# Spencer Gulf Ecosystem & Development Initiative

## Report on Scenario development, Stakeholder workshops, Existing knowledge & Information gaps

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# EXECUTIVE SUMMARY

## Scope and context for document

1. Spencer Gulf is an important area for the State with significant opportunities for expansion of mining and associated infrastructure (e.g. port development, desalination plants), important wild catch fisheries and aquaculture, and marine parks being implemented.
2. The ultimate aim of the Spencer Gulf Ecosystem Development Initiative (SGEDI) is to provide all stakeholders with access to independent and credible information about Spencer Gulf and opportunities to better understand any potential impacts so that informed decisions can be made.
3. This document considers scenarios for development, reports on stakeholder workshops and synthesises existing knowledge relevant to Spencer Gulf whilst also highlighting information gaps. Specifically, the review:
    - Summarises current knowledge on the environment and ecology of the region,
    - Investigates the current situation, proposed development and expansion, and potential stressors and impacts of the full range of activities likely to affect the Gulf.
    - Provides an overview of marine spatial planning including consideration of cumulative impacts, tradeoffs, shifts in ecosystems, and on-going engagement.
    - Synthesises the above information to suggest an approach for ongoing research.

## Stakeholder workshops

4. Ten stakeholder workshops encompassing sector-specific, regional and synthesis workshops were held to inform people of SGEDI and to identify key concerns and issues.
5. General points to emerge included a need for evidence-based decision making, incorporation of climate scenarios in models, consideration of cumulative impacts and future environmental repair, recognition that recreational use should be part of any tradeoffs and the requirement for a greater understanding of threshold levels, buffering capacity and resilience of the system.

## Environment and Ecology

6. Spencer Gulf occurs in the coastal geomorphological region of the Gulfs Province in South Australia, and is a large, sheltered, inverse estuary surrounded by arid lands. The region experiences relatively low rainfall and high evaporation rates.
7. The physical oceanography of Spencer Gulf consists of warm, saline waters during summer which are prevented from mixing with offshore waters by a front at the mouth of the Gulf. During the remaining time periods the cold, dense plumes of water flow from the Gulf out onto the shelf.
8. Large tidal velocities and sea level displacement are observed in the middle to upper Gulf, along with “dodge” tides, with minimal tidal amplitudes every 15 days or so.
9. Information on biological oceanography can be gleaned from existing information on temporal variation in plankton, remote sensing and sardine surveys, but there has not been a focus on all of the Gulf.
10. Light is unlikely to limit primary productivity, but there may be potential nutrient limitation of phytoplankton growth.
11. Of the nine species of small pelagic fishes in southern Spencer Gulf, the Australian sardine is the most widely researched as it supports Australia’s largest fishery by weight.
12. Spencer Gulf supports a diverse range of subtidal benthic habitats, although only a small proportion of the Gulf has been mapped at fine resolution. These habitats include some of the largest seagrass beds in the world.

13. The region is an area of high conservation significance providing important foraging and breeding habitats for iconic and threatened, endangered and protected species. Iconic species include apex predators and the giant Australian cuttlefish.
14. Several diseases and pests are recorded in Spencer Gulf but most records are incidental findings and few studies have integrated knowledge on these important organisms of relevance for the area.
15. The whole of Spencer Gulf has not been modelled as a single economic region, although there have been several recent regional and industry-focused assessments, as well as assessments of proposed developments.

### Activities, stressors and impacts

16. Thirteen different activities in and around Spencer Gulf encompassing fishing, aquaculture, desalination, urban development, resource development, energy and industrial, power production, shipping, ports and dredging, defence, other infrastructure development, agriculture, recreation and ecotourism, and conservation were considered in terms of their potential impacts on the Gulf and other activities.
17. Fishing includes commercial, recreational and charter fishing operations. The landed annual value of commercial fisheries of Spencer Gulf averaged over the last 5 years was $65.9M. The Spencer Gulf king prawn fishery is one of only eight Marine Stewardship Council certified prawn/shrimp fisheries in the world. The region supports 25% of the total recreational effort including the largest catches of a number of species. Several towns have fishing charters that operate from them. Key issues of relevance to fisheries include climate change, other anthropogenic impacts, access to and use of existing fishing groups, redistribution of fishing effort due to marine parks, and increasing demand for seafood.
18. Eighty percent of South Australian aquaculture production is from Spencer Gulf and product is estimated at $229M for 2010/11. Only finfish (southern bluefin tuna and yellowtail kingfish) and bivalves (Pacific oysters and blue mussels) are currently farmed in the sea. Similar issues as fishing apply to aquaculture, as well as effects from addition of feed and wastes into the system and emerging diseases.
19. With water being a scarce resource and our main water supply from the River Murray construction of desalination plants for augmentation of water as well as supply to industry is proposed. If not managed properly, the saline concentrate from desalination plants may pose a local threat to planktonic and benthic ecosystems.
20. The main urban centres of Spencer Gulf are coastal. Increases in coastal urban populations are likely which may bring more marine infrastructure for leisure activities that may act as novel habitats for invasive species and emerging disease. Other potential issues include declining water quality associated with nutrients and pollutants.
21. South Australia has a diverse commodity base for mineral exploration. At the time of writing there were 20 major operating/approved mines and 925 exploration licences. The key link to marine waters in terms of potential impacts and stressors is through additional infrastructure required for development including water, power and ports.
22. Although much of the electricity in the region is sourced from the national grid, there are two coal-fired power stations near Port Augusta and several companies investigating green-energy options. At present, cooling water and ash are discharged, although there is little evidence of impacts.
23. Major shipping routes in Spencer Gulf intersect commercially important fishing grounds and are close to some coastal aquaculture operations. Increased maritime trade has the potential to produce both direct stressors and indirect effects due to increased port use and port expansion.
24. Five existing port facilities occur in Spencer Gulf, and the lack of deep-water bulk commodity port facilities to meet future demand has led to proposals for up to four more. Potential impacts relate to location of the port, construction activities and operation of the port.
25. The Cultana Training Area, between Fitzgerald Bay and Port Augusta, is a major training area for South Australian based army units and is expanding to support future joint

training needs including ship to shore training activities. There is potential for marine-based impacts from such activities.

26. A range of other infrastructure exists around Spencer Gulf including boat ramps, jetties, navigation markers and permanent moorings. New environmental industries such as organic glasshouse vegetable production and biofuel generated from saltwater algae, utilising the excellent solar resources of the region, are in development or expansion phases. Similar stressors and impacts as to those found for desalination, ports and dredging and shipping are possible.
27. Aboriginal groups are represented around the Gulf. Some areas are covered by Indigenous Land Use Agreements and fishing agreements are being negotiated.
28. Agricultural activities including mixed farming with cereals, canola and legumes, as well as sheep and some cattle, extend close to the coastline. With a drying climate, dust storms from northerly and westerly winds may affect Gulf waters, although land cover maintenance may minimise such impacts.
29. A range of tourism and recreational activities occur in Spencer Gulf waters. These activities may increase if expansion of mining and other industrial activities attracts more people to the region. The extent and frequency of recreational boating activity and potential impacts on habitats is poorly understood. In addition, the impacts of tourism and recreational activities on iconic, threatened and endangered species is not well known for many species.
30. Marine parks are currently being implemented in South Australia and along with aquatic reserves should be considered as part of any spatial or multiple use management plan. Many of the activities have the potential to impact the effectiveness of marine parks, and redirected pressure from other activities may put added pressure on other areas of the Gulf.

## Marine spatial planning

31. Spencer Gulf provides an ideal area for marine spatial planning, in which an assessment of multiple objectives, potential conflicts and synergies among users, the risk of cumulative impacts of various activities, a range of spatial zoning and management options and scenario testing is required.
32. Decision support tools can help visualise cumulative impacts in an area, the number of conflicts between users, and between users and the ecosystem, and the number of tradeoffs required by each sector.
33. Ecosystem models may assist in decision-making by providing a means to address ‘what-if’ management questions or scenarios.
34. The next planning stage of Australia’s national Integrated Marine Observing System could include a focus on coastal waters of Spencer Gulf.

## Synthesis and integration

35. Spencer Gulf is on the verge of major expansion in industrial activity, with associated increases in other activities, but is a relatively unimpacted system thereby providing an opportunity for South Australia to become a world leader in marine ecosystem-based management.
36. Understanding and quantifying the spatial distribution of the full range of activities in Spencer Gulf, as well as the vulnerability of marine ecosystems to these activities, is required. Such an analysis would then allow a cumulative impact map to be calculated.
37. A range of different models that complement each other to give a more robust understanding of the system is required including conceptual qualitative models. A whole of ecosystem model focusing on the fisheries and aquaculture sectors is currently being developed, but could be expanded to include other sectors and activities.
38. A single integrated project around oceanography, biology and ecology is required to gain a better understanding of the Gulf and the key drivers. Priority research areas include biosecurity, shipping, port development and desalination. Research should include an

assessment of cumulative impacts both within an activity, as well as among multiple activities.

39. The Spencer Gulf Ecosystem Development Initiative represents an opportunity to get things right from the beginning rather than to incur costly restoration efforts in future.

# SUMMARY OF MAIN KNOWLEDGE GAPS

The main knowledge gaps are summarised in this section. They are ordered as in the main body of the report and are listed in no particular order in terms of priority. Additional detail can be found in the body of the report. On-going stakeholder engagement and communication, as well as review of knowledge gaps is required.

## Environment and Ecology

### Physical oceanography

- The role of sea breezes in circulation of the gulf
- Temporal and spatial distribution of vertical mixing and dissolved oxygen
- Physics associated with flushing over time scales of years, and under what conditions the flushing might change
- Spatial and temporal nature of the front that forms near the mouth of Spencer Gulf

### Biological oceanography

- Spatial and temporal variation in nutrient and plankton throughout Spencer Gulf
- Importance and coupling between the microbial (both pelagic and benthic), benthic (seagrass, mangroves, sediments) and macroalgal communities in biogeochemical cycles and ecosystem productivity
- Quantities and characteristics of industrial and other anthropogenic nutrient inputs entering the gulf
- Biology and ecology of a number of the small pelagic fish in the gulf
- How the frequency and strength of upwelling influence recruitment success, growth rates and movement patterns of Australian sardine and other pelagic fish
- Effects of environmental factors including climate variables on composition and structure of the pelagic fish assemblage

### Terrestrial and coastal environment

- Investigation of coastal marine environments including inland wetlands
- Influence of physico-chemical factors on distribution and abundance of mangroves and saltmarsh
- Understanding of biodiversity and benthic communities associated with intertidal areas
- Temporal nature and influence of ephemeral streams and short run creeks on the gulf

### Benthic environment and ecology

- Distribution and abundance of biota, as well as how assemblages respond to changes in physico-chemical factors and biotic interactions
- Ecological processes structuring benthic assemblages
- Mechanisms of seagrass loss and early indicators of seagrass decline
- Food chain links between seagrass production and fisheries production

### Iconic and threatened, endangered & protected species

- Critical habitat and movement corridors in Spencer Gulf for southern right whales

- Importance of commercial fish and aquaculture species in diets of sharks
- Status and trends in abundance for key seabird species (little penguin, fairy tern), including factors contributing to changes in abundance
- Status, trends in abundance and resilience of key shark and dolphin species, as well as connectivity between key populations
- Survival rates of giant Australian cuttlefish returned to the water following line fishing and prawn trawling
- Movement patterns of giant Australian cuttlefish throughout their life history

Pests and pathogens

- A complete risk profile incorporating all vessel traffic, to outline which species of pests and pathogens are likely to arrive, successfully establish and what their probable impacts will be
- Surveillance for marine species and mechanisms for managing established pests and diseases
- Understanding of potential consequences posed from new and emerging pests and pathogens

Economy as a whole

- Capacity to understand the current Spencer Gulf economy from both a market and non-market perspective
- The relationship between the economy and the ecosystems

### Activities, stressors and impacts

Fishing

- How variation in the physical environment affects other elements in the ecosystem
- Biosecurity risks associated with bait translocation and use
- Impacts of fisheries bycatch on fish and marine mammals

Aquaculture

- Bivalves: What the key aquaculture and naturally occur species consume; how food of key aquaculture species fluctuates over time and in relation to environmental parameters; how farmed bivalves may control phytoplankton and seston concentrations; effect of bivalve aquaculture on density of predators and detrivores; interaction between bivalve aquaculture and other ecosystem components
- Finfish: Spatial and temporal understanding of relationships between quantity and ingredients of aquaculture feed, quantity of fish farm waste and environmental impact of organisms on the seafloor and in the water column; determine how naturally occurring species associated with aquaculture assimilate and disperse fish farm wastes; refinement of hydrodynamic-biogeochemical model for managing finfish aquaculture zones, future planning and carrying capacity
- General: Improve knowledge of integrated multi-trophic aquaculture; refine environmental monitoring of aquaculture sectors to include cumulative effects and ecosystem-based management

Desalination

- Spatial and temporal variation in the fate of saline concentrate discharge at a range of scales
- Impact of saline concentrate of benthic and pelagic communities including how effects may change with different environmental conditions
- Identification of benthic and pelagic species suitable for use in monitoring studies to indicate salinity/environmental stress
- Monitoring studies to assess spatial extent (if any) of potential impacts
- Manipulative experimental field studies on the effects of saline concentrate
- Impact of entrainment of microbes and plankton on primary and secondary productivity and food web dynamics

Urban development

- Assessment of how urban structures affect the marine environment
- Understanding of how nutrients and pollutants impact marine ecosystems including levels at which these inputs may lead to deleterious environmental consequences

Power production

- Effects of warm water on fish assemblages including potential effects on growth and movement

Shipping

- Economic and other impacts of shipping on commercial fisheries and aquaculture
- Impacts of shipping on marine species
- Risk profiles for biological invaders
- How Spencer Gulf shipping trade fits within the global transport network including scenarios around future increases in ship size, number and residence times

Ports and dredging

- Potential cumulative impacts of multiple port developments
- How turbidity and resuspended solids impact flora and fauna
- Impacts of noise from construction activities on key fauna
- Modelling of plume pathways under different current and wind scenarios including monitoring of potential impacts and an understanding of impacts on other activities
- Characterisation and mapping of pollutants in sediments around proposed developments; toxicity tests using identified pollutants

Defence

- Greater understanding of proposed ship to shore activities to identify potential impacts

Agriculture

- Impact of dust on Spencer Gulf waters
- Immediate and longer term effects of water discharge from surface and groundwaters in the Gulf

Recreation and tourism

- Residency period and relative population size of white sharks at Neptune Islands, as well as population structure
- Understanding of how shark cage diving operations affect life history traits and energy budgets of white sharks
- Spatial and temporal extent and frequency of recreational boating activity
- Impacts and frequency of propeller scarring and anchoring from recreational vessels

Conservation

- Information on current baseline conditions from which to assess change through time
- Understanding and monitoring the effectiveness of marine parks including how design of marine parks may influence effectiveness, how distribution and abundance of key species changes with marine park implementation
- Characterise larval dispersal and demographic connectivity of organisms

**Marine spatial planning**

- Mapping of current and anticipated uses of Spencer Gulf including potential stressors for individual and all activities
- Overlay social and ecological values onto individual and cumulative stressor maps
- Identification of spatial and temporal boundaries of activities with consideration of biophysical and ecosystem processes
- Consideration of alternative management scenarios and trade-offs
- Assessment and quantification of trade-offs among uses from different management decisions
- Development of simulation models to assess "what if" scenarios
- Conceptual models of relationships and interactions in the system
- Understanding of relative importance of different stressors and their interactions
- Identification of ecological indicators that are sensitive to ecosystem change that may be used to measure ecological health in Spencer Gulf
- Understanding of resilience of the system and what the key tipping points and critical thresholds are
- Observations of physical, biological and chemical parameters through (for example) a marine observing system

# 1.0 BACKGROUND

South Australia, and in particular the Spencer Gulf region, has significant opportunities for expansion of mining, with a large number of new mineral/mineral processing ventures possible. Associated with such development will be increased shipping and associated infrastructure (port development, desalination plants, power plants) along with biosecurity risks. Spencer Gulf is also recognised for its clean, green image in terms of its seafood production and has several tourism ventures based on environmental assets. Both wildcatch (e.g. prawns, snapper, garfish, King George whiting, abalone, southern rock lobster) and aquaculture (southern bluefin tuna, yellowtail kingfish, abalone, oysters, mussels) in Spencer Gulf provide important economic returns to the State and are expanding. Spencer Gulf is also the focus of several marine parks and zoning of sanctuary areas is underway. These are likely to conflict with both existing and proposed policy commitments associated with transport, aquaculture and fishing. The region has important relict populations of tropical species (e.g. commercially fished blue crab), and is the only area in the world known to support a breeding aggregation of cuttlefish. It is an important nursery area for fish. The key question to answer is how South Australia can support development of mining ventures, expansion of fishing and aquaculture, and conservation and recreation needs, while simultaneously delivering on the environmental, social and economic objectives associated with Spencer Gulf. The ultimate aim of an integrated research project around Spencer Gulf is to provide all stakeholders with access to independent and credible information about Spencer Gulf and opportunities to better understand any potential impacts so that informed decisions can be made. This will be achieved by creating an independent and credible decision support system to enable evidence-based assessment of development options with full consideration of social and economic benefits and cumulative environmental implications in a rapidly developing region.

Scenarios for development in Spencer Gulf will focus on:

1. Development Scale
2. Key activity that will affect health of the Gulf
3. Regions

Consultation with industry and government suggests that considerable development of the Spencer Gulf region is likely and that the information needed to manage resultant cumulative impacts may not be available. One of the main drivers of this development is expansion of the mining and mineral processing industry in South Australia. Expansion of aquaculture and the development of marine protected areas are other drivers.

The proposed focal point for analysis is a comparison between the immediate past and scenarios for development of the Gulf over the next 15 years. Therefore, the time frame for analysis is between now and 2030. Where possible, the data needed to model out to 2050 will also be collected.

## 1.1 REGIONS

Following discussions with research scientists, eight regions are proposed (Figure 1). The boundaries for each of these regions need to be developed further and will be determined by data availability, existing regions used for other purposes (e.g. for fisheries or aquaculture), and depth contours. The proposed regions currently take into account the marine bioregions with some consideration of marine biounits. The outer boundary for Spencer Gulf will be the 100m-depth contour – this boundary has been used for the Fisheries Research and Development

Corporation (FRDC) trophodynamic modelling component of the Spencer Gulf ecosystem and development initiative (SGEDI). Regions at the lower end of Spencer Gulf (centred around Port Lincoln and Lower Yorke Peninsula) and extending to the 100 m depth contour are not delineated in Figure 1.

For working purposes, a town (where possible) will be used as a descriptor for the broader region.

| | |
|---|---|
| Region 1 | Port Augusta |
| Region 2 | Whyalla |
| Region 3 | Port Pirie |
| Region 4 | Arno Bay |
| Region 5 | Port Victoria |
| Region 6 | Port Lincoln (outer boundary yet to be determined) |
| Region 7 | Lower Yorke Peninsula (outer boundary yet to be determined) |
| Region 8 | Offshore of mouth of Spencer Gulf to 100m-depth contour (need to determine whether to include this region and if so, what are its boundaries). |

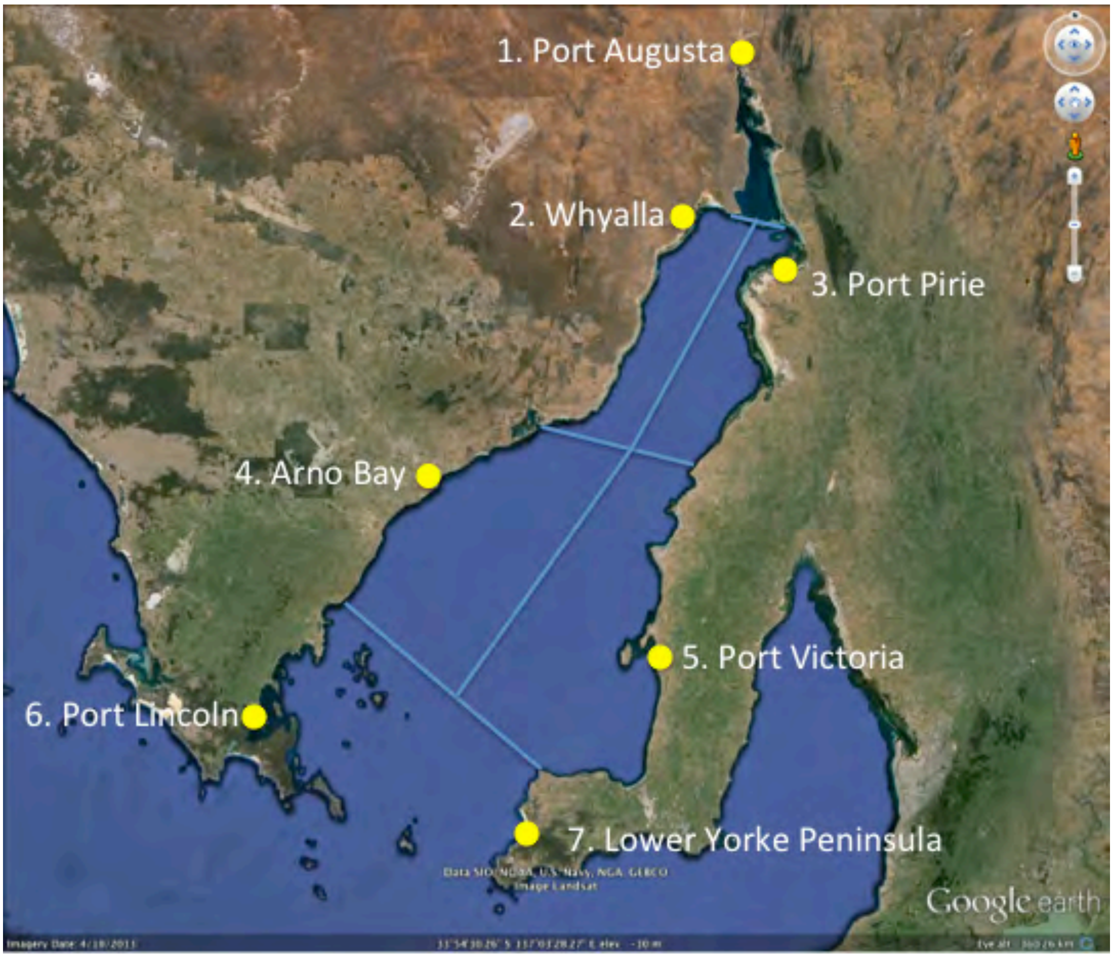

Figure 1. Map of Spencer Gulf showing proposed regions. Boundary for region 6 and 7 still need to be determined.

## 1.2 ACTIVITIES

For each region, data for each of the following activities will be collected for a baseline scenario and then used to develop the three development scenarios.

1. Commercial fishing (tonnes caught per annum by species)
2. Aquaculture production (tonnes produced, and feed inputs, per annum by species)
3. Recreational fishing
4. Desalination (gigalitres of water per year)
5. Water use from and waste water disposed of to the marine environment – industry (gigalitres of water abstracted and returned by temperature class per year, and its constituents (e.g. nutrient levels))
6. Waste water disposed of to the marine environment – urban (gigalitres of water returned to the sea per year, and its constituents (e.g. nutrient levels))
7. Ships moving and anchoring in the Gulf (number of vessel movements by size class)
8. Loading ships (tonnes loaded from a port, tonnes barged out to a loading platform per year, by product type)
9. Dredging (cubic meters of sediment dredged every 5 years)
10. Recreational boating (number of recreational vessels in different size categories moored in region per year or launched for trailerable vessels)
11. Dust load (tonnes per hectare per year deposited into the region)
12. Degree of marine protection (hectares closed as sanctuary areas, habitat protection zones)

While potential quantitative indicators for each activity are given above, these will be refined to ensure that the best indicators are used. As far as possible, there should only be one indicator per activity.

## 1.3 DEVELOPMENT SCENARIOS

Development scenarios will be prepared for each region and each activity through a process of consultation with industry and government (Figure 2). To the extent possible, use will be made of recent infrastructure and other studies.

Three scenarios are envisaged:

1. A "**Steady As She Goes Scenario**" with growth continuing at a rate similar to that which has occurred recently (e.g. last 5 years). (Any negative rates of growth within an activity will be assumed to be zero for the next 15 years.)
2. A "**Rapid Development Scenario**" with a doubling of the baseline rate of growth in each region.
3. An "**Extremely Rapid Development Scenario**" which would begin by assuming that all identifiable but non-competing proposals would get up in the time frame proposed by the proponents.

Great care will be taken when developing scenarios for the entire Gulf. We will not assume that the scenarios developed for each region can be added together. When summed together to provide a perspective for the entire Gulf, it would be assumed that no more than 50% of the Extremely Rapid Development Scenario proposals established for each of the regions would proceed. When modelling aggregate impacts, a similar approach would be taken for the Rapid Development Scenario.

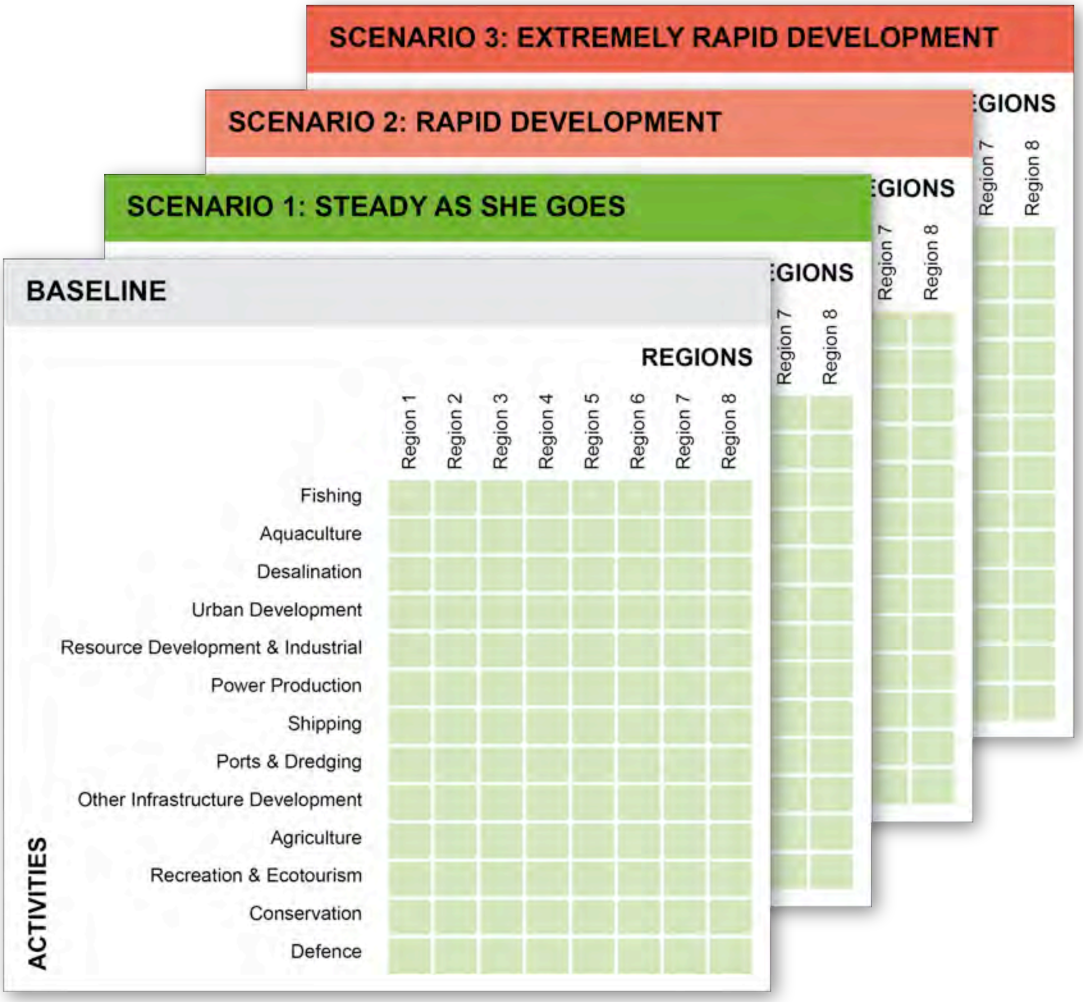

Figure 2. Summary of the proposed approach showing key activities, regions and scenarios.

