

Desalination and potential marine environmental impacts with a focus on Spencer Gulf

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1. Executive Summary

The South Australian government through the Northern Waters Supply project is considering infrastructure investment in Upper Spencer Gulf including a coastal desalination plant. This investment would provide economic, environmental, cultural and social benefits to the region. The most common desalination process involves using semi-permeable membranes to remove salts and suspended solids from saltwater to produce freshwater for urban and industrial uses. The brine (return water) is then usually released back into the marine environment. Although there are potential impacts of desalination plants related to emissions and energy consumption, this report will focus on the impacts on the marine environment, primarily associated with water intake and waste output (predominantly brine discharge). This report synthesises the relevant work in Spencer Gulf, including review of the studies undertaken as part of the Olympic Dam Expansion Environmental Impact Statement, the Spencer Gulf Ecosystem Development Initiative (SGEDI) and more recent research. It also reviews relevant peer reviewed and published scientific papers on desalination with a focus on the marine environment.

Current reviews, including from the Olympic Dam Expansion EIS, SGEDI knowledge review, and the Spencer Gulf natural history book, all provided an overview of biotic and abiotic characteristics of Spencer Gulf. The SGEDI report also highlighted the existing activities in Spencer Gulf indicating the then current situation (in 2013), proposed expansions and developments, and potential stressors and impacts. Additional research has focused on oceanography including the eSA-Marine system which provides an understanding of past, present and future ocean conditions to inform activities in marine waters. There are also a number of tools or models that can be used to examine the spatial footprint of existing activities and calculate the cumulative impact of multiple activities as well as address 'what if' scenarios in relation to fishing and aquaculture in Spencer Gulf.

The Olympic Dam Expansion EIS focused on four key components: site selection (not addressed in this report), hydrodynamic modelling and ecotoxicology studies, potential impact of the return water discharge and measures to avoid, mitigate or manage marine impacts. While information on these components was provided in the EIS, there was often acknowledgement of need for further work, improved data, and a monitoring program as part of any desalination project. These points were also raised in public submissions.

A systematic review of peer reviewed literature on desalination impacts on marine ecosystems found increased salinity caused by hypersaline brine discharge was the most commonly tested impact, and benthic habitats were identified as the most vulnerable ecosystems. Fish assemblages have physiological responses to hypersalinity, and are also able to move between environments, and are therefore considered resistant to the effects of increased salinity. However, studies looking at the long-term monitoring of brine impacts are rare, representing a knowledge gap. We highlight potential knowledge gaps and future directions for additional research.

This report helps further our understanding of marine ecosystem responses to desalination impacts. We highlight gaps in knowledge and make recommendations on what the Northern Waters project may be able to address.

2. Introduction

The SA Government is considering the infrastructure required to provide a sustainable water supply to the far north and Upper Spencer Gulf regions of South Australia. The Northern Water Supply project recognises that economic growth in the region requires a new water supply as the existing sources through the River Murray and Great Artesian Basin are unable to support the proposed growth. As part of this project, a coastal desalination plant in Upper Spencer Gulf is being considered along with a new pipeline to take water north. This infrastructure investment would provide economic, environmental and cultural, along with social benefits to the region. Further information on the Northern Water Supply project can be found at <https://northernwatersupply.sa.gov.au>.

Desalination involves the removal of salt and other impurities to create freshwater (Williams 2022). Desalinated water is used to supply water requirements for people across the world, as well as for industrial purposes. Total global capacity of freshwater via desalination has increased significantly and is predicted to continue to do so – for example, around 5 million cubic metres (m³) of freshwater per day was produced via desalination in 1980, quadrupling to 20 million m³/day in 1980 and 90 million m³/day in 2020 (Williams 2022). As water resources decline, desalinated water may provide a sustainable, albeit costly, freshwater supply. The oceans are the predominant supplier of desalinated water accounting for around two-thirds of desalination capacity (Figure 1). Although different techniques can be used to remove salt from water, reverse osmosis, which forces water through semi-permeable membranes at high pressure, dominates (Figure 2).

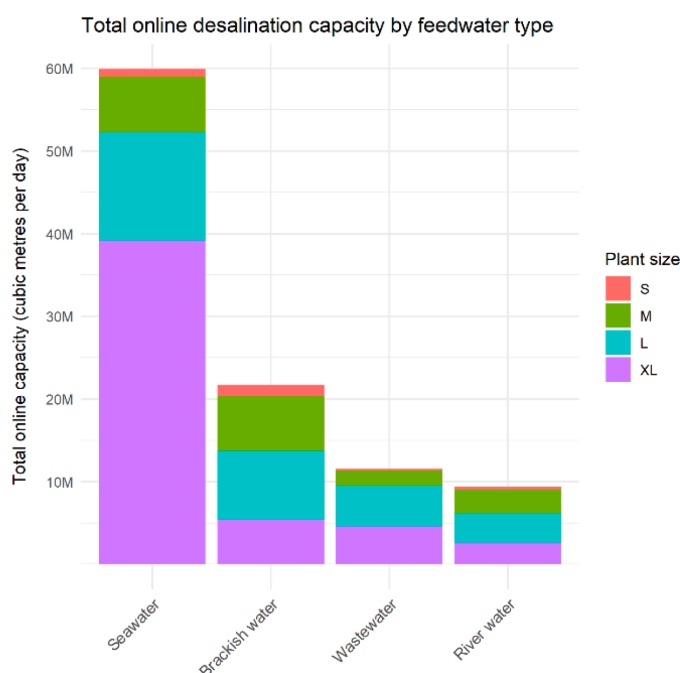


Figure 1. Desalination capacity by feedwater type categorised by plant size. Note: S = under 1000 m³/day; M = 1000 to 10,000 m³/day; L = 10,000 to 100,000 m³/day; XL = over 100,000 m³/day. Source: (Williams 2022), with data sourced from GWI DesalData (2021).

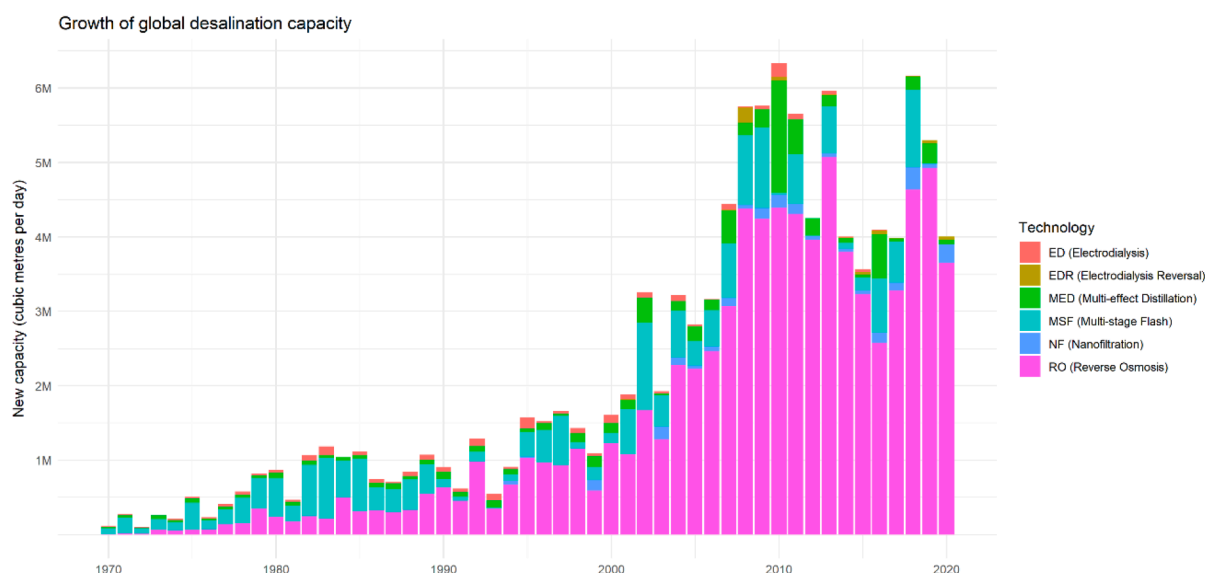


Figure 2. Global desalination capacity by technology type between 1970 and 2020. Source: (Williams 2022), with data sourced from GWI DesalData (2021).

Desalinated water may provide a sustainable water supply, but it is not without potential impacts. These impacts generally relate to water intake and waste output and energy supply. Coastal desalination plants have often focused on saline brine discharge into the marine environment. Concern has also been raised around water intakes which may draw in marine organisms. Energy supply impacts were deemed outside the scope of this report and are not considered further.

This report provides an independent review of literature related to marine environmental impacts of desalination that are relevant to the Northern Water Supply Project and Spencer Gulf. A review of the following is provided:

- Past research on Spencer Gulf including relevant work in Upper Spencer Gulf;
- Studies undertaken as part of the prior Olympic Dam Expansion Environmental Impact Statement process; and
- Relevant peer reviewed and published scientific papers on desalination.

3. Past research on Spencer Gulf

There are several reviews of existing knowledge for Spencer Gulf including the Olympic Dam Expansion draft Environmental Impact Statement (BHP 2009), the Spencer Gulf Ecosystem Development Initiative (SGEDI) report on existing knowledge and information gaps (Gillanders *et al.* 2013) and the *Natural History of Spencer Gulf* book published by the Royal Society of South Australia (Shepherd *et al.* 2014). The contents of each are briefly described below. Additional research, since these publications, that may be relevant to Spencer Gulf is then discussed. Unpublished and grey literature (e.g. reports on government websites and theses) are difficult to find and access as they are not generally found in database searches. We have however searched the SARDI research reports from 2010 to 2022 for relevant publications (https://www.pir.sa.gov.au/research/publications/research_reports; website updated 8 Sept 2022), but other unpublished/grey literature may exist that has not been incorporated into this review.

The Olympic Dam Expansion Draft Environmental Impact Statement (2009) contains a section on the existing marine environment which provides an overview of the Spencer Gulf, its oceanography, existing marine discharges, marine habitats and biota including listed marine species, other species of conservation significance and additional information on giant Australian cuttlefish. Further, overviews on commercial and recreational fisheries, aquaculture and marine and coastal protected areas are also provided. See also section below on studies undertaken as part of the prior Olympic Dam Expansion Draft Environmental Impact Statement process.

The Spencer Gulf Ecosystem Development Initiative (SGEDI) recognised the multiple activities in the gulf and set out to drive sound outcomes for all gulf users and the environment. It was initially setup when iron ore prices were increasing and considerable investment in mining was occurring with proposals for around 5 new ports in Spencer Gulf capable of taking cape size vessels (180,000 standard deadweight tonnage). The initiative was supported with investment from both industry and government, as well as through research institutions. Its vision was a thriving Gulf region, where progressive developments occur, community opportunity is optimised and the unique ecosystem is protected and enhanced – specifically through effective consideration of cumulative, chronic and long-term environmental stresses. An initial output from the initiative was a report that summarised stakeholder workshops, along with the existing knowledge and information gaps for the region. Existing knowledge and information gaps focused on three broad areas: Environment and ecology; activities, stressors and impacts; and marine spatial planning (or integrated marine management; Gillanders *et al.* 2013). Within the environment and ecology section four broad areas of focus were physical oceanography, biological oceanography, terrestrial and coastal environments including intertidal regions, and benthic subtidal environments. Sections also focused on key groups of organisms including iconic and threatened, endangered and protected species, as well as pests and pathogens. A summary of the key information gaps, as taken from this report, is provided in Appendix A.

