Urban development		No suitable data identified
Resource development	Employment in mining	Mining production, economic value
Energy and industrial power production		No suitable data identified
Defence		No suitable data identified
Other infrastructure development		No suitable data identified
Conservation	Support for marine parks	No data for direct conservation measures

Table 6: List of key habitat types for Spencer Gulf and potential indicators for which data could be identified. Adapted from Gillanders et al. (2016) and Doubleday et al. (2017). Potential indicators are based on the availability of suitable long-term and/or ongoing monitoring data. Short-term historical data sets are not considered, although may provide useful baselines for any new monitoring initiatives.

Habitat types	Candidate performance indicators	
	Data available	Data gaps
Intertidal (soft)		No suitable data identified
Intertidal (rocky)		No suitable data identified
Saltmarshes	Area of saltmarsh	No measure of habitat condition Classification algorithms need improvement
Mangroves	Area of mangrove	No measure of habitat condition Classification algorithms need improvement
Seagrasses	Change in percent cover	No measure of total area Shallow subtidal and intertidal meadows not included
Soft bottom		No suitable data identified
Shellfish reefs		No suitable data identified
Rocky Reef	Change in percent cover of macroalgae	Spatially limited, but being improved
Rhodolith beds		No suitable data identified
Sponge gardens		No suitable data identified
Pelagic	Physico-chemical indicators (e.g. temperature, salinity, waves, aragonite saturation, pH), chlorophyll	Data primarily from outside Spencer Gulf *sensu stricto*, but new data streams from near Whyalla will soon come online No data on phytoplankton composition, or zooplankton

Table 7: List of iconic, threatened, endangered and protected marine species for Spencer Gulf. Adapted from Gillanders et al. (2016). Potential indicators are based on the availability of suitable long-term and/or ongoing monitoring data. Short-term historical data sets are not considered, although may provide useful baselines for any new monitoring initiatives.

Species	Candidate performance indicators Data available	 No suitable data located
Marine mammals		
Short -beaked common dolphin, *Delphinus delphis*		No suitable data identified
Indo-Pacific bottlenose dolphin, *Tursiops aduncus*		No suitable data identified
Common bottlenose dolphin, *Tursiops truncates*		No suitable data identified
Southern right whale, *Eubalaena australis*		No suitable data identified
Humpback whale, *Megaptera novaeangliae*		No suitable data identified
Australian sea lion, *Neophoca cinerea*	Pup production	Continuation relies on short-term funding arrangements
Long nose fur seal, *Arctocephalus forsteri*	Pup production	Continuation relies on short-term funding arrangements
Birds		
Eastern Osprey, *Pandion cristatus*		No suitable data identified
White-bellied sea eagle, *Haliaeetus leucogaster*		No suitable data identified
Waders: Common greenshank, ruddy turnstone, red knot, sharp-tailed sandpiper, curlew sandpiper, red-necked stint *Tringa nebularia, Arenaria interpres, Calidris canutus, C. acuminate, C. ferruginea, C. ruficollis*	BirdLife Australia has abundance data	
Pacific gull, *Larus pacificus*		No suitable data identified
Silver gull, *Larus novaehollandiae*		No suitable data identified
Flesh-footed shearwater, *Puffinus carneipes*		No suitable data identified
Short-tailed shearwaters, *Ardenna tenuirostris*		No suitable data identified
White-faced storm petrel, *Pelagodroma marina*		No suitable data identified
Crested tern, *Thalasseus bergii*		No suitable data identified
Caspian tern, *Hydroprogne caspia*		No suitable data identified
Fairy tern, *Sterna nereis*		No suitable data identified
Little penguins, *Eudyptula minor*		No suitable data identified
Cormorants: black-faced and pied, *Phalacrocorax fuscescens, P.varius*		No suitable data identified

Elasmobranchs (sharks and rays)		
White shark, *Carcharodon carcharias*		No suitable data identified
Shortfin mako, *Isurus oxyrinchus*		No suitable data identified
Dusky shark, *Carcharhinus obscurus*		No suitable data identified
Coastal stingaree, *Urolophus orarius*		No suitable data identified
Melbourne skate, *Spiniraja whitleyi*		No suitable data identified
Common thresher, *Alopias vulpinus*		No suitable data identified
Smooth hammerhead, *Sphyrna zygaena*		No suitable data identified
School shark, *Galeorhinus galeus*		No suitable data identified
Bronze whaler, *Carcharhinus brachyurus*		No suitable data identified
Invertebrates/teleost fish		
Syngnathids: all species		No suitable data identified
Western blue groper, *Achoerodus gouldii*		No suitable data identified
Giant Australian cuttlefish, *Sepia apama*	Abundance and biomass	May not be ongoing

Table 8: List of threats to the ecological assets of Spencer Gulf. Adapted from Gillanders et al. (2016). Potential indicators are based on the availability of suitable long-term and/or ongoing monitoring data. Short-term historical data sets are not considered, although may provide useful baselines for any new monitoring initiatives.