# 2.0 STAKEHOLDER WORKSHOPS

Ten stakeholder workshops were held in November and December 2012. Initial workshops focused around key industry sectors:

- Fishing and aquaculture
- Recreation and conservation
- Mining, energy, ports and other major developments.

At each workshop we discussed key concerns of stakeholders, what they saw as important information gaps that could be included in future research, what their aspirations for the region were, what they considered the key influences in the region and what outcomes from a Spencer Gulf ecosystem development initiative they thought were most important.

There was reasonable cross over between concerns and foci discussed at all three workshops. Differences tended to be from the focus of activity, a viewpoint based on activities, rather than completely separate issues. For example, water based activities – fishing and aquaculture – more than the other sectors considered issues from a boat and ship based perspective. Mining, partially, looks at the Gulf through a planning and regulation lens. These perspectives are important, as it is sometimes hard to see commonality and differences without recognising that the manner in which we look at issues is framed by our activities. Key concerns and issues that emerged were:

- Transport corridor issues
- Dredging & heavy metal mobilisation
- Pollution (sediments, marine debris) / oil spill
- Marine pests / ballast water
- Single Large Or Several Small (SLOSS) infrastructure (Ports, desalination plants)
- Lack of infrastructure
- Land-based impacts
- Cuttlefish declines

Other general points to emerge were:

- Evidence-based decision making required
- Climate scenarios to be considered in models and the need to adapt to mitigate impacts and repair environments
- Cumulative impacts to be considered
- Recreational use to be part of any trade-offs
- What are threshold levels, buffering capacity & resilience of the system?

Following these three workshops, a synthesis workshop was held in which stakeholders looked at what influences what, possible decision drivers and important research areas. A summary of previous workshops was provided based around *driving processes* (e.g. government laws, global drivers, climate, mining pipeline, agricultural products, community aspirations/objectives), *consequences* (e.g. water demand and supply, power demand and supply, agricultural products, marine infrastructure, land infrastructure, human population, imports, threats), *assets* (amenity value, fish population, fish catch, aquaculture, marine access, ships, non-accessible coast, discharges, other industrial production, water quality), *socio-economic values* (e.g. biodiversity and ecosystem services, habitats, commercial fishing and aquaculture stocks, aesthetic values, fishing and aquaculture production, mineral production, regional development, agricultural production, defence expenditure). There was group discussion around synthesis information from the previous workshops (fisheries and aquaculture; conservation and recreation; industry, mining, energy, port and other major developments) before some of the key driving processes were investigated in more detail.

A series of workshops were then held in the key regional centres of Whyalla, Port Augusta, Port Pirie, Wallaroo and Port Lincoln (Figure 3).

A final concluding workshop was held in Adelaide.

In total, more than 500 people and 200 companies representing a large range of stakeholders were invited to participate. One hundred people were directly involved in the workshops.

Figure 3. Locations of key regional workshops.

# 3.0 EXISTING KNOWLEDGE AND INFORMATION GAPS

## 3.1 BRIEF BACKGROUND

Spencer Gulf in South Australia (Figure 1) is a large (area of approximately 7500 km$^2$), sheltered, tidal, inverse estuary[1]. The gulf is 325 km long with a mean width of ~ 60 km; it is a shallow body of water with a mean depth of ~22 m, decreasing to ~7 m in the upper reaches. The gulf is surrounded by arid lands due to low rainfall in the region (rainfall range 250 – 600 mm per annum). The region also experiences high evaporation rates (2400 mm per annum) compared to precipitation. The combination of low rainfall and high evaporation results in the top of the Gulf reaching salinities in excess of 40‰ (Nunes and Lennon, 1986). Inverse-estuaries are not unique to the South Australian gulfs (Spencer Gulf and Gulf St Vincent). They are also found at Shark Bay in Western Australia, and in the Northern Hemisphere, (e.g. Red Sea, the Persian and Arabian Gulfs and the Mediterranean).

Spencer Gulf is within the coastal geomorphological region called the Gulfs Province, extending from Cape Catastrophe, on the south eastern tip of Eyre Peninsula, to Rapid Head on the Fleurieu Peninsula, which also includes Gulf St Vincent, and covers all of two marine bioregions, Northern Spencer Gulf (Point Riley to Port Augusta to Shoalwater Point) and Spencer Gulf (Peake Bay – West Cape – Point Riley – Shoalwater Point), with the lower part of Spencer Gulf forming part of the Eyre bioregion (Edyvane, 1999). Two natural resource management (NRM) regions, Northern and Yorke NRM and Eyre Peninsula NRM, surround Spencer Gulf waters. There are 31 offshore islands within Spencer Gulf waters, with the majority near Port Lincoln in the Sir Joseph Banks Group. The remaining islands are mostly located between Thistle Island and the mainland, although Wardang Island is further up the Gulf.

The Spencer Gulf region is inhabited by several indigenous groups. Larger groupings include the Nawu, Banggaria, Nukunu and Narangga (http://www.abc.net.au/indigenous/map/). Indigenous land use agreements (ILUA) exist for some areas of Spencer Gulf and fishing ILUAs are being developed.

This section of the document focuses on reviewing existing knowledge and information gaps around three broad areas (1) Environment and ecology, (2) Activities, stressors and impacts, and (3) Marine spatial planning.

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[1] An inverse estuary is one in which seawater is measurably more concentrated by the removal of freshwater, in comparison to more common 'positive estuaries' whereby seawater is measurably diluted with freshwater towards the head of the estuary.

## 3.2 ENVIRONMENT AND ECOLOGY

Four broad areas are initially discussed focusing around physical oceanography, biological oceanography, terrestrial and coastal environments including intertidal regions, and benthic subtidal environments. Several key groups of organisms namely iconic and threatened, endangered and protected species, as well as pests and pathogens are then investigated in further detail in terms of what is currently known for Spencer Gulf and where the key knowledge gaps are. Finally, this section looks at the economy as a whole and non-market benefits.

### 3.2.1 PHYSICAL OCEANOGRAPHY

Over the last 33 years, considerable progress has been made in understanding the physical oceanography of Spencer Gulf. During summer, the warm and saline waters of the Gulf are sub-tropical in nature, in contrast to the colder, fresher temperate waters of the continental shelf (Middleton and Bye, 2007). The upwelled nutrient rich waters on the shelf are largely prevented from entering the gulf due to a front that separates the warm gulf waters from the colder shelf waters. During autumn, winter and early spring, atmospheric cooling and evaporation leads to the formation of cold dense plumes of gulf water that flow from the upper gulf and out onto the shelf (Nunes Vaz et al., 1990). This process typically begins in April–May and drives an inflow of relatively nutrient rich water on the western side of the gulf (Doubell et al., 2013).

The tides of the region are also unusual in that the gulf acts as a ¼ wave resonator (Easton 1978) leading to very large tidal amplitudes in the mid to upper gulf (1.2 m/s) and strong horizontal mixing (Middleton et al., 2013).

**Surface Waves and Sediment Transport**

Models of surface waves within the gulf have been developed for the Boston Bay region (Jones et al., 2012) and the entire gulf (James 2013), with each model validated against data. Waves may be expected to lead to enhanced bottom friction, although James (2013) found the effects to be generally small in a coupled hydrodynamic model. These studies, however, did not consider the effects of Stokes drift, which acts to move buoyant surface material in the downwind direction, or breaking waves, which can set up alongshore currents that are important to sand transport and beach morphology.

**Circulation in the Tidal Band (6 – 30 hours)**

Very large tidal velocities (0.4 – 1.4 m/s) and sea level displacements (1-2 m) are observed in the middle to upper gulf (Figure 4), along with the “dodge” tide, whereby tidal amplitudes become relatively small every 15 days or so. The former is due to the length of the gulf resulting in a quarter wave resonance of the semi-diurnal tides. The dodge tide arises from the fact that the amplitudes and phases of the semi-diurnal $M_2$ and $S_2$ constituents are approximately equal.

Hydrodynamic models have been developed for the gulf and have very good predictive skill for the tides (e.g. Herzfeld et al., 2009; Luick et al., 2013). In addition, the recent study by Middleton et al. (2013) shows that the strong tidal velocities give rise to enhanced horizontal mixing (shear dispersion) that is very important to the flushing of anthropogenic nutrients, including aquaculture, industry and sewage outfalls.

## Mean (seasonal) circulation

Inferences from conductivity, temperature and depth (CTD) data, current meter data and numerical models indicate a generally clockwise circulation in the southern and middle gulf regions during winter and to a lesser extent during summer. The circulation (< 2 cm/s) is very weak compared to the tides but is very important for large scale flushing. The clockwise circulation is driven by the very strong evaporation and cooling that occurs during the onset of autumn.  Relatively cold, salty, dense water is formed during late summer and early winter in the upper gulf. This water flows down into the deeper, middle and southern gulf regions and exits on the eastern side of the gulf until the following spring. In turn, this water is replaced by fresher shelf water that is drawn in on the western side. The physics of this process has been well established and most recently, Teixeira (2010) has shown the dense water outflow along the eastern side breaks up into 40 km scale Spencer Gulf eddies (SPeddies). A second impact of the large evaporation is that the water lost to the atmosphere must be replaced by a net inflow into the gulf, with velocities of only a cm/s or so (Nunes Vaz, 2014).

The flushing mechanism outlined above leads to a distribution of salinity that changes only a little on inter-annual time scales. In part, this is because larger salinities that might result from above normal evaporation (or desalination plants) create denser outflows that are accompanied by larger inflows of fresher shelf water (Nunes Vaz, 2014). Indeed, it has been shown (Nunes Vaz, 2014) that the observed salinity levels in the upper gulf and at a given time, are well predicted by the net evaporation over the previous six months. The upper gulf has a flushing time of six months. These results are very important as they relate to the maintenance of the distributions of heat and salt that in turn supports the ecosystems of the gulf.

In conjunction with an observational program, hydrodynamic and biogeochemical models have been developed for the gulf to assess the importance and fate of anthropogenic nutrient sources that arise from aquaculture, industry and sewage outfalls (Middleton, 2013). A key finding here is that the dominant source of nitrates is the adjacent shelf during autumn and winter. The inflow is that described above and driven by the overall flushing of the gulf.

During summer, nutrient rich water is upwelled onto the shelf near Kangaroo Island and thought to support the rich ecosystems of the South Australian region. However, the model results for summer indicate that these nutrient rich waters are blocked from entering the gulf (Luick et al., 2013). The mechanism for this is likely the formation of a density minimum near the gulf mouth that is accompanied by localised upwelling on both the gulf side and shelf side (Nunes Vaz, 2014). This density minimum is often evident as a sharp front in satellite temperature data.

## Weather-band circulation (30 hrs – 30 days)

Weather band currents in the gulf are relatively weak (< 5 cm/s). The hydrodynamic models of Luick et al. (2013) and Herzfeld et al. (2009) generally predict amplitudes of this order although the predictive skill can be poor. The reason for this is thought to be due to the highly variable temperature and salinity fields that can affect density and the vertical profiles of velocity. A detailed examination of all conductivity, temperature and depth (CTD) data from the gulf was done by Teixeira (2010). He found that there was no typical summer or winter profiles of temperature and salinity. During summer, a warm surface mixed layer can be found, but the effects on density can be modified by changes in the salinity field due to evaporation. During winter, and as noted above, the cold, dense SPeddies that flow southwards along the eastern side of the gulf will also affect the weather-band velocity field. Increasing model resolution should go part way to improving modelled weather-band currents.

### Knowledge gaps

Despite the progress outlined above, there remain a number of areas that need further research. In summary:

- An area that has not received any attention is the role of the sea breeze in the circulation of the gulf. The sea breeze can be quite large (10 m/s) during summer and can extend well into the middle gulf. The effects on gulf circulation and mixing are unknown but may be important.
- A study is needed to quantify the temporal and spatial distribution of vertical mixing (i.e. turbulence vs. stratification) and dissolved oxygen, particularly during summer periods around the dodge tide, to determine the transport of oxygen to the bottom waters which support a diverse range of flora and fauna.
- Further measurements and modelling are needed to determine the detailed physics of flushing over the time scales of years and under what conditions the flushing might change.
- A study is needed to determine the temporal and spatial nature of this blocking as the front may at times break down and allow the nutrient rich waters to penetrate into the gulf.

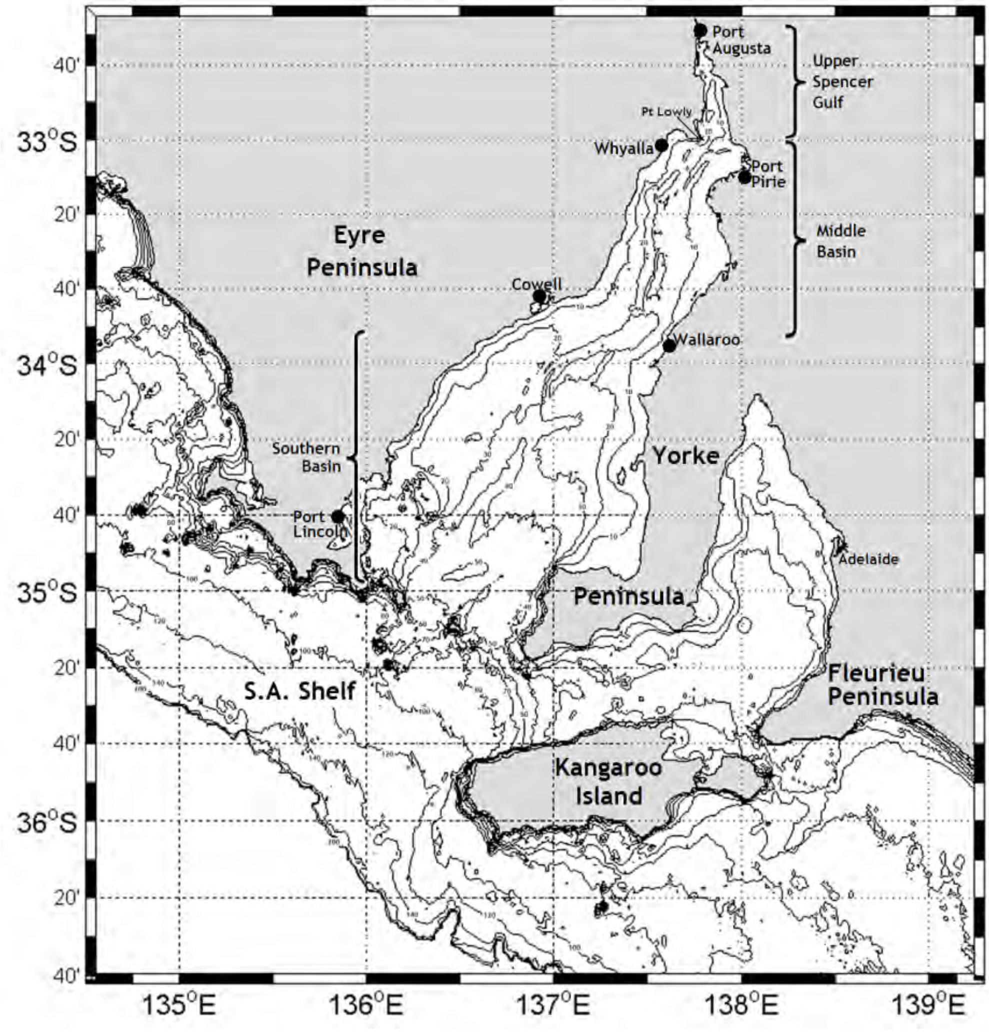

Figure 4. Spencer Gulf and Gulf St Vincent in the context of the South Australian Seas. The three regions of the Gulf referred to in the text are indicated. Bathymetry contours are annotated in metres.

### 3.2.2 BIOLOGICAL OCEANOGRAPHY

To date, there have been few studies focusing on the biological oceanography of Spencer Gulf. Temporal variations in plankton communities, however, may be drawn from a limited number of studies with adequate temporal coverage (Tanner and Volkman, 2009; van Ruth et al., 2009a; van Ruth et al., 2009b; Doubell et al., 2013; van Ruth and Doubell, 2013), remote sensed data and data derived from South Australian Research and Development Institute (SARDI) sardine surveys. Overall, the annual cycle of productivity in Spencer Gulf begins with a bloom of high primary and secondary productivity through late summer/early autumn. Decreasing secondary productivity in late autumn subsequently promotes high phytoplankton biomass at a time when primary production remains high. The decline of the phytoplankton bloom then begins during a winter period of low productivity, which continues into spring indicating the "bottoming out" of productivity and the beginning of a new cycle. Remote sensing data suggest increasing productivity from south to north with some inter-annual variability. Clearly, however, more data on the spatio-temporal distribution of plankton and variations in primary and secondary productivity are required to test this hypothesis.

**Physical and chemical drivers of productivity**

As expected, the underwater light field in Spencer Gulf varies with season and latitude. The attenuation of light with depth also varies in space and time, with no clear seasonal or spatial pattern, and is typically greater than that observed on the shelf due to high levels of turbidity and particulate organic matter (POM). Nonetheless, euphotic depths in Spencer Gulf typically exceed the maximum water depth indicating that the water column is well-lit from surface to bottom and irradiance is unlikely to limit primary productivity (van Ruth and Doubell, 2013).

Macro-nutrient concentrations (nitrogen oxides, ammonia, phosphorus and silica) are generally lower than those observed on the adjacent shelf region (van Ruth et al., 2010a, b) (Southern Australian Integrated Marine Observing System (SAIMOS) program), and nutrient stoichiometry indicates periods of potential nutrient limitation of phytoplankton growth (van Ruth and Doubell, 2013). Despite generally low nutrient concentrations, clear spatial and temporal patterns have been observed in the Gulf. Nitrogen oxide concentrations are generally < 3 μM, with clear peaks along the western side of the southern basin during winter and spring. These peaks are separated by periods of very low concentrations, typically below detection limits, during summer and autumn. Nitrogen oxide concentrations in the middle basin and along the eastern side of the southern basin remain low throughout the year (< 0.5 μM). A coupled hydrodynamic-biogeochemical model for the Gulf indicates that the spatial and temporal distribution of nitrate is strongly associated with estuarine ciriculation and seasonal flushing (Doubell et al., 2013). Ammonia concentrations across the Gulf are relatively stable throughout the year (< 0.3 μM), with maximum concentrations occuring during the autumn and winter periods, particulary in the middle basin where concentrations exceeded 1 μM. Again, modelling studies indicate that anthropogenic nutrient loads from aquaculture and other sources (i.e. waste water treatment plants (WWTP), industry), as well as the re-mineralization of organic material through coupled ammonification, nitrification and de-nitrification processes, assists in maintaining ammonia levels (Doubell et al., 2013). Phosphorous concentrations across the Gulf are typically very low, often below detection limits. Intermittent high concentrations of phosphorous, as large as 1.07 μM, have been observed but show no clear pattern in space or time.

Silica levels are also typically low, with concentrations ranging from ~0.5 - 1 μM in the southern basin. Silica concentrations are greatest in the middle basin, with a clear peak in concentrations (~2 - 5 μM) during the autumn/winter period (van Ruth and Doubell, 2013).

## Microbial dynamics

There is only one known study which has investigated the microbial dynamics in the Gulf (Seuront et al., in prep.). Seasonal surveys and flow cytometric analyses show that viral and bacterial abundances are in the order of $10^6$ cells $ml^{-1}$ and have seasonal peaks in autumn and summer, respectively. Minimum abundances occur in winter. Three pico-phytoplankton populations have been identified throughout the year with cell abundance for *Synechococcus*, *Prochlorococcus* and pico-eukaryotes in the order of $10^2$ to $10^4$ cells $ml^{-1}$ for each population. All three pico-phytoplankton populations are more abundant in northern Spencer Gulf during summer (Seuront et al., in prep.). Genetic analyses of the microbial community also show that the microbial phyla are typically marine and comprise mainly *Cyanobacteria* and *Proteobacteria.* The cyanobacteria are dominated by *Synechococcus*, a dominant prokaryotic phototroph in most coastal regions, particularly temperate environments. *Prochlorococcus* is also a dominant oceanic cyanobacterium, thriving in tropical open ocean waters, but is has only been observed in the southernmost part of the southern basin, consistent with the horizontal exchange with shelf waters (Seuront et al., in prep.).

Incubation experiments, which quantify seasonal change in the rate of micro-zooplankton grazing, viral lysis on heterotrophic bacteria and pico-phytoplankton mortality, show that mortality rates are typically low in the Gulf. Bacterial mortality rates are highly variable among locations and seasons, and occur due to micro-zooplankton grazing in summer and winter, and viral lysis in autumn. In general, these findings suggest that the locations investigated in the Spencer Gulf are characterized by weak microbial activity and that the losses of pico-phytoplankton are minimal when compared to other coastal waters (Seuront et al., in prep.).

## Phytoplankton dynamics and primary productivity

A full annual cycle of phytoplankton biomass, abundance and community composition in Spencer Gulf has been recently investigated (van Ruth and Doubell, 2013). Phytoplankton biomass levels (chlorophyll a (chl a)) are generally < 1.0 μg $L^{-1}$, with the highest levels (~0.8 μg $L^{-1}$) occurring in summer in the middle basin. A clear seasonal pattern occurs in the southern basin, characterised by winter/spring biomass minima and summer/autumn maxima (van Ruth and Doubell, 2013). These patterns are also evident in remote-sensed fluorescence data (Bierman et al., 2009), van Ruth unpublished data). Size fractionated analysis shows that the phytoplankton biomass in Spencer Gulf is always dominated by cells smaller than 5 μm (van Ruth and Doubell, 2013). The ratio of different phytoplankton accessory pigments to total chl a concentration, also shows that the phytoplankton community is dominated by three main taxa; diatoms, cyanobacteria and haptophytes. Cyanobacteria generally dominate the community in the southern basin, with diatoms dominating in the middle basin (van Ruth and Doubell, 2013).

Primary productivity in Spencer Gulf is lowest in winter/spring (<200 mg C $m^{-2}$ $d^{-1}$) and highest in summer/autumn (~300 – 900 mg C $m^{-2}$ $d^{-1}$) (van Ruth et al., 2009b; van Ruth and Doubell, 2013). These high summer productivities are comparable to the lower range reported for mid-shelf and coastal waters of the eastern Great Australian Bight during the summer/autumn upwelling season (800-1600 mg C $m^{-2}$ $d^{-1}$, van Ruth et al., 2010), and for localised upwellings off southwestern Western Australia (Hanson et al., 2005). There are no clear spatial patterns in primary productivity, although it is generally higher along the eastern side of the southern basin (van Ruth and Doubell, 2013). Gross phytoplankton growth rates are high in spring/summer, decrease throughout summer/autumn, and increase again in autumn/winter (van Ruth and Doubell, 2013).

## Zooplankton dynamics and secondary productivity

There are no clear spatial or temporal patterns in mean meso-zooplankton abundance in Spencer Gulf, indicative of the typical patchy nature of plankton community dynamics (van Ruth and Doubell, 2013). There is a general decrease through winter into spring before an increase through summer, decreasing again through autumn into winter. Abundances are generally < 40,000 organisms $m^{-3}$, with peaks in the southern basin occurring in autumn/winter, and the middle basin in summer. Meso-zooplankton grazing impact is also highly spatially and temporally variable. Impacts are generally higher through summer/autumn (20 -51 mg C $m^{-3}$ $d^{-1}$) and lower in winter/spring (5 – 20 mg C $m^{-3}$ $d^{-1}$).

## Pelagic fish

At least nine species of small pelagic fishes occur in southern Spencer Gulf. One of these species, the Australian sardine (*Sardinops sagax*) supports Australia's largest fishery by weight, the South Australian Sardine Fishery (SASF), and the majority of the catch from this fishery (~30,000 t per annum) is taken from southern Spencer Gulf (e.g. Ward et al., 2011; Ward et al., 2012). Considerable information is available on the reproductive biology, patterns of age and growth and population size of Australian sardine (Ward et al., 2001a; Ward et al., 2001b; Ward and Staunton-Smith, 2002; Ward et al., 2006; Rogers and Ward, 2007a; Strong and Ward, 2009; Ward et al., 2011) and Australian anchovy (*Engraulis australis*), which is also a permitted species in the SASF (Dimmlich et al., 2004; Dimmlich and Ward, 2006; Dimmlich et al., 2009).

More limited information is available on age, growth and reproductive biology of three other species: blue sprat (*Spratelloides robustus*) (Rogers et al., 2003) and white bait or sandy sprat (*Hyperlophus vittatus*) (Rogers and Ward, 2007b) which can also be taken by the SASF; and blue mackerel (*Scomber australisicus*; (Ward and Rogers, 2007; Rogers et al., 2009b; Ward et al., 2009; Izzo et al., 2012; Schmarr et al., 2012) which is a quota species in the Commonwealth Small Pelagic Fishery, which operates outside Spencer Gulf. Other small pelagic fishes that occur in the Gulf but have not been studied locally include jack mackerel *(Trachurus declivis*), yellowtail scad (*Trachurus novaezelandiae*), redbait (*Emmelichthys nitidis*) and round herring (*Etrumeus teres*).