Thirteen different activities with potential to impact Spencer Gulf were considered (Table 1). For each activity, the then current situation (in 2013), proposed expansion and developments, and potential stressors and impacts were examined. Key information gaps from this assessment are also provided in Appendix A. Almost 10 years have elapsed since this initial assessment and therefore Table 1 briefly updates some of the key activities.

Table 1. Key activities occurring in Spencer Gulf with some updates to information since 2013.

Activity	Brief summary of activities
Fishing	<i>Commercial, recreational & charter fishing operations</i> Key commercial fisheries – Sardine, western king prawn, greenlip and blacklip abalone, blue crab, snapper (currently closed), King George whiting; https://pir.sa.gov.au/primary_industry/commercial_fishing Recreational fishing https://pir.sa.gov.au/recreational_fishing Charter boat fishery – Spencer Gulf has 36.9% of the catch (2020/2021; Durante <i>et al.</i> 2022) https://www.pir.sa.gov.au/primary_industry/commercial_fishing/commercial_fisheries/charter_boat_fishery This report does not intend to capture fisheries stock assessments and the reader is referred to PIRSA for more information.

Aquaculture	Key species – Southern bluefin tuna, yellowtail kingfish, blue mussels, Pacific oyster, abalone Managed through aquaculture zones https://www.pir.sa.gov.au/primary_industry/aquaculture
Desalination	Sundrop farms near Port Augusta – privately owned solar powered seawater desalination plant supplying freshwater for horticulture. Capacity (freshwater/year) – 330 ML; Brine discharge – 2.5 GL/year; Completion - 2020 Sus Tech Pty Ltd – desalination plant located in Port Pirie providing freshwater for irrigation. Capacity (freshwater/year) – 330 GL; Brine discharge - 450 KL/year (mixed with SA water effluent discharge); Completion – 2015/16 Lower Eyre Peninsula – Billy Lights; estimated completion end 2023 See also recent SARDI report of Tanner and Drabsch (2021)
Urban development	Six large regional communities – Whyalla, Port Pirie, Copper Coast, Port Lincoln, Port Augusta, Yorke Peninsula. Other communities – Lower Eyre Peninsula, Mount Remarkable, Tumby Bay, Barunga West, Cleve, and Franklin Harbour – much smaller (see Nursey-Bray <i>et al.</i> 2021) Large non-resident population in the region.
Resource development, energy & industrial	South Australia's mineral exploration expenditure was \$91.8 million in 2020/2021, a 7-year high. Copper accounted for \$44 million with other commodities including iron ore, uranium, mineral sands (DEM 2021). See Appendix B for SA Mineral Industry Project Pipeline. Spencer Gulf is seen as a major renewable energy and hydrogen export hub therefore further development is likely.
Power production	Northern Power Station ceased operation in May 2016, has now been decommissioned and demolished. Playford Power Station A and B both now demolished. Energy Australia hydropower project being developed, 225 MW project due for commissioning 2023. Renewable energy (e.g. wind) occurs in the region, but on land.
Shipping	http://www.marinetraffic.com/en See Appendix C for 2021 shipping density in Spencer Gulf.
Ports & dredging	Currently five port facilities in Spencer Gulf, with three operated by Flinders Ports (Port Lincoln, Port Pirie, Wallaroo) and the remaining two by Santos (Port Bonython) and OneSteel Manufacturing Pty Ltd (trading as SIMEC Mining) (Whyalla Port). Proposed ports include Port Spencer (20km NE of Tumby Bay; Peninsula Ports), Port Playford (former Port Augusta power station site), Cape Hardy (7km south of Port Neill; Iron Road), Myponie Point (Hawsons Iron Project). It is unlikely that all these will proceed.
Defence	Cultana Training Area is between Whyalla and Port Augusta. Covers the original Commonwealth-owned Cultana Training Area along with the Cultana Training Expansion area.
Other infrastructure development	Boat ramps and jetties mostly owned by local councils. See https://location.sa.gov.au/viewer/?map=hybrid&uids=90.
Agriculture	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. The SA Drought Resilience and Adoption Hub, recently funded through the commonwealth government, aims to help mixed farmers adopt tools to be more

	resilient to drought and has three of its six nodes around Spencer Gulf, in Minnipa, Port Augusta, Orroroo. More information: https://www.agriculture.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/research-adoption-program/adoption-innovation-hubs/south-australia-hub Also Sundrop farms (https://www.sundropfarms.com) is located near Port Augusta.
Recreation & ecotourism	A number of ecotourism activities exist around the gulf including Calypso Star Charters (shark cage diving, swim with sea lions), Rodney Fox Shark Expeditions, Swim with Tuna, Goin' off Safaris, Cuttys Tours Whyalla (glass bottom boat). Other activities include kayaking, snorkelling/diving and dolphin watching.
Conservation	Land – National Parks (e.g. Lincoln, Coffin Bay, Innes, Mt Remarkable), Conservation Parks (e.g. Telowie Gorge, Middlecamp Hills, Franklin Harbour) Within Spencer Gulf – Aquatic Reserves (Yatala Harbour, Blanche Harbour – Douglas Bank, Whyalla – Cowleds Landing, Goose Island); https://www.pir.sa.gov.au/recreational_fishing/rules/fishing_closures; Marine Parks (Upper Spencer Gulf, Franklin Harbour, Eastern Spencer Gulf, Sir Joseph Banks Group, Southern Spencer Gulf, Thorny Passage, Gambier Islands Group and Neptune Islands Group); https://www.marineparks.sa.gov.au

The *Natural History of Spencer Gulf* book, has five parts providing an excellent overview of the Gulf (Shepherd *et al.* 2014). It starts with a historical overview before three chapters on the oceanography of the gulf (historical perspective, physical characteristics and system models; Bye 2014; Kämpf 2014; Nunes Vaz 2014). There are then 18 chapters that cover biological systems focusing on habitats and organisms including giant Australian cuttlefish (Gillanders and Payne 2014). Part 4 investigates resource use, conservation and management including commercial and recreational fisheries, aquaculture, impact of prawn trawling, marine pollution, and management and protection (Gaylard 2014; Heaven *et al.* 2014; Jones *et al.* 2014; Paxinos *et al.* 2014; Steer *et al.* 2014; Svane and Shepherd 2014). Finally, there are two chapters investigating the future including one on climate change (Botello *et al.* 2014) and one on the population of the Spencer Gulf region (Hugo 2014).

Since these three significant works, additional research has been undertaken as part of, or aligned to the SGEDI project, as well as through SARDI Aquatic Sciences and other research organisations and universities. Much of the research has been focused on fisheries and aquaculture, with little focused specifically on Upper Spencer Gulf. SGEDI undertook two major projects, one using ports and shipping as a case study for integrated marine management and the other a socio-ecological assessment of the ecosystems, industries and communities of Spencer Gulf. An ecosystem model was also developed for fisheries and aquaculture to test 'what-if' scenarios such as the effects of increased nutrient inputs from aquaculture or increased fishing effort and catches of sardines and/or western king prawns (Gillanders *et al.* 2015). This project provided a proof-of-concept to assess how two types of human activities (aquaculture and fishing) interacted with each other and affected ecosystem structure and function. It provided a first step towards establishing tools to determine the individual and cumulative impacts of all industries that operate in and around Spencer Gulf (see below). The spatial component of the model was not fully utilised and it was not expanded beyond fishing and aquaculture.

The ports and shipping research:

- Synthesised existing information on all current activities and impacts in Spencer Gulf (Doubleday *et al.* 2017; Jones *et al.* 2018);

- Conducted a detailed analysis of current shipping activities and predicted likely future scenarios for shipping and port development;
- Conducted a risk analysis for introduction and establishment of exotic pests and pathogens under a range of future ports and shipping scenarios;
- Conducted a risk assessment to identify key iconic and threatened species, data deficiencies and needs, and species status for Spencer Gulf focusing particularly around shipping (Robbins *et al.* 2017);
- Developed tools for predicting interactions of future ports and shipping scenarios with other industries (<https://taaprowse.shinyapps.io/SGEDlvis01/>); and
- Engaged broadly and used the findings to inform managers, leaders, stakeholders, government and the broader community.

The socio-ecological assessment investigated the status of the ecosystems, industries and communities of Spencer Gulf (Tanner *et al.* 2019). The ecological, economic and social indicators established can be used to evaluate the benefits and impacts of current and future activities within and around the gulf (Bailleul and Ward 2019; Tanner *et al.* 2019; Nursey-Bray *et al.* 2021). Gulfview was developed as an interactive tool that allowed stakeholders, including potential investors, to obtain essential information on the environmental characteristics, existing uses and social values of sites throughout the gulf. This tool was an update of that produced as part of the ports and shipping project (see link above; Bailleul and Ward 2019). Tanner *et al.* (2019) identified opportunities to enhance future socio-economic assessments of the gulf and further integrate the management of South Australia's marine ecosystems.

SGEDI had a strong focus on an integrated approach to marine management rather than a sector-based approach. Several publications examined a practical approach to implementing ecosystem-based management and/or integrated marine management (Begg and Cadrin 2016; Smith *et al.* 2017). While an integrated approach to marine management was supported by industry, without the legislation to support such an approach it was not progressed further.

Considerable research has been undertaken on the oceanography of Spencer Gulf. An understanding of past, present and future ocean conditions can inform a number of activities in marine waters. The eSA-Marine system maps 'hind-cast' (past), 'now-cast' (present) and 'forecast' (future) ocean currents, temperature and sea level and while developed for fisheries and aquaculture have applications beyond these sectors (Middleton *et al.* 2013; https://pir.sa.gov.au/research/esa_marine). Additional smaller scale investigations of sea state have also been undertaken, for example, in Sleaford Bay near Port Lincoln to inform potential siting of a desalination plant (McShane 2021). Studies investigating the carrying capacity of Spencer Gulf for aquaculture often undertake hydrodynamic modelling and may also be relevant to desalination projects (e.g. Middleton *et al.* 2013; Doubell *et al.* 2015). Nunes-Vaz (2012) investigated the effects of disturbances from climate change (e.g. increasing trend of evaporation in the gulf) and desalination on the salinity of the system using Spencer Gulf as a case study. He found that salt accumulated for ~6 months following environmental forcing, but there has been no substantial increase in salinity compared to 25 years ago. Evaporation where freshwater is lost to the atmosphere may be viewed similarly to discharge of desalination return water. The gulf was largely self-regulating with respect to increased evaporation through time (Nunes-Vaz 2012), although evaporation which creates higher salinity waters operates across the entire gulf whereas desalination provides a point source of increased salinity water.

Some of the fisheries related projects may also have relevance to desalination projects in Spencer Gulf. For example, an understanding of the trawl footprint of the Spencer Gulf prawn fishery can indicate whether desalination brine is likely to impact the fishery. Noell (2017) found that total effort in the fishery had declined by 60% from 1976 to 2002 and then stabilised at around 18,622 hectares per annum from 2003 onwards. Spatial depictions of effort demonstrated that trawl intensity generally reduced in most of

the middle of the gulf but there was some redistribution of effort such that intensity was more concentrated near Wallaroo (Noell 2017). Past studies of prawn trawl bycatch may also provide baseline data on the composition and distribution of benthic species in Spencer Gulf (e.g. Currie *et al.* 2011; Burnell *et al.* 2015). Several of the submissions to the BHP draft EIS comment on the poor species distribution lists for the region therefore these reports and other unpublished data may assist.