Threat	Candidate performance indicators	
	Data available	No suitable data located
Acid sulfate soil disturbance		Mapped, but no time series data
Aquaculture: mussels	Production	
Aquaculture: Pacific oyster		Data only available at a statewide level
Aquaculture: predatory fish	Production of tuna and kingfish	Total nutrient inputs not collated
Boating		No suitable data identified
Climate change: changing rainfall patterns	Rainfall data	
Climate change: global/ocean warming	Water temperature	
Climate change: increased storm activity		Could be derived from wind data
Climate change: increase in hot weather	Temperature	
Climate change: increased salinity	Salinity	
Climate change: ocean acidification	pH and aragonite saturation	
Climate change: sea level rise	Sea level	
Coastal activities		No suitable data identified
Coastal habitat modification		No suitable data identified
Disease and pathogen outbreaks		No suitable data identified
Fishing: demersal trawl	Prawn trawl footprint, catch and effort	
Fishing: hand collection	Catch and effort of relevant fisheries	Spatial footprint
Fishing: handline, longline	Catch and effort of relevant fisheries	Spatial footprint
Fishing: haul nets, gillnets	Catch and effort of relevant fisheries	Spatial footprint
Fishing: illegal		No suitable data identified
Fishing: pots	Catch and effort of relevant fisheries	Spatial footprint
Fishing: purse seine	Catch and effort of relevant fisheries	Spatial footprint – data available but not analysed
Harmful algal blooms		South Australian shellfish quality assurance program data available, but doesn't readily lend itself to developing an indicator
Invasive species: benthic filter-feeders		No suitable data identified
Invasive species: encrusting, fouling		No suitable data identified

Invasive species: predators, parasites		No suitable data identified
Marine habitat modification: dredging		No suitable data identified
Marine habitat modification: harbors, ports		Could be mapped from aerial imagery with appropriate resources
Marine habitat modification: jetties, seawalls		Could be mapped from aerial imagery with appropriate resources
Marine habitat modification: marinas, boat ramps		Could be mapped from aerial imagery with appropriate resources
Pollution: brine discharge		No suitable data identified
Pollution: heavy metals		No suitable data identified
Pollution: marine debris		No suitable data identified
Pollution: noise		No suitable data identified
Pollution: nutrient discharge (point source)	Wastewater and industrial nutrient discharges	No data on septic runnoff
Pollution: oil spill (100s of tonnes)		No suitable data identified
Pollution: sediment runoff and dust		No suitable data identified
Pollution: thermal		No suitable data identified
Shipping	Movement and activity data	Data for ports not controlled by Flinders Ports were not obtained Vessel tracks only analysed for 2013/14

10 Discussion and conclusions

This report builds on a series of projects undertaken through the Spencer Gulf Ecosystem Development Initiative (SGEDI) since 2011 that have begun to develop a framework to inform a more integrated approach to management of Spencer Gulf. Previous work has identified knowledge gaps (Gillanders et al. 2013), developed a suite of ecosystem models for fisheries and aquaculture (Gillanders et al. 2015), and examined some of the key threats to the gulf ecosystems (Gillanders et al. 2016). Here, we collate a wide range of data sets that provide some indication as to the current status of the communities, economies and ecosystems of the Spencer Gulf region, and undertake a gap analysis against a range of identified assets, benefits, stressors and threats in the gulf. Concurrently, Bailleul and Ward (2019), have developed an online tool to allow stakeholders to interrogate a range of spatial data sources pertaining to the environmental characteristics, ecological assets, human activities, management arrangements and socio-economic values of Spencer Gulf.

While we there are a broad range of valuable data sets for Spencer Gulf, there are also many data gaps, and a number of data sets that are only collected sporadically and for which there is no guarantee of continuation. If integrated management of the gulf is to become a reality, these gaps will need to be prioritised, and mechanisms identified for filling those regarded as high priorities.