The three smallest species found in the gulf, i.e. white bait, blue sprat and Australian anchovy, are endemic to Australian waters whereas the larger species are distributed widely (e.g. Rogers et al., 2008). These smaller, shorter-lived species also tend to be found in the shallow and/or northern parts of the gulf whereas the larger, longer-lived species tend to occur further south and in deeper water (e.g. Rogers et al., 2003; Dimmlich and Ward, 2006; Ward et al., 2006; Rogers et al., 2009b). An ontogenetic shift in the distribution of Australian anchovy has also been observed with smaller, younger fish occurring in the northern Gulf and larger, older fish further south (Dimmlich and Ward, 2006). However, when mass mortality events in 1995 and 1998 significantly reduced the spawning biomass of Australian sardine (Ward et al., 2001b; Whittington et al., 2008) there was a significant expansion in the distribution and abundance of Australian anchovy (Ward et al., 2001a; Dimmlich et al., 2009), especially in the southern Gulf where productivity is enhanced by upwelling (Middleton and Bye, 2007).

The spawning seasons of most small pelagic fishes in Spencer Gulf and other waters off South Australia coincide with the upwelling period during summer-autumn (e.g. Ward et al., 2001a; Ward et al., 2001b; Ward and Staunton-Smith, 2002; Rogers et al., 2003; Dimmlich et al., 2004; Ward et al., 2006). The large spawning biomass (by Australian standards) of Australian sardine off South Australia (~200,000 t) appears to reflect the enhanced productivity of the region due to nutrient enrichment through upwelling (Kampf et al., 2004; McClatchie et al., 2006; Ward et al., 2006; Middleton et al., 2007). A large number of studies have emphasised the importance of Australian sardine and other small pelagic fishes in the diets of predatory fishes, seabirds and marine mammals of South Australia (e.g. McLeay et al., 2009). Those studies have shown that none of these species are obligate predators on Australia sardine or any other individual species and that the recent level of fishing pressure on Australian sardine population has not had deleterious effects on apex predators or ecosystem function (Goldsworthy et al., 2013).

**Knowledge gaps**

- Considering the overall paucity of data there remain a number of areas that require further monitoring and research. These include: long term (monthly) monitoring of spatial and temporal variation in nutrient and plankton dynamics across the whole of Spencer Gulf to understand inter- and intra-annual variations in the cycles of productivity and biogeochemistry. In particular, a monthly sampling of nutrients and irradiance, and plankton biomass, abundance and community composition is needed at several (inshore to offshore) sites within the three regions of the gulf. In addition, seasonal examinations of primary and secondary productivity (photosynthesis and grazing) and nutrient uptake could be conducted in parallel to the monthly monitoring.
- Key gaps exist in understanding the importance and coupling between the microbial (both pelagic and benthic), benthic (seagrass, mangroves, sediments) and macroalgal communities in biogeochemical cycles and ecosystem productivity for the estuarine ecosystem. Each of these components plays a critical role in estuarine ecosystems and must be considered in a holistic approach if the predictive capability of ecosystem models is to be developed.
- More information is also required in regard to the quantities and characteristics of industrial and other anthropogenic nutrient inputs entering the gulf.
- The biology and ecology of the key small pelagic fish in Spencer Gulf have been studied, but little is known locally for a number of species including jack mackerel *(Trachurus declivis*), yellowtail scad (*Trachurus novaezelandiae*), redbait (*Emmelichthys nitidis*) and round herring (*Etrumeus teres*).
- How the frequency and strength of upwelling influence recruitment success, growth rates and movement patterns of Australian sardine and other pelagic fish is required.
- Information is required on the effects of environmental factors including climate variables on composition and structure of the pelagic fish assemblage (e.g. relative abundance of anchovy and sardine).

### 3.2.3 TERRESTRIAL AND COASTAL ENVIRONMENT

The land area surrounding Spencer Gulf is primarily developed for rain dependant agriculture. There is a marked north to south gradient in rainfall as indicated by the median rainfall at Port Augusta (237 mm) in the north, and Port Lincoln (487 mm) and Warooka (438 mm) in the south. There are no permanent river flows into the Gulf – the few ephemeral streams (Broughton River, Mambray Creek on the east side and the Tod River on the lower west side) and short run creeks from the southern Flinders only contribute run-off episodically. There are likely areas of discharging groundwater along the coastline, particularly on the eastern side. Nutrients, for example, from land based aquaculture, septic tanks and agricultural run-off need to be considered (Environment Protection Authority, 2013).

**Wetlands**

A range of wetlands occur in the Spencer Gulf region including mangroves, saltmarsh, coastal saline swamps, saltwater lakes and swamps, freshwater lakes and swamps, seasonal and ephemeral streams, springs, seasonal rock-pools and artificial wetlands. On Eyre Peninsula the main wetlands are salt lakes and coastal wetlands (Boggon and Evans, 2006). The latter include mangroves, saltmarshes, coastal saline marshes and marine springs or soaks.

Saline lakes are generally surrounded by tea trees and on Eyre Peninsula are mainly confined to the southwest of the Peninsula. The following inland wetlands are listed in the Directory of important wetlands for South Australia: Big Swamp (freshwater lake), Little Swamp (freshwater lake) and Sleaford Mete (salt lake) (Seaman, 2002) (see also Conservation). There are also saline wetlands on southern Yorke Peninsula. There is generally a poor understanding of inland wetlands in the region with few having been mapped, or monitored for any length of time, and a number have been lost or are degraded (Boggon and Evans, 2006).

Spencer Gulf supports some of the largest stands of mangroves in South Australia. Only one species of mangrove, the grey mangrove, *Avicennia marina*, occurs in temperate Australia where they grow in sheltered bays and estuaries. There are stands of mangroves in Tumby Bay, Arno Bay, Franklin Harbour (near Cowell), Whyalla, around the head of Spencer Gulf (Two Hummock Point to Port Augusta to Yatala Harbour), Port Germein, Port Pirie, Port Broughton and near Wallaroo (Bulter et al., 1977). Sediments associated with mangroves in northern Spencer Gulf are predominantly gray carbonate mud, but with significant amounts of terrigenous clay, plant organic matter and gypsum (Cann et al., 2000). Few studies have investigated fish assemblages in mangroves of Spencer Gulf (but see Payne and Gillanders, 2009). Benthic communities in mangroves (and unvegetated tidal flats) of Upper Spencer Gulf have been studied by Dittmann and co-workers (Flinders University, unpublished data), including assemblages around mussel beds. Further studies by Dittmann et al. include surveys of introduced species on fouling communities, as well as temporal variation in abundances of introduced amphipods (Conlan et al., Flinders University, unpublished data).

Besides mangroves, the intertidal and sublittoral fringe of sandy or muddy flats or beaches is dominated by salt marsh, the brown alga Neptune's necklace (*Hormosira banksii)*, the razor fish (*Pinna bicolour)* and filamentous red algae (*Hypnea* and *Spyridia)*. Salt marshes, which are comprised of herbs and low shrubs that are tolerant of saline conditions, occur inland from mangroves. They are often referred to as samphire. Many of the plant species are from the Chenopodiaceae family.

Carbonate bare sands with many shells occur where there is little tidal inundation (Cann et al., 2000). There is evidence of regressing shorelines as one moves landward. Other intertidal habitats also include mudflats and rocky reefs.

### Estuaries around Spencer Gulf

There are currently 19 estuaries identified as occurring around Spencer Gulf including 9 in the Eyre Peninsula Natural Resources Management Region and 10 in the Northern and Yorke Natural Resources Management Region (Department of Environment and Heritage, 2007b, a). Six of these occur in the Port Pirie region. There are no estuaries south of Port Broughton on the eastern side of Spencer Gulf. Little research has been undertaken in most of these estuaries. Gillanders and Elsdon (unpublished data) investigated environmental conditions and fish in five of the estuaries during winter 2007 and summer 2008, as part of a broader investigation of South Australian estuaries.

### Knowledge gaps

Prioritisation and threat identification has been undertaken for some of the coastal areas which interface with the Spencer Gulf. This work includes identifying conservation priorities as well as climate threats through studies such as the Eyre Peninsula Coastal Action Plan and Conservation Priority Study (Caton et al., 2011) and Central Local Government Region Integrated Climate Change Vulnerability Assessment (Balston et al., 2011).

There have been few systematic investigations of the coastal marine environment throughout Spencer Gulf and few studies of inland wetlands and how they may change over time. While mangroves and saltmarsh throughout South Australia have been mapped, the influence of physico-chemical factors on distribution and abundance is poorly known. Biodiversity and benthic communities associated with intertidal areas deserve further attention. In addition, occasional discharge events from ephemeral streams and short run creeks may have important effects on the restricted waters of the Gulf and so should be monitored. The contribution of groundwater is likely to be small, but further quantification is warranted (See also Benthic Ecology and Environment section for more detail). Other land, and coastal climate change planning priorities need to be considered for the significance the processes identified have on the Gulf's environment.

### 3.2.4 BENTHIC ENVIRONMENT AND ECOLOGY

Spencer Gulf supports a diverse range of subtidal benthic habitats including subtidal sand patches and "megaripples", offshore islands, subtidal reefs and benthic faunal beds on muddy substrates (Edyvane, 1999). Despite the diversity of habitats, only 17% of the Gulf has been mapped at fine resolution.

**Northern habitats**

The Northern Spencer Gulf bioregion has sheltered habitats of mainly sandy and muddy substrates and is characterised by a significant relict tropical element resulting in distinctive benthic flora and fauna. Below the low tide level, a diverse range of algal species are common (see references in Edyvane, 1999).

The subtidal benthic habitats of Northern Spencer Gulf have been variously surveyed in past decades (see references in Edyvane, 1999). These surveys indicated dense monospecific stands of the seagrasses *Amphibolis antarctica, Posidonia australis* and *P. sinuosa* and scattered stands of *Heterozostera tasmanica*, *Halophila ovalis* and the alga *Caulerpa cactoides* in depths to 10 m. Dominant animal assemblages included a mixed sponge/cnidarian/echinoderm assemblage on rocky and consolidated substrate, a bryozoan/ascidian/sea pen assemblage in the troughs of sand waves called "megaripples", and molluscan aggregations of hammer oysters and razorfish. Algal species that have been recorded in this bioregion are typically intermediate warm to cool temperate species (e.g. *Asparagopsis taxiformis* and *Platysiphonis mutabilis*), but there are also some algal species that are distinctly tropical and sub-tropical in distribution (e.g. *Hormophysa triqueta* and *Sargassum decurrens*). A number of cnidarians (e.g. *Echinogrogia* sp. and *Scytalium* sp.) appear to be endemic to the upper Spencer Gulf. There are also members of other phyla known only in this bioregion including the bryozoan *Bugula* sp., the flatworm, *Ancoratheca australiaensis* and an opisthobranch, *Discodoris*.

**Central and southern habitats**

In contrast, few systematic subtidal studies have been carried out for the Spencer Gulf bioregion, which encompasses the central and southern parts of the gulf (see references in Edyvane, 1999). The southern coasts are subject to moderate wave energy and the intertidal and subtidal fringe of rocky shores is dominated by the brown algae *Hormosira banksii* and *Cystophora* spp. On rocky coasts with more wave action, the upper sublittoral zone is dominated by a range of large brown algae. The understorey is typically coralline algae, *Cladostephus spongiosus* and *Caulerpa* spp. On sandy bottom, the seagrasses *Amphibolis* and *Posidonia* dominate extensively.

In the subtidal areas of the central gulf, the mixed sand and rock substrates are covered with mixed *Sargassum* and *Cystophora* species, with *Lobophora variegata* as the dominant understorey species. A variety of large brown macroalgae (*Carpoglossum confluens*, *Seirococcus axilaris*, *Acrocarpia paniculata* and mixed *Sargassum* and *Cystophora* species) dominate the reefs in the wave exposed southern and southeastern areas of the gulf. Understorey species are dominated by diverse green and red algal assemblages.

### Seagrasses

Spencer Gulf harbours some of the largest seagrass meadows in the world, which form the foundation of diverse and highly productive ecosystems (Irving, 2014). Australian shores support 33 of the 59 or so species of seagrass found throughout the world, displaying the greatest diversity of any country. Of these species, Spencer Gulf supports 12 belonging to five genera, including both members of the Australian endemic *Amphibolis* (*A. antarctica* and *A. griffithii*). Along the South Australian coastline, estimates of seagrass abundance were originally put at ~5 000 km$^2$ (Kirkman, 1997), but an extensive coastal seafloor mapping study revealed at least 8,508 km$^2$ of seagrass, with the number possibly as high as ~9,600 km$^2$ (Edyvane, 1999). Currently, it is estimated that 4,787 km$^2$ (56%) of South Australia's seagrass occurs within Spencer Gulf, while 2,180 km$^2$ (25%) occurs in the Gulf St Vincent – Fleurieu Peninsula region. Within both gulfs, seagrasses of the genus *Posidonia* are the most abundant, estimated at ~3,700 km$^2$ for Spencer Gulf and ~1,530 km$^2$ for Gulf St Vincent (Shepherd and Robertson, 1989). The seagrasses are important habitats for a wide range of marine species from bacteria and micro-invertebrates to many commercially-important fish and crustacean species (McDonald, 2008; Tanner and McDonald, 2014). The seagrass meadows in Spencer Gulf have recently been listed as 'endangered' by the International Union for the Conservation of Nature (IUCN).

### Subtidal benthic communities

More recent work on the subtidal benthic communities of Spencer Gulf includes a study of bycatch from the Spencer Gulf Prawn Fishery (Currie et al., 2009; Dixon et al., 2014). While the aim of this study was to investigate the impacts of trawling on benthic communities, it also provided information on the spatial distribution of benthic organisms, establishing a baseline for future assessments. Patterns of total abundance and biomass appear to reflect differences in oceanographic conditions. High levels recorded for the western side of the gulf reflect the inflow of nutrient-rich water from the shelf, while low levels on the eastern side reflect where nutrient-depleted water flows outward. Species richness was inversely correlated with total abundance and biomass, being high on the eastern side and low in the west. At a whole of gulf scale, there is a strong north-south gradient in species composition, with four community regions characterized by differences in the number of species: North (<120 km from top of gulf), Mid-North (120-160 km from top), Central (160-220 km from top) and South (220-300 km from top). The South region has the richest collection of species, followed by the Central and North regions. More recent studies on subtidal rocky habitats and kelp forests suggest that there is large variation at small scales, which emphasises the idiosyncratic nature of populations (see references in Connell, 2007).

### Infauna

Studies of the infauna of Spencer Gulf are few, and there have been no systematic surveys carried out across the entire gulf. An early study in 1979 near Port Pirie in Upper Spencer Gulf investigated the infauna in intertidal and shallow subtidal habitats, including bare intertidal mudflats, intertidal and subtidal seagrass beds and subtidal bare unvegetated sediments (Hutchings et al. 1993). A total of 372 taxa were represented in the samples collected across all habitats, dominated by polychaetes, followed by molluscs and crustaceans. The number of species was variable across the habitats sampled, with a higher number recorded for subtidal habitats compared to intertidal. More recent infaunal studies are mostly based around localised environmental impact assessment or monitoring projects (e.g. Loo et al., 2004; Tanner and Bryars, 2007; Loo et al., 2011; Loo and Mantilla, 2012).

**Knowledge gaps**

There are three broad areas of knowledge gaps:

1. What is there (i.e. what is the distribution and abundance of the biota)?
2. How is this distribution and abundance influenced by physico-chemical factors and biotic interaction?
3. How will distribution and abundance change with changes in the environment?

With ongoing habitat mapping around South Australia by the Department for Environment, Water and Natural Resources (DEWNR), information on the spatial distribution of various habitats is increasing. However, as indicated by Miller et al. (2014), there are still large areas in Spencer Gulf that are yet to be mapped. To reliably document the habitats present in these areas would require either swath sonar or lidar mapping. Priority areas for mapping should be based on areas of predicted disturbance, as well as areas of particular conservation interest. Future studies of subtidal benthos in Spencer Gulf should take into account the structural differences among the four benthic communities as described by Currie et al. (2009) and Dixon et al. (2014).

Most research has focused on documenting what is present and very little effort has been focussed on the ecological processes structuring benthic assemblages, or linking them to the rest of the ecosystem. Further work is needed on the mechanisms of seagrass loss and early indicators of seagrass decline, and food chain links between seagrass production and fisheries production. Indeed, we know remarkably little about the association between seagrasses and their fauna and flora. Important questions that remain to be answered include how faunal and floral assemblages change with depth and seagrass species, and the exact trophic role seagrasses play in the Spencer Gulf. In particular, we have little understanding of the importance of micro-herbivore grazing and the connectivity between seagrass and other habitats, as many larger species that utilise seagrass do so for only a part of their life cycle. There is also a lack of knowledge of infaunal assemblages living in the unvegetated soft sediment, their spatial and temporal distribution, or how they contribute to the broader food web.

Once we know where organisms occur, and how they respond to their environment, we can begin to understand how they might respond to changes in that environment. Within the context of Spencer Gulf, it will be particularly important to determine how benthic assemblages may respond to changes in the physico-chemical environment, including climate change, increased turbidity/sedimentation, and increased nutrients (both in the water column and deposited on the seafloor). Priorities will depend on the nature and extent of predicted disturbances.

### 3.2.5 ICONIC AND THREATENED, ENDANGERED & PROTECTED SPECIES

Spencer Gulf is an area of high marine conservation significance and provides important foraging and breeding habitats for a range of iconic and threatened, endangered and protected species

(TEPS), including those listed under the Environment Protection and Biodiversity Conservation Act (EPBC Act). For the Spencer Gulf region TEPS include all cetaceans, listed threatened species (e.g. southern right whale, Australian sea lion, white sharks), listed migratory species (migratory cetaceans and seabirds, white sharks and shortfin makos), listed conservation dependent species (school shark) and listed marine species (all seabirds, seals, marine turtles and syngnathids). Iconic species include apex predators or species with significant cultural or ecotourism significance such as the giant Australian cuttlefish. Shelf waters of South Australia's Great Australian Bight (GAB) contain the greatest densities of apex predators and iconic species in Australia. Spencer Gulf, as part of this broader marine domain, provides important year-round habitat for resident species, as well as seasonal habitat for many migratory species.

### Marine Mammals

Spencer Gulf is important to many marine mammal species. Historically, small shore based whaling activities targeting southern right whales (*Eubalaena australis*) were located at Thistle Island and Sleaford Bay, suggesting the lower Gulf region was historically important to this species (Robinson et al., 1996). However, it is unclear from historic records if the region was an important calving ground for the species. Southern right whales are seen regularly in southern Spencer Gulf between May and November, as they migrate from foraging grounds in the Southern Ocean up to their calving grounds at the Head of Bight (in SA) and Israelite and Doubtful Bays (WA). There are at least three dolphin species that occur in Spencer Gulf; the short-beaked common dolphin (*Delphinus delphis*), and two bottlenose dolphin species, *Tursiops australis* and possibly *T. truncatus*. The first gulf-wide aerial surveys of the common dolphin were undertaken in 2011, which indicated that it was most abundant in the lower half of the Gulf (Möller et al. unpublished data). During these surveys the distribution and abundance of bottlenose dolphins were also recorded. Bottlenose dolphins are distributed throughout the Gulf but are less abundant than common dolphins (Möller et al. unpublished data). Common dolphins are known to interact with purse seine vessels in the South Australian sardine fishery which previously led to bycatch entanglement and mortality (Hamer et al., 2008). Bottlenose dolphins also occasionally interact with fisheries in the Gulf leading to mortalities (Kemper et al., 2005). Dolphins are important bioindicators, with detections of high concentrations of heavy metals, which is associated with renal damage and bone malformations to the animals (Lavery et al., 2008; Lavery et al., 2009).

Two pinnipeds are resident in Spencer Gulf, the Australian sea lion (*Neophoca cinerea*) and New Zealand fur seal (*Arctophoca forsteri*). Both species were subject to unregulated harvesting by early colonial sealers, which resulted in major reductions in abundance and range from which neither species has fully recovered. The Australian sea lion is only found in South Australia (SA) and Western Australia (WA) and is one of the rarest sea lions, with a population size estimated at 14,730 (Shaughnessy et al., 2011). In South Australia, it is widespread with 48 breeding sites and a population size estimated at 12,700, based on estimates of 3,100 pups; this comprises 86% of the total population of the species. Australian sea lions breed at six sites in southern Spencer Gulf, and two additional sites at the mouth of the Gulf (East and South Neptune Islands). The region forms a critical part of the range of the species, containing over a third (~35%) of the SA population, and about 30% of the species (Goldsworthy et al., 2010; Shaughnessy et al., 2011; Goldsworthy et al., 2014). In addition, Australian sea lions are known to haul out at 30 sites in the southern part of Spencer Gulf, and there may be others. The largest sea lion colony is at Dangerous Reef, which is the largest colony for the species, and more than twice as large as other breeding sites (Goldsworthy et al., 2014).

For the New Zealand fur seal, large breeding colonies occur at three islands near the mouth of Spencer Gulf (North and South Neptune Island and Liguanea Island), where around 10,000 pups are born annually (Goldsworthy and Page, 2007; Goldsworthy et al., 2014). There are at least 15 known haulout sites within the Gulf, most in the southern region. The last 25 years have seen a 3.5 fold increase in the population size of New Zealand fur seals in SA. It is unclear how long this recovery will continue and what ultimate population size will be attained. New haulout sites and breeding colonies are establishing across the State, some in close proximity to finfish aquaculture, and major commercial and recreational fishing areas in Spencer Gulf. There is also growing concern from the seafood and ecotourism (little penguins, giant Australian cuttlefish) industries that fur seals are overabundant and that their populations and impacts need to be managed.

**Seabirds**

Spencer Gulf forms important foraging and breeding habitats for a diverse range of seabird species. This includes resident species present year-round and migratory species, such as shearwaters and waders, that return to the region to breed and/or feed for several months of the year. Only key species or species groups that utilise Spencer Gulf are discussed here. Little penguins (*Eudyptula minor*) are permanent residents and breed on many islands in southern Spencer Gulf. Individuals exhibit strong site fidelity, returning to the same breeding colony each year to breed in the winter and spring months. Most populations forage on small pelagic fishes, including Australian anchovies, and breeding success is partly dependent on the availability of this species (Wiebkin, 2011, 2012).

The dominant petrel species in the eastern GAB region are the short-tailed shearwater (*Puffinus tenuirostris*) and the white-faced storm petrel (*Pelagodroma marina*) that breed in large numbers on many of the islands in southern Spencer Gulf. Small numbers of flesh-footed shearwaters (*Puffinus carneipes*) are known to breed on at least two islands in southern Spencer Gulf, geographically isolated from major population centres off south western and eastern Australia and New Zealand. For all these species there is limited information on the size of their populations and trends in abundance (Copley, 1996). Australasian gannets (*Morus serrator*) are common visitors to Spencer Gulf where they plunge dive on small pelagic fish such as sardines. The main breeding areas are in southeastern Australia, the nearest (and only SA) breeding colony is at Margaret Brock Reef off Cape Jaffa. Two tern species are common in Spencer Gulf: the crested (*Sterna bergii*), and Caspian tern (*Sterna caspia*). Crested terns are the most abundant and form dense breeding colonies on several islands in southern Spencer Gulf. Fairy terns (*Sterna nereis nereis*) are a vulnerable species, and recent surveys indicate populations in SA have undergone a substantial decline in recent decades (Department of Environment and Natural Resources, 2012).

Four species of cormorants (little pied, black-faced, pied and little black) and the Australian pelican are common in Spencer Gulf, and all feed on fish or benthic invertebrates and breed in dense colonies on offshore islands and in coastal mangroves. The black-faced cormorant is more marine in its foraging compared to the other species that forage more inshore. Silver gulls (*Chroicocephalus novaehollandiae*) are the most common gull species in Spencer Gulf and their numbers have increased considerably over the last 50 years. They are scavengers and omnivorous opportunists. Spencer Gulf hosts large and diverse assemblages of over 50 wader species, about half of which are resident and half migratory. Key resident species include dotterels, ibises, avocets, egrets and spoonbills, with large differences in body size and bill morphology reflecting the broad feeding ecology of species foraging in exposed mudflats, samphire and other inter-tidal areas. Most migratory species arrive in spring from northern breeding ranges as far as Alaska and Asia, key species being sandpipers, stints and greenshanks. These birds spend the summer feeding on the abundant invertebrate fauna of Spencer Gulf mudflats.

White-bellied sea eagle (*Haliaeetus leucogaster*) and eastern osprey (*Pandion cristatus*) are conspicuous iconic marine raptors in SA. Spencer Gulf represents an important part of these species breeding and foraging habitats, especially in the southern sections. Spencer Gulf contains around 28% of the state's white-bellied sea eagle breeding territories and 13% of the osprey breeding territories (Dennis et al., 2011). Both species have suffered territory abandonment in recent years, with coastal development and human disturbance identified as key factors (Dennis et al., 2011).

## Chondrichthyans

Two species of mackerel sharks (Family Lamnidae) occur in Spencer Gulf, the white shark (*Carcharodon carcharias*) and shortfin mako (*Isurus oxyrinchus*). Like other lamnids, white sharks and shortfin makos are considered apex predators (Cortes, 1999; Malcolm et al., 2001; Rogers et al., 2012) and are often associated with seal colonies on islands (Malcolm et al., 2001). White sharks move into Spencer Gulf in spring and summer to hunt snapper and other large prey (Bruce et al., 2006). The shortfin mako is a highly migratory threatened species, and live sharks are protected in commercial fisheries. They are pelagic and occur in Spencer Gulf during summer (Rogers et al. unpublished data). Both lamnids are subject to bycatch by fisheries that operate in Spencer Gulf, however limited data on bycatch rate is available. Common thresher sharks (*Alopias vulpinus*) can be found within Spencer Gulf, where they have been caught by commercial longlines and within the sardine fishery. The school shark (*Galeorhinus galeus*) is found in Spencer Gulf, they are highly migratory (Stevens and West, 1997) and currently subject to a stock rebuilding strategy due to historical over-fishing (Australian Fisheries Management Authority, 2009). Two carcharhinids frequent Spencer Gulf; the bronze whaler, *Carcharhinus brachyurus*, and the dusky shark, *C. obscurus* (Jones, 2008). There is currently conservation concern for these whaler shark species, both of which are migratory and often confused due to their similar external appearance. Dusky sharks are slow growing and long-lived and migrate from Spencer Gulf to Western Australia during autumn and winter months (Rogers et al., 2013). In South Australia, movement data obtained conventional and acoustic tagging of bronze whalers and dusky sharks suggests some level of philopatry (Huveneers et al., 2012; Rogers et al., 2013). They also move seasonally to northern gulf waters, which could be important nursery and feeding areas for their young (Rogers et al., 2013). Recreational and commercial catches in Spencer Gulf confirm the occurrence of pregnant bronze whalers inside the gulf (Rogers et al., 2009a; Rogers et al., 2013). Four species of stingaree (Family Urolophidae), the southern fiddler ray (*Trygonorrhina dumerilii*), and Port Jackson sharks (*Heterodontus portusjacksoni*) occur in Spencer Gulf waters and may be taken as trawl bycatch.