Studies have also investigated iconic and threatened, endangered and protected species in Spencer Gulf. Northern Spencer Gulf is particularly important for the giant Australian cuttlefish, which each winter aggregate to breed on rocky reef near Point Lowly. After numbers declined to 13,492 individuals in 2013, the lowest since estimates of abundance had commenced, there was considerable concern for the species and additional research was undertaken to try and ascertain reasons for the decline, as well as identify and address knowledge gaps. This decline occurred not only on the breeding aggregation near Point Lowly but also across northern Spencer Gulf (Prowse *et al.* 2015). Little evidence of spawning has been found outside the Point Lowly breeding aggregation and surveys suggested little suitable breeding habitat occurred elsewhere in northern Spencer Gulf (Steer 2015). Cuttlefish were not found to spawn on artificial habitats placed where giant Australian cuttlefish breed suggesting that deployment of such habitat is unlikely to promote recovery of the population (Steer 2015). These results demonstrate the importance of Point Lowly to the northern Spencer Gulf population. In addition, genetic research also suggests that individuals that aggregate near Point Lowly are restricted to Northern Spencer Gulf (north of a line between Wallaroo and Lucky Bay; Gillanders *et al.* 2016). The importance of continued annual monitoring has been highlighted to provide an increased understanding of the natural dynamics of the population (Steer 2015). The predictable dynamics of the giant Australian cuttlefish spawning aggregation, both spatially and temporally, also increases its vulnerability to development (Hall *et al.* 2018). While the effects of desalination brine on the development of eggs has been investigated (Dupavillon and Gillanders 2009), no studies of the effects of brine on larger juvenile or adult individuals has been investigated. It is therefore unknown how giant Australian cuttlefish approaching the breeding aggregation site may respond to potential plumes of higher salinity waters (e.g. from a desalination plant off the Point Lowly coast).

Investigations of cumulative impacts in Spencer Gulf have been undertaken. Initially, as part of the SGEDI ports and shipping project, an ecological risk assessment of 38 human-mediated threats on eight marine habitats in Spencer Gulf was undertaken (Doubleday *et al.* 2017). Key threats to each habitat were identified with climate change considered an important global scale threat and nutrient discharge an important local scale stressor. Invasive species and most fishing-related threats ranked as low-tier threats to Spencer Gulf. Using data from the expert elicitation of threats in Spencer Gulf undertaken by Doubleday *et al.* (2017), along with the spatial pattern and intensity of threats, a cumulative impact map was developed for Spencer Gulf (Jones *et al.* 2018; see Appendix D). Subsequent research on cumulative impacts in Spencer Gulf has focused on seagrass habitats including a meta-analysis assessing how stressors interact (Stockbridge *et al.* 2020), and the use of empirical data to evaluate cumulative impact assessment methods (Stockbridge *et al.* 2021). The latter found little relationship between cumulative impact assessment outputs and seagrass condition hence new approaches incorporating interactions and non-additive stressor combinations are being investigated (Stockbridge *et al.* unpublished data). Further work is also required to determine whether the metrics currently used to assess seagrass condition (often percent cover) adequately capture condition. Empirical assessment of relationships between cumulative impact and seagrass condition were possible because the EPA aquatic ecosystem monitoring, evaluation and reporting (AECR) project undertakes fieldwork in Spencer Gulf (Gaylard *et al.* 2012, 2013). The AECR is used to inform the State of the Environment Report and the South Australian Environmental Trend and Condition Report Cards published by Department for

Environment and Water (DEW; <https://data.environment.sa.gov.au/Trend-and-condition-reports/Pages/default.aspx>). Northern Spencer Gulf was monitored in 2012 and 2018 and Southern Spencer Gulf in 2010 and 2016 (https://www.epa.sa.gov.au/environmental_info/water_quality/water_quality_monitoring).

4. Overview of previous Olympic Dam expansion environmental assessment

In 2009 BHP published a draft environmental impact statement in relation to the Olympic Dam Expansion (BHP 2009). The EIS was required for approvals from the Australian, South Australian and Northern Territory governments. A component of this related to the marine environment (Chapter 16 and Appendix O). The marine component was relevant to BHPs need to obtain freshwater for mining operations at Olympic Dam with the proposal to desalinate seawater by reverse osmosis at Point Lowly in Upper Spencer Gulf. A 280 megalitre per day (ML/day) desalination plant at Point Lowly and water supply pipeline to Olympic Dam was proposed. While water would be taken from Point Lowly for desalination, the return water which would contain anything added to the water as part of the desalination process (e.g. anti-scalants) as well as increased concentrations of salt, would be returned to Upper Spencer Gulf. Other coastal infrastructure proposed for Upper Spencer Gulf included a landing facility near Port Augusta. Following submissions, there were 391 unique submissions that were addressed in the supplementary EIS (BHP 2009). Chapter 17 and Appendix H are most relevant to the marine environment. Both the draft and supplementary EIS are available on the BHP website under copper and Olympic Dam: <https://www.bhp.com/sustainability/environment/regulatory-information>.

The marine chapter of the draft EIS summarised four key components associated with:

- Site selection and design of the desalination plant (not addressed in the current review)
- Hydrodynamic modelling and ecotoxicology studies
- Potential impact of the return water discharge, construction activities etc
- Measures to avoid, mitigate or manage impacts on the marine environment

Information in the draft EIS was obtained from a literature search, although this does not appear to have been a systematic search, and from government databases.

The Olympic Dam Expansion Draft EIS provides a list of species recorded in the vicinity of Point Lowly or likely to occur in Upper Spencer Gulf. Some surveys were undertaken but these were not intended to provide a baseline against which to assess potential impact. Rather this was expected to occur 2-3 years prior to construction and would incorporate smaller scale temporal variation. Surveys were undertaken at 37 uniformly spaced sites ranging in depth from 5-29 m between April and November 2006 to assess the distribution and composition of benthic and jetty pile assemblages. Sediment samples were also taken and measured for grain size and a range of contaminants. No surveys of intertidal areas were made. Additional surveys were undertaken in the vicinity of the proposed landing facility near Port Augusta during August 2007.

The supplementary EIS (2011) focused on additional ecological surveys, water/sediment surveys, return water characteristics, ecotoxicology, hydrodynamic model validation and reliability, salt balance in Spencer Gulf, plume dispersion at Point Lowly, potential ecological effects of return water discharge, significant species and communities, giant Australian cuttlefish, fisheries and aquaculture, stratification and deoxygenation, entrainment, marine construction, marine blasting, landing facility, introduced pest

and climate change. These sections were included as submissions specifically addressed comments around these.

Habitat maps for Spencer Gulf have been put together using multiple data sources and therefore there may be some variation between them. New surveys of habitats in Upper Spencer Gulf could be undertaken. Although an updated species list was provided in Appendix H1 of the supplementary EIS, more rigorous assessment of sub-tidal and inter-tidal organisms to provide baseline data are also recommended. These should encompass both spatial (including control sites) and temporal components. Similarly, comments around baseline water quality surveys and sediment were also made suggesting the need to sample multiple sites and seasons including areas where hypersaline water may pool.

4.1. Ecotoxicology tests

Ecotoxicology tests on a range of species were undertaken using the proposed return water, and undertaken by three different organisations. These tests used seawater from Port Lowly (that was desalinated using a portable reverse osmosis plant) and the anti-scalant Nalco PermaTreat PC 1020. Approximately 78g/L salt and 7 mg/L anti-scalant were used in test solutions. It was suggested that additional tests would be undertaken once the design of the plant, anti-scalant and other additives were known.

All ecotoxicology tests were laboratory based whole effluent toxicity studies done as acute tests (2-3 days exposure), short-term sub-chronic (sub-lethal; 2-3 days exposure of sensitive life stages), and chronic tests (weeks-months of exposure). A species protection trigger value was obtained for the discharge. Table 16.1 of the BHP draft EIS summarises the species used and tests undertaken (Appendix E).

Results suggested that both salinity and anti-scalant could be contributing to a toxic effect for some organisms (Table 2). Despite this, dilution of the return water was considered great enough that there would be negligible impact on giant Australian cuttlefish, although some commercial species close to the outfall may be affected. Based on the draft EIS effects on giant Australian cuttlefish were observed between 43.6 and 45.6 g/L, which is similar to the results of Dupavillon and Gillanders (2009).

Many submissions were concerned with the ecotoxicology testing including that they were not conducted using consistent, representative conditions for Upper Spencer Gulf or using the same chemicals as would be used in a desalination plant. In addition, species more relevant to the local area were suggested. It is noted that the ecotoxicology studies followed the process recommended by ANZECC/ARMCANZ (2000) Guidelines for Fresh and Marine Water Quality.

Table 2. Results of whole effluent toxicity testing for different species. EC₁₀ values represent the concentration that causes an effect of 10% when compared to controls. SPTV are species protection trigger values.

Table 16.8 Results of whole effluent toxicity (WET) testing

Species	Test	Salinity of test solutions (g/L)		EC ₁₀					Values used to calculate SPTV ¹	
		Diluent	Return water	% return water	Dilution ²	Equivalent salinity (g/L)	Salinity increase (g/L)	% increase above ambient	Primary dataset	Secondary dataset
Microalga <i>Nitzschia closterium</i>	72-hour growth (chronic)	37	77	12.8	1:8	42.1	5.1	13.8	n.a. ³	n.a.
Microalga <i>Isochrysis galbana</i>	72-hour growth rate inhibition test (chronic)	41.2 ⁴	78	84.4	1:2	72.3	31.1	75.4	84.4	84.4
Macroalga <i>Ecklonia radiata</i>	72-hour germination success (chronic)	41.2 ⁴	78	27.6	1:4	51.4	10.2	24.7	27.6	27.6
Macroalga <i>Hormosira banksii</i>	72-hour germination success (chronic)	36.3	78	16.5 ⁵	1:7	43.2	6.9	19.0	n.a.	16.5
Copepod <i>Gladioferens imparipes</i>	28-day reproduction (chronic), 48-hour pulse exposure	41.2 ⁴	78	10.9	1:10	45.2	4.0	9.7	n.a.	10.9
Western King Prawn <i>Melicertus latisulcatus</i>	28-day growth (chronic) – adult	41.2 ⁴	78	7.5 ⁶	1:14	44.0	2.8	6.7	7.5	7.5
Pacific Oyster <i>Crassostrea gigas</i>	48-hour larval development (sub-chronic)	41.2 ⁴	78	3.3	1:31	42.4	1.2	2.9	3.3	3.3
Australian Giant Cuttlefish <i>Sepia apama</i>	Post-hatch survival (chronic)	45	78	1.9 ⁷	1:55	45.6	0.6	1.4	n.a.	n.a.
Australian Giant Cuttlefish <i>Sepia apama</i>	Embryo development (chronic)	45	78	2.4	1:42	45.8	0.8	1.8	n.a.	n.a.
Australian Giant Cuttlefish <i>Sepia apama</i>	Embryo development (chronic)	41.2 ⁴	78	6.4	1:16	43.6	2.4	5.7	6.4	6.4
Yellowtail Kingfish <i>Seriola lalandi</i>	96-hour imbalance (acute)	40	84	12.5 ⁵	1:8	45.5	5.5	13.8	n.a.	n.a.
Yellowtail Kingfish <i>Seriola lalandi</i>	7-day larval growth (sub-chronic)	35.2	78	10.6 ⁶	1:10	39.7	4.5	12.9	n.a.	10.6
Snapper <i>Pagrus auratus</i>	7-day larval growth (sub-chronic)	41.2 ⁴	78	22.2	1:5	49.4	8.2	19.8	22.2	22.2
Mulloway <i>Argyrosomus japonicus</i>	7-day larval growth (sub-chronic)	41.2 ⁴	78	11.6	1:9	45.5	4.3	10.4	11.6	11.6

¹ See following section and Dr Warne's report (Appendix O10) for explanation of primary and secondary datasets.