From a socio-economic perspective, there are good data available from the Australian Bureau of Statistics on a wide range of indicators, such as population, demographics, employment, housing, education, care requirements and volunteering. However, apart from data on employment in fisheries and aquaculture, none of this is directly related to the marine systems contribution to the region. We have identified some one-off data on this marine contribution, but there is no ongoing mechanism in place to ensure that this work continues. From a cultural perspective, there are little data that we have been able to identify, with the exception of perception surveys undertaken for marine parks.

There are a wider range of data sets available on the marine ecosystem, although there are still many gaps. From a habitat perspective, there is particular paucity of data on unvegetated soft sediments, which dominate the deeper waters of the gulf, but can also be important in shallow and intertidal areas. Seagrass has also not been mapped for the entire gulf region. From a faunal perspective, there are good data sets on commercially important species, but few on non-commercial species. There are a few data on threatened, endangered and protected species, but these have been pieced together from a range of projects, and there are no established, ongoing monitoring programs.

Many of the threats to the gulf are also poorly monitored. We have good data on fishing and aquaculture, and on discharges from waste water treatment plants, but little else for local threats. There are also a number of data sets available on climate change, while is likely to impact the structure and function of the gulf, but which is not amenable to local control.

One of the challenges of this study is that a number of potentially important data sets are collected and reported at spatial scales that are not useful for examining the status of Spencer Gulf, even if much of the data is from Spencer Gulf. This data is either collected/reported at a statewide scale (e.g. oyster aquaculture production), or for terrestrially-based natural resources management regions. The later groups the eastern half of Spencer Gulf with western Gulf St Vincent, and the western half with much of the west coast, thus confounding what may be happening in Spencer Gulf and elsewhere. In some cases, obtaining the original data may allow that for Spencer Gulf to be considered separately, although resources were not available to do that for this report. In other cases there may be a need to modify existing data collection protocols. In either case, these data streams have the potential to fill some key data gaps relatively easily.

Overall, we identified approximately 170 different data time-series that could be used as the basis for a developing a suite of indicators of the overall social, economic and ecological status of Spencer Gulf. The obvious next step would be to consolidate these datasets into a smaller subset that provide a useful and amenable set of indictors that can be utilised to monitor the status of the gulf into the future. To do this, redundancies between data sets would need to be identified, and the potential for integrating multiple data sets examined. The data gaps would also need to be prioritised, as it will not be feasible to fill all of the gaps that have been identified here. To aid in the final selection of the indicator set, there will be a need to develop hypotheses about the underlying drivers of some of the changes in individual indicators (or suites of indicators), and test some of these through scenario analyses in statistical/ecosystem models. Once a final set of indictors is established it would be appropriate to conduct an integrated assessment of the status of the gulf, and present the results a simple visual score-cards similar to those produced in current SOE and NRM reporting (EPA 2018, Government of South Australia 2012). The final report for this project will provide recommendations about how to streamline and integrate future reporting on the status of South Australia's marine environments at regional and State levels.

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Appendix 1: Compilation of existing monitoring programs in or including Spencer Gulf

ID	Program title	Primary purpose	Scope	Objectives	Lead organisation	Contact	Geographic coverage	Location	Baseline and/or monitoring	Temporal coverage	Reporting	Data accessibility	How to access data
SA 1	Southern Australian Integrated Marine Observing System (SAIMOS)	Provide an understanding of long-term changes in physical oceanography and associated structure and function of planktonic ecosystem	physical, biological chemical	water quality, climate change	SARDI	John Middleton / Paul van Ruth	regional	3 long-term moorings in Spencer Gulf and adjacent shelf seas and biogeochemical sampling	baseline and monitoring	2008-present	research reports and publications	accessible to public	Australian Ocean Data Network (AODN)
SA 2	Wave Rider Buoy	To understand ocean wave conditions informing decision making	physical	To assess both typical and extreme sea states for estimating spatial, seasonal and interannual variations in wave conditions	BOM	John Nairn	regional	Cape du Couedic	baseline and monitoring	2000-present		accessible to public	http://www.bom.gov.au/products/IDS65030.shtml
SA 3	Coastal Radar	Monitor wave height and surface currents	physical	To monitor environment and inform meteorological forecasting	SARDI	Charles James	regional	Cape Spencer, Cape Wiles	baseline and monitoring	2009-present		accessible to public	AODN
SA 4	Commercial Fisheries Monitoring Program	Monitor fishery catch and effort data (all sectors)	biological	To inform and underpin sustainable management of fisheries resources	PIRSA	Angelo Tsolos	state-wide	various	monitoring	1983-present	Reports	confidential	PIRSA request (non-confidential data)
SA 5	Fishery-independent monitoring programs	Monitor fish stocks	finfish plankton surveys; lobster, prawn, crab fishery	To inform and underpin sustainable management of fisheries resources	SARDI	Stephen Mayfield	state-wide	various	baseline	various	Reports	restricted access	SARDI