## Giant Australian Cuttlefish

The giant Australian cuttlefish (*Sepia apama*) is the largest cuttlefish in the world, and is distributed around the southern coastline of Australia from Ningaloo in Western Australia to Moreton Bay in southern Queensland (Lu, 1998). At a single location in northern Spencer Gulf (subtidal reef near Point Lowly) it forms the only known dense spawning aggregation of cuttlefish in the world. They aggregate here to breed once only at the end of their life cycle. At non-breeding times *S. apama* is dispersed and generally solitary.

Two genetically and morphologically distinct populations of cuttlefish exist in Spencer Gulf. The breeding aggregation in northern Spencer Gulf is a distinct population from the others in the species' range, with a second population encompassing individuals from southern Spencer Gulf, Gulf of St Vincent and Victoria. The range of these two populations does not overlap, as the northern Spencer Gulf population is restricted to an area just north of Wallaroo (north of 33$^o$55'S). Further investigations aimed at resolving the taxonomic status of cuttlefish are currently underway (FRDC 2013/010).

Cuttlefish abundance and biomass has only been estimated in northern Spencer Gulf. Surveys suggest that no cuttlefish are present at the breeding aggregation site in early May, abundance then peaks between mid-May and early July, depending on the site, and by early August few cuttlefish are found (Hall and Fowler, 2003). No cuttlefish have been found in mid-September. Estimates of abundance (and biomass) from the breeding aggregation site provide a relative estimate of abundance, as cuttlefish are not resident on the breeding aggregation site for the full breeding period of 4 months (Payne et al., 2011). Abundance of cuttlefish on the breeding aggregation site has declined by more than 90% over the last 13 years and biomass by more than 95% (Steer et al., 2013).

Cuttlefish aggregate at the small area of subtidal rocky reef near Point Lowly (approximately 0.64 $km^2$) to breed, displaying elaborate mating and reproductive behaviours that are dependent on visual cues. Eggs are then deposited on the underside of rocks or in rocky crevices where they develop for 3-5 months and hatch from mid-September through to early November.

Two alternative life cycles occur for both sexes based on growth increments in cuttlebones. The first involves rapid juvenile growth in the first summer following hatching with maturity in 7-8 months leading to spawning in their first year as small individuals. The second involves slower growth during the first summer, and spawning in their second year, since maturity is deferred. Thus, there are two-year classes within the population, but no suggestion that individuals return to spawn a second time (Hall et al., 2007). The life span therefore appears limited to 1–2 years.

Whilst there is substantial concern over the decline in abundance and biomass of cuttlefish, it is not clear what has contributed to this decline, or whether it may represent a natural cycle in the population. Activities which have potential to impact cuttlefish are:

- Recreational and commercial fishing, however, the recent closure of northern Spencer Gulf to fishing of cuttlefish means that impacts from fishing are less likely. There has also been a ban on removal of cephalopods from the False Bay area (near Whyalla), including the main breeding aggregation site, since the late 1990s. Bycatch associated with commercial fishing may also impact cuttlefish abundance especially if individuals returned to the water do not survive;
- Desalination saline concentrate (and associated chemicals), which may affect egg survival, migration routes and mating behaviour;
- Nitrogen loads via industrial or other (e.g. waste water treatment plants or aquaculture) activity, which may have direct and indirect impacts, such as increased fouling to eggs or egg-laying sites;
- Metal pollutants from industrial activity (e.g. Whyalla, Port Pirie) and hydrocarbons (e.g. associated with an oil spill);
- Noise pollution associated with shipping;
- New port or other developments;
- Dredging, which may affect turbidity levels and impact mating behaviour, which relies on visual cues;
- Recreational snorkelling and SCUBA diving, although cuttlefish do not appear to respond to divers in the water.

**Knowledge gaps**

Historical data indicate that southern right whales were common in southern Spencer Gulf. In addition, short term whaling stations existed at Thistle Island and Sleaford Bay. In the Southern Right Whale Recovery Plan, ship collision and noise issues are listed as key threatening processes. Knowledge about the natural behaviour of southern right whales in the region, particularly of mother-calf pairs, will be important for future assessment. Understanding potential for interference as numbers change will also be important.

Fur seals, sea lions and sharks may cause significant financial impacts to the finfish aquaculture industry in Spencer Gulf. At present the potential impacts of recovering populations of seals on the seafood sector is uncertain. The importance of commercial fish and aquaculture species in the diets of fur seals, sea lions and sharks is a key knowledge gap, although the diet of fur seals is being investigated as part of FRDC 2013/011.

Many little penguin colonies in SA have declined in recent years, including those in Spencer Gulf (Wiebkin, 2011), however, for most colonies no quantitative survey data are available. Information on the status and trends in abundance of the species and the causes for population decline remains key knowledge gaps. Information on the status and trends in the abundance of fairy tern populations and the causes for population decline are also key knowledge gaps. For many seabird species there is little information on the size of their populations in Spencer Gulf, their trends in abundances, diets and ecological roles in coastal ecosystems.

Considering the slow life history characteristics of many chondrichthyan species, anthropogenic impacts, such as from commercial fisheries, can result in declining shark populations. The resilience of Spencer Gulf shark populations and trends in abundance are current key knowledge gaps. Tagging of white sharks at the Neptune Islands has shown limited incursion of these sharks within Gulf St Vincent. The connectivity between white sharks visiting Spencer Gulf, those frequenting the Neptune Islands, and in relation to the likely two Australian white shark sub-populations (Blower et al., 2012) is unknown. Similar knowledge gaps apply to common and bottlenose dolphins. These animals also show slow life history characteristics and are caught by fisheries in the Gulf. Key knowledge gaps include fine-scale population structure, abundance and trends in the region, which would inform the long-term viability of their populations. The potential health effects associated with high concentrations of heavy metals found in dolphins stranded in the Gulf is another knowledge gap.

In regards to the giant cuttlefish, key knowledge gaps include survival rates of individuals returned to the water following line fishing or prawn trawling, movement patterns throughout the life history, potential factors contributing to population decline (such as saline concentrate, increased nutrients, hydrocarbons, shipping noise, and turbidity, and recreational activities), and taxonomic status of the species. An FRDC funded project is currently addressing some of these key knowledge gaps and the State government is providing funding which will allow the aggregation to be monitored in 2013. There are also additional funds to investigate habitat characteristics of egg-laying sites such that this information could be used to inform construction of artificial habitats. Habitat does not appear to be limiting on the breeding aggregation site, but use of artificial habitat could be investigated as a means of rebuilding populations elsewhere.

### 3.2.6 PESTS AND PATHOGENS

Several diseases and pests are recorded in Spencer Gulf, but most records are incidental findings and few studies have integrated knowledge on these important organisms of relevance for the area.

Pilchard herpes virus (PHV) caused some of the largest recorded fish kills in and around Spencer Gulf, in 1995 and 1998 (Gaut, 2001), but has stabilized in the host population and no longer causes clinical disease. A nodavirus has been recorded from finfish, but appears not to cause overt disease. Abalone as far north as Cowell are subject to *Perkinsus olseni*, a protozoan that causes mortality and lost fisheries value, and a variety of aquaculture-related parasites and diseases also affect production of yellowtail kingfish and southern bluefin tuna. Serious exotic diseases threaten commercially important species, such as ostreid herpesvirus type 1 microvariant of Pacific oysters and abalone viral ganglioneuritis. *Bonamia* sp. of flat oysters has been detected in the area (Network of Aquaculture Centres in Asia-Pacific and Food and Agriculture Organization of the United Nations, 2013) and threatens proposed flat oyster aquaculture. Primary Industries and Regions South Australia (PIRSA) coordinates passive surveillance of commercially important aquaculture and fisheries species, but no structured disease surveillance is currently in place for Spencer Gulf.

Numerous introduced marine species are recorded as established including fanworms, tubeworms, oysters, crabs and dinoflagellates (Wiltshire et al., 2010) although no *National Marine Pest Monitoring Manual* (National system for the prevention and management of marine pest incursions, 2010) compliant surveys have been undertaken in Spencer Gulf. Few impacts caused by pests in this area are recorded. Pest and pathogen species, however, can cause loss of biodiversity, have impacts on commercially and recreationally important species, increase maintenance costs of marine infrastructure and vessels, and reduce the cultural and recreational value of an area. Once established, marine pests are usually ineradicable and their management is very costly.

High-risk pests such as Pacific seastars (*Asterias amurensis*) and wakame (*Undaria pinnatifida*), and pathogens such as abalone viral ganglioneuritis, are established in Victoria and Tasmania. Proposed expansion in aquaculture production and mining in the Gulf, and the associated increases in shipping and development, are likely to drive increased propagule pressure. Pest and pathogen establishment is linked to propagule pressure (Lockwood et al., 2005) and the changes in Spencer Gulf are likely to increase the incidence of incursions of pests and pathogens. Specific influences include:

- Increased shipping, cargo and passenger traffic from within South Australia, interstate and internationally will increase the risk of incursion by new species transported on the hulls of ships or with ballast water;
- The construction of new ports and marinas, and dredging, will modify marine habitats, which will favour the colonisation of exotic species;
- Increased aquaculture production may augment opportunities for disease translocation and transmission of pathogens between farms and between farmed and wild organisms;
- Escaped stock will change localised densities of endemic species and spread pathogens over long distances if they migrate;
- Greater use of marine amenities will increase disease and pest transmission risks from local commercial and recreational vessels, and raise use of imported (including domestic imported) fishing bait that can vector pests and diseases.

### Knowledge gaps

Assessment of the combined effects on Spencer Gulf ecosystems and primary industries from multiple biosecurity stressors associated with development is difficult. The draft Biosecurity Act (Commonwealth) is likely to influence management frameworks, but supporting science is required. Significant knowledge gaps include:

- **Risk identification and prioritisation.** The Australian Ballast Water Management Requirements (Department of Agriculture Fisheries and Forestry, 2011) and associated controls mitigate risks from ballast water from vessels arriving from international ports. Risks from ballast water from domestic and local commercial vessel traffic are uncontrolled, and biofouling guidelines (National system for the prevention and management of marine pest incursions, 2009) are voluntary. Data and education to support the guidelines are lacking. A complete risk profile incorporating all vessel traffic, to outline which species of pests and pathogens are likely to arrive, successfully establish and what their probable impacts will be, is required. Techniques for this work have changed markedly in the last decade.

- **Surveillance and risk management options.** Cost effective technology to undertake surveillance for marine species, including species that have not been identified as invasive, and mechanisms for managing established pests and diseases, need to be developed. No systematic surveys to nationally agreed standards for marine pests exist for Spencer Gulf Ports, and surveillance technology has changed enormously in the last decade.
- **Response options.** Support frameworks should be developed for robust decision making about responses when incursions occur, and cost effective options for responding should be identified.
- **Economic impact assessment.** The costs of prevention, response and management should be understood and compared and the cost-effectiveness of ongoing preventative measures should be emphasized.

To address these knowledge gaps requires a better understanding of the inputs, risks and potential consequences posed from new and emerging pests and pathogens. There is a need to collect the data required to model the effects of changes in shipping pathways, aquaculture production, species use, and environmental change on the Gulf and the regions dependent upon it. In addition, this research will need to address the identification of hazards and provide fully integrated evidence-based risk management procedures. There is also a need to develop generic biosecurity frameworks to provide cost-effective best-practice protection for industries. We expect that this will include use of emerging surveillance technologies (including cutting-edge molecular tools) that have the potential to provide enhanced detection capacity at greater efficiency and lower costs than traditional assessment methods.

### 3.2.7 ECONOMY AS A WHOLE AND NON-MARKET BENEFITS

The land-based focus of economic development around Spencer Gulf is such that it has never been modelled as a single economic region. The more usual approach has been to either model:

(1) the contribution that one or more of its sub-regions, like the Iron Triangle, makes to the economy of South Australia and Australia; or
(2) assess the likely impact of a policy change or development on South Australia as a whole.

Moreover, most analysis has taken a partial view and, typically, assumed that the environmental health of Spencer Gulf will not change. Attempts to assess the consequences of an investment beyond direct effects are rare – even though many of these can be very positive.

Examples of recent regional and industry-focused assessments include:

- The Upper Spencer Gulf Marine Park Regional Impact Assessment and its sister Lower Spencer Gulf Marine Park Regional Impact Assessment (Econsearch, 2012c, b);
- The RESIC 2011 Resources and Energy Infrastructure Demand Study (RESIC, 2011);
- The PIRSA 2012 Economic Impact of Aquaculture on the South Australian State and Regional Economies study (Econsearch, 2012a).

Specific assessments of proposed developments are common. For example, in 2009, Centrex contracted Golder Associates to prepare a baseline study of the Sheep Hill Marine Port Facility (now referred to as Port Spencer). Similar studies have been prepared for the desalination plant at Port Bonython that BHP Billiton will build if the Olympic Dam development goes ahead (see http://www.olympicdameis.sa.gov.au). Typically, such studies assume a large degree of project independence and assume that flow-on consequences and cumulative impacts can be managed and, in aggregate, will be positive.

A related consideration is the possibility that Port Lincoln and the economy of the Eyre Peninsula could grow if gas and oil exploration in the Great Australian Bight results in development of a new industry. In anticipation of this possibility, BP has identified a need to establish a socio-economic and environmental baseline that will enable the consequences of this development to be separated from other development both in the Bight and in Spencer Gulf. When push comes to shove, each industry and each business needs to be able to identify the impact of their activities and separate these impacts from those caused by others.

### Ecosystem impacts and the economy

When considered from an ecosystem perspective, stress on part or all of the Spencer Gulf ecosystem will come from disturbance of an existing function as a result of increased activity and/or a failure to manage risk (Figure 5). The *proximate* causes of this disturbance include increased shipping, aquaculture, and fishing and increased contamination of the Gulf as a result of urban and industrial development. However, the *underlying* causes that may identify failure of the project approval process to take adequate account of cumulative impacts and changes that occur as a result of approvals already given, need to be considered. It is possible, for example, that a new mine could attract a different type of shipping to the Gulf and bring with it new biosecurity risks and or changes in turbidity.

As well as impacts on the ecosystem itself, it is likely that changes in the health of the Gulf's ecosystems could have flow on effects for the regional economy. Some of these are likely to be positive and others negative. Population increase, for example, can be expected to result in increases in non-market recreational values and through this increase the value of tourism in the region.

The South Australian Centre for Economic Studies (SACES) is in the process of completing research on the likely impacts of anticipated mining and other developments in Spencer Gulf but as is the case with other studies of this form, they are assuming that the resultant developments will have no environmentally adverse impacts that will undermine the scale of the development they predict will occur.

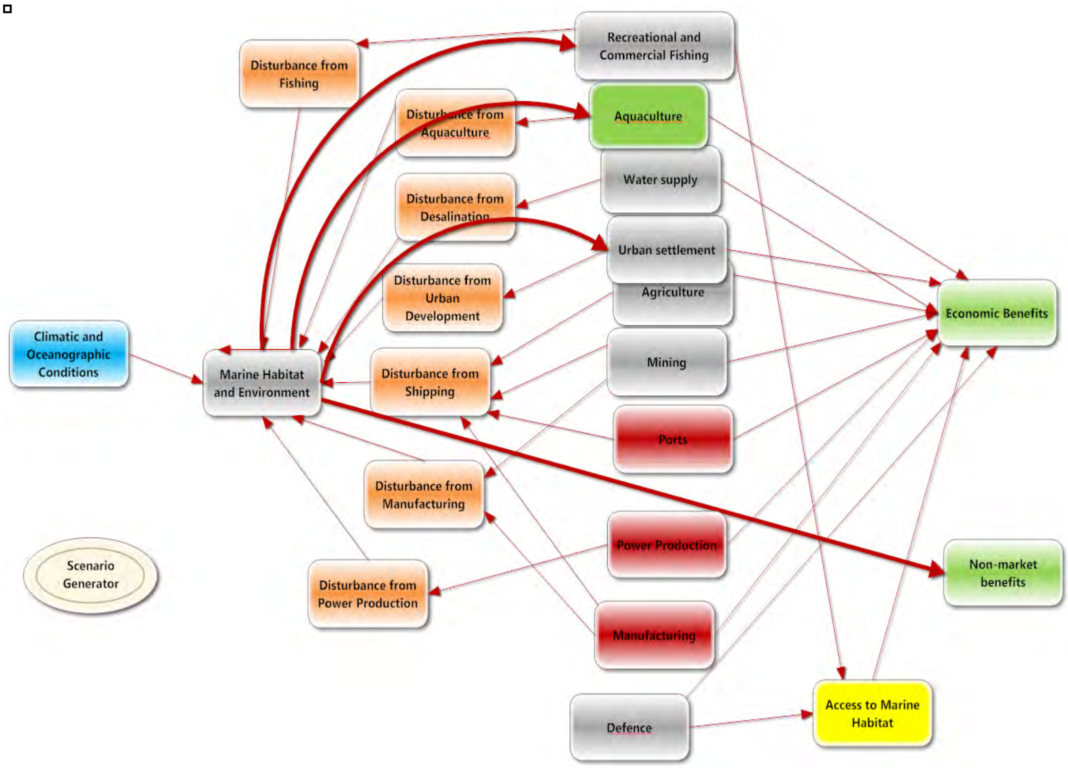

Figure 5. Influence diagram mapping key relationships between forms of ecosystem disturbance and sectors

## Knowledge gaps

As far as we are aware, there has been little if any assessment of the role that ecosystem health plays in the development of Spencer Gulf. There has also been little assessment of the opportunities to search for development synergies. Moreover, there appears to be no ongoing dialogue between the social and biophysical scientists working on issues associated with development of regions dependent upon the health of Spencer Gulf ecosystems.

As explained elsewhere, it appears likely that the degree of use to which Spencer Gulf is put is likely to increase and that the cumulative impacts of these developments could change the way the Spencer Gulf ecosystems function. Two broad categories of adverse impact can be identified

- Impacts that result from a gradual increase in use such as shipping
- Impacts that result from a specific event that had not been anticipated.

Little is also known about the regional extent of ecosystem impacts on the local, regional and state economy. A capacity to model these impacts in an integrated manner is needed.

The key knowledge gap is a capacity to provide an integrated assessment of the cumulative impact of a change in one part of the system on all other parts of the system and assess the social and economic consequences of this for the region, South Australia and Australia.

To assess risks it is necessary to establish a baseline set of data and a baseline model of the system that can describe the nature of changes that are already occurring and those that result from the introduction of new processes.

This part of the initiative should be seen also as an opportunity to contribute to the development of the region by identifying opportunities for industries and businesses to work together and, in particular, coordinate infrastructure developments so that benefits are maximised and risks minimised.

In short, it is necessary to build a capacity to understand the current structure of the Spencer Gulf economy from both a market and non-market perspective, and the relationship of these considerations with its ecosystem and the changes that this system may go through. The search is for opportunities to take greater advantage and make greater use of the Gulf whilst minimising harm to the environment.

## 3.3 ACTIVITIES, STRESSORS AND IMPACTS

Thirteen key activities that have potential to impact on Spencer Gulf are discussed here focusing around the current situation, proposed development and expansion, potential stressors and impacts and key knowledge gaps. The focus is largely around the potential impacts of each activity on the Gulf rather than the impacts on the activity from the other developments. All these activities require consideration for an assessment of cumulative impacts and for any spatial or multiple use management plans.

### 3.3.1 FISHING

**Current situation**

Fishing includes commercial, recreational and charter fishing operations. Annual production from the commercial fisheries of Spencer Gulf over the last five years has been 33,178 t per annum with a landed value of $65.9M (see Knight and Tsolos, 2012), with the South Australian Sardine Fishery dominating catches (29,382 t) (Table 1). The most valuable fisheries are western king prawn (~$28.8M), sardine ($19.2M), greenlip and blacklip abalone ($6.2M), blue crab ($3.0 M), snapper ($2.5M) and King George whiting ($1.6M). The 28.8 million dollar Spencer Gulf king prawn fishery is one of only eight Marine Stewardship Council "certified sustainable seafood" prawn and shrimp fisheries in the world (as at 14 February 2013; see http://www.msc.org/track-a-fishery/fisheries-search/).

Table 1. Average annual production and value of the commercial fisheries of Spencer Gulf over the last five years.

| Fishery | Species | Production (t) | Value ($M) |
|---|---|---|---|
| Spencer Gulf Prawn | Western king prawn | 1,973 | 28.8 |
| | Southern calamary | 26 | 0.2 |
| Blue Crab Fishery | Blue crab | 381 | 3.0 |
| Marine Scalefish Fishery | All shark | 87 | 0.3 |
| | Australian herring | 82 | 0.3 |
| | Australian salmon | 96 | 0.2 |
| | Garfish | 140 | 0.9 |
| | King George whiting | 108 | 1.6 |
| | Snapper | 365 | 2.5 |
| | Snook | 26 | 0.1 |
| | Southern calamari | 168 | 1.6 |
| | Yellow-eye mullet | 16 | 0.6 |
| | Yellowfin whiting | 71 | 0.6 |

| | | | |
|---|---|---|---|
| | Other species – amalgamated | 74 | 0.3 |
| Rock Lobster (NZRL) | Southern rock lobster | 3 | 0.1 |
| Abalone Fisheries | Greenlip and blacklip abalone | 182 | 6.2 |
| Sardine Fishery | Sardine | 29,382 | 19.0 |
| **Total** | | **33,178** | **65.9** |

Recent stock assessment reports and management plans for the key commercial fisheries of Spencer Gulf can be found at the following links:

http://www.sardi.sa.gov.au/fisheries/publications/2013_publications

http://www.pir.sa.gov.au/fisheries/commercial_fishing

Spencer Gulf is also a key component of South Australia's recreational fishery (http://www.pir.sa.gov.au/fisheries/recreational_fishing) supporting about 25% of total effort and the largest regional catches of King George whiting, snapper, snook, yellowfin whiting and blue crab (Jones and Doonan, 2005; Jones, 2009). There have only been two recreational fishing assessments in South Australia (in 2000/01 and 2007/08).

Fishing charters operate out of many of the towns surrounding Spencer Gulf, including Whyalla, Port Augusta and Moonta, targeting species such as snapper, yellow fin and King George whiting, snook, shark, squid and blue swimmer crabs among others. The Spencer Gulf/Coffin Bay region supports approximately 40% of the South Australian Charter Boat Fishery (Tsolos, 2013).

### Proposed expansion and development

Most current fisheries species in Spencer Gulf are fully exploited. The main issue for these fisheries is maintaining current access and production levels as other activities increase. Unexploited species in Spencer Gulf (e.g. Australian anchovy, *Engraulis australis*) provide significant potential protein sources for direct human use and food production (e.g. Dimmlich et al., 2009). Utilisation of these resources is currently impeded by lack of markets, technological constraints, low prices and high costs of production. Increased demand for seafood, aquaculture fodder, pet food and recreational fishing bait in coming decades may provide opportunities to utilize species that are currently unexploited.

### Potential stressors and impacts

A wide range of current and future activities have the potential to cause biological and ecological changes that will reduce future fisheries production (e.g. terrestrial run-off, etc.). Climate variability may influence future recruitment, abundance and productivity of Spencer Gulf's fisheries (Pecl et al., 2011). Fisheries production may also be reduced by a range of anthropogenic impacts (e.g. terrestrial run-off, pollution), and access to and use of existing fishing grounds will be potentially affected by other users (e.g. commercial shipping).

Most species are currently fished within sustainable limits (Sloan et al., PIRSA Fisheries and Aquaculture, unpublished data). Bycatch of non-target species, including some Threatened, Endangered or Protected Species, has been assessed and mitigated in several fisheries (Tsolos and Boyle, 2013). For example, the Spencer Gulf Prawn Fishery has reduced the area and time trawled (Currie et al., 2009), the Marine Scalefish Fishery has undertaken gear modifications to reduce bycatch of non-target species (Fowler et al., 2009) and the Sardine Fishery has developed a Code of Practice to mitigate interactions with the short-beaked common dolphin (Ward et al., 2012). Furthermore, a recent study of the trophodynamic effects of the South Australian Sardine Fishery on the ecosystem and key predatory species found that impacts were low (Goldsworthy et al., 2013).

**Knowledge gaps**

An improved understanding of variation in the physical environment and how these changes affect other elements in the ecosystem is required. Research priorities for individual fisheries species are identified in the stock assessment reports. Biosecurity risks associated with bait translocation and use, including diversion of imported product for use as bait, need to be identified and management strategies developed. The impacts of fisheries bycatch on fish and marine mammals is also an important knowledge gap.

## 3.3.2 AQUACULTURE

**Current situation**

In 2010/11, aquaculture in South Australia produced 20,247 t of product, worth $229M, and employing 2,649 people full-time in regional communities (Econsearch, 2012a). Spencer Gulf produces about 80% of the aquaculture production in South Australia; this makes it significant on a national scale. Southern bluefin tuna (SBT; *Thunnus maccoyii*), yellowtail kingfish (YTK; *Seriola lalandi*) and blue mussel (*Mytilus galloprovincialis*) industries are exclusively within the marine waters of Spencer Gulf, whereas the Pacific oyster (*Crassotrea gigas*) and abalone (*Haliotis laevigata*) industries occur in Spencer Gulf, as well as other regions. In terms of production values the top five sectors in the state are: 1) SBT ($125M, 5800 t); 2) Pacific oysters ($35M, 654 t); 3) marine finfish ($27.9M, 3620 t, majority YTK); 4) abalone ($11M, 317 t); and 5) blue mussels ($2M, 1174 t).

In Spencer Gulf, only finfish (SBT and YTK) and bivalves (Pacific oysters and blue mussels) are currently farmed in the sea. Tuna ranching typically involves capturing 2 to 3 year old tuna in late December to March each year, and growing them in sea-cages with “baitfish” (mainly sardines) feed until they are ready for market. Almost all fish are harvested by August. At present tuna farms occupy 2,286 hectares of water immediately seaward of Boston Island (1,715 hectares) and in deeper waters near the Sir Joseph Banks Group of islands (571 hectares) in the south west of Spencer Gulf. The YTK sector occupies 692 hectares, in Boston Bay, Louth Bay, Arno Bay and Fitzgerald Bay. Fingerlings are produced from the land-based hatcheries at Arno Bay and Port Augusta and transferred to marine sea-cages at approximately 10 mm long.