² Dilutions are rounded up, percentages and salinities rounded to one decimal place.

³ n.a. = Not applicable.

⁴ Based on salinity measurement discussed in Appendix O9.

⁵ No Observable Effect Concentration (NOEC) used because EC₁₀ was not calculated.

⁶ Adjusted following peer review (see Dr Warne's report, Appendix O10).

⁷ Most conservative EC₁₀ used to verify SPTV.

4.2. Plume modelling of return water

Three hydrodynamic models were constructed based on existing information on oceanography and meteorology of Upper Spencer Gulf and supported by additional data collection at Point Lowly. The three models were:

- A whole of Spencer Gulf model (far-field) using Estuary, Lake and Coastal Ocean Model (ELCOM) and had a 2km horizontal resolution and a 2m vertical resolution. Oceanographic time scales of months to years to decades can be achieved with this model.
- A mid-field model (ELCOM) nested in the far-field model with 200m horizontal and 2m vertical resolution was developed to test mixing and plume behaviour at time scales of hours to months for Upper Spencer Gulf.
- A near-field model using the CORMAX modelling program was used to determine behaviour of plume water within 100m of the diffuser and relates to time scales of minutes to hours.

For these models it was assumed that the return water discharge rate would be 370 ML/day, salt concentration of the return water would average 75g/L, and temperature of discharge water would be 1°C higher than ambient seawater. Additional assumptions were made in relation to the diffuser used to return water along the seabed. The return water would also be well oxygenated prior to discharge.

The near-field model suggested that the return water would initially rise 2-7m above the diffuser ports before being entrained in currents. It would then sink to the seafloor as the return water would be denser than ambient water (see Figure 3). Results suggested that 100m from the outfall there would be less than 10% increment above ambient salinity.

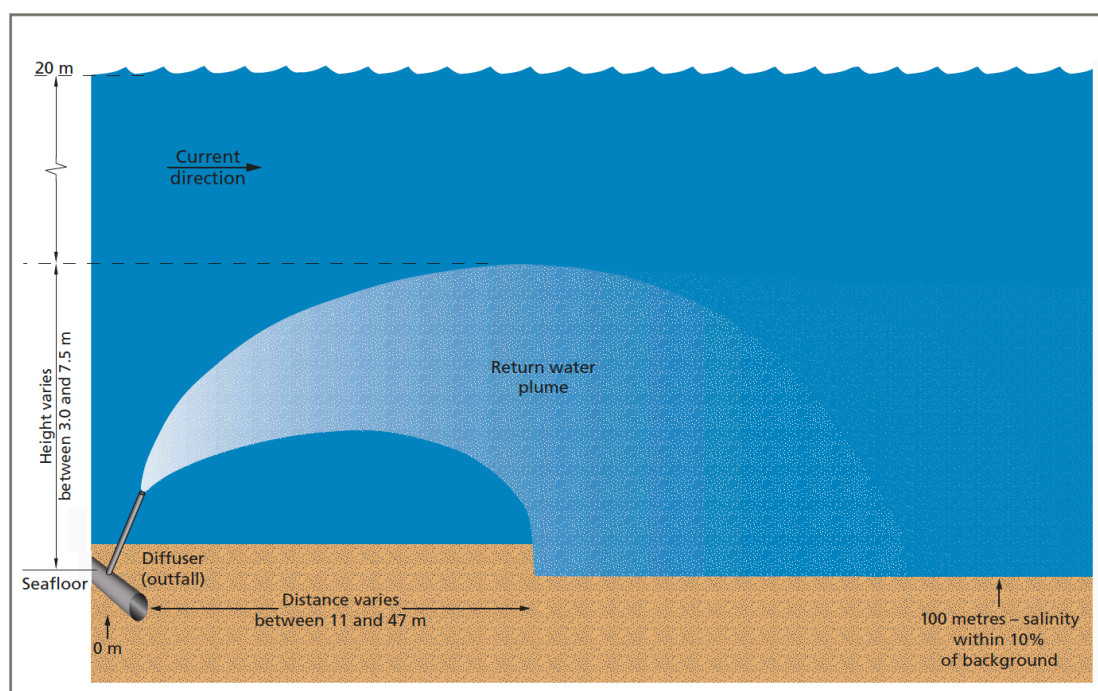


Figure 3. Profile of return water discharge based on the near-field model. Taken from Figure 16.13 in the BHP draft EIS (BHP 2009).

For the mid-field model dilutions and salinities at a range of sites were investigated with summary results shown in Table 3. The minimum dilution at cuttlefish habitat involved a maximum salinity increase of 0.3 g/L whereas the salinity increase at the closest prawn habitat was 0.9 g/L. By comparison the aquaculture sites in Fitzgerald Bay had showed a salinity increase of 0.1 g/L. The sponge community off

the end of Point Lowly had the greatest salinity increase (1.9 g/L). Depth, current speed and direction all affect the dilutions and therefore salinity at key sites. Deeper sites are affected more as the return water is denser than seawater. Stronger currents also rapidly disperse the return water. As the tide turns and current speed is reduced and when there are dudge tides dispersion is poorest.

Table 3. Summary of return water dilutions and salinity increases. For location of sites see Figure 16.14, page 510 of the BHP draft EIS.

Table 16.10 Summary of return water dilutions and salinity increases at key locations near Point Lowly compared with species protection trigger values¹

Receptor	Site (Figure 16.14)	Return water dilution		Return water concentration (%)		Salinity increase (g/L) ²		Breaches of protection value (% of time steps)	Maximum duration of breach (hours)	Conclusion
		Protection value	Minimum	Protection value	Maximum	Protection value	Maximum			
Marine ecosystem (outfall and three indicative sites)	a	>1:85 ³	1:8 ⁴	<1.2	11.2	<0.4	3.7	100	Continuous	Continual effect
	b		1:37		2.4		0.9	7	7	Occasional effect
	c		1:27		3.4		1.2	10	20	Occasional effect
	d		1:35		2.6		0.9	4	10	Occasional effect
Australian Giant Cuttlefish	e	>1:55 ⁵	1:247	<1.9	0.4	<0.6	0.1	0	n.a. ⁶	No effect
	f		1:116		0.9		0.3	0	n.a.	No effect
	g		1:211		0.5		0.2	0	n.a.	No effect
	h		1:230		0.4		0.1	0	n.a.	No effect
	i		1:184		0.5		0.2	0	n.a.	No effect
	j		1:184		0.5		0.2	0	n.a.	No effect
	k		1:393		0.3		0.1	0	n.a.	No effect
Prawns	l	>1:14 ⁵	1:37	<7.5	2.7	<2.6	0.9	0	n.a.	No effect
	m		1:152		0.7		0.2	0	n.a.	No effect
Kingfish	n	>1:10 ⁵	1:319	<10.6	0.3	<3.5	0.1	0	n.a.	No effect
Sponge community	p	>1:85 ²	1:17	<1.2	5.9	<0.4	1.9	30	16	Regular effect

¹ Dilutions rounded up for protection values, down for model predictions. Concentrations and salinities rounded to one decimal value.

² Based on return water salinity = 15 g/L; ambient salinity = 42 g/L.

³ Species protection trigger value (see Section 16.4.2).

⁴ Near field results (see Table 16.9).

⁵ Lowest EC₅₀ for individual species (see Table 16.8).

⁶ n.a. = not applicable.

Dilution contours were also used to show the maximum extent of the stated dilution factor and provide more than just a snapshot view at a particular time. The dilution contours are modelled for a 40-day period (see Figure 4).

To determine potential salt increase through time from continual discharge of return water to Spencer Gulf the model was run for a simulated period of 5 years. The model reached quasi-steady state conditions in less than a year. Long-term increases in salinity were between 0.01 and 0.07 g/L depending on the site.

Far field model results were able to confirm evaporation relative to desalination inputs and reproduce the gulf-wide clockwise circulation pattern. Flushing times of 1 year in Upper Spencer Gulf were supported.

Submissions wanted clarification as to whether the hydrodynamic model was applicable to Upper Spencer Gulf. These models are informed by existing data and therefore some concerns around the quantity of data collected for model calibration and validation were raised. The far field model generally provided a good representation of Spencer Gulf hydrodynamics including the salt mixing mechanisms. Additional data was used to further calibrate and validate refined models. More detailed bathymetry data for Upper Spencer Gulf is required.

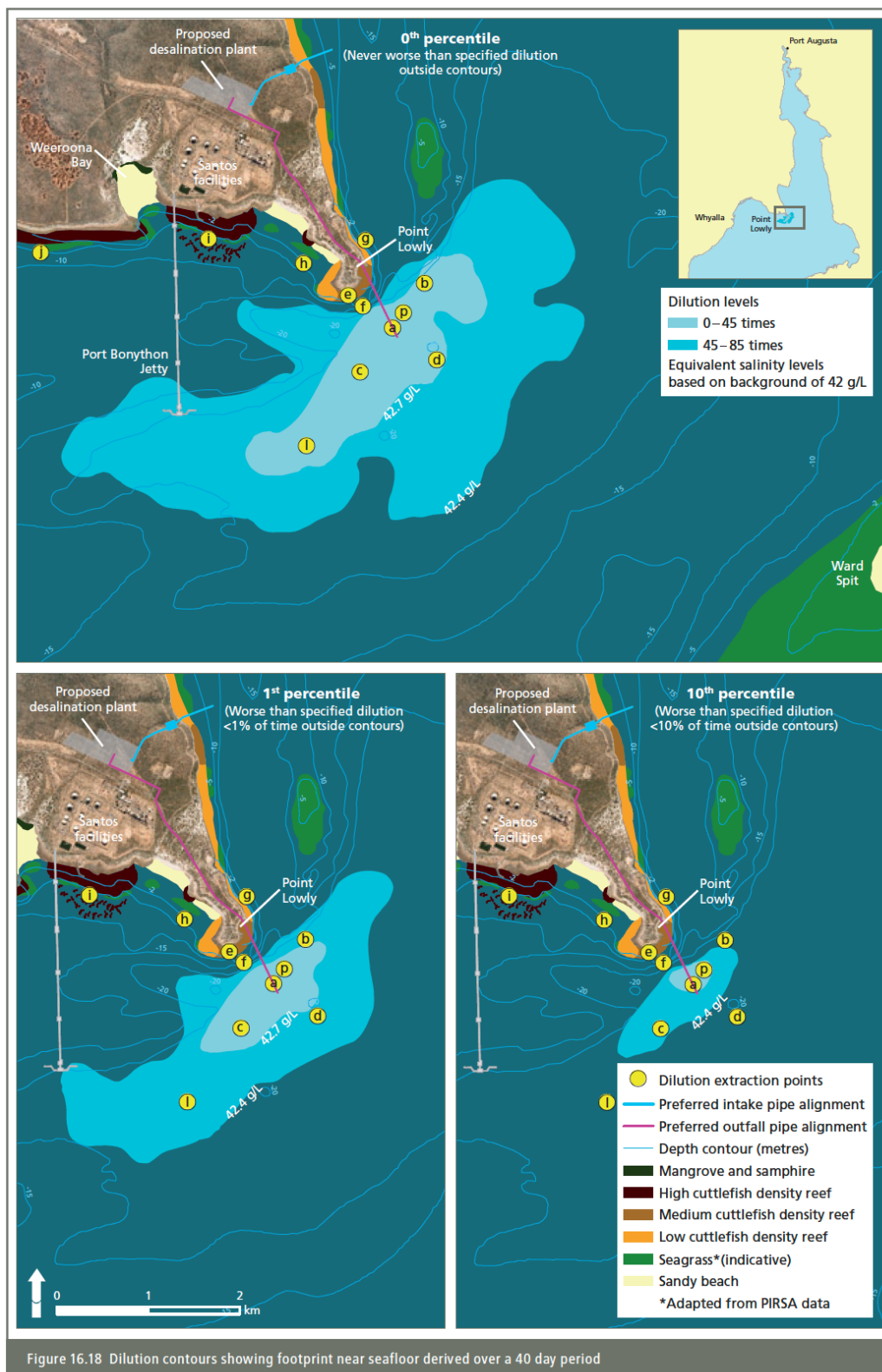


Figure 4. Dilution contours showing the salinity footprint near the seafloor.