			independ ent surveys										
SA 6	Recreational Fishery Monitoring	Measure recreational catch and effort	fishery	To inform sustainable management of fisheries resources	PIRSA	Keith Rowling	state-wide	various	monitori ng	2001, 2006, 2014	Reports	restrict ed access	PIRSA request (non-confidenti al data)
SA 7	Economic performance of fisheries	Measure economic performance of fisheries	economic	To inform fisheries management	PIRSA/Econse arch	Julian Morrison	state-wide	various	monitori ng	1998-present	Reports	restrict ed access	PIRSA request (non-confidenti al data)
SA 8	Aquaculture Environmental Monitoring Program	Provide an understanding of changes in water quality and benthic infauna to inform decision making re. finfish aquaculture	physical, biological & chemical	water quality / environmental regulation	SARDI	Jason Tanner / Mark Doubell	regional	farm sites	baseline and monitori ng	2016 -2018	2019 Report	restrict ed access	SARDI
SA 9	Finfish Environmental Monitoring Program	Provide an understanding of changes in benthic infauna to inform decision making re. finfish aquaculture	biological	environmental regulation	SARDI	Jason Tanner	regional	Finfish Aquacultur e zones	baseline and monitori ng	2000-2015	Annual report	confide ntial	SARDI
SA 10	South Australian Shellfish Quality Assurance Program	To understand changes in public health suitability of shell fish	chemical & biological	To inform decision making on matters of public health relating to bivalve mollusc consumption	PIRSA	Clinton Wilkinso n	state-wide	localised production areas	monitori ng	2000-present	annual report	restrict ed access	PIRSA request (non-confidenti al data)
SA 11	EPA Aquatic ecosystem condition reports (AECR)	To evaluate changes in nearshore habitat condition to inform decision making for management of pollution	physical, biological (benthic habitat and phytopla nkton) & chemical	Regional scale evaluation of habitat condition including change over larger time periods. Listing pressures likely to be acting on the current condition and management actions currently undertaken to address pressures.	EPA	Sam Gaylard	state-wide	various (approxima tely 330 across the State)	baseline and monitori ng	2010-current	EPA web site	accessi ble to public	EPA web site

SA 12	Metals in sentinel mussels	Establish levels of metals accumulating in sentinel species (*Mytilus galloprovincialis*) throughout SA.	chemical	Assessing metal levels in marine waters using sentinel biological species	EPA	Sam Gaylard	state-wide	~70 sites assessed during 2005	baseline and monitoring	2005 - 2019	publication & EPA website	accessible to public	EPA request
SA 13	Boston & Louth Tier 3 assessment	Ecological assessment of high risk areas in Boston & Louth Bays	physical, biological (benthic habitat and phytoplankton) & chemical	Assessing areas at risk from nutrient discharges in Boston & Louth Bays. Develop CHEMTAX library for Spencer Gulf	EPA	Sam Gaylard	regional	Boston & Louth Bays	monitoring	2010, 2016, 2018	2019 report	unknown	EPA request
SA 14	Wallaroo seagrass assessment	Establish baseline of seagrass condition around Wallaroo	biological and chemical	Establish seagrass condition to evaluate change over time due to increased development	EPA	Sam Gaylard	local	Wallaroo, Port Hughes, Port Broughton	baseline	2016-2018	TBA	accessible to public	EPA request
SA 15	Paleoreconstruction of historic pollution in seagrass rhizome mat	Examine very long-term ('000 yrs) changes in metal and carbon concentrations	chemical	Test using seagrass rhizome mat as a long-term indicator of pollution. Assess changes in contamination (metals) and carbon storage over time	Edith Cowan University	Paul Lavery	local	Port Pirie, Whyalla, Port Broughton	baseline and monitoring	2016	publication	accessible to public	EPA request
SA 16	Liberty Onesteel seagrass assessment	investigate changes to seagrass cover adjacent to the steelworks marine discharge	biological	Examine seagrass cover and epiphyte growth throughout False Bay to inform regulation of steelworks marine discharge	Liberty Onesteel	Bradley Mansell	local	False Bay	baseline and monitoring	1992-current	technical reports	restricted access	TBA
SA 17	Persistent pollutants in dolphins	Use SA Museum's tissue library to investigate temporal changes in persistent pollutant levels in dolphins	chemical	Examine large scale spatial and temporal changes in persistent and emerging pollutants in dolphins	EPA	Sam Gaylard	state-wide	state-wide	baseline and monitoring	1995 - current	technical reports	not accessible to public	EPA request
SA 18	SA marine parks underwater visual census (UVC) program	To monitor for changes in biological assemblages due to marine parks	biological	To meet objects of Marine Parks Act 2007	DEW	Danny Brock	state-wide	Various	baseline and monitoring	Since 2005	DEW reports	accessible to public	DEW website