Pacific oysters are grown intertidally using a rack and rail system, a long-line system or a combination of both. Oyster farms are mainly located in Franklin Harbour adjacent to Cowell. Blue mussels are mostly grown in shallow waters using long-line culture techniques, which involve a system of horizontal ropes with buoys to provide flotation. Commercial mussel farming occurs in Boston Bay, although mussel farming did occur at Wallaroo for a period of time. Currently Pacific oyster spat are provided from land-based hatcheries, while blue mussel spat are collected from the wild. Both species are generally harvested after an on-growing period of approximately 12 to 18 months depending on farm location.

**Proposed development and expansion**

Aquaculture development in South Australia has been managed and planned through the designation of aquaculture zones, which broadly define where aquaculture can and cannot occur and the types and quantities of species that can be farmed. Aquaculture zones have been steadily implemented since 2003, with further zone development still occurring. Although zones are located throughout the state (Figure 6), the overall area of state waters set aside for them is low (~3%) and within these, only a small area is used for aquaculture (generally 10%).

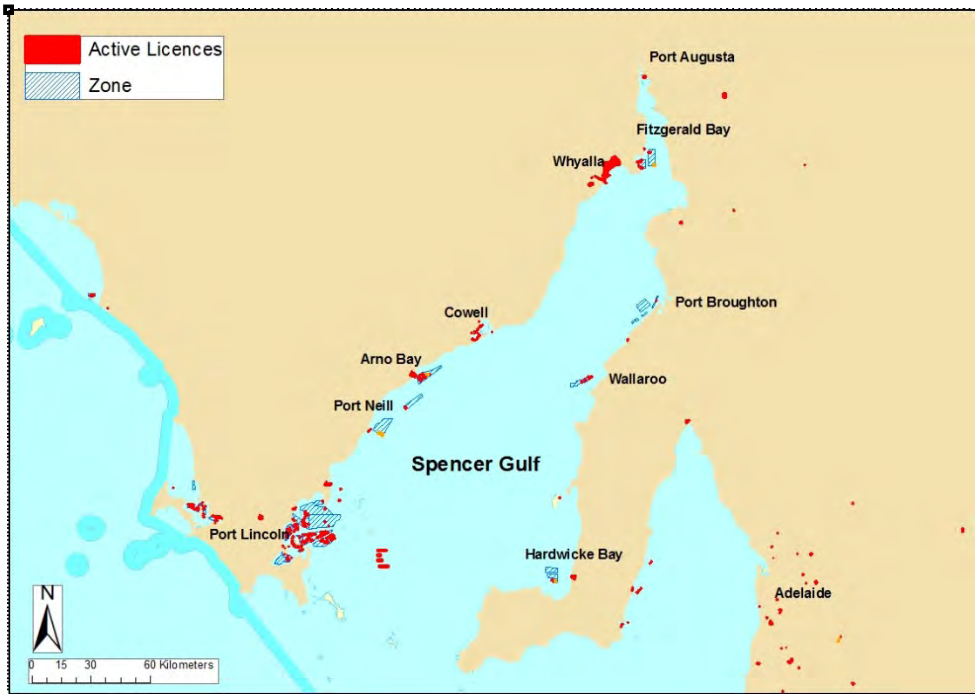

Figure 6. Current (2012) major areas of aquaculture production in Spencer Gulf and surrounds. Active marine and land-based aquaculture licences are shown in red (provided by PIRSA Fisheries & Aquaculture).

As the demand for seafood exceeds the total potential catch from exploited and underexploited aquatic resources globally (Tucker and Jory, 1991), aquaculture is becoming increasingly crucial to fill this gap and Spencer Gulf will continue to be a major focus of such developments in SA. Opportunities exist to grow and diversify the existing aquaculture industry sectors as well as establish new novel aquaculture species (e.g. micro- and macro-algae, select finfish and shellfish species, sea cucumbers, sea urchins and octopus), locations, systems, products and technologies (e.g. Integrated Multi-Trophic Aquaculture).

## Potential stressors and impacts

Finfish culture involves the addition of feed (baitfish and manufactured diets) and the release of a number of wastes into the system. These include uneaten fish food, fish excretory products, and organic matter from net cleaning. The major components of solid and dissolved waste are various forms of carbon, nitrogen and phosphorous. The effects on the food chain from this additional organic input are many and varied, from water column nutrient enrichment to accumulation of organic matter in the sediments.

In the water column, soluble nutrient can alter the species composition and increase the density of phytoplankton. The accumulation of organic matter on the seabed, especially in areas of poor current flow, can produce major changes in the sediment chemistry. These include the reduction in sediment oxygen, release of toxic hydrogen sulphide, and further changes in species composition of sediment flora and fauna. In shallow subtidal waters and intertidal zones, nutrient enrichment can stimulate the extensive development of macroalgae, which in turn can form shading of seagrasses.

In contrast, bivalves are predominately farmed using techniques that rely on a net removal of nutrients from the water column as bivalves filter suspended particles including phytoplankton, detritus, and some auto- and heterotrophic pico-plankton and micro-zooplankton. They sort captured particles prior to ingestion and reject non-ingested ones as mucus-bound pseudofaeces. The undigested particles are ejected as mucus-bound faeces. The feeding response of bivalves to changes in particle concentrations varies considerably among species. Some species such as oysters and mussels maintain relatively high clearance rates when particle concentrations increase, whereas other species such as cockles and scallops regulate their ingestion rates by reducing clearance rates and to a lesser degree rejecting excess particles as pseudofaeces.

Both pseudofaeces and faeces rapidly settle to the seabed. These activities divert primary production and energy flow from planktonic to benthic food webs. The increased coupling of planktonic and benthic food webs by cultured bivalves has the potential to change energy flow pattern, including altering food availability to zooplankton, other filter feeders (such as wild bivalves) and larval fish. The consumption and deposition of suspended particulate matter by bivalves, as well as the excretion of dissolved nutrients, can play a significant role in controlling the amounts and forms of nitrogen in the ecosystem where they are farmed and the rate of nitrogen cycling. In addition, the nutrients and minerals stored in the cultured biomass are removed at the harvest and no long available to the marine food web.

Key impacts to finfish aquaculture are those activities and processes that affect the capacity of the local environment to disperse or otherwise assimilate the wastes. While impacts to bivalve aquaculture are those activities and processes that influence ecological processes that could affect bivalve growth, health and product qualities, such as water circulation, mixing and exchange (including spatially dependent tidal flushing and upwelling), water quality/nutrients, the replenishment of food particles through primary production and other sources, chemical/dissolved containments and habit degradations (including human inputs from coastal development). Other impacts to aquaculture include effects of climate change and emerging diseases.

## Knowledge Gaps

Bivalves

- Differential feeding between bivalves: investigate what the key aquaculture species (e.g. Pacific oysters and blue mussels) consume, as well as what other naturally occurring bivalves species (e.g. cockles, native oysters and razor fish) in the same area consume.
- Understand how the food of key bivalve aquaculture species fluctuates over time and how these fluctuations are linked to key environmental drivers.
- Quantify the density-dependant role of farmed bivalves in controlling phytoplankton and seston concentrations, and study their correlation with bivalve performance.
- Quantify the effect of bivalve aquaculture on the density of predators and detritivores within and adjacent to farms.
- Use ecosystem modelling to assess the interaction between bivalve aquaculture and major ecosystem components and to address issues of aquaculture production capacity and sustainability as well as ecosystem assimilative capacity.

Finfish

- Improve spatial and temporal quantification of the relationship between aquaculture fish diet quantity and ingredients, fish farm waste quantity and type, and the environmental impact of the organisms on the seafloor and water column.
- Quantify how naturally occurring species associated with aquaculture are important in assimilating and dispersing farm wastes.

- Refine the hydrodynamic-biogeochemical model used to manage finfish aquaculture zone and farm planning and carrying capacity.

General

- Integrated multi-trophic aquaculture (IMTA): improve the knowledge of how likely IMTA species can best be farmed in an integrated manner to optimise waste utilisation thereby maximising farm productivity and minimising environmental impacts.
- Refine the environmental monitoring of aquaculture sectors to be more inclusive of potential regional, cumulative effects.
- Move from individual operator and industry sector based environmental monitoring undertaken independently for a number of regulatory agencies to embrace the principles of ecosystem based management, with its focus on location based ecosystem monitoring, with greater consideration of cumulative regional effects, broader stakeholder involvement and coordination.

### 3.3.3 DESALINATION

**Current situation**

South Australia's arid environment means that water is a scarce resource. South Australia's main water supply comes via the River Murray although there is some drinkable water supplied by local groundwater on the Eyre Peninsula, but this requires augmentation (Government of South Australia, 2005). Northern Yorke Peninsula and Upper Spencer Gulf are dependent on water from the River Murray, whereas the southern Yorke Peninsula relies on aquifer and rainwater supplies (Government of South Australia, 2005). There is some recycling of stormwater for use on golf courses and parklands (e.g. Copper Coast). Currently little desalination of water in the Spencer Gulf coastal region occurs, although several of the towns further north (e.g. Coober Pedy, Roxby Downs) supply their own water via desalination of water from the Great Artesian Basin. The current Infrastructure Strategic Plan suggests that opportunities may exist to construct additional desalination plants strategically around the state (Government of South Australia, 2005). Desalination may be an option for augmentation of supply of water to Eyre Peninsula. At present, Arrium has a desalination plant at Whyalla (capacity 1.5 GL/year).

**Proposed expansion and development**

Demand for water from desalination is expected to increase with expansion of the resources and energy sectors, and as a result of climate change. The currently proposed desalination plants for Spencer Gulf are detailed in Table 2.

Table 2. Proposed desalination plants for Spencer Gulf region. Estimated completion dates are only shown where indicated in company documents.

| Location | Capacity | Developer | Estimated completion |
|---|---|---|---|
| Point Lowly | 100 GL/year | BHP Billiton | |
| Point Paterson | 5.5 GL/year | Sundrop/Acquasol | *2013-2015* |
| Port Pirie | 50 GL/year | Braemar Alliance | |
| Port Spencer | 4 GL/year | Centrex/Osmoflo | *2015* |
| Sleaford | | SA Water | |
| Whyalla | 5 GL/year | Arafura Rare Earth | |

### Potential impacts and stressors

Desalination is becoming a more viable and economically attractive option to satisfy the demand for freshwater. If not managed appropriately, the saline concentrate generated by desalination plants can pose a threat to planktonic and benthic ecosystems, depending on its salinity level and on the dilution rate used for the discharge. The salinity of Spencer Gulf naturally increases progressively from 36‰ on the shelf to more than 45‰ near the head of the Gulf at Port Augusta (Nunes-Vaz, 2012). The salinity level of the saline concentrate generated by desalination plants is generally around 48-65‰ and can go up to 80‰ (Dupavillon and Gillanders, 2009). The potential effect of saline discharge from desalination is a local phenomenon, whereas the natural removal of freshwater by excess evaporation acts uniformly across the region (Nunes-Vaz, 2012).

Roberts et al. (2010) reviewed the environmental, ecological and toxicological effects of saline concentrate on organisms and the receiving environment. Changes in aquatic species composition and population density are commonly observed in the area of saline discharge (Lattemann and Höpner, 2008), but the response of organisms is species specific (Einav and Lokiec, 2003). While some species are resistant to high salinity levels and can survive changes in environmental conditions, other species can tolerate a smaller range of salinity and will not survive if the salinity exceeds that range. Dupavillon and Gillanders (2009) investigated the impact of saline concentrate on the growth, survival and condition of cuttlefish (*Sepia apama*) embryos from Spencer Gulf and found that they do not survive salinities over 50‰. Recent studies have also found that desalination plants have the potential to adversely affect aquatic communities via impingement and entrainment of organisms on intake screens/structures and in cooling water systems (Miria and Chouikhi, 2005; Lattemann and Höpner, 2008). Furthermore, saline discharge can contain higher concentrations of nutrients and heavy metals than are present *in situ*, as well as excess chemicals used in the water pre-treatment process, which can potentially adversely affect benthic communities in surrounding areas (Sadiq, 2002). Depending on the location of the desalination plant and method of saline concentrate return to the environment, changes in species assemblages have been observed to a maximum distance of 10 m, 30 m and 1 km from the diffuser heads (Gacia et al., 2007). Dispersal of the saline concentrate and associated ecological impacts are linked to the hydrological properties of the receiving environment. Nunes-Vaz (2012) showed that the discharge of saline concentrate in upper Spencer Gulf would lead to an increase in salinity of 0.003‰ at the scale of the Gulf. Given a specific desalination plant location, it is important to understand localised impacts of increases in salinity as well as impacts at the scale of the Gulf. The positioning of the intake and outlet of a desalination plant determines the extent to which the local marine ecosystem will be impacted.

Potential impacts on desalination plants from other activities are also possible. Developments that impact water quality have the potential to impact operation of desalination plants.

**Knowledge gaps**

The current knowledge gaps are:

- Spatial and temporal variation in the fate of saline concentrate discharge at local to whole-of-Gulf scales (To where does the discharge flow? How quickly does it dissipate?).
- The impact of saline concentrate on benthic and pelagic communities in Spencer Gulf, including the impact of antifoulants, antiscalants and other chemicals (e.g. copper) used in desalination plants. Similar descalants to that used in the final design should be used and tests should consider how effects may change with different environmental conditions (e.g. temperature). Although some chronic tests over short time periods have been undertaken, these should be used as a guide for longer-term tests across all life history stages. Such research should build on the toxicity studies undertaken for the Olympic Dam environmental impact statement (BHP Billiton, 2009).
- The identification of benthic and pelagic species suitable for use in monitoring studies as indicators of salinity/environmental stress in Spencer Gulf.
- Well-designed monitoring studies are lacking in the literature, but should be used to assess the spatial extent of any impacts. Such studies should utilize Before-After Control-Impact (BACI) designs including multiple reference locations, and replicated sampling prior to and after construction of a desalination plant.
- There is a lack of manipulative experimental field studies on the effects of saline concentrate. Although challenging to conduct, such studies provide significant insight into potential impacts.
- The impact of entrainment of microbes and plankton through intake structures on primary and secondary productivity and food web dynamics is poorly understood.

### 3.3.4 URBAN DEVELOPMENT

**Current situation**

Spencer Gulf and the surrounding rural areas support a population of approximately 70,000 people, the majority concentrated in the large urban centres on the coast, including Whyalla (~22,500), Port Pirie (~17,000), Port Lincoln (~14,000) and Port Augusta (~13,000). Throughout the region there is a large non-resident population which predominantly use their properties for holidays, adding a transient population that can be a large proportion of the total population (Hugo and Harris, 2012).

**Proposed expansion and development**

The population of the Spencer Gulf region has been predicted to decline to ~60,000 (~15%) by 2016 (Government of South Australia, 2005). However, much of the decline (if any) is likely to be in inland areas, with the population likely to increase in many coastal towns and centres. For example, the Copper Coast region is predicted to increase in population by ~2000 people (~15%) by 2021, largely as a result of the immigration of retirees who are currently non-resident owners of property in the region (Hugo and Harris, 2012). In addition, a number of planned developments such as the potential expansion of mining activities in the state may lead to an increase in the resident population of the area. To support urban development, there is a plan to increase the number of water connections to developments by 19% because the increase in population in coastal areas is associated with a projected 15% increase in demand for potable water by 2032 (Water for Good, 2012). This increased use will then require increased capacity in wastewater treatment and potentially increased discharge of treated wastewater into Gulf waters.

The increase in population will require not only more housing and urban development in the coastal towns of the region, but also more infrastructure for leisure activities. There are currently several development plans in the region for marinas and other urban structures, which will encroach into marine waters. These plans are not yet approved, but it is likely that population expansion will also be accompanied by developments such as marinas and jetties.

### Potential stressors and impacts

One very real effect of coastal urbanisation in the Gulf is that urban marine structures (e.g. jetties, pontoons, pilings, and walls) act as novel habitats for a diverse suite of organisms, and appear particularly favourable to invasive species (Glasby et al., 2007) and emerging disease (Harvell et al., 1999). Therefore, in addition to any short to medium impact of the construction of these structures, there can be an ongoing impact on the diversity of local flora and fauna due to an increase in invasive species. Because nonindigenous epibiota also have the propensity to colonise nearby reefs, the creation of artificial structures in gulfs and estuaries could be a threat to native biodiversity on a larger scale. In Gulf St Vincent, this is particularly true in areas where other environmental conditions are also altered (e.g. enclosed harbours/marinas where water flow is restricted, pollutant levels increased, and potentially with elevated water levels due to thermal pollution), and the same is likely to apply in Spencer Gulf.

Declining water quality in South Australia, generally as a result of increased population and greater wastewater and storm water discharge, favours small fast-growing or “weedy” species that are able to displace slower-growing species (Connell et al., 2008). This model appears to have application to human-dominated coasts, such as the Spencer Gulf. The novel environments created by human pollution (e.g. sedimentation and eutrophication) do not appear to have strong direct negative effects on seagrasses and kelps *per se*, but rather act in conjunction with ‘natural’ disturbances that remove canopies (e.g. storms) to create conditions needed for the rapid colonisation by turfs which accumulate sediment.

In kelp forests, these short, densely packed turfs have limited capacity to store nitrogen and are normally ephemeral, but persist under conditions of high nutrient and sediment loads. A key condition is sediment accumulation, which inhibits the recruitment of kelp. Vulnerable localities appear to be associated with conditions that enhance sediment deposition (e.g. dredging and intensive land use) and sediment accumulation (e.g. rocky substratum that is low-lying and of low relief or in close proximity to sand). Furthermore, turfs inhibit the recovery of kelp (Gorman and Connell, 2009), possibly because of the large amount of sediment they trap.

Similar mechanisms seem to work with seagrass loss, where any loss is maintained by sediment re-suspension making recolonisation difficult. In some areas of the northern Spencer Gulf, areas of seagrass which were harvested in the early 20th century have still not recovered (Irving, 2013).

### Knowledge gaps

The major knowledge gaps on the impacts of urban development in Spencer Gulf surround two main areas; (1) the effects of urban structures built in the marine environment to support increasing population (e.g. jetties and marinas); and (2) increased input of nutrients and other pollutants into coastal waters.

(1) Urban structures

The notion that urban structures may have positive and negative impacts on the environment parallels developments in fisheries science. Although artificial structures are seen as effective tools to enhance the diversity and productivity of commercially important species, it is recognised that they can degrade the environment. Consequently, fisheries science has identified the need for and begun research on how different types of structures affect a fishery. In a similar context, assessments of how alternative urban structures affect the broader marine environment are required.

(2) Nutrients and pollutants

In addition, any developments that alter the physico-chemical properties of the Gulf waters, such as desalination or introduction of nutrients (e.g. wastewater and stormwater) or iron, could have effects on ecosystem functioning. It is well established that such inputs can have disproportionately large effects in South Australian waters (Russell et al., 2005), but there is little information to determine what threshold levels of these inputs may lead to deleterious environmental consequences, particularly with regard to the loss of habitat forming species (e.g. seagrass and kelps) and the flow-on effects through the system. A key concern is to ensure that we do not make the same mistakes as were made in Adelaide, where anthropogenic inputs related to urbanisation have resulted in extensive seagrass loss and degradation of coastal reefs.

### 3.3.5 RESOURCE DEVELOPMENT, ENERGY AND INDUSTRIAL

**Current situation**

South Australia has a diverse commodity base for mineral exploration, attracting the World's leading explorers and producers (Department for Manufacturing Innovation Trade Resources and Energy, 2012). The State's mineral exploration expenditure increased by 29% to $328.4M in 2011-12, with copper and iron ore accounting for 68% of spending (Department for Manufacturing Innovation Trade Resources and Energy, 2012). There are currently 925 exploration licences (at 30 June 2012) covering 424 000 km$^2$ in South Australia (Department for Manufacturing Innovation Trade Resources and Energy, 2012). Mineral commodities include copper, gold, graphite, iron ore, kaolin, manganese, nickel, potash, zinc, lead and silver. Energy commodities include coal and uranium.

There are 20 major operating/approved mines (http://outernode.pir.sa.gov.au/__data/assets/pdf_file/0005/157793/MajorOperatingMineReport20130624.pdf). South Australia has three of Australia's four operating uranium mines (Olympic Dam, Beverley and Honeymoon) including the world's largest uranium deposit. There are two iron ore producers (Arrium Ltd and IMX Resources) producing hematite and/or magnetite, with two more iron ore mines approved (Wilgerup and Wilcherry Hill). Almost all iron ore is used in steel production. The three most significant copper discoveries, in terms of total contained resource, in the last 10 years (Carrapateena, Prominent Hill and Hillside) are in South Australia; Olympic Dam, Prominent Hill and Kanmantoo are all operating copper-gold mines. There are three major gold mines, Olympic Dam, Challenger and Prominent Hill.

South Australia makes extensive use of gas for electricity generation and industrial use. The Cooper Basin produces sales gas and ethane for processing at Moomba and Ballera with liquids transported from Moomba to Port Bonython via a 659 km pipeline for crude oil and gas liquids processing. The Cooper and Eromanga basins (northeastern SA and southwest Queensland) are Australia's largest onshore petroleum areas.

### Proposed expansion and development

There are many developing and exploration projects in South Australia (Figure 7). SA has a significant number of iron ore development projects and prospects, including two approved mines (Wilgerup and Wilcherry Hill). A number of the development projects are on Eyre Peninsula. There are also several major expansion projects associated with the Middleback Ranges magnetite and haematite deposits, which have led to expansion of Whyalla Port. South Australia is a destination for copper exploration, with copper the commodity most explored for. There is some interest in coal seam methane, but it is less than in eastern Australia.

Exploration and development activity for petroleum in South Australia remains focused on the Cooper basin, although unconventional gases are now being investigated (e.g. shale gas). Petroleum exploration licences for tenements in northern Spencer Gulf cover marine waters and geothermal exploration licences and applications for tenements surround waters of northern Spencer Gulf (see also power production; http://www.petroleum.pir.sa.gov.au/prospectivity/exploration_and_development). Port Bonython fuels plans to construct and operate a fuel storage and distribution facility at Port Bonython. There is also a substantial focus by several companies offshore from Spencer Gulf, with potential implications for southern Gulf waters.

## South Australia's Mining Pipeline
## October 2012

**MAJOR MINES**

1. Olympic Dam (Cu-U-Au-Ag)
2. Challenger (Au)*
3. Beverley (U)
4. Middleback Range (Iron ore)*
5. Leigh Creek (Coal)
6. Malu (Prominent Hill Open Cut) (Cu-Au)*
7. Angas (Pb-Zn)*
8. Honeymoon (U)*
9. Jacinth-Ambrosia (HM)
10. Beltana (Zn)
11. White Dam (Au)
12. Cairn Hill ($Fe_3O_4$)
13. Iron Chieftain (Iron ore)
14. Ankata (Prominent Hill Underground) (Cu-Au)
15. Kanmantoo (Cu, Au, Ag)
16. Beverley North (U)
17. Peculiar Knob ($Fe_2O_3$)
18. Wilgerup ($Fe_2O_3$)*
19. Wilcherry Hill ($Fe_3O_4$)
20. Mindarie (HM)

**DEVELOPING PROJECTS**

Arckaringa (CTL)*
Atacama/Typhoon/Sonoran (HM)
Beverley South (U)
Bird-in-Hand (Au)*
Bungalow ($Fe_3O_4$)
Carrapateena (Cu-Au)*
Crocker Well (U)
Flinders-Reliance (Zn)
Four-Mile (U)*
Fusion ($Fe_3O_4$)
Giffen Well ($Fe_2O_3$)
Gum Flat ($Fe_2O_3$)
Hawks Nest ($Fe_2O_3$)
Hematite Extension Project – HEP ($Fe_2O_3$)
Hillside (Cu, Au)
Junction Dam (U)
Kalkaroo (Cu-Au-Mo)*
Maldorky ($Fe_3O_4$)
Menninnie Dam (Pb-Zn-Ag)*
Mutooroo (Cu-Co)
Mutooroo ($Fe_2O_3$)
Olympic Dam Expansion (Cu-U-Au-Ag)
Paris (Ag)
Poochera (Kaolin)
Portia (Au)*
Razorback ($Fe_3O_4$)
Samphire (U)*
Snaefell ($Fe_3O_4$)
Tripitaka (HM)
Tunkillia (Au, Ag)*
Uley (Graphite)
Warramboo ($Fe_3O_4$)
White Dam North (Au)

**PROSPECTS**

Acropolis (Cu-U-Au-Ag)
Alvey (Pt, Pd)*
Aphrodite (U)*
Aristotle (Zn)
Armchair (U)
Aroona 2 (Zn, Pb)
Baggy Green (Au)*
Bagot Well (Cu)
Bald Hill Iron (Fe)
Barns (Au)*
Barton West (HM)*
Becaroo (U, REE)
Big Lake 20 (U)
Big Lake 28 (U)
Black Hills (Au)*
Blanchewater (U)
Blinman (Cu)
Blue Rose (Cu, Au)*
Burra (Cu)
Carrow (Fe)
Claude Hills (Ni)*
Clinton (CTL)
Coolybring ($Fe_3O_4$)*
Deloraine (Au)
Dromedary (HM)*
Emmie Bluff (Cu)*
Emmie North (Cu)
Eurelia (Diamonds)
Eurinilla Dome (Cu, Au)
Flinders Island (Diamond)
Glenrae (IOCG)
Golf Bore (Au)
Goulds Dam (U)
Greenpatch ($Fe_3O_4$)
Gullivers (HM)
Hercules ($Fe_3O_4$)*
Hicks Hill (Fe)
Jamieson Tank (Mn)
Jungle Dam (Ag, Au, Fe)*
Kangaroo Dam (Pt, Pd, Au)*
Kenmore II (Ni, Cu)
Kingston (CTL)
Kopi (Fe)
Lady Jane (Au)
Lilydale (Fe)
Lock (Coal)
Mainwood (Au)
Malache (Zn, Pb)
Melton (Cu, Au)
Minbrie (Fe)
Miranda (Cu)
Mojave (HM)
Mongolata (Au)*
Monsoon (Au)
Moonta (Cu)*
Moorilyanna (Cu)
Mount Brady (Fe, Cu, REE)
Mount Caroline (Ni, Cu, Pt, Pd)*
Mount Christie Siding ($Cr_2O_3$)
Mount Cora (Fe)
Mount Davies (Ni)
Mount Distance (U)
Mount Gunson (Cu, Co)*
Mount Torrens (Cu-U-Au-Ag)
Mount Woods (IOCGU)*
Mulyungarie (U)
Netherleigh Park (Cu)
Netley Hill (Cu, Mo)*
North Kalkaroo (Cu, Au)
North Portia (Cu, Au)
Notrab (HM)
Oakdale (Zn, Cu)*
Parara (IOCGU)
Parkinson Dam (Ag, Zn, Cu, Au)*
Pindari (Ni, Cr)
Pollinga (Mn)
Princess Royal (Cu)
Prospect Hill (Sn)*
Pundinya (U)*
Punt Hill (Cu, Au)
Radium Hill (U, Th, Ra)
Sequoia (Fe, U)
Sheoak (Au, Ag)
Shylock (Cu, Au)
Skye (Au, Ag)
Springfield (Diamond)
Stuart (IOCGU)*
Taurus (Pt, Pd, Cu)
Telephone Dam (Pb, Zn)
Titan (Cu, Au)*
Tomahawk/Tunkillia area 191 (Au)
Toondulya (Cu, Au)
Torrens South JV (Cu, Au)
Typhoon (Au)
Ultima Dam (Au, U)
Victory (U, REE)
Vulcan (Cu, Au, U)*
Weednanna (Pb, Zn, Ag, Cu, Au)
Wheal Ellen (Zn, Pb, Ag)
Willamulka (Cu, Au)
Willy Willy (HM)
Winjabbie East (Cu, REE)
Wirrda (Cu, Au)
Yadglin (U)*
Yanyarrie (Ba)
Yarramba (U)
Zeus (Cu, Ni)

* PACE Co-funded * Mine expansion

**PROSPECTS**
Anomalous drillhole intersections, and encouraging geochemical and/or exploration results.

**DEVELOPING PROJECTS**
JORC Resource. Possibly undertaking or have completed feasibility studies. Possibly progressing mine proposals, assessment and approvals stages.