4.3. Plume modelling of silt

Two models were used – the ELCOM model (unclear if the far-field or mid-field model was used) coupled to a Computational Aquatic Ecosystem Dynamics model – these were used to investigate sediment deposition and resuspension processes in relation to cuttlefish habitats, aquaculture facilities and seagrass habitats. Again, a series of assumptions were required (see page 484 of BHP 2009).

BHP (2009) indicates that before a desalination plant commenced operation, a monitoring program incorporating seasonal surveys of benthic communities, water quality data and sediment sampling would be undertaken. It is important that such sampling occurs prior to operation and involves appropriate control locations. In addition, programs would be established to monitor giant Australian cuttlefish populations and salinity within their habitat.

4.4. Other considerations

Intake of water for a desalination plant could trap or impinge marine organisms against the intake screens. Organisms including eggs, larvae, plankton and juveniles could also be entrained within the intake water. Review of these impacts is considered below but these issues are also pertinent to power stations with cooling water intakes.

5. Review of published scientific papers on desalination relevant to Upper Spencer Gulf

Major urban cities in Australia generally have desalination plants including Gold Coast, Sydney, Melbourne, Adelaide and Perth. With the exception of Adelaide and Sydney, there is little published information on potential environmental impacts and very little of the environmental monitoring is publicly available (Tanner and Drabsch 2021). Even where published data are available, these publications often focus on a few key groups (e.g. invertebrates - Clark *et al.* 2018; fish - Kelaher *et al.* 2020; Whitmarsh *et al.* 2021). No holistic analyses of all data collected since the commencement of any of Australia's desalination plants exist (Tanner and Drabsch 2021). Despite this, there are some reviews of the impacts of desalination plants and their ecological impacts (e.g. Roberts *et al.* 2010; Elsaid *et al.* 2020). Below we undertake a systematic review of published literature to investigate potential impacts of desalination plants worldwide.

5.1. Approach

We followed the preferred reporting items for systematic review and meta-analysis (PRISMA) protocol to identify and extract information from global studies on the impacts of desalination on marine ecosystems (Moher *et al.* 2010; Figure 5). We conducted a systematic review of the literature using the online search tool Web of Science (WoS) on 19 Sept 2022 using the search terms: marine AND desalination AND (impact* OR effect*) where the asterisks represent all derivatives of the term's "impact" and "effect". Results were limited to studies conducted after 2000 and excluded review papers. Finally, we used references from recent reports monitoring areas impacted by South Australian desalination plants. Studies were excluded if they focussed on desalination and/or membrane technological development, or brine treatment methods (Figure 5). We also excluded studies that were not specific to desalination, for example, those focussed on ballast water, low salinity effects, or non-marine impacts (Figure 5).

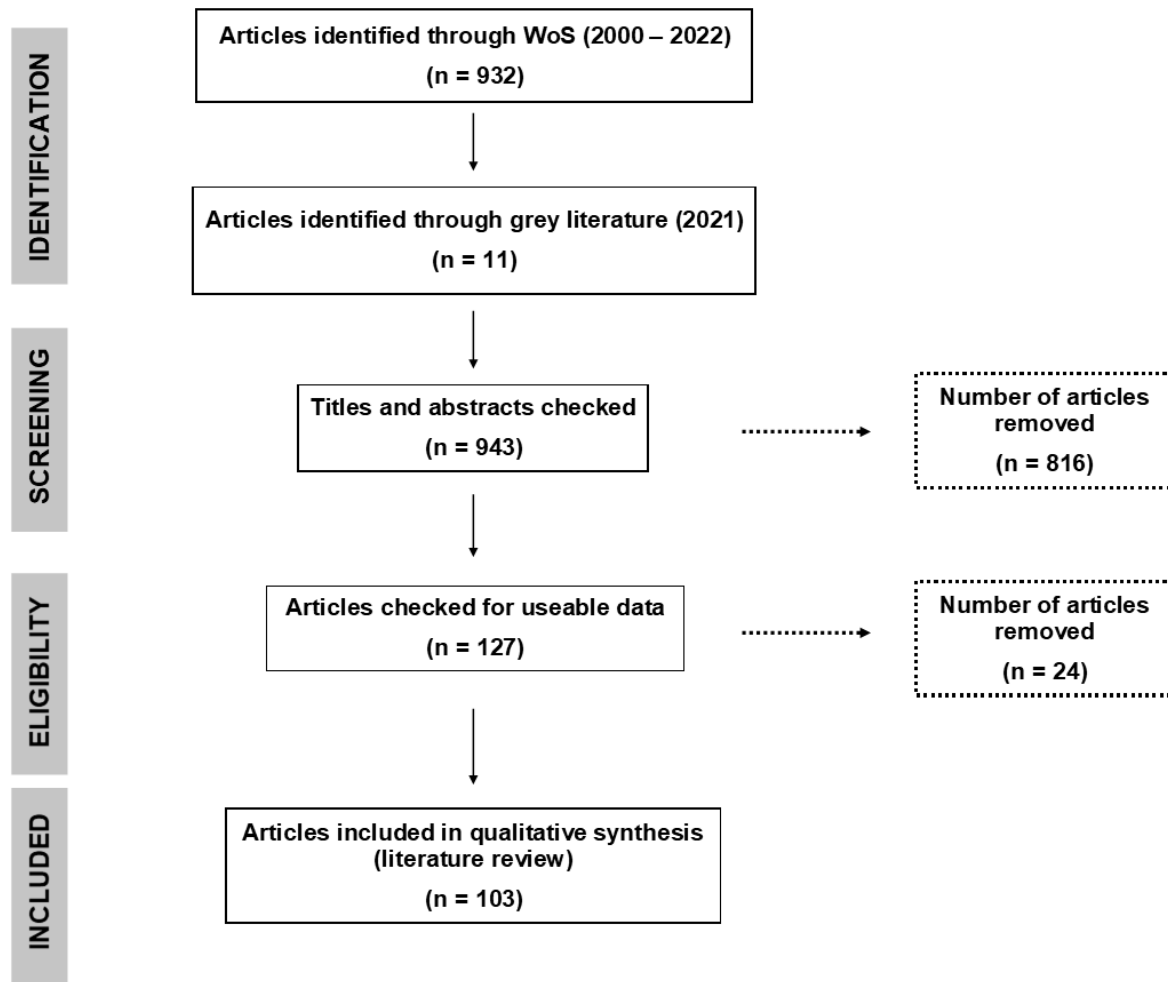


Figure 5. Articles used in a systematic review of desalination following the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) methodology (Moher *et al.* 2010).

5.2. Findings

In total, 932 studies were identified by our literature search, with 11 studies added from monitoring reports (grey literature; Figure 5). After studies not relevant to desalination were removed (Figure 6), we were left with 103 papers (Appendix F). Some articles tested the impact of desalination on multiple responses, or used multiple methodological approaches to test impacts (e.g. modelled and experimental data; Figure 7). We were left with 162 total combinations of study conditions and marine impacts from desalination.

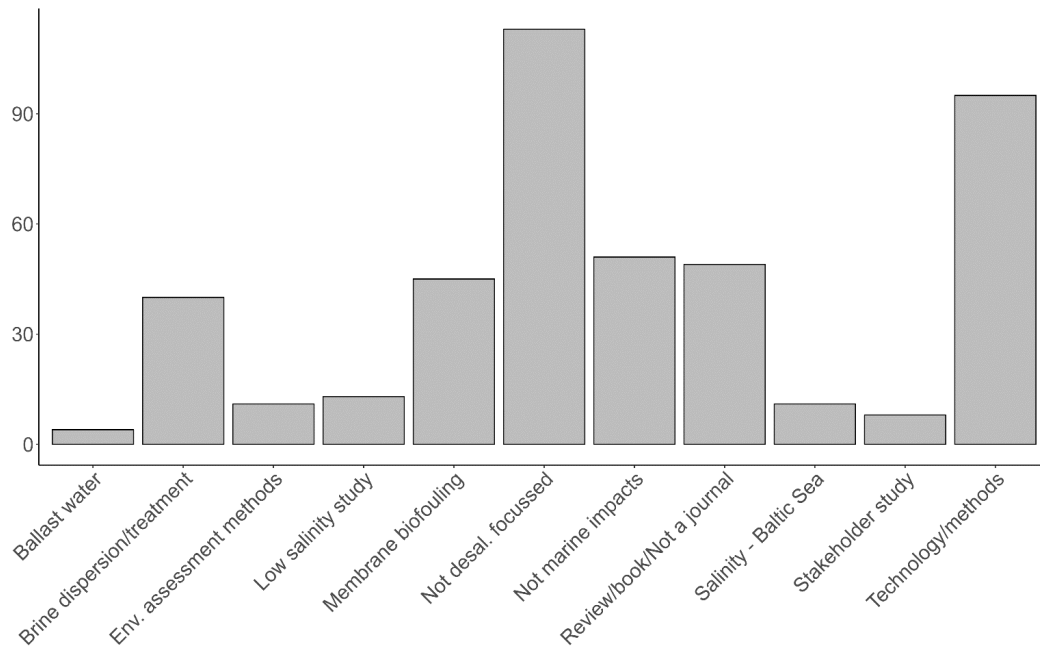


Figure 6. Reasons why papers were excluded following the literature search. Studies focussed on ‘Brine dispersion/treatment’ tested how brine was diluted in seawater or looked at ways to pre-treat seawater to minimise the impacts of brine but did not test any marine impacts. ‘Membrane biofouling’ and ‘Technology/methods’ focussed on improving the desalination process. ‘Low salinity study’ and ‘Salinity – Baltic Sea’ were salinity studies that did not test hypersaline conditions. ‘Stakeholder study’ characterises studies that interviewed various stakeholders on desalination activity (e.g. opinions of local communities) and reported the responses. ‘Ballast water’, ‘Not desal. Focussed’, and ‘Not marine impacts’ were all not relevant to the purpose of this report.