SA 19	SA marine parks baited remote underwater video systems (BRUVS) program	To monitor for changes in biological assemblages due to marine parks	biological	To meet objects of Marine Parks Act 2007	DEW	Danny Brock	state-wide	Various	baseline and monitoring	Since 2014	DEW reports	accessible to public	DEW website
SA 20	SA marine parks habitat inventory mapping program	To document habitats in previously unmapped sanctuary zones	biological	To meet objects of Marine Parks Act 2007	DEW	Danny Brock	state-wide	Various	baseline	Since 2012	DEW reports	accessible to public	DEW website
SA 21	SA marine parks state benthic nearshore habitat mapping program	To map the seafloor	biological		DEW	David Miller	state-wide	Various	baseline	Since 2007	DEW reports	accessible to public	DEW website
SA 22	SA marine parks public perception survey	To monitor for changes in the public's understanding, support for and perceptions of marine parks	Social	To meet objects of Marine Parks Act 2007	DEW	Simon Bryars	state-wide	Various	baseline and monitoring	Since 2006	DEW reports	accessible to public	DEW website
SA 24	SA marine parks tour operator numbers	To monitor for changes in the number of coastal & marine tour operators that may be related to marine parks	Economic	To meet objects of Marine Parks Act 2007	DEW	Simon Bryars	state-wide	Various	baseline and monitoring	Since 2014	DEW reports	accessible to public	DEW website
SA 25	SA sea eagle and osprey	To monitor number and distribution of nesting pairs	biological		DEW	Sharie Detmar	state-wide	Various	baseline and monitoring	Since 2008	DEW internal reports	restricted access	DEW request
SA 26	SA shorebirds	To monitor populations of shorebirds	biological		BirdLife Australia	Jane Cooper	state-wide	Various	baseline and monitoring	Since 2000	??	unknown	BirdLife Australia
SA 28	Port monitoring marine pests	assess pest populations to support ballast water arrangements	biological	Biosecurity Act	PIRSA	Will Zacharin	state-wide	Ports	baseline and monitoring		PIRSA	restricted access	PIRSA request
SA 29	SA White shark cage diving participation at Neptune Islands	To track visitor numbers	Social and economic		DEW and Flinders University	Simon Bryars, Charlie Huveneers	local	Neptune Islands	baseline and monitoring	Since 2008	DEW reports, peer reviewed publications	accessible to public	DEW website

SA 33	Australian sea lion monitoring - State-wide	Colony status, trends in abundance	Biological	Species status and trends	SARDI	Simon Goldsworthy	state-wide	State-wide	Baseline, opportunistic monitoring	1980-2015	DotE	restricted access	SARDI request
SA 35	Long-nosed fur seal	Trends in pup production	Biological	Species status and trends in abundance	SARDI	Simon Goldsworthy	state-wide	state-wide	Baseline, opportunistic monitoring	1988-2014	DotE/DEW	restricted access	SARDI request
SA 36	Seabird monitoring	Opportunistic surveys on little penguins, crested terns, flesh-footed shearwaters	Biological	Species status and trends in abundance	SARDI	Simon Goldsworthy	state-wide	state-wide	Baseline, opportunistic monitoring	1988-2014	DEW	restricted access	SARDI request