**MAJOR MINES**
Operating or under construction.

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Government of South Australia
Department for Manufacturing, Innovation, Trade, Resources and Energy

Figure 7. South Australia's mining pipeline. Prospects include encouraging geochemical and/or exploration results, which lead to development projects. These are projects that are undertaking or have completed feasibility studies and are progressing towards mine proposals, assessment and approval stages. Major mines are operating mines or those under construction. From: Department for Manufacturing, Innovation, Trade, Resources and Energy.

**Potential impacts and stressors**

Resource, energy and industrial development generally occur on land and often some distance from marine waters, therefore there are likely to be limited direct impacts. An exception may be any proposed seismic testing associated with oil and gas exploration or development in Gulf waters. In addition, there may be runoff of waste and other materials into coastal waters for developments occurring nearby. The key links to marine waters are through additional infrastructure required for development such as water (e.g. coastal desalination), power and ports (see Desalination, Power production and Ports and dredging for more details).

### 3.3.6 POWER PRODUCTION

**Current situation**

Much of the electricity in the region is currently sourced from the national grid (RESIC, 2011). Alinta Energy has two coal-fired power stations, the Northern Power Station and the Playford Power Station situated in Port Augusta. These plants are part of Alinta Energy's Flinders Operations Division. They are supplied by coal transported by train from the Leigh Creek coalfield located approximately 250km north of Port Augusta. The Playford Power Station has been operating since the 1950s, and the Northern Power Station since the 1980s.

**Proposed expansion and development**

In 2013, Alinta Energy is continuing its commitment to a sustainable future in regional South Australia by generating and selling affordable local energy, researching regional renewable opportunities, including solar thermal, continuing to provide local jobs and contribute to regional South Australian communities and economy.

There are several companies (Green Rock Energy, Torrens Energy Limited) investigating geothermal energy options and others looking at solar thermal and wind options. Green Rock Energy's Upper Spencer Gulf Project covers 1,938 km$^2$ along the Upper Spencer Gulf coast (see below), and has the potential to provide geothermal energy to power seawater desalination projects or electricity production. A 275 kV power line is situated along the eastern edge of the geothermal licences and two 275 kV lines are situated at the northern edge. Green Rock Energy's exploration licences cover an area from south of Whyalla on the Eyre Peninsula, north to Port Augusta and then south along the east coast of Spencer Gulf to below Port Pirie. Sections of the tenements are underlain by the prospective Hiltaba Suite granitic rocks. These granites contain the same radiogenic hot granite suite that the company is exploiting at Olympic Dam, and provide the heat source for the geothermal energy. Torrens Energy, an upstream geothermal exploration company, has several projects in South Australia including the Port Augusta geothermal field, which is close to the national electricity market, and has potential to augment existing power infrastructure. The Parachilna Geothermal Play project, situated 230 km north of Port Augusta is however, Torrens Energy's lead project. This project was established as the world's first geothermal resource.

There is also an independent, not-for-profit organisation with a proposal, Repowering Port Augusta, to replace the two coal-fired power stations in Port Augusta, with six solar thermal plants and 95 wind turbines. This project is estimated to create 1800 jobs, save 5 million tonnes of greenhouse gas emissions, improve the health of the local community and ensure energy security and stable electricity prices.

The 2011 RESIC report suggests that approximately 45% of peak electricity demand could be provided via renewable energy if it were cost-effective (RESIC, 2011). Distance to the grid and available grid capacity are issues of concern for the resources and energy sector.

**Potential impacts and stressors**

Cooling water discharge from the power stations can result in surface water temperatures about 6°C above ambient, but the effect is thought to be local. Several studies have monitored the impacts of the thermal discharge on seagrasses (Ainslie et al., 1994), intertidal communities (Thomas et al., 1986; Ainslie et al., 1989) and fish (Jones et al., 1996) either in northern Spencer Gulf or in the Port River estuary, Gulf St Vincent, although we acknowledge that the two systems may not be directly comparable. From the early studies in northern Spencer Gulf, no impact of warmed water from power stations could be discerned on intertidal assemblages or seagrasses (Ainslie et al., 1989, 1994). Longer term effects on seagrasses are being examined through Alinta's Environmental Compliance Agreement where they are taking aerial photographs on a biennial basis to estimate depletion or growth of seagrass and mangrove assemblages adjacent to the power station. Results from 2000 to the present day show marked growth in seagrass and mangrove extent (Williams, Alinta, pers. comm.).

Coal-fired power plants also discharge ash through settling ponds. A study undertaken by SARDI Aquatic Sciences did not detect impacts of ash on sediments in terms of benthic infauna or sediment characteristics including heavy metals, particle size, oxidation-reduction potential, and organic carbon (Tanner, SARDI Aquatic Sciences, pers. comm.). Similarly, no effects were found on mangroves, seagrass or saltmarsh.

Compounds used to clean pipes are not purposefully discharged into marine waters, although there have been several instances of sodium hypochlorite escaping from the cooling water dosing systems into the marine environment. The effect of these chemicals on marine organisms is unknown. Marine pests also have the potential to clog pipes and interrupt power generation.

**Knowledge gaps**

The effects of warm water on fish assemblages require investigation. In the Port River estuary, there was a decrease in number of fish species close to thermal effluent, with several estuarine opportunist species avoiding the area during summer/autumn but being attracted during winter/spring months (Jones et al., 1996). Whether similar patterns are found for Spencer Gulf is unknown. Jones et al. (1996) also suggested direct effects on growth of fish and premature movement out of the estuary; the impacts of warm water in northern Spencer Gulf on growth of fish requires investigation. There has been limited marine testing to determine if heavy metals from ash may bioaccumulate through the food web.

Entrainment of organisms in cooling water intake pipes has not been investigated. It is not thought to be a significant issue, but would require investigation of volumes of water being processed to determine potential impact.

### 3.3.7 SHIPPING

**Current Situation**

Maritime transportation is the dominant mechanism for the distribution of international freight. Economic growth in Australia and overseas has led to increases in the size and number of ships visiting our waters and these trends are forecast to continue (DEWHA, 2007; RESIC, 2011).

Spencer Gulf accommodates both international and domestic shipping, and particularly attracts export ships specialised for the transport of ores, minerals, grain and seeds, although imports of fertiliser, coal, minerals and petroleum products are also important (Office for Infrastructure Development, 2005). The major shipping routes intersect commercially important fishing grounds and, in some locations, approach coastal aquaculture operations (DEWNR, 2011). Currently maintained databases of ship statistics and movements relevant to Spencer Gulf include: (1) The Australian Marine Safety Authority's (AMSA) databases derived from the Australian Ship Reporting System (AUSREP) and the Automated Ship Identification System (AIS), (2) the Department of Agriculture, Fisheries and Forestry's (DAFF) Quarantine Pre-Assessment Database, and (3) shipping schedules maintained by the operators of specific ports.

### Proposed development and expansion

South Australia's growing mining sector is putting pressure on existing Spencer Gulf ports. Since visiting bulk and container ships are increasing in size and draught, the deepening and widening of many existing shipping channels has already been planned (RESIC, 2011). It is probable that the next decade will see the development of up to five new ports dedicated primarily to iron ore exports. For example, the Spencer Gulf Port Link consortium is proposing to construct a deep-sea port (the 'Port Bonython Bulk Export Facility') at Port Bonython near Whyalla in Upper Spencer Gulf. The expansion plan includes a new jetty (approximately 3km long and accessing 20m depth of water), wharves catering to Cape size vessels, iron ore storage and unloading facilities, and other ancillary structures (Flinders Ports South Australia, 2012).

### Potential stressors

Increased maritime trade within Spencer Gulf will produce both direct stressors and indirect effects due to increased port use and port expansion, as follows:

- **Marine pests and diseases.** The risk of incursion by new exotic species transported on the hulls of ships or within ballast water will increase.
- **Traffic.** Shipping traffic on existing routes will increase and additional routes will be established to service new ports. Traffic congestion near ports will likely result in longer average residence times for ships within Spencer Gulf.
- **Pollution.** Chemical, oil, noise and light pollution from ships and land-based port activities will all increase.
- **New port structures.** The construction of new port structures will provide new habitats for marine species and modify local hydrodynamic processes (including wave exposure), which will affect sediment transportation, and deposition processes.
- **Port channel dredging.** The creation/expansion of port channels, together with their future maintenance requirements, will produce sediment and require enlargement of existing placement areas or creation of new areas.
- **Water turbidity.** Turbidity from dredging and vessel turbulence will increase and turbid plumes may result.

### Potential impacts

- **Water Quality.** Increased pollution from shipping, including oil spills, chemicals, sewage and anti-fouling paints, directly threatens water quality. Further, catchment land use and coastal development have contributed to elevated levels of nutrients and other contaminants in surface ocean sediments (Brown, 2001; DSEWPAC, 2012). Dredging and turbidity resulting from shipping activity (e.g. docking, manoeuvring) remobilises sediments and releases such contaminants, threatening shellfish and other filter feeders (Knott et al., 2009).

- **Commercial/Recreational Fishing and Aquaculture.** Increased shipping traffic on existing routes and the creation of new routes will interfere with commercial and recreational fishing activities and increase the risk of vessel collisions. The passage of fishing vessels will be restricted surrounding high-traffic shipping lanes, particularly near ports. The introduction of new marine pests and pathogens potentially threatens the viability of native fish stocks and aquaculture industries (Ross et al., 2002). Turbid plumes may also impact aquaculture operations, particularly those focused on filter feeders (e.g. Pacific oysters) (EPA Victoria, 2001). Similarly, finfish may be affected by turbid sediment. Dredged sediment from port channels must be deposited somewhere and may contain contaminants which can then bioaccumulate through the food web (Mearns et al., 2010) and affect the suitability of local seafood for human consumption.
- **Marine Ecology and Conservation.** The dredging of port channels impacts the sediment-dwelling microbes, vegetation and animals and may impact estuarine nutrient cycling and have subsequent effects on higher trophic levels (Bolam and Rees, 2003; Sheridan, 2004). Turbid plumes resulting from dredging may directly smother important habitats (e.g. seagrass beds) or affect them indirectly through shading and subsequent reductions in primary productivity (Erftemeijer and Lewis, 2006). Increased shipping traffic will potentially impact marine fauna (including megafauna such as whales, sharks and dolphins) through noise generation (Erbe et al., 2012), vessel strikes (Laist et al., 2001) and marine pollution events (DEWHA, 2007). The increase in ships' draughts and associated water turbulence may directly threaten sensitive benthic habitats in the shallow, high-traffic regions of Spencer Gulf (Ellis et al., 2005). The modification of local currents, tidal range and wave action due to new port structures may also impact important intertidal habitats such as mangroves.

### Knowledge gaps

Whereas the impacts of port creation and expansion are typically assessed through local environmental impact assessments, a far greater challenge is to assess the combined effects on Spencer Gulf ecosystems and primary industries resulting from multiple stressors associated with increased shipping trade. Significant knowledge gaps include the following:

1. **The economic impacts** of increased shipping on commercial fisheries and aquaculture. In particular, significant unknowns are the impacts of interference from large ships on commercial fishing, the effects of increased pollution and turbidity on aquaculture operations, and the potential for negative, bottom-up effects on fisheries resulting from damage to important benthic habitats and nursery grounds.
2. **The impacts on marine species conservation** and the optimal configuration of buffer zones to protect threatened species or populations (e.g. Redfern et al., 2013).
3. **Risk profiles for biological invaders** that will change with modification of shipping transport pathways (Chivers and Leung, 2012), resulting in new high-risk invaders for Spencer Gulf ports.
4. **Economic and political uncertainty**, for example, uncertainty regarding the timing of BHP's Olympic Dam mining expansion, the development and placement of new aquaculture industries, and the ratification of international regulations for the treatment/exchange of ship ballast water (Albert et al., 2013).

To address these knowledge gaps requires detailed examination of the shipping pathways that link Spencer Gulf to domestic and international transport nodes, as well as the characteristics of ships traversing certain transport routes. The movement of individual ships can now be accurately reconstructed using AIS tracking data, which provides frequent position reports and associated metadata for all large trading vessels. Using these data, we will investigate how

Spencer Gulf shipping trade fits within the global transport network and develop scenario forecasts regarding future increases in ship size, number and residence times. We will also develop detailed scenarios regarding the use of existing and newly created shipping lanes along with the potential environmental and economic impacts of these changes.

### 3.3.8 PORTS AND DREDGING

**Current situation**

There are five port facilities in Spencer Gulf, with three operated by Flinders Ports (Port Lincoln, Port Pirie, Wallaroo) and the remaining two by Santos and Arrium:

- Port Bonython (north east of Whyalla) – Managed by Santos and used for export of petroleum products (e.g. liquefied petroleum gas (LPG) and crude oil from Cooper Basin). The maximum sized tanker that can currently be loaded has a capacity of 110,000 tonnes, and there are around 30 ships loaded per year.

- Port Lincoln – grains and seeds are the principal exports, and fertilizer and petroleum are the principal imports. This port is a natural deepwater port able to cater to Panamax size vessels. In 2011/2012 2.9 million tonnes (Mt) of cargo went through the port.

- Port Pirie – Large quantities of zinc concentrate and lead (from Nyrstar smelter), as well as grain and seeds are exported through this port, with principal imports being minerals, coal and ores. In 2011/2012 0.651 Mt of cargo was moved through this port.

- Wallaroo – Grain and seed exports with fertilizer imports are the principal products. In 2011/2012 0.95 Mt of cargo was moved through this port.

- Whyalla – This port operates as an Inner Harbour and an Outer Harbour (ore jetty) and is owned (under an indenture agreement) and operated by Arrium with a capacity of approx. 6 Mt per annum. The Outer Harbour has dredged channels to the open water and Inner Harbour with a Cape-size transhipment point at 7 nautical miles distance and includes an iron ore loading jetty. The Inner Harbour services the Steelworks. Both harbours have a 10.7 m berth depth.

Dredging has been defined as the removal of solid matter (over 9 $m^3$) from the seabed by digging or suction apparatus. Several of the ports have not required dredging (e.g. Port Bonython, Port Lincoln, Wallaroo) over the last 5 years. Port Pirie may require some, but due to the heavy metals in the sediments it has not been undertaken. Recent development in Whyalla (see below) involved some dredging but not of the channel, and transhipment off Whyalla and Port Pirie appears to have negated the need to dredge channel and wharf areas (Gerard Hocking, EPA pers. comm.). Dredging in Lucky Bay was undertaken to create the ferry terminal, and, due to lack of use for a period of time, further dredging was required when it was subsequently used again. Similarly, the Wallaroo ferry terminal requires periodic dredging over time. Several boat ramps (e.g. Point Turton boat ramp, Port Hughes boat ramp) have also been dredged several times over the last 5 years.

### Proposed development and expansion

New facilities proposed include:

- Cape Hardy – Iron Road's proposed deepwater port, 30 Mt per annum bulk export facility (20 Mt per annum for iron concentrates from their Central Eyre iron project and 10 Mt per annum for third party users), which would be capable of loading various vessels including Cape-size vessels.

- Lucky Bay port (near Cowell) – Iron Clad's iron ore export facilities involves construction of infrastructure at Lucky Bay port; they will initially transport iron ore from this port to vessels anchored offshore with potential to upgrade to a floating harbour allowing Cape-size vessels (150,000 t) to be loaded.

- Port Spencer – Centrex Metals proposed deepwater port located between Tumby Bay and Port Neill for the export of magnetite ore, but also with potential to become a multiuser facility to provide export services to other mining and rural industries (e.g. grain). The proposed port will accommodate Cape-size vessels.

- Port Bonython – Spencer Gulf Port Link Consortium plans to build and operate a common user bulk export facility, which is capable of handling Cape-size vessels. A three km long jetty that reaches into deep water is proposed along with enclosed conveyers and a ship loader. Discussions have also occurred in relation to a bulk fuels facility at Port Bonython.

- Whyalla Port expansion – Expansion to 13 Mt per annum with Outer Harbour export capability of >6 Mt per annum and Inner Harbour development of 7 Mt per annum capability (more than doubles port capacity); to be completed by mid-2013. The port is capable of further expansion if necessary.

The 2011 RESIC report also identified a lack of deep-water bulk commodity port facilities available to meet demand forecast for 2017 and beyond (RESIC, 2011). Access to suitable port infrastructure was highlighted as an issue in the RESIC report and one of the recommendations was that the South Australian Government facilitates the development of three new deep-sea ports in three regions (Eyre Peninsula proposed Port Spencer project, Upper North proposed Port Bonython project, Yorke Peninsula along the eastern side of Spencer Gulf).

### Potential stressors and impacts

Potential impacts relate to location of the port, construction activities and operation of the port. Besides water quality, other marine environmental considerations for port development include effects on coastal hydrology, bottom contamination, marine and coastal ecology, noise and vibration, and waste management.

Many of the potential stressors and impacts of port development and dredging are included under shipping (see above). For example, stressors include potential pollutants and changes to water turbidity. Impacts on water quality through changes to turbidity are likely around initial capital works and any maintenance dredging that may be required. Sediments may be remobilized releasing contaminants and affecting biota. A survey of potential contaminants in bottom sediments should be undertaken prior to construction as this will assist with identifying additional impacts. Bioaccumulation of contaminants through the food web is possible.

Dredging of port channels directly impacts sediment-dwelling organisms. Smothering of benthic organisms and physical habitats (e.g. seagrass beds) may also occur. Turbidity may also affect visual organisms (e.g. feeding, reproductive activities). There is a risk of harmful algal blooms associated with dredging.

Pile driving, deposition of rubble, dredging, compaction and other construction work in water can cause resuspension of sediments and turbid water leading to increased levels of suspended sediment, but these adverse effects can be minimised by use of silt curtains and suitable transport of materials. Considerable thought is required around appropriate disposal of dredged material. Discharges from ships (e.g. oily wastes, sewage, garbage) can also be sources of water pollution. Pile structures may also shade the bottom and provide new habitats for organisms.

Cargo operations on the waterfront are potential sources of contamination. Product spills may have localised impacts on sediments. For example, anoxic sediment may be found around grain spills. Minerals may have a greater impact on the marine environment (e.g. iron enrichment through dust), although with closed conveyors spills and dust are likely to be extremely limited.

Construction of breakwalls can change current patterns and drift of material due to alteration of waves, which can erode or accrete shorelines. Information can be obtained from simulation using oceanographic models to ensure impacts are minimised.

Noise associated with construction of new ports has potential to impact organisms. Transmission of noise will reduce with increasing distance from the source.

**Knowledge gaps**

Development of ports in Spencer Gulf can take advantage of previous developments (e.g. Port of Melbourne) to ensure that any impacts are minimised. As multiple ports are proposed, cumulative impacts should be determined. Well designed monitoring programs with multiple port and reference sites could be examined both prior to, during and following any port construction or dredging.

**Flora and fauna** – A critical knowledge gap for South Australia is how turbidity and resuspended solids, including toxins, may impact flora and fauna, especially seagrasses. Information is lacking on the impacts of noise from construction activities for key fauna.

**Plume pathways** – These are dependent on the exact location of the project and how it is carried out, but should be modelled under different current and wind scenarios to ascertain areas that may be impacted. This would then allow appropriate monitoring to ensure impacts are minimised. In addition, impacts on other activities (e.g. marine parks, aquaculture leases) could also be ascertained (see below).

**Pollutants in sediments** – Characterisation and mapping of pollutants in sediments around proposed port developments should be undertaken to determine which heavy metals and other pollutants are likely of greatest concern. Toxicity tests using these pollutants could then be undertaken.

### 3.3.9 DEFENCE

**Current situation**

The Cultana Training Area stretching from Fitzgerald Bay to Port Augusta and covering an area of 500 km$^2$, is a major area for South Australian based army units providing year round training for armoured, mechanised and cavalry forces training.

### Proposed development and expansion

Plans are underway for an expansion of Cultana Training Area westward, increasing from 500km$^2$ to 2,300km$^2$, to support future joint training needs, and offering an environment to conduct future air to ground, ground to air and ship to shore training activities. Expansion will be achieved through the acquisition of surrounding pastoral leases. Although the expansion does not alter the current shoreline used by the Cultana Training Area, it limits opportunities for the coastal road to be used as a tourist attraction, as the road would encroach upon existing training activities.

### Potential stressors and impacts

The Department of Defence is committed to sustainable environmental management in supporting its capability to defend Australia and its national interests, and strives to produce sustainable outcomes across every aspect of its work including planning and implementation. The Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) issued Defence with Guidelines for a Public Environment Report, which has now been finalised incorporating public comments on the draft, and is currently being assessed by the Minister for Environment.

The proposed land acquisition required to expand Defence capabilities does not affect existing mineral exploration or mining. A Memorandum of Understanding between Defence and the South Australian Government establishes the broad principles with respect to mining operations and access to the Cultana Expansion Area by mining interests. Cooperation between Defence and the South Australian Government and its agencies will ensure that mining interests and Defence activities can co-exist.

The proposed expansion of Cultana Training Area includes ship to shore activities. Amphibious vehicles moving over shallow seagrass or reef areas could impact these habitats and therefore any ship to shore activities should operate over a confined area. Any impacts of amphibious vehicles would be localised. Active sonar, which can be used to locate objects, may impact the marine environment depending on the output power, transmission frequency and sound transmission characteristics of the environment. Potential impacts will also depend on individual species characteristics and how close they are to the sound source. Activities involving use of sonar by the military are subject to thorough defence environmental assessment procedures.

### Knowledge gaps

The impact of defence activities on marine waters is unknown but thought to be minimal. Given the proposed expansion includes ship to shore activities, there is potential for marine-based impacts, but these would require investigation. It is important that defence are updated on any research outcomes from the Spencer Gulf project.

## 3.3.10 OTHER INFRASTRUCTURE DEVELOPMENT

### Current situation

Around Spencer Gulf, there are over 40 boat ramps (http://www.dpti.sa.gov.au/recboatingfacilities/boat_ramp_locations) and over 15 jetties (http://www.dpti.sa.gov.au/recboatingfacilities/jetty_locations), as well as a number of navigation markers and permanent moorings. Boat ramps are generally owned by local councils.

Sundrop farms near Port Augusta harnesses solar energy to desalinate seawater to produce freshwater for irrigation, produce electricity to power greenhouses and provide energy to heat and cool greenhouses and produce organic vegetables. Salt and other minerals gained in the desalination process are utilised. The minerals are used as crop nutrients and the salt is sold on to other agricultural users (mostly in the livestock industry).

A $10.7 million biofuel demonstration plant is proposed at Whyalla. Muradel's system uses salt-water algae to produce biofuel (http://www.muradel.com.au/pressrelease_1.html). The algae are grown in ponds, on land, and tolerate hyper saline conditions reducing the need for discharges to the environment.

**Proposed development and expansion**

Local councils are responsible for upgrading boat ramps or developing new facilities. A facilities levy is applied to registration of commercial and recreational vessels, which goes into a boating facilities fund. Through this fund, local councils or large community organisations can apply for up to 50% of total project costs to upgrade boat facilities.

Based on the highly successful commercial trial of the Sundrop Farms technology, the company has decided to significantly expand its current operations by 20 hectares. Construction will begin shortly and is due to be completed in 2014.

**Potential stressors and impacts**

See desalination, ports and dredging, and shipping sections.

### 3.3.11 AGRICULTURE

**Current Situation**

Agricultural activities extend close to the coast line, although the often extensive low lying tidal areas and near surrounds are too salty and prone to waterlogging to be cultivated and grazed. These areas are likely to be ecologically significant for carbon and nutrient exchange as well as for local biota. With drier areas in the north, there is very little cultivated agriculture north of Nectar Brook on the eastern side of the Gulf, while on the west side this form of agriculture begins around Cowell. The effect of the southern Flinders ranges on the eastern side results in higher rainfall further north than directly across the Gulf on the western side. Agricultural activity is around rain dependant mixed farming with cereals (wheat and barley), canola, and legumes (beans, peas and lentils). Cropping is mixed, with pastures mostly for sheep and some cattle. In the drier areas outside of those cultivated, there is extensive pastoral activity based on grazing sheep and cattle (see Australian Bureau of Statistics, 2008).

**Proposed expansion and development**

The type and intensity of agricultural practice is highly influenced by commodity prices and input costs, while output is clearly very rainfall dependant. The evidence from the last couple of decades shows that farm outputs have generally increased as the result of better farming practices, machinery, chemicals and varieties. Of particular note is the greatly expanded area that is farmed with minimum tillage systems (Sabeeney, 2007). This has had a beneficial effect in that the land has retained more cover even in the late summer and autumn period with a consequent reduction in erosion risk. Reduced grazing pressure through reduced sheep numbers and reduced rabbit populations has also been positive for soil maintenance. It is reasonable to think that this form of agriculture will continue in the future. It will become more productive as better management is applied because of farm consolidation and inputs such as machinery, chemicals and varieties improve.

Projections of the effects of climate change consistently indicate a general warming and drying for this region (Suppiah et al., 2006). This will likely result in a gradual contraction of the cultivated, cropping areas from the northern limits. Cropping will be replaced by increased grazing and in some cases by adapted perennial plantings, the timing and extent of this will depend on the relative financial costs and returns from crops, livestock and carbon. In the wetter areas of the southern Eyre and Yorke Peninsulas the increased $CO_2$ and accompanying warming and drying will lead to some districts having increased crop yields (Meyer et al., 2013). This along with anticipated increased world demand for grain and meat will likely result in greater agricultural output – provided energy costs remain constrained. Transport and export facilities around the coast will be in demand and will very likely need to expand.