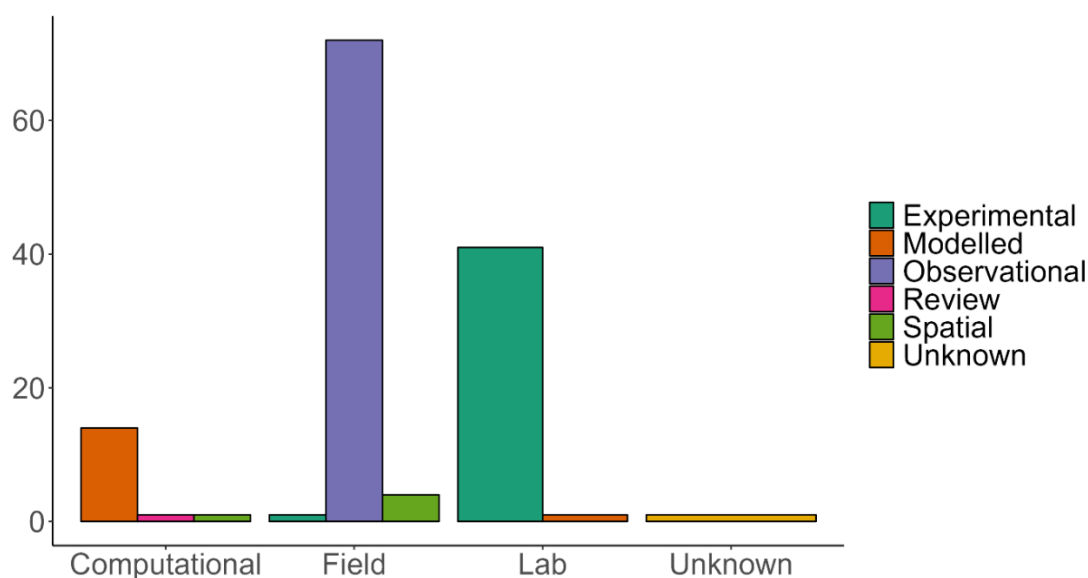


Figure 7. The number of study types identified in our literature search, including those that used modelled, spatial, observational or experimental data.

The number of desalination studies steadily increased between 2003 and 2015, with a sharp incline after 2017 (Figure 8). There has been a decrease in papers since 2020, with only 20 papers being published since 2020 compared to 21 in 2019 alone (Figure 8). Over 88 % of studies were undertaken in the Mediterranean Sea, and almost 20 % in the Persian Gulf or Red Sea; two gulfs either side of Saudi Arabia (Figure 9). Of all studies, 94 % took place between latitudes of 53.93 and 17.55 (Figure 9), in hotter, arid regions (Figure 10). Most studies were observational field studies or were conducted in mesocosms where salinity levels were manipulated to simulate hypersaline conditions (Figure 7).



Figure 8. Studies on desalination impacts on marine areas over time.

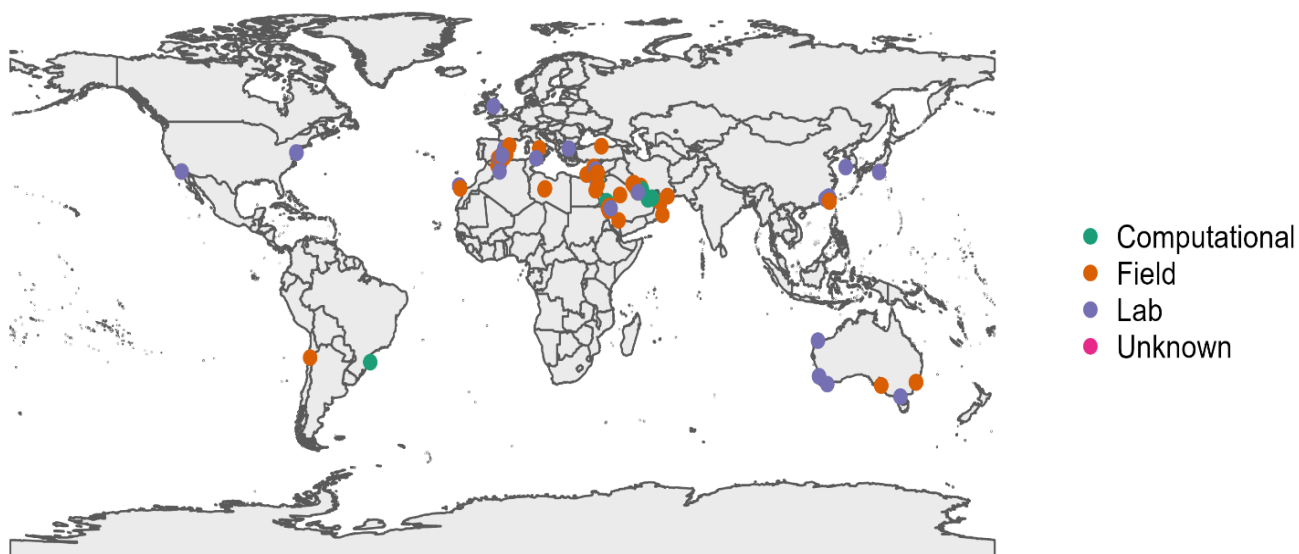


Figure 9. Global desalination study locations (points). Colours differentiate between computational, field, laboratory and unknown studies.

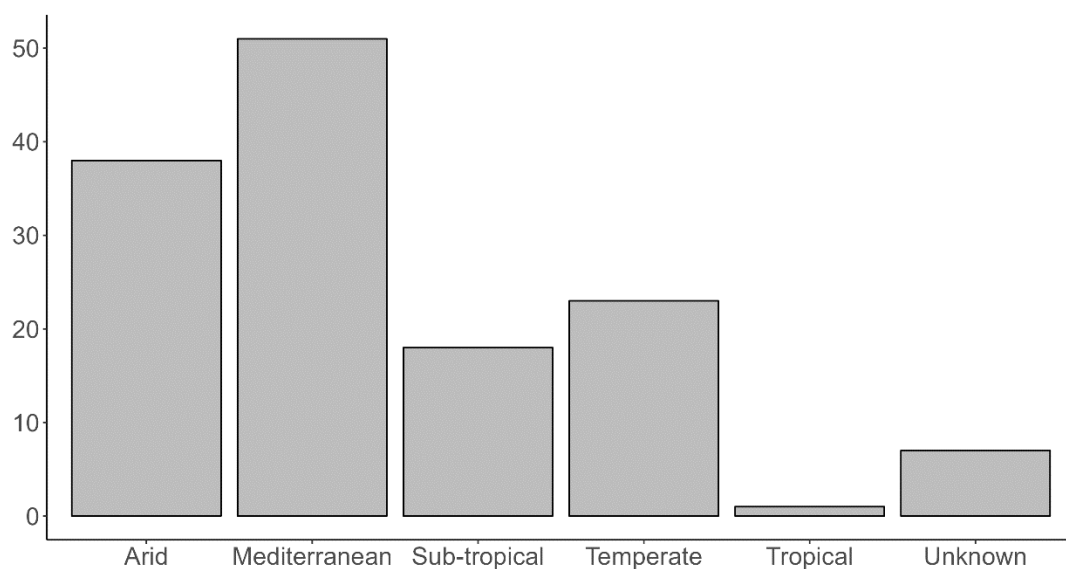


Figure 10. Number of studies undertaken across different climates.

5.3. Desalination impacts on marine systems

The majority of studies (66 %) investigated the impacts of brine discharge (Table 4) on marine ecosystems. Since brine tends to sink when discharged into seawater, benthic ecosystems are vulnerable to any negative associated impacts (Ihsanullah *et al.* 2021). Half of studies we identified were conducted on benthic or sessile organisms and/or communities (Table 4). A common assumption around desalination impacts is that any adverse effects on marine ecosystems is due to salt stress caused by hypersaline brine discharge (Koch *et al.* 2007; Touchette 2007), which has salinity levels that are approximately twice that of seawater (Kenigsberg *et al.* 2020). Previous studies have demonstrated the detrimental effects that high salinity can have on the different trophic levels of marine ecosystems, for example, lowering bacterial productivity (Montgomery *et al.* 2009), increasing oxidative stress in seagrasses (Capó *et al.* 2020), and altering benthic faunal assemblages (Ruso *et al.* 2007; Riera *et al.* 2011). Commercially important crustaceans, such as the brown crab and European lobster, moved away from hypersaline conditions, demonstrating how desalination impacts can directly impact revenue in temperate fishery areas (Smyth *et al.* 2014).

Studies have reported that salinity was not a significant factor in the alteration of fish communities (Brook 2018; Kelaher *et al.* 2022), since fish are highly mobile and can move to lower salinity areas. Furthermore, fish can osmoregulate to offset the negative effects of high salinity (Kelaher *et al.* 2022). However, osmoregulation is an energy intensive process (Johnson 2009) and long-term reliance on osmoregulation may restrict growth or reproductive output. Long-term studies (7 years) have monitored fish abundances and found no significant impacts of high salinity water (Kelaher *et al.* 2022; Kelaher and Coleman 2022), however, none of the studies identified by our literature search monitor fish growth over time. Since brine discharge may alter seawater salinity, more studies that look at the long-term impacts on fish communities are needed, as reproductive rate and biomass are important factors in aquaculture. Furthermore, all the studies we identified tested impacts on adult fish and did not consider how high salinity affected juvenile survival or egg development. Embryo survival of cuttlefish decreased in high salinity waters in South Australia (Dupavillon and Gillanders 2009), indicating that there are potentially differences in the way different life stages will respond to hypersaline conditions. This represents another important gap in the knowledge, as it highlights the importance in understanding the long-term impacts of desalination. It would be expected that eggs, larvae and potentially juveniles would be more susceptible to the high salinity of desalination brine than adults.

Table 4. The number of studies that tested impacts related to desalination and each combination of biotic/abiotic responses

Impact	Biotic/abiotic response	Parameters measured	No. of studies
Acidification	Fish	Survival	1
	Seagrass		1
Anoxia	Fish	Survival	1
	Seagrass		1
Anti-scalants	Corals	Physiology	1
	Microbes	Composition	1
Brine discharge	Acid effluents	NA	1
	Algae	Abundance	1
		Physiology	1
	Amphipods	Abundance	1
	Benthic fauna	Abundance	1
		Physiology	1
		Structure	10
	Chemicals	NA	2
	Crustaceans	Behaviour	1
		Physiology	2

	Currents	NA	2
	Cuttlefish	Growth	1
		Survival	1
	Echinoderms	Abundance	4
	Eutrophication	NA	2
		Abundance	3
		Diversity	1
		Physiology	3
	Fish	Structure	1
		Impact	1
			1
		Sediment	5
	Fishing	NA	1
		Abundance	1
	Habitat	Impact	1
		Physiology	1
		Structure	4
	Microbes	Composition	2
	Molluscs	Physiology	2
	pH	NA	1
	Plankton	Abundance	1
		Physiology	1
	Salinity	NA	12
	Seagrass	Abundance	1
		Growth	1
		Physiology	3
		Shoot density	4
	Sediment properties	NA	3
	Sponges	Abundance	1
	Temperature	NA	6
		Toxicity	3
	Turf	Abundance	1
	Water quality	NA	10
	NA	NA	1
Chlorine	Algae	Physiology	1
	Crustaceans	Survival	1
Coagulants	Microbes	Productivity	1
Density current	Seagrass	Growth	1
		Survival	1
Irradiance	Seagrass	Biomass	1
pH	Microbes	Composition	1
Pollutants	Molluscs	Physiology	1
Salinity	Algae	Biomass	1
		Physiology	1
	Benthic fauna	Abundance	1
		Physiology	1
		Structure	1
	Corals	Physiology	2
	Crustaceans		1
	Fish		1
	Food-webs	Biomass	1
	Microbes	Composition	2
		Productivity	2
	Molluscs	Physiology	1
		Biomass	5
		Growth	1
		Mortality	1
		Physiology	7
		Seedlings	1
		Shoot density	1
Temperature	Benthic fauna	Survival	2
		Structure	2
	Corals	Physiology	1
	Food-webs	Biomass	1
	Seagrass		1
Toxic trace elements	Molluscs	Physiology	1
	Sediment properties	NA	1
			1

Although an increase in salinity is considered the greatest risk, there are other modifications to the marine environment associated with brine discharge from desalination plants. These include thermal pollution, acidification, deoxygenation, and chemical pollution from membrane treatment solutions. However, only 11 % of studies looked at the effect of these other impacts on a biotic response, with varying results and conclusions. Several studies and reports conclude that temperature is likely to have

little effect on fish assemblages in South Australia (Tanner and Drabsch 2021) or marine food webs in arid regions (Garrote-Moreno *et al.* 2014; van der Merwe *et al.* 2014). Conversely, studies in the Mediterranean found that a reduction in benthic populations was associated with thermal pollution from desalination effluents (Titelboim *et al.* 2016; Grossowicz *et al.* 2020). Conflicting results also occurred between studies that looked at impacts associated with pH and chemical pollution. Seagrass habitats in the Canary Islands were unaffected by chemical pollutants that affect oxygen availability and pH in seawater (Portillo *et al.* 2014). However, other anti-scalant solutions interacted synergistically with high salinity and negatively impacted microbial compositions (Belkin *et al.* 2017). Further research on specific membrane treatments are needed to identify where these synergistic interactions with salinity are likely to occur to inform better management and planning of desalination operations.