Appendix 2: Details of how to obtain individual data sets used in this report

#	Data set	Figure	Page	Organisation	Contact	Accessibility	How to access	Post-processing required
1	Marine industry value	Figure 9	13	Deloitte Access Economics	T Ward	Public	http://www.misa.net.au/	No
2	Marine industry employment	N/A	13	Deloitte Access Economics	T Ward	Public	http://www.misa.net.au/	No
3	Population size	Figure 12	25	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
4	Median age	Figure 12	25	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
5	Working age population	Figure 12	25	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
6	Median house price	Figure **13**	26	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
7	House sales	Figure **13**	26	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
8	Unemployment	Figure 14	28	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
9	Part-time employment	Figure 14	28	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
10	Women employed	Figure 14	28	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
11	Assistance with core activities	Figure 15	29	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
12	Year 12 education	Figure 15	29	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
13	Unpaid disability assistance	Figure 16	31	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
14	Unpaid child care	Figure 16	31	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
15	Volunteering	Figure 16	31	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
16	Unchanged residence	Figure 17	32	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
17	One-parent families	Figure 17	32	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
18	Monthly mortgage	Figure 18	34	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
19	Weekly rental	Figure 18	34	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
20	Weekly household income	Figure 18	34	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
21	Home ownership	Figure 19	35	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
22	Business ownership	Figure 19	35	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
23	Employment by industry sector	Figure 20, Figure 21	37	Australian Bureau of Statistics	N/A	Public	http://stat.abs.gov.au/itt/r.jsp?databyregion#/	No
24	Sea surface temperature	Figure 23	40	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	Yes - low
25	Sea surface temperature anomaly	Figure 24	41	SARDI	M. Doubell	Public	Request to SARDI	Yes - moderate

#	Data set	Figure	Page	Organisation	Contact	Accessibility	How to access	Post-processing required
26	Summer sea surface temperature	Figure 25	42	SARDI	M. Doubell	Public	Request to SARDI	Yes - moderate
27	Winter sea surface temperature	Figure 26	43	SARDI	M. Doubell	Public	Request to SARDI	Yes - moderate
28	Bottom temperature - NRSKAI	Figure 27	45	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	No
29	Bottom temperature – SAM8SG	Figure 27	45	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	No
30	Bottom temperature LRS	Figure 27	45	SARDI	M. Doubell	Restricted	Request to SARDI	No
31	Bottom salinity – NRSKAI	Figure 27	45	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	No
32	Bottom salinity – SAM8SG	Figure 27	45	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	No
33	Bottom salinity - LRS	Figure 27	45	SARDI	M. Doubell	Restricted	Request to SARDI	No
34	Sea level residuals	Figure 28	47	Bureau of Meteorology (BOM)	N/A	Restricted	Request to BOM	Yes
35	Wave statistics – Cape Du Couedic	Figure 29	48	Bureau of Meteorology (BOM)	N/A	Restricted	Request to BOM	Yes
36	Air temperature	Figure 30	49	Bureau of Meteorology (BOM)	N/A	Restricted	Request to BOM	Yes
37	Precipitation	Figure 31	50	Bureau of Meteorology (BOM)	N/A	Restricted	Request to BOM	Yes
38	Nino3.4	Figure 32	52	NOAA Earth System Research Laboratory	N/A	Public	https://www.esrl.noaa.gov/psd/data/correlation/nina34.data	No
39	SOI	Figure 32	52	Bureau of Meteorology (BOM)	N/A	Public	http://www.bom.gov.au/climate/current/soihtm1.shtml	No
40	SAM	Figure 32	52	National Centre for Atmospheric Research (NCAR) Climate Data Guide	N/A	Public	https://climatedataguide.ucar.edu/climate-data/marshall-southern-annular-mode-sam-index-station-based	No
41	DMI	Figure 32	52	NOAA Earth System Research Laboratory (ESRL)	N/A	Public	https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/dmi.long.data	No
42	Aragonite saturation - NRSKAI	Figure 33	54	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	Yes - Moderate
43	Total pH – NRSKAI	Figure 34	55	Integrated Marine Observing System (IMOS)	N/A	Public	https://portal.aodn.org.au/	Yes - Moderate
44	Shipping routes	Figure 35	57	Australian Maritime Safety Authority	Tom Prowse	Restricted	Contact University of Adelaide for information	Yes - high
45	Shipping movements	Figure 36	58	Flinders Ports	N/A	Public	https://www.flindersports.com.au/ports-facilities/port-statistics/	Yes - low