**Potential stressors and impacts**

The potential stressors to Spencer Gulf associated with surrounding agriculture are likely to be associated with an increased demand for transport access via coastal facilities and from changes in the deposition and discharge from terrestrial sources (see also Terrestrial and Coastal Environment section). Deposition of dust associated with poor ground surface cover is increasingly likely from the pastoral areas during periods of drought. Climate change estimates project an increase in frequency and duration of dry periods. Severe dust storms are generally associated with northerly and westerly winds. The extensive dry pastoral areas to the north and west of the Gulf predispose it to this increased risk. The effect of this deposition on the ecology of the Gulf is unknown. Maintenance and extension of minimum tillage and a greater emphasis on land cover maintenance in the cultivated agricultural areas will minimise but not eliminate dust deposition from these areas. The immediate and longer term effects of water discharge from surface and groundwaters into the Gulf are also largely unknown. Climate change projections again indicate a likely increase in the intensity of summer storms and in this case increased large flushes of materials from catchments on the eastern side of the Gulf may become more frequent. With decreases in rainfall, it could be expected that groundwater discharge may decrease. It would be prudent to assess the likelihood and extent of this influence.

**Knowledge gaps**

The impacts of dust deposition on Spencer Gulf waters are unknown. Similarly the immediate and longer term effects of water discharge from surface and groundwaters into the Gulf are largely unknown. These waters will no doubt contain a variable range of materials and chemicals that have the potential to influence the interfacing areas between land and the Gulf and hence in turn the near shore ecosystems of the Gulf. Monitoring these material and chemical exchanges, and identifying potential sensitive or vulnerable areas, should be done. The impact of more extreme weather events should also be considered.

### 3.3.12 RECREATION & ECOTOURISM

**Current Situation**

Ecotourism Australia defines ecotourism as "ecologically sustainable tourism with a primary focus on experiencing natural areas that fosters environmental and cultural understanding, appreciation and conservation". Established in 1991, Ecotourism Australia is an incorporated non-profit organisation, and is the peak national body for the ecotourism industry. The organisation has four globally recognised key certifications, Ecotourism Certification, Respecting Our Culture Certification, Climate Action Certification and the EcoGuide Certification. Ecotourism products provide an opportunity to learn about the environment with an operator who is committed to achieving best practice, contributing to the conservation of the environment and helping communities.

ECO Certified-Advanced Tourism organisations operating in the Gulf are:

- **Adventure Bay Charters, Port Lincoln.** Adventure Bay Charters offers a range of ecotourism experiences from swimming with tuna, sea lions or white sharks, to multiple day adventures, which include encounters with dolphins and whales (seasonal) in addition to the other experiences. They have a focus on educating guests about the importance of conservation, sustainability and environmental protection, as well as on local flora and fauna to help to minimise their impact. In addition, each activity adheres to specific guidelines to help minimise the impact they have both on the fauna and environment. The organisation is committed to maintaining a low impact tourism industry, working with scientists and other government department staff to minimise the impact they have on the environment and the wildlife they encounter.
- **Calypso Star Charters – Port Lincoln**. This company is fully licensed by the South Australian Department of Environment, Water and Natural Resources (DEWNR) and are permitted by the Fisheries Department (PIRSA) to use berley to attract sharks to the boat at the Neptune Islands Marine Park. The charter company educates people on behaviour as well as the significance of white sharks in the ecosystem which they inhabit. The company is also involved with the CSIRO white shark research, helping to better understand the movement patterns and behaviour. Calypso Star Charters also offer the opportunity to swim with sea lions, a new attraction to the company.
- **Rodney Fox Shark Expeditions South Australia –** This company provides white shark cage diving, visiting the Neptune Islands, and en route may stop to snorkel with Australian sea lions. They pioneered shark cage diving over 40 years ago and are the only operator to offer ocean floor cage dives. The company conducts its own research and also supports research projects with other scientists including those from CSIRO and SARDI. Adventure Bay Charters, Calypso Star Charters and Rodney Fox Shark Expeditions all provide support to the white shark cage-diving industry monitoring program funded by DEWNR and undertaken by SARDI.
- **Swim with Tuna – Port Lincoln**. Swim with Tuna offers an adventure and educational experience whereby visitors are transported out to a specially designed pontoon, where they can swim and hand feed tuna. There is also a touch pond and underwater observatory to cater for visitors who may not want to get wet. Information on the importance of marine conservation is also provided.
- **Goin' Off Safaris – Port Lincoln**. This company also offers white shark cage diving (through one of the above companies), swimming and feeding blue fin tuna, as well as swimming with dolphins and sea lions, and fishing safaris.

In addition to the Eco certified organisations, other tourism opportunities and recreational activities in the Spencer Gulf include boating activities, kayaking, snorkelling/diving and dolphin watching. Information on recreational fishing is provided under Fisheries above.

Giant Australian cuttlefish aggregate to breed at Point Lowly between May and August (see also iconic and threatened, endangered and protected species section). A vessel is not required to access the site and the giant Australian cuttlefish can be observed through a shore dive from Point Lowly using snorkel or SCUBA equipment. Whyalla Diving Services offers seasonal giant Australian cuttlefish tours, however, the majority of visitors access the site independently. The unique and spectacular opportunity to view large numbers of spawning giant cuttlefish began attracting divers to this site in the late 1990's. This spawning event obtained an international profile after it was featured in wildlife documentaries and SCUBA diving publications. Over recent years cuttlefish abundance has declined dramatically, resulting in a decline in ecotourism activity. Although unlikely, it is unknown if ecotourism has contributed to this decline.

### Proposed expansion and development

The implementation of marine parks in South Australia (see conservation section below) may provide additional opportunities for recreation and tourism in the region. In addition, if there is significant expansion of mining and other industrial activities, which attracts people to the region, then it is likely that recreational activities (e.g. fishing, boating) will increase.

The white shark cage-diving industry is currently restricted to the Neptune Islands. Recent increases in operations by current operators and applications for licenses by potential new companies led to a review of the white shark cage-diving tourism policy. As a result of the review, a new policy was instated restricting the number of licenses to three businesses. Further expansion of the number of licenses at this site is unlikely until the policy is reviewed. However, several businesses have shown interest in undertaking white shark cage-diving activities at different locations, which are not restricted under the current white shark cage-diving industry policy.

### Potential stressors and impacts

The white shark is listed nationally as a vulnerable species and is protected under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. The white shark recovery plan[2] identifies ecotourism and cage-diving as a potential threat to the Australian white shark population. The main stressors likely to affect white sharks as a result of cage-diving operations were identified during a workshop in September 2012 and include: berley and tethered baits (olfactory and visual cues), sound (music), and physical presence of vessels. Secondary stressors likely to affect white sharks include: anchorages and debris from operators (potential entanglement and ingestion), cleaning and dumping activities by commercial and recreational vessels, and bilge pumping or oil spills.

In 2011–12, two studies investigated some of the potential effects of ecotourism on white sharks and showed that the cage-diving industry led to increases in residency, duration of visits, average number of sharks, changes in the temporal and fine-scale spatial distribution of sharks to match cage-diving operations, and reduction in the rate of movement (Bruce and Bradford, 2013; Huveneers et al., 2013). In response, the number of licenses and days of operations were restricted to limit impacts. A scientific monitoring program has been initiated since mid 2013 to assess the effects of the new policy. However, the complex relationship between wildlife tourism and its effects on white sharks requires further research.

Recreational boating can lead to environmental damage in areas such as Spencer Gulf with extensive shallow subtidal and intertidal seagrass meadows. Boats operating in these areas can easily leave propeller scars, leading to seagrass loss and sediment destabilisation. Anchoring can cause similar damage in any depth. Increased activity could also result in faunal disturbance, especially to seabird rookeries.

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[2] Initial plan was in 2002, the plan was reviewed in 2009, but the release of the reviewed plan has been slowed down. It is apparently currently with the Minister and should be released soon.

**Knowledge gaps**

The residency period and relative population size of white sharks visiting the Neptune Islands should be monitored to determine the effects of the new cage-diving industry policy. The disturbance caused by the cage-diving industry is currently confined to one location so that only a fraction of the Australian white shark population is potentially currently impacted. A better understanding of white shark population structure and the fraction of the Australian population visiting the Neptune Islands would provide a better understanding of the extent of the population impacted.

The changes observed at the Neptune Islands were not all consistent, with the level of interaction with shark cage-diving operators (SCDO) and behavioural responses varying between individual sharks. The degree of variation between individual sharks and the different levels of interaction (e.g. presence, proximity to SCDO, and consumption of tethered bait) highlights the complexity of the relationships between SCDO and the effects on sharks. To improve our understanding of these relationships, future monitoring of shark cage-diving operations should be performed at the individual level and requires proximity to SCDO to be recorded. Further work is needed to assess whether the observed behavioural changes would affect individual fitness and ultimately population viability, which are critical information to unambiguously assess the potential impacts of wildlife tourism targeting white sharks.

The combination of the potential increased energy requirements, due to interactions with tethered baits, and reduced energy intake, due to disrupted natural foraging behaviour, could unbalance the energy budget and has long-term effects on life history traits, such as growth and reproduction. However, the tethered bait can sometimes be consumed by sharks regardless of the attempts by the SCDO to prevent feeding, and the energy gained from the baits might compensate for the additional activity and disrupted natural foraging incurred by interacting with SCDO. No data are currently available on the number of baits consumed by individual sharks, or the effects of interacting with SCDO on the energy budget of white sharks. The potential impacts on individual fitness and population viability highlight the need to compare the energy expenditure of sharks closely interacting with SCDO to a recently calculated baseline field routine metabolic rate (Semmens et al., 2013), and to quantify energy intake from tethered baits.

The extent and frequency of recreational boating activity is poorly understood. There is also no understanding of local impacts (and frequency) associated with propeller scarring and anchoring, although these can be extensive in other shallow subtidal areas (e.g. Florida Bay).

## 3.3.13 CONSERVATION

While conservation is not strictly an activity, we have included it here as marine parks need to be considered as part of any spatial or multiple use management plans.

**Current situation**

The Department of Environment, Water and Natural Resources (DEWNR) has an interactive online mapping site for identifying a range of features relevant to natural resource management (http://www.naturemaps.sa.gov.au/about.html). Land surrounding or nearby Spencer Gulf forms part of several national parks (e.g. Lincoln, Coffin Bay, Innes, Mt Remarkable) and a number of conservation parks (e.g. Leven Beach, Warrenben, Telowie Gorge, Winninowie, Mt Brown, The Dutchmans Stern, Whyalla, Munyaroo, Ironstone Hill, Lake Gilles, Sheoak Hill, The Plug Range, Middlecamp Hills, Yeldulknie, Franklin Harbour, Sir Joseph Banks Group, Neptune

Islands, Sleaford Mere). There are also a number of heritage sites (e.g. ship wrecks) throughout Spencer Gulf.

Within Spencer Gulf there are several Aquatic Reserves under the Fisheries Act (Yatala Harbour, Blanche Harbour – Douglas Bank, Whyalla – Cowleds Landing, Goose Island). There are also some additional fishing closures that may restrict taking of some species either spatially or seasonally. For example, blue groper cannot be removed from Spencer Gulf at any time of year, the taking of razorfish is restricted in an area of Spencer Gulf during some months and taking of cephalopods is restricted from an area near False Bay, Whyalla. Recently, northern Spencer Gulf has been closed to the taking of cuttlefish. Further details can be found at: http://www.pir.sa.gov.au/fisheries/recreational_fishing/closures/closed_areas. In addition, some seasonal closures exist, for example, snapper fishing is prohibited in all South Australian waters from November to mid December.

Of South Australia's 19 marine parks, eight are within Spencer Gulf or encompass the nearby islands. These include: Upper Spencer Gulf, Franklin Harbour, Eastern Spencer Gulf, Sir Joseph Banks Group, Southern Spencer Gulf, Thorny Passage, Gambier Islands Group and Neptune Islands Group. Marine Parks have been zoned such that there are four different zones: general managed use, habitat protection, sanctuary and restricted access. Most existing activities can occur within a general managed use zone (exception: mineral or petroleum processing). Several other activities such as direct drilling for mining or petroleum, anchoring of large vessels (>80 m), trawling on or near the seabed, and collecting seagrass, algae and sessile animals are also restricted within habitat protection zones and there is a limit to dredging. Sanctuary areas, which occupy a very small area of marine parks, have further restrictions including fishing and collecting. Very little is allowed within a restricted access zone. There are also special purpose areas (SPAs) within marine parks, which allow specified activities to occur in that area that would not otherwise be allowed. For example, in the Upper Spencer Gulf marine park there are several SPAs allowing shipping and transhipment around ports, submarine cables and pipelines, and shore-based recreational fishing.

The marine park boundaries were implemented in 2009. Zoning arrangements were in place in December 2012. At present, sanctuary areas do not represent a comprehensive, adequate and representative system, which should be noted for any assessments of effectiveness. A phased approach is being used for implementation of regulations.

### Proposed expansion and development

South Australia's marine parks will be reviewed every 10 years based on information from marine parks monitoring, evaluation and reporting (MER) program. The MER framework is currently (2013) being developed but will utilise an integrative and collaborative approach focused around three themes: communities (social, cultural and economic), ecological systems (status and pressures) and management effectiveness.

### Potential stressors and impacts

Many of the activities listed above have potential to impact the effectiveness of marine parks. Likewise, some zones of marine parks remove areas from other activities (e.g. commercial and recreational fishing). In the case of commercial fishing, this can put added pressure on other areas of the Gulf if schemes are not implemented which reduce overall activity. Habitat protection zones may be particularly vulnerable as many activities such as aquaculture, coastal developments and infrastructure, wastewater disposal and discharges (e.g. from desalination plants), some dredging and depositing of dredged material, and all recreational activities may still be permitted.

**Knowledge gaps**

Whilst significant research has been undertaken on marine park effectiveness around the world, it is important that the effectiveness of South Australia's marine parks is determined. At present there has been some focus on habitat mapping, but significant gaps exist in relation to monitoring of abundance and distribution of key species, and even determining their baselines. Predictions of change are required to properly evaluate effectiveness. In the short term, responses are most likely to be found for fished species where fishing was previously high, and it may be prudent to ascertain how fishing effort overlaps with sanctuary zones, and focus on monitoring sanctuary areas that previously had high fishing effort. Comparisons could then be made relative to similar effort fishing areas outside of marine parks. Key questions around the design of marine parks (e.g. optimal size of sanctuary areas, how far apart sanctuary areas should be located) should be addressed. If marine parks are to be effective, then it will also be important to characterise larval dispersal and demographic connectivity of organisms.

# 4.0 MARINE SPATIAL PLANNING

This section reviews marine spatial planning approaches with a strong focus around the ecological principles. Cumulative impacts, tradeoffs, shifts in ecosystems and the on-going need for engagement are considered. Finally, the need to capture long term changes in the physical, chemical and biological environment is highlighted through a marine observing system.

Spencer Gulf represents a multiple use area and provides a range of ecosystem services. The Millennium Ecosystem Assessment defined the following categories of ecosystem services: provisioning (e.g. production of seafood), regulating (e.g. of climate, water quality), supporting (of other services, e.g. nutrient cycling) and cultural (e.g. recreational, spiritual value). Frequently, management and decision making does not consider ecosystem services or cumulative impacts, in large part because it focuses on a single sector or activity (Day et al., 2008; Halpern et al., 2008; Tallis et al., 2010).

Marine spatial planning represents a comprehensive, adaptive, integrated, ecosystem-based process that uses sound scientific data to analyse current and anticipated uses of an area. South Australia embarked on a marine planning process over 10 years ago, with a pilot marine plan for Spencer Gulf (a plan for lower Spencer Gulf was also envisaged) developed based on principles of ecosystem based management (EBM), ecologically sustainable development (ESD) and adaptive management (Government of South Australia, 2006; Day et al., 2008; Paxinos et al., 2008). A zoning model was developed that grouped habitats and species into four ecologically rated zones that each had an impact threshold (Day et al., 2008; Paxinos et al., 2008). The marine planning process was meant to complement the marine parks process. However, the marine planning framework was not implemented as Government policy and has not been developed further than the initial pilot project in Spencer Gulf. The framework may provide a basis for review, but likely requires broadening to encompass all activities and uses of the Gulf. Combining a range of information from bathymetric and oceanographic models through to ecological and human use information into decision support tools has many advantages as it allows agencies and stakeholders to visualise, evaluate and select viable locations for various potentially competing uses.

A marine spatial planning approach that identifies suitable areas for various activities will also reduce potential conflict among users, as well as reducing environmental impacts and preserving ecosystem services to meet environmental, social and economic objectives. Literature on marine spatial planning has expanded rapidly in the last decade. There have now been several reviews of the tools and the process (Collie et al., 2013; Stelzenmueller et al., 2013), as well as overviews on evaluating tradeoffs among ecosystem services (White et al., 2012; Lester et al., 2013), ecological principles (Foley et al., 2010), stakeholder engagement (Gopnik et al., 2012) and future priorities (Halpern et al., 2012) of marine spatial planning. At present it is difficult to evaluate the performance of marine spatial plans against metrics (e.g. reduced permitting costs, reduction in conflict, improved ecosystem condition), although this should be possible in future (Collie et al., 2013).

Marine spatial planning requires an assessment of (1) multiple objectives, (2) conflicts and synergies of marine users, (3) the risk of cumulative impacts of various activities, (4) spatial zoning or management options and (5) scenario testing (Stelzenmueller et al., 2013). A range of models and tools are required to address questions regarding risk assessment, forecasting and modelling, as well as simulation models to address "what if" scenarios in relation to planning options. The spatial component suggests benefits from implementation of a Geographic Information System (GIS) framework. Value trees may help identify various objectives for which measurable attributes are then identified which allow decision alternatives to be evaluated (Stelzenmueller et al., 2013). A comprehensive approach to ranking human activities and assessing cumulative impacts is important (see cumulative impacts below). A recent review suggested that decision support tools for use in ecosystem-based marine spatial planning were currently being developed, although many of the models were technically complex and could only be used by scientists or programmers despite a need to engage stakeholders and decision makers (Stelzenmueller et al., 2013).

Models provide a means of understanding the system since they can synthesise existing knowledge, explore various management alternatives and identify and evaluate uncertainty (Addison et al. 2013). The three key attributes of models are generality, precision and reality. If all three are maximized then an overly complex model is produced, therefore the strategy is usually to trade off one attribute for the other two. Depending on which attribute is traded off different types of models are produced (e.g. generality and precision = statistical model, precision and reality = process model, generality and reality = quantitative model). Therefore, models range along a spectrum from simple single-species models (e.g. used in fishery management) to complex whole-of-system (or end-to-end) ecosystem models (see Espinoza-Tenorio et al., 2012). At least from a fisheries management context, no single ecosystem model is likely to accomplish all goals of ecosystem based management (Fulton et al., 2011; Espinoza-Tenorio et al., 2012), therefore a range of models may be required.

Whole of system ecosystem models include all relevant processes in the model including abiotic (e.g. atmospheric inputs, currents and other water body features), ecological (nutrients and biogeochemical cycling, all trophic groups), and dominant processes (water column fluxes, feeding, growth, reproduction and movement of ecological groups), as well as long-term climate forcing and environmental variability (Fulton, 2010). Whilst many of these models were initiated for fisheries management, increasingly, competing and cumulative impacts of human activities on marine systems are being dynamically considered within these models (Fulton, 2010). Such models push the bounds of scientific understanding, complication and complexity, which can lead to uncertainty. They are therefore best utilised to consider 'what-if' management questions or scenarios. Both qualitative and quantitative ecosystem models can be used in decision-making. Generally, different modelling approaches can be used to complement each other to get a more robust understanding of the system.

Decision support tools have been used in the marine planning process but rarely dynamically over time (Collie et al., 2013). Decision support tools can help to visualize the level of cumulative impacts in an area, the number of conflicts between users, and between users and the ecosystem, and the number of tradeoffs required by each sector (Foley et al., 2010). Dynamic models are required such that future ecosystem health can be assessed under different management strategies (Foley et al., 2010). Such models provide a rational and transparent means to synthesise existing knowledge, explore management alternatives and identify and evaluate uncertainty (Addison et al., 2013). It is important to recognise that models are tools to assist in decision-making, and that structured decision making provides a sound foundation for use of models in decision making.

Structured decision making has been defined as "collaborative and facilitated application of multiple objective decision making and group deliberation methods to environmental management and public policy problems" (Gregory et al., 2012). It is designed to aid and inform decision makers through an in-depth understanding of what is important (values) and what is likely to happen if an alternative is implemented (consequences). Six core steps characterize most environmental management decisions starting with clarifying the decision context (Figure 8).

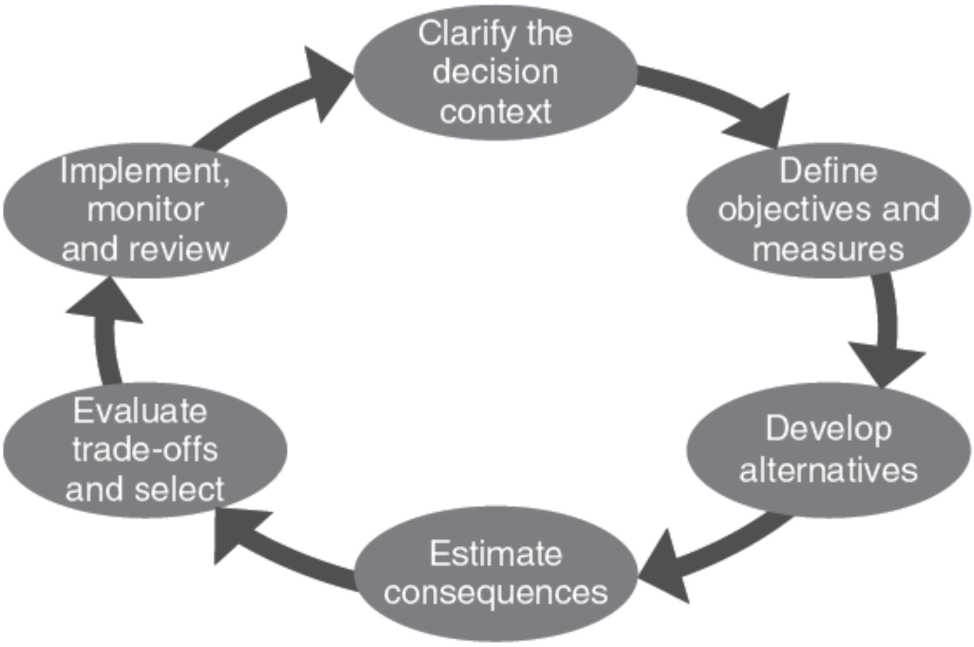

Figure 8. Steps in structured decision making. From: Gregory et al. (2012).

## 4.1 ECOLOGICAL PRINCIPLES

The integrated planning process around marine spatial planning emphasises a multi-objective framework around the legal, social, economic and ecological complexities of governance (Figure 9) (Foley et al., 2010). To sustain ecosystem services, ecosystem-based marine spatial planning needs to consider what ecological principles are most pertinent. Foley et al. (2010) reviewed past literature and suggested that two ecological attributes (connectivity or the exchange of individuals among spatially separated subpopulations, and native species diversity or variety and abundance of species within an area) were essential to maintain functioning ecosystems. Two further principles were identified from literature and a workshop of academic, government and non-government organisation (NGO) scientists, namely maintaining habitat diversity and heterogeneity (number of different habitat types within a given area and spatial arrangement of habitat patches across the marine environment) and maintaining key species (whether they be keystone, foundation, basal prey or top predators) (Foley et al., 2010). These ecological principles provide a focus for monitoring programs such that the effectiveness of spatial planning can be evaluated, and provide a basis for Spencer Gulf (see also shifts in ecosystems).

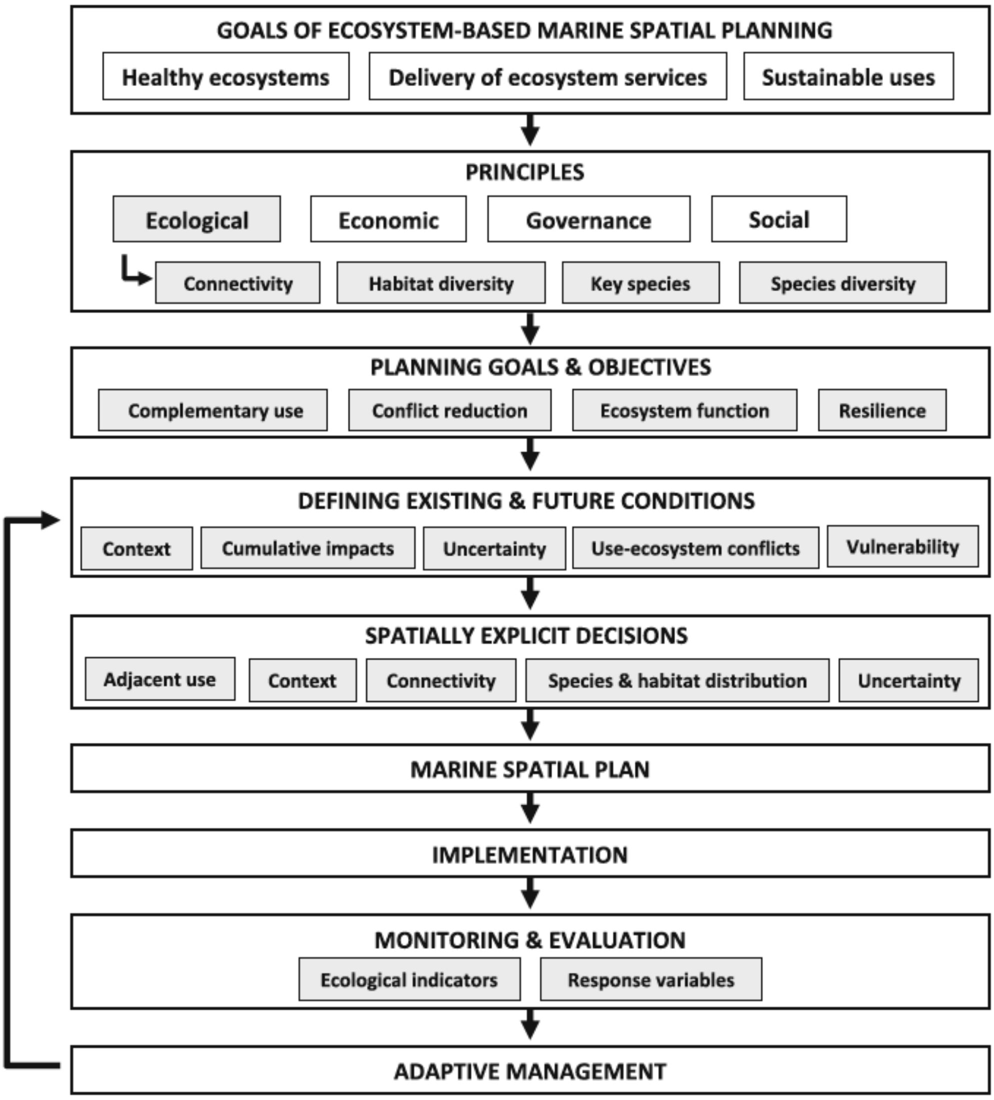

Figure 9. Flow diagram outlining key aspects of marine spatial planning in terms of ecological principles. Shaded grey boxes pertain to components of an ecosystem-based process. Similar diagrams could be used to outline economic, social and governance principles. From: Foley et al. (2010).