Laboratory experiments conducted in mesocosms often only manipulated one parameter (e.g. salinity, pH, chemical concentration) to reflect what is expected to occur in marine ecosystems impacted by brine discharge. However, nine laboratory experiments recreated conditions that are more representative of real-world desalination impacts by treating mesocosms with diluted brine (e.g. Cambridge *et al.* 2019). Seven of these studies reported significant effects on marine biota, suggesting that potential interactions are occurring between pollutants and salinity that may negatively affect marine ecosystems. Furthermore, one study that reported non-significant effects was conducted in an area heavily impacted by anthropogenic activity (Petersen *et al.* 2019), suggesting this as a potential reason that no further impact was detected.

5.4. Gaps in knowledge

There are a large number of studies (n=45) that manipulated brine discharge or salinity in a laboratory experiment to observe the impacts on marine ecosystems. However, only five studies monitored changes for longer than 6 months and only one of these long-term studies looked at the combined effects of salinity and other constituents of brine. Long-term monitoring of desalination impacts is a knowledge gap that is frequently mentioned in the literature (Gillanders *et al.* 2013; Ihsanullah *et al.* 2021; Tanner and Drabsch 2021). Periodic monitoring reports that describe the impacts of desalination plants are often confined to the grey literature and are not readily accessible. These reports are important in furthering our understanding of desalination impacts but are often not available for consideration during the planning and environmental assessment stages.

Long-term studies may be particularly important when it comes to fish assemblages, which are often believed to be resistant to changes caused by hypersalinity. Fish growth and abundance are influential factors in the revenue generated by the fisheries industry. Studies on fish assemblages over a longer temporal scale will inform as to how long-term osmoregulation affects growth. Furthermore, long-term studies over a larger spatial scale will help us understand how populations change as fish move to escape hypersaline conditions, similar to what has been observed in crustaceans (Smyth *et al.* 2014).

Brine discharge affects multiple water quality parameters, including salinity, pH, temperature, and dissolved oxygen. Mesocosm experiments commonly manipulate one or more of these in separate experiments. However, there are few studies that attempt to identify and quantify how these changes combine to impact marine ecosystems. This is a crucial knowledge gap as in a real-world scenario, marine ecosystems will be subjected to these changes occurring concurrently. Being able to identify which changes are interacting with others to produce a greater than expected negative impact would be an important consideration for brine treatment methods. For example, if there was a consensus that salinity synergistically interacted with a specific anti-fouling chemical, then treatment methods could potentially be modified to minimise the impact of this interaction. A recent meta-analysis on stressor

interactions identified synergies between salinity and photosynthesis inhibiting compounds in seagrass ecosystems (Stockbridge *et al.* 2020). This has potential implications for desalination impacts, as seagrasses are ecosystems that are vulnerable to brine discharge, and was the target ecosystem for 33 studies identified here. However, only five studies monitored impacts for longer than six months, highlighting the need for more research on how salinity interacts with chemical compounds to impact seagrasses over time.

There is an imbalance in where desalination impact studies are conducted and how experiments are designed (Roberts *et al.* 2010; Williams 2022). There is a paucity of research conducted on impacted areas in the southern hemisphere compared to the northern hemisphere (Williams 2022). More field studies where conditions are experimentally manipulated are needed (e.g. Sanchez-Lizaso *et al.* 2008), particularly in regards to how different flow conditions impact marine ecosystems (Roberts *et al.* 2010). However, these types of experiments can be costly, and there are a number of influences outside of the researchers control that can cause data to be lost (e.g. unpredictable weather, materials going missing, many confounding variables). Therefore, conducting field experiments over the temporal scale that is required to broadly inform the field of desalination impacts would be difficult. As an alternative, future research should aim to compare long-term monitoring of sites before the construction of desalination plants with that of sites following impact from brine discharge. Such studies need to have suitable control sites that are not impacted by brine discharge.

There is a general consensus among desalination impact studies and review papers that more research is needed to study the long-term impacts of high salinity on marine ecosystems. More studies are needed in the southern hemisphere, particularly in Australia where there are a number of active desalination plants. Manipulative field experiments are preferred, however, empirical data from before/after impact comparisons, or comparisons between reference and impacted sites, will also help to fill knowledge gaps regarding marine impacts of desalination.

5.5. Recommendations

Studies are needed on the long-term impacts of hypersalinity, preferably sampled from areas extending out from the mixing zone of desalination plants. However, capturing changes over the necessary temporal scale (>2 years) is likely not realistic given time budgets. Alternatively, collating and analysing existing data from operational desalination plants in Australia may assist with this task noting that little publicly available information exists that tracks water quality parameters or assesses potential impacts. Additional ecotoxicology testing using water from the proposed site along with anything that would be added to the water as part of the desalination process (e.g. anti-scalants) could also be undertaken on relevant species to the Upper Spencer Gulf.

To determine potential desalination impacts baseline data at multiple sites that would encompass impact and control sites and through time is required. It is recommended that sampling programs are put in place to allow such data to be collected in advance of any desalination plant becoming operational.

The hydrology of Spencer Gulf is unique, leading to conditions we may not expect when comparing to other temperate estuaries. Spencer Gulf is an inverse estuary where annual evaporation frequently exceeds precipitation, leading to salinity levels being higher than the average of the open ocean. Salinity levels are particularly high in the northern areas of the gulf, as salinity in Spencer Gulf increases with latitude. Thermohaline circulation leads to high salinity water within the gulf being flushed out and replaced by lower salinity water from the open ocean. Global ocean hydrological models may not capture the variation in water condition that results from this flushing as they are not at a fine enough scale. More

observational data are needed to provide more information on the effect of thermohaline circulation on water quality of Spencer Gulf. This includes conductivity-temperature-depth (CTD) observations to provide measurements on water properties such as temperature and salinity.

The effectiveness of flushing activity and thermohaline circulation at diluting hypersaline waters varies with ocean depth, with shallower waters more vulnerable to changes in water chemistry. Water quality observations are particularly important in northern Spencer Gulf, as these areas are shallower and experience less flushing, and reduced dilution of hypersaline waters. Furthermore, more recent and representative bathymetry data of Spencer Gulf will help us identify areas more vulnerable to increased salinity.

Finally, studies are needed that further our understanding of climate change impacts on Spencer Gulf. In particular, the interactions between climate change impacts, such as acidification and increased temperature, and salinity need to be understood, as stressor interactions can lead to unpredictable effects. These studies should be conducted in mesocosms if possible to simulate conditions in Spencer Gulf.

6. References

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The Corporate Affairs team from BHP have approved the use of figures and tables from the Olympic Dam Draft EIS (2009) (email from November 14, 2022). This includes Table 2 and 3, Figures 3 and 4, and the table in Appendix E of this report.

8. Appendix A. Summary of key information gaps from Gillanders et al. (2013)

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 physio-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 physio-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 detritivores; 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 on 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

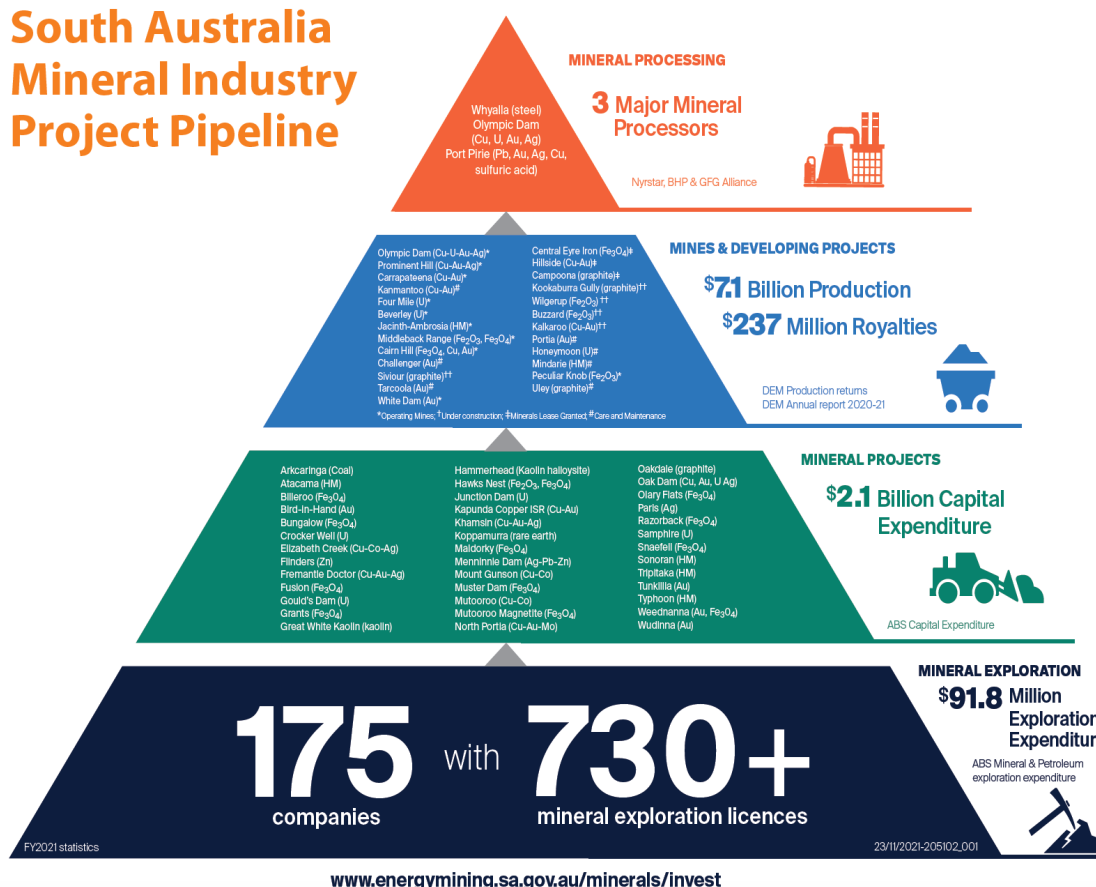
Marine spatial planning

- 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

9. Appendix B. South Australia Mineral Industry Project Pipeline

The mineral industry pipeline in South Australia in 2021.

South Australia Mineral Industry Project Pipeline



From: Mineral Exploration in South Australia 2021: Commodity Report. Available at:

<https://www.energymining.sa.gov.au/industry/minerals-and-mining/exploration/mineral-exploration-in-south-australia>

10. Appendix C. Shipping intensity in Spencer Gulf for 2021

Shipping intensity in Spencer Gulf in 2021.