#	Data set	Figure	Page	Organisation	Contact	Accessibility	How to access	Post-processing required
46	Import/export volume	Figure 37	58	Flinders Ports	N/A	Public	https://www.flindersports.com.au/ports-facilities/port-statistics/	Yes - low
47	Abalone fishery catch/effort	Figure 38	60	SARDI	A. Tsolos	Restricted	Request to SARDI	No
48	Abalone fishery employment	Figure 38	60	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
49	Abalone fishery value	Figure 38	60	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
50	Blue crab fishery catch/effort	Figure 39	61	SARDI	A. Tsolos	Restricted	Request to SARDI	No
51	Blue crab fishery value	Figure 39	61	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
52	Prawn fishery catch/effort	Figure 40	63	SARDI	A. Tsolos	Restricted	Request to SARDI	No
53	Prawn fishery employment	Figure 40	63	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
54	Prawn fishery value	Figure 40	63	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
55	Prawn trawl footprint	Figure 41	64	SARDI	C. Noell	Restricted	Needs to be commissioned from SARDI	No
56	Calamari by-catch	Figure 42	64	SARDI	A. Tsolos	Restricted	Request to SARDI	No
57	Sardine fishery catch/effort	Figure 43	66	SARDI	A. Tsolos	Restricted	Request to SARDI	No
58	Sardine fishery employment	Figure 43	66	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
59	Sardine fishery value	Figure 43	66	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
60	Charter boat fishery catch/effort	Figure 44	67	SARDI	A. Tsolos	Restricted	Request to SARDI	No
61	Marine scalefish fishery catch/effort	Figure 45	69	SARDI	A. Tsolos	Restricted	Request to SARDI	No
62	Marine scalefish fishery employment	Figure 45	69	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
63	Marine scalefish fishery value	Figure 45	69	BDO EconSearch	J. Morison	Restricted	Needs to be commissioned from BDO EconSearch	No
64	Tuna aquaculture production	Figure 46	71	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
65	Tuna aquaculture employment	Figure 46	71	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
66	Tuna aquaculture value	Figure 46	71	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
67	Finfish aquaculture production	Figure 47	73	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
68	Finfish aquaculture employment	Figure 47	73	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low

#	Data set	Figure	Page	Organisation	Contact	Accessibility	How to access	Post-processing required
69	Finfish aquaculture value	Figure 47	73	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
70	Mussel aquaculture production	Figure 48	75	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
71	Mussel aquaculture employment	Figure 48	75	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
72	Mussel aquaculture value	Figure 48	75	PIRSA	N/A	Public	https://pir.sa.gov.au/aquaculture/publications Needs to be manually collated from annual reports	Yes - low
73	Shark cage diving	Figure 49	77	Flinders University	C. Huveneers	Restricted	Needs to be commissioned from Flinders University	No
74	Cuttlefish abundance and biomass	Figure 50	78	SARDI	M. Steer	Restricted	Contact SARDI to determine if any updates are available	No
75	Australian sea lion pup abundance	Figure 53	81	SARDI	S. Goldsworthy	Restricted	Contact SARDI to determine if any updates are available	No
76	Long-nosed fur seal pup abundance	Figure 54	82	SARDI	S. Goldsworthy	Restricted	Contact SARDI to determine if any updates are available	No
77	Seagrass cover	Figure 55	84	EPA	N/A	Public	https://www.epa.sa.gov.au Needs to be collated from regional reports	Yes – moderate
78	Macroalgal cover	Figure 57	86	EPA	N/A	Public	https://www.epa.sa.gov.au Needs to be collated from regional reports	Yes - moderate
79	Mangrove area	Figure 58	88	DEW	N/A	Public	https://data.environment.sa.gov.au/Land/Data-Systems/SA-Land-Cover/Pages/default.aspx	Yes - high
80	Saltmarsh area	Figure 58	88	DEW	N/A	Public	https://data.environment.sa.gov.au/Land/Data-Systems/SA-Land-Cover/Pages/default.aspx	Yes - high
81	Ecopath ecosystem indicators	Figure 59	89	SARDI	S. Goldsworthy	Restricted	Model updating needs to be commissioned from SARDI	No
82	Water pollution	Figure 60 - Figure 62	90 - 92	National Pollution Inventory	N/A	Public	http://www.npi.gov.au/	No
83	Marine parks perception	Figure 64 - Figure 67	95 - 98	DEW	S. Bryars	Restricted	Contact DEW to determine if any updates are available	Yes - low

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