## 4.2 CUMULATIVE IMPACTS

Cumulative impacts are not generally considered, as individual activities are often managed on a sector-by-sector basis (Halpern et al., 2008). Similarly, individual proponents for developments usually only consider the impacts of their own development. Multiple activities over space or time may, however, have greater impacts than an individual activity because of interactive or multiplicative effects. Individual activities can interact in several ways such that there is no cumulative impact, accumulative impact or additive impacts, whereas multiple activities can interact such that there is dominance of one activity, pure addition of impacts, multiplicative impacts that are larger than the sum of the individual impacts and mitigation of the impact of one activity by the impact of the others (Figure 10) (Halpern et al., 2008; Stelzenmueller et al., 2013).

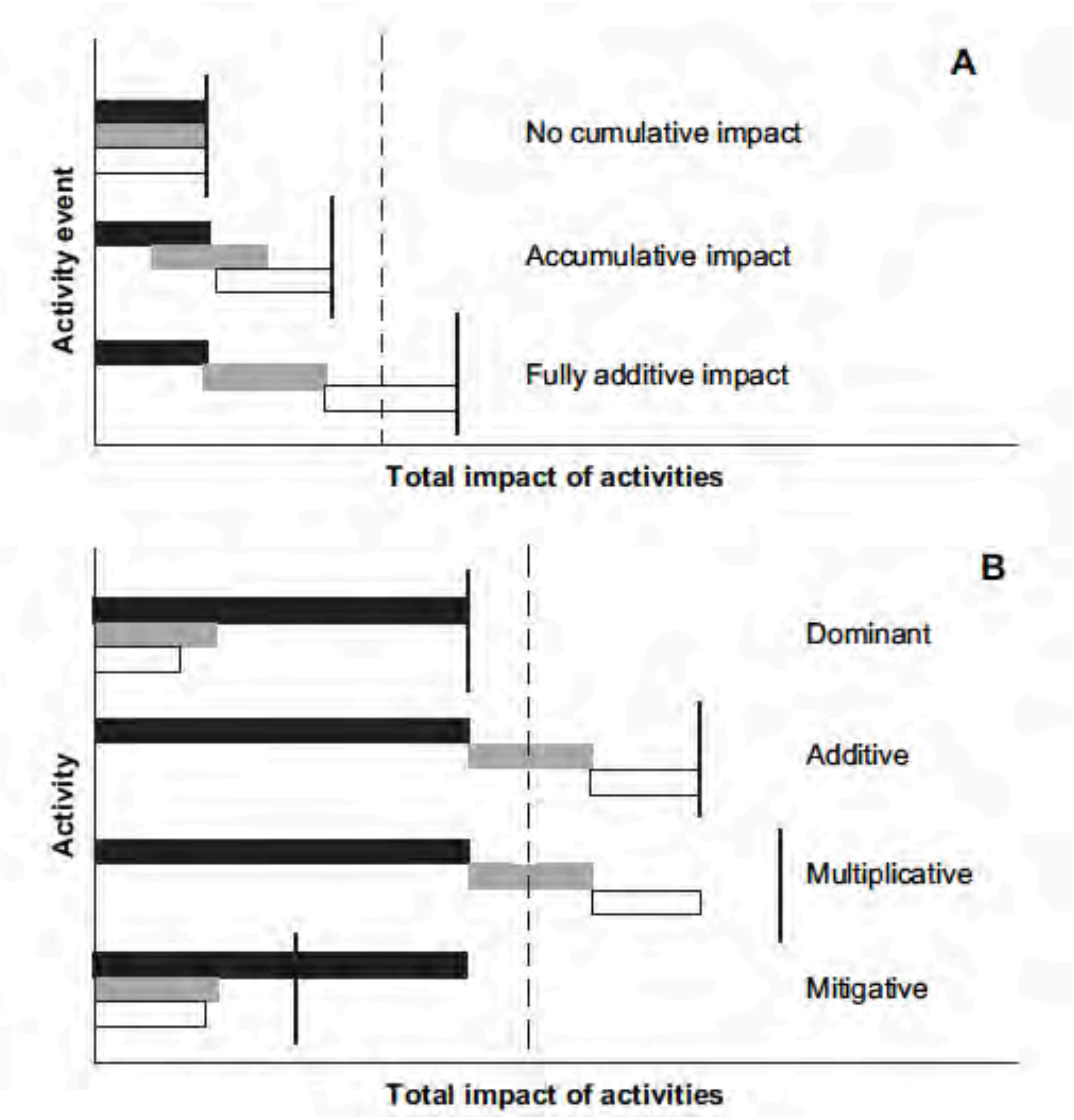

Figure 10. Schematic of the different types of cumulative impacts showing (A) within activity impacts from an individual event and (B) four possibilities for interaction of multiple activities, where bars represent different activities, solid lines indicate the total impact of the activities and dashed lines represent a hypothetical threshold of ecosystem function. From: Halpern et al. (2008).

Different activities may affect ecosystems (or components of ecosystems) differently and the frequency of the activity may also influence the strength of the environmental change. In addition, pristine versus disturbed ecosystems may respond differently. There have been few experimental studies testing the relative importance of multiple activities/environmental drivers on any ecosystem particularly in South Australia (but see Gorgula and Connell, 2004; Russell et al., 2009; Connell and Russell, 2010). A quantitative, replicable and transparent method of determining impacts on particular ecosystems was developed by Halpern et al. (2007). Briefly, the scale of the impact from single species to the entire ecosystem for a full suite of ecosystem types and potential threats, as well as uncertainty in rankings, is determined. The spatial scale, and frequency of the threat (ranging from never occurs to persistent), as well as the functional impact (ranging from no impact to impacts entire community), resistance (ranging from no impact to low resistance), and recovery time (ranging from no impact to >100 years) of the ecosystem were combined into a single score representing how vulnerable a given ecosystem is to a given threat (Halpern et al., 2007). The uncertainty is used to weight individual scores such that scores with higher certainty are of greater importance. Impact scores can be mapped especially if the analysis is more regional, although a greater understanding of how stressors interact is required to improve accuracy of impact maps (e.g. Ban et al., 2010). Such an assessment at the scale of Spencer Gulf is required, as a quantitative and transparent approach is an important indicator of information gaps and research needs. In addition, an understanding of dominant and weak stressors may also assist in identifying cumulative and interactive effects of different activities.

Identification of spatial and temporal boundaries for the full range of activities is required to assess cumulative impacts, but these also need consideration of scales of biophysical and ecosystem processes to determine if there is likely a consequence. Determining the zone of influence of stressors is critical.

## 4.3 TRADEOFFS

Consideration of cumulative impacts of different activities also requires an understanding of tradeoffs among ecosystem services. Assessing and quantifying tradeoffs among uses that result from different management decisions is difficult partly because services are not easily valued or traded on markets (Lester et al., 2013). Because not all services can be maximised simultaneously, decisions about relative preferences are required. Lester et al. (2013) discuss how to evaluate tradeoffs among ecosystem services in an ecosystem based management context where services are not readily valued in monetary terms or are measured in different units. They examine the shape of the efficiency frontier (with a visual focus on pairs of services) and some approximation of the indifference curve to assist with finding optimal management decisions (see Figure 1 in Lester et al. 2013). The challenge in examining tradeoffs among ecosystem services in marine environments has been highlighted given the wide range of human activities and fragmented governance, but several recent case studies using data have shown the benefits of such an approach (e.g. White et al., 2012; Lester et al., 2013). For example, tradeoffs between biomass conservation and sustainable fishery profit suggest that it is possible to deliver one service without a large cost for the other – such models may help reduce conflicts among sectors (Lester et al., 2013). For new industries and activities, tradeoff analyses can be used proactively to inform siting of facilities and infrastructure to minimise conflicts among multiple users. In addition, such analyses have increasing value where there are increasing numbers of sectors being considered and for larger areas (White et al., 2012).

Using a structured decision making process means that most decisions will involve trade-offs, but having an open dialogue about trade-offs is important. While quantitative trade-off methods, such as those mentioned above, can be helpful, a multi-method approach may provide more insight (Gregory et al., 2012). A well-structured process is key for productive discussions regarding trade-offs.

## 4.4 SHIFTS IN ECOSYSTEMS: TIPPING POINTS, CRITICAL THRESHOLDS & RESILIENCE

Stakeholder workshops highlighted significant concern about the resilience of the system and what the key tipping points and critical thresholds may be. Populations generally fluctuate around a trend or average value. Determining the resilience of the system or its capacity to experience disturbance while essentially maintaining similar structure and function is difficult (Folke et al., 2004). Human activities are capable of transforming ecological systems and the services they provide into less desirable states (often referred to as regime or phase shifts) (Folke et al., 2004). The system may become vulnerable as resilience declines. A gradual change in the system can bring the system to a bifurcation point (a tipping point) where a small change can result in a shift to an alternative state, however the drivers or values at which responses are triggered (critical threshold) are not generally known (Scheffer and Carpenter, 2003; Dakos et al., 2012). Sudden transitions may then require costly restoration. Indicators are often monitored in an attempt to detect the tipping point. There are generally few warning signs, but specific knowledge of the system particularly drivers and driver-response relationships can help build mechanistic models and reduce uncertainty (Dakos et al., 2012). Time series of ecological data require further exploration, although in many instances there are insufficient time series for organisms and environmental parameters suggesting a need to collect such data (see Synthesis and Integration). Spatial patterns may also be particularly informative. Controlled experiments are the most powerful way to understand mechanisms contributing to change, but the challenge is conducting these experiments at realistic spatial and temporal scales, although small scale experiments can assist in explaining large-scale patterns (Scheffer and Carpenter, 2003).

Two features appear crucial to the overall response of complex systems, heterogeneity of the components and their connectivity (Scheffer et al., 2012). In networks where the components differ (heterogenous) and there is limited connectivity then environmental change may cause the system to change gradually, whereas homogeneity and a highly connected network may show resistance to change until a critical threshold is reached (Scheffer et al., 2012). Thus, strong connectivity promotes local resilience because there are inputs from the broader system to local populations, which can give the false impression of a resilient system. Early warning signals for critical transitions may be ‘critical slowing down’ (the rate at which a system recovers from small perturbations becomes very slow, but there is also increased autocorrelation and increased variance) near tipping points suggesting that the system is close to fundamental change (Scheffer et al., 2009; Scheffer et al., 2012). A further phenomenon called flickering, where the system moves back and forth between two alternative attractors as the system is in the bistable region, also signals a potential transition (Scheffer et al., 2009).

## 4.5 ENGAGEMENT

Three key groups need engagement in ecosystem-based marine spatial planning including those with legal/regulatory responsibilities, those involved in or affected by decisions, and scientists and others with experience or knowledge that is directly applicable to the region or issue (Addison et al., 2013). Although participants can span multiple roles, these groups can broadly be known as decision-makers, stakeholders and experts.

The importance of stakeholder participation and engagement is frequently highlighted for effective ecosystem based marine spatial planning (Foley et al. 2010; Halpern et al. 2012; Gobnik et al. 2012). Stakeholder engagement within sectors (e.g. fishing) is common, but the diversity of groups that need to be engaged for marine spatial planning may require modified approaches if it is to be effective (Halpern et al. 2012). Stakeholder engagement in planning, evaluation and implementation phases is necessary. It is important that no stakeholders are omitted from the process (Gobnik et al. 2012).

Good communication is critical for effective engagement. Addison et al. (2013) list seven key competencies around communication including active listening, questioning and clarification, feedback, self-monitoring, dialogue, model constructive communication behaviour and collaborative/constructive argument. They also mention that building mutual trust is an essential element in decision making. On-going engagement with the diverse range of stakeholders will be important for the Spencer Gulf initiative.

## 4.6 MARINE OBSERVING SYSTEM

A Spencer Gulf Integrated Marine Observing System (SG IMOS) should be designed to capture long term changes in the physical, chemical and biological environment, as well as provide needed information at local scales of proposed development. The approach should be designed in collaboration with the key research providers to satisfy the needs of the research program as well as the needs of South Australian government agencies so as to ensure the program is well supported.

The next planning stage of Australia's national Integrated Marine Observing System (IMOS) will occur later in 2013 and may include an additional focus on coastal waters, including the SA gulfs. At present Southern Australia Integrated Marine Observing System (SAIMOS) (the Southern Australian node of IMOS) is mostly shelf based, with only one monitoring station in the lower region of the Gulf. The opportunity exists to influence the future focus of SAIMOS, and of IMOS as a whole, through the development of a similar system for Spencer Gulf.

The following provides a summary of the likely data needed for each of the ecosystem components:

- Over the long term (years), the key science questions here relate to the flux and state of the Gulf waters and possible impacts of climate change. From the physical, biological and chemical perspective, observations of ocean currents, temperature, oxygen, phytoplankton, bacteria, viruses and nutrients are needed.
- At the mouth of Spencer Gulf and on the nearby shelf, four SAIMOS moorings exist where sampling is done for nutrients, particulate organic and inorganic matter, as well as microbial and phytoplankton community composition. In addition, the moorings measure physical properties including currents, temperature etc. and data describing the outflows and CTD structure of the Gulf mouth is available on a long-term basis. These moorings should be maintained.
- Point Lowly (near Whyalla in northern Spencer Gulf) is a site sensitive to Gulf flushing, anthropogenic nutrient inputs from industry and WWTP, as well as host to the iconic giant Australian cuttlefish. BHP Billiton has run a measurement program for currents, salinity, and temperature and these data might be supplemented by long-term moorings, monthly sampling of water quality and phytoplankton abundance, and community composition. This sampling might be done off the end of the SANTOS jetty at Point Bonython.
- A third observing site could be Arno Bay, which is a host to aquaculture and lies to the north (on the advective path) of the intensive aquaculture undertaken in the Boston Bay region near Port Lincoln.

- At each of these sites offshore transects of profiles for key physical, biological (e.g. chlorophyll, turbidity) and chemical (oxygen) parameters should be made.

# 5.0 SYNTHESIS AND INTEGRATION

Spencer Gulf provides an ideal opportunity for South Australia to become a world leader in marine ecosystem-based management. We are currently on the verge of a major expansion in industrial activity, with associated increases in other activities, yet we still have a relatively unimpacted system. The anticipated expansion in activity has the potential to lead to many resource-use conflicts, not just between industry and the environment, but also between different industries. If we continue with the existing approach of evaluating each development in isolation, we will both miss the cumulative impacts that could lead to unexpected system failure, and close off future opportunities for development because we have not considered what other industries may need tomorrow. By taking a whole of system perspective and focusing on integrated ocean management, we can instead optimise resource allocation to achieve superior economic and environmental outcomes for the state. The need for such integrated planning has also been identified and discussed at a range of regional forums. This includes the Eyre Peninsula Integrated Climate Change Assessment process (currently, as of late 2013, being discussed) and Central Local Government Region Integrated Climate Change Vulnerability Assessment (Balston et al., 2011) (which identifies the need for adaptation planning particularly for water-dependant and coastal, estuarine and marine ecosystems).

Several approaches warrant further investigation. A range of different models that complement each other to give a more robust understanding of the system is required. There are a number of existing datasets for Spencer Gulf (see Appendix 2) that can be utilised in modelling approaches, but there are likely other existing datasets that need to be identified. A book on the Natural History of Spencer Gulf is currently being edited and is due for release later in the year or early 2014 – this book provides a historic overview of the Gulf as well as detailed information on physical oceanography, biological systems (habitats and biology of key organisms), and resource utilisation, conservation and management.

A Driver-Pressure-State-Impact-Response (DPSIR) framework was used in Australian Commonwealth marine planning to theoretically identify ecological indicators (Hayes et al., 2012). The South Australian Gulfs, whilst included in the south-west marine region, were not particularly prominent in the analyses as they lie within state waters (Hayes et al., 2012); such an approach could be used for a more detailed analysis of Spencer Gulf with the focus on the full range of potential activities in the region (see also Cumulative impacts above). Stakeholder and expert scientific and policy group workshops form the basis of qualitative modelling, identification of existing information and conceptual models for Spencer Gulf, and ranking of potential ecological indicators.

Many methods are available to identify potential ecological indicators, but Hayes et al. (2012) recommend initially using a qualitative model to identify ecological indicators that are sensitive to ecosystem change including from a range of pressures. Valued features and species of interest in Spencer Gulf should be identified ideally through stakeholder engagement, along with the range of human activities or sectors that may affect key ecological features and species. Within each sector and area of the Gulf, anthropogenic drivers and pressure indicators and trends for various time scales can be identified. A spatial analysis could be used to identify areas of overlap of key ecological features and species, and activities that may impact them, followed by a risk assessment identifying the probability and consequences of any interactions. Ideally such an analysis would consider not only spatial trends in pressures, but also temporal trends. These analyses would identify ecological feature/species and pressure interactions. A preliminary analysis that warrants further attention included the Gulfs of South Australia, but was largely focused around small pelagic fish (Hayes et al., 2012).

Conceptual models using signed diagraphs, which are analysed through qualitative modelling, can be built showing relationships and interactions in the system. Such an approach allows plausible alternative models to be quickly explored, can include stakeholder views thereby capturing a diverse array of beliefs which assists to build consensus, and helps make predictions that can be scientifically tested (Hayes et al., 2012). The qualitative modelling will indicate a range of potential indicators which ideally respond in a similar manner to the various pressure scenarios with a high probability of sign determinancy or are idiosyncratic across pressure scenarios and potentially diagnostic of a particular anthropogenic pressure (Hayes et al., 2012). Potential ecological indicators can then be ranked using a series of decision criteria including can we measure the indicator, can we interpret the signal that the indicator provides, will the indicator lead to improved management or policy and will the indicator inform decisions for multiple objectives (Hayes et al., 2012). Using this framework a series of indicators would be developed to measure the ecological health of Spencer Gulf. These indicators would also align with a national approach.

A whole of ecosystem model (FRDC project 2011/205) is currently being developed for Spencer Gulf focusing on the fisheries and aquaculture sectors, but with the capability to address 'what if' scenarios. A suite of habitat, biophysical, trophodynamic and economic models will be used to assess and optimise the future ecological and economic performance of the seafood industry in Spencer Gulf. Key outputs will be steady-state (Ecopath), temporal (Ecosim) and spatially explicit (Ecospace) trophodynamic models of Spencer Gulf that incorporate 20 years of change in fishery catch, effort and aquaculture development that are coupled to biophysical and habitat models. In addition, a dynamic habitat model for Spencer Gulf to predict the distribution of seagrass under future scenarios has been developed. This model can be used to provide an indication of how seagrass may change with future developments, and how changes in seagrass will impact the ecology of Spencer Gulf including the likely distribution and abundance of commercially fished species. These models are currently focused around fisheries and aquaculture sectors, and their ability to incorporate other sectors and activities requires further investigation.

A single integrated project around oceanography, biology and ecology is required to gain a better understanding of the Gulf and the key drivers. It is recommended that a capability in wave/current drift and sediment transport be developed in South Australia in conjunction with Marine Innovation Southern Australia partners who have expertise in beach morphology and oceanography. This would also enable assessment of new coastal developments in the Gulf (break-waters, dredging, desalination) and also the effects of sea level rise due to climate change. This capability can be developed through extension of SARDI's use of the internationally recognised Regional Ocean Modelling System (myroms.org), and the use of Delft3D, which both have the needed modules for this capability. The capability should allow very high resolution nested models to be rapidly implemented for coastal regions at the kilometre scale of development. Such an approach would allow identification of suitable sites for a range of developments, but needs to be underpinned by suitable observing systems (see Marine Observing System above) to allow testing of models. An increased understanding of the biology and ecology of habitats and key species in the Gulf is critical to a whole of system understanding including under a range of environmental scenarios.

Other key research areas include threatened, endangered and protected species, which could form part of the impact assessment around potential threats. Such an assessment would then identify priority areas of future research for important species, which trigger additional requirements for developments. Spencer Gulf is likely to see a significant increase in shipping (international, domestic and local), along with port development including some dredging activities and development of desalination plants with attendant biosecurity risks. Therefore priority research projects around activities in Spencer Gulf should focus around biosecurity, port development and desalination, and include considerations of cumulative impacts both within activities as well as among multiple activities. For many activities, the opportunity exists to undertake baseline monitoring prior to development and to utilise sound experimental designs (e.g. BACI designs incorporating multiple reference locations and multiple times before and after development). Experimental studies can also assist in identifying cause-effect relations.

An important aspect of the synthesis and integration is to direct development of a systematic information storage, analysis and management option. This then becomes part of the decision support capability, which is vital to help understand the interactions and complexity associated with these spatially variable areas. Examples of systems include the St Laurence Seaway (Montreal, Canada) and the Southern Baltic (Kiel, Germany). It would also be sensible to have a look at the Landscape Futures Analysis Tool (LFAT; http://www.lfat.org.au/lfat/) with a view to identifying how a compatible spatially informed system of bringing the information, analysis and projections for management option assessment could be developed. Such a development would make the link between terrestrial and marine explicit. It would give effect to the often expressed (but rarely seen) desirability of having a more complete system description available.

The Spencer Gulf Ecosystem Development Initiative represents an opportunity for South Australia to use Spencer Gulf as a model for ecosystem based marine spatial management and for this to occur well before significant development in the Gulf. There are numerous world-wide examples of significant restoration efforts often at considerable cost (e.g. Chesapeake Bay, Baltic Sea), but Spencer Gulf represents an opportunity to get things right from the beginning rather than have to incur costly restoration efforts in future. There is much to be gained from decision support tools that would assist with multiple use management of the Gulf waters. These tools will allow all users to obtain a common understanding of the consequences of any particular development decision for all other parties, and thus provide a common framework to discuss tradeoffs between industry sectors, rather than the current approach, which is essentially based on pre-emption, and which is unlikely to provide the best outcomes for the state as a whole.

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# APPENDIX 1 – GLOSSARY

AODN – Australian Ocean Data Network

Chl a – chlorophyll a

CTD – Conductivity temperature depth

DEWNR – Department for Water, Environment and Natural Resources

DPSIR – Driver-Pressure-State-Impact-Response framework

EBM – Ecosystem based management

EPBC – Environment Protection and Biodiversity Conservation

ESD – Ecologically sustainable development

GAB – Great Australian Bight

GIS – Geographic Information System

ILUA – Indigenous land use agreements

IMOS – Integrated Marine Observing System

IMTA – Integrated multi-trophic aquaculture

IUCN – International Union for the Conservation of Nature

LFAT – Landscape Futures Analysis Tool

LPG – Liquefied petroleum gas

MER program – Monitoring, evaluation and reporting program

Mt – Million tonnes

NGO – Non-government organisation

NRM – Natural resource management

PHV – Pilchard herpes virus

PIRSA –Primary Industries and Regions South Australia

POM – Particulate organic matter

SA – South Australia

SACES – South Australian Centre for Economic Studies

SAIMOS – Southern Australian Integrated Marine Observing System

SARDI – South Australian Research and Development Institute

SASF – South Australian Sardine Fishery

SBT – Southern bluefin tuna

SCDO – Shark cage-diving operators

SPeddies – Spencer Gulf eddies

SEWPAC – Department of Sustainability, Environment, Water, Population and Communities

SGEDI – Spencer Gulf ecosystem and development initiative

SPAs – Special purpose areas

YTK – Yellowtail kingfish

WA – Western Australia

WWTP – Wastewater treatment plant

# APPENDIX 2 – DATASETS

Metadata for the following datasets are available via the Australian Ocean Data Network (AODN).

- Spencer Gulf fisheries, Sardine Research Catch and Effort Logbook Data
- Spencer Gulf fisheries, Marine Scalefish Fishery Catch and Effort Logbook Data (includes Miscellaneous Fisheries)
- Spencer Gulf fisheries, Prawn Fisheries Catch and Effort Logbook Data
- Spencer Gulf fisheries, Abalone Fisheries Catch and Effort Logbook Data
- Spencer Gulf fisheries, Charter Boat Fishery Logbook Data
- Spencer Gulf Fisheries, Rock Lobster Fisheries Catch and Effort Logbook Data (includes Giant Crab)
- Spencer Gulf fisheries, Blue Crab Pot Fishery Catch and Effort Data
- Spencer Gulf Abalone biological sampling
- Spencer Gulf Abalone fishery monitoring
- Gulf St Vincent benthic habitat survey
- Gulf St Vincent marine ecology: seagrass cover survey
- Spencer Gulf and Gulf St Vincent marine ecology: reef health
- Spencer Gulf marine ecology: biological and physico-chemical habitat characteristics for aquaculture management planning
- Spencer Gulf Threatened, Endangered & Protected Species (TEPS) population surveys
- Spencer Gulf Threatened, Endangered & Protected Species (TEPS) diet
- Spencer Gulf Trophodynamic modelling
- Spencer Gulf Threatened, Endangered & Protected Species (TEPS) foraging behaviour
- Spencer Gulf and Gulf St Vincent oceanography: biogeochemical data
- Spencer Gulf and Gulf St Vincent oceanography: moored data
- Spencer Gulf and Gulf St Vincent oceanography: CTD profiling data
- Spencer Gulf and Gulf St Vincent oceanography: sea level and meteorological data
- Spencer Gulf prawn fishery-independent survey data
- Spencer Gulf prawn trawl bycatch data
- Spencer Gulf Blue Crab fishery-independent survey data
- Spencer Gulf Blue Crab pot-sampling
- Spencer Gulf, South Australia key finfish fisheries ecology
- Spencer Gulf, South Australia key finfish fisheries biology
- Assemblages of fish along a mangrove-mudflat gradient in temperate Australia
- Impacts of seawater desalination on the giant Australian cuttlefish *Sepia apama* in the upper Spencer Gulf, South Australia
- Fish and Invertebrate Assemblages in Seagrass, Mangrove, Saltmarsh, and Nonvegetated Habitats
- SA Water, environment impact: water quality survey Spencer Gulf