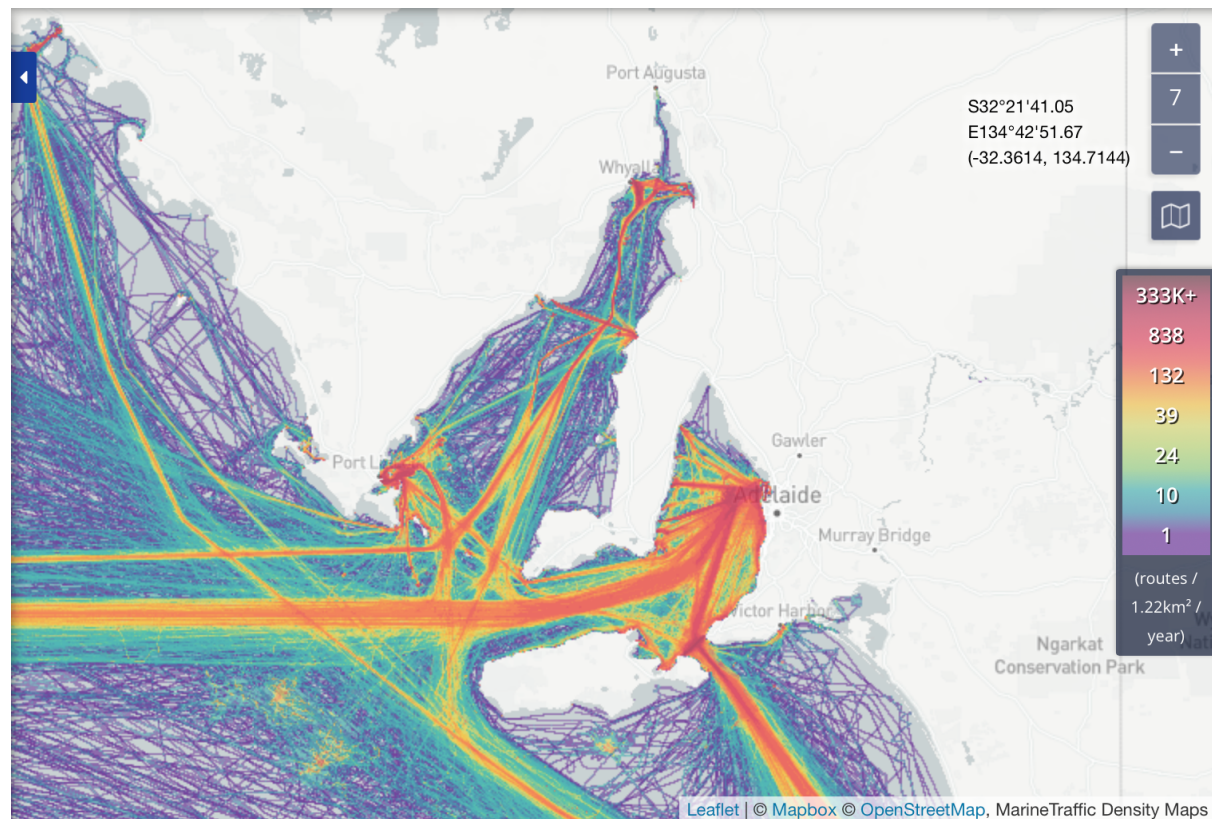
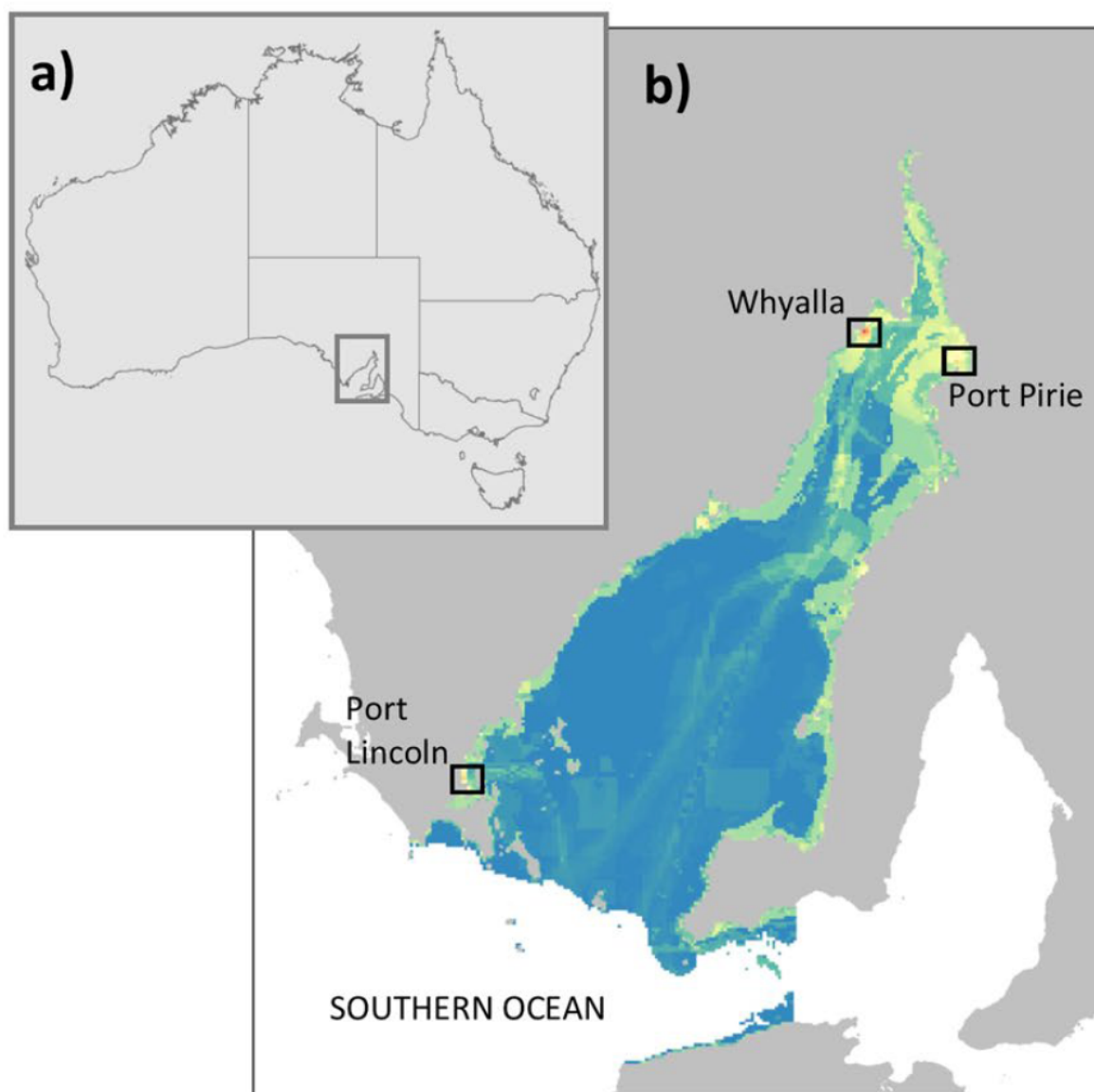


Figure from <https://www.marinetraffic.com/en/ais/home/centerx:135.9/centery:-34.4/zoom:7>

11. Appendix D. Cumulative impacts map of Spencer Gulf

Cumulative impact map for benthic systems in Spencer Gulf (from Jones et al. 2018).



12. Appendix E. Species used and tests undertaken as part of the BHP EIS

Table 16.1 Species and tests used during ecotoxicology studies

Species	Present in USG ¹	Test	Description	Laboratory	Year
Microalga <i>Nitzschia closterium</i>	Yes	72-hour growth rate inhibition test (chronic)	Widely distributed in Australian waters Widely used in WET testing in Australia and SE Asia	CECR ² , (New South Wales)	2006
Microalga <i>Isochrysis galbana</i>	Several unidentified <i>Isochrysis</i> species	72-hour growth rate inhibition test (chronic)	Species of the genus <i>Isochrysis</i> have been used in toxicity tests for over 15 years	GS ³	2007
Macroalga Common Kelp <i>Ecklonia radiata</i>	No	72-hour germination success (chronic)	Widely distributed throughout SA waters but not found in USG	GS	2007
Macroalga Neptune's Necklace <i>Hormosira banksii</i>	Yes	72-hour germination success (chronic)	Widely distributed throughout SA waters Widely used for WET testing in Australia	ESA ⁴	2006
Copepod <i>Glabioferens imparipes</i>	Unknown	28-day reproduction (chronic), 48-hour pulse exposure	Distribution includes south-western Australia Used in toxicity tests for over 15 years	GS	2007
Tiger Prawn <i>Penaeus monodon</i>	No	96-hour toxicity test of 15-day post-larvae (acute)	One of the most widely used tests to assess effluents in Australia	ESA	2006
Western King Prawn <i>Melicerus latisulcatus</i>	Yes	21 and 28-day growth tests on juvenile and adult prawns respectively (chronic)	Of significant commercial importance in USG Test developed for this study based on background laboratory work undertaken for aquaculture research	GS	2007
Blue Swimmer Crab <i>Portunus pelagicus</i>	Yes	7-day larval growth test (sub-chronic)	Of significant commercial importance in USG Test developed for this study	GS	2007
Pacific Oyster <i>Crassostrea gigas</i>	Aquaculture	48-hour larval development (sub-chronic)	Found in temperate waters throughout the world but introduced to South Australia for aquaculture Used in toxicity tests throughout the world for more than 25 years	ESA	2007
Sydney Rock Oyster <i>Saccostrea commercialis</i>	No	48-hour larval development test (sub-chronic)	Widely used for WET testing in Australia Pacific Oyster <i>Crassostrea gigas</i> that does occur in Spencer Gulf were not spawning during the 2006 testing period	ESA	2006
Sea urchin <i>Heliocidaris tuberculata</i>	No	72-hour fertilisation success test (sub-chronic)	Widely used in Australian toxicity assessment programs Sensitive to a range of heavy metals, ammonia and surfactants Distributed on rocky reefs from southern Queensland to central New South Wales	ESA	2006
Yellowtail Kingfish <i>Seriola lalandi</i>	Yes	96-hour imbalance test and mortality in 8–12 mm larvae (acute)	Important aquaculture species in Fitzgerald Bay	CECR, Adelaide	2006
Yellowtail Kingfish <i>Seriola lalandi</i>	Yes	7-day larval growth test (sub-chronic)	As above	GS	2007
Snapper <i>Pagrus auratus</i>	Yes	7-day larval growth test (sub-chronic)	Important commercial and recreational species distributed throughout Spencer Gulf	GS	2007

Table 16.1 Species and tests used during ecotoxicology studies (cont'd)

Species	Present in USG ¹	Test	Description	Laboratory	Year
Mulloway <i>Argyrosomus japonicus</i>	Yes	7-day larval growth test (sub-chronic)	Small recreational and commercial quantities caught in USG Juveniles favour estuarine environments	GS	2007
Australian Giant Cuttlefish <i>Sepia apama</i>	Yes	Developmental and hatching tests (chronic)	Very important breeding habitat at Point Lowly Tests developed for this study	GS	2006, 2007

¹ Upper Spencer Gulf.

² Centre for Environmental Contaminants Research, Commonwealth Scientific and Industrial Research Organisation.

³ Geotechnical Services Pty Ltd.

⁴ Ecotox Services Australia Pty Ltd.

13. Appendix F. References of studies included in our literature review